GROWTH, YIELD, AND STEM WATER POTENTIAL OF SOUTHERN HIGHBUSH BLUEBERRIES (VACCINIUM CORYMBOSUM) IN PINE BARK AMENDED SOILS

By

LUIS EDUARDO MEJIA CARDONA

A THESIS PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE

UNIVERSITY OF FLORIDA

2011

To my family

ACKNOWLEDGMENTS

I thank my parents and brothers for their unconditional love and patience which has been the foundation in my life. I acknowledge my advisor Dr. Jeffrey G. Williamson and my committee, Dr. Rebecca L. Darnell, Dr. Paul M. Lyrene, and Dr. Thomas A. Obreza for their advice and guidance during this degree. I express gratitude to Paul Miller, Natalia Celeste Nequi, Juan Carlos Rodriguez, and Alyssa Cho for their support and dedication during these past years. I also acknowledge my statistician consultant James Colee for his help with data analysis. I would like to thank the staff from the Science Research and Education Unit located in Citra, Florida and the staff of Horticultural Sciences Department. Finally, I also show appreciation to all the people that I met in Gainesville; they made me feel at home.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

CEC	Cation exchange capacity
CWR	Crop water requirement
ET_0	Reference crop evapotranspiration
SHB	Southern highbush blueberry

Abstract of Thesis Presented to the Graduate School
of the University of Florida in Partial Fulfillment of the
Requirements for the Degree of Master of Science

GROWTH, YIELD, AND STEM WATER POTENTIAL OF SOUTHERN HIGHBUSH BLUEBERRIES (VACCINIUM CORYMBOSUM) IN PINE BARK AMENDED SOILS

By

Luis Eduardo Mejía Cardona

May 2011

Chair: Jeffrey G. Williamson
Major: Horticultural Science

Southern highbush (SHB) blueberry (*Vaccinium corymbosum*) requires acidic soils that are well-drained and have high organic matter content. These studies were conducted to determine the most suitable system for SHB using pine bark as a soil amendment in a well-drained sandy soil with the goal of reducing pine bark inputs without affecting plant growth or berry yield. The first objective was to compare vegetative (plant canopy and pruning weights) and reproductive growth (total yield and mean berry weights) of SHB plants using four soil management treatments. A non-amended treatment (Soil) was compared to three amended treatments: 1) Incorporated (8 cm of pine bark incorporated into the top 15 cm of soil); 2) Incorporated +Mulch (Incorporated plus 8 cm layer of pine bark mulch on top); and 3) Bed (15 cm of pine bark on top of non-amended soil. Plant canopy volumes and pruning weights were similar among the amended treatments but were less for plants in the non-amended treatment. Fruit yields for the amended treatments were similar, but yields for the non-amended treatment were consistently lower. However, total yield (summed across 2007-2009) was greater for the Incorporated +Mulch treatment (9,477 g/plant) than for

the Bed (8,037 g/plant) or the Soil (2,085 g/plant) treatments but was not different from the Incorporated treatment (8,768 g/plant).

The second objective was to evaluate stem water potential during short and extended drought conditions and measure root density and distribution under the soil management systems described above. Plants under irrigated (midday) and short term drought conditions (predawn and midday) had lower stem water potentials during fruit development in non-amended than in amended soils. Also, during short drought conditions after the summer growth flush, plants in non-amended soils had lower midday stem water potential than plants in amended soils. However, following long term drought conditions during fall, plants in non-amended soils had greater predawn stem water potentials than plants in the amended treatments. Root densities were similar for the amended soils and much greater than in the non-amended soil. Higher root densities in the amended treatments may have resulted in more efficient water uptake under short drought conditions resulting in greater midday stem water potentials. During long-term droughts, available soil moisture was probably depleted faster from the amended treatments where plant canopies were larger and root densities were higher. This resulted in lower predawn stem water potentials for the amended treatments compared with the non-amended treatment.

Amending Florida sandy soils with pine bark resulted in greater vegetative growth, higher berry yields, lower soil pH, and greater stem water potential during short term drought conditions compared to non-amended soils. Incorporation of pine bark into the soil may offer cost savings compared to traditional pine bark beds because 50% less pine bark was used without affecting canopy growth or yield.

CHAPTER 1
INTRODUCTION

Blueberry Industry

From 1961 to 2009, world blueberry production and the land area in production have increased dramatically. In 2009, total world production was 306,383 tons and the US was the largest producer with 54% of the share. Total harvested area in the world was 72,554 hectares with Canada accounting for 47% and the US for 35% (FAOSTAT, 2010).

In the last decade, blueberry has been the fastest growing industry among all temperate fruit crop industries in Florida (Williamson and Crane, 2010). From 2000 to 2010, blueberry production in Florida increased around 700% to 7,277 tons, which represents 7% of the total production in US. In 2010, 1,416 hectares of blueberry were harvested in Florida with a yield of 5.3 tons per ha (both have doubled since 2000). More than 99% of the production is sold for fresh consumption. Florida blueberries are harvested from April to May, filling a market window that is unique to Florida, giving Florida blueberry producers a higher price. During this time, Florida is the only state in the US that is able to produce blueberries. From 2000 to 2010, the seasonal average grower price for Florida blueberries was $10.70 per kilogram. During the same period, seasonal average grower price for blueberry averaged across the US was only $3.81 per kilogram. In 2010, the value of Florida’s blueberry crop was over $48 million (an increase of 400% since 2000), which represents 8% of the value for the US crop that was estimated at $590 million (USDA ESMIS, 2010; USDA NASS, 2011).

Blueberry Cultivation in Florida

There is a long history of attempts to grow blueberries in Florida. Records of cultivated production in northeast Florida date back to 1887. Five years later in the northwest part of the state, selected wild plants were transplanted to farms for annual cultivation and sold to local markets. In 1920, there was a sudden increase in blueberry production due to the successful shipment of blueberries to northern cities. However most of these new plantings were created using wild plants of rabbiteye blueberry (*Vaccinium virgatum*), disregarding their natural growing conditions such as soil pH, soil type, and drainage (Florida Dept. of Agriculture, 1945). Indiscriminate use of these wild plants led to poor overall plant health, poor fruit quality, uneven ripening, and irregular fruit size. This series of problems led to the demise of rabbiteye blueberry farms in north Florida. In 1906, Dr. F.V. Coville of the United States Department of Agriculture began to improve northern highbush blueberry through selection and hybridization of improved cultivars of *Vaccinium corymbosum*. Northern highbush blueberry proved to have uniformly large fruit and better fruit quality leading to the virtual extinction of the rabbiteye industry in Florida in the late 1920s (Lyrene and Sherman, 1979).

In 1949, Professor R.H. Sharpe used northern highbush blueberry as the foundation for the blueberry breeding program at the University of Florida. Southern races of wild blueberry were bred with the northern highbush to improve adaptation to Florida's harsh environmental conditions while maintaining desirable characteristics such as early ripening, uniform fruit size, and good fruit quality. The southern highbush blueberry (SHB) was the result of this breeding program - a blueberry plant with a low chilling requirement that was adapted to a long warm, humid, growing season (Lyrene, 1997). The majority of the cultivated area for commercial blueberry production in

Florida is composed of SHB with the exception of small plantings of rabbiteye blueberry in the northern part of the state for local consumption. SHB is grown commercially throughout Florida, except in the most northwestern and southern regions.

Cultural Practices for Blueberry

Soil Management Systems

Blueberry plants require acidic soils (pH 4.0 to 5.5) that are well-drained and have high organic matter content (Coville, 1910; Florida Dept. of Agriculture, 1941; Gougg, 1994). In Florida, SHB is grown using one of three different soil management systems. The pine bark bed system is most commonly used. SHB is planted in a 15 to 18-cm thick pine bark bed (1 meter wide) on top of deep, non-amended sandy soil. One of the problems with this system is that roots reside only in the pine bark bed, resulting in an extremely shallow root system that may leads to fertilizer leaching and excessive watering. In an alternative system, SHB is planted in a soil/bark mixture (30-50%, v/v) where pine bark is incorporated into the top layer of soil. At times, pine bark mulch may be used on top of the soil/bark mixture. In the third system, SHB is planted in non-amended soils suitable for blueberry production, and is sometimes mulched with pine bark. Soils that are naturally suited for blueberry production are uncommon in Florida and are generally situated in low areas that are prone to late spring freezes (Williamson and Crane, 2010).

Fertilization

Blueberry plants respond better to ammonium (NH_4^+) more than nitrate (NO_3^-) nitrogen because they have a limited ability for nitrate uptakes (Bryla et al., 2010; Merhaut and Darnell, 1995; Takamizo and Sugiyama, 1991; Throop and Hanson, 1998). In Florida, fertilizer rates applied and application schedules depend on the type of soil management system used. In pine bark beds, SHB plants require more total fertilizer and more frequent applications compared with non-amended soils. The pine bark bed system requires 168-252 kg N per hectare per year. Eight applications are recommended each year starting in late February and ending in early October (Williamson et al., 2006). The non-amended system requires 100-135 kg N per hectare per year. Five applications are recommended per year starting in early April and ending in September (Williamson and Lyrene, 1995). At this time, fertilization recommendations for the incorporated system are not available in Florida. However, in western Oregon douglas-fir sawdust is used as the main soil amendment for blueberry production to reduce pH and increase soil organic matter. Normally, 9 cm of douglas-fir sawdust is incorporated into the top 25 cm of soil and the recommended fertilizer rate for matured plants (over 7 years old) is 160-185 kg N per hectare per year. Each year, three applications are made starting late April to mid June (Hart et al., 2006). However, growing seasons in northern latitudes are shorter and annual N requirements for blueberry are probably less compared with N requirements in southern latitudes (Williamson et al., 2006).

Irrigation

Factors that influence irrigation needs for SHB in Florida include the soil management system, plant age, stage of plant development, temperature, rainfall, solar irradiation, time of year, and water holding capacity of soil or pine bark bed. In Florida, dual irrigation systems are common. A low-volume system is used to supply the water needs of the plant, while overhead sprinklers are used for plant establishment and frost protection. Mature SHB plants require about 1,000 mm of water per year (Williamson and Lyrene, 2004). Rainfall in central and northern Florida ranges from 1,100-1400 mm per year, but usually the highest water demand of the plant does not coincide with the timing of rainfall (Current Results Nexus, 2010).

Water demand in the winter is low because plants are dormant. The most critical periods for irrigation are from the beginning of fruit set until the conclusion of harvest (March-May when little rainfall typically occurs) and during the summer during the highest evapotranspiration demand of the year (June-September) (Williamson and Lyrene, 2004). In Florida, crop water requirement (CWR) of mature SHB plants changes drastically from month to month. From October to February, low CWR occurs, ranging from 70 to 90 mm per month. From April to August, high CWR occurs ranging from 160 to 190 mm per month. In March and September, medium CWR occurs, ranging from 100 to 120 mm per month (Dourte, 2007). In the same experiment, it was suggested that growers may be over-irrigating pine bark beds because they tend to apply higher quantities of water in fewer applications. Hanson et al. (2004) demonstrated that plant-available water in the top (6 cm) and middle sections of small containers filled with aged pine bark was low due to high evaporation rates of these upper sections. However, the middle sections of larger containers held more plant available water because they were further below the layers exposed to evaporation. In the same study, poor lateral movement of water in the pine bark substrate was observed.

Larger quantities of irrigation spread across fewer applications could allow pine bark beds to dry out between irrigations, leaving plants under mild water stress until the next irrigation. Periodic over-irrigation can also led to leaching of plant nutrients from the pine bark bed and out of reach of SHB roots.

Pruning

In Florida, pruning is a valuable cultural practice for blueberry plants that has been practiced since the beginning of the industry (Florida Dept. of Agriculture, 1941; Lyrene and Crocker, 1984; Williamson and Lyrene, 2004). Pruning in Florida can be done with hand pruners, saws and mechanical pruners. Various types of pruning are practiced in Florida such as heading-back cuts, thinning out cuts, summer topping, and dormant pruning. Each type of pruning results in different plant responses, but in general all types of pruning help shape plants for better production. Heading-back cuts are made at planting to re-establish a suitable root to shoot ratio (Williamson et al., 2004). Thinning out cuts is made after harvest during the summer for increased plant vigor, growth of new wood, larger fruit size, earlier ripening, and to improve sunlight penetration throughout the canopy. Thinning is done by hand to remove older and less productive canes. Summer topping is done by mechanically by removing the tops of plant canopies to stimulate a strong summer growth flush. . Dormant pruning is done in mature plants when canes are 5 to 6 years old by removing approximately 25% of the older, less vigorous canes (Williamson et al., 2004).

Pest Management

For SHB grown in Florida, soil type needs to be considered before selecting pesticides due to the risk of ground water contamination. Excess water from overhead irrigation and rainfall can move pesticides to water bodies faster. Factors including soil leaching rate, surface runoff, soil organic matter content, distance to water bodies, and depth to ground water need to be evaluated at each site before applying any type of pesticide (Hornsby et al., 1991).

The pine bark bed system offers some weed control for mature SHB plants; however, young blueberry plants in these systems have shallow root systems and during establishment, these shallow root systems fail to compete with weeds for nutrients and water. In Florida, recommended weed management practices include use of localized irrigation systems (microsprinklers and drip irrigation), localized fertilization, and use of herbicides. A variety of pre-emergence and post-emergence herbicides are accessible to growers throughout Florida. Use of these herbicides depends on the soil type and the specifics of the pesticide label. Williamson (2007) provides a detailed list of herbicides that are labeled for use in blueberries in Florida.

In the southern US, insects can cause economical damage reducing yield and growth of blueberry especially because damage of insects can be mistaken with other types of damage (freeze damage and fungal symptoms). Turner and Liburd (2007) compiled a management guide with the most problematic insects of blueberry such as blueberry gall midge (*Dasineura oxycoccana* Johnson), blueberry maggot fly (*Rhagoletis mendax* Curran), and thrips (Florida flower thrips, *Frankliniella bispinosa* Morgan; eastern flower thrips, *Frankliniella tritici* Lindeman; and the western flower thrips, *Frankliniella occidentalis* Pergrande). They also mentioned insects that can be found in blueberry plants but are less problematic such as blueberry bud mite (*Acalitus vaccinii* Keifer), blueberry flea beetle (*Altica sylvia* Malloch), blueberry spanworm (*Itame argillacearia* Packard), cranberry fruitworm (*Acrobasis vaccinii* Riley), flower beetle (*Euphoria sepulcralis* Fabricius), Japanese beetle (*Popillia japonica* Newman), Oblique-banded Leafroller (*Choristoneura rosaceana* Harris), Sparganothis Fruitworm (*Sparganothis sulphureana* Clemens) and scale insects (superfamily Coccoidea and families are the armored scales, Diaspididae; the soft scales, Coccidae; and Mealybugs, pseudococcidae).

Several fungal diseases can cause economical damage ranging from reduced yield and growth to death of the entire plant. The most problematic diseases are blueberry stem blight (Botryosphaeria spp.) and Phytophthora root rot (*Phytophthora cinnamoni*) which kill plants and cause decline of established fields. Botrytis blossom blight (*Botrytis cineara)* can infect flowers and young fruit, and is problematic during the pre-harvest season. Blueberry rust (*Naohidemyces vaccinii*), Septoria leaf spot (*Septoria albopunctata*), Anthracnose (*Gloeosporium minus*), and Phyllosticta leaf spot (*Phyllosticta vaccinii*) are post-harvest leaf diseases that generally occur during the summer. The incidence of each varies with cultivar and location (Williamson and Lyrene, 2004; Williamson et al., 2008). One negative effect of these blueberry diseases is early fall defoliation. Williamson et al. (2003) found negative effects of early fall defoliation on reproductive growth of SHB compared with mid or late fall defoliation. Early fall defoliation led to a reduction in flower buds and total yield of SHB, stressing the importance of maintaining foliage until mid to late fall to avoid yield reductions.

Chilling Hours and Breaking Dormancy

Lyrene and Williamson (2004) reported that the optimum accumulation of chill hours for blueberry in Florida occurs between mid-November and mid-February, when temperatures range from 0°C to 7°C. Outside the optimal temperature range for chill hour accumulation, different reactions take place. In the range of 7-12°C some portion of chill accumulation occurs; below 0°C, no chill accumulation occurs; at temperatures above 21°C some accumulated chilling may be negated. It was also mentioned, that defoliated blueberry plants accumulate chill hours faster than foliated plants. After sufficient chill accumulation, flower buds break dormancy when temperatures begin to rise during late January and February.

In blueberry production, synthetic growth regulators are often applied to reduce the time to break dormancy. Williamson et al. (2002) studied the effects of the plant growth regulator hydrogen cyanamide (H_2CN_2) on SHB at several application rates. They observed that H_2CN_2 reduced the time to vegetative bud break and increased the number of vegetative bud breaks per plant. The study also found a positive linear relationship between application rate and vegetative bud number. In addition to advancing vegetative bud breaks, H_2CN_2 also advanced harvest and increased yield and mean berry weight. However, at high application rates, hydrogen cyanamide injured flower buds and reduced total SHB yield.

Frost Protection

Most years in Florida, mild freezes occur from February to April that can be considered the greatest risk for blueberry production in the state. Overhead irrigation is used to protect fruits, flowers, and flower buds during freeze events. Temperature, wind speed, and dew point need to be accounted for prior to using overhead irrigation since they can determine the minimum effective application rate. The most problematic factor is high wind speed, because uniform irrigation through the field is harder to achieve and evaporative cooling is increased, removing heat from the field. Overhead irrigation can cause damage to blueberries, both from evaporative cooling, and from the heavy weight of ice that can break branches and uproot plants (Lyrene and Williamson, 2004).

