AN ABSTRACT OF THE THESIS OF

Shara E. Alexander for the degree of Master of Science in Horticulture

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Title: Effect of Row Cover and Supplemental Calcium Fertilization on Blossom-end Rot in Bell Pepper

(Capsicum annuum var. annuum, Grossum Group).

Abstract approved :_____
George H. Clough

A 2-year trial was conducted at Oregon State University's Hermiston Agricultural Research and

Extension Center to examine the effects of spunbonded row cover and supplemental calcium fertilization

on blossom-end rot in two varieties of bell pepper. Blossom-end rot is a common cause of bell pepper yield

losses, especially at the first harvest.

The experimental design was a complete factorial with Ca fertigation rates at 0, 34 and 68 kg·ha^{-1}

(as Ca(NO$_3$)$_2$), with and without spunbonded polypropylene row cover, and two varieties, 'Vidi'

(Vilmoren), and 'Ranger' (Asgrow). Bell pepper seedlings were transplanted into drip-irrigated beds

covered with black plastic mulch in May, 1995 and June, 1996. Calcium nitrate was applied in three

fertigations with Urea Ammonium Nitrate (32% N) added to total 22 kg N·ha^{-1}, per fertigation. Two

additional N fertigations were applied for a total of 112 kg N·ha^{-1} in 1995 and 90 kg N·ha^{-1} in 1996. A

hoop-supported row cover was applied at transplanting and removed at first harvest.

Anthesis was delayed under row cover in 1995. Leaf area and specific leaf area increased under row

cover as compared to no row cover, and leaf dry weight was lower with row cover than without in 1995.

An increase in the Ca fertilization rate linearly increased leaf dry weight and decreased specific leaf area

in 1995, but had no effect in 1996.

Tissue Ca concentration was lower in BER-affected fruit than in marketable fruit. Fruit Ca concentration was higher with row cover than without in 1996. Fruit Ca concentration increased linearly as supplemental Ca rate increased in 1995, but was not affected by Ca rate in 1996.

Row cover increased first harvest and total yield of marketable fruit, by 1.25 and 4.75 t·ha^{-1}, respectively. Row cover increased the yield of first harvest fancy-grade fruit in 1995. First harvest BER and total BER yields decreased substantially under row cover, but the difference in BER fruit yield between row cover treatments was larger in 1996 than in 1995. The percent BER fruit of total first harvest yield, by weight, decreased from 51% without row cover to 25% with row cover. The percent BER fruit of season total yield decreased from 24% to 15% in 1995, and 26% to 6% in 1996. Yield of first harvest sunscald fruit decreased under row cover for 'Vidi'. Total sunscald fruit yield decreased for 'Ranger' in 1995, and 'Vidi' in 1996, while percent sunscald decreased for 'Vidi' both years under row cover.

First harvest fancy-grade and total marketable fruit yields, and total seasonal yield of fancy-grade fruit increased linearly with an increase in Ca rate. First harvest BER and SS-affected fruit yields and first harvest total cull yield decreased linearly as Ca rate increased, as did total seasonal yield of sunscald and total cull fruit.

Effect of Row Cover and Supplemental Ca Fertilization on Blossom-end Rot in Bell Pepper

(Capsicum annuum var. annuum, Grossum Group)

by

Shara E. Alexander

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Dean of Graduate School

I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

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Shara E. Alexander, Author

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Chapter 1

INTRODUCTION

Bell Pepper (<u>Capsicum</u> <u>annuum</u> L.) is a high-value vegetable crop which is increasing in popularity and total acreage. The most significant regions for pepper production are Florida, California and the Southeastern states. In Florida, peppers are grown on about 8000 hectares, with the crop valued at $179 million dollars in 1992-1993 (Florida Ag. Stats, 1994). Pepper production in the U.S. more than doubled from 1983 to 1992, from 11 million to 26 million kg (USDA Ag. Stats., 1993). The USDA National Agricultural Statistics Service no longer collects data on pepper production, but the estimated area planted to bell peppers in the U.S. is about 24,300 ha (Andrews, 1995). Currently, about 162 ha of peppers are grown in Oregon, mostly for fresh market sales (Stan Miles, pers. comm.).

Umatilla County has many sites which are well-suited to pepper production. The high winds necessitate windrows for plant protection and the sandy soils require a black plastic mulch and drip irrigation system to reduce water losses to evaporation. Blossom-end rot (BER) is a perennial problem in areas such as the Columbia river terraces of Umatilla County, dominated by eolian sandy loam. Early in the season the crop is particularly susceptible to BER, with losses often exceeding 50% of the first harvest.

In 1995, a Hermiston area grower lost his entire first harvest (16 ha) of fresh market peppers of the variety 'Camelot' to BER. An examination of irrigation, fertilization and other cultural practices did not provide an explanation for the losses. That variety was subsequently dropped by the grower (Phil Walchli, pers. comm.). However, at other sites in the area, 'Camelot' did not sustain losses of the same magnitude, and one grower kept 'Camelot' in production the following year (Lane Pollock, pers. comm.). This type of localized BER development is common. Often it is related to site-specific soil variability, fluctuations in wind velocity, water availability, temperature or plant nutrition, but to isolate the cause in the field can be difficult.

Decreases in BER with the use of $Ca(NO_3)_2$ have been documented since 1944 (Shear, 1975). However, Ca fertilization and foliar sprays, while significantly increasing the Ca content of plant tissues, are not always effective in reducing BER in fruit (Kirkby, 1979). Unfavorable leaf/fruit transpiration ratios can bring about BER even when surplus Ca is available in the soil solution. Antitranspirants sprayed on pepper foliage have been found to reduce BER and to increase fruit Ca concentration, but at the expense of total fruit production (Schon, 1993).

In 1988, Dr. Fred Harper, an extension agent at the University of Arizona, observed decreases in the number of BER affected bell peppers under spunbonded polyester row covers (Harper, 1989). No BER developed in fruit under the row covers, as compared to a 9 to 15% incidence in the uncovered plots. A review of the literature revealed no published studies pertaining to the relationship between BER and row covers in pepper or tomato (Lycopersicon esculentum Mill.)

This two year study examined the effect of row covers and three rates of $Ca(NO_3)_2$ on BER and yield in two varieties of bell peppers. Additional goals were to further quantify changes in plant growth associated with the row cover which may affect plant transpiration and yield, and to identify changes in fruit Ca concentration due to row cover and Ca fertilization.

Chapter 2

LITERATURE REVIEW

Comprehensive reviews of the function, uptake, and transport of Ca have been compiled by Bangerth (1979), Hanson (1984), Kirkby (1979) and Marschner (1983), among others. This review is restricted to the relationship between Ca uptake, Ca distribution and BER. Biochemical functions of Ca, including Ca/phytohormone interactions and Ca messenger functions are covered by Evans (1991), Hepler and Wayne (1985), and Ride (1983).

Blossom-end Rot and Calcium Functions

Blossom-end rot is one of 35 related physiological disorders associated with inadequate Ca in developing plant tissues (Shear, 1975). Blossom-end rot occurs in pepper, (Capsicum species) tomato, melon and other horticultural crops. Cells in the distal end of the fruit collapse due to the loss of Ca from cell membranes, or the lack of adequate Ca in the fruit during the period of cell expansion. Cells become increasingly permeable to ions, membranes disintegrate and organelles become disordered (Van Goor, 1968). The tissue at the blossom-end of the fruit turns brownish gray and becomes susceptible to secondary fungal or bacterial pathogens. The change in tissue color is due to the leakage of phenolic precursors from cell vacuoles and their subsequent oxidation to polyphenols (Dekock et al., 1975).

Calcium is essential in the growth and function of all cells, and is required in the stabilization of cell membranes (Hecht-Buchholz, 1979). Calcium binds hydrophilic regions of membrane phospholipids to one another, and to negatively-charged membrane proteins (Williams, 1976). Most of the structural Ca in fruit tissues is bound in an exchangeable form, in pectins in the middle lamella and at the exterior of the plasma membranes. (Marschner, 1996). Calcium may become immobilized by oxalate, which is the by-product of high respiration during the cell division process and times of water stress (Carolus, 1975). This reduces the amount of Ca available for cell wall strengthening.

Calcium may inhibit oxidation by binding to phenolic compounds as they are released (Dekock et al., 1975). The transport of Ca and indoleacetic acid are causally connected, and much has been written lately about the functions of Ca as a cellular messenger (Marschner, 1996)

Bangerth (1979) lists four functions of Ca which are associated with Ca deficiency disorders: effects on membranes; effects on enzymes; effects on cell walls; and Ca-phytohormone interactions. Blossom-end rot appears to be primarily a Ca deficiency of the cell membranes, resulting in the disorganization of the organelles and fluid leakage into the surrounding tissues. Because Ca deficiency affects the integrity of the cell membranes and cell walls, fruit which is internally low in Ca but does not exhibit external symptoms may have a greatly decreased storage life, as has been shown in apples (Bangerth, 1979; Wiersum, 1979).

The low Ca concentration associated with BER-affected tissue is not necessarily found throughout the plant, but instead is most often specific to the affected fruit area (Ward, 1973). Tissue Ca content in healthy fruit declines uniformly from the pedicel end of the fruit to the blossom end (Morley and Hardgrave, 1993).

Blossom-end rot symptoms are accompanied by localized below average fruit tissue Ca, and widely varying tissue concentrations have been reported in the literature. Whole fruit Ca requirements of 0.18% (Hamilton and Ogle, 1962) and 0.1% (Kratky, 1989) of dry weight have been cited for bell pepper. In a study by Marti and Mills (1991) pepper fruit with Ca levels below 0.18% did not exhibit symptoms of BER. Where BER was induced by drought, tomato fruit tissue Ca at the distal end of the fruit was 0.07%, as opposed to 0.02% in fruit with BER induced by Ca deficient rooting media (Ward, 1973). Other authors have found no relationship between tissue Ca and BER (Millikan et al., 1971; Pill and Lambeth, 1980). Part of the disagreement over plant Ca requirements undoubtedly stems from inadequate measurement techniques. Using chelates to draw out unbound and loosely bound Ca (fractionated extraction) may be more accurate in identifying functioning Ca than measuring total Ca, including insoluble forms stored in the vacuole (Marschner, 1996). Leaf Ca concentration, typically 3-5% dry wt., is not a good predictor of Ca availability to the fruit, as Ca deficiencies severe enough to affect leaves are rare (Bangerth, 1979; Shear, 1975).

Calcium requirements vary greatly by plant species. Calcium accumulation on a millequivalent basis in the tomato vine is 55% of cations, and in the fruit is only about 3%, compared to pea with 55% and 35%, for leaf and fruit respectively (Carolus, 1975). Monocots have a much lower requirement for Ca than dicots, due to the lower cation exchange capacity (CEC) of the cell walls in the root and along the vessel members. In species with higher cell wall CEC's, the ratio of divalent to monovalent cations bound at the exchange sites is much higher, resulting in a total increase of movement through the uptake sites at the plasmalemma.

