Calcium fertilization for raspberry fruit characteristics and leaf elemental composition

A senior project presented to the faculty of the Agribusiness and the
Earth and Soil Sciences Departments of
California Polytechnic State University
San Luis Obispo, California

In partial fulfillment of the requirements for the degree of Bachelor of Science
in Agricultural Business with concentration in
Farm and Ranch Management

By
Justin Scurich

Abstract

Calcium fertilization can improve fruit production. Calcium binds pectin in the middle lamella of cell walls thereby reinforcing cell wall strength and improving quality. High concentrations of calcium are required to ensure diffusion to the blossom end will occur. Calcium absorption by plant roots is partly regulated by cation competition with magnesium being a main competitor. Common industrial calcium fertilizers are calcium-ammonium-nitrate 17-0-0 and calcium-nitrate 9-0-0. Growers are reluctant to apply nitrogen fertilizer during fruit and flower set because nitrogen encourages vegetative growth thereby lowering fruit production. Biomin Calcium® is a 2-0-0 fertilizer with 5 % chelated calcium and is manufactured by JH Biotech, Inc. Biomin Calcium® was chosen because of the low nitrogen content and the chelation of calcium. Chelated cations have the benefit of being more easily plant available. Biomin Calcium® was drip fertigated to raspberries (*Rubus ideaus* L. cv. 'Isabel') at a rate of two gallons per acre the first week and one gallon per acre per week the following thirteen weeks beginning with flower bloom initiation. The split-block design was embedded in a commercial production field in Watsonville, CA. Leaf blade tissue samples and fruit samples were taken weekly for one season. Tissue samples indicated plants were not nutrient stressed. Biomin Calcium® treated raspberries yielded 426 more crates per acre and had lower magnesium concentrations than did non-treated plants. The calcium / magnesium ratio increased in the Biomin Calcium® treated plants demonstrating cation competition. Brix, individual berry weights, and raspberry juice pH were not statistically different.

Key words: calcium, raspberry, cation competition, mineral nutrition, Biomin Calcium®

Special Thanks

There are individuals deserving special recognition for the successful completion of this project. Firstly, I thank my parents Bill and Tisha Scurich for all of their support throughout my college career. Bill and Mark Scurich and Scurich Brothers Inc. employees including Fernando Alvarez, Elida Jacquide, and Atzi Barajas made this project possible by helping incorporate the experiment into a commercial production field. Sage Finch and JH Biotech, Inc. provided the Biomin Calcium®, laboratory work, and advice throughout the experiment. Dr. Wayne Howard, current Agribusiness department head, approved this blended Soil Science and Agribusiness senior project. Dr. Tom Ruehr served as advisor on this project. His expertise in soil fertility and plant nutrition guided me through the data collection and analysis. Craig Stubler, the Soil Science Department technician, helped tremendously with laboratory procedures and interpretation of data. I want to thank everyone mentioned and anyone not mentioned for their contribution to this project.

TABLE OF CONTENTS

List of Figures

List of Tables

Introduction

Background

In general, fruit production can be improved by calcium fertilization. Strawberry fruit shelf life (Makus and Morris, 1989) and firmness (Bradfield and Guttridge, 1984) have been increased by calcium fertilization. Strawberry yield and Brix have been increased by calcium fertilization (Finch, 2006 unpublished).

Calcium competes with magnesium and sodium on the soil cation exchange sites. Calcium deficiencies can be experienced when growing crops in soil with high magnesium or sodium (Bradfield and Guttridge, 1984; Bradfield and Guttridge, 1981).

Plants need a constant supply of calcium; calcium is rarely remobilized in plants (Marschner, 1995). Calcium ions reach the ends of fruit through diffusion requiring a high concentration of calcium on the stem end of fruit. The need is highest as the plant prepares to make seeds and fruit. A short disruption in calcium supply at the critical time can ruin fruit.

Calcium deficiency causes 'blossom end rot of tomato' and 'catfacing' of strawberry. When the blossom end of a tomato is soft and mushy the term is 'blossom end rot'. When strawberries are malformed the term is 'catfacing'.

Calcium ensures proper cellular strength and shape in plants. Calcium binds pectin in the middle lamella of cell walls reinforcing the cell wall strength (Marschner, 1995). Strong cell walls support turgor pressure. Low turgor pressure leads to misshaped cells resulting in soft and deformed fruit.

Common industrial calcium fertilizers are CAN-17 (calcium-ammonium-nitrate, 17-0-0) and CN-9 (calcium-nitrate, 9-0-0). Growers are reluctant to apply nitrogen fertilizers during fruit set because nitrogen encourages vegetative growth thereby lowering fruit production if applied

during flower and fruit set. Biomin Calcium® is a 2-0-0 fertilizer with 5 % chelated calcium product manufactured by JH Biotech, Inc. Chelated cations do not bind to the soil exchange sites; instead they remain in the soil-water solution being more plant available (Mengel and Kirkby, 1979). Biomin Calcium® was chosen as the source of calcium for this study because of the lower nitrogen content than in CAN-17 or CN-9 and for the chelation of calcium.

Overall goal

To measure the response of raspberry plant nutrition and fruit characteristics to calcium application.

Objectives

To measure yield, Brix, pH, and individual berry weights and to estimate the amount of various elements removed by harvested raspberries and to measure the elemental concentrations of leaves throughout the growing season.

Importance

Growers using Biomin Calcium® may benefit from the information provided. Literature on raspberry plant nutrition is scarce; published critical nutrient concentration ranges are not entirely congruent. Existing literature is primarily sourced from the Pacific Northwest (not primarily a fresh market region for raspberry production). Raspberry production on the California Central Coast is primarily for fresh market and follows a different season than occurs in the Pacific Northwest. Growers on the California Central Coast using this particular cultivar may benefit from the conclusions of this study.

General Approach

A one season field trial was conducted in a commercial production field in Watsonville, CA. Leaf and fruit samples were taken weekly. Two soil tests and one well test were taken to

document field conditions. Weather data were recorded to establish environmental conditions. All cultural practices remained constant among test and control blocks.

Scope

Calcium applications began July 28, 2007 at flower bloom initiation. Calcium was applied weekly for fourteen weeks. The initial harvest date was September 15, 2007 and the final harvest date was November 15, 2007.

Assumptions

Published elemental concentration ranges were used to determine whether plant growth was limited for this cultivar.

Irrigation water requirements were determined by the irrigator to ensure water did not limit plant growth.

No other external factors limited plant growth.

Literature Review

Introduction

The supply and absorption of chemical compounds needed for growth and metabolism may be defined as *nutrition* and the chemical compounds required by an organism are termed *nutrients*. The mechanisms enabling nutrients to be converted to cellular material or used for energetic purposes are metabolic processes. *Metabolism* encompasses the various reactions occurring in a living cell to maintain life and growth (Mengel and Kirkby, 1979).

The essential nutrients required by plants are exclusively inorganic in nature. An essential element can be defined as required for the normal life cycle of an organism whose functions cannot be substituted by other chemical compounds. Additionally, the element must be directly involved in nutrition (i.e. as a constituent of an essential metabolite or is required for the action of an essential enzyme) (Mengel and Kirkby, 1979).

Plant nutrients can be divided into macronutrients and micronutrients. Macronutrients are needed in relatively higher amounts than are micronutrients. The division is somewhat arbitrary and in various cases the concentrations of micronutrients are higher than macronutrients.

Macronutrients include carbon (C), hydrogen (H), oxygen (O), nitrogen (N), phosphorus (P), sulfur (S), potassium (K), calcium (Ca), magnesium (Mg), sodium (Na), and silicon (Si). Na, Si, and Cobalt (Co) have not been established as essential for all higher plants. Micronutrients include iron (Fe), manganese (Mn), copper (Cu), zinc (Zn), molybdenum (Mo), nickel (Ni), boron (B), and chloride (Cl) (Mengel and Kirkby, 1979).

Metal atoms can be chelated. A chelated atom is bound to an organic compound (ligand) by two or more bonds forming a ring structure. Chelation forms highly water soluble and stable

complexes. The chelate remains stable during pH fluxes making the chelated atom more plant available (Mengel and Kirkby, 1979).

The role of calcium in the plant-soil system must be understood before forming conclusions regarding calcium fertilization and nutrition.

Review of Calcium

Calcium in soil

Calcium (Ca^{2+}) is a cation. Cations in soil are in dynamic equilibrium between the cation exchange sites on the cation exchange capacity (CEC) due to the soil clay minerals or organic colloids and the soil water solution. When a cation moves into the solution, the exchange site previously filled is replaced with other cations to balance the charge. Ca in soil can be utilized by organisms, leached with drainage water, adsorbed to the CEC sites, or precipitate as a calcareous compound. Plants can absorb cations from the soil solution and from the CEC sites (Brady and Weil, 2004).

Calcium and cell wall strength

Ca covalently bonds with polygalacturonic acid to form pectin in the middle lamella. Ca facilitates cell wall strength by cross linking pectin chains of the middle lamella thereby holding two cells together (Taiz and Zeigler, 2006; Havlin et al., 2005).

Cell wall degradation is accompanied by increases in cellulase and polygalacturase activity (Fischer and Bennett, 1991). Polygalacturase enzyme degrades polygalacturonic acid pectins (Havlin et al., 2005). Increasing calcium concentration will decrease polygalacturase activity resulting in less or slower cell wall degradation (Havlin et al., 2005). Logically, cell wall degradation increases with calcium deficiency and is associated with soft leaky tissue, increased

membrane permeability, and decreased turgor pressure. Increased fungal infection is associated with rapidly degrading cell walls (Miedes and Lorences, 2006).

Organic acids are formed during normal cellular respiration and can degrade cell walls. Calcium neutralizes the electrical charges of organic acids (Havlin et al., 2005).

Calcium and nutrient interactions

Ca enhances nitrate (NO_3^-) absorption; nitrate is used in protein formation and nitrogen metabolism (Havlin et al., 2005) (Proteins are important functional groups of plants regulating nearly every metabolic process).

Ca regulates monovalent cation absorption [potassium (K^+) and sodium (Na^+)]. Sodium can decrease plant photosynthetic rates and disrupt mineral nutrition (Montesano and Van Iersel, 2007). Sodium absorption is reduced when calcium occurs in a concentration sufficient (Havlin et al., 2005). Potassium is important to phloem sugar transport (Lester et al., 2005).

Functions of calcium in plant

Ca is essential for the translocation of carbohydrates and nutrients on a one time basis (Havlin et al., 2005; Follet et al., 2003). Carbohydrates remain in the leaves of Ca deficient plants making roots and stems experience deficiency. Carbohydrates are the product of photosynthesis and energy storage for plants. Ca in plants is considered immobile in plant tissues (Marschner, 1995). Only a small amount of Ca is phloem translocated after initial absorption through the xylem.

Ca is essential for cellular elongation; a calcium deficiency can reduce apical meristem growth (Havlin et al., 2005). A calcium deficiency is commonly referred to as ‘tip burn’, ‘die back’, ‘blossom end rot’, or ‘catfacing’ (malformations of fruit).

Ca is required for pollen germination and establishes cellular polarity to control the direction of pollen tube growth (Ge et al., 2007; Havlin et al., 2005). Raspberries and other flowering plants require pollen germination and pollen tube growth for fertilization to occur. Fertilization results in fruit.

Calcium mobilization has been implicated in papillae formation (Kohle et al., 1985; Marshall et al., 1985). Papillae are the accumulation of material between a host plant's cell wall and cell membrane at the point of fungal penetration. A papilla is usually composed of silicon, lignin and proteins (University of Sydney, 2008).

Calcium in raspberries

The Ca concentration of floricane leaves rises sharply at the very end of the season nearing a 2 % concentration (Wright and Waister, 1980). The rapid rise in Ca at the final sampling date was attributed to leaf senescence leading to the export of assimilates (Brierley and Landon, 1936). Ca tends to be bound in older leaves; however as a plant prepares for dormancy the bound nutrients are recovered from the leaves and exported to developing seeds.

Reported critical ranges for Ca in raspberry leaves are 0.6 - 2.5 % (U. of Minnesota, 2008; JH Biotech, Inc., 2007) and 0.5 - 2.5 % (Crandall, 1995).

This study was primarily concerned with calcium application. Secondary factors required attention. Plant growth can be limited by numerous elements. Leaf elemental concentrations measured were N, P, K, Ca, Mg, Zn, Mn, Fe, B, and Cu. The critical concentrations and use of these elements must be identified and understood before conclusions can be made regarding the crop response to the calcium application.

Methods and materials

Planting design and application

Rubus ideaus L. cv. 'Isabel' (US patent #9340) (Okie, 2000), a Driscolls proprietary variety, was planted February 6, 2006 on a 0.52 ha (1.3 acre) block in Watsonville, CA (36° 56' 10.07" N, 121° 42' 5.62" W). Rows measured 47.2 m (155 ft) in length with a 2.2 m (88 in) inter-row spacing. A split-block design was used consisting of six rows per treatment block. No replications existed. A total of two gallons per acre (8.46 L Biomin Calcium® ha^{-1}) was fertigated through a drip irrigation system at flower bloom initiation the first week; one gallon per acre (4.23 L Biomin Calcium® ha^{-1}) was applied weekly during the following thirteen weeks. The initial application was made on July 28, 2007. Biomin Calcium® weight 10.8 lbs gal^{-1}; thus one gallon contained 0.22 lb N (98 g) and 0.54 lb Ca (245 g).

Leaf sampling

Two areas of equal size within the control and treatment blocks were tissue sampled. The most recently matured leaves of fruiting canes (floricanes) were sampled. Approximately 50 leaves per treatment were sent weekly to SaferGro Laboratory, Inc. (in Ventura, CA) for analysis of N, P, K, Ca, Mg, Zn, Mn, Fe, Cu, and B. The first sampling date was July 28, 2007 and the last was November 15, 2007.

One tissue sample was taken from 'anchor' and 'middle' rows on October 30, 2007. (Raspberries in Watsonville are grown under annually installed steel arches covered with polyethylene. Rows with the 'anchors' for the arches often became compacted because a tractor cannot drive through for tillage and rain water drains to these central rows.) Control and treatment blocks contained an equal area of 'anchor' and 'middle' rows.

Soil and water sampling

Soil samples were taken from the root zone before the initial application (July 28, 2007) and near the end of the season (October 9, 2007). An 18 inch auger was used to remove soil plugs (Oakfield Apparatus Company. Oakfield, WI.). Samples were analyzed at SaferGro Laboratory Inc. for organic matter, S, P, K, Mg, Ca, Na, Zn, Mn, Fe, Cu, B, NO_3^-, pH, and total CEC with % of exchangeable K, Mg, Ca, and Na.

One well water sample was tested at SaferGro Laboratory Inc. for pH, EC (mmhos cm^{-1}), and hardness (as $CaCO_3$), plus Ca, Mg, K, and Na as mg L^{-1}).

Fruit sampling

Whiteboards were installed on the end posts of two rows in the test and control block. Each time rows were harvested, the number of crates and baskets was recorded (September 25, 2007 was the first day of harvest).

One basket from each whiteboard row was saved weekly. Fruit was measured for individual berry weight with a digital scale (Myweigh®, Flipscale F2, China). The Brix (sugar concentration) was measured using a hand held digital refractometer (Atago®, Pocket Refractometer PAL-1, Tokyo, Japan). A garlic press was used to squeeze juice from the fruit (eliminating seeds, etc.) onto the refractometer lens. The Brix of thirty berries was measured weekly. Juice was saved for pH measurements (pH Testr BNC Waterproof, Oakton Instruments™; Vernon Hills, IL). Six pH readings per treatment were taken weekly.

Fruit mineral analysis

Raspberry fruit harvested on November 7 and 15, 2007 was frozen for nutrient analysis. Additionally, the 'Pacifica' variety fruit from a Ventura, CA field and two store bought samples (purchased February 26, 2008) were analyzed.