Blueberry Soil Management

Sandy Soils in Florida

Florida soils are located on the southeastern coastal plain which is formed on top of ancient marine deposits. Physiographic characteristics of the panhandle (western highlands) and peninsular Florida (central ridge and Everglades) tend to match the distribution of the seven soil orders present in Florida. Most of the soils in the central and northern part of the state consist of sandhills that formed from sandy to loamy and fluvio-marine parent materials. Sandhills are characterized by being extremely well drained, small slopes with high infiltration rates, high hydraulic conductivity, no subsurface aquitard or permeable substrate, and minimum soil organic matter content. Total- and plant- available water are low in sandhills because of the small surface area and low hydrophilic character of sands. In sands, plant available water varies widely depending on the amount of coatings on sand particles, because these grain coatings are formed by clay and silt with large surface areas. Highly-coated sands are brownish in color while clean coated sands are whiter quartz sands (the majority of sands in Florida are clean quartz sands) (Harris et al., 2010). Sandhills typically occupy the Entisol soil order and represent more than 3.0 million hectares.

Entisols can be formed from quartz sand (central ridge), soluble limestone rocks (southern part of the state), or recent alluvial deposits. In Florida, Entisols are characterized by mineral soils having weak or no diagnostic horizons. The exceptions are an ochric epipedon (failed to be considered as any of the other seven epipedons), an albic horizon (oxides and clays were leached leaving a white/light horizon), and a spodic (illuvial horizon where organic matter, oxides, and iron have accumulated) or argillic diagnostic subsurface horizon (accumulated clays) 2 meters deep (Brady and

Weil, 2002; Collins, 2009). Obreza and Collins (2009) compiled the physical and chemical properties of Entisols in the root zone (top 91cm of soil) of mature citrus in Florida. In general, results suggested that native Entisols are normally acidic (pH values ranged drastically from 3.6 to 7.3), have little cation exchange capacity (CEC) (2-4 meq/100 c^3), and low organic matter content (0.5 to 1.0%).

Pine Bark Amendment

As previously mentioned, blueberry plants require acidic soils (pH 4.0 to 5.5) that are well-drained with high organic matter content, but these soils are uncommon in Florida. The lack of suitable blueberry soils has lead to the necessity of amending the soils present in the state for blueberry production.

Physical and chemical characteristics of pine bark have been studied intensely in past decades due to its availability, moderate cost, and favorable physical properties as a substrate and/or soil amendment for agriculture production (Bender, 1968; Daniels and Wright, 1988; Guedes de Carvalho et al., 1984; Jackson et al., 2009; Lemaire, 1995; Naasz et al., 2005; Niemiera et al., 1994; Odneal and Kaps, 1990; Owen et al., 2008).

Physical properties of fresh pine bark reported by Jackson et al. (2009) included large particle size (>2 mm: 49%; >0.5 mm to <2.0 mm: 36%; and <0.4: 15% by weight), high total porosity (83% v/v), large air space (26% volume of water drained/volume of container), low bulk density (0.18 g/cm^3), and large substrate shrinkage 70 weeks after planting (16% by v/v). These results were similar to those found by Owen et al. (2008) and Lemaire (1995). Owen et al. (2008) also reported high unavailable water (38%, v/v at -1,500 kPa) and low available water (12%, v/v) of fresh pine bark. Physical and chemical properties of pine bark are known to change as it decomposes with time.

Niemiera et al. (1994) showed changes in physical characteristics of aged pine bark such as smaller particle sizes, less total porosity and less air space, but higher water holding capacity.

Chemical properties of fresh pine bark reported by Lemaire (1995) include acidic pH (5.1), low CEC (9.5 meq/100 c^3), and high C/N ratio (400-600). Naasz et al.(2005) reported characteristics of aged pine bark including organic matter (88%), total C (54%), total N (1.1%), C/N ratio (51.4), pH (7.1), and CEC (19.8 meq/100 c^3). In this evaluation there were increases in soil pH (due to the use of H_2O without any acidifying material) and CEC (due to a higher contact surface area), and a lower C/N ratio (due to breakdown of material). Daniels and Right (1989) studied the CEC of pine bark as influenced by pH, particle size and cations. The results showed that CEC had a positive relationship with pH (CEC doubled when pH in pine bark increased from 4.0 to 7.0), but there was no relationship to particle size, and pine bark had greater capacity to hold cations than anions.

Since the 1980s, pine bark has been used as an amendment for highbush blueberry because of the similarities between pine bark properties and requirements for optimum blueberry growth. Odneal and Kaps (1990) studied pine bark as an amendment for establishment of northern highbush using fresh and aged pine bark compared with sphagnum peat. No significant differences were observed among the amendments for reproductive growth but incorporating pine bark helped with aeration around the root zone of the plants and plants appeared more vigorous. In Florida, a study was conducted by Norden (1989) to compare SHB grown with the pine bark bed system or under polypropylene fabric ground cover. Vegetative growth was greater with the pine bark bed system.

Today, pine bark is the most common substrate for nursery production in the southern US (Owen et al., 2008) and the most common soil amendment for SHB in Florida (Williamson and Crane, 2010). The incorporation of pine bark in Florida's sandy soils lowers pH, increases organic matter, and improves porosity.

CHAPTER 2
MATERIALS AND METHODS

Location and Experimental Design

The experiment was conducted at the University of Florida Plant Science Research and Education Unit located in Citra, Florida (29°24′16″N, 82°8′30″W). The soil series was Arredondo sand (from the Entisol order) with the characteristics of good drainage, low available water holding capacity, less than 5% slope, and a sand profile depth of 165 cm (full description: http://websoilsurvey.nrcs.usda.gov. Coordinate System: UTM Zone 17N NAD83) (USDA-NRCS, 2010). Five months prior to planting, elemental sulfur was applied to adjust soil pH to between 4.0 and 5.0. Beds were prepared 1 month before planting. Four rows of southern highbush blueberry (SHB) plants (cultivars 'Emerald' and 'Star') were established in Jan. 2006, with 0.91 meters between plants and 3.05 meters between rows (3,588 plants·ha^{-1}). Rows were oriented north to south. Four soil amendment treatments were evaluated: non-amended soil (Soil); 8 cm of pine bark incorporated into the top 15 cm of soil (Incorporated); Incorporated plus an 8-cm deep pine bark mulch layer on top (Incorporated +Mulch); and a 15-cm pine bark layer on top of non-amended soil (Bed). In the Soil, Incorporated, and Incorporated +Mulch treatments, plants were planted in the soil or soil/bark mixture and in the Bed treatment plants were planted directly in the pine bark layer (Figure 2-1). Treatments were arranged in a randomized complete block design with six replications. Each plot consisted of four 'Emerald' plants and data were taken from the two plants in the middle of each plot. Four 'Star' plants were used between plots as buffers and for cross pollination. The buffer plants were planted with the Bed treatment. Planted nearby were SHB plants of the cultivars ‘Jewel’, ‘Springhigh’, and ‘Windsor’ that contributed to cross pollination.

Cultural Practices

Irrigation and Frost Protection

Max-360º Blueberry Jet micro sprinklers (Maxijet, Inc., Dundee, FL) (40 L/h) were situated midway between plants. A 13 station Rain Bird® ESP-Modular Irrigation Controller (Rain Bird Corporation, Azusa, CA) controlled the irrigation and contained a sensor that turned the system off during rainfall. During the 2006 and 2007 growing seasons, irrigation was applied at 2 to 3 day intervals in the absence of rain to minimize drought stress based on visual observations of the soil profile in the root zone. After April, 2008, irrigation was based on reference crop evapotranspiration (ET_0) as determined by an on-site weather station [Florida Automated Weather Network (FAWN)] website (http://fawn.ifas.ufl.edu/). A detailed outline of the irrigation schedule can be found in Table 2-1.

The frost protection system consisted of 67 risers/ha (spaced 12.2 m x 12.2 m) with Rain Bird® 30EP brass impact sprinklers heads (Rain Bird Corporation, Azusa, CA) (18 L/min) elevated 1.8 m above the ground. Overhead irrigation was applied during and after bloom as needed in early spring for frost protection in 2008, 2009 and 2010.

Pruning

Summer pruning was done in June 2008 and June 2009. Dead tissue, new sprouts, and over-crowded branches were removed using hand pruners and saws. Prunings were collected from each plot and dried at 45.6°C until a constant weight was achieved (minimum of 5 weeks). Dry weights were taken and analyzed to determine differences in shoot growth. Additionally, after prolonged freeze protection events in

Feb. 2009, some branches broke due to the weight of the ice and these were collected and processed as described above.

Fertilization

A commercial dry fertilizer formulation, Blueberry Mix (12N–1.8P–6.6K) (Southern States CO-OP, Cordele, GA) was used throughout the experiment. The N sources were 8.21% ammoniacal N and 3.79% water-soluble organic N (urea). The fertilizer was broadcasted by hand evenly to the soil treatment surface area at monthly intervals. Each year, eight applications were made starting in early February and ending in early September, except during the harvest season when no fertilizer was applied (April and May). Fertilization rates were equal for all treatments and the total amount applied each year can be found in Table 2-2.

Weed Control

Weeds were controlled as necessary to maintain 1 meter wide, in-row, vegetation-free strips. Weed control included applications of post-emergent herbicide (glyphosate) and hand hoeing. A 15 L Yard Tender Backpack Sprayer 189 (Rittenhouse & Sons Ltd., St. Catharines, Ontario, Canada) was used to apply post-emergence herbicides.

Insect and Disease Control

Recommended fungicides were used as needed pre-harvest to control Botrytis blossom blight (*Botrytis cinerea)* and post-harvest to control summer leaf diseases, such as blueberry rust (*Naohidemyces vaccinii*), Septoria leaf spot (*Septoria albopunctata*), Anthracnose (*Gloeosporium minus*), and Phyllosticta leaf spot (*Phyllosticta vaccinii*).

No insecticide applications were made during the experimental period because insect pests did not pose a significant problem for plant growth or yield.

Breaking Dormancy

The plant growth regulator hydrogen cyanamide (H_2CN_2) (Dormex^{TM}, Dormex Co US LLC, Fresno, CA) was applied at a rate of 0.88% a.i. (v/v) in early January prior to the start of each growing season (2007, 2008, 2009, and 2010).

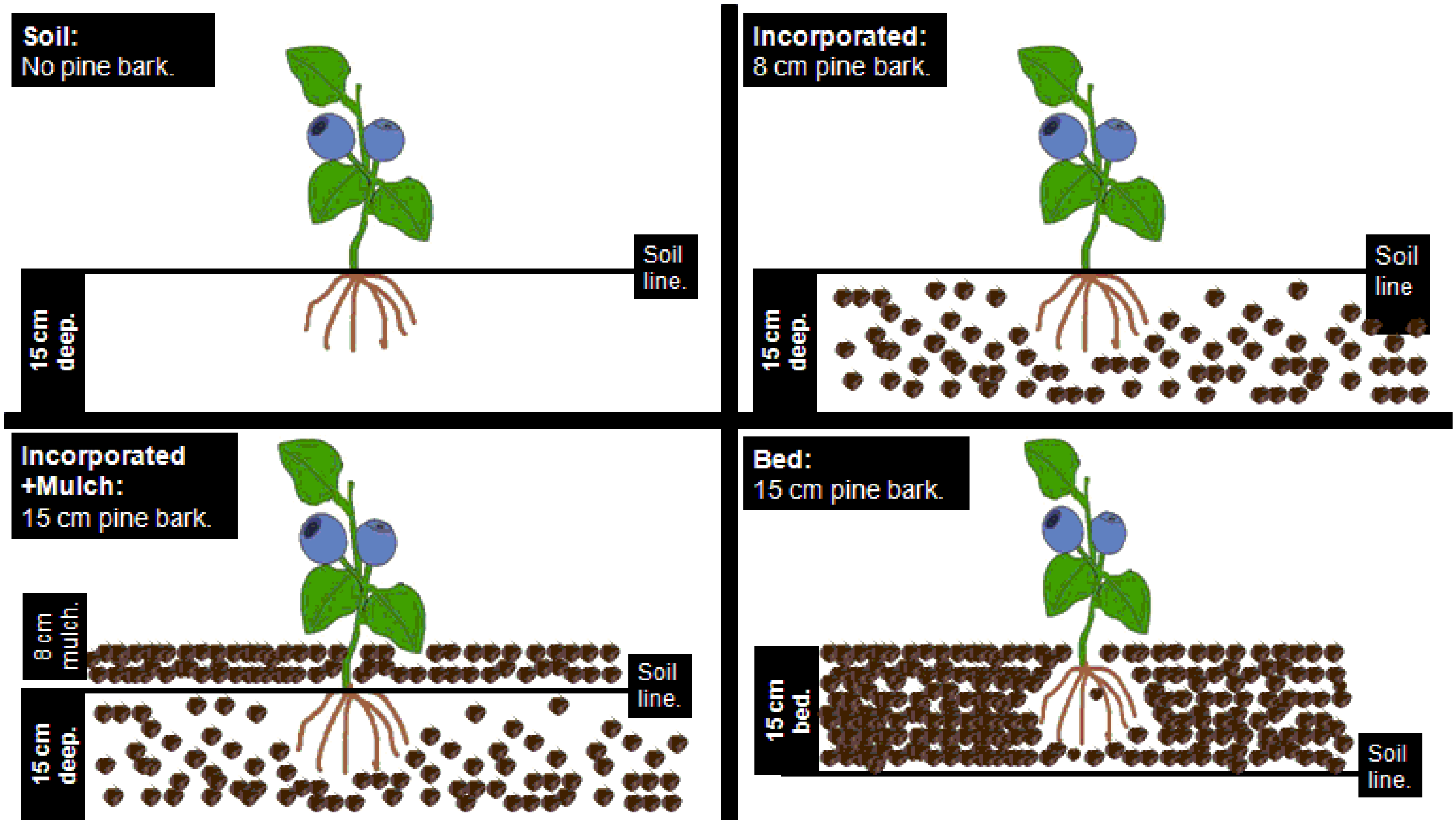

Figure 2-1. Four soil amendment treatments were evaluated from 2006 to 2010. Non-amended soil (Soil); 8 cm of pine bark incorporated into the top 15 cm of the soil (Incorporated); Incorporated plus 8 cm of pine bark mulch layer on top (Incorporated +Mulch); and 15 cm of pine bark layer on top of non-amended soil (Bed). In the Soil, Incorporated, and Incorporated +Mulch treatments plants were planted in the soil or soil mixture and in the Bed treatment plants were planted in the pine bark layer as the growing medium

Table 2-1. Irrigation schedule for southern highbush blueberry during the experiment.

	Date					
	Jan. 2006 to Mar. 2008[z]	Apr. 2008 to Feb. 2009	Mar. 2009 to Apr. 2009	May 2009 to Aug. 2009	Sept. 2009 to Mar 2010	Apr. 2010 to Aug. 2010
Treatment		% of Reference Crop Evapotranspiration (ET_0)				
Incorporated +Mulch	--	100	100	150	150	150
Bed	--	120	150	200	200	200
Incorporated	--	100	100	150	150	150
Soil	--	80	80	80	80	80
Irrigation Frequency						
Predawn Irrigation (4:00 AM)	Yes	Yes	Yes	Yes	Yes	Yes
Midday Irrigation (1:00 PM)	No	Yes	Yes	Yes	Yes	Yes
Clock Changed	As needed	Monthly[y]	Twice a week[x]	Twice a week[x]	Monthly[x]	Weekly[x]

[z]From Jan. 2006 to Mar. 2008, irrigation was applied at 2 to 3 day intervals in the absence of rain to minimize drought stress based on visual observations of the soil profile in the root zone.
[y]Monthly average of the last 8 years of available data from Florida Automated Weather Network (FAWN).
[x]Based on existing weather conditions from FAWN.
.

Table 2-2. Fertilization rates applied in southern highbush blueberries for the experimental period (2006-2010)[z].

	Kg/ha[y]		
Year	N	P	K
2006	115.2	17.3	63.4
2007	147.7	22.2	81.2
2008	206.7	31.0	113.7
2009	206.7	31.0	113.7
2010	206.7	31.0	113.7

[z]Commercial dry fertilizer called Blueberry Mix (12N–1.8P–6.6K).
[y]Based on 3.588 plants/ha.

CHAPTER 3
VEGETATIVE AND REPRODUCTIVE GROWTH OF SOUTHERN HIGHBUSH BLUEBERRIES (VACCINIUM CORYMBOSUM) GROWN UNDER DIFFERENT SOIL MANAGEMENT SYSTEMS

Introductory Overview

Blueberries require acidic (pH 4.0-5.5), well-aerated, and high organic matter soils (Coville, 1910; Florida Dept. of Agriculture, 1945; Gougg, 1994). Central and north Florida soils are mostly Entisols, which are deep sands, with low organic matter content and water holding capacity, and pH ranging from fairly acidic to neutral (Harris et al., 2010). Therefore, soil amendments are necessary for blueberry production in these soils. Today, pine bark is the most common substrate for nursery production in the southern US (Owen et al., 2008) and the most common soil amendment for SHB in Florida (Williamson and Crane, 2010). Pine bark has characteristics that are optimum for SHB production in Florida, including acidic pH (5.1), high total porosity (83% v/v), large air space (26%v/v), and some cation exchange capacity (CEC) (9.5 to 19.8 meq/100 c^3, fresh and aged pine bark, respectively) (Jackson et al., 2009; Lemaire, 1995). In Florida, fresh pine bark is locally available, and growers have easy access to the large quantities needed for blueberry production.