Calcium Availability in the Soil Solution

Calcium is one of the most abundant elements found in soils. The exchangeable Ca of a typical soil is 65 to 85% of its total CEC (Chapman, 1966). Calcium concentrations vary from 3.4 to 14 mM in most soil solutions (Fried and Shapiro, 1961), and a concentration of 0.1 to 1 mM has been shown to be adequate for plant development given a balanced cation ratio in the soil solution (Wiersum, 1979). Experiments with maize and tobacco have found that as little as 0.05 mM can be adequate if other divalent cations are at low concentrations (Wallace, 1966).

Soil type can influence the availability of Ca. Kirkby (1979) listed four factors influencing exchangeable Ca: the amount of exchangeable Ca present; the degree saturation of the exchange complex; the type of soil colloid; and the nature of the other cations adsorbed by the clay. In an organic soil, free H ions, released from the oxidation of NH_4, will be available to exchange on the soil colloids for Ca ions, releasing Ca to the soil solution. In an alkaline sandy soil, with little organic matter, Ca on the exchange sites will be released more slowly. The availability of Ca to the plant also differs with clay type. A 2:1 clay type requires higher saturation for the same level of solution Ca than a 1:1 clay type (Tisdale and Nelson, 1985). In recognition of the circumstance-dependent nature of plant Ca requirements, Loneragan and Snowball (1969) have suggested the concept of the variable critical level. They suggest that the critical level for Ca can be defined in three ways: 1) The solution Ca required for minimum root growth. 2) The minimum Ca required at functional site to sustain maximum growth. And 3) the Ca content actually present when Ca becomes deficient for growth.

Calcium Uptake at the Root

Calcium moves to the root primarily by mass flow, and is taken up passively. In studies conducted by Armstrong and Kirkby (1979), Ca concentration in the sap exudate of decapitated tomato plants remained approximately the same as the external solution, regardless of plant energy status; root uptake of Ca was independent of metabolic inhibitors (Wallace and Mueller, 1980). As mass flow increases via an increase in transpiration, Ca in the leaves increases proportionally, whereas Mn increases only slightly (Barber, 1971). The amount of Ca supplied by mass flow depends on the concentration of Ca in the soil solution, and the rate of plant transpiration. Even under depressed rates of transpiration, over 50% of plant uptake of Ca can be accounted for by mass flow. At higher transpiration rates, mass flow accounts for most of the Ca uptake. Calcium is also taken up by root interception. Diffusion accounts for only a fraction of uptake (Kirkby, 1979).

Calcium uptake in the root occurs only in the unsuberized portions of the root, mainly the root tip and temporarily at root branching sites before the Casparian strip is established in the endodermal cells (Robards, 1973; Russell and Clarkson, 1976). Potassium uptake, in contrast, occurs along the entire length of the root. Accumulation of Ca around the root is common when mass flow is in excess of uptake (Barber and Ozanne, 1970).

The mode of transfer of Ca from root to shoot varies depending on the plant species and the concentration of Ca in the solution. There is some evidence that uptake into plant shoots is an energy-dependent process at low solution Ca concentrations (Bangerth, 1979; Kirkby and Pilbeam, 1984).

In studies conducted as early as 1937, high osmotic pressures in nutrient solutions decreased water uptake into the roots and increased BER (Robbins, 1937). Nighttime Ca uptake is dependent on root pressure, which greatly decreases under increased soil salinity. In tomato solution culture studies, Bradfield and Guttridge (1984) compared tissue Ca under diurnal changes in solution osmotic potential (-52 and -208 kPa). An increase in nutrient solution concentration decreased tissue Ca in the distal end of the fruit, and fruit tissue Ca was lowest when the nighttime solution was concentrated. Increases in

BER and decreases in tissue Ca occur when soil solution salinity increases, even when accompanied by an increase in solution Ca (Ehret and Ho, 1986).

Ammonium, Mg, K, Na, Al and H were all shown to compete at low levels of Ca (Miller, 1960; Wallace and Mueller, 1980). Excess NH_4, Mg and Na caused BER, and excess soluble salts increased BER despite high levels of Ca (Geraldson, 1956). Supplemental Ca fertilization increased yields and decreased BER in containerized tomatoes (Geraldson, 1957). Calcium ions rapidly leach out of containers, and soluble salts build up, resulting in Ca deficiency and BER. Calcium plays a role in regulating the uptake of trace metals including Al, Mn, Mo, Ag, Cd, and Ni. When these metals are at high levels, they can inhibit Ca uptake (Wallace and Mueller, 1980).

Some findings in K and Mg competition studies contradict the simple cation antagonism model. Ward (1973) found no evidence of decreased Ca uptake with increase of K or Mg. Increased K in an apple orchard had a negative effect on Ca uptake (Lewis, 1977), but in a study on bell pepper, increasing K had a synergistic effect on leaf Ca, and no effect on BER of the fruit (Hamilton and Ogle, 1961).

High root temperatures can also increase BER due to potassium competition. An increase in root temperature favors K uptake (Q10 of 2.0) over Ca (Q10 of 1.2) (Wallace and Mueller, 1980; Wiersum, 1979). In a 2-year study on the effect of black polyethylene mulch on soil and air temperatures and yield of Muskmelon, black plastic mulch increased soil temperature (Bonanno and Lamont, 1987). Temperatures at a depth of 5 cm were measured for 18 days following transplanting. Black plastic had higher minimum and maximum soil temperatures, and an average increase of 3.5 C in 1984 and 2.8 C in 1985. In tomato, early season incidence of BER increased with black plastic mulches compared to paper mulch or bare ground, and late season BER decreased with black plastic mulches compared to no mulch (Elmer, 1991). The study was conducted on rain-fed, not irrigated, tomatoes. The early season BER increase was attributed to the reduced rainwater penetration through the plastic mulch, but another possible factor is the early season root-zone temperature increase associated with black plastic mulch. It is likely that as the plant begins to shade the root zone the black plastic is no longer as effective in increasing root-zone temperatures.

Low pH has both direct and indirect inhibitive effects on Ca uptake. Aluminum and H become available at pH below 5.0, and Al can strongly inhibit Ca uptake (Ryan and Kochian, 1993). Low pH can also negatively impact root growth, making a higher Ca concentration necessary in the soil solution to protect roots (Lund, 1970). Lime applications to increase pH do not always result in increased Ca availability because of competition by K, Mg, or NH_4 (Van Lune and Van Goor, 1977; Riekerk, 1977; Pill and Lambeth, 1977).

The most significant nutrient factor in BER development is N form. In a hydroponic study on bell pepper, any inclusion of NH_4 in the fertilization regime reduced the Ca content in the distal end of the fruit (Marti and Mills, 1991). Nitrate, on the other hand, enhances the uptake of Ca and has a general stimulating effect on the uptake of cations (Kirkby, 1968). In studies on tobacco, the Ca content of stem exudate was 34 µg/L when roots were bathed in deionized water, 70 µg/L in 10^{-3} N $Ca(NO_3)_2$, and 24 µg/L in 10^{-3} N KNO_3 (Wallace and Mueller, 1980). Nitrate ion concentration dominated root pressure and Ca passively followed into the xylem. The relationship between N form and Ca uptake is considerably more complex in a typical soil solution, where the pH is buffered and H ions can exchange on soil colloids for Ca, increasing the Ca availability to the plant.

Calcium Transport in the Plant

After Ca passes into the root cell, it is transferred into the xylem either actively or through controlled leakage, down an electrochemical gradient from the xylem parenchyma cells into the vessel elements. Once Ca is inside the apoplast, it moves primarily through mass flow, but also by a series of exchange reactions on negatively charged sites along the xylem vessel walls. Increases in mobile Ca can occur when other divalent cations replace Ca on exchange sites, or with the chelation of Ca by organic acids (Kirkby and Pilbeam, 1984; Marschner, 1983).

There are four salient pieces of evidence for nearly exclusive xylem transport for Ca, 1) Phloem Ca concentration is far below requirements for cell growth, 2) Ionic Ca is maintained by the plant at micromolar levels in the cytoplasm because of its ability to form salts of ATP, and inhibit cytoplasmic streaming, 3) Callose formation is promoted by even a few micromoles of free Ca^{2+} in the phloem,

causing sieve tube blockage (Marschner, 1996) and 4) Autoradiographic evidence has shown that Ca is not retranslocated from the leaf into actively growing regions (Barber, 1970).

Supplemental Calcium and Blossom-end Rot

It is possible to increase the Ca available to the plant by fertilizing with $Ca(NO_3)_2$, liming, or spraying Ca salts on fruit. Whether the supplemental Ca treatments decrease BER depends on the plant growth media and environment. In container culture BER was identified not with low Ca in the soil solution, but with a low Ca to soil solution salts ratio (Geraldson, 1954). Calcium sprays are very effective in reducing deficiency disorders in leafy vegetables such as celery, and Ca salts sprayed on apple fruit can increase fruit Ca content and compensate for reduced internal transportation, decreasing bitter pit and increasing storage longevity (Wiersum, 1979). Calcium sprays are effective in reducing BER in tomato, both in solution culture (Geraldson, 1956) and in the field (Dekock, 1979). A 0.04 M $CaCl_2$ foliar spray was highly effective in reducing BER in tomatoes, regardless of the concentration of Ca in the root solution (Geraldson, 1956). Applications of $Ca(NO_3)_2$ and gypsum, with two biweekly additional $CaCl_2$ sprays from time of flowering reduced BER incidence from 17% to 13% in the field. Calcium chloride sprays alone reduced BER from 38% to 26% on container-grown tomatoes (Evans and Troxler 1953). In bell pepper, $CaCl_2$ sprays reduced BER (Schon, 1993; Harper, 1989), but also decreased yield when peppers were harvested at the red ripe stage (Schon, 1993). Calcium sprays have been found to delay ripening in tomato (Wills et al., 1977). It is possible that they would have a similar effect on bell pepper. Excess Ca can cause pitting in bell pepper, and a condition called gold fleck in tomato, due to the build up of Ca oxalate crystals (Janse and deKreis, 1988).

Plant response to supplemental Ca fertilization is subject to many conditions. If cation competition or leaching are restricting the uptake of Ca, a plant may respond favorably to the addition of Ca to the soil. However, because Ca is not remobilized in the phloem, increased leaf Ca concentration does not necessarily indicate increased transport to tissues with high phloem import and high Ca demand (Gerard and Hipp, 1968; Loneragan and Snowball, 1968). Plant physiologists and plant nutritionists

agree that Ca deficiency disorders are most often due to insufficient Ca transportation and distribution to low respiring tissues, rather than insufficient availability (Bangerth, 1979; Marschner, 1983).