Approximately 50 grams of berries per sample were oven dried 24 hours at 105 °C (Isotemp oven, Fisher-Scientific; Pittsburg, PA). Oven dry fruit were homogenized with mortar and pestle. Approximately one gram of homogenized dry fruit was weighed into separate ceramic crucibles with two replicates per treatment and sample. Crucibles with dry matter were dry-ashed in a muffle furnace (Isotemp programmable muffle furnace Model 14, Fisher-Scientific; Pittsburg, PA). The temperature was adjusted at 200 °C for two hours and ramped up to 550 °C for 5 hours (Onyeike and Acheru, 2002). Ashed samples were allowed to cool overnight. Dry ash in the crucibles was dissolved into 5.0 ml of 2 N HCl. Samples were heated without boiling and stirred periodically with glass stirring rods for 15 minutes. Liquid emulsion was passed through Whatman number 42 filter paper into 100 ml volumetric flasks by gravity flow. Crucibles and filter paper were rinsed five times with de-ionized water into the same volumetric flasks. The volumetric flasks were brought to the 100 ml total liquid volume with de-ionized water. Samples were analyzed for Ca, Mg, K, and Na using atomic absorption using the SpectrAA 55B Atomic Absorption Spectrometer (Varian Inc., Palo Alto, CA). Potassium samples were diluted 100 x to provide the appropriate reading range of the instrument. Approximately 0.2 g of oven dry homogenized fruit was weighed into crucibles for C, N, and S analysis. Two replicates per treatment were completed. Raspberry samples were combusted at 1150 °C and the gas stream was measured for C, N, and S (Elementar vario MAX CNS, Elementar Analysensysteme GmbH; Hanau, Germany).

Statistical evaluation

Basic descriptive statistics and paired t-test were performed with Minitab15 (Minitab Inc.®; State College, PA). Excel was used to produce tables (Microsoft Corporation©; Redmond, WA). Figures were created in SigmaPlot (SyStat Software Inc.©; San Jose, CA).

Results and Discussion

Introduction

The nutrient concentration of raspberry leaves differs with plant position (Hughes et al., 1979), genotype, date of sampling, and age of plant (John and Daubeny, 1972). Thus, comparisons throughout the season were only used to observe trends. Differences in element concentrations can exist between floricanes and primocanes (John et al., 1976; Wright and Waister, 1980). Thus, only floricanes were sampled.

Macronutrients

Nitrogen

N is the most limiting element for plant growth and is assimilated into amino acids and proteins (the building blocks for living organisms). Plant sources for N are nitrate (NO_3^-) and ammonium (NH_4^+). Most of the ammonium absorbed must be incorporated into organic compounds in the roots, whereas nitrate is xylem mobile. Thus, nitrate fertilizers stimulate plant growth faster than do ammonium fertilizers (Marschner, 1995).

Before the plant can use nitrate, it must be reduced to ammonium by nitrate reductase and nitrite reductase. Nitrate reductase activity can be inhibited or suppressed by a high ammonium concentration. Acidification results from ammonium absorption by roots (NH_4^+ exchanges two H^+ when NH_4^+ is assimilated). Nitrate reduction is an active process requiring energy (ATP) and reductants used in photosynthesis (i.e. creating competition for use). Additionally, nitrate (and ammonium) assimilation require carbohydrates having to be transported to the assimilation sites (Marschner, 1995). Thus, nitrogen metabolism in plants is a highly important process, but nitrogen metabolism is regulated by the availability of other elements and enzymes.

N concentrations decreased over the season with the initial decrease fastest in the pre-harvest growth period. The N levels fluctuated during the harvest period (Table 1, Fig. 1). N levels were higher in treated raspberries at the end of the season and on nine sample dates.

N concentrations were not significantly different using a paired t-test for each sample date (t = -0.69, 13 df, p-value = 0.505). Biomin Calcium® application did not change the nitrogen concentration.

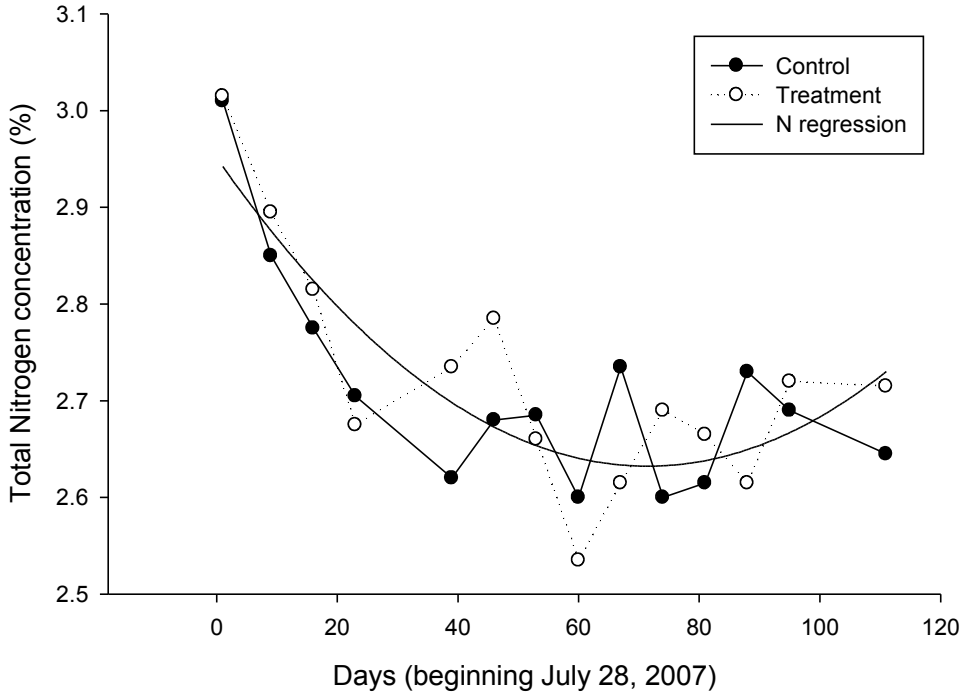

Figure 1. The total nitrogen concentration (%) of raspberry leaves. The ending date was November 15, 2007. The regression line for both control and treatment leaves was N – concentration = -0.0086*days + 0.000515*days^2 + 10.824 r^2= 0.76**.

N concentrations of raspberry floricane leaves decreased rapidly over the season from 3 % to 2 % (Wright and Waister, 1980). Decreasing N concentration from about 3.5 % to 2.5 % over a season was interpreted (Kowalenko, 1981; Papp et al., 1984). High nutrient levels exist in actively growing tissues, but the nutrients become diluted as the tissues enlarge (Smith, 1962).

Raspberry can be N-limited during periods of rapid growth (Kowalenko et al., 2000). Blackberry (*Rubus* spp.) plants (close relatives of raspberry) partition early season N into primocanes and fruit; late season N is partitioned into roots, crowns, and over-wintering primocanes (Malik et al., 1991; Mohadjer et al., 2001; Naraguma et al., 1999). Late season applied N partitioned into storage organs used for new growth the following season (Khemira et al., 1998; Sanchez et al., 1992). The pruning of canes (17 %) and normal leaf senescence (12 %) can represent significant percentages of total N lost throughout the growing season (Rempel et al., 2004). Increasing the N concentration in leaves can increase the yield (Papp et al., 1984), but must be done with caution to avoid encouraging vegetative growth instead of reproductive growth (fruiting).

The maximum N level was 3.02 % and the minimum was 2.54 % (Table 1). Reported critical ranges of nitrogen are 2.26 % - 3.0 % (Wilder and Righetti, 1991), less than 2.4 % (Chaplin and Martin, 1980), 2.75% - 4.00 % (JH Biotech, Inc., 2007), 2.2% - 3.5 % (U. of Minnesota, 2008), and 2.5 % - 4.0 % (Crandall, 1995). Plant growth was not N limited in this experiment and the N concentration decrease over the season was consistent with the published literature.

Table 1. Elemental concentration of most recently matured floricane raspberry leaves sampled in 2007. 'C' denotes non-treated control; 'T' denotes calcium treated plants.

Date	Total N^C	Total N^T	P^C	P^T	K^C	K^T	Ca^C	Ca^T	Mg^C	Mg^T
	Percent in dry tissue									
07/28	3.01	3.02	0.30	0.28	1.72	1.58	0.79	0.75	0.53	0.54
08/06	2.85	2.90	0.27	0.30	1.61	1.75	0.75	0.83	0.54	0.50
08/13	2.78	2.82	0.31	0.33	1.61	1.75	0.79	0.79	0.49	0.49
08/20	2.71	2.68	0.25	0.31	1.49	1.40	0.81	0.75	0.58	0.51
09/05	2.62	2.74	0.30	0.34	1.64	1.54	0.78	0.72	0.55	0.50
09/12	2.68	2.79	0.34	0.38	1.63	1.81	0.59	0.78	0.46	0.46
09/18	2.69	2.66	0.29	0.34	1.66	1.63	0.64	0.64	0.49	0.37
09/25	2.60	2.54	0.30	0.31	1.64	1.63	0.75	0.64	0.49	0.43
10/02	2.74	2.62	0.34	0.34	1.67	1.73	0.69	0.71	0.47	0.44
10/09	2.60	2.69	0.38	0.34	1.61	1.68	0.65	0.80	0.43	0.44
10/16	2.62	2.67	0.40	0.47	1.58	1.69	0.66	0.73	0.52	0.48
10/23	2.73	2.62	0.43	0.46	1.66	1.69	0.60	0.78	0.47	0.42
10/30	2.69	2.72	0.46	0.42	1.63	1.76	0.60	0.70	0.48	0.50
[1]11/08	2.68	2.76	0.38	0.25	0.83	0.73	0.21	0.30	0.38	0.43
11/15	2.65	2.72	0.33	0.27	1.56	1.59	0.90	0.18	0.50	0.48
Ave	2.71	2.72	0.33	0.35	1.62	1.66	0.71	0.77	0.50	0.47
± SE	0.03	0.03	0.02	0.02	0.01	0.03	0.03	0.03	0.01	0.01

Date	Zn^C	Zn^T	Mn^C	Mn^T	Fe^C	Fe^T	Cu^C	Cu^T	B^C	B^T
	Parts per million in dry tissue									
07/28	31.00	21.00	148.50	162.00	131.00	135.00	5.00	4.50	50.0	56.5
08/06	28.50	28.50	157.00	156.50	122.00	133.00	6.00	7.00	50.0	47.0
08/13	31.00	33.50	148.0	162.0	126.5	119.5	5	6	58.5	52.0

			0	0	0	0	.00	.00	0	0
			171.0	190.5	123.0	139.0	6	5	50.0	52.5
08/20	38.50	33.50	0	0	0	0	.50	.50	0	0
			171.0	177.5	135.0	139.0	5	5	55.0	48.5
09/05	37.50	36.50	0	0	0	0	.50	.00	0	0
			182.5	212.5	132.0	134.5	5	5	50.0	54.0
09/12	33.50	36.50	0	0	0	0	.00	.00	0	0
			172.0	179.5	132.0	122.0	4	7	56.0	55.5
09/18	33.50	30.50	0	0	0	0	.50	.00	0	0
			164.5	167.0	131.0	136.0	6	5	56.5	49.5
09/25	35.50	37.00	0	0	0	0	.00	.50	0	0
			179.5	196.0	119.5	125.0	7	7	50.0	59.0
10/02	39.00	38.50	0	0	0	0	.50	.00	0	0
			175.5	165.0	125.0	132.5	6	7	51.5	56.0
10/09	27.50	43.50	0	0	0	0	.00	.50	0	0
			192.5	210.0	144.5	137.0	7	8	52.0	54.0
10/16	35.50	42.50	0	0	0	0	.00	.00	0	0
			206.0	199.0	122.0	131.5	7	6	51.5	48.5
10/23	39.00	43.50	0	0	0	0	.00	.00	0	0
			203.5	217.5	128.5	131.0	5	6	50.5	57.5
10/30	34.00	43.50	0	0	0	0	.00	.50	0	0
[1]11/0			192.5	134.5	129.5	137.5	3	4	57.0	61.5
8	9.50	8.50	0	0	0	0	.50	.00	0	0
			185.5	215.0	136.0	164.5	6	4	57.0	49.0
11/15	37.50	41.00	0	0	0	0	.50	.00	0	0
			175.5	186.4	129.1	134.2	5	6	52.7	52.8
Ave	34.39	36.39	0	3	4	5	.89	.04	5	2
							0	0		
± SE	1.02	1.76	4.79	5.90	1.81	2.82	.25	.32	0.84	1.03

[1]Date was not included in analysis. Lab samples were possibly contaminated.

Phosphorus

P availability in soil can be limited. Adsorption, desorption, precipitation, dissolution, mineralization, immobilization, and leaching processes control P availability (Havlin et al., 2005). P is utilized by the plant as phospholipids (cell membranes), in nucleic acids (phosphate forms the backbone between ribonucleoside units of DNA and RNA), and as energy transfer molecules (ATP and ADP) (Marschner, 1995). P deficiencies can cause slow or stunted growth, delayed maturity, and poor fruit development.

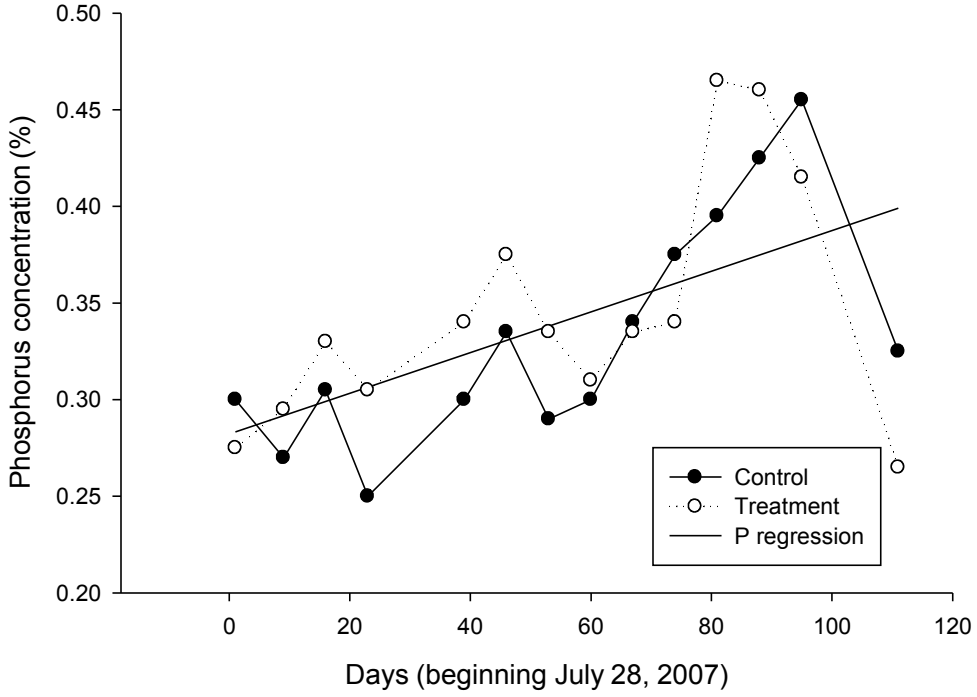

Figure 2. The Phosphorus concentration (%) of raspberry leaves. The ending date was November 15, 2007. The regression line for both control and treatment leaves was P – concentration = 0.0011*days + 0.2823, r = 0.59*.

Initially the P concentrations increased from July 28 until October 30, and afterwards the P concentration decreased. P concentrations were higher in the treatment nine sample dates (Table 1 and Fig. 2) and the concentrations were not significantly different using a paired t-test

for each sample date (t = -1.21, 13 df, p-value = 0.247). Biomin Calcium® application did not change the phosphorus concentration.