Most growers use a pine bark bed, where SHB is planted in 15-18 cm of pine bark that is placed on top of non-amended sandy soils (1 m wide). A major constraint of pine bark beds is the shallow root system. Roots do not grow beneath the pine bark bed; the resulting shallow root systems lead to fertilizer leaching and over-watering (Williamson and Crane, 2010). An additional constraint to the pine bark bed system is the need to reapply pine bark beginning in the 3rd year of production and every two or three years thereafter. Due to the decomposition of substrate and the shallow root system, many growers are exploring an alternative soil management system, which uses incorporation of pine bark into the soil. Pine bark is incorporated into the top layer of soil, and SHB are then planted into the soil/bark mixture (30-50%, v/v) (Williamson and Crane, 2010). Sometimes growers also apply a layer of pine bark on top of the soil/bark mixture. Some growers prefer this method of soil management due to the belief that the incorporated pine bark does not restrict root growth. Incorporation also reduces the decomposition rate and the need for additional pine bark applications. The least commonly used system is planting SHB into non-amended soils that are suitable for blueberry production (Williamson and Crane, 2010). These soils are the less commonly found Spodosols. Pine bark is used as a soil amendment in two of the three soil management systems for Florida SHB production.

Studies have evaluated SHB while using pine bark beds (Dourte, 2007; Williamson and Miller, 2009; Williamson et al., 2002; Williamson et al., 2003). Additionally, these studies have focused on improving growth and yield in the pine bark bed system without exploring other soil management methods. Despite the wide adoption by growers of incorporating pine bark into the soil, there are no studies comparing the effects of this soil management system on vegetative or reproductive growth of SHB with the more traditional pine bark bed system. Pine bark is a commonly used substrate in many horticultural sectors including nursery production, greenhouse production, landscaping, and of course blueberry production (Owen et al., 2008; Williamson and Crane, 2010). As a result, fresh and aged pine bark are in high demand leading to high prices, and for aged pine bark availability is variable. Growers are constantly trying to minimize inputs and costs for SHB production. Minimizing inputs such as pine bark, fertilizers, and water would reduce costs to growers and address increasing pressure for environmental regulations.

The objectives of this study were to compare the effects of pine bark as a substrate or soil amendment on vegetative and reproductive growth of southern highbush blueberry and determine the most efficient use of pine bark under Florida conditions with the goal of reducing pine bark inputs. The hypothesis is that pine bark use can be reduced by incorporation into soil versus the traditional pine bark bed system without affecting vegetative and reproductive growth of southern highbush blueberry in Florida.

Materials and Methods

The experiment was conducted at the University of Florida Plant Science Research and Education Unit in Citra, Florida. Four rows of southern highbush blueberries (cultivars 'Emerald' and 'Star') were established in January 2006. Rows were spaced 3.05 meters apart with 0.91 meters between plants (3,588 plants·ha^{-1}). Four soil amendment treatments were evaluated: 1) non-amended soil (Soil); 2) 8 cm of pine bark incorporated into the top 15 cm of the soil (Incorporated); 3) Incorporated plus an 8-cm pine bark mulch layer on top (Incorporated +Mulch); 4) and a 15-cm pine bark layer on top of non-amended soil (Bed). In the Soil, Incorporated, and Incorporated +Mulch treatments plants were planted in the soil or soil/bark mixture and in the Bed treatment plants were planted directly in the pine bark layer. Treatments were characterized as amended treatments (2-4) and a non-amended treatment (1). Treatments were arranged in a randomized complete block design with six replications. Four plants of the cultivar 'Emerald' were used as a plot and data were taken from the two plants in the middle of each plot. Four plants of the cultivar 'Star' were used as cross pollinizers between plots. The pollinizers were planted using the Bed treatment. Planted nearby were SHB plants of the cultivars 'Jewel', 'Springhigh', and 'Windsor' that also contributed to cross pollination. Cultural practices followed the recommended guidelines for Florida commercial blueberry production.

Plant Canopy

Plant canopy volume was calculated pre- or post-growing season for 2006, 2007, 2008, and 2009. Measurements were taken in Feb. 2007, Nov. 2007, Dec. 2008, and Feb. 2010. An additional canopy measurement was calculated in Feb. 2009 following a severe freeze event when ice loads broke some canes. Measurements included plant height, width, and depth. Plant height was measured from the soil line to the top of the plant. Plant width was measured within the row and plant depth was measured from the row middle. Plant canopy volume was calculated using the ellipsoid volume formula recommended by Thorne et al. (2002):

$$Plant\ Canopy\ Volume = \frac{2}{3}\pi H\left(\frac{A}{2} \times \frac{B}{2}\right)$$

Where *H* is height, *A* is width, and *B* is the depth of the plant.

Fruit Harvest

Total fruit yield was determined during the spring of 2007, 2008, and 2009. Mature fruit was harvested twice a week from two data plants in each plot from early April to late May or early June. During harvest, fruit was placed in resealable quart-sized polyethylene bags and weighed within 48 hours. If fruit was not weighed on the day of harvest, bags were stored in a cold room at approximately 1.9 °C. Fruit was weighed with a Scout® PRO 4001 portable scale (Ohaus Corporation, Pine Brook, NJ). Fruit were harvested 28 times in 2007, 12 times in 2008, and 11 times in 2009.

During each harvest date a sub-sample was randomly selected from each data plant to measure average fruit weight. In 2007, 10-fruit sub samples were used, but in 2008 and 2009, 20 fruit were collected for each sub-sample. The total weight of the sub-samples represented 10-15% of the total berry yield for the amended treatments and 40-50% for the non-amended treatment. Mean berry weight per harvest date was calculated using the formula:

$$Mean\ Berry\ Weight\ Per\ Harvest\ Date = \frac{Weight\ sub\ sample}{\#of\ fruit\ per\ sub\ sample}$$

Weighted mean berry weight for the harvesting season was calculated using the following formula:

$$Weighted\ Mean\ Berry\ Weight\ Per\ Season$$
$$= \sum_{k=m}^{n} \left(\frac{Weight\ sub\ sample}{\#of\ fruit\ per\ sub\ sample} \times \frac{Weight\ harvest\ date}{Total\ yield\ of\ the\ season}\right)^{k}$$

Sum starts at *m* (first harvest) and ends at *n* (last harvest).

Statistical Analysis

Data were statistically analyzed using SAS software version 9.2 (SAS Institute Inc., Cary, NC). Means for plant canopy were calculated using PROC GLIMMIX accounting for the repeated measurements design. Means were separated using the PDIFF option of the LSMEANS statement at α=0.05 level of significance. Plant prunings, berry yield, and weighted mean berry weight were analyzed using PROC GLM and means were separated using Duncan's test at α=0.05 level of significance. Spearman's correlation coefficient (r) for plant canopy volume, berry yield and weighted berry weight were determined using the PROC CORR procedure.

Results

Plant Canopy

After the growing season (2006-2009), amended soils produced larger plant canopies (m^3/plant) compared with the non-amended soil (Figure 3-1). After the 2006 and 2007 growing seasons no canopy volume differences were observed among the amended treatments; however, differences were observed among the amended treatments after the 2008 growing season (Figure 3-1). For the first measurement in Dec. 2008, canopy volume of plants in the Incorporated +Mulch treatment were larger than plant canopies in the Bed treatment. In Feb. 2009, a second measurement was taken after a severe freeze when large sections of the canopy were broken by the weight of ice that formed on canes during freeze protection. At this time plant canopy volume for the Incorporated +Mulch treatment was greater than the Bed or Incorporated treatments. After the 2009 growing season (Feb. 2010), canopy volumes were larger in the Incorporated treatment than in the Bed treatment (Figure 3-1). At this time, there was a trend showing that the Incorporated +Mulch treatment also had larger canopy volumes than the Bed treatment using a significance level of α=0.10 (Appendix A-1). This difference agrees with the results seen in the previous growing season between the Incorporated +Mulch and the Bed treatments.

Plant Pruning Weights

There were no differences in post fruit harvest pruning dry weights (g/plant) among plants in the amended treatments in 2008 or 2009; however, pruning weights were greater for the amended treatments compared with the non-amended treatment (Table 3-1). In Feb. 2009, dry weights of branches that broke due to freeze protection were measured. There were no differences among treatments for the broken plant material collected after the freeze (Table 3-1). The dry weights of prunings were summed across years, and no differences among amended treatments were observed, but fewer prunings were removed from the non-amended treatment than from the amended treatments (Table 3-1).

Total Yield

In all years (2007-2009) berry yield (g/plant) was greater for plants in the amended treatments compared with plants in non-amended soil (Table 3-2). During 2008 and 2009, no differences in berry yield were observed among the amended treatments (Table 3-2). In 2007, the Incorporated +Mulch treatment yielded more than the Bed treatment, but the Incorporated treatment yield was not significantly different from either the Incorporated +Mulch or the Bed treatments (Table 3-2). Berry yield was summed across years, and similar results to those found in 2007 were observed; the Incorporated +Mulch treatment had greater yield than the Bed treatment, but the Incorporated treatment was not significantly different from either the Incorporated +Mulch or the Bed treatment (Table 3-2).

Mean Berry Weight

In all years (2007-2009) mean berry weights (g/berry) of the amended treatments were significantly greater than the non-amended soil treatment, but no differences were observed among amended treatments (Table 3-3).

Correlations

Positive relationships were found for plant canopy volume versus berry yield and mean berry weight (Figure 3-2). A strong correlation coefficient was seen between plant canopy volume and berry yield ($r = 0.69699$, at $\alpha=0.0001$). Moreover, significant correlation coefficients were seen between plant canopy volume and mean berry weight (r = 0.64522, at α=0.0001), and berry yield and mean berry weight (r = 0.57483, at α=0.0001) (Figure 3-2).

Discussion

In this study, plants in all three amended treatments were consistently larger than plants in the non-amended treatment and differences among the amended treatments were only seen after the third growing season (2008). Our work agrees with other studies that have shown the benefits of using pine bark as a soil amendment for increased growth of SHB (Norden, 1989; Odneal and Kaps, 1990; Spiers, 1998). In the present study we did not measure soil characteristics while using pine bark, but Odneal and Kaps (1990) concluded that the incorporation of pine bark into soil improved aeration around the root zone, Norden (1989) found that mulching with pine bark prevented soil compaction in Florida, and Spiers (1998, 2000) found that using pine bark as mulch maintained soil moisture and lowered soil temperature.

Berry yield and berry size are both important aspects for blueberry production but berry yield may be the most important factor over any other factor (reproductive and vegetative growth). During the experiment, all amended treatments had similar berry size, but the non-amended treatment had smaller berries and lower yields compared with any of the amended treatments. Smaller berries and lower yields in the non-amended soil treatment may be explained by the consistently smaller size of plants grown in the non-amended soil compared with plants in the amended soils. Positive correlations for canopy size versus yield and mean berry weight were found in the present study and previous work by Williamson and Miller (2009) also showed a strong positive correlation for berry yield and canopy volume of SHB. When summed across years, berry yield was greater for the Incorporated +Mulch treatment than for the Bed or

Soil treatments but was not different from the Incorporated treatment. This difference in total yield could be explained by greater plant canopy volume of the Incorporated +Mulch treatment compared with the Bed treatment at the end of the growing seasons 2008 (α=0.05) and 2009 (α=0.10). However since the Incorporated treatment used only half as much pine bark as the other amendment treatments without affecting vegetative or reproductive growth, it offers a potential cost savings advantage over the traditional pine bark bed system where the bark is applied to the soil surface. Alternatively, the Incorporated +Mulch treatment uses twice as much pine bark as the Incorporated treatment but may offer some benefits that were not addressed in this study such as increased weed control and soil moisture conservation (Cregg and Schutzki, 2009). The Incorporated +Mulch treatment used the same amount of pine bark as the Bed treatment but produced slightly higher total berry yield over the three-year period and larger plants in the last two growing seasons.

Blueberry growers are interested in reducing production costs, increasing yields, and addressing potential regulations for fertilizer and water use. Additional studies with SHB subjected to Florida conditions are needed to determine fertilization and irrigation requirements when pine bark is incorporated into the soil. This study suggested that incorporation of pine bark into the top layer of soil is an adequate amendment for SHB production in well-drained sandy soils. Incorporation alone can substantially reduce establishment costs by reducing the amount of pine bark used compared to the traditional Bed system without reducing growth or yield during the first few years of production. Where similar amounts of pine bark are used, incorporation of pine bark plus pine bark mulch may slightly increase total berry yields during the early years of a planting compared to traditional pine bark beds.

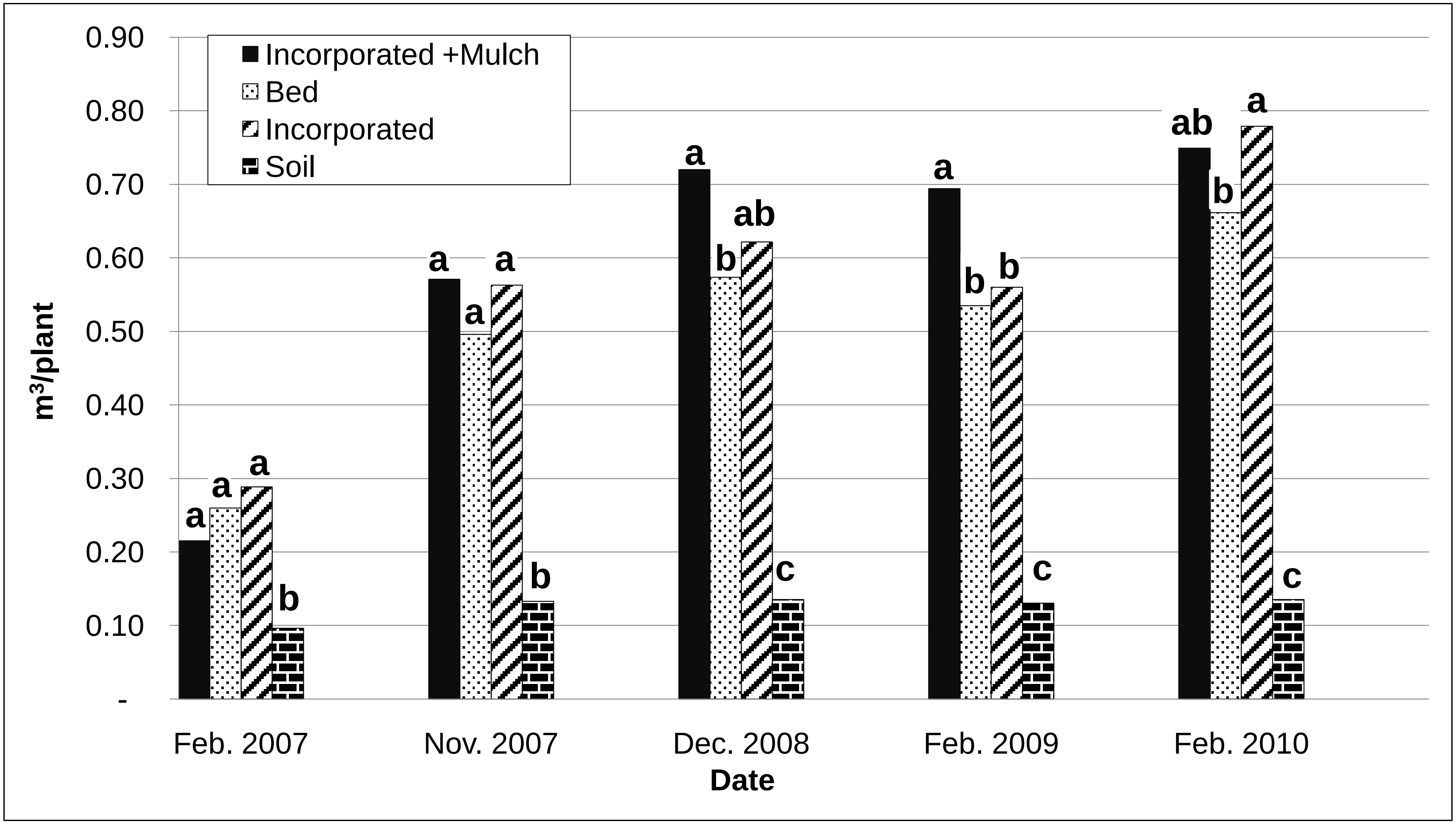

Figure 3-1. Effect of soil amendments on plant canopy of southern highbush blueberry in 2007, 2008, 2009, and 2010. Plant canopy was measured at the end of each growing season, except for Feb. 2009 where a prolonged freeze occurred and new canopy measurements were taken due to damage from the ice load. Means for plant canopy were calculated using PROC GLIMMIX accounting for the repeated measurements design. Means were separated using the PDIFF option of the LSMEANS statement at α=0.05 level of significance.

Table 3-1. Effect of soil amendments on dry weight removed by pruning southern highbush blueberry in 2008 and 2009[z,y].

	Pruning Dry Weights (g/plant)			
	Date			Total
Treatment	June 2008	Feb. 2009[x]	June 2009	2008-2009
Incorporated +Mulch	233.3 a	27.9 a	341.2 a	602.3 a
Bed	222.4 a	57.2 a	332.1 a	611.6 a
Incorporated	240.1 a	55.9 a	287.6 a	583.7 a
Soil	31.5 b	13.8 a	48.4 b	93.7 b

[z]Means followed by the same letters within a column indicate no significant differences, Duncan's test, α=0.05.
[y]Dead tissue, new sprouts, and over-crowded branches were removed using hand pruners and saws.
[x]A severe freeze occurred.

Table 3-2. Effect of soil amendments on yields of southern highbush blueberry in 2007, 2008 and 2009[z].

	Berry Yield (g/plant)			
	Year			Total
Treatment	2007[y]	2008[x]	2009[x]	2007-2009
Incorporated +Mulch	2,849 a	3,082 a	3,546 a	9,477 a
Bed	2,312 b	2,711 a	3,014 a	8,037 b
Incorporated	2,678 ab	3,183 a	2,909 a	8,769 ab
Soil	548 c	709 b	827 b	2,085 c

[z]Means followed by the same letters within a column indicate no significant differences, Duncan's test, α=0.05.