Fruit Developmental Stage and Calcium Uptake

The largest incidence of BER in tomatoes seems to occur early in the growing season (Geraldson, 1957), although this generalization has been disputed (Gerard and Hipp, 1968). In bell pepper, plant Ca uptake peaks at bloom and during fruit expansion (Marti and Mills, 1991). In general, as fruit carbohydrate import increases, or when fruit temperature increases, Ca is needed for plasmalemma synthesis (Ho and Adams, 1989). The phloem supplies all the water, sugars and most of the nutrients needed by the enlarging fruit, but very little of the Ca (Marschner, 1983). As phloem imports increase, xylem transport to the fruit decreases or even reverses, so the amount of Ca being supplied to the fruit decreases substantially. The faster the fruit growth the more phloem dependent it is, and the less likely to maintain adequate Ca for growth. A rapid change in volume to surface area ratio corresponds to a lower transpiration rate per unit weight of the fruit, which further reduces Ca availability (Kirkby and Pilbeam, 1984). In bell pepper, as fruits reach the mature green stage, Ca uptake and requirement declines (Marti and Mills, 1991).

Nitrogen application rates which cause excessive shoot growth may put the fruit at a competitive disadvantage. In apples, 90% of Ca accumulation occurs in the six weeks after bloom, and later Ca accumulation will not compensate for early deficiencies (Shear, 1975). The N/Ca ratio has been found to be more accurate in predicting bitterpit and corkspot than Ca alone in apple. Similar results were found in tomato, where blossom-end rot did not develop when the N/Ca ratio in tomato leaflets was less than one (Wojciechowski, 1969).

Genetic Aspects of Calcium Uptake

Varietal differences in BER susceptibility are most likely attributable to differing rates of cell enlargement and Ca transport within the fruit (Adams and Ho, 1992). Differences in BER susceptibility among tomato cultivars were linked more closely to the total area of fruit tissue served by a vascular

bundle than with total Ca uptake (Ho, 1993). The high incidence of the less severe, internal form of BER in a cultivar such as 'Calypso' may result from poor Ca transport within the fruit, whereas a highly susceptible cultivar such as 'Spectra' with a high incidence of external BER may suffer from both poor Ca uptake by roots and poor xylem transport within the fruit, especially under high salinity (Adams and Ho, 1992).

In a study of fifteen bell pepper cultivars, no discernible difference was found in fruit Ca content; instead, susceptibility was linked to fruit load (Morley et al., 1993).

Transpiration and Calcium Distribution

A high rate of leaf transpiration decreases, and low rate increases the transport of Ca into tomato fruit (Bangerth, 1979; Gerard and Hipp, 1968). Fruit may even lose water and Ca to high transpiring leaf organs (Marschner, 1996). In bell pepper, increasing the rate of fruit transpiration relative to the leaves was more effective in increasing fruit Ca uptake than increasing the Ca content of the soil solution (Marschner, 1983). Ho and Adams (1994) studied Ca uptake rates and distribution in cucumber, which is not normally susceptible to BER, and a susceptible tomato cultivar. They attributed the difference in susceptibility to differences in fruit transpiration. Cucumber fruit have a much higher number of stomates, about 20 to 30 mm^{-2}, and a higher rate of transpiration than tomato fruit, which have few if any stomates.

Antitranspirants have been shown to significantly decrease BER and increase fruit Ca, without affecting leaf Ca concentration (Schon, 1993). In greenhouse studies on 'Hungarian Wax' peppers an antitranspirant (1% 'Vapor Guard') applied early in the fruiting stage increased fruit Ca by 57%. Weekly antitranspirant (1% 'Folicote') applications increased fruit Ca by 38% and reduced BER by 24% (31 total applications), but also decreased yields due to a reduction in CO_2 assimilation and gas exchange.

Humidity strongly affects transpiration, Ca transport and BER. Blossom-end rot increases under high or very low vapor-pressure deficits (VPD). A VPD above 14 to 15 mmHg increased BER significantly, and above 25 mmHg VPD, all tomato fruit developed BER symptoms (Gerard and Hipp,

1968). In a growth chamber, relative humidity (RH) of 70% and 7.9 mmHg VPD decreased BER by 62% when compared to RH 35% and 17.1 mmHg. Night-time RH of 93% and 1.1 mmHg VPD and daytime RH at 65% and 6.9 mmHg VPD promoted the transport of Ca into tomato fruit compared to low day and night humidity (Bradfield and Guttridge, 1984). Calcium is supplied mostly by root pressure at night, and fruit growth is greater at night, so high nighttime humidity increases fruit Ca preferentially. However, constant high humidity may lower transpiration so much that Ca does not reach the developing leaves and fruit. Wiersum (1966) found that increasing humidity around tomato fruit selectively by bagging them in plastic led to an increase in BER. Tomato plants grown at a constant 95% RH, (less than 1 mmHg), developed nearly 100% BER, and had lower leaf Ca concentration than plants kept at 53% RH (Banuelos, 1985).

Under intense solar radiation, leaf temperatures may be substantially higher than air temperatures, leading to higher vapor-pressure deficits. Aikman and Houter (1990) describe tomato leaf transpiration as the sum of two terms: transpiration driven by radiation absorption and diffusion driven by the water vapor deficit and velocity of the air. If leaf temperatures are higher than surrounding air, water vapor can be lost from the leaf, even at 100% relative humidity (Gaffney, 1978). In many plant species stomates close at temperatures above 32C (90°F). Leaf cooling is then dependent on conductive and convective heat loss, rather than evapotranspiration. While the stomates are open, transpiration losses are heavy. Climactic analysis of three years' data linked significant increases in BER with temperatures above 32C in 'Chico' tomatoes (Gerard and Hipp, 1968).

In a study of two tomato cultivars, the incidence of BER linearly increased with an increase in the product of daily solar radiation and temperature (Ho, 1993). A higher incidence of bitter pit occurs in apples grown on exposed positions on the tree (Wallace, 1953), and a reduced incidence of BER in tomatoes with increased shading (Wedgeworth et al., 1927). A reflective coating applied to leaf surfaces increased Ca in tomato fruit and decreased BER and sprinkler irrigation of tomato during periods of high evaporative stress decreased BER, but may have increased Ca lost to leaching (Gerard and Hipp, 1968).

Row Cover Influence on Plant Microclimate and Yield

Spunbonded polyester and polypropylene row covers (SPC) are used to increase temperatures in the plant environment, extend harvests and increase early and total yields. Other benefits include insect exclusion and reduced virus transmission. Spunbonded row covers decreased southern blight on peppers grown in Florida (Brown, 1987) and reduced insect-transmitted viruses in the desert agriculture of Arizona (Natwick, 1987). Row covers are often used to protect plants from late frosts and to extend the growing season. Frost protection can be significant (1 to 2C) during advective frosts, but row covers can actually increase frost damage in desert climates where frosts are commonly radiative, rising from the ground (Reed et al., 1989). Wells and Loy (1985) provide a useful history of row covers.

Different row cover materials can have widely varying effects on yield and pepper development. Polyethylene sheet plastics allow the transfer of much greater amounts of light and increase daytime temperatures far above increases under SPC. Yield decreases in pepper and tomato have sometimes resulted from the above optimum air temperatures common under polyethylene materials, even when ventilated with slits or perforations (Wells and Loy, 1985; Wolfe and Bell, 1987). Peppers can be very temperature-sensitive depending on the cultivar. Optimum air temperatures for pepper fruit development are 18C to 27C, but 'Tabasco' (C. frutescens) requires higher temperatures to reach maturity (Kratky, 1989). Air temperatures above 31C during anthesis cause blossom abscission in many bell pepper cultivars.

The effect of row covers is also environment-dependent. Bell pepper early yield increased under SPC in one Illinois study (Mohd Khir, 1987), and decreased in another study conducted two years later in the same state (Call, 1989). In a northern short-season climate, (Fraser Valley, B.C.), early yields increased under SPC one year (Maurer, 1987), and total and early yields increased the next year (Maurer and Frey, 1988). In southern Oklahoma, SPC was used to shade pepper plants and increase yield (Roberts and Anderson, 1994). Total yield under SPC increased significantly in two out of three years as compared to black plastic mulch, and one out of three years compared to bare soil. Average marketable weight over the three years was 22.3 T · ha^{-1} for the row-covered plots, compared to 11.4 T · ha^{-1} with

black plastic mulch. Spunbonded polypropylene row covers also reduced sunscald in two out of three years.

Heat units typically accumulate two times faster under SPC than with black plastic mulch alone. In a study on muskmelon, daytime air temperatures under SPC with black plastic mulch were higher than air temperatures above bare soil by an average 5C, while night temperatures were 1.4C higher (Loy and Wells, 1982). On a cloudy day, midday average air temperatures under SPC were 1.4C higher and on a sunny day 10.4C higher than temperatures above clear plastic mulch (Wolfe, et al., 1986).

Sunscald in tomato is associated not only with high irradiance but also with fruit temperatures above 45C for tomato fruit, even in darkness (Adegoroye and Jolliffe, 1983). For bell pepper, fruit temperatures above 50C result in sunscald (Barber and Sharpe, 1971). The temperature of dark-green bell pepper fruit can increase up to 24C above ambient temperature when exposed to full sun. Although air temperatures under row cover are typically higher than ambient, the net effect on fruit may be a reduction of temperature when compared to exposed fruits, due to shading.

A direct relationship has been established between heat, light exposure and development of sunscald symptoms (Morley et al., 1993). Light-colored Capsicum have a lower incidence of sunscald, apparently due to their increased reflectivity (Barber and Sharpe, 1971). Solar injury decreased substantially under SPC, and plant moisture stress was lower under SPC than with bare soil or black plastic mulch (Roberts and Anderson, 1994).

High temperatures typically increase solar injury and BER, but increased air temperatures under SPC may be mitigated by shading. Spunbonded materials decrease total photosynthetically active radiation by 10 to 20% or more, but do not significantly change light quality, such as the ratio of far red to red light (Decoteau and Friend, 1991; Friend and Decoteau, 1990). Irradiance levels under cloudless conditions are typically 1/2 to 2/3 above light saturation point (increasing light no longer increases photosynthesis) for most C-3 species, thus most of the solar radiation absorbed by a plant under full sun is converted to heat. Spunbonded polypropylene row covers reduce above-maximal light, lowering leaf temperatures (Roberts and Anderson, 1994). Average midday leaf temperatures under SPC decreased

from 35.1 to 31.9C when compared to black plastic mulch, and were 1C lower than leaf temperatures above bare soil.