Critical ranges reported for phosphorus are 0.19 % - 0.45 % (Wilder and Righetti, 1991), 0.25 % - 0.60 % (JH Biotech, Inc., 2007), and 0.20 % - 0.50 % (U. of Minnesota, 2008). Phosphorus concentrations ranged from 0.25 % to 0.47 % (Table 1 and Fig. 2.) Raspberry growth was not likely P-limited.

Potassium

The ion K^+ is the most abundant cation in the cytoplasm making a major contribution to osmotic potential of cells and tissues. K is highly mobile in plants within cells, tissues, and the vascular system. K acts mainly as a charge carrier forming weak bonds with the complexes it is associated with (i.e. the bonds break and K^+ switches with another cation upon arrival at the plant destination). K in the cytoplasm and chloroplasts neutralizes the electrical charges of organic acids. K (and other univalent cations) induces conformational changes in enzyme proteins; over 50 plant enzymes require K^+ for activation. K deficient plants commonly accumulate carbohydrates (i.e. instead of partitioning the carbohydrates to other plant parts) and have a decreased starch concentration.

The K concentration fluctuated, but remained relatively constant (Table 1 and Fig. 3). The K concentration was not significantly different using a paired t-test for each sample date (t = -1.36, 13 df, p-value = 0.198). Biomin Calcium® application did not change the K concentration.

The K concentration decreased over the season from about 2 % (beginning) to about1.2 % (end) (Wright and Waister, 1980; Kowalenko, 1994b). All raspberries in the present study were fertigated with K throughout the fruiting cycle. This K fertilization may explain why K concentrations did not decrease (as occurred in previous studies).

The K concentration ranged from 1.4 % to 1.76 % (Table 1 and Fig. 3) Critical ranges reported for K in raspberry are 1.26 % - 2.00 % (Wilder and Righetti, 1991), 1.5 % - 3.00 % (JH Biotech, Inc., 2007), 1.1 % - 3.0 % (U. of Minnesota, 2008), and 1.0 % - 3.0 % (Crandall, 1995). Raspberry growth was not likely K limited.

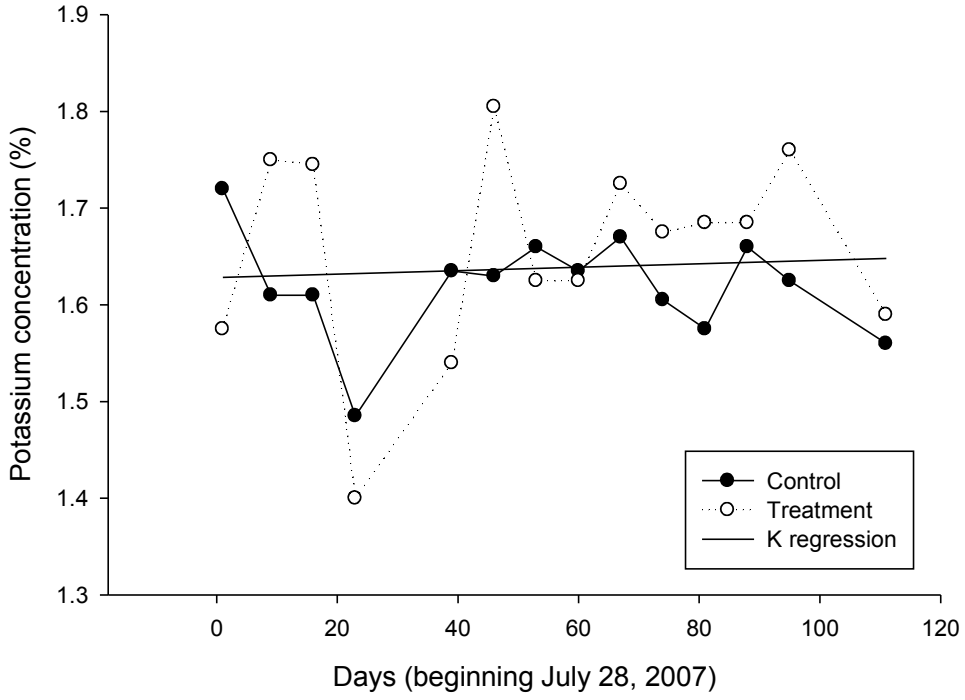

Figure 3. The Potassium concentration (%) of raspberry leaves. The ending date was November 15, 2007. The regression line for both control and treatment leaves was K – concentration = 0.0002*days + 1.6284, r = 0.07.

Calcium

The Ca concentration remained relatively constant with the control having higher Ca concentration on four sample dates (Table 1 and Fig. 4). The Ca concentration was not significantly different using a paired t-test for each sample date (t = -1.86, 13 df, p-value = 0.085). Biomin Calcium® application did not increase or decrease the calcium concentration of the sampled leaves.

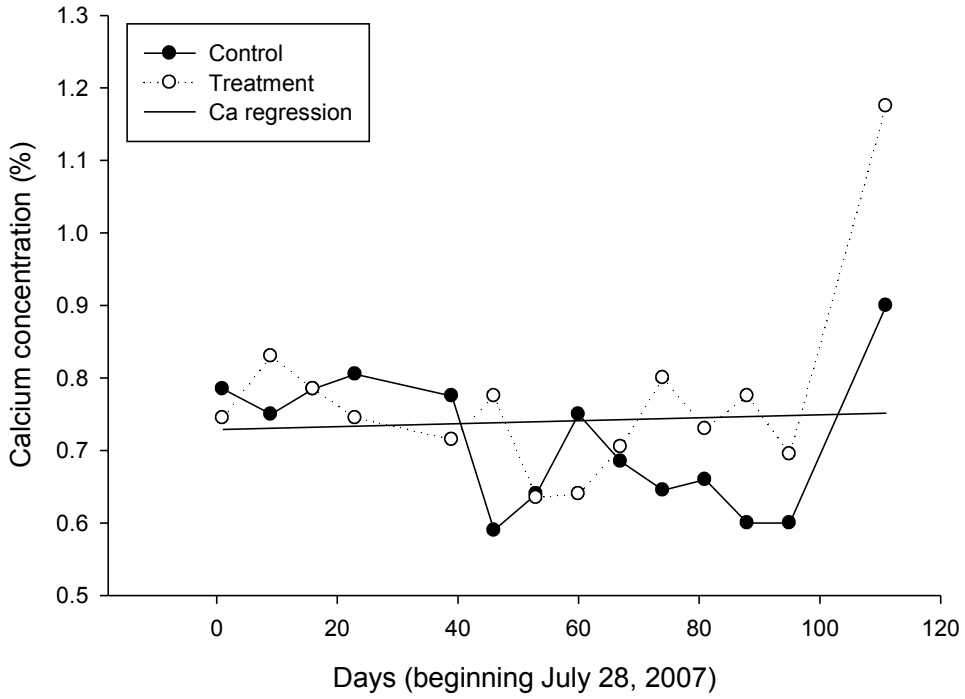

Figure 4. The Calcium concentration (%) of raspberry leaves. The ending date was November 15, 2007.
The regression line for both control and treatment leaves was Ca – concentration = 0.0002*days + 0.7288, r = 0.06.

The Ca concentration of various crops increases with age (Smith, 1962). The Ca concentration of floricane leaves rises sharply at the very end of the season (consistent with the observations of the present study) (Table 1 and Fig. 4) (Wright and Waister, 1980). Conversely, the Ca concentration of raspberry remained stable or slightly decreased depending upon the sampling position on the cane (Hughes et al., 1979).

The Ca concentration ranged from 0.59 % to 1.18 % (Table 1). Reported critical ranges for Ca in raspberry leaves were 0.6 % - 2.5 % (U. of Minnesota, 2008; JH Biotech, Inc., 2007) and 0.5 % - 2.5 % (Crandall, 1995). Raspberry growth was not likely limited by calcium.

Magnesium

Mg is the central atom of the chlorophyll molecule working during photosynthesis. Additionally, Mg plays a role in protein and ATP synthesis. A Mg deficiency cause decreases photosynthesis and reduces the accumulation of starches and sugars in leaves (Marschner, 1995). Sugars and starches are energy reserves for plants and their seeds (fruit). Excessive Mg in the soil can reduce absorption of Ca (and other cations).

The Mg concentration remained relatively stable (slightly decreasing over the season) (Table 1 and Fig. 5). The Mg concentration fluctuated over time with the control having a higher concentration on ten sample dates. The Mg concentration was significantly lower ($t_{.05}$) in the treatment using a paired t-test for each sample date ($t = -3.09$, 13 df, p-value = 0.009). Biomin Calcium® application decreased the Mg concentration in treated plants compared to non-treated control.

The Mg concentration was stable in floricane leaves at concentrations near 0.35 % (Wright and Waister, 1980). Conversely, the Mg concentration increases in various crops with tissue age (Smith, 1962).

The Mg concentration ranged from 0.37 % to 0.58 % (Table 1). Reported critical ranges for Mg were 0.3 % - 1.0 % (JH Biotech, Inc., 2007), 0.31 % - 0.60 % (Wilder and Righetti, 1991), 0.25 % - 0.80 % (U. of Minnesota), and 0.2 % - 1.0 % (Crandall, 1995). The Mg concentration was within the critical range, remained stable (consistent with previous studies), and decreased very slightly (as opposed to increasing as reported in previous studies). Thus, plant growth was likely not Mg limited.

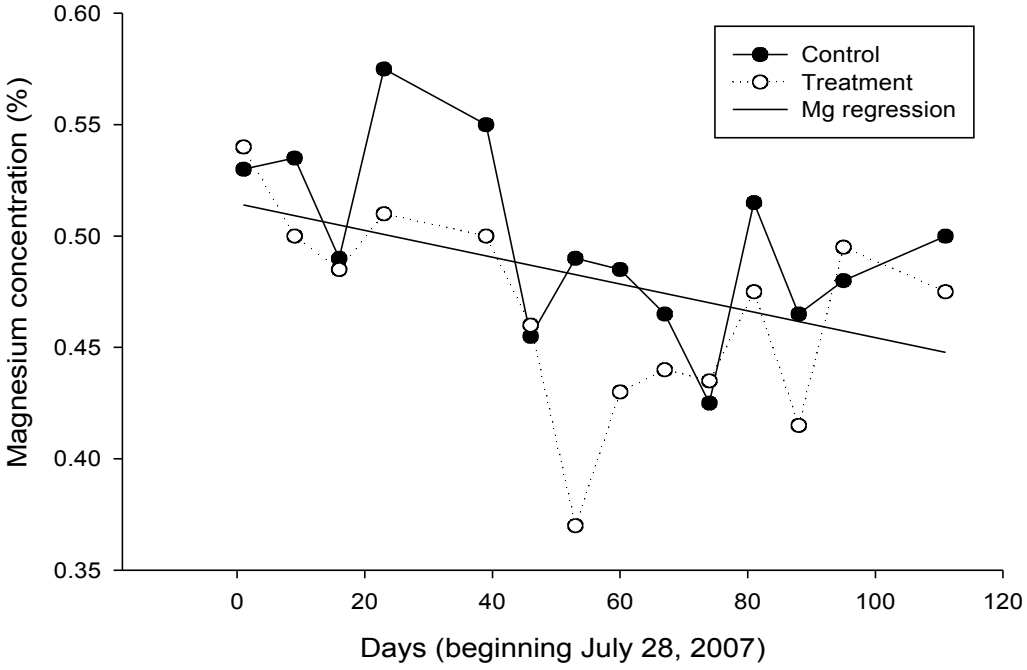

Figure 5. The Magnesium concentration (%) of raspberry leaves. The ending date was November 15, 2007. Regression line for both control and treatment leaves was Mg – concentration = -0.0006*days + 0.5146, r= -0.45.

Micronutrients

Zinc

Zn has structural and catalytic roles in enzyme reactions. Zn deficient plants accumulate amino acids rather, than synthesizing them into proteins. Zn is primarily ssociated with indoleacetic acid (IAA), the plant hormone responsible for cell elongation. Thus, Zn deficient plants often have stunted growth (Marschner, 1995).

The Zn concentration increased from 31 to 37.5 ppm Zn in the control and from 21 to 41 ppm Zn in the treatment (Table 1 and Fig. 6). Treatment concentrations were higher for eight sample dates. The Zn concentration was not significantly different using a paired t-test for each sample date (t = -1.18, 13 df, p-value = 0.260). Biomin Calcium® application had no effect on zinc concentration between treatments.

The Zn concentrations of raspberry primocane leaves decreased from about 70 ppm Zn (at the beginning) to about 15 ppm Zn (at the end) over a season, while floricane leaf concentrations decreased from about 60 to 20 – 40 ppm Zn in mid-season, and then increased to 20 – 60 ppm Zn by the end of the season (Kowalenko, 2005).

The Zn concentration ranged from 21 to 43.5 ppm Zn (Table 1). Reported critical concentrations for Zn were 25 – 80 ppm Zn (JH Biotech, Inc., 2007), 15 – 60 ppm Zn (U. of Minnesota, 2008), 16 – 50 ppm Zn (Wilder and Righetti, 1991), and 13 – 80 ppm Zn (Crandall, 1995). Plant growth was not likely Zn limited.

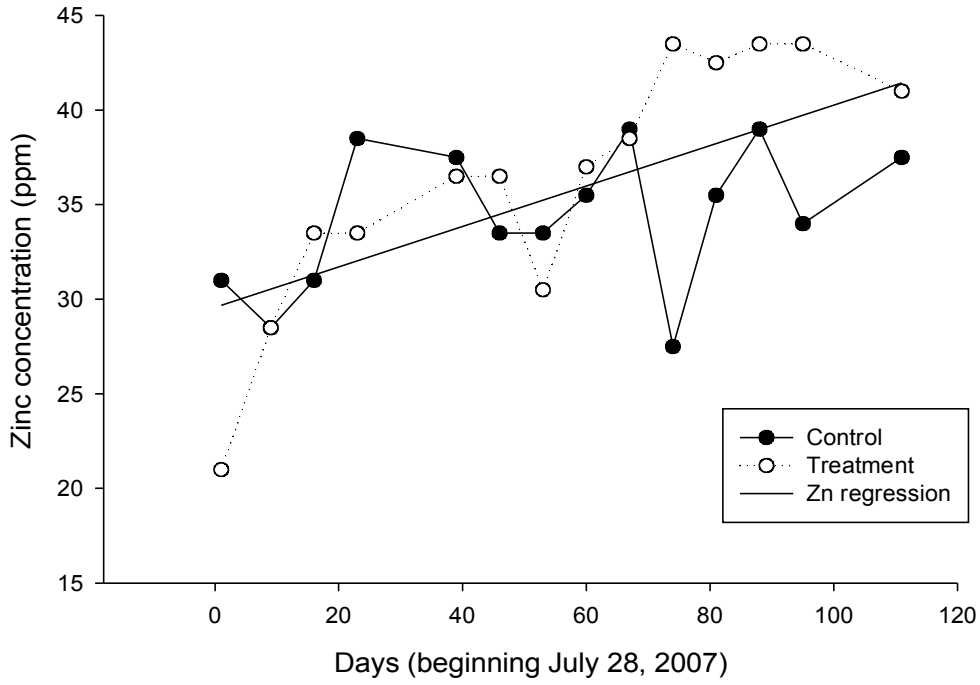

Figure 6. The Zinc concentration (ppm) of raspberry leaves. The ending date was November 15, 2007. Regression line for both control and treatment leaves was Zn – concentration = 0.1068*days + 29.5729, r= 0.66*.

Manganese

Mn has an important functional role in oxidation-reduction reactions. Mn is primarily utilized by photosystem II reactions when water molecules are split and electrons must be absorbed quickly (Marschner, 1995). Most Mn in plants is sequestered in the vacuoles creating a high tolerability to excessive Mn. Inadequate compartmentalization or toxicity of Mn causes a decrease in net photosynthesis. This decrease is caused by inhibition of RuBP (Ribulose biphosphate) carboxylase reactions occuring when Mg is replaced by Mn in the RuBP carboxylase enzyme binding to carbon dioxide in the stomata during transpiration.