[y]Mature fruit was harvested three times a week from the two data plants from early April to early June. Fruit was harvested 28 times.

[x]Mature fruit was harvested twice a week from the two data plants from early April to late May. Fruit was harvested 12 times in 2008 and 11 times in 2009.

Table 3-3. Effect of soil amendments on weighted mean berry weight of southern highbush blueberry in 2007, 2008, and 2009[z].

	Mean Berry Weight (g/berry)		
	Year		
Treatment	2007[y]	2008[x]	2009[x]
Incorporated +Mulch	1.7 a	2.0 a	1.9 a
Bed	1.7 a	1.9 a	1.9 a
Incorporated	1.6 a	1.9 a	1.9 a
Soil	1.2 b	1.6 b	1.7 b

[z]Means followed by the same letters within a column indicate no significant differences, Duncan's test, α=0.05.
[y]10 fruits were sampled at each harvesting date (28 times).
[x]20 fruits were sampled at each harvesting date (12 times in 2008, 11 times in 2009).

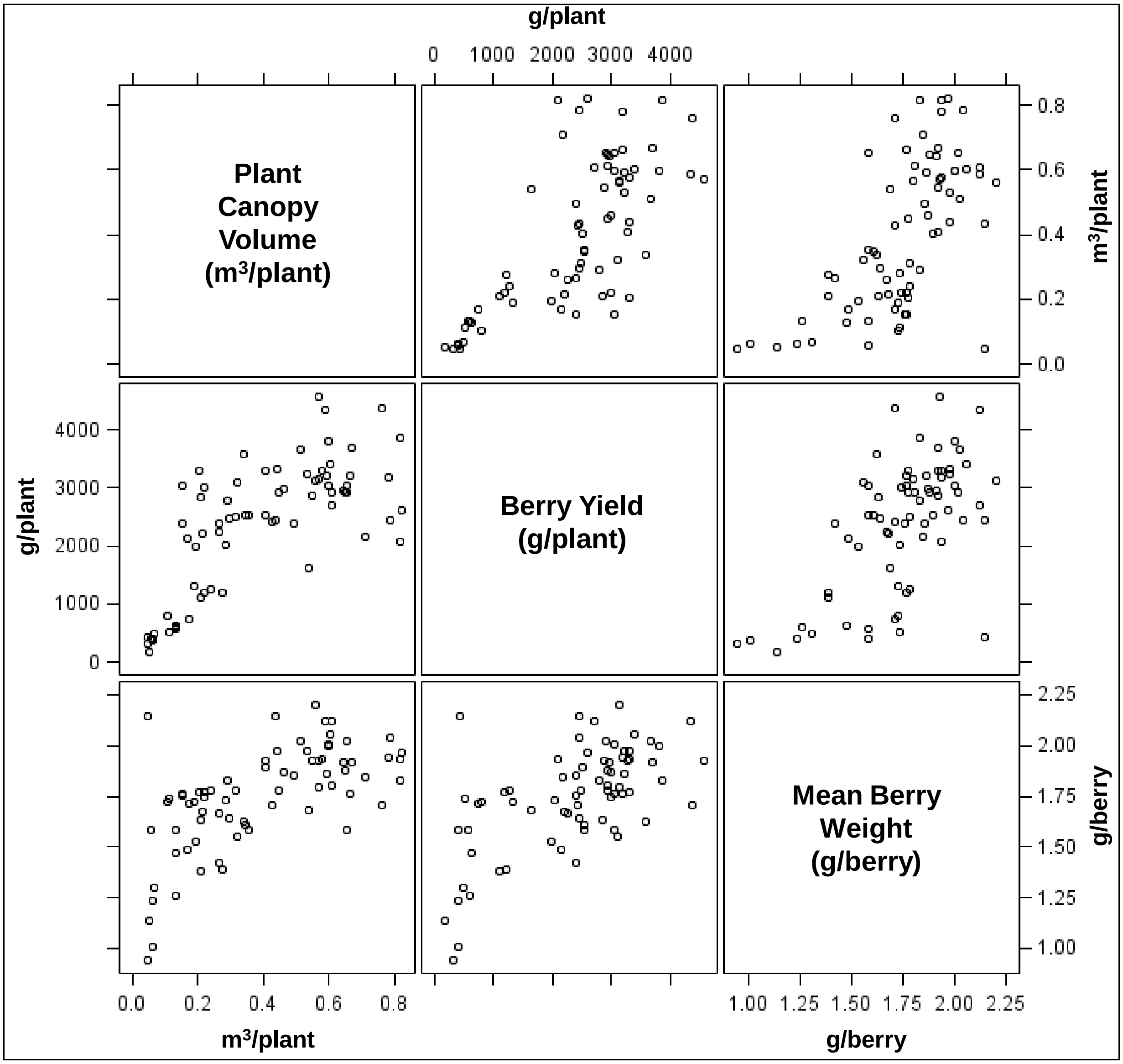

Figure 3-2. Effect of soil amendments on relationships among plant volume (m^3), berry yield (g/plant) and weighted mean berry weight (g/berry) of southern highbush blueberry (2007-2009). Spearman's correlation coefficient (r) was strong between plant canopy volume and berry yield ($r = 0.69699$, at $\alpha=0.0001$). Correlation coefficients were significant between plant canopy volume and mean berry weight ($r = 0.64522$, at $\alpha=0.0001$), and between berry yield and weighted mean berry weight ($r = 0.57483$, at $\alpha=0.0001$). Correlation coefficients for plant canopy volume, berry yield and weighted berry weight were determined using the PROC CORR procedure at $\alpha=0.05$ level of significance. Plot is symmetric (upper and lower half are identical).

CHAPTER 4
STEM WATER POTENTIAL AND ROOT DISTRIBUTION OF SOUTHERN HIGHBUSH BLUEBERRIES (VACCINIUM CORYMBOSUM) GROWN UNDER DIFFERENT SOIL MANAGEMENT SYSTEMS

Introductory Overview

Soil requirements of blueberry plants have been documented since the early 1900s. For optimum growth, plants require well-drained acidic soils (pH 4.0 to 5.5) with high organic matter content (Coville, 1910; Florida Dept. of Agriculture, 1941; Gougg, 1994). Florida's commercial blueberry plants are grown using one of three soil management systems. The pine bark bed system is most widely used. In this system, southern highbush blueberry (SHB) is planted directly in a 15-18 cm pine bark bed (1 meter wide) on top of non-amended deep sandy soils. In this system, roots are primarily confined to the pine bark bed, resulting in an extremely shallow root system that often leads to over-irrigation and fertilizer leaching (Dourte, 2007; Williamson and Crane, 2010; Williamson and Miller, 2009). Alternatively, SHB are sometimes planted into a soil/bark mixture (30-50%, v/v) where pine bark is incorporated into the top layer of soil and at times an additional pine bark mulch may be applied after planting. Rarely, SHB are planted into non-amended soils that are naturally suited for blueberry production and pine bark may be used as mulch. Soils naturally suited for SHB production are relatively uncommon and tend to be situated in low areas that are prone to late spring frosts (Williamson and Crane, 2010).

Dourte (2007) observed that root depth of SHB in the pine bark bed systems was less than 12 cm, and these roots did not grow out of the bed. Shallow root systems result in irrigation and fertilization difficulties that lead to inefficiencies of both (Dourte, 2007; Williamson and Crane, 2010). Also, shallow root systems may result in drought stress during the growing season (Hanson et al., 2004; Bryla and Strik, 2007). Blueberry stem blight (*Botryosphaeria dothidia*) is the major cause of plant death in Florida. This malady is believed to be related to various plant stresses including drought stress (Lyrene, 1997; Williamson and Lyrene, 2004; Wright and Harmon, 2010). Plants with a shallow root system may experience drought stress even when irrigated (Hanson et al., 2004). Incorporation of pine bark may result in deeper rooting and less drought stress compared with pine bark beds.

The objective of this study was to evaluate stem water potential of southern highbush blueberry grown using four soil management systems during short term and extended drought conditions. The hypotheses tested were: 1) incorporation of pine bark into soil will increase stem water potential of SHB compared with pine bark beds during dry periods without irrigation; 2) incorporation of pine bark into soil increases rooting depth of SHB compared with the traditional pine bark bed system.

Materials and Methods

Four-year-old SHB plants (cultivars ‘Emerald’ and ‘Star’) grown under four different soil management systems were studied. The experiment was conducted at the University of Florida Plant Science Research and Education Unit in Citra, Florida. Rows were spaced 3.05 meters apart with 0.91 meters between plants (3,588 plants$\cdot$ha^{-1}). Four soil amendment treatments were evaluated: 1) non-amended soil (Soil); 2) 8 cm of pine bark incorporated into the top 15 cm of the soil (Incorporated); 3) Incorporated plus 8 cm of pine bark mulch layer on top (Incorporated +Mulch); and 4) 15 cm of pine bark layer on top of non-amended soil (Bed). In the Soil, Incorporated, and Incorporated +Mulch treatments, plants were planted in the soil or soil/bark mixture while in the Bed treatment plants were planted in the pine bark layer. Treatments were arranged in a randomized complete block design with five replications. Four plants of the cultivar 'Emerald' were used as a plot and data were taken from the two plants in the middle of each plot. Four plants of the cultivar 'Star' were used as cross pollinizers between plots. The pollinizers were planted using the Bed treatment. SHB plants of the cultivars 'Jewel', 'Springhigh', and 'Windsor' were planted nearby to assist with cross pollination.

Cultural practices followed the recommended guidelines for commercial Florida blueberry production. Microsprinkler irrigation was used to supplement rainfall. During the 2006 and 2007 growing seasons, irrigation was applied at 2 to 3 day intervals in the absence of rain to minimize drought stress based on visual observations of the soil profile in the root zone. After April, 2008, irrigation was based on reference crop evapotranspiration (ET_0) as determined by a nearby weather station [Florida Automated Weather Network (FAWN)] website (http://fawn.ifas.ufl.edu/).

Experiment I - Stem Water Potential

Stem water potential of SHB shoots was measured using a 3005 series portable plant water status console (SoilMoisture Equipment Corp., Santa Barbara, CA) filled with compressed N gas. Stem water potential was measured during two periods of growth; following the summer growth flush (September-October, 2009) and during late fruit development (May, Spring 2010). Readings were taken from one shoot of each of the two data plants from each plot for the Bed, Incorporated, and Incorporated +Mulch treatments. One shoot was selected from the upper-mid section of the plant canopy from each of the sample plants. The shoot was selected from the east side of one plant and the west side of the other plant, and alternated each day. Predawn and 2 hours after solar noon readings were taken on the same side of the plant. Only one data plant was available in the soil treatment. One shoot was randomly selected from the upper mid-section of the plant canopy on the east or west side of the plant alternating sides each day.

Readings were taken at predawn (plant equilibrium with soil moisture) and 2 hours after solar noon (midday) in an attempt to target maximum diurnal water stress. For the predawn readings, shoots were covered with 1-quart polyethylene bags (Figure 4-1A) the night before to avoid dew formation on the leaves. For the midday readings, shoots were covered 30 minutes before with black plastic bags (Figure 4-1B) covered with aluminum foil to stop photosynthesis and avoid further transpiration of leaves. After stopping transpiration, leaves equilibrated with the stem water potential of the shoot.

In order to determine the effects of the soil treatments on stem water potential, irrigation was withheld until the plants began to exhibit extreme water stress (leaf scorching) or until a large rain event occurred. In Fall 2009 following summer growth flush, pressure chamber readings were taken during a 26-day period from 29 Aug. 2009 to 24 Oct. 2009. On 28 Aug., 1 day before the readings began, 10 mm of water was applied through the overhead irrigation system to ensure that stem water potential at predawn in all the treatments was relatively close to 0 kPa. Afterwards, irrigation was withheld for the duration of the experiment. Pressure chamber readings were taken every day from 29 Sept. to 4 Oct. After 13 Oct., readings were taken every other day to insure that shoots of the right size for the pressure chamber were available for the duration of the experiment. Pressure chamber readings were not taken during two light rainy periods in Fall 2009. During the first period, rain occurred on 5 Oct. (17.6 mm) and 7 Oct. (3.2 mm); during the second period, rain occurred on 15 Oct. (0.5 mm) and 16 Oct. (3.3 mm). Midday readings (2 shoots per treatment) were done following these rain events to determine when to resume measurements. When the midday readings were close to the value of the midday readings prior to the rain event, data collection resumed. The experiment was terminated on 24 Oct. when plants began to exhibit extreme drought stress symptoms (leaf scorching).

In Spring 2010 during late fruit development, readings were taken from 10 May 2010 until 16 May 2010 (7 days). Irrigation was applied on 10 May (the first day of readings) but was withheld for the remainder of the experiment. Pressure chamber readings were taken every day from 10 May to 14 May, but no readings were taken in 15 May because shoots of the right size for the pressure chamber were becoming scarce. The experiment was terminated on 16 May due to an unexpected 14-mm rain on 17 May.

Experiment II - Root Density and Distribution

In Summer 2010, root distribution and density was measured from one data plant in each plot using four of the replications. Trenches were dug 26 cm away from the south side of each plant. Trenches were as wide as the bed and 40 cm deep (Figure 4-2). A metal can (dimensions of 7.3 cm x 11 cm, volume of 0.046 dm^3) was used as a soil core sampler to collect soil cores of known volume from the soil profile to determine root distribution and density. Nine samples were taken per plant. Three samples were taken horizontally from the upper (0 to 9 cm), middle (10 to 18 cm), and lower (19 to 27 cm) layers (Figure 4-3). Samples were stored in polyethylene re-sealable bags and kept in a cooler with ice to keep roots from dehydrating. Roots were carefully washed from the soil using low pressure water and 1.016 mm and 1.058 mm sieves. Washed roots were stored in a cooler with ice until root scans were done the following day.

Roots were scanned using the program WinRHIZO Pro® (Regent Instruments Inc.,Quebec, Quebec, Canada) (Figure 4-4A and B). Root density was recorded as total surface area (cm^2), total length (cm), and length of roots (cm) by diameter category (mm). These response variables were divided by the volume of the soil core and expressed per unit volume of soil. Average root diameter of each sample was also calculated.

Soil pH

In August 2010, pine bark was reapplied (15 cm deep) to the four soil treatments after root density and distribution experiment was completed. In March 2011, soil pH was measured from the north data plant in each plot using six replications. Reapplied pine bark was removed from the soil surface and four subsamples (13 cm deep) were taken at 25 cm from the base of the plant (at the northwestern, northeastern, southwestern, and southeastern corners of the plant). Subsamples were then mixed and soil pH was calculated using the pH in water by electrometric method (EPA method 150.1) in UF/IFAS Analytical Services Laboratories.

Statistical Analysis

Data were statistically analyzed using SAS software version 9.2 (SAS Institute Inc., Cary, NC). Pressure chamber readings (predawn and two hours after solar noon), root density (root length and root surface area), average root diameter, root percentages by soil layer, and soil pH were analyzed using PROC GLM and means were separated using Duncan's test at α=0.05 level of significance. Spearman's correlation coefficients (r) for soil pH, pine bark used per plant, total root length and total root surface area were determined using the PROC CORR procedure.

Results

Experiment I - Stem Water Potential

Fall 2009, predawn

In Fall 2009 following summer growth flush, no significant differences were observed for predawn stem water potential (kPa) among the treatments during the first 2 weeks of the experiment (from 29 Sept. to 4 Oct. and from 13 Oct. to 15 Oct.) (Figure 4-5). Differences occurred only during the last 5 days (20 Oct. to 24 Oct.) of an extended period without irrigation (26 days) and little rainfall, when plants in the non-amended treatment (Soil) had different predawn stem water potentials from the Bed and Incorporated +Mulch treatments (Figure 4-5). During this period, predawn stem water potential of the Soil treatment was higher than the Incorporated +Mulch treatment at all three measuring dates and higher than the Bed treatment at two of the three measuring dates. Overall from 29 Sept. to 24 Oct., no differences were observed for predawn stem water potential among the three amended treatments (Figure 4-5).

Fall 2009, midday

In Fall 2009 following the summer growth flush, no differences were observed among treatments for midday stem water potential (kPa) for most of the measuring dates (Figure 4-6). Significant differences were only seen during days 3 and 4 (2 Oct. and 3 Oct, respectively) during prolonged non-irrigated conditions (29 Sept. to 24 Oct.). On 2 Oct., the non-amended treatment had significantly lower midday stem water potential than the amended treatments. On 3 Oct., the Soil treatment had significantly lower midday stem water potential measurements than the Bed and Incorporated treatments (Figure 4-6). Overall from 29 Sept. to 24 Oct., no differences were observed for midday stem water potential among the three amended treatments (Figure 4-6).

Towards the end of the experiment (20 Oct. to 24 Oct.) severe water stress (shown as leaf scorching) was seen in all SHB plants (Figures 4-7, 4-8, and 4-9). Visual differences of the effects between the cultivars ‘Emerald’ (data plants) and ‘Star’ (pollinizer) were noticed. ‘Star’ showed necrotic leaf tips and marginal leaf burn, while the middle of the leaves remained green (Figure 4-7). ‘Emerald’ showed yellowing and the appearance of small necrotic spots throughout the leaves, then tips and edges of leaves became necrotic (Figure 4-8). Also, symptoms in ‘Star’ were seen throughout the plant while symptoms in ‘Emerald’ were seen only in a few canes (Figure 4-9).