Peppers are tropical short-day plants, reaching highest yield potential in eight- to twelve-hour days of equatorial sun (Dorland and Went, 1947). In a tropical region, bell pepper responded positively to a 45% reduction in light (Schoch, 1972). The decrease in light caused several morphological changes: the number of leaf stomata were reduced, 17% of the epidermal cells formed stomata under full sun as opposed to 7% under shade; leaf area increased by 75%, and there was a 40% increase in dry weight of leaves. Row cover and shade cloth were removed after anthesis. Number of fruits, fruit weights and total weights of the shaded plants were significantly greater than those grown in full sun.

Very little research has been done on absolute humidity changes under rowcovers. Daytime relative humidity decreases under SPC due to temperature increases (Maurer and Frey, 1988). As plants reach maturity, the increased leaf cover under SPC may cause a reversal of the initial trend, with cooler temperatures and higher relative humidities.

Wind speeds decrease with use of SPC tunnels. Wind speed was reduced by 88%, from 3.5 to 0.4 $m \cdot s^{-1}$ under SPC (Schloupt, 1991). Wind velocity is negatively correlated with internode length, fresh and dry weight, leaf number and leaf area index, and increased wind velocity results in greater lignification of plant stems. Plant movement, such as that caused by high winds, increases cytosolic Ca levels (Knight et al. 1992), which in turn cause the closure of stomates (Gilroy, 1990), reducing Ca availability to growing tissues.

Chapter 3

MATERIALS AND METHODS

Experiments were conducted in 1995 and 1996 at the Hermiston Agricultural Research and

Extension Center in Hermiston, Oregon to determine the effect of spunbonded polyester row cover, Ca

fertilization and cultivar on blossom-end rot, yield and quality of bell pepper (Capsicum annuum var.

annuum, Grossum Group). The experiment was a complete factorial with four replications of two

varieties, with and without row covers, and three levels of supplemental Ca: 0, 34 and 68 kg Ca·ha⁻¹ .

Data were analyzed with SAS Proc GLM, using orthogonal contrasts for Ca treatment effects (SAS

institute, Cary, N.C.).

Transplant Establishment

Bell pepper varieties 'Vidi' (Vilmoren, France) and 'Ranger' (Asgrow, USA) were seeded into a

commercial soilless peat-based medium (Sunshine mix number 3: 3 parts peat to 1 part vermiculite,

dolomitic lime added for pH adjustment) in 96-cell trays (24.6 cm³/cell) on 5 April 1995 and 18 May

1996, and placed in the greenhouse. Seedlings were fertilized two times per week with a 20-10-20 N-P-

K complete fertilizer at 200 ppm N.

Plot Preparation - 1995

In 1995 field plots were established in an Adkins Series fine sandy loam (coarse-loamy, mixed

Mesic Xerollic Camborthid) by rototilling and sub-soiling on 14 March. Metham ('Vapam', 560 L·ha⁻¹)

was incorporated to a depth of 0.3 m with overhead irrigation on 18 March, and a spring wheat

windbreak was seeded on 31 March at a spacing of 2.3 m. A pre-plant soil test reported pH 6.9, soluble

salts ratio of 0.20 mmhos·cm⁻¹ and Ca at 5.1 meq·l⁻¹. Fertilizer (89 kg N·ha⁻¹, 112 kg P·ha⁻¹, 179 kg

K·ha⁻¹ and 45 kg S ·ha⁻¹ and micronutrients copper, zinc and boron at 4.5, 3.4 and 1.7 kg·ha⁻¹,

respectively) was broadcast in a 0.8 m band in each bed and rototilled to a 0.3 m depth on 3 May.

Planting beds were established by subsoiling the area between windbreaks on 4 May and rototilling on 6

May. On 9 May a single drip irrigation line (Roberts Ro-Drip, 0.02 cm- thick plastic, emitter spacing at 20 cm, 150 L·hour^{-1} /30.5 m delivery rate) was buried 5 cm deep in the center of the bed, and the bed was covered with 1.2 m wide black plastic mulch (0.003 cm thick). Drip lines were plumbed to three separate ball valves according to Ca treatment level so that the treatment blocks could be fertigated independently.

Seedlings were placed in a cold frame to harden off on 25 May, and transplanted on 27 May. The planting beds were 76 cm wide and consisted of two plant rows, 41 cm between rows and 31 cm between plants, 20 plants per plot. A 31 cm border between covered and uncovered plots was included for securing the ends of the material. Wire was used as a support hoop for the row cover, with center height and hoop spacing at approximately 45 and 152 cm, respectively. A polypropylene spunbonded row cover, (Gromax "Gro-shield" partially opaque 20 g · m^{-2}, transmission quality from 80 to 90%) was applied immediately after transplanting.

Plot preparation - 1996

Preparation of the 1996 planting site began 29 March by rototilling 1.8 m swaths in a winter wheat cover crop, leaving 15 cm wide stands of wheat as a windbreak. According to a soil test taken in 1994, the soil pH was 7.1, the soluble salts ratio was 0.12 mmhos·cm^{-1}, and Ca was 5.5 meq·l^{-1}. Fertilizer (89 kg N·ha^{-1}, 90 kg P·ha^{-1}, 146 kg K·ha^{-1} and 36 kg S·ha^{-1}, and micronutrients 3.4, 2.8, and 1.1 kg·ha^{-1} Cu, Zn and B, respectively) was broadcast in a 0.8 m wide band, and rototilled in on 5 April. On 8 April the plot area was subsoiled, and fumigated by incorporating Metham ('Vapam', 560L· ha^{-1}) in the 1.8 m strips with a rototiller. The plot areas were rototilled again on 29 April, and black plastic mulch and drip tape were installed.

On 18 May 1996, immediately after transplanting the seedlings, a severe hailstorm caused an 80% to 90% stand loss. The peppers were re-seeded in the greenhouse on 18 May, as previously described. The 'Vidi' and 'Ranger' seedlings were placed in the cold frame 17 and 19 June, respectively. The seedlings were transplanted and the row covers put in place on 25 June 1996. Other cultural practices were as described for 1995.

Irrigation and Fertilization

Irrigation requirements were determined according to the formula: $ET_{crop} = K_c \cdot K_p \cdot E_{pan}$, where K_c is the bell pepper crop coefficient, K_p is the pan coefficient and E_{pan} is the pan evaporation in mm·day^{-1} (Doorenbos and Pruitt, 1975).

Weekly fertigation began approximately four weeks after the planting date. In 1995, plots were fertigated on 22 June, and 6 and 26 July with 0, 34 or 68 kg Ca ·ha^{-1} (Solution Grade $Ca(NO_3)_2$: 19% Ca, 1% NH_4, 14.5% NO_3) plus urea ammonium nitrate (UAN-32: 7.8% NO_3 , 7.8 % NH_4, 16.4% Urea to make 22 kg·ha^{-1} N. Additionally, plots were fertigated with 22 kg N·ha^{-1} (UAN-32) on 29 June and 20 July. A major hailstorm on 9 July caused approximately 60% to 80% defoliation, loss of many of the plant stems, buds and branches, and damage to the fruits. Row covers were replaced immediately after the storm, and damaged fruit was removed on 17 July. Due to the hail storm, wheat from the wind rows seeded into rips in the black plastic mulch, requiring herbicide sprays (Sethoxydim) on 25 July and 1 August.

In 1996, plots were fertigated on 17 July, 31 July and 8 August; and N alone was applied through the drip lines on 23 July. Because of the delayed planting date the fertigation schedule was shortened to a total of four fertigations, reducing the total N fertigated to 90 kg·ha^{-1} from the previous year's 112 kg·ha^{-1}. The total Ca application was unchanged.

Data Collection

The number of plants with open blossoms in each plot was tallied on 29 June and 5 July, 1995. In 1996, blossoming plants were counted every other day beginning 16 July until over 90% of the plants in each plot were in blossom.

One week after final fertigation in 1995 and 1996, the above ground portion of two plants/plot was destructively harvested for leaf area (Li-Cor Model LI-3000) and dry weight measurements. In 1995 the area of the leaf blade only (without petioles) was measured, dried at 63C and weighed. In 1996, the entire leaf area, with petiole, was measured and the leaves and stems were weighed separately after drying. Because of this change in method, leaf areas could not be compared by year. Specific leaf area,

(leaf area cm^2/g dry weight) was calculated from the leaf area and dry weight measurements. Specific leaf area is a measurement of leaf density which is especially sensitive to environmental changes such as shading; it is also used to compare growth across varieties and species because it is more reflective of the energy expenditure and growth efficiency of the plant than dry weight or leaf area alone (Hunt, 1978).

In both years, samples of unblemished and BER affected mature fruit were taken from each of the plots at first harvest, graded, counted and weighed, and prepared for tissue analysis. A sample size of six fruit (1/4 section of each) was targeted, but there was a shortage of BER affected fruit under the row cover and a shortage of healthy fruit outside the row covers. The sample collection time was extended to cover the first two harvests, but despite the extended time line, some plots were not represented in the final analysis and some had as few as one or two fruit per sample. Pepper sections were dried in an oven at 63C for four days and ground in a Wiley mill (40 mm mesh screen). One-gram subsamples were ashed at 500C, solubilized in 1N HCl, filtered (Whatman No.42 filter paper) and diluted to 50 ml final volume with 1 N HCl. Analysis for P, K, Ca, and Mg content was conducted by inductively-coupled plasma spectrometry (Kuo Testing Labs, Othello, Wa.).

In 1995, weekly harvests began 132 days after seeding on 15 August, and continued until 30 September, for a total of six harvests. In 1996, harvest began 7 September, 112 days after seeding, and continued until 27 September, for a total of four harvests. Prior to each harvest, the plots were scouted for virus, and symptomatic plants were removed. The number of plants was then established for the plot and used in calculating the average fruit per plant and yield. Mature green fruit were collected, sorted according to US Department of Agriculture standards (USDA, 1981) counted and weighed. Fruit with defects were sorted into three categories: blossom-end rot, sunscald, and other (primarily insect damage, misshapen fruit and bacterial rot). Sunscald (SS) was identified by the usually dry, papery consistency and the light color of the affected area. At the early stages SS appears water-soaked, and can be difficult to distinguish from other disorders, including BER (Barber and Sharpe, 1971). In 1996, pepper fruit was sorted into BER and SS categories in the field during harvest, based on the position of the fruit on

the plant (sun exposure) as well as the above criteria. This gave an added degree of confidence in the nature and cause of the fruit injury.

Chapter 4

RESULTS AND DISCUSSION

Plant Growth and Development

Anthesis

The timing of first anthesis was similar for both varieties in 1995 (Table 1), but in 1996 'Vidi' bloomed earlier than 'Ranger' on the first count date and on two subsequent dates (Table 2). Supplemental Ca rate did not affect anthesis in 1995 (Table 1). In 1996, plots receiving the 68 kg·ha^{-1} Ca treatment had a greater percent of plants in bloom at the second blossom count date, 5 days after the first Ca application (23 kg·ha^{-1} Ca applied) (Table 2). At the later dates there were no differences in anthesis.