The Mn concentration increased from 148.5 to 185.5 ppm Mn in the control and from 162 to 215 ppm Mn in the treatment (Table 1 and Fig. 7). The Mn concentrations fluctuated with the treatment having a higher concentration at eleven sampling dates. The Mn concentration was highly significantly higher ($t_{.01}$) in the treatment using a paired t-test for each sample date ($t = -3.39$, 13 df, p-value = 0.005). Biomin Calcium® application increased the Mn concentration in treated plants compared to non-treated control.

The Mn concentration was as high as 600 ppm in raspberry leaves (Kowalenko, 1981). The high Mn concentration was associated with the high N-fertilizer application and a subsequent soil pH drop. (When NH_4^+ is nitrified the soil pH decreases; a decrease in pH is associated with higher metal micronutrient solubility). The Mn concentration in old and young canes began below 200 ppm and increased with increasing N-application.

The Mn concentration ranged from 148 to 217.5 ppm Mn (Table 1.). Reported critical concentrations for Mn in raspberry leaves were 50 – 150 ppm Mn (JH Biotech, Inc., 2007), 25 – 300 ppm Mn (U. of Minnesota), 51 – 300 ppm Mn (Wilder and Righetti, 1991), and 20 – 300 ppm Mn (Crandall, 1995). Plant growth was not likely Mn limited.

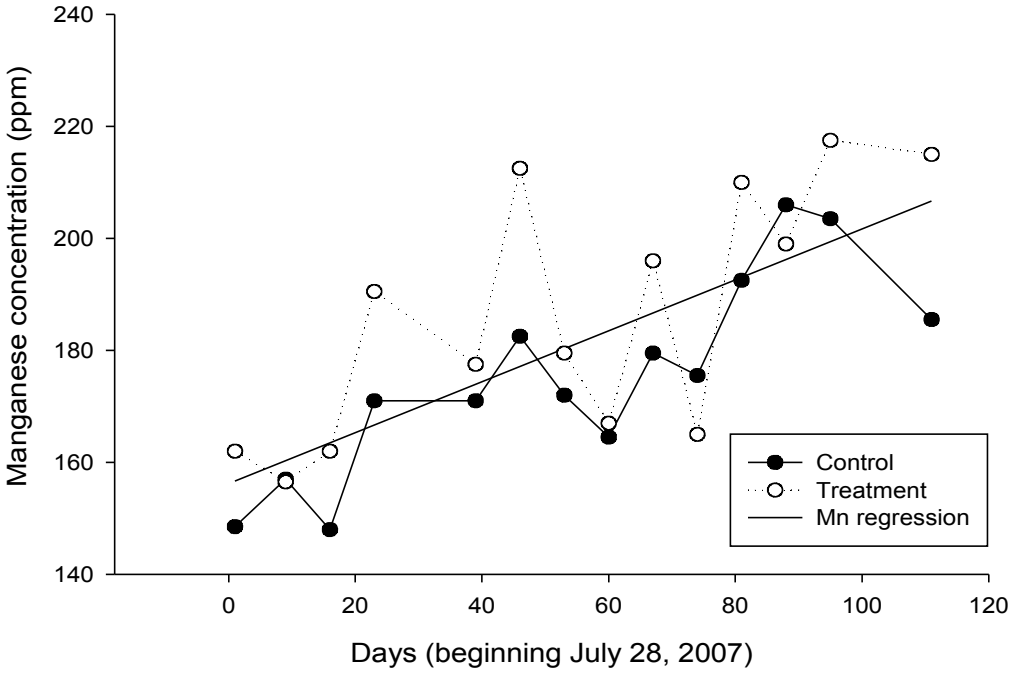

Figure 7. The Manganese concentration (ppm) of raspberry leaves. The ending date was November 15, 2007. The regression line for both control and treatment leaves was Mn – concentration = 0.4544*days + 156.1958, r = 0.73**.

A 150 ppm Mn concentration was a toxicity threshold for Mn (JH Biotech, Inc., 2007). Mn concentrations have been reported (U. of Minnesota; Wilder and Righetti, 1991; Kowalenko, 1981). Additionally, 1000 ppm Mn was a toxic concentration for Mn (Crandall, 1995). Mn toxicity was not likely experienced in these raspberries.

Iron

Fe functions in oxidation-reduction reactions. Cytochromes contain Fe. Cytochromes are constituents of the redox system in plant chloroplasts, mitochondria, and the redox chain in nitrate reductase. Fe is a part of the catalase and peroxidase enzymes decomposing hydrogen peroxide into water. Hydrogen peroxide is a harmful byproduct of photosynthesis (given certain parameters) denaturing proteins and degrading cell membranes (Marschner, 1995).

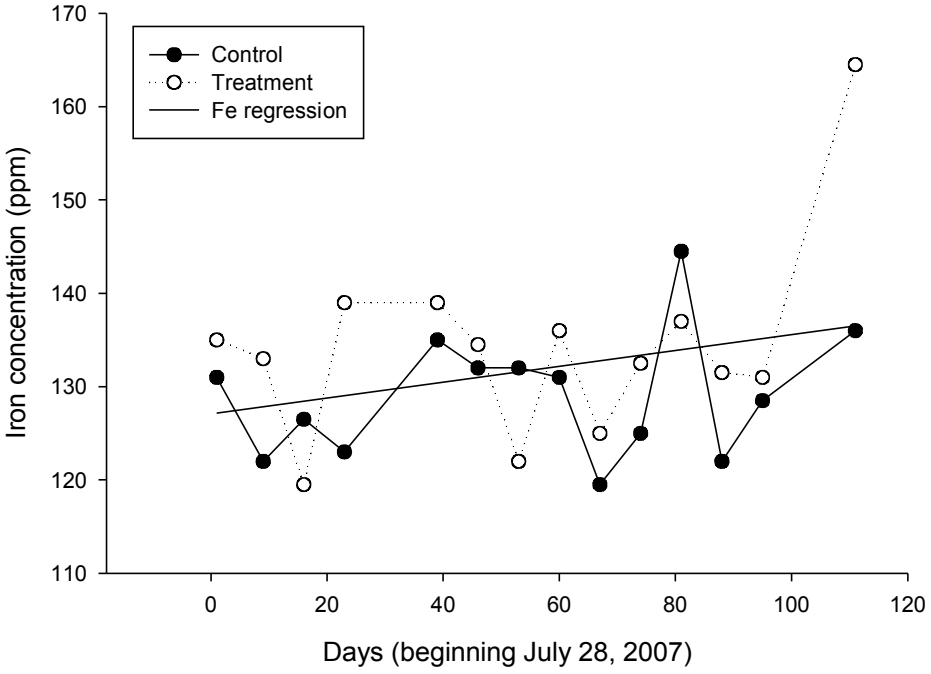

Figure 8. The Iron concentration (ppm) of raspberry leaves. The ending date was November 15, 2007. The regression line for both control and treatment leaves was Fe – concentration = 0.848*days + 127.0739, r = 0.31.

The Fe concentrations fluctuated with the treatment having a higher concentration for twelve sample dates (Table 1 and Fig. 8). The Fe concentration was not significantly different using a paired t-test for each sample date (t = -1.93, 13 df, p-value= 0.076). Biomin Calcium® application did not increase or decrease the Fe concentration.

The floricane leaf Fe concentrations of raspberry were variable, but increased throughout the season in a range of 100 to 600 ppm Fe (Kowalenko, 2005). The Fe concentrations ranged from 148 to 157 ppm Fe (Nelson and Jolley, 1984).

The Fe concentrations ranged from 119.5 to 164.5 ppm Fe (Table 1). Reported critical concentrations for Fe in raspberry were 50 – 200 ppm Fe (JH Biotech, Inc., 2007; U. of Minnesota, 2008) and 30 – 150 ppm Fe (Crandall, 1995). Fe was toxic at a concentration exceeding 250 ppm Fe (Crandall, 1995). The Fe concentration was within the reported critical ranges and below toxic concentration, and was consistent with previous studies making plant growth not likely limited by Fe.

Copper

The majority of Cu functions are enzymatic oxidation-reduction reactions. Plastocyanin (a component of the electron transport chain in photosystem I) and plastoquinones (electron carriers between photosystem II and I) contain Cu. Other chloroplast enzymes require Cu. Cu-Zn-superoxide dismutase is an enzyme capable of detoxifying peroxides produced during photorespiration (Peroxides are reduced oxygen species capable of destroying cell membranes.). Cytochrome oxidase (the terminal oxidase of the mitochondrial electron transport chain) contains Cu (and Fe). The mitochondria are the energy processing components of cells. Numerous other enzymes require copper to function properly. Redox reactions decrease sharply with a Cu deficiency (Marschner, 1995).

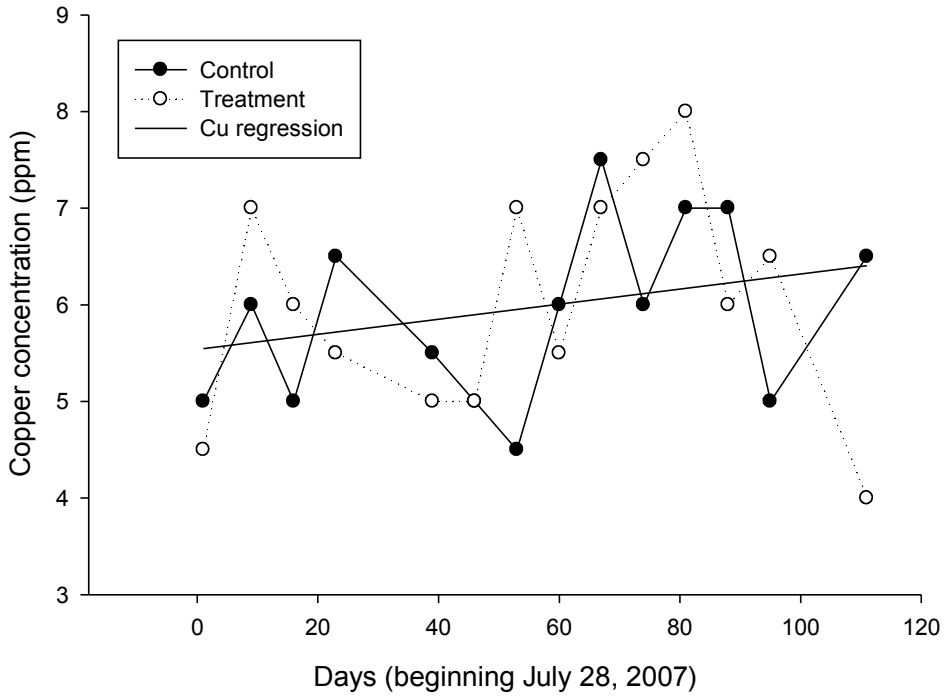

Figure 9. The Copper concentration (ppm) of raspberry leaves. The ending date was November 15, 2007. The regression line for both control and treatment leaves was Cu – concentration = 0.0078*days + 5.5384, r= 0.24.

The Cu concentration remained relatively stable throughout the season, with the treatment concentration being higher for seven times (Table 1 and Fig. 9). The Cu concentration was not significantly different using a paired t-test for each sample date ($t = -0.40$, 13 df, p-value = 0.693). Biomin Calcium® application did not increase or decrease the Cu concentration.

The Cu concentration of floricane leaves decreased as the season progressed from about 17 to about 6 ppm Cu, while the primocane leaves followed a similar pattern (Kowalenko, 2005).

The Cu concentration ranged from 4 to 8 ppm Cu (Table 1). Reported critical concentration ranges for Cu were 5 – 50 ppm Cu (JH Biotech, Inc., 2007), 6 – 15 ppm Cu (Wilder and Righetti, 1991), 4 – 20 ppm Cu (U. of Minnesota), and 1 – 50 ppm Cu (Crandall, 1995). The Cu concentration was within the lower portion of the critical range reported by other researchers. Plant growth was not likely limited by Cu.

Boron

B is neither an enzyme constituent nor a plant catalyst. Sugar transport, cell wall synthesis, lignifications, cell wall structure, carbohydrate metabolism, RNA metabolism, respiration, indole acetic acid metabolism, phenol metabolism, and membranes are hypothesized purposes for B (Marschner, 1995). B has been the main micronutrient increasing yields of raspberries in various places worldwide (Dale, 1986).

The B concentration in primocane leaves decreased from 80 - 20 ppm B (at the beginning) to 80 ppm – 10 ppm B (at the end) during the growing season (Kowalenko, 2005). Floricane leaves remained relatively constant in B concentration over the season ranging between 15 – 50 ppm B. The primocane leaf B concentration decreased from 45 to about 15 ppm B over the season (Kowalenko, 2006).

Boron deficiency decreased the plant size, growth of laterals, and caused "die-back" symptoms (Askew et al. 1951; Monk 1955). Delayed bud break, dead buds near primocane tips, fern-like leaves, and dieback of new growth were common B deficiency symptoms (Crandall, 1995).

B and Mn concentrations did not respond to B and Mn applications (Askew et al., 1951b; Monk, 1955; Ljones, 1963; Chaplin and Martin, 1980; Kowalenko 1981). The lack of response could represent a direct source-sink relationship of B within the fruit.

The B concentration remained relatively stable with the treatment having higher concentrations for nine sample dates (Table 1 and Fig. 10). The B concentration was not significantly different using a paired t-test for each sample date ($t = -0.05$, 13 df, p-value = 0.964). Biomin Calcium® application did not increase or decrease the B concentration.

The B concentration ranged from 48.5 to 59 ppm B (Table 1). Reported critical ranges for B concentration were 31– 70 ppm B (Wilder and Righetti, 1991), 30– 80 ppm B (JH Biotech, Inc., 2007; Crandall, 1995), and 25– 300 ppm B (U. of Minnesota, 2008). The B concentration was within the critical range making plant growth not likely B limited.

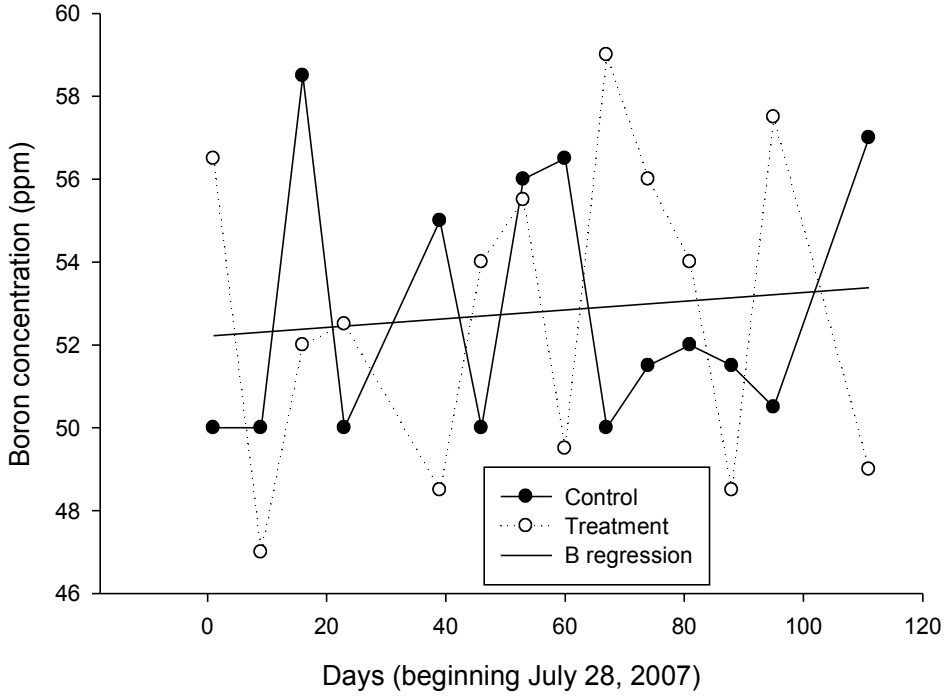

Figure 10. The Boron concentration (ppm) of raspberry leaves. The ending date is November 15, 2007. The regression line for both control and treatment leaves was B – concentration = 0.0105*days + 52.2132, r= 0.1.