Spring 2010, predawn

In Spring 2010 during late fruit development, no differences in predawn stem water potential (kPa) were observed among treatments at the initiation of the experiment and for the first day without irrigation (10 May and 11 May) (Figure 4-10). However, on day 2 and 3 without irrigation (12 May and 13 May), predawn stem water potential of the non-amended Soil treatment was lower than any of the amended treatments (Figure 4-10). By day 6 without irrigation (16 May), the Incorporated treatment had a lower predawn stem water potential than the Bed treatment but the non-amended Soil treatment was not different from any of the amended treatments (Figure 4-10).

Spring 2010, midday

In Spring 2010 during late fruit development, the non-amended treatment had significantly lower midday stem water potential than the amended treatments even before irrigation was withheld (10 May) and for the first three days without irrigation (11 May and 13 May) (Figure 4-11). On day 4 and 6 without irrigation (14 May and 16 May), the Soil treatment had significantly lower midday stem water potential than the Bed treatment (Figure 4-11). Overall from 10 May to 16 May, no differences were observed for midday stem water potential among the three amended treatments (Figure 4-11).

Experiment II - Root Density

In Summer 2010, the pine bark mulch in the Bed and Incorporated +Mulch treatments had decomposed greatly. The Bed treatment had 7-9 cm of pine bark mulch on top of the soil (originally there was 15 cm of mulch) and the Incorporated +Mulch had 3-4 cm of pine bark mulch on top of the soil/bark mixture (originally there was 8 cm of mulch) (Figure 4-12).

Within each depth (upper, middle, and lower), no differences were observed for average root diameter (mm) among the four soil treatments) (Table 4-1). In the upper layer, the amended treatments had significantly greater total root surface area (cm^2/dm^3 soil) and total root length (cm/dm^3 soil) than the non-amended treatment (Table 4-1). In the middle layer, the Soil treatment had significantly less total surface area and total root length than the Incorporated or the Bed treatments but there were no differences between it and the Incorporated +Mulch treatment. In the lower layer, the Soil treatment had significantly less total surface area and total root length than the Bed treatment but there were no differences between the Soil treatment and the Incorporated or Incorporated +Mulch treatments (Table 4-1). Overall, no differences were observed in total length and total surface area of roots among the three amended treatments within each layer (Table 4-1). Averaged across all layers (0 to 27 cm), higher root densities were observed for all the soil amended treatments compared with the non-amended treatment, but no differences were observed among the three amended treatments (Table 4-1).

No differences were observed for the relative distribution of roots (% of total root surface area and % of total root length) among the four soil treatments within each layer (upper, middle, and lower) (Table 4-2). Root surface area and total root length had higher concentrations in the upper (49-54%) and middle layers (31-43%) for all treatments (Table 4-2). Only 7-17% of root surface area and total root length were located in the lower layer. Overall, 83-93% of roots of SHB were located in the upper 18 cm of soil in the four soil treatments (Table 4-2).

Soil pH

In March 2011, there were no differences in soil pH among plants in the amended treatments; however, soil pH was higher for the Soil treatment compared with the Bed and the Incorporated + Mulch treatments (Figure 4-13). A negative relationship ($r = -0.50869$, at $\alpha=0.0132$) was seen for soil pH versus pine bark used per plant (Figure 4-14). However, relationships between soil pH versus total root length and total root surface area, and pine bark used per plant versus total root length and total root surface area were not significant (Appendix A-17).

Discussion

Shallow root systems of blueberry plants have been reported before (Hanson et al., 2004; Bryla and Strik, 2007), in our experiment 83-93% of the root systems were concentrated in the upper 18 cm of soil in all four soil treatments. However, contrary to the observations of Dourte (2007), and Williamson and Miller (2009), the root system in the pine bark bed system is not confined to the bed and a large proportion of roots are able to penetrate the non-amended soil under the bed. The Bed treatment only had 7-9 cm of pine bark mulch remaining (half of the original amount applied), but roots in the middle and lower layers of soil (from 10 to 27 cm deep) added up to 50% of the total root density and the proportion of roots within each soil layer was not different from the other soil treatments. Two factors: 1) better irrigation practices; and 2) optimum soil pH for blueberries may have contributed to the roots growing into the soil under the bed. Dourte (2007) reported that growers may over-irrigate pine bark beds because they tend to apply higher quantities of water in fewer applications with overhead irrigation systems. In our experiment, frequent and light irrigations using microsprinklers, and based on reference crop evapotranspiration, were managed diligently. Also, in the Bed treatment soil pH in the first 15 cm of soil was optimum for blueberry production averaging pH 5.48.

Using organic soil amendments such as pine bark, lowers soil pH (Billeaud and Zajicek, 1989; Williamson et al., 2006). In this study, soil pH was negatively correlated to the amount of pine bark used for the four different soil management systems, but soil pH from the 15 cm pine bark amended treatments (Bed and Incorporated +Mulch treatments) was not different from the 8 cm of pine bark amended treatment (Incorporated treatment).

The results from this study suggest that plants under irrigated (at midday) and short term (5-day) drought conditions (at predawn and midday) showed lower stem water potential (higher water deficit) during late fruit development in non-amended soils than in amended soils. Also, during early stages of drought after summer growth flush, plants in non-amended soils had higher midday water deficit than plants in amended soils. However, following a long-term drought (22 to 26 days) after the summer growth flush, plants in non-amended soils experienced lower predawn water deficits than plants in the amended treatments. This result could be explained by the higher root density in the amended soils (compared with the non-amended soils) that may have resulted in more efficient water uptake under relatively high soil moisture conditions resulting in lower water deficits during the early stages of drought. But under prolonged drought conditions, available water in the rhizosphere was depleted more rapidly from the amended treatments where root densities are high resulting in higher predawn water deficits compared with the non-amended treatment.

During spring (late in fruit development) differences in water deficit among the amended treatments were only seen after 6 days without irrigation. At this time, the Incorporated treatment showed greater water deficit than the Bed treatment, but the Incorporated +Mulch treatment was not different from either. These results for the amended treatments agree with the results for plant canopy volume taken in Feb. 2010 (see Chapter 3) where plant canopy volume for the Incorporated treatment was larger than for the Bed treatment but the Incorporated +Mulch treatment was not different from either. Plants with larger canopy volumes, but with similar root densities, required more water and experienced greater predawn water deficits under short-term drought conditions during the latter stages for fruit development.

The advantages of pine bark as a soil amendment were apparent with respect to minimizing short term water deficits during late fruit development (predawn and midday) and after summer growth flush (midday). Although, predawn water deficit was greater for amended soils than non-amended soils following long-term drought conditions, generally irrigation is available in commercial plantings so severe, prolonged, water deficit is not common. However, incorporation of pine bark into soil did not increase root density or decrease water deficits during dry periods compared with pine bark beds. The physical characteristics of pine bark change during decomposition resulting in smaller particle size with better water holding capacity (Odneal and Kaps, 1990; Niemiera et al., 1994). The amended soil treatments were established 4 years prior to this study. The aged pine bark beds in this study most likely retained more water than beds composed of fresh pine bark. If a similar study were conducted with fresh pine bark, differences in stem water potential between the pine bark bed and the incorporated (soil/bark mixture) treatments might occur.

Increasing demand for pine bark, potential environmental regulations for fertilizer and water use, and production costs, are becoming increasingly important to Florida blueberry growers. More studies are needed to clarify optimum fertilization and irrigation practices for various soil management systems, but this study suggests that Florida's sandy soils should be amended (with pine bark) to improve root development, lower soil pH, and to minimize short term water deficits on SHB. Although, there was no apparent advantage of incorporating pine bark into soil compared with pine bark beds relative to rooting depth, soil pH, or short term water deficits, the Incorporated treatment used half as much pine bark and reduced the cost of establishment.

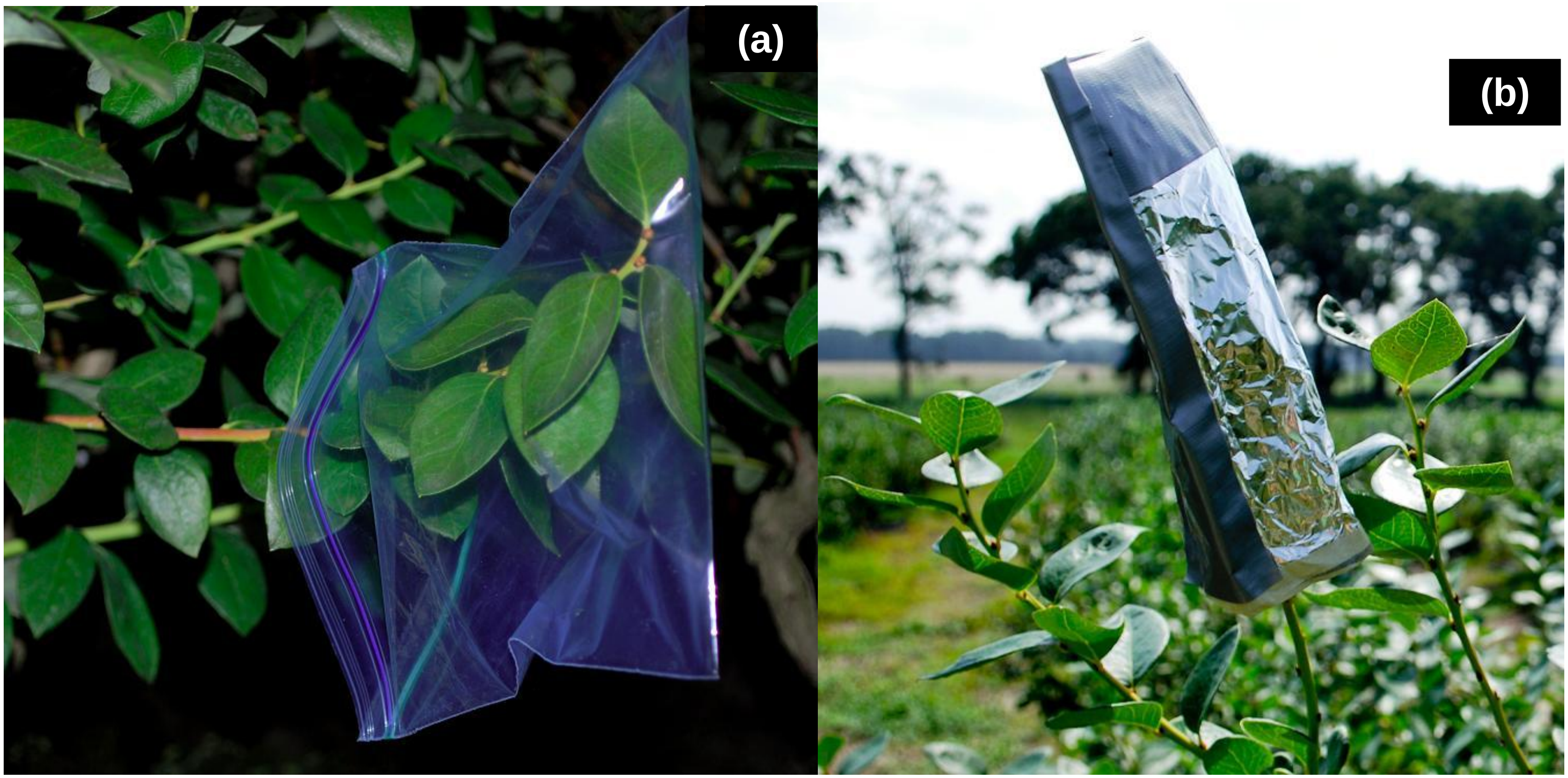

Figure 4-1. Shoots were covered prior to taking pressure chamber readings. For the predawn readings, polyethylene quart size bags were used the night before the readings (a). Shoots were covered 30 minutes before midday readings with black plastic bags (16 cm length and 4 cm wide) covered with aluminum foil to stop photosynthesis and avoid further transpiration of the leaves (b).

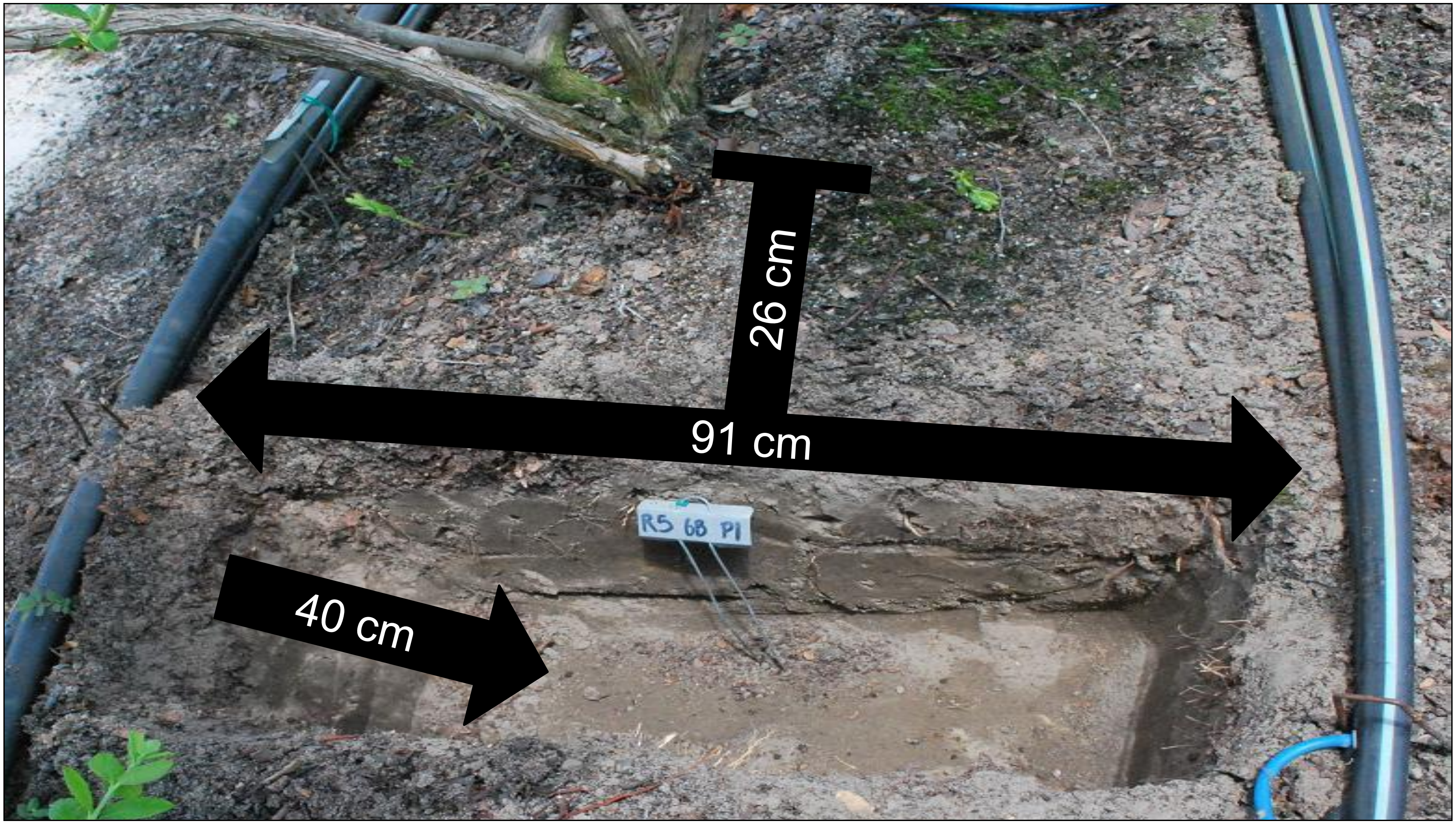

Figure 4-2. Root density was calculated by sampling soil from the south side of one sample plant per plot. Trenches were dug 26 cm away from the south side of the plant. Trenches were 91 cm wide and 40 cm deep.