Anthesis was delayed by the row cover in 1995 (Table 1), but not in 1996 (Table 2). In a study of Capsicum frutescens 'California Wonder', light intensity did not affect time of flowering in bell pepper, anthesis was delayed at night-time air temperatures of 12C compared to 18C, and a decrease in light intensity and night-time air temperature increased the number of flowers produced as a result of increased branching (Deli, 1969). In a study conducted at the Hermiston Agricultural Research and Extension Center, late spring night-time temperatures under row cover materials were lower than ambient, most likely due to radiative cooling (Reed et al., 1989). Cooler spring temperatures under row cover could have delayed anthesis in 1995. Row cover may not have had the same effect in 1996 because of the delayed planting date.

Leaf Area, Leaf Dry Weight and Specific Leaf Area

Leaf area, leaf dry weight and specific leaf area did not differ between varieties in either 1995 (Table 3) or 1996 (Table 4), but fruit fresh weight taken at the time of leaf area measurements in 1996 was higher with 'Vidi' than with 'Ranger'.

In 1995 increasing Ca rate did not affect leaf area, but leaf dry weight increased linearly and a 0.07 p-value suggested a linear decrease in specific leaf area as Ca rate increased (Table 3). In 1996, Ca rate did not affect leaf area, dry weight, specific leaf area or fruit fresh weight/plant (Table 4).

Leaf area increased with row cover in 1995, as did leaf dry weight and specific leaf area when compared to no cover (Table 3). In 1996, leaf area and specific leaf area increased under row cover (Table 4). Schoch (1972) also reported increased leaf area and dry weight following 55% shading during the vegetative growth phase of bell pepper. Fruit fresh weight, measured in 1996 when most plants sampled for growth analysis had fruit set, was lower with the row cover than without.

Fruit Calcium Concentration

Fruit Ca concentration was approximately two times higher in 1995 than in 1996 (Table 5). Others have reported 0.18% (Hamilton and Ogle, 1962; Marti and Mills, 1991) and 0.1% (Kratky, 1989) Ca concentration of dry weight for healthy bell pepper fruit tissue. Although Ca concentration in fruit tissues varies considerably, the 1996 values may have been lower than average. Differences in growth rates between years may account for the variation in fruit Ca concentration. Fruit growth was accelerated with the later planting date in 1996, and fruit Ca concentration decreases with increased fruit growth rate (Marschner, 1996).

Fruit with BER had a lower Ca concentration than fruit without BER. Fruit Ca concentration was higher for 'Vidi' than for 'Ranger'. An increase in Ca fertilization rate linearly increased fruit Ca concentration in 1995, but Ca rate did not affect fruit Ca concentration in 1996.

Row cover did not affect fruit tissue Ca concentration in 1995, but in 1996 tissue Ca was higher with row cover than without. Leaf/fruit competition for Ca may be reduced under row cover due to decreased leaf transpiration, augmenting Ca transport to the fruit.

Table 1. Percent plants in blossom as affected
by variety, supplemental Ca fertilization,
and row cover, 1995.

	Date	
	6/29	7/5
Variety	%	
Ranger	33	81
Vidi	26	85
	NS	NS
Ca rate (kg·ha^{-1})		
0	29	83
34	31	84
68	29	82
	NS	NS
Row cover		
Gromax	24	77
None	35	89
	(p=0.08)	**

**,NS Significant at P ≤ 0.01 or not significant,
respectively.

Table 2. Percent plants in blossom as affected by variety, supplemental Ca
fertilization and row cover, 1996.

	Date			
	7/19	7/22	7/24	7/26
Variety		%		
Ranger	1	19	36	61
Vidi	6	25	58	81
	(p=0.06)	NS	***	****
Ca rate (kg·ha^{-1})				
0	5	19	49	74
34	2	16	40	65
68	4	33	53	73
Ca vs none	NS	*	NS	NS
Row cover				
Gromax	2	21	46	69
None	5	23	48	72
	NS	NS	NS	NS

****,***,*,NS Significant at P ≤ 0.0001, 0.001, 0.05 or not significant,
respectively.

Table 3. Leaf area, leaf dry weight and specific leaf area of leaf blade as affected by variety, supplemental Ca fertilization and row cover, 1995.

	Leaf area	Dry weight	Specific leaf area
Variety	cm^2	g	$cm^2 \cdot g^{-1}$
Ranger	6090	30.8	199
Vidi	5903	30.4	193
	NS	NS	NS
Ca rate (kg·ha⁻¹)			
0	5657	26.9	209
34	5940	30.9	191
68	6393	34.0	188
Ca, linear	NS	**	(p=0.07)
Ca vs none	NS	**	*
Row cover			
Gromax	7238	34.4	214
None	4755	26.8	178
	****	****	***

****, ***, **, *, NS Significant at P ≤ 0.0001, 0.001, 0.01, 0.05 or not significant, respectively.

Table 4. Leaf area, leaf dry weight, and specific leaf area of leaf blade and petiole, and fresh fruit weight/plant as affected by variety, supplemental Ca fertilization, and row cover, 1996.

	Leaf area	Dry weight	Specific leaf area	Fruit fresh weight
Variety	cm^2	g	$cm^2 \cdot g^{-1}$	g
Ranger	6798	31.4	215	129
Vidi	6053	28.0	208	183
	NS	NS	NS	*
Ca rate (kg·ha⁻¹)				
0	6140	28.4	215	132
34	6241	29.2	202	150
68	6951	31.7	218	186
	NS	NS	NS	NS
Row cover				
Gromax	7275	31.6	229	124
None	5626	27.2	194	186
	**	NS	****	*

****, **, *, NS Significant at P ≤ 0.0001, 0.01, 0.05 or not significant, respectively.

Table 5. Fruit Ca concentration as affected by blossom-end rot (BER),variety, supplemental Ca fertilization, and row cover, 1995 and 1996.

	Year	
	1995	1996
BER	%	
Yes	0.16	0.08
No	0.17	0.08
	(p=0.08)	*
Variety		
Ranger	0.16	0.07
Vidi	0.18	0.09
	****	****
Ca rate (kg·ha^{-1})		
0	0.16	0.08
34	0.16	0.08
68	0.18	0.08
Ca, linear	**	NS
Ca vs none	(p=0.08)	NS
Row cover		
Gromax	0.17	0.09
None	0.16	0.08
	NS	*

****, **, *, NS Significant at P ≤ 0.0001, 0.01, 0.05, or not significant, respectively.

Early Yield

The early (first harvest) yield of fancy, 1&2-grade and total marketable bell pepper fruit was lower in 1995 than in 1996 (Table 6), most likely due to plant damage from the hailstorm in July of 1995, and later planting date in 1996 than in 1995. Fancy-grade yield increased with use of row cover in 1995, but not in 1996 (Table 7). Fancy-grade yield was higher for 'Vidi' than 'Ranger' except in 1995, under row cover. Yield of BER-affected fruit was higher for 'Vidi' than for 'Ranger'; however, the difference was greater in 1995 than in 1996 (Table 8). Blossom-end rot yield was lower with row cover in both years, although the yield difference with and without row cover was greater in 1996. The early yield of other cull fruit was higher in 1995 than 1996 (Table 6). Sunscald fruit yield was not different between years.

First harvest total cull yield was higher in 1995 than in 1996 with row cover, and lower in 1995 than 1996 without row cover (Table 9). Early total yield was lower in 1995 than in 1996 (Table 10). In 1995 row cover had no effect on early total yield, but in 1996 early total yield was lower with row cover than without due to the reduced yield of cull fruit with row cover.

The first harvest percent BER fruit in 1995 was 59.2% compared to 27.5% in 1996 (Table 11). The percent of fruit with sunscald was also higher in 1995 than in 1996, with 3.8% compared to 1.7%, respectively.

First harvest fancy-grade fruit weight depended on year, variety and row cover (Table 12). 'Vidi' had higher fancy-grade fruit weight than 'Ranger' both years, and row cover increased for fancy-grade fruit yield for 'Vidi', in 1996 only (p=0.08). First harvest grade 1&2 and BER fruit weight also were lower in 1995 than in 1996 (Table 13), but year interacted with each of the treatment variables to affect BER fruit weight (Table 14).

In 1995, the first harvest fancy-grade fruit yield was higher with 'Vidi' than with 'Ranger' without row cover, but did not differ between varieties with row cover (Table 7). First harvest fancy-grade yield was higher with row cover than without for both varieties in 1995, but was not affected by row cover in 1996. In 1996, 'Vidi' first harvest fancy yield was higher than 'Ranger'. First harvest yield of grades 1&2 was similar by variety (Table 6), but first harvest total marketable yield of 'Vidi' was higher than 'Ranger'. First harvest yield of BER fruit was higher for 'Vidi' than 'Ranger' both years, but the

difference between varieties was greater in 1995 than in 1996 (Table 8). The yield of SS fruit was not different between varieties with the row cover, but without the row cover, 'Vidi' had more SS than 'Ranger' (Table 15). The leaf areas were not different between varieties, and 'Vidi' fruit are larger and longer than 'Ranger', so 'Vidi' fruit are more exposed than 'Ranger'. Row cover decreased SS yield for 'Vidi', but not for 'Ranger'.

There was no Varietal difference in the yield of other cull fruit (Table 6). First harvest total cull yield was higher in 'Vidi', as was the first harvest total yield. There was no difference in percent BER with variety (Table 11), nor was there any difference between varieties in percent SS fruit, although there was an interaction between variety and row cover. The row cover decreased percent SS yield for 'Vidi' but not for 'Ranger' (Table 16).

At the first harvest, fancy-grade fruit weight was higher for 'Vidi' than 'Ranger', although the difference between varieties was smaller in 1995 than in 1996 (Table 12). First harvest fruit weight of grades 1&2 was not significantly different by variety (Table 13). First harvest BER fruit weight did not significantly differ between varieties in 1995, but was higher with 'Vidi' than 'Ranger' in 1996 (Table 14).

The first harvest yields of fancy-grade fruit increased linearly as rate of supplemental Ca fertilization increased, and a 0.06 p-value suggests a linear increase in total marketable yield as Ca rate increased (Table 6). First harvest BER yield decreased linearly as Ca rate increased. These results agree with the research of Marti and Mills (1991) which found that any increase in the NO_3^- / NH_4^+ ratio decreased BER due to reduced cation competition with Ca and the positive effect of NO_3^- on Ca uptake.

As the Ca rate increased, the ammonium to nitrate ratio decreased. For the 0 kg·ha^{-1} Ca treatment, the ratio of ammonium to nitrate was 3/1. For the 34 kg·ha^{-1} Ca treatment, the ratio was 1.4/1 in 1995 and 1.2/ 1 in 1996, and for the 68 kg·ha^{-1} Ca treatment, the N ratio was 0.71/1 in 1995 and 0.49/1 in 1996.