Conclusion of macro and micro element concentrations

The elemental concentrations of the most recently mature floricane leaves fluctuated throughout the season for each element tested. Deciding if plant growth was limited by mineral nutrition became a difficult task. First, the reported critical element concentrations were not entirely congruent. Additionally, the elemental concentrations vary with position on the cane (Hughes et al., 1979), genotype, date of sampling, and cane age (John and Daubeny, 1972). Finally, floricane leaf sampling was not a representative sample of whole plant elemental nutrition (Kowalenko, 1981, 1994a, 1994b).

To make a decision regarding nutrient sufficiency, consistencies had to be found. The element concentration fluctuations were consistent with previous studies (Kowalenko, 1981; Kowalenko, 1994a, 1994b; Wright and Waister, 1980; Kowalenko, 2005; Kowalenko, 2006).

The concentration of each element was within the published critical ranges at nearly every sample date. The growth of raspberry was not likely limited by any one of the tested elements (given the current literature found on raspberry plant nutrition).

Nutrient ratios

Nutrient ratios are a method of examining nutrient interactions. When plotted against time, one can see antagonism or synergism of elements as time progresses. Certain elements are involved in aggregated functions; pairing elements by function and plotting over time is useful when examining functional response of plants over time.

Nitrogen / Phosphorus ratio

The N / P ratio represents overall shoot growth. N is a constituent of amino acids and proteins, while P is involved in metabolic energy. Amino acids and proteins are fundamental functional groups regulating growth, while P supplies the energy needed for growth.

The N / P ratio decreased as the season progressed (Figure 11, Table 2). As the raspberry plant entered reproductive growth, the overall modular growth decreased. The N / P ratio was not significantly different using a paired t-test for each sample date ($t = 0.91$, 13 df, p-value= 0.381). Biomin Calcium® application had no effect on the N / P ratio between treatments.

N / P ratio was 16:1 (Kowalenko, 1994b) and 10:1 (Kowalenko, 1994a). A N / P ratio of 7.14:1 occurred at the beginning, and 12.67:1 occurred at the end of the season (Wright and Waister, 1980).

A season N / P ratio was 1.7: 1 from the apical portion of raspberry cane leaves (Hughes et al., 1979). The N / P ratio was 2.3:1 for the lower portion of the cane in the beginning of the season, and 5.4:1 for the end of the season. The lower ratio occurred at the top of the cane

representing fruit set, and subsequent ending of modular growth. The increasing N / P ratio at the bottom of the cane remains unexplained.

The N / P ratio relatively high or increased as the season progressed in other studies. The opposite was observed in the current study. The explanation could lie in the genotype differences of element absorption and assimilation. The current study focused on fruit set. Vegetative growth was not desired once flower set and bloom initiated and was demonstrated by the decreasing N / P ratio (Fig. 11).

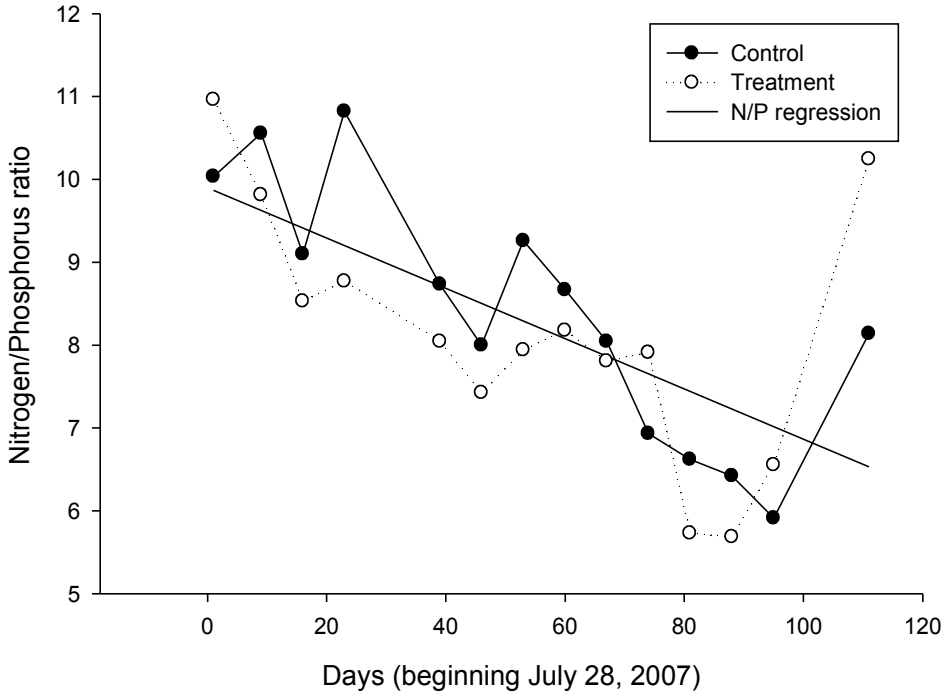

Figure 11. The Nitrogen / Phosphorus ratio of raspberry leaves. The ending date was November 15, 2007. The regression line for both control and treatment leaves was N /P ratio = 0.0105*days + 52.2132, r = -0.1.

Table 2. The 2007 nutrient concentration ratios of raspberry leaves. 'C' denotes control; 'T' denotes treatment.

Date	N/P^C	N/P^T	K/Mg^C	K/Mg^T	Ca/Mg^C	Ca/Mg^T	Ca/K^C	Ca/K^T
07/28	10.03	10.96	3.25	2.92	1.48	1.38	0.46	0.47
08/06	10.56	9.81	3.01	3.50	1.40	1.66	0.47	0.47
08/13	9.10	8.53	3.29	3.60	1.60	1.62	0.49	0.45
08/20	10.82	8.77	2.58	2.75	1.40	1.46	0.54	0.53
09/05	8.73	8.04	2.97	3.08	1.41	1.43	0.47	0.46
09/12	8.00	7.43	3.58	3.92	1.30	1.68	0.36	0.43
09/18	9.26	7.94	3.39	4.39	1.31	1.72	0.39	0.39
09/25	8.67	8.18	3.37	3.78	1.55	1.49	0.46	0.39
10/02	8.04	7.81	3.59	3.92	1.47	1.60	0.41	0.41
10/09	6.93	7.91	3.78	3.85	1.52	1.84	0.40	0.48
10/16	6.62	5.73	3.06	3.55	1.28	1.54	0.42	0.43
10/23	6.42	5.68	3.57	4.06	1.29	1.87	0.36	0.46
10/30	5.91	6.55	3.39	3.56	1.25	1.40	0.37	0.39
11/15	8.14	10.25	3.12	3.35	1.80	2.47	0.58	0.74

Date	B/Ca^C	B/Ca^T	Mn/Fe^C	Mn/Fe^T	Fe/Zn^C	Fe/Zn^T	Zn/Cu^C	Zn/Cu^T
07/28	63.69	75.84	1.13	1.20	4.23	6.43	6.20	4.67
08/06	66.67	56.63	1.29	1.18	4.28	4.67	4.75	4.07
08/13	74.52	66.24	1.17	1.36	4.08	3.57	6.20	5.58
08/20	62.11	70.47	1.39	1.37	3.19	4.15	5.92	6.09
09/05	70.97	67.83	1.27	1.28	3.60	3.81	6.82	7.30
09/12	84.75	69.68	1.38	1.58	3.94	3.68	6.70	7.30
09/18	87.50	87.40	1.30	1.47	3.94	4.00	7.44	4.36
09/25	75.33	77.34	1.26	1.23	3.69	3.68	5.92	6.73
10/02	72.99	83.69	1.50	1.57	3.06	3.25	5.20	5.50
10/09	79.84	70.00	1.40	1.25	4.55	3.05	4.58	5.80
10/16	78.79	73.97	1.33	1.53	4.07	3.22	5.07	5.31
10/23	85.83	62.58	1.69	1.51	3.13	3.02	5.57	7.25
10/30	84.17	82.73	1.58	1.66	3.78	3.01	6.80	6.69
11/15	63.33	41.70	1.36	1.31	3.63	4.01	5.77	10.25

Calcium / Potassium ratio

The Ca / K ratio is representative of plant structure formation. Ca binds cell walls together and K regulates sugar and cellulose formation. The Ca / K ratio could indicate quality of fruit. Quality would be measurable with Brix (sugar content) and firmness (not tested). If cell walls were firmer, fewer fruit would be culled. Fewer culled fruit could be one component of increased yield (marketable yield instead of total yield was analyzed).

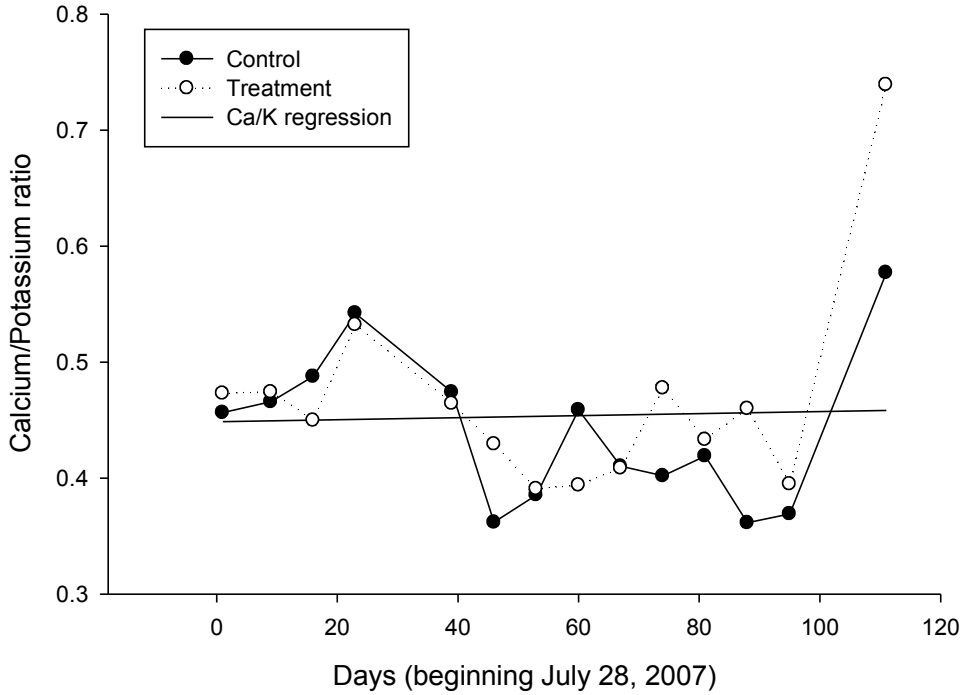

Figure 12. The Calcium / Potassium ratio of raspberry leaves. The ending date was November 15, 2007. The regression line for both control and treatment leaves was Ca / K ratio = 0.00008*days + 0.4485, r = 0.03).

The Ca / K ratio remained stable throughout the season (Table 2 and Fig. 12). The Ca / K ratio was not significantly different using a paired t-test for each sample date (t = -1.60, 13 df, p-value = 0.134). Biomin Calcium® application did not increase or decrease the Ca / K ratios.

Ca / K ratio was interpreted from a previous study (Hughes et al., 1979). The apical section had a Ca / K ratio of 1.35:1 at the beginning and a Ca / K ratio of 1.5:1 at the end. The

bottom leaves had a Ca / K ratio of 2.5:1 at the beginning of the season and a Ca / K ratio of 3.9:1 for the end of season. The ratio was higher than was found in the current study.

Ca / K ratio from floricane leaves was interpreted from a previous study (Kowalenko, 1994b). The Ca / K ratio of 0.47:1 occurred in floricane leaves at the beginning and the Ca / K ratio was 1.25:1 at the end of the season. The beginning Ca / K ratio of Kowalenko (1994b) was consistent with those in the current study.

Comparing the interpreted ratio from previous studies allowed differences in cultivars, soils, and cultural practices to skew comparisons. The Ca / K ratio in the current study remained stable throughout the growing season.

Calcium / Magnesium ratio

Both Ca and Mg compete with each other for absorption and use within the plant. Mg can cause a Ca deficiency by suppressing Ca absorption. Ca and Mg deficiencies can occur for short periods of time; sampling may not always coincide with the specific deficiency conditions. Plants need a constant supply of Ca, because Ca is rarely remobilized within the plant. The Ca / Mg ratio represents competition between these two cations.

The Ca / Mg ratio increased more in the treatment than in the control (Table 2 and Fig. 13). The Ca / Mg ratio was significantly higher ($t_{.01}$) in the treatment using a paired t-test for each sample date ($t = -3.55$, 13 df, p-value = 0.004). The Biomin Calcium® application increased the Ca / Mg ratio in treated plants compared to non-treated control. The Mg concentration of treated plants was significantly decreased by the Biomin Calcium® application. The decrease in Mg concentration in treated plants was reflected in the increase in the Ca / Mg ratio for treated plants.

The Ca / Mg ratio was interpreted from Kowalenko (1994b). The Ca / Mg ratio was 3:1 at the beginning and was 5:1 at the end of the season. The Ca / Mg ratio of 1.48:1 in the beginning of the season and the Ca / Mg ratio of 1.7:1 at the end of the season were interpreted for the apical section of the cane (Hughes et al., 1979). Lower leaves had a beginning Ca / Mg ratio of 2.1:1 and ending Ca / Mg ratio of 1.9:1. The increasing ratios reported by Hughes et al. (1979) are more consistent with those of the current study.

A Ca / Mg ratio less than 1:1 can cause Ca deficiency symptoms (Bradfield and Guttridge, 1981). The Ca / Mg ratio in the current study was sufficiently above 1:1 to preclude a possible calcium deficiency. Competition between Ca and Mg probably did not cause any Ca deficiency. Treated plants responded to the increased Ca concentration in the root zone by increasing the Ca / Mg ratio thereby demonstrating cation competition.

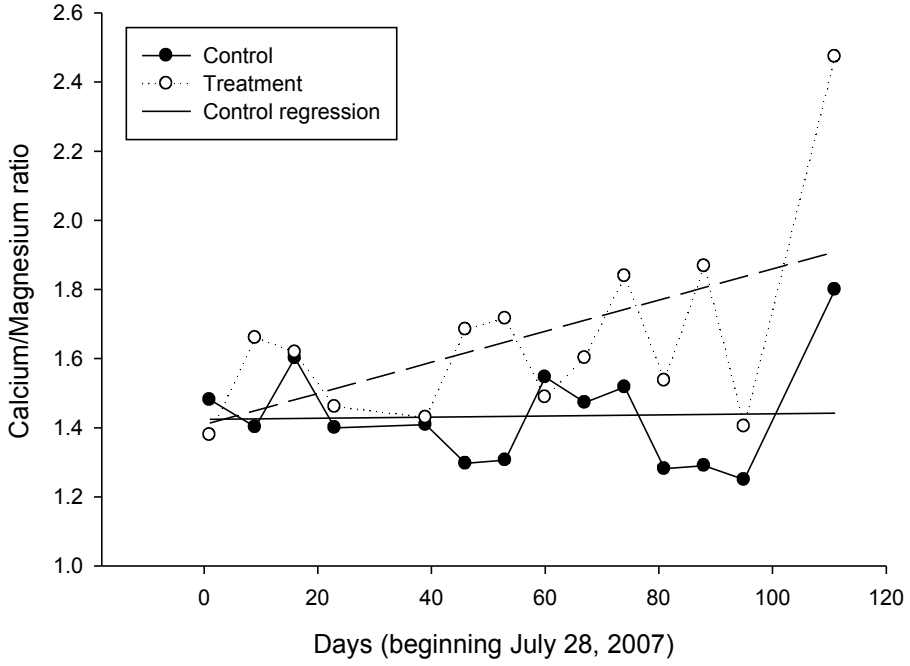

Figure 13. The Calcium / Magnesium ratio of raspberry leaves. The ending date was November 15, 2007. The regression lines for both control and treatment leaves were Control

Ca / Mg ratio = 0.0002*days + 1.4238, r = 0.03 and Treatment Ca / Mg ratio = 0.0045*days + 1.4091, r = 0.54*.