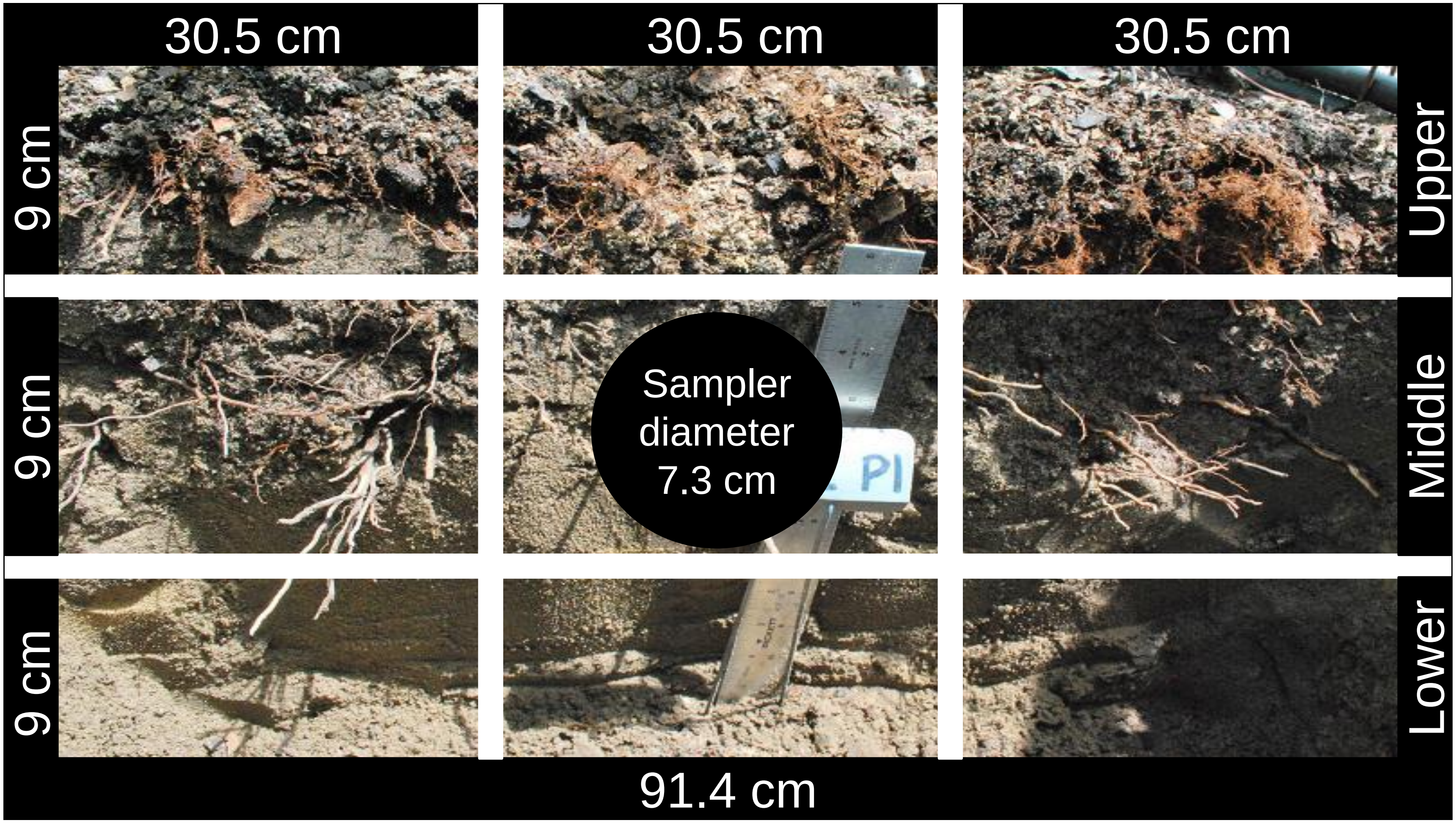

Figure 4-3. Trenches were dug 26 cm from the plant to sample roots of southern highbush blueberry during the summer of 2010. Trenches were separated into nine sectors (9 cm by 30.5c m) and samples were taken from the center of each sector. Three samples were taken horizontally from the upper (0 to 9 cm), middle (10 to 18 cm), and lower (19 to 27 cm) layers. A metal can (dimensions of 7.3 cm x 11 cm or volume of 0.046 dm^3) was used as a soil core to take soil samples. Sectors in figure are not on scale.

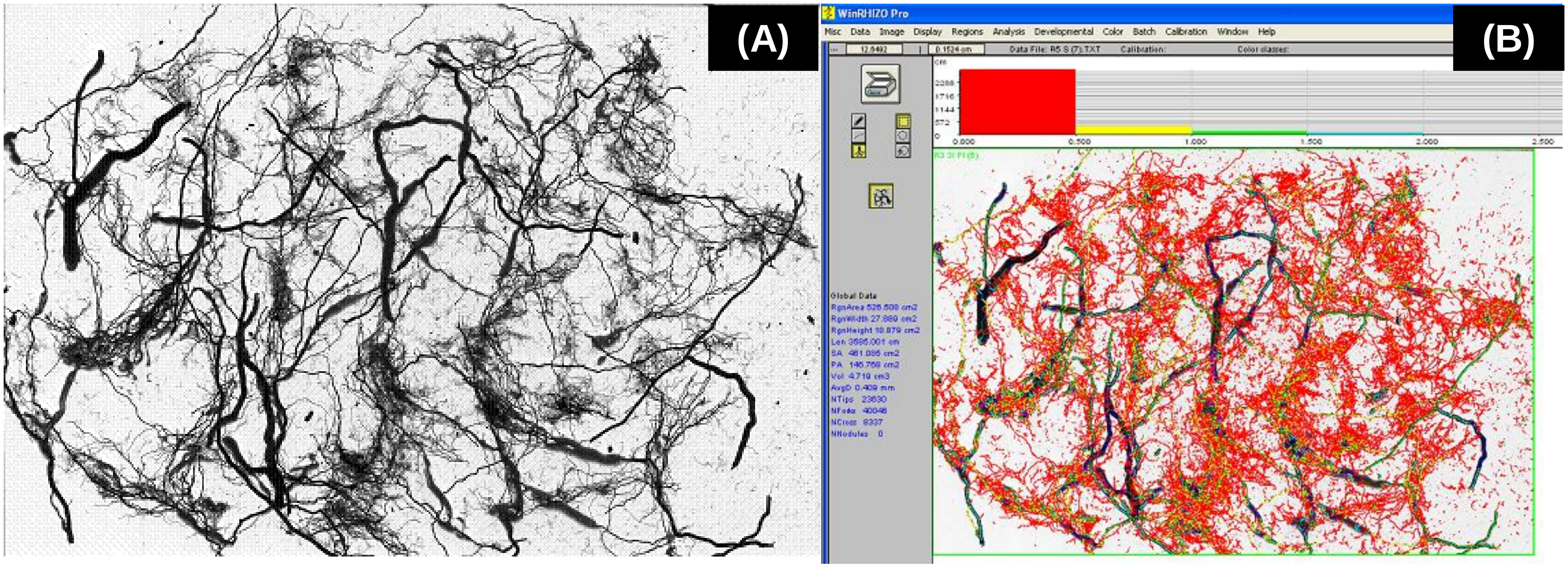

Figure 4-4. Scans of a root sample of southern highbush blueberry (A) and calculated characteristics of the root sample using the program WinRHIZO Pro® (B).

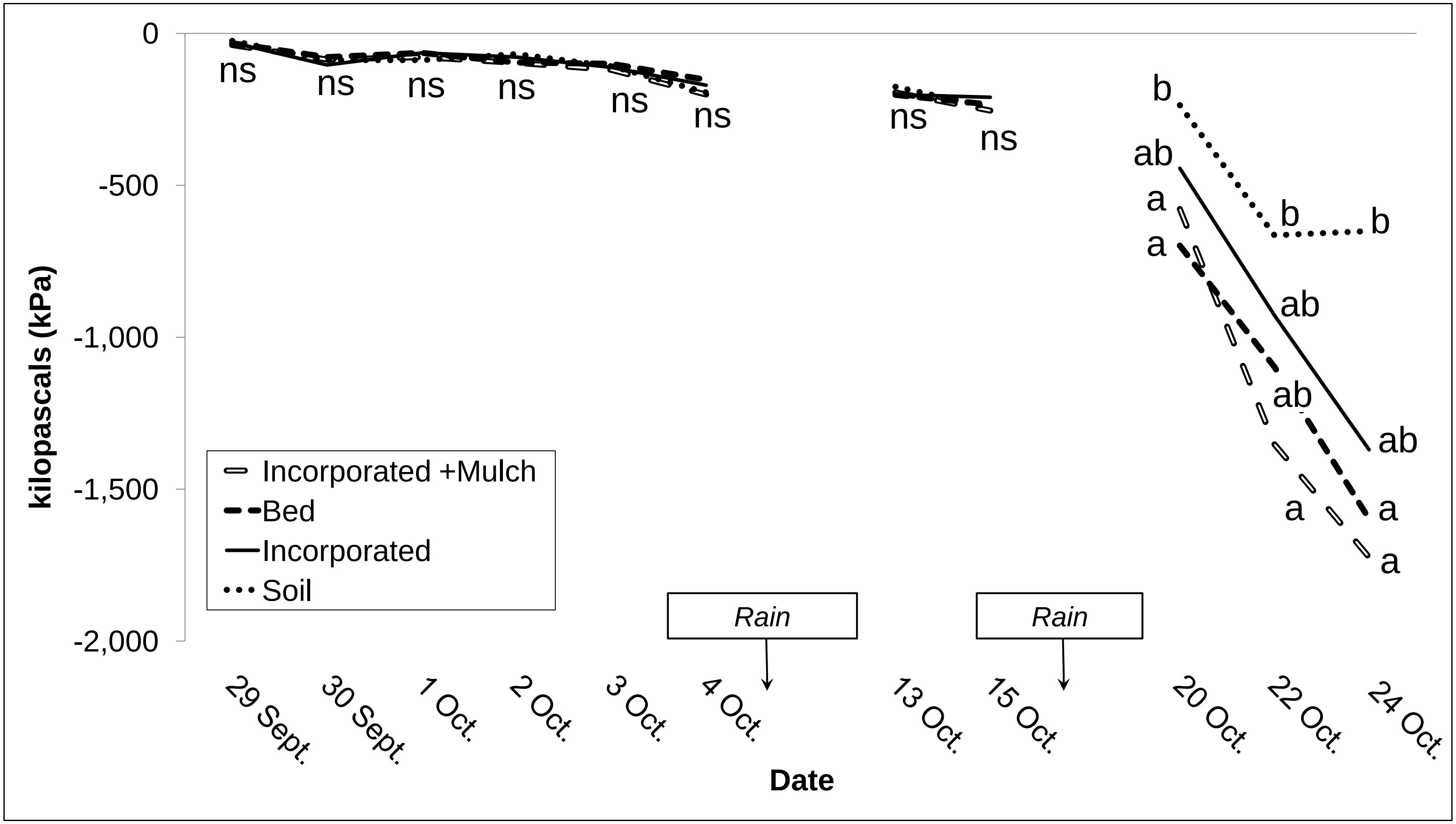

Figure 4-5. Predawn pressure chamber readings of shoots of southern highbush blueberry were taken during Fall 2009. Pressure chamber readings were not taken during two light-rainy periods in Fall 2009. The same letters or ‘ns’ within a date indicate no significant differences, using Duncan’s test, α=0.05.

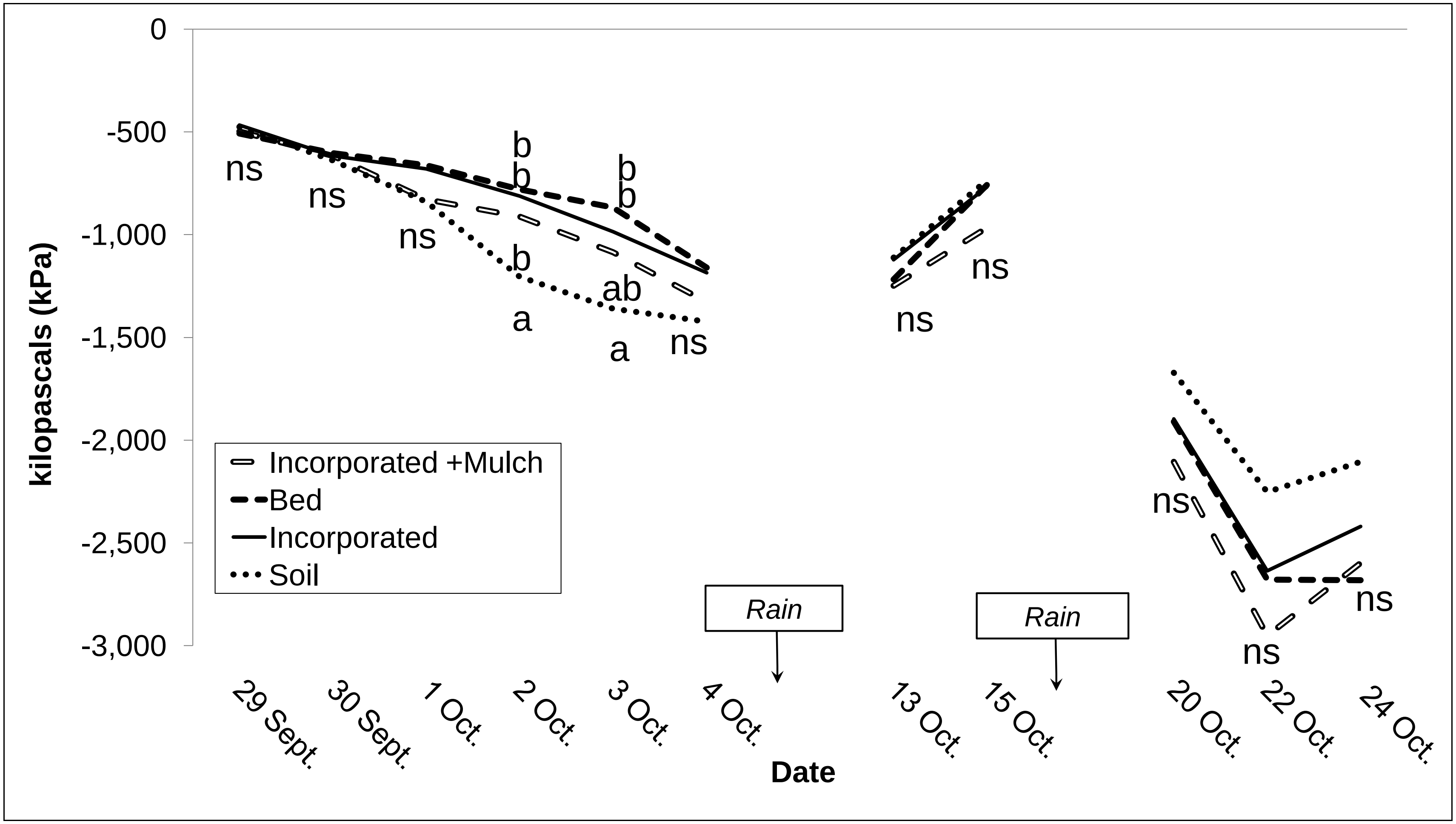

Figure 4-6. Two hours after solar noon pressure chamber readings of shoots of southern highbush blueberry were taken during Fall 2009. Pressure chamber readings were not taken during two light-rainy periods in Fall 2009. The same letters or 'ns' within a date indicate no significant differences, using Duncan's test, α=0.05.

Figure 4-7. Water stress symptoms during prolonged drought conditions in the leaves of the cultivar 'Star' of southern highbush blueberry in Fall 2009. Leaf burning started at the tips or margins of the leaf and then extended through the entire leaf.

Figure 4-8. Water stress symptoms during prolonged drought conditions in the leaves of the cultivar 'Emerald' of southern highbush blueberry in Fall 2009. Plant of the cultivar 'Emerald' showed yellowing and the appearance of small necrotic spots throughout the leaves, then tips and edges of leaves became necrotic.

Figure 4-9. Comparison of extreme water stress symptoms during prolonged drought conditions showing large portions of plant canopies of cultivars ‘Star’ and ‘Emerald’ southern highbush blueberry in Fall 2009. Symptoms in ‘Star’ were seen throughout the plant while symptoms in ‘Emerald’ were seen only in a few canes. Photos were taken after a 26-day without irrigation and low rainfall.

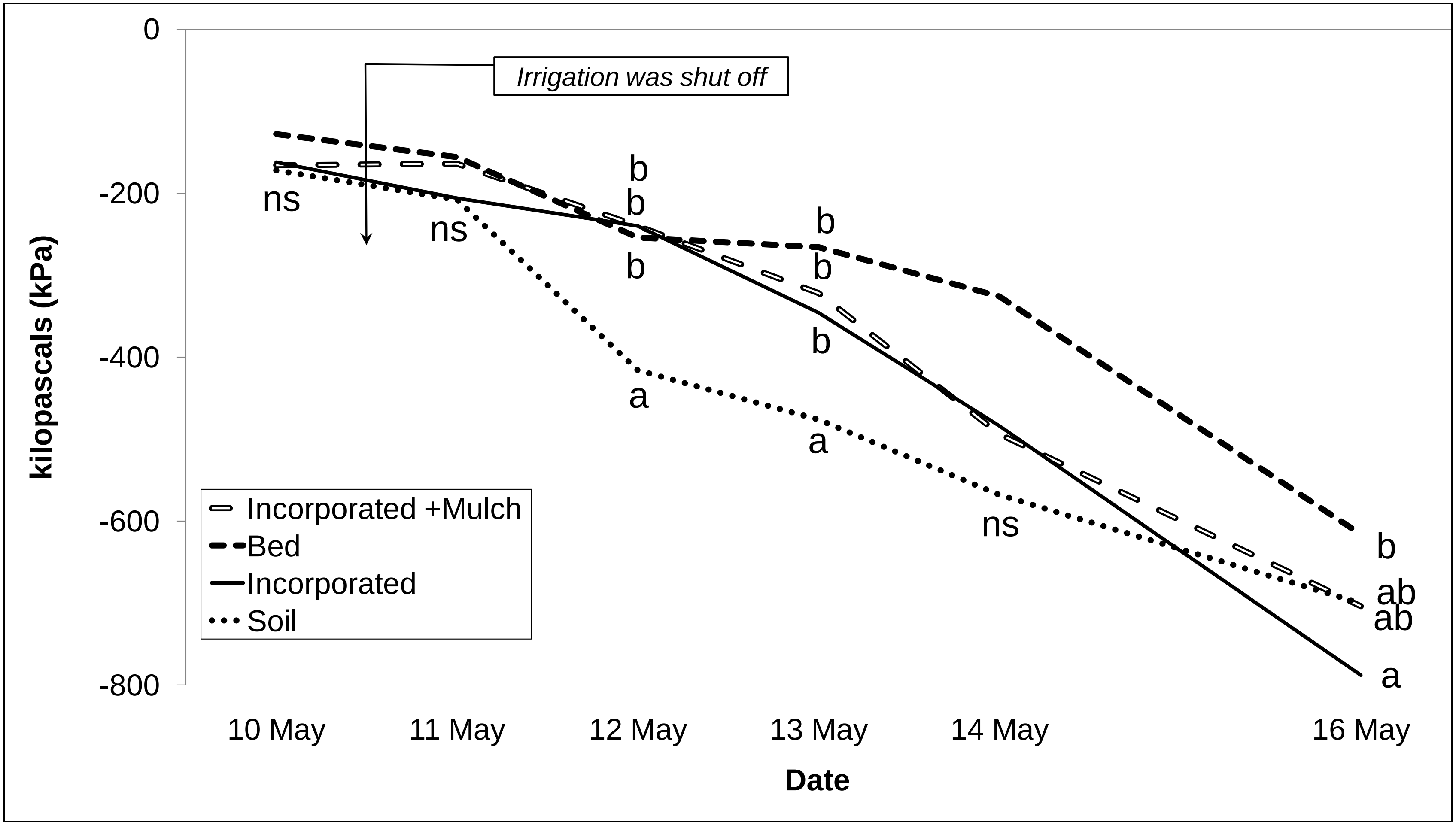

Figure 4-10. Predawn pressure chamber readings of shoots of southern highbush blueberry were taken during Spring 2010. The same letters or ‘ns’ within a date indicate no significant differences, using Duncan’s test, α=0.05.