First harvest SS fruit yield also decreased as Ca rate increased. The total first harvest yield of cull fruit declined linearly with increased Ca rate, reflecting the reduction in blossom-end rot and sunscald.

The proportion of cull fruit decreased and the marketable fruit yield increased, resulting in no change in total yield with increased Ca rate. Blossom-end rot and SS as a percent of total early yield decreased linearly as Ca rate increased (Table 11).

Calcium nitrate fertilization increased the early yield of larger, fancy-grade fruit but did not significantly increase the yield of 1&2-grade fruit. The total first harvest yield was not affected by $Ca(NO_3)_2$ fertilization, suggesting that overall productivity is not increased with use of $Ca(NO_3)_2$. Perhaps more large-size fruit, which might have been culled due to BER or SS, remained free of the disorders until harvest. Calcium nitrate may have a disproportionate effect on fruit with faster growth rates. An increased growth rate has been linked to susceptibility to localized Ca deficiencies due to increased phloem relative to xylem import (Bangerth, 1979; Shear, 1975). Use of $Ca(NO_3)_2$ may increase Ca concentration in the xylem enough to compensate for the increased phloem/xylem import ratio in faster growing fruit. It is possible that there are two modes of BER development, one brought on by increased growth rate leading to Ca-deficient tissues, the other brought on by leaf/fruit competition for xylem water. Where the former mode would effect plants with fewer, larger fruit, the latter mode might affect plants with a greater overall fruit load, and thus smaller individual fruit.

The first harvest weight of fancy and 1&2-grade fruit increased linearly as rate of Ca increased (Table 13). The effect of supplemental Ca on first harvest weight of BER fruit depended on interactions between year and variety, year and Ca rate, year and row cover, and Ca rate and row cover treatments. Increasing supplemental Ca rate had no effect in 1995, but caused a linear decrease in the first harvest BER fruit weight in 1996 (Table 14). First harvest BER fruit weights were approximately two times lower in 1995 than in 1996, most likely due to the hailstorm in 1995 and the later first harvest date in 1996. An increase in the supplemental Ca rate linearly decreased the first harvest BER fruit weight in the covered plots, but not in the uncovered plots (Table 17).

Row cover increased the early yield of fancy-grade fruit in both varieties in 1995, but did not affect fancy fruit yield in 1996, possibly due to the later planting date (Table 7). Row cover increased first harvest yield of 1&2-grade and total marketable fruit (Table 6). Blossom-end rot decreased more under row cover in 1996 than in 1995, but in both years the reduction was significant (Table 8). Row cover

reduced first harvest SS fruit yield for 'Vidi', but not for 'Ranger' (Table 15). Row covers have been used successfully in the South to reduce solar injury in bell peppers (Roberts and Anderson, 1994).

Row cover significantly reduced the first harvest total cull fruit yield in both years, but the difference between plots with row cover and without was larger in 1996 than in 1995 (Table 9). Early total fruit yield was not different between row cover treatments in 1995, but was higher without row cover than with row cover in 1996, due to the greater yield of cull fruit that year (Table 10).

Percent BER fruit at first harvest decreased from 51.4% to 25.4% with row cover (Table 11). Row cover had no effect on percent yield of SS fruit in 'Ranger', but decreased first harvest percent SS fruit from 6.1% to 0.8% for 'Vidi' (Table 16).

First harvest fancy (Table 12) and 1&2-grade (Table 13) fruit weights were not affected by row cover. The effect of row cover on weight of BER fruit depended on year and Ca rate. In 1995, BER fruit weight was higher with than without row cover, and in 1996, the reverse was true (Table 14). Blossom-end rot fruit weight decreased when plants were grown with as compared to without row cover at 68 kg·ha^{-1} Ca (Table 17). Contradictory effects of row cover on fruit weight have been reported in the literature. A 15% decrease in bell pepper fruit weight under row cover has been reported, while at the same time total yield increased (Gent, 1989). Others report no effect of row covers on fruit weight (Gaye, 1989; Maurer, 1987).

Table 6. Early (first harvest) bell pepper yield as affected by year, variety, supplemental Ca fertilization, and row cover.

	Marketable			Cull				Total yield
	Fancy	No. 1&2	Total	BER	Sunscald	Other	Total	
Year (Y)				t · ha⁻¹				
1995	1.10	0.64	1.73	2.98	0.21	0.13	3.33	5.06
1996	4.24	2.22	6.46	2.80	0.20	0.05	3.04	9.50
	****	****	****	NS	NS	*	NS	****
Variety (V)								
'Ranger'	2.06	1.46	3.52	2.27	0.15	0.09	2.52	6.04
'Vidi'	3.26	1.37	4.63	3.51	0.25	0.09	3.85	8.49
	****	NS	**	****	NS	NS	****	****
Ca rate(kg·ha⁻¹)								
0	2.32	1.40	3.72	3.27	0.28	0.09	3.65	7.37
34	2.66	1.35	4.01	2.70	0.18	0.08	2.96	6.97
68	2.98	1.51	4.50	2.69	0.13	0.10	2.93	7.43
Ca linear	**	NS	(p=0.06)	*	*	NS	**	NS
Ca vs. none	*	NS	NS	*	*	NS	***	NS
Row cover (C)								
Gromax	2.99	1.71	4.70	1.65	0.07	0.09	1.82	6.52
None	2.32	1.11	3.45	4.09	0.32	0.09	4.51	7.96
	***	**	***	****	****	NS	****	**
Interactions								
Y x V	****	NS	NS	*	NS	NS	NS	NS
Y x C	*	NS	NS	****	NS	NS	****	***
V x C	NS	NS	NS	NS	**	NS	NS	NS
Y x V x C	*	NS	NS	NS	NS	NS	NS	NS

****, ***, **, *, NS Significant at P ≤ 0.0001, 0.001, 0.01, 0.05 or not significant, respectively.

Table 7. Bell pepper early fancy-grade yield as affected by year x variety x row cover interaction.

	1995				1996		
	Ranger	Vidi			Ranger	Vidi	
Row cover				t·ha⁻¹			
Gromax	1.61	1.85	NS		2.90	5.83	****
None	0.26	0.69	**		3.46	4.90	*
	****	**			NS	NS	

****, **, *, NS Significant at P ≤ 0.0001, 0.01, 0.05 or not significant, respectively.

Table 8. Bell pepper early blossom-end rot (BER) fruit yield as affected by year x variety and year x row cover interactions.

	Year		
	1995	1996	
Variety		t · ha⁻¹	
Ranger	2.15	2.40	NS
Vidi	3.79	3.22	NS
	****	*	
Row cover			
Gromax	2.38	0.90	****
None	3.57	4.62	**
	***	****	

****, ***, **, *, NS Significant at P ≤ 0.0001, 0.001, 0.01, or 0.05 or not significant, respectively.

Table 9. Bell pepper early total cull fruit yield as affected by year x row cover interaction.

	Year		
	1995	1996	
Row cover	t·ha^{-1}		
Gromax	2.60	1.01	****
None	4.04	4.98	*
	***	****	

****, ***, * Significant at P ≤ 0.0001, 0.001, or 0.05 respectively.

Table 10. Bell pepper early total yield as affected by year x row cover interaction.

	Year		
	1995	1996	
Row cover	t·ha^{-1}		
Gromax	5.32	7.78	***
None	4.79	11.14	****
	NS	***	

****, ***, NS Significant at P ≤ 0.0001, 0.001, or not significant, respectively

Table 11. Bell pepper first harvest percent yield (by
weight) with blossom-end rot (BER) or sunscald (SS),
as affected by year, variety, supplemental Ca
fertilization and row cover.

	BER	SS
Year	%	
1995	59.2	3.8
1996	27.5	1.7
	****	**
Variety (V)		
Ranger	37.6	2.6
Vidi	41.4	2.9
	NS	NS
Ca rate(kg·ha⁻¹)		
0	44.4	3.8
34	38.7	2.7
68	36.2	1.8
Ca linear	**	*
Ca vs. none	*	*
Row cover (C)		
Gromax	25.4	1.1
None	51.4	4.1
	****	****
Interactions		
V x C	NS	*

****, **, *, NS Significant at P ≤ 0.0001, 0.01, 0.05
or not significant, respectively.

Table 12. Bell pepper first harvest fancy-grade fruit weight as affected by year x variety x row cover interaction.

	1995				1996		
	Ranger	Vidi			Ranger	Vidi	
Row cover				kg			
Gromax	0.19	0.21	*		0.22	0.27	****
None	0.17	0.21	(p=0.07)		0.23	0.26	****
	NS	NS			NS	(p=0.08)	

****,*,NS Significant at $P \leq 0.0001$, 0.05 or not significant, respectively.

Table 13. First harvest fancy, no. 1&2-grade and blossom-end rot (BER) fruit weight as affected by year, variety, supplemental Ca fertilization and row cover.

	Fancy	No. 1&2	BER
Year (Y)		kg	
1995	0.20	0.14	0.09
1996	0.25	0.20	0.19
	****	****	****
Variety (V)			
Ranger	0.21	0.17	0.13
Vidi	0.24	0.18	0.15
	****	NS	**
Ca rate (kg·ha⁻¹) (R)			
0	0.22	0.16	0.14
34	0.22	0.17	0.14
68	0.23	0.18	0.13
Ca linear	*	*	NS
Row cover (C)			
Gromax	0.22	0.17	0.14
None	0.23	0.17	0.14
	NS	NS	NS
Interactions			
Y x V	NS	NS	**
Y x R	NS	NS	*
Y x C	NS	NS	****
C x R	NS	NS	**
Y x V x C	*	NS	NS

****,**,*,NS Significant at $P \leq 0.0001$, 0.01, 0.05 or not significant, respectively.

Table 14. Bell pepper first harvest blossom-end rot fruit weight as affected by year x variety, year x supplemental Ca and year x row cover interactions.

	Year		
	1995	1996	
Variety		kg	
Ranger	0.09	0.18	****
Vidi	0.09	0.21	****
	NS	***	
Ca rate(kg·ha^{-1})			
0	0.09	0.20	****
34	0.09	0.19	****
68	0.09	0.18	****
Ca, linear	NS	*	
Row cover			
Gromax	0.10	0.18	****
None	0.08	0.20	****
	****	*	

****, ***, *, NS Significant at P ≤ 0.0001, 0.001, 0.05 or not significant, respectively.

Table 15. Bell pepper first harvest sunscald fruit yield as affected by row cover x variety interaction.

	Variety		
	Ranger	Vidi	
Row cover		t·ha^{-1}	
Gromax	0.11	0.04	NS
None	0.20	0.45	**
	NS	****	

****, **, NS Significant at P ≤ 0.0001, 0.01, or not significant, respectively.

Table 16. Bell pepper first harvest percent yield (by
weight) with sunscald as affected by row cover x
variety interaction.