Iron / Manganese ratio

The Fe / Mn ratio represents electron transfer in the plant. Electron transfer is the ultimate form of energy used by plants. Both Fe and Mn are involved in oxidation-reduction reactions within plant cells.

The Fe / Mn ratio decreased as the season progressed (Table 2 and Fig. 14). The Fe / Mn ratio was not significantly different using a paired t-test for each sample date (t = 0.84, 13 df, p-value 0.415). The Biomin Calcium® application did not change the Fe / Mn ratio.

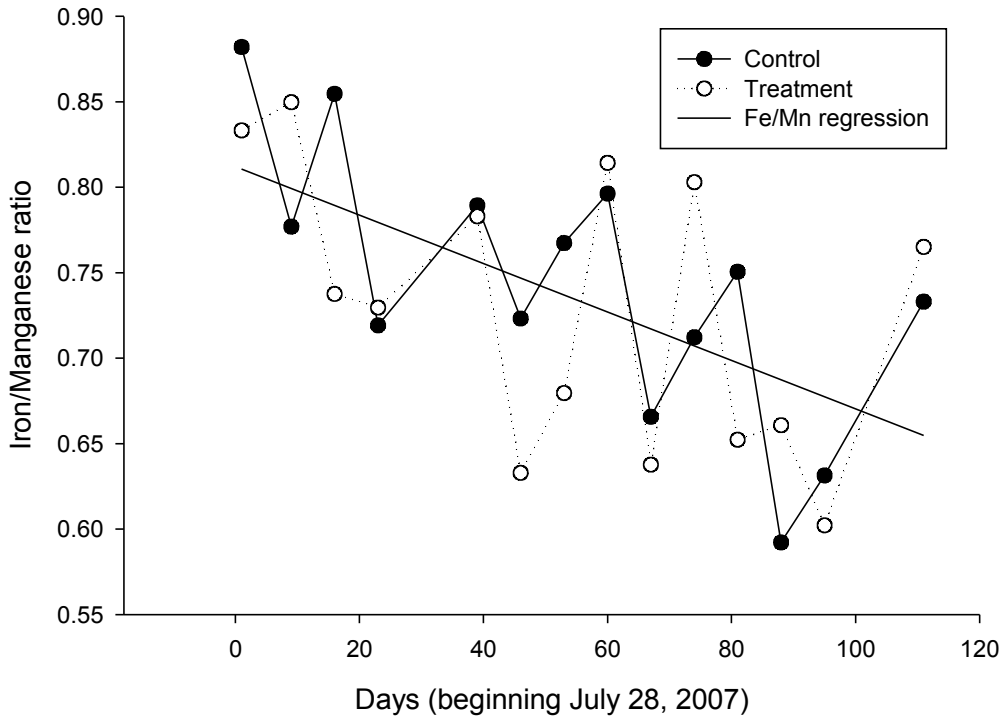

Figure 14. The Iron / Manganese ratio of raspberry leaves. The ending date was November 15, 2007. The regression line for both control and treatment leaves was Fe /Mn ratio = -0.0014*days + 0.8121, r = -0.59**).

Mn absorption was aided by short term anaerobic conditions in the soil. Manganese oxide precipitates were probably made soluble because of precipitation in September and October (Table 3). Water drained off the hoops and into the 'anchor' rows. (Recall, raspberries were grown under polyethylene hoops. 'Anchor' rows were rows with the bracing for the arches.). Compaction and excessively wet soil conditions were observed in 'anchor' rows following rainfall.

Table 3. Nutrient concentrations for the most recently mature raspberry leaves sampled 10/30/2007 from 'middle' and 'anchor' rows.

Row	Total N	P	K	Ca	Mg	Zn	Mn	Fe	Cu	B
	% dry weight					ppm dry weight				
Anchor	2.69	0.49	1.65	0.55	0.43	27	221	117	6	48
Middle	2.73	0.43	1.70	0.68	0.50	31	197	153	4	55

Anaerobic conditions increase the solubility of Mn^{2+} ions via reduction by anaerobic microbial organisms. A tissue sample of 'anchor' and 'middle' rows confirmed increased Mn concentration in 'anchor' rows (Table 4). This increased Mn concentration was coupled with a decreased Fe concentration in 'anchor' row plants. Normally Fe and Mn ions would increase in concentration in the plants with anaerobic conditions. The Fe decrease may reflect cation competition in the plant. Leaf samples for the treatments were possibly skewed by the differing conditions in 'anchor' and 'middle' rows.

The treatment and control blocks had equal numbers of 'anchor' and 'middle' rows thereby removing any possible outside error. Treatment and control Fe / Mn ratio followed each other closely (Fig. 14). Increased Mn absorption was coupled with a decreased Fe absorption, but this was not reflected in any change in plant health; both elements were within the critical concentration ranges.

Conclusion nutrient ratios

Nutrient ratios are a valuable tool for analyzing whole plant functions or nutrient interactions. The N / P ratio was not changed by Ca application. The N / P ratio declined in modular growth as the season progressed. The Ca / K ratio was not changed by the Ca application. Structural formation was relatively stable as the season progressed. The Fe / Mn ratio was not changed by the Ca application. The decreasing Fe / Mn ratio over the season could be partially attributable to the anaerobic conditions in the root zone leading to microbes solubilizing Mn more effectively than CO_2.Rainfall draining into the 'anchor' rows caused anaerobic conditions to exist. The Ca / Mg ratio increased from the Ca application. Both the Ca absorption and concentration in the plant was increased due to the Ca application.

Fruit analysis

Brix

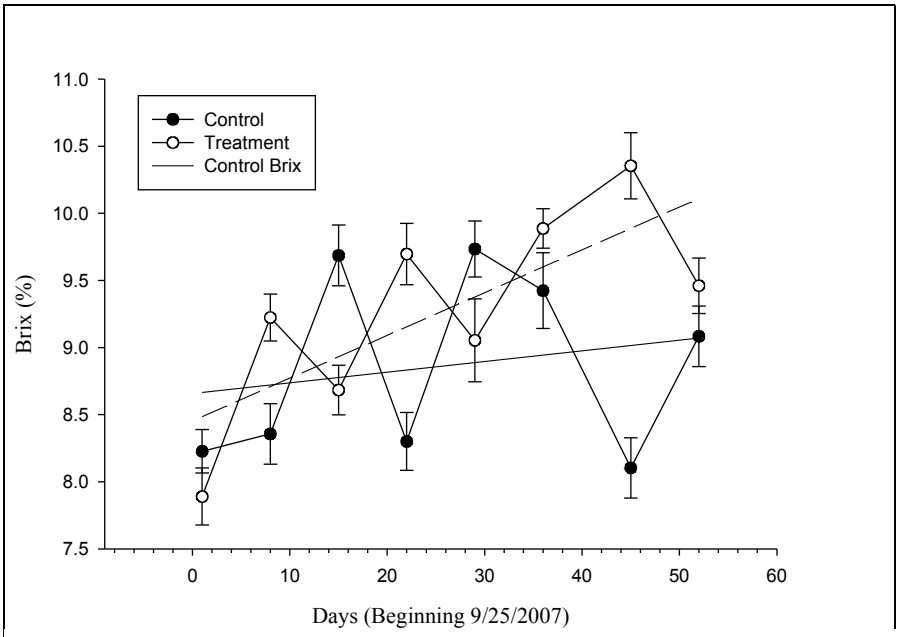

Figure 15. The Brix concentration over the season. Error bars represent the standard error bar of the mean. (Control Brix = 0.0079*days + 8.6577, r=0.2) (Treatment Brix = 0.0319*days + 8.4523, r= 0.75**).

Brix is a measurement of the mass ratio of dissolved sugar to water in a liquid. Brix is representative of sugar concentration (sucrose, glucose, fructose, etc.).

Brix concentrations were highly variable over the season (Table 4 and Fig. 15). The control Brix value was 8.86 ± 0.24 % [mean ± SE (standard error) of mean] and treatment Brix value was 9.28 ± 0.27 % for the whole season. The treated fruit had a higher Brix value four sample dates, and a lower Brix value for two sample dates. The trend was for Brix to be higher in the treatment, but the equation was not significantly different for predicting the Brix value. No significant difference was found using a paired t-test (t-value = -1.08, 7 df, p-value = 0.315).

Table 4. The 2007 average raspberry Brix concentration with the standard error of the mean, count, and range.

	Control					Treatment				
				Range					Range	
Date	Brix	SE	N	Min	Max	Brix	SE	N	Min	Max
	%					%				
09/25	8.23	0.16	30	6.6	10.0	7.89	0.21	30	5.0	9.5

10/02	8.36	0.23	30	6.1	11.6	9.22	0.18	30	7.3	11
10/09	9.69	0.23	30	6.4	11.5	8.68	0.18	30	6.8	11
10/16	8.30	0.22	30	5.8	10.4	9.70	0.23	30	6.6	12
10/23	9.73	0.21	30	6.5	12.0	9.05	0.31	30	5.8	14
10/30	9.42	0.28	30	6.6	13.5	9.89	0.15	30	8.4	12
11/08	8.10	0.22	30	6.1	11.1	10.35	0.25	30	8.2	14
11/15	9.08	0.23	30	7.1	11.9	9.46	0.21	30	7.3	12
Ave	8.86					9.28				
± SE	0.24					0.27				

The Brix of raspberry ranges from 9 % - 11 % (Papp et al., 1984). The Brix value for ten cultivars was measured at various degrees of ripeness and ranged from 8 % to 14 % (Durst et al., 1995). A Brix value of 10.5 % was the proposed universal value for raspberry juice (U. S. FDA, 1991). The Brix value ranged from 7.89 % to 10.35% falling within the range of previous studies (Table 6 and Fig. 15).

Brix of raspberry juice can be influenced by cultivar and physiological age of fruit (Durst et al., 1995). In the current study Brix had a tendency to increase with Ca application but was not statistically proven.

Juice pH

The pH of the juice is a measure of the active acidity; free H^+ ions comprise the acidity. Organic acids produced during normal cellular respiration are sources of H^+ ions. Common organic acids of raspberry juice and associated pK_a values are malic (3.40, 5.2), isocitric, citric (3.09, 4.75, and 5.41), and fumaric (3.03, 4.54) (Durst et al., 1995; Serjeant and Dempsey, 1979). Citric acid is the major constituent of acids ranging from 89.8 to 98.9 % of the total acids present. A pH value of 3.47 was reported as normal for red raspberry (Jennings, 1988).

The control juice pH was 3.12 ± 0.06 and treatment juice pH value was 3.12 ± 0.04 for the whole season. No significant difference occurred between the pH of treated and control

raspberries using the mean ± SE of the mean and paired t-test (t-value = 0.15, 6 df, p-value = 0.884). The juice pH was significantly different in the control for one sample date (Table 7 and Fig. 16). The juice pH declined over the season, but the regression equation was not significant at $p > 0.05$. The middle five sample dates had consistent pH measurements. An explanation for the seasonal decline in pH was not apparent; measurements could have been skewed by sampling error. It is possible the raspberries produced a greater proportion of organic acids with a lower pK_a value later in the season.

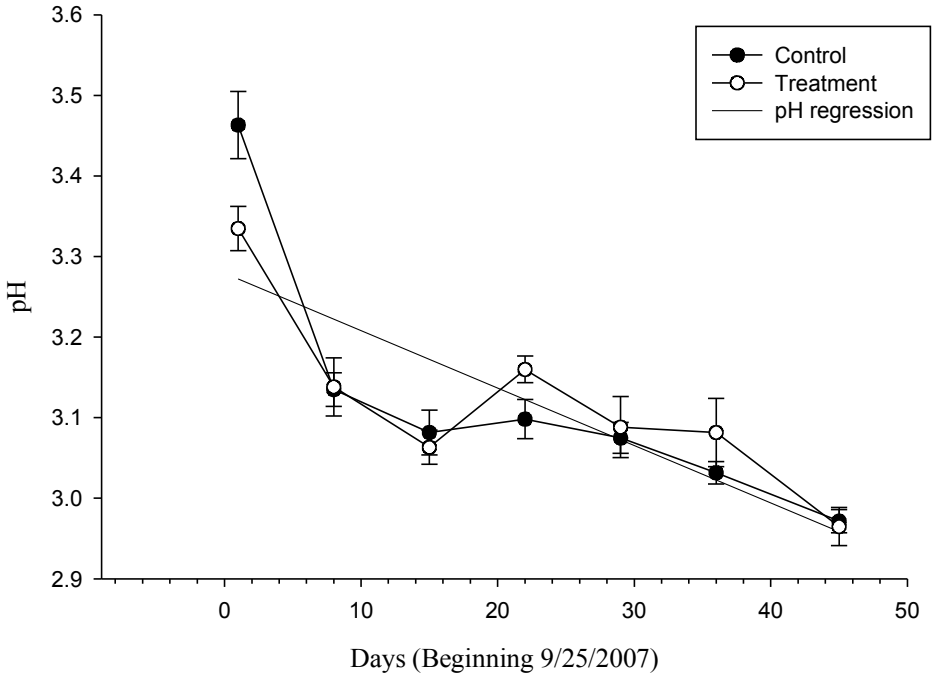

Figure 16. The raspberry juice pH during the season. The error bars represent the standard error of the mean. The regression line for both control and treatment was juice pH = -0.0071*days + 3.2800, r = -0.81***)

Table 5. The 2007 average raspberry juice pH with the standard error of the mean, count, and range.

Control	Treatment

				Range					Range	
Date	pH	SE	N	Min	Max	pH	SE	N	Min	Max
10/02	3.46	0.04	6	3.32	3.62	3.34	0.03	6	3.26	3.44
10/09	3.14	0.02	6	3.05	3.21	3.14	0.04	6	3.03	3.26
10/16	3.08	0.03	6	2.97	3.18	3.06	0.02	6	3.00	3.14
10/23	3.10	0.02	6	3.03	3.17	3.16	0.02	6	3.12	3.23
10/30	3.08	0.02	6	3.01	3.14	3.09	0.04	6	3.00	3.24
11/08	3.03	0.01	6	2.98	3.07	3.08	0.04	6	2.90	3.18
11/15	2.97	0.01	6	2.95	3.04	2.97	0.02	6	2.88	3.02
Ave	3.12					3.12				
±SE	0.06					0.04				

Individual Berry Weights

Individual berry weights varied for each sample date (Table 8 and Fig. 17). Berry weights for the control were 4.33 ± 0.13 g and were 4.42 ± 0.10 g for the treated berries during the whole season. Berry weights were not significantly different using mean ± SE of mean and the paired t-test (t-value = -0.72, 7df, p-value = 0.493). Berry weights remained relatively stable throughout the season and the regression equations were flat and significant ($p < 0.05$). Individual berry weight decreased slightly as the season progressed. This may mean a stress was beginning to occur in terms of plant nutrition and could be associated with the decline in one of the essential nutrients during the season.