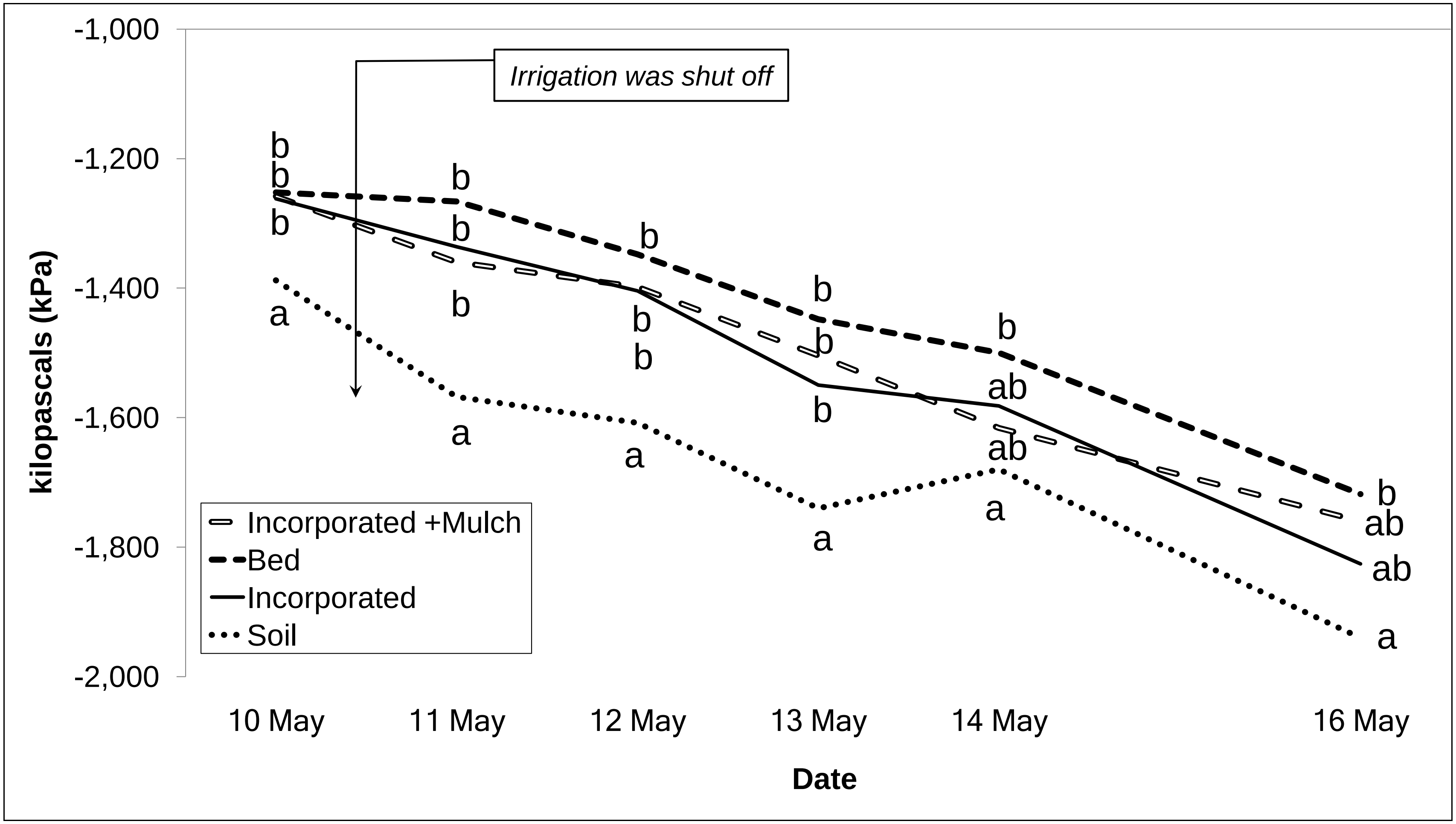

Figure 4-11. Two hours after solar noon pressure chamber readings of shoots of southern highbush blueberry were taken during Spring 2010. The same letters or 'ns' within a date indicate no significant differences, using Duncan's test, α=0.05.

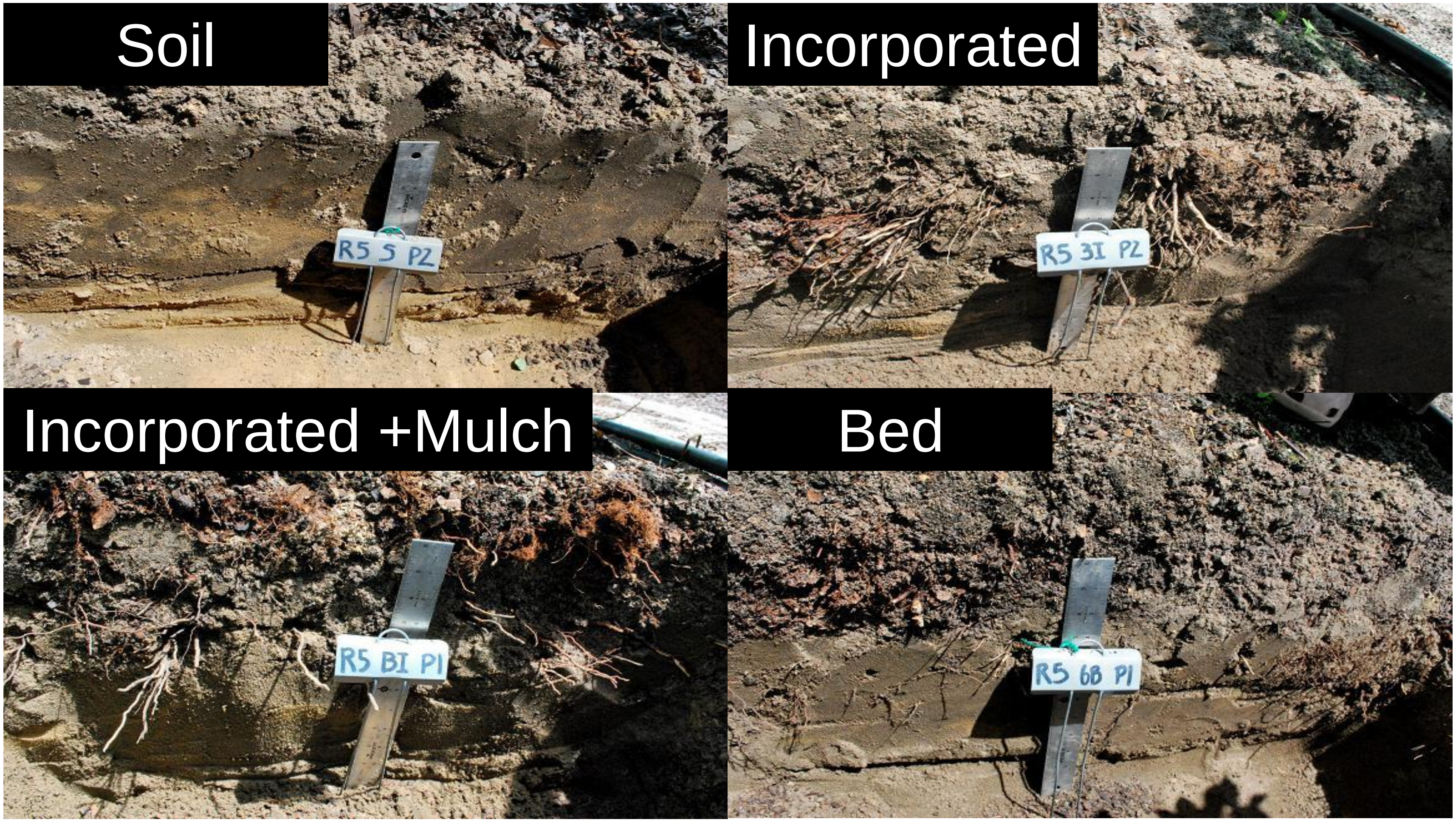

Figure 4-12. Trenches showing visual differences in root density between the amended (Incorporated, Incorporated +Mulch, and Bed) and non-amended (Soil) treatments. The Bed treatment had 7-9 cm of pine bark mulch on top of the soil (originally there was 15 cm of mulch) and the Incorporated +Mulch had 3-4 cm of pine bark mulch on top of the soil/bark mixture (originally there was 8 cm of mulch).

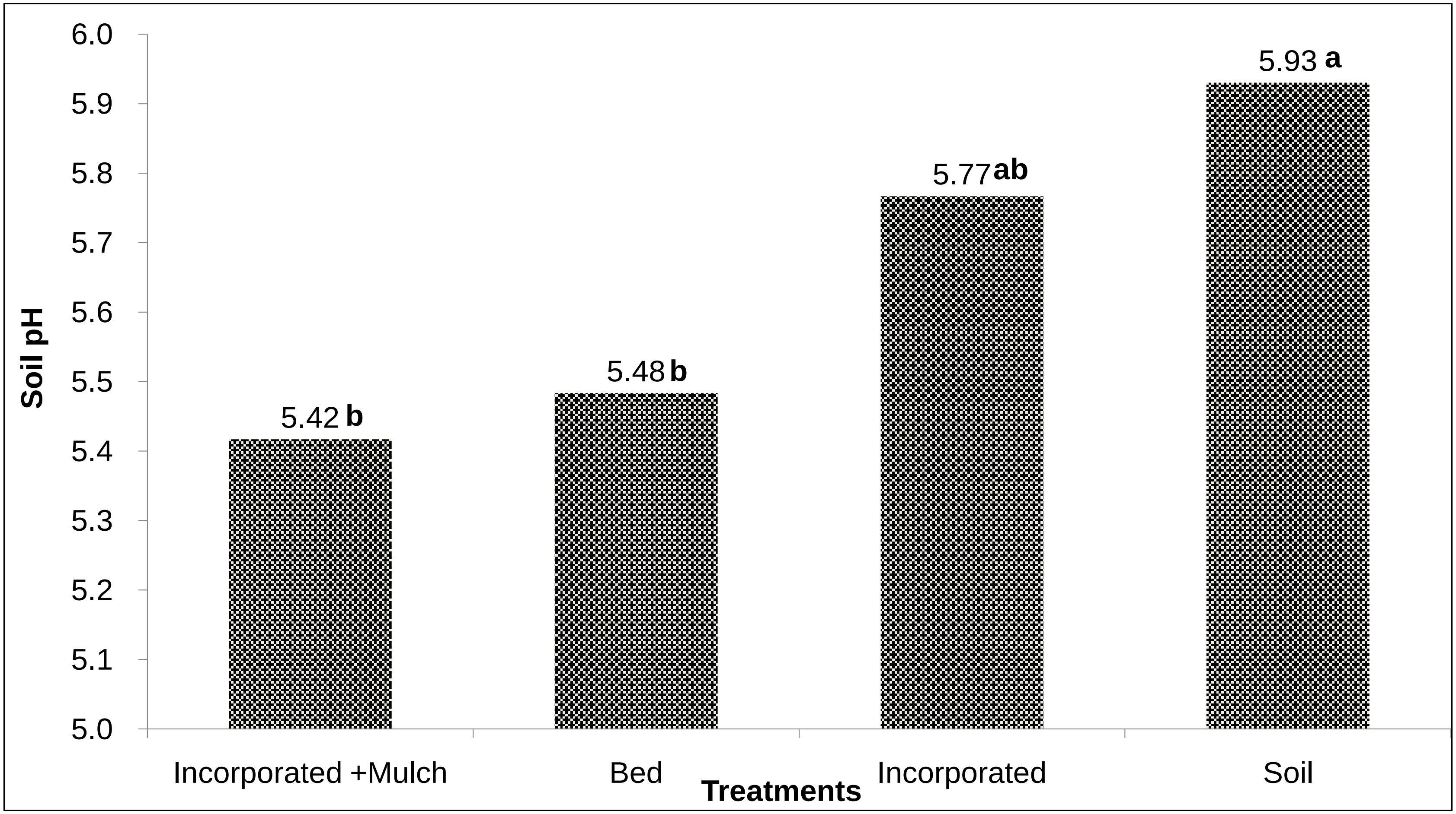

Figure 4-13. Effect of soil amendments on soil pH in March 2011. Plants of southern highbush blueberry were planted in January 2006. Means followed by the same letters indicate no significant differences, Duncan's test, α=0.05.

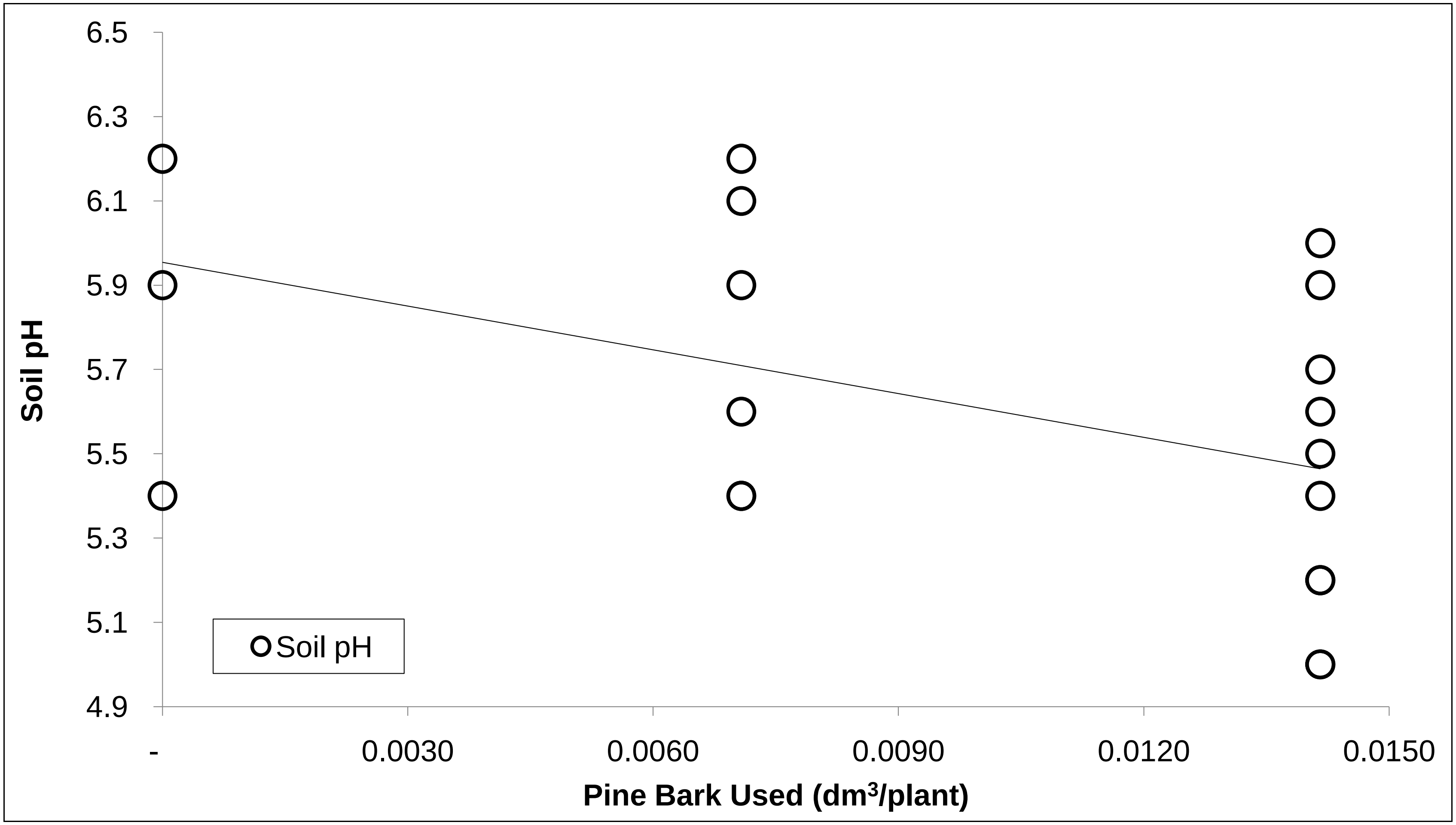

Figure 4-14. Effect of soil amendments on the relationship between soil pH and pine bark used per plant in March 2011. Plants of southern highbush blueberry were planted in January 2006. Spearman's correlation coefficient (r) was significant (r = 0.50869, at α=0.0132). Correlation coefficients for soil pH and pine bark used per plant were determined using the PROC CORR procedure at α=0.05 level of significance.

Table 4-1. Root density (root length/dm^3 soil and root surface area/dm^3 soil) and average root diameter for southern highbush blueberry in amended and non-amended soils, Summer 2010[z].