	Variety		
	Ranger	Vidi	
Row cover	%		
Gromax	2.3	0.8	NS
None	4.1	6.1	NS
	NS	****	

****, NS Significant at P ≤ 0.0001, or not significant,
respectively.

Table 17. Bell pepper first harvest blossom-end rot
fruit weight as affected by row cover x supplemental
Ca interaction.

	Row cover		
	Gromax	None	
Ca rate(kg·ha^{-1})	kg		
0	0.15	0.14	NS
34	0.15	0.14	NS
68	0.12	0.14	**
Ca linear	*	NS	

**, *, NS Significant at P ≤ 0.01, 0.05 or not
significant, respectively.

Total Yield

Total yield was lower in 1995 than in 1996 for fancy-grade fruit (Table 18), although the year response differed slightly with variety (Table 19). The 1995 total yield of 'Ranger' 1&2-grade fruit was lower than the 1996 yield, and 'Ranger' yielded more 1&2-grade fruit than 'Vidi' in 1996 but not in 1995.

Total marketable yield was lower in 1995 than in 1996 (Table 18). The yield of BER fruit with row cover was higher in 1995 than in 1996, while without row cover, BER fruit yield was lower in 1995 than in 1996 (Table 20). Yearly differences in sunscald fruit yield depended on variety and row cover treatment (Table 21). 'Vidi' produced more SS fruit than 'Ranger' except in 1996 with row cover. Sunscald yield was higher without than with row cover for 'Ranger' in 1995, and for 'Vidi' in 1996. Total cull yield was consistently reduced by row cover and was generally higher for 'Vidi' than for 'Ranger', except with row cover in 1996 (Table 22). The season total yield was lower in 1995 than in 1996 (Table 18).

The percent yield of BER fruit with row cover was higher in 1995 than in 1996, but without row cover there was no difference in percent BER between years (Table 23). Percent yield of SS fruit (Table 24) and percent yield total cull fruit (Table 25) were generally higher in 1995 than in 1996, most likely due to the reduced leaf area in 1995 which resulted from the hailstorm. Percent yield of SS fruit was higher without row cover than with row cover except for 'Ranger' in 1996 (Table 24). 'Vidi' had higher percent yield SS than 'Ranger' without row cover in 1995, and with row cover in 1996. The percent yield of cull fruit was higher without row cover than with both years. In 1995 'Vidi' had a higher percent yield of total cull fruit than 'Ranger' (Table 25). Weights of fancy-grade and BER fruit were lower in 1995 than in 1996 (Table 26).

Total yield of fancy-grade fruit was higher with 'Vidi' than 'Ranger' both years (Table 18), although there was a year by variety interaction (Table 19). Yield of 1&2-grade fruit was similar with each variety in 1995, but in 1996 'Ranger' had a higher yield of 1&2-grade fruit than 'Vidi'. Total marketable fruit yield was not different between varieties (Table 18). Yield of BER fruit was higher for 'Vidi' than 'Ranger'.

Sunscald fruit yield was higher for 'Vidi' than 'Ranger' except in 1996, without row cover (Table 21). Varietal differences in SS may be due to differences in total leaf area relative to fruit size and fruit shading. 'Ranger' had larger average leaf areas both years, though not significantly different at the 5% level, and had smaller fruit, so that fruit shading for 'Ranger' was likely greater than for 'Vidi'. The effect of row cover on sunscald is greatest at first harvest, when plants are most susceptible to the effects of high irradiance and inadequate fruit shading.

Total yield of cull fruit was greater with 'Vidi' than 'Ranger' in 1995, but in 1996 'Vidi' yield was higher only in the plots without row cover (Table 22). Total seasonal yield of marketable and cull fruit was higher for 'Vidi' than for 'Ranger' (Table 18).

Variety did not have an effect on the season total percent of fruit with BER (Table 27). In 1995, the season total percent SS was higher for 'Vidi' than 'Ranger' with row cover, and in 1996, without row cover (Table 24). The total cull fruit percentage was higher for 'Vidi' than for 'Ranger' with row cover in 1995, and not different between varieties in 1996 (Table 25). Fancy-grade average fruit weight was not different by variety in 1995, but was higher for 'Vidi' than 'Ranger' in 1996 (Table 28). Weight of 1&2-grade fruit was similar for each variety but BER fruit weight was higher for 'Vidi' than for 'Ranger' (p=0.06)(Table 26).

Blossom-end rot fruit yields and marketable yields were greater for 'Vidi' than for 'Ranger', but BER as a percentage of total yield was similar for each variety. This suggests that there is not a disproportionate increase in BER with increased fruit load. In a study of BER in fifteen cultivars of bell pepper, BER susceptibility (percent BER) increased with increased fruit load in some varieties, but for several cultivars no link was established (Morley et al. 1993). In general, the yields of both marketable and cull fruit were higher in 'Vidi', a larger and longer-fruited variety commonly grown for processing.

The season total fancy-grade fruit yield increased linearly as Ca fertilization rate increased (Table 18). Yields of grades 1&2, total marketable, and BER fruit were not affected by Ca rate. The total SS fruit yield decreased in plots fertigated with 34 and 68 kg·ha^{-1} Ca compared to no supplemental Ca, and the total yield of cull fruit decreased linearly as supplemental Ca rate increased. Total yield was not affected

by Ca rate. Season total fancy, 1&2-grade and BER fruit weights were not affected by supplemental Ca rate (Table 26).

Sunscald and total cull yield as a percent of season total yield decreased linearly with increasing Ca rate (Table 27). In a study of fifteen bell pepper cultivars no difference was found in tissue Ca concentration between sunscald-affected and unaffected fruit tissue (Morley et al., 1993), but no research was found on the effect of Ca and N form on sunscald. Clearly more research is needed to determine whether nutrition and SS are related.

Row cover increased season total 1&2-grade and total marketable fruit yields but did not affect yield of fancy-grade fruit, other cull fruit or total yield (Table 18). The total yield of BER fruit decreased both years with row cover, but the magnitude of the decrease was greater in 1996 (Table 20). Total yield of SS fruit decreased with row cover for 'Ranger' in 1995, and for 'Vidi' in 1996 (Table 21). Total cull yield decreased with row cover both years for both varieties, although in 1995 the effect of the row cover was not as great for 'Vidi' as it was for 'Ranger' (Table 22).

Row cover decreased season total percent BER both years, from 23.5% to 14.7% in 1995, and from 26% to 6% in 1996 (Table 23). Season total percent SS fruit decreased with row cover for 'Vidi' both years and for 'Ranger' in 1995 (Table 24). Percent yield of cull fruit also decreased with row cover both years for both varieties, with a year, row cover and variety interaction (Table 25). The season total average fruit weights of fancy, 1&2-grade and BER fruit were not affected by row cover (Table 26).

The row cover was more effective in reducing cull fruit in 1996 than in 1995. Plants fruited later the second year due to the delayed planting, which suggests that during early fruit development they would have been under greater temperature stress. Daytime temperatures generally increase under row cover, but light intensity decreases, as the fabric transmits about 80% of available light. The Umatilla basin has high light intensity and very infrequent cloud cover, long summer days with very low humidity, and high wind velocities, occasionally above 40 $km \cdot h^{-1}$. These factors combine to increase leaf transpiration and water loss, and each of these factors is influenced by row covers. Decreasing extremes in leaf transpiration is crucial to maintaining balanced Ca distribution between fruit and leaves.

Table 18. Bell pepper total yield as affected by year, variety, supplemental Ca fertilization and row cover.

	Marketable			Cull				Total yield
	Fancy	No. 1&2	Total	BER	Sunscald	Other	Total	
Year (Y)				$t \cdot ha^{-1}$				
1995	7.51	19.17	26.68	7.08	3.19	0.58	10.88	37.56
1996	11.59	21.76	33.34	6.85	1.59	0.29	8.79	42.13
	****	NS	***	NS	****	**	****	*
Variety (V)								
'Ranger'	6.22	22.28	28.51	6.06	1.76	0.35	8.21	36.73
'Vidi'	12.88	18.55	31.42	7.88	3.05	0.52	11.50	42.92
	****	*	NS	***	****	NS	****	**
Ca rate(kg·ha^{-1})								
0	8.92	21.13	30.06	7.39	2.85	0.44	10.71	40.77
34	9.50	19.90	29.38	6.74	2.15	0.44	9.41	38.80
68	10.15	20.27	30.43	6.74	2.18	0.43	9.38	40.74
Ca, linear	*	NS	NS	NS	**	NS	*	NS
Ca vs. none	(p=0.08)	NS	NS	NS	***	NS	*	NS
Row cover (C)								
Gromax	9.56	22.80	32.35	3.99	1.91	0.51	6.47	38.82
None	9.47	18.12	27.60	9.87	2.87	0.37	13.14	40.74
	NS	**	**	****	****	NS	****	NS
Interactions								
Y x V	**	*	NS	NS	NS	NS	NS	NS
Y x C	NS	NS	NS	****	NS	NS	****	NS
Y x C x V	NS	NS	NS	NS	****	NS	**	NS

****, ***, **, *, NS Significant at P≤ 0.0001, 0.001, 0.01, 0.05 or not significant, respectively.

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Table 19. Fancy and no. 1&2-grade bell pepper fruit yield as affected by year x variety interaction.

	Fancy				No. 1&2		
	1995	1996			1995	1996	
Variety				t · ha⁻¹			
Ranger	4.97	7.50	***		19.27	25.30	(p=0.06)
Vidi	10.03	11.40	****		19.04	17.99	NS
	****	****			NS	*	

****,***,* NS Significant at P≤ 0.0001, 0.001, or 0.05 or not significant, respectively.

Table 20. Blossom-end rot fruit yield as affected by
year x row cover interaction.

	Year		
	1995	1996	
Row cover	t·ha⁻¹		
Gromax	5.60	2.32	****
None	8.55	11.18	***
	****	****	

****,*** Significant at P≤ 0.0001, 0.001, respectively.

Table 21. Yield of sunscald fruit as affected by year x row cover x variety interaction.