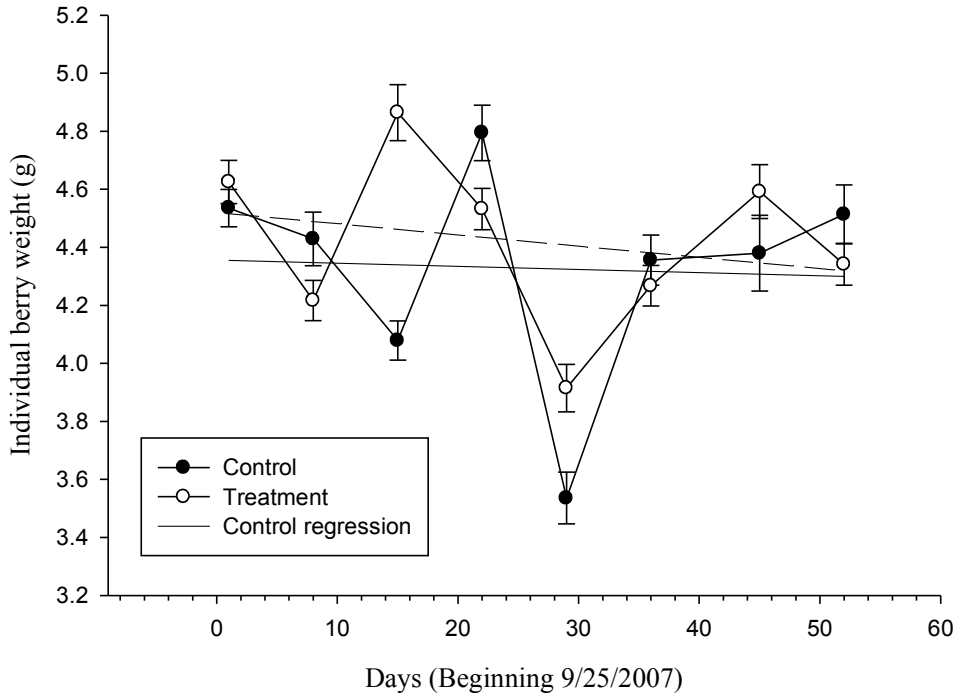

Figure 17. Individual berry weights during the season. The error bars represent the standard error of the mean. The regression lines were Control berry weight = -0.0011*days + 4.3562, r = -0.05 and Treatment berry weight = -0.0039x + 4.5200, r = -0.22.

Berry weights are more a function of osmotic potential, than purely dry matter accumulation. The weight of a berry is comprised mainly of water. The application of Ca did not significantly change the individual berry weight.

Table 6. The 2007 harvested raspberry average berry weights with the standard error of the mean, count, and range.

	Control					Treatment				
				Range					Range	
Date	Weight	SE	N	Min	Max	Weight	SE	N	Min	Max
	grams					grams				
09/25	4.54	0.06	165	2.85	6.40	4.63	0.07	153	2.95	7.10
10/02	4.43	0.09	78	2.85	6.65	4.22	0.07	84	2.95	5.85
10/09	4.08	0.07	96	2.60	6.25	4.86	0.10	78	2.95	6.55
10/16	4.79	0.10	78	3.35	6.95	4.53	0.07	89	3.20	6.35
10/23	3.54	0.09	94	2.20	6.45	3.92	0.08	92	2.70	7.00
10/30	4.36	0.09	82	3.10	6.40	4.27	0.07	89	3.10	5.80

11/08	4.38	0.13	43	2.90	6.05	4.59	0.09	39	3.25	5.80
11/15	4.51	0.10	84	2.75	6.85	4.34	0.07	83	3.25	6.50
Ave	4.33					4.42				
± SE	0.13					0.10				

Total yield

Total raspberry yield was measured on a crate basis. The recorded yields from the control and treatment blocks were extrapolated to a crate per acre basis. One crate was equivalent to four pounds.

The control and treatment rows had similar production curves (Fig. 18). Treatment rows had higher yields during the final seven weeks of the season totaling 22.25 more crates than did the control rows (Table 7). The treatment rows produced 426.34 more crates per acre than did the control rows, representing about a 10 % increase (due to the calcium application) compared with common yields.

Table 7. The 2007 raspberry crate totals for treatments, plots, and per acre.

	Control	Treatment	Control	Treatment
	Crates per plot		Crates per acre	
09/15	18.17	18.08	348.07	346.48
09/22	24.33	22.42	466.23	429.50
09/29	32.58	30.75	624.30	589.17
10/06	16.08	23.00	308.16	440.68
10/13	25.67	29.17	491.77	558.83
10/20	17.25	25.75	330.51	493.37
10/27	5.83	7.00	111.77	134.12
11/03	3.67	6.50	70.25	124.54
11/10	4.08	6.50	78.24	124.54
11/17	1.67	2.42	31.93	46.30
Total	149.33	171.58	2861.23	3287.54
Difference	22.25		426.31	

Fewer culled fruit and / or decreased flower abortion in the treated plants could cause the increased berry production. Individual berry weights were not significantly different and thus cannot explain the yield increase. Growth was not likely limited by any of the measured nutrients. The Biomin Calcium® application increased the Ca / Mg ratio in the sampled floricane leaves. The increased Ca in the tissues relative to Mg could have increased the individual berry strength. If the berries were firmer, fewer berries would have been culled. Fewer culled fruit would result in more crates being produced. Flower abortion percentages were not measured, but perhaps should have been.

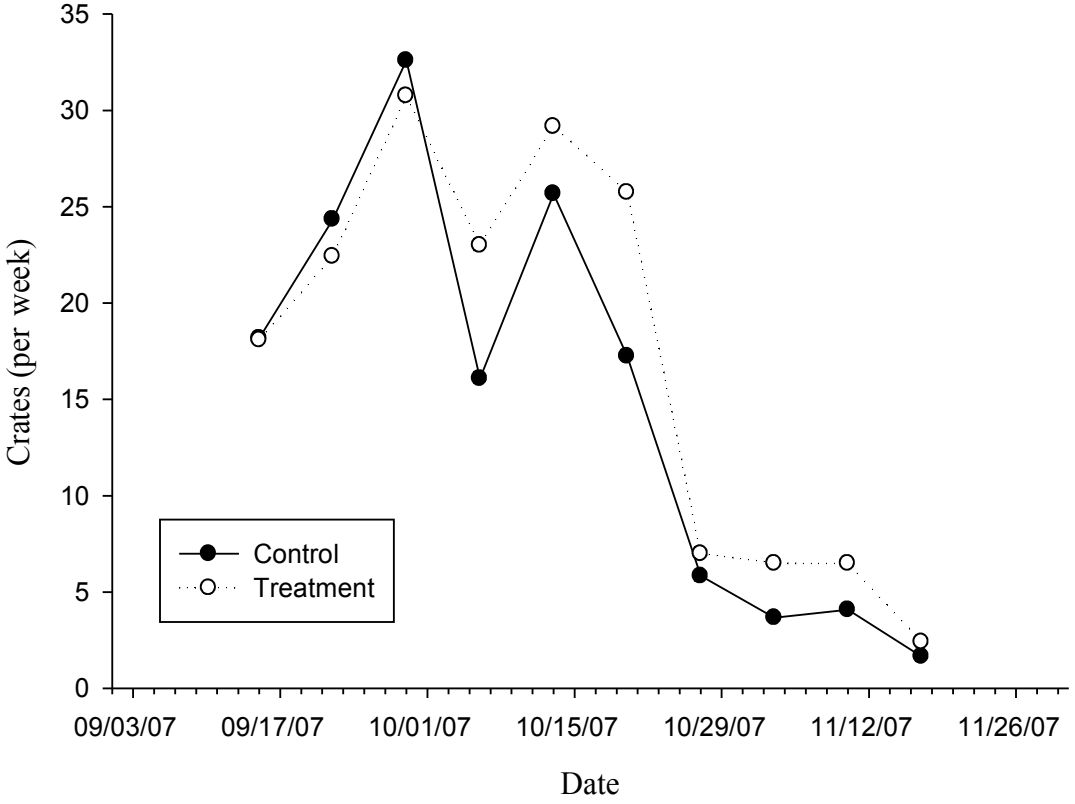

Figure 18. Weekly production of raspberry crates per plot.

Fruit elemental composition

The part per million value is equivalent to mg kg^{-1}. Converting the berry yield to kg and multiplying by a Table 8 ppm value results in the amount of an element leaving the field with harvested fruit (in mg). Multiplying yield by the % value for N or S gives the amount of the element removed by harvest in the same units as yield weight. Thus, Table 8 can be used to estimate how much of an element left the field in the harvested fruit.

Table 8. Elemental concentration of raspberry fruit and weight of elements leaving the field with harvest. SE represents standard error of the mean. Each crate weighs about four pounds.

	Ca	Mg	K	Na	N	S
	parts per million dry weight				%	
Average	523.04	1049.82	8931.20	309.41	1.19	0.10
± SE	55.08	33.93	288.28	39.05	0.01	0.01
g /1000 crates	950.98	1908.77	16238.55	562.56	2.16	0.17
oz /1000 crates	33.54	67.33	572.80	19.84	0.08	0.01
g /acre (control)	2720.98	5461.42	46462.17	1609.61	6.18	0.50
oz /acre (control)	95.98	192.65	1638.90	56.78	0.22	0.02
g /acre (calcium)	3126.39	6275.15	53384.83	1849.43	7.10	0.57
oz /acre (calcium)	110.28	221.35	1883.09	65.24	0.25	0.02

Cost Analysis

Assumptions were made in the creation of the creation of the partial budget.

Firstly, the price of $ 15 per gallon for Biomin Calcium® was quoted from Western Farm Service (Watsonville, CA in April of 2008). Prices will change over time.

Second, labor wages will change with time; $ 10 per hour was used for reporting purposes. In reality, the irrigator was a salaried employee.

Third, the application equipment and hardware was pre-existing and should be present on any type of farm using drip irrigation. Thus, equipment costs were negligible.

Fourth, the yield change was experienced in this particular season, but may not be experienced for other growers in other years.

Fifth, the average return per crate was a 'ball-park' figure. The actual returns per crate varied weekly and across years. The $ 2 figure was arbitrarily chosen for this particular season.

Partial Budget

Alternative: Not applying Biomin Calcium (for 1 acre)

Additional Costs:		**Additional Revenue:**	
Fixed Costs:		(426 CPA @ $2 profit / crate)	$880.00
None			
Variable Costs:			
Labor (4.67hrs @ $10/hr)	$46.70		
Biomin Calcium® (15 gal @ $15 / gal)	$225.00		
Reduced Revenue:		**Reduced Costs:**	
None		None	

Total addititional costs and reduced revenue	$271.70	Total additional revenue and reduced costs	$880.00

Net change in profit = $608.30

References

Askew, H. O., E.T. Chittenden, and J. Watson. 1951. Boron, copper, manganese, and zinc in the nutrition of the Red Antwerp raspberry. N.Z.J. Sci. Technol. 33: 13-26.

Bradfield, E. G. and C. G. Guttridge. 1981. The effect of Mg:Ca ratio and osmotic potential of nutrient solutions on calcium transport into emergent leaves of the strawberry plant cv. Cambridge Favourite. J. Plant Nutrition 4(1):33-44.

Bradfield, E. G. and C. G. Guttridge. 1984. Effects of sale concentration and cation balance in soils on leaf tipburn and calcium content of strawberry leaves and fruit. Commun. in Soil Sci. Plant Anal. 15(6): 681-693.

Brady, N. C., and R. R. Weil. 2004. Elements of the nature and properties of soils, 2nd ed. Pearson Education, Inc. Upper Saddle River, NJ.

Brierley, W. G., and R. H., Landon. 1936. Some evidence relating to the downward movement of photosynthate in fruiting cane of red raspberry. Proc. Amer. Soc. Hort. Sci. 34: 377-380.

Chaplain, M. H. and L. W. Martin. 1980. The effect of nitrogen and boron fertilizer applications on leaf levels, yield and fruit size of the red raspberry. Comm. in Soil Science and Plant Analysis 11(6): 547-556.

Crandall, P. 1995. Bramble production: The management and marketing of raspberries and blackberries. Food Products Press, an imprint of The Haworth Press, Inc. Binghamton, NY.

Dale, A. 1986. Some effects of the environment on red raspberry cultivars. Acta Hortic. 183:155-161.

Durst, R. W., R. E. Wrolstad, and D. A. Krueger. 1995. Sugar, nonvolatile acid, $^{13}C/^{12}C$ ratio, and mineral analysis for determination of the authenticity and quality of red raspberry juice composition. J. AOAC International 78(5):1195-1204.

Finch, S. M. 2006. The effects of Biomin Calcium applied through drip irrigation on strawberries in the Santa Maria Valley. Unpublished. JH Biotech, Inc. in-house research. 4951 Olivas Park Dr, Ventura, CA 93003.

Fischer, R. and A. B. Bennett. 1991. Role of cell wall hydrolases in fruit ripening. Ann. Rev. Plant Physiol. and Plant Molecular Bio. 42:675-703.

Follett, R. H., L. S. Murphy, and R. L. Donahue. 2003. Fertilizers and soil amendments. Ceramic book and literature service. New Dehli, India. Reprint.

Ge, L., H. Q. Tian, and S. D. Russell. 2007. Calcium function and distribution during fertilization in angiosperms. Am. J. of Botany 94:1046-1060.

Havlin, J. L., S. L. Tisdale, J. D. Beaton, and W. L. Nelson. 2005. Soil fertility and fertilizers: An introduction to nutrient management 7th ed. Pearson Education Inc., Upper Saddle River, NJ.

Hughes, M., M. H. Chaplain, and A. R. Dixon. 1979. Elemental composition of red raspberry leaves as a function of time of season and position on cane. Hortsci. 41:46-47.

Jennings, D. 1988. Raspberries and blackberries: Their breeding, diseases and growth. Academic Press: Harcourt Brace Javonovich, Publishers. New York, NY.

JH Biotech, Inc. 2007. Raspberry leaf tissue analysis report: Critical concentrations. In-house publication. 4951 Olivas Park Dr, Ventura, CA 93003.

John, M. K. and H. A. Daubeny. 1972. Influence of genotype, date of sampling and age of plant on chemical leaf composition of red raspberry (*Rubus idaeus*). J. Amer. Soc. Hort. Sci. 97:740-742.

John, M. K., H. A. Daubeny, and H. H. Chuah. 1976. Factors affecting elemental composition of red raspberry leaves. J. Sci. Fd. Agric. 27: 877-882.

Khemira, H., T. L. Righetti, and A. N. Azarenko. 1998. Nitrogen partitioning in apple as affected by timing and tree growth habit. J. Hort. Sci. Biotechnol. 73:217-223.

Kohle, H., W. Jeblick, F. Poten, W. Blaschek, and H. Kauss. 1985. Chitosan-elicited callose synthesis in soybean cells as a calcium-dependent process. Plant Physiol. 77: 544-551.

Kowalenko, C. 1981. The effect of nitrogen and boron soil applications on raspberry leaf N, B, and Mn concentrations and on selected soil analyses. Comm. in Soil Sci. Plant Anal. 12(11): 1163-1179.

Kowalenko, C. 1994a. Growing season dry matter and macroelement accumulations in Willamette red raspberry and related soil-extractable macroelement measurements. Can. J. Plant Sci. 74:565-571.

Kowalenko, C. 1994b. Growing season changes in the concentration and distribution of macroelements in Willamette red raspberry plant parts. Can. J. Plant Sci. 74:833-839.

Kowalenko, C. G., J. C. Keng, and J. A. Freeman. 2000. Comparison of nitrogen application via a trickle irrigation system with surface banding of granular fertilizer on red raspberry. Can. J. Plant Sci. 80:363-371.

Kowalenko, C. 2005. Accumulation and distribution of micronutrients in Willamette red raspberry plants. Can. J. Plant Sci. 85:179-191.

Kowalenko, C. 2006. The effect of nitrogen and boron fertilizer applications on Willamette red raspberry growth, and on applied and other nutrients in the plant and soil over two growing seasons. Can. J. Plant Sci. 86:213-225.

Lester, G., J. L. Jifon, and G. Rogers. 2005. Supplemental foliar potassium applications during muskmelon fruit development can improve fruit quality, ascorbic acid, and beta-cartene contents. J. of the Am. Soc. for Hort. Sci. 130(4):649-653.

Ljones, B. 1963. Leaf composition in apple, raspberry, and black currant as related to nutrient elements in the soil. Meldinger fra Norges Landbrukshogskole 42:1-90.

Makus, D. J. and J. R. Morris. 1989. Influence of soil and foliar applied calcium on strawberry fruit nutrients and post harvest quality. Proc. Int. Strawberry Sym. 265:443-448.

Malik, H., D. Archbold, and C. T. MacKown. 1991. Nitrogen partitioning by 'Chester Thornless' blackberry in pot culture. HortSci. 26:1492-1494.

Marschner, H. 1995. Mineral nutrition of higher plants 2nd ed. Academic Press, London, UK.

Marshall, M. R., M. G. Smart, J. R. Aist, H. W. Israel. 1985. Chlortetracycline and barley papilla formation: localization of calcium and alteration of the response induced by *Erysiphe graminis*. Can. J. Bot. 63: 876-880.

Mengel, K. and E. A. Kirkby. 1979. Principles of plant nutrition 2nd ed. International Potash Institute. Worblaufen-Bern, Switzerland. 593 pp.

Miedes, E., and E. P. Lorences. 2006. Changes in cell wall pectin and pectinase activity in apple and tomato fruits during *Penicillium expansum* infection. J. Sci. Fd. Agric. 86:1359-1364.

Mohader, P., B. C. Strik, B. J. Zebarth, and T. L. Righetti. 2001. Nitrogen uptake, partitioning and remobilization in 'Kotata' blackberry in alternate-year production. J. Hort. Sci. Biotechnol. 76:700-708.

Monk, R. J. 1955. Boron deficiency symptoms in raspberries. N. Z. J. Sci. Technol. 1955:610-613.

Montesano, F., and M. W. Van Israel. 2007. Calcium can prevent toxic effects of Na^+ on Tomato leaf photosynthesis but does not restore growth. J. of the Am. Soc. for Hort. Sci. 132(3): 310-318.

Naraguma, J., J. R. Clark, R. J. Norman, and R. W. McNew. 1999. Nitrogen uptake and allocation by field-grown 'Arapaho' thornless blackberry. J. Plant Nutr. 22:753-768.

Nelson, S. D. and V. D. Jolley. 1984. Effect of an acidified iron-sulfur-rich mining residue (iron-sul) on soil and plant nutrient relationships in drip-irrigated raspberry and strawberry. J. Plant Nutr. 7:251-257.

Okie, W. 2000. Register of new fruit and nut varieties: List 40. HortSci. 35:812-826.

Onyeike, E. N. and G. N. Acheru. 2002. Chemical composition of selected Nigerian oil seeds and physiochemical properties of the oil extracts. Food Chemistry 77:431-437.

Papp, J., I. Kobzos-Papai, and J. Nagy. 1984. Effect of nitrogen application on yield, leaf nutrient status and fruit chemical composition of raspberry and red currant varieties. Acta Agronomica Academiae Scientarum Hungaricae, Tomus 33(3-4): 337-343.

Rempel, H. G., B. C. Strik, and T. L. Righetti. 2004. Uptake, partitioning, and storage of fertilizer nitrogen in red raspberry as affected by rate and timing of application. J. Amer. Soc. Hort. Sci. 129:439-448.

Sanchez, E. E., T. L. Righetti, D. Sugar, and P. B. Lombard. 1992. Effects of timing of nitrogen application on nitrogen partitioning between vegetative, reproductive, and structural components of mature pear. J. Hort. Sci. 1:51-58.

Serjeant, E. P. and B. Dempsey. 1979. Ionization constants of organic acids in solution, IUPAC Chemical Data Series No. 23, Pergamon Press, Oxford, UK.

Smith, P. F. 1962. Mineral analysis of plant tissues. Ann. Rev. Plant Physiol. 13:81-108.

Taiz, L. and E. Zeiger. 2006. Plant Physiology 4th ed. Sinauer Associates, Inc. Sunderland, MA.

United States Food and Drug Administration. 1991. Federal Register 21 CFR 101.30. 56:30466.

University of Minnesota. 2008. Extension. www.extension.umn.edu/distribution/cropsystems/components/5886_32-34.pdf

University of Sydney. 2008. Plant pathology. Glossary. http://bugs.bio.usyd.edu.au/PlantPathology/glossary.html

Wilder, K. L. and T. L. Righetti. 1991. Identifying nutrient deficiency and toxicity in red raspberry. Pacific Northwest Extension Publication Oregon, Idaho, and Wash. PNW 372. 12 pp.

Wright, C. J. and P. D. Waister. 1980. Seasonal changes in the mineral nutrient content of the raspberry. Acta horticulturae 112:295-304.

Appendix

Table 9. Soil data before and during 2007 Biomin Calcium® treatment. Samples were from the top 12 inches of the root zone.

	Organic Matter		Sulfur		Phosphorus		Potassium		Magnesium	
	%		ppm - S		ppm - P		ppm - K		ppm - Mg	
Date	Control	Ca added	Control	Ca added	Control	Ca added	Control	Ca added	Control	Ca added
07/28	2.30	2.50	23.50	*191.50	25.00	27.50	167.50	207.50	37.50	41.50
10/09	1.35	1.65	4.00	8.50	22.00	22.00	177.50	192.50	41.50	38.00

	Calcium		Sodium		Zinc		Manganese		Iron	
	ppm - Ca		ppm - Na		ppm - Zn		ppm - Mn		ppm - Fe	
Date	Control	Ca added	Control	Ca added	Control	Ca added	Control	Ca added	Control	Ca added
07/28	525.00	602.50	154.50	172.00	1.35	2.00	4.40	5.55	15.00	21.00
10/09	491.00	525.00	151.50	222.00	1.30	1.40	4.60	4.65	13.00	14.50

	Copper		Boron		NO_3^-		pH		CEC	
	ppm - Cu		ppm - B		ppm - NO_3^-		soil pH		meq /100 g	
Date	Control	Ca added	Control	Ca added	Control	Ca added	Control	Ca added	Control	Ca added
07/28	1.10	1.35	1.00	0.95	18.00	23.00	6.30	6.25	4.04	4.64
10/09	0.90	1.05	1.25	1.30	17.00	29.50	6.55	6.35	3.91	4.39

	Base saturation		Base Saturation		Base Saturation		Base Saturation		Excess lime	
	% K		% Mg		% Ca		% Na		Qualitative	
Date	Control	Ca added	Control	Ca added	Control	Ca added	Control	Ca added	Control	Ca added
07/28	10.65	11.55	10.65	11.55	65.10	65.00	16.60	16.10	Very low	Very low
10/09	11.70	11.15	8.70	7.05	62.85	59.80	16.75	22.00	Very low	Very low

* Possible contamination

Table 10. 2007 monthly weather data from CIMIS [1] weather stations in surrounding area.

Station	Date	Total precipitation	Average solar radiation	Average vapor pressure	Average maximum air temperature	Average minimum air temperature	Average air temperature
		inches	Ly /day	mBars	°F	°F	°F
111	Jul	0.00	557	15.1	73.0	52.9	61.8
111	Aug	0.01	535	15.0	73.1	52.0	61.6
111	Sep	0.78	406	14.1	73.3	49.6	61.0
111	Oct	0.02	265	12.3	71.0	45.2	56.9
111	Nov	0.03	176	10.8	68.1	41.3	52.8
129	Jul	0.17	475	14.6	70.2	53.4	61.0
129	Aug	0.01	448	14.6	70.4	52.3	60.7
129	Sep	0.52	364	13.7	71.8	50.3	60.6
129	Oct	0.31	286	11.6	69.8	46.4	57.2
129	Nov	0.30	196	10.2	66.9	43.7	54.0

Station	Date	Average maximum relative humidity	Average minimum relative humidity	Average relative humidity	Average dew point	Average wind speed	Average soil temperature
		%	%	%	°F	miles per hour	°F
111	Jul	96	60	80	55.6	4.5	69.3
111	Aug	96	60	80	55.3	4.2	68.9
111	Sep	95	52	77	53.8	4.1	65.0
111	Oct	96	53	78	49.8	3.6	59.4
111	Nov	96	51	78	45.8	3.1	54.4
129	Jul	91	65	79	54.5	5.4	69.8
129	Aug	91	65	80	54.6	4.8	69.1
129	Sep	90	57	76	52.9	4.7	66.3
129	Oct	89	53	73	48.2	4.2	60.5
129	Nov	88	51	71	44.2	3.6	56.3

[1]California Irrigation Management Information System, Department of Water Resources: Office of Water Use Efficiency.

Table 11. The regression equations and r values for the control, Ca amended, and combined raspberry data. Astericks' represent level of significance (0.05 = *, 0.01 = **, 0.001 = ***).

Variable		Treatment	Regression equation.	r	Significance
X	Y				
Day	N	Control	$Y = -0.05916X + 0.00207X^2 + 10.761$	0.832	***
		Ca amended	$Y = -0.11184X + 0.000823X^2 + 10.888$	0.769	**
		Combined	$Y = -0.0086X + 0.000515X^2 + 10.824$	0.755	**
Day	P	Control	$Y = 0.0016X + 0.2646$	0.721	**
		Ca amended	$Y = 0.0008X + 0.3000$	0.458	NSD
		Combined	$Y = 0.0011X + 0.2823$	0.583	*
Day	K	Control	$Y = -0.002X + 1.6319$	0.141	NSD
		Ca amended	$Y = 0.0006X + 1.6249$	0.173	NSD
		Combined	$Y = 0.0002X + 1.6284$	0.071	NSD
Day	Ca	Control	$Y = -0.0008X + 0.7547$	0.283	NSD
		Ca amended	$Y = 0.0012 + 0.7028$	0.316	NSD
		Combined	$Y = 0.0002X + 0.7288$	0.063	NSD
Day	Mg	Control	$Y = -0.0006X + 0.5304$	0.510	NSD
		Ca amended	$Y = -0.0006X + 0.4988$	0.447	NSD
		Combined	$Y = -0.0006X + 0.5146$	0.447	NSD
Day	Zn	Control	$Y = 0.0457X + 31.8977$	0.412	NSD
		Ca amended	$Y = 0.1678X + 27.2481$	0.860	***
		Combined	$Y = 0.1068X + 29.5729$	0.663	**
Day	Mn	Control	$Y = 0.4458X + 151.2028$	0.843	***
		Ca amended	$Y = 0.4631X + 161.1887$	0.714	**
		Combined	$Y = 0.4544X + 156.1958$	0.735	**
Day	Fe	Control	$Y = 0.0494X + 126.4461$	0.245	NSD
		Ca amended	$Y = 0.1201X + 127.7016$	0.387	NSD
		Combined	$Y = 0.848X + 127.0739$	0.316	NSD
Day	Cu	Control	$Y = 0.0108X + 5.3048$	0.400	NSD
		Ca amended	$Y = 0.0048X + 5.7722$	0.141	NSD
		Combined	$Y = 0.0078X + 5.5384$	0.245	NSD
Day	B	Control	$Y = 0.0114X + 52.1292$	0.141	NSD
		Ca amended	$Y = 0.0096X + 52.2973$	0.084	NSD
		Combined	$Y = 0.0105X + 52.2132$	0.100	NSD
Day	N /P	Control	$Y = -0.0369X + 10.3875$	0.819	***

		Ca amended	Y = -0.0237X + 9.4053	0.520	NSD
		Combined	Y = -0.0303X + 9.8964	0.671	**
Day	K /Mg	Control	Y = -0.0034X + 3.0950	0.374	NSD
		Ca amended	Y = 0.0054X + 3.2949	0.400	NSD
		Combined	Y = -0.0044X + 3.1950	0.346	NSD

Table 11. Continued.

Day	Ca /Mg	Control	Y = 0.0002X + 1.4238	0.032	NSD
		Ca amended	Y = 0.0045X + 1.4091	0.539	*
		Combined	Y = 0.0023X + 1.4165	0.316	NSD
Day	Ca /K	Control	Y = -0.0004X + 0.4634	0.200	NSD
		Ca amended	Y = 0.0006X + 0.4336	0.224	NSD
		Combined	Y = 0.00008X + 0.4485	0.032	NSD
Day	Ca /B	Control	Y = -0.00002X + 0.0146	0.412	NSD
		Ca amended	Y = 0.00002X + 0.0135	0.245	NSD
		Combined	Y = 0.000001X + 0.0140	0.017	NSD
Day	Fe /Mn	Control	Y = -0.0016X + 0.8313	0.693	**
		Ca amended	Y = -0.0012X + 0.7930	0.490	NSD
		Combined	Y = -0.0014X + 0.8121	0.592	*
Day	Fe /Zn	Control	Y = -0.0037X + 4.0016	0.283	NSD
		Ca amended	Y = -0.0177X + 4.7913	0.671	**
		Combined	Y = -0.0107X + 4.3964	0.520	NSD
Day	Cu /Zn	Control	Y = 0.00005X + 0.1681	0.095	NSD
		Ca amended	Y = -0.0007X + 0.2093	0.600	*
		Combined	Y = -0.0003 + 0.1887	0.324	NSD
P	N	Control	Y = -0.5002X + 2.8767	0.265	NSD
		Ca amended	Y = -0.7367X + 2.9789	0.374	NSD
		Combined	Y = -0.6039X + 2.9221	0.316	NSD
Ca	K	Control	Y = -0.2031X + 1.7647	0.346	NSD
		Ca amended	Y = -0.0397X + 1.6866	0.045	NSD
		Combined	Y = -0.0504X + 1.6753	0.071	NSD
Ca	Mg	Control	Y = 0.2610X + 0.3112	0.608	*
		Ca amended	Y = 0.0762X + 0.4079	0.224	NSD
		Combined	Y = 0.0974X + 0.4097	0.245	NSD
Mn	Fe	Control	Y = 0.0481X + 120.6930	0.141	NSD

		Ca amended	Y = 0.1825X + 100.2338	0.387	NSD
		Combined	Y = 0.1541X + 103.8127	0.346	NSD
Zn	Fe	Control	Y = 0.1300X + 124.6695	0.071	NSD
		Ca amended	Y = 0.3229X + 122.4990	0.200	NSD
		Combined	Y = 0.3564X + 119.0825	0.200	NSD
Zn	Cu	Control	Y = 0.1281X + 1.4880	0.529	NSD
		Ca amended	Y = 0.0522X + 4.1341	0.283	NSD
		Combined	Y = 0.0711X + 3.4449	0.361	NSD
Day	Brix	Control	Y = 0.0079X + 8.6577	0.200	NSD
		Ca amended	Y = 0.0319X + 8.4523	0.748	*
		Combined	Y = 0.0199X + 8.5550	0.469	NSD
Day	pH	Control	Y = -0.0083X + 3.3075	0.812	*
		Ca amended	Y = -0.0060X + 3.2516	0.812	*
		Combined	Y = -0.0071X + 3.2800	0.806	*

Table 11. Continued.

Day	Wt. (g)	Control	Y = -0.0011X + 4.3562	0.055	NSD
		Ca amended	Y = -0.0039X + 4.5200	0.224	NSD
		Combined	Y = -0.0025X + 4.4381	0.100	NSD

Table 12. Well water data sampled 11/26/2007.

pH	6.7
EC (mmhos/cm)	1.1
Ca (mg/L)	123.0
Mg (mg/L)	44.0
Na (mg/L)	45.0
K (mg/L)	2.0
Hardness as $CaCO_3$ (mg/L)	500.0