	1995				1996		
	Ranger	Vidi			Ranger	Vidi	
Row cover				t·ha⁻¹			
Gromax	1.60	3.68	****		1.18	1.11	NS
None	3.21	4.28	*		1.02	2.98	****
	**	NS			NS	****	

****,**,* NS Significant at P≤ 0.0001, 0.01, or 0.05 or not significant, respectively.

Table 22. Cull yield as affected by year x row cover x variety interaction.

| | 1995 | | | | 1996 | | |
	Ranger	Vidi			Ranger	Vidi	
Row cover				t·ha⁻¹			
Gromax	6.09	11.76	***		3.54	4.30	NS
None	11.43	14.21	**		11.81	15.11	**
	****	(p=0.06)			****	****	

****,***,**, NS Significant at P≤ 0.0001, 0.001, 0.01, or not significant, respectively.

Table 23. Percent yield (by weight) fruit with
blossom-end rot as affected by year x row cover
interaction.

| | Year | | |
	1995	1996	
Row cover	%		
Gromax	14.7	6.0	****
None	23.5	26.0	NS
	****	****	

****, NS Significant at P≤ 0.0001, or not significant,
respectively.

Table 24. Percent yield of fruit with sunscald (by weight) as affected by year x row cover x variety
interaction.

| | 1995 | | | | 1996 | | |
	Ranger	Vidi			Ranger	Vidi	
Row cover				%			
Gromax	5.1	8.3	**		3.0	2.8	NS
None	9.3	11.0	NS		2.3	6.6	****
	**	**			NS	***	

****,***,**, NS Significant at P≤ 0.0001, 0.001, 0.01, or not significant, respectively.

Table 25. Percent yield of cull fruit (by weight) as affected by year x row cover x variety interaction.

	1995				1996		
	Ranger	Vidi			Ranger	Vidi	
Row cover				%			
Gromax	19.2	27.0	*		9.5	10.3	NS
None	33.3	36.6	NS		28.9	33.5	NS
	****	**			****	****	

****,**,* NS Significant at P≤ 0.0001, 0.01, or 0.05 or not significant, respectively.

Table 26. Bell pepper fruit weight as affected by year, variety, supplemental Ca fertilization and row cover.

	Fancy	No. 1&2	BER
Year (Y)		kg	
1995	0.20	0.17	0.11
1996	0.24	0.16	0.18
	****	NS	****
Variety (V)			
Ranger	0.21	0.15	0.13
Vidi	0.23	0.18	0.16
	****	NS	(p=0.06)
Ca rate (kg·ha⁻¹)			
0	0.22	0.15	0.14
34	0.22	0.18	0.16
68	0.21	0.16	0.14
	NS	NS	NS
Row cover			
Gromax	0.22	0.15	0.14
None	0.22	0.18	0.15
	NS	NS	NS
Interactions			
Y x V	*	NS	NS

****,*, NS Significant at P≤ 0.0001, 0.05 or not significant, respectively.

Table 27. Percent yield (by weight) of blossom-end rot (BER),
sunscald (SS), and total cull fruit as affected by year, variety,
supplemental Ca fertilization and row cover.

	BER	SS	Total Cull
Year (Y)		%	
1995	19.1	8.4	29.0
1996	16.2	3.7	20.8
	*	****	****
Variety (V)			
Ranger	16.5	4.8	22.4
Vidi	18.4	7.1	26.8
	NS	****	**
Ca rate (kg·ha^{-1})			
0	18.1	7.0	26.3
34	17.4	5.5	24.3
68	16.9	5.5	23.6
Ca, linear	NS	***	*
Ca vs. none	NS	****	(p=0.08)
Row cover (C)			
Gromax	10.3	4.9	16.7
None	24.2	7.0	32.3
	****	****	****
Interactions			
Y x C	*	*	***
Y x C x V	NS	**	*

****, ***, **, *, NS Significant at P≤ 0.0001, 0.001, 0.01, 0.05 or
not significant, respectively.

Table 28. Fancy grade fruit weight as affected by year x
variety interaction.

	Year		
	1995	1996	
Variety	kg		
Ranger	0.19	0.22	****
Vidi	0.20	0.25	****
	NS	****	

****, NS Significant at P≤ 0.0001 or not significant,
respectively.

Conclusions and Recommendations for Future Research

An increased rate of $Ca(NO_3)_2$ reduced BER and increased the yield of fancy fruit, but the relative importance of the Ca and N form to this outcome were not determined in this experiment. Due to the importance of N form on the uptake of Ca and on plant growth, future studies on BER should look more closely at N form.

Spunbonded row cover reduced BER and increased yields with and without supplemental Ca, and had a similar effect on both varieties. These observations suggest that row covers provide one or more of the following benefits: 1) Conditions conducive to increased uptake and/or distribution of Ca to the fruit. Row cover may increase Ca uptake due to reduced root-zone temperatures or may reduce evapotranspiration, resulting in more consistent soil water availability. 2) Reduction of fruit Ca losses. If leaf transpiration was reduced either due to reduced leaf irradiation and temperature or physiological changes such as reduced numbers of stomates or changes in leaf/fruit ratio, Ca distribution to the fruit would likely increase. 3) Reduction of fruit Ca requirements. Since no change in average fruit size could be attributed to the row cover, it is difficult to say how fruit Ca requirements might have been affected by the row cover. Reduced solar irradiation or anatomical or physiological changes may result in reduced Ca requirements, but it is difficult to speculate with the limited information available.

A closer look at the impact of the row cover-modified environment on plant physiology is needed. A photosynthesis meter could be used to measure leaf transpiration in and outside the row cover. Separation of the environmental influences on the plant is critical to determining whether BER can be reduced economically with shade cloth, more protective wind rows, or foliar anti-transpirants. It would also be important to determine the best application window for the above treatments, should they be found effective.

The role that root-zone temperatures play in this disorder may be significant. Soil temperatures under red and white polyethylene mulches were lower than black mulch (Decoteau and Kasperbauer, 1990) and they might prove effective in reducing BER.

The number of environmental factors involved in the development of BER is daunting. There were fewer row cover interactions with variety and supplemental Ca than might have been expected, which suggests that environment plays the largest part in the development of BER.

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APPENDIX

Table A1. Maximum and minimum air temperatures, dew point and
kilowatt hours·m^{-2}, June 1995/1996. Hermiston, Oregon.

Date	Maximum temperature	Minimum temperature	Dew point	kwh·m^{-2}
	°C	°C	°C	
6/1	29/26	15/11	10/11	6/8
6/2	24/31	15/11	13/13	4/7
6/3	29/31	14/16	9/14	8/6
6/4	24/25	13/14	10/8	4/9
6/5	18/25	9/10	6/8	6/9
6/6	12/29	8/8	7/9	2/8
6/7	20/33	8/13	9/11	7/8
6/8	22/30	9/13	8/6	6/9
6/9	24/23	13/12	7/7	8/9
6/10	31/27	9/9	11/7	5/8
6/11	24/24	11/11	8/7	7/9
6/12	24/28	9/8	8/6	6/9
6/13	18/29	10/9	9/9	3/8
6/14	17/29	12/12	13/9	3/9
6/15	21/29	11/13	13/8	6/8
6/16	24/26	14/9	12/8	6/8
6/17	24/19	13/10	10/5	6/6
6/18	20/20	12/6	8/4	6/8
6/19	18/25	11/5	9/4	4/9
6/20	21/27	12/6	9/4	7/3
6/21	25/26	11/13	9/9	7/4
6/22	28/25	13/12	11/7	8/9
6/23	32/20	12/13	12/12	7/3
6/24	34/22	14/8	13/11	8/6
6/25	32/24	16/11	10/11	8/7
6/26	33/27	17/11	8/13	8/6
6/27	28/22	11/14	5/13	8/5
6/28	29/23	9/12	8/11	7/8
6/29	33/27	9/10	9/9	8/9
6/30	35/31	13/11	11/12	7/8
Avg.	25/26	12/11	9/10	6/7

Table A2. Maximum and minimum air temperatures, dew point and kilowatt hours· m^{-2}, July 1995/1996. Hermiston, Oregon.

Date	Maximum temperature	Minimum temperature	Dew point	kwh·m^{-2}
	°C	°C	°C	
7/1	37/35	12/15	9/12	8/9
7/2	26/36	17/16	12/13	8/6
7/3	27/32	15/18	12/14	8/8
7/4	27/24	15/13	11/10	8/7
7/5	30/26	12/10	11/7	7/9
7/6	28/29	16/8	9/6	5/9
7/7	31/34	14/8	13/9	7/9
7/8	32/36	16/13	16/11	6/9
7/9	29/31	17/18	17/12	7/8
7/10	26/31	14/12	11/9	8/8
7/11	27/34	14/13	9/9	8/8
7/12	28/35	14/12	9/9	7/9
7/13	26/38	16/13	8/10	7/9
7/14	29/38	14/16	11/12	8/7
7/15	32/36	13/21	12/13	8/8
7/16	34/29	13/18	11/9	8/8
7/17	36/24	13/13	9/12	9/5
7/18	37/23	16/11	10/9	5/8
7/19	38/24	18/9	14/8	8/8
7/20	36/28	24/14	15/12	8/7
7/21	33/31	22/14	13/13	7/8
7/22	31/35	18/12	12/12	8/8
7/23	- /38	- / 13	- / 12	- /8
7/24	31/39	17/13	11/11	8/7
7/25	34/38	16/17	12/11	8/8
7/26	28/41	16/14	13/10	5/8
7/27	31/38	15/18	12/13	8/7
7/28	36/36	14/21	12/14	8/6
7/29	26/26	14/22	7/16	8/6
7/30	27/35	12/20	7/17	8/6
7/31	33/34	9/17	6/7	8/8
Avg.	29/33	14/14	10/11	7/8

Table A3. Maximum and minimum air temperatures, dew point and
kilowatt hours·m^{-2}, Aug. 1995/1996. Hermiston, Oregon.

Date	Maximum temperature	Minimum temperature	Dew point	kwh·m^{-2}
	°C	°C	°C	
8/1	36/33	12/17	9/8	8/8
8/2	32/25	17/14	12/11	8/7
8/3	33/24	17/12	13/8	7/8
8/4	36/26	17/13	14/11	8/7
8/5	35/23	18/13	13/8	8/8
8/6	29/28	17/10	12/9	6/7
8/7	23/34	14/11	8/9	7/7
8/8	26/37	13/12	6/9	8/8
8/9	30/38	8/14	7/9	8/8
8/10	26/40	13/14	10/10	4/7
8/11	27/33	14/17	9/10	8/7
8/12	24/31	12/11	8/8	5/8
8/13	24/33	8/11	7/9	6/5
8/14	32/35	8/20	8/13	7/7
8/15	26/34	16/17	11/7	5/7
8/16	23/33	12/16	7/9	5/7
8/17	23/27	10/14	7/7	7/7
8/18	26/26	8/13	8/8	7/7
8/19	30/28	11/8	8/8	7/7
8/20	33/26	11/15	8/10	7/5
8/21	34/28	13/9	7/8	7/7
8/22	33/31	12/7	8/7	7/7
8/23	28/34	15/9	9/7	5/7
8/24	24/36	10/12	7/9	7/6
8/25	28/37	8/14	6/9	7/6
8/26	27/32	15/15	6/9	7/4
8/27	28/27	9/18	7/14	6/3
8/28	28/31	11/16	9/11	6/6
8/29	25/36	14/12	10/12	7/6
8/30	28/28	10/17	9/12	7/6
8/31	32/26	9/14	9/10	7/7
Avg.	29/31	12/13	9/9	7/7