Treatments	Total Root Surface Area (cm^2/dm^3 soil)		Average Root Diameter (mm)		Total Root Length (cm/dm^3 soil)		Length of Roots by Diameter (cm/dm^3 soil)							
							0 to 1 mm		1 to 2 mm		2 to 4.5 mm		> 4.5 mm	
UPPER LAYER (0 to 9 cm)														
Incorporated	549.0	a	0.33	a	6152.8	a	5835.9	a	233.2	a	71.7	a	12.0	a
Incorporated +Mulch	474.8	a	0.31	a	5622.6	a	5361.3	a	195.2	a	60.3	a	5.9	ab
Bed	484.0	a	0.30	a	5987.1	a	5734.5	a	185.9	a	55.5	a	11.1	ab
Soil	141.4	b	0.29	a	1602.8	b	1525.2	b	59.8	b	15.0	b	2.9	b
MIDDLE LAYER (10 to 18 cm)														
Incorporated	541.1	a	0.35	a	6064.8	a	5726.0	a	252.1	a	78.1	a	8.7	a
Incorporated +Mulch	319.8	ab	0.36	a	3765.7	ab	3574.6	ab	139.0	ab	44.7	ab	7.5	a
Bed	420.9	a	0.30	a	5021.1	a	4795.0	a	176.4	ab	47.1	ab	2.6	a
Soil	127.5	b	0.31	a	1094.1	b	1002.8	b	65.6	b	18.6	b	7.1	a
LOWER LAYER (19 to 27 cm)														
Incorporated	98.5	ab	0.31	a	1114.3	ab	1055.8	ab	41.5	ab	15.2	a	1.8	a
Incorporated +Mulch	171.4	ab	0.30	a	2054.1	ab	1961.4	ab	65.1	ab	21.8	a	5.9	a
Bed	233.8	a	0.28	a	2719.4	a	2588.7	a	101.3	a	26.2	a	3.2	a
Soil	24.9	b	0.24	a	287.8	b	273.0	b	11.1	b	2.8	a	0.9	a
ALL LAYERS (0 to 27 cm)														
Incorporated	182.4	a	0.33	a	2046.0	a	1936.4	a	80.8	a	25.3	a	3.4	a
Incorporated +Mulch	148.2	a	0.32	a	1756.0	a	1672.3	a	61.3	a	19.5	a	3.0	a
Bed	174.8	a	0.29	a	2106.7	a	2013.2	a	71.2	a	19.8	a	2.6	a
Soil	45.1	b	0.28	a	458.0	b	429.8	b	20.9	b	5.6	b	1.7	a

[z]Means followed by the same letters within a column indicate no significant differences, Duncan's test, α=0.05.

Table 4-2. Percentage of root length and root surface area by layer of soil for southern highbush blueberry in amended and non-amended soils, Summer 2010^{z}.

Treatments	Percent: Soil Layer: Upper (0 to 9 cm)	Middle (10 to 18 cm)	Lower (19 to 27 cm)	Upper+Middle Layers: 0 to 18 cm
TOTAL ROOT SURFACE AREA				
Incorporated	50.4 a	42.6 a	7.0 a	93.0 a
Incorporated +Mulch	52.4 a	31.6 a	16.0 a	84.0 a
Bed	49.3 a	34.0 a	16.7 a	83.3 a
Soil	51.2 a	35.8 a	13.0 a	87.0 a
TOTAL ROOT LENGTH				
Incorporated	50.7 a	42.1 a	7.2 a	92.8 a
Incorporated +Mulch	53.5 a	31.0 a	15.4 a	84.6 a
Bed	49.8 a	33.9 a	16.3 a	83.7 a
Soil	53.7 a	33.5 a	12.8 a	87.2 a

^{z}Means followed by the same letters within a column indicate no significant differences, Duncan's test, α=0.05.

CHAPTER 5
CONCLUSIONS

In Florida, southern highbush blueberry (SHB) (*Vaccinium corymbosum*) is grown using one of three soil management systems. The lack of documented information comparing plant growth and yield among these systems led to the development of this study. The overall objective was to determine the most suitable soil management system using pine bark as a soil amendment for SHB under Florida conditions with the goal of reducing pine bark inputs. The objectives of this study were 1) to evaluate the effect of several soil management systems on plant canopy, fruit yield, and mean berry weight of SHB; and 2) to evaluate stem water potential (during short term and extended periods without irrigation and little rainfall) and to measure root distribution of SHB grown in several soil management systems.

To achieve the first objective, a study was conducted to measure vegetative and reproductive growth on SHB plants grown in four different soil treatments. The treatments were 1) Incorporated; 2) Bed; 3) Incorporated +Mulch; and 4) a Soil treatment. The treatments were characterized as amended treatments (1-3) and a non-amended treatment (4). Similar vegetative growth (plant canopy and pruning dry weights) was observed in all the amended treatments during the study, but plants in the non-amended treatment were smaller and less vigorous than the amended treatments. Reproductive growth (total yield and mean berry weight) was similar for all the amended treatments, but the non-amended treatment produced lower yields and smaller berries than the amended treatments. However, total yield (yield summed across years 2007-2009) was greater for the Incorporated +Mulch treatment than for the Bed treatment, but not different from the Incorporated treatment. Incorporating pine bark into the top layer of soil is a sufficient amendment treatment to increase vegetative and reproductive growth in Florida's sandy soils.

The second objective was to evaluate stem water potential (during short term and extended periods without irrigation and little rainfall) and to measure root distribution of SHB grown in several soil management systems. This study suggests that plants under irrigated (midday) and short term drought conditions (predawn and midday) had lower stem water potentials during late fruit development in non-amended than in amended soils. Also, during short drought conditions after the summer growth flush, plants in non-amended soils had lower midday stem water potentials than plants in amended soils. However, during long-term drought conditions during fall (22 to 26 days), plants in non-amended soil experienced less predawn water deficits than plants in the amended soils. However, such extended drought conditions in irrigated commercial plantings would be unlikely. Root densities (length and surface area per dm^3 soil) were similar for the amended treatments and much greater than in the non-amended soil. Higher root densities in the amended soils may allow efficient water uptake under relatively moist soil conditions resulting in lower water deficit under irrigated conditions and during the early stages of drought. But under prolonged drought conditions, available water in the rhizosphere is depleted more rapidly from the amended treatments where root densities are high resulting in higher predawn water deficits compared with the non-amended treatment. However, prolonged drought conditions are uncommon in irrigated blueberry fields.

After 6 days without irrigation during late fruit development, the Incorporated treatment showed higher water deficit than the Bed treatment, but the Incorporated

+Mulch treatment was not different from either. This could be explained by results for plant canopy volume taken in Feb. 2010 where plant canopy volume for the Incorporated treatment was larger than for the Bed treatment but the Incorporated +Mulch treatment was not different from either. Plants with larger canopy volumes, but with similar root densities, required more water and experienced greater predawn water deficits during late fruit development under drought conditions. Incorporation of pine bark into soil did not increase root density or decrease drought stress during dry periods compared with pine bark beds. This study suggests that Florida's sandy soils need to be amended with pine bark to improve root development and lower short-term water deficits in SHB.

In Florida, amending soils with pine bark resulted in greater vegetative growth, higher berry yields, larger berry size, improved short-term water deficit, lower soil pH, and higher root density compared with non-amended soils. Incorporating pine bark into the soil may offer cost savings compared with traditional pine bark beds because 50% less pine bark was used without affecting canopy growth, root density, stem water potential or yield. Additional studies with SHB are needed under Florida conditions to determine fertilizer and water requirements when pine bark is incorporated into the soil.

APPENDIX
ADDITIONAL TABLES AND FIGURES

A) TABLES

Table A-1. Effect of soil amendments on plant canopy volume of southern highbush blueberry using a significance level of α=0.10 (2006-2009) (Chapter 3)[zy].

	m^3/plant						
	Date						
Treatment	Feb. 2007	Nov. 2007	Dec. 2008	Feb. 2009[x]	Jun. 2009[w]	Jun. 2009[v]	Feb. 2010
Incorporated +Mulch	0.22 a	0.57 a	0.72 a	0.69 a	0.70 a	0.69 a	0.76 a
Bed	0.26 a	0.50 a	0.57 b	0.54 b	0.60 b	0.63 a	0.66 b
Incorporated	0.29 a	0.56 a	0.62 b	0.56 b	0.65 ab	0.66 a	0.78 a
Soil	0.10 b	0.13 b	0.14 c	0.13 c	0.15 c	0.15 b	0.14 c

[z]Means for plant canopy were calculated using proc glimmix accounting for the repeated measurements design. Means were separated using the pdiff option of the lsmeans statement at α=0.10 level of significance.
[y]Plant canopy was measured at the end of each growing season 2006, 2007, 2008, and 2009.
[x]Extra canopy measurement was taken due to damage from the ice load during a prolonged freeze event.
[w]Extra canopy measurement was taken before June pruning.
[v]Extra canopy measurement was taken after June pruning.

Table A-2. Effect of soil amendments on fruit harvest date (percentage of total yield by harvest period) of southern highbush blueberry in 2007 (Chapter 3)[z].

Treatment	% of Total Yield by Harvest Period			
	3 April to 18 April	20 April to 4 May	7 May to 21 May	23 May to 8 June
Incorporated +Mulch	7.0 b	15.5 b	44.5 b	33.0 ab
Bed	6.8 b	25.2 a	52.8 a	15.1 c
Incorporated	9.0 b	13.4 b	37.7 b	39.9 a
Soil	27.2 a	20.7 a	29.8 c	22.3 bc

[z] Means followed by the same letters within a column indicate no significant differences, Duncan's test, α=0.05.

Table A-3. Effect of soil amendments on fruit earliness (percentage of total yield by harvest period) of southern highbush blueberry in 2008 (Chapter 3)[z].

Treatment	% of Total Yield by Harvest Period			
	4 April to 17 April	21 April to 28 April	1 May to 8 May	12 May to 19 May
Incorporated +Mulch	9.9 b	72.0 a	14.0 a	4.1 a
Bed	12.6 ab	70.0 ab	13.1 a	4.3 a
Incorporated	9.2 b	69.1 ab	13.9 a	7.7 a
Soil	15.8 a	60.8 b	16.1 a	7.3 a

[z] Means followed by the same letters within a column indicate no significant differences, Duncan's test, α=0.05.

Table A-4. Effect of soil amendments on fruit earliness (percentage of total yield by harvest period) of southern highbush blueberry in 2009 (Chapter 3)[z].

Treatment	% of Total Yield by Harvest Period			
	11 April to 20 April	23 April to 30 April	4 May to 11 May	14 May to 21 May
Incorporated +Mulch	40.6 a	40.4 a	15.7 a	3.2 a
Bed	42.2 a	43.1 a	13.1 a	1.5 bc
Incorporated	40.4 a	41.0 a	16.5 a	2.1 b
Soil	46.8 a	39.4 a	12.8 a	0.9 c

[z] Means followed by the same letters within a column indicate no significant differences, Duncan's test, α=0.05.

Table A-5. Effect of soil amendments on fruit earliness (percentage of total yield in the first half of the season) of southern highbush blueberry in 2007, 2008, and 2009 (Chapter 3)[z].

Treatment	% of Total Yield During First Half of the Season					
	2007		2008		2009	
Incorporated +Mulch	22.5	c	81.9	a	81.1	a
Bed	32.0	b	82.6	a	85.4	a
Incorporated	22.4	c	78.3	a	81.4	a
Soil	47.9	a	76.6	a	86.2	a

[z] Means followed by the same letters within a column indicate no significant differences, Duncan's test, α=0.05.

Table A-6. Effect of soil amendments on mean berry weight by harvest period of southern highbush blueberry in 2007 (Chapter 3)[zy].

Treatment	Mean Berry Weight (g/berry) by Harvest Period							
	3 April to 18 April		20 April to 4 May		7 May to 21 May		23 May to 8 June	
Incorporated +Mulch	1.74	a	1.70	a	1.80	a	1.49	a
Bed	1.52	b	1.73	a	1.64	ab	1.13	b
Incorporated	1.82	a	1.63	a	1.57	b	1.43	a
Soil	1.40	b	1.26	b	1.07	c	0.78	c

[z] Means followed by the same letters within a column indicate no significant differences, Duncan's test, α=0.05.
[y]10 fruits were sampled at each harvesting date (28 times).

Table A-7. Effect of soil amendments on mean berry weight by harvest period of southern highbush blueberry in 2008 (Chapter 3)[zy].

Treatment	Mean Berry Weight (g/berry) by Harvest Period							
	4 April to 17 April		21 April to 28 April		1 May to 8 May		12 May to 19 May	
Incorporated +Mulch	2.56	a	1.92	a	1.78	a	1.13	a
Bed	2.45	a	1.82	a	1.61	a	1.03	a
Incorporated	2.48	a	1.92	a	1.63	a	0.93	a
Soil	2.04	b	1.54	b	1.35	b	0.80	a

[z] Means followed by the same letters within a column indicate no significant differences, Duncan's test, α=0.05.
[y]20 fruits were sampled at each harvesting date (12 times).

Table A-8. Effect of soil amendments on mean berry weight by harvest period of southern highbush blueberry in 2009 (Chapter 3)[zy].

Treatment	Mean Berry Weight (g/berry) by Harvest Period			
	11 April to 20 April	23 April to 30 April	4 May to 11 May	14 May to 21 May
Incorporated +Mulch	1.83 ab	1.84 ab	1.96 a	1.59 a
Bed	1.83 ab	1.89 a	1.90 a	1.20 b
Incorporated	1.93 a	1.95 a	2.04 a	1.35 ab
Soil	1.70 b	1.62 b	1.45 b	0.56 c

[z] Means followed by the same letters within a column indicate no significant differences, Duncan's test, α=0.05.
[y]20 fruits were sampled at each harvesting date (12 times).

Table A-9. Effect of soil amendments on mean berry weight of southern highbush blueberry during the first half of the harvest season in 2007, 2008, and 2009 (Chapter 3)[z].

Treatment	Mean Berry Weight (g/berry) During First Half of Harvest Season		
	2007[y]	2008[x]	2009[x]
Incorporated +Mulch	1.72 a	2.24 a	1.83 a
Bed	1.63 a	2.13 a	1.86 a
Incorporated	1.71 a	2.20 a	1.94 a
Soil	1.32 b	1.79 b	1.66 b

[z] Means followed by the same letters within a column indicate no significant differences, Duncan's test, α=0.05.
[y]10 fruits were sampled at each harvesting date (28 times).
[x]20 fruits were sampled at each harvesting date (12 times in 2008, 11 times in 2009).

Table A-10. Effect of soil amendments on berry yield adjusted for plant canopy volume of southern highbush blueberry in 2007, 2008, and 2009 (Chapter 3)[z].

Treatment	Berry Yield [(g/plant)/(m^3/plant)] by Year		
	2007	2008	2009
Incorporated +Mulch	5,121.4 a	4,454.7 a	4,743.5 b
Bed	4,730.7 a	4,821.7 a	4,592.0 b
Incorporated	4,831.9 a	5,260.4 a	3,781.7 b
Soil	4,863.4 a	5,064.6 a	7,137.2 a

[z] Means followed by the same letters within a column indicate no significant differences, Duncan's test, α=0.05.

Table A-11. Effect of soil amendments on weighted mean berry weight adjusted for plant canopy volume of southern highbush blueberry in 2007, 2008, and 2009 (Chapter 3)[z].

	Mean Berry Weight [(g/berry)/(m^3/plant)] by Year		
Treatment	2007	2008	2009
Incorporated +Mulch	3.0 b	2.9 b	2.5 b
Bed	3.4 b	3.4 b	3.0 b
Incorporated	2.9 b	3.1 b	2.5 b
Soil	12.2 a	13.8 a	17.7 a

[z] Means followed by the same letters within a column indicate no significant differences, Duncan's test, α=0.05.

Table A-12. Effect of soil amendments on berry yield adjusted for plant pruning dry weights of southern highbush blueberry in 2007, 2008, and 2009 (Chapter 3)[zy].

	Berry Yield [(g/plant)/(g/plant)]		
	Year		Total
Treatment	2008	2009	2007-2009
Incorporated +Mulch	14.9 b	9.7 a	15.9 a
Bed	12.3 b	7.8 a	13.3 a
Incorporated	14.0 b	9.2 a	15.5 a
Soil	23.9 a	32.7 a	36.2 a

[z] Means followed by the same letters within a column indicate no significant differences, Duncan's test, α=0.05.
[y]No plant prunings in 2007.

Table A-13. Effect of soil amendments on plant pruning dry weights adjusted for plant canopy volume of southern highbush blueberry in 2007, 2008, and 2009 (Chapter 3)[z].

	Pruning Dry Weights [(g/plant)/(m^3/plant)]		
	Date	Year	
Treatment	Feb. 2009[y]	2008	2009
Incorporated +Mulch	56.9 a	339.3 a	495.0 a
Bed	141.2 a	393.4 a	601.7 a
Incorporated	107.1 a	390.0 a	438.3 a
Soil	209.1 a	239.4 a	412.7 a

[z] Means followed by the same letters within a column indicate no significant differences, Duncan's test, α=0.05.
[y]Plant prunings during freeze event adjusted for plant canopy volume after freeze event.

Table A-14. Root density (root length/dm^3 soil and root surface area/dm^3 soil) and average root diameter for center, east and west sides of row middles of southern highbush blueberry grown in amended and non-amended soils, Summer 2010 (Chapter 4)[z].

Treatments	Total Root Surface Area (cm^2/dm^3 soil)		Average Root Diameter (mm)		Total Root Length (cm/dm^3 soil)		Length of Roots by Diameter (cm/dm^3 soil)							
							0 to 1 mm		1 to 2 mm		2 to 4.5 mm		> 4.5 mm	
CENTER SIDE														
Incorporated	447.1	a	0.37	a	4651.9	a	4371.1	a	200.6	a	67.2	a	13.1	a
Incorporated +Mulch	325.2	ab	0.32	a	3980.3	ab	3808.9	ab	128.1	ab	35.9	ab	7.3	a
Bed	343.3	ab	0.29	a	4507.5	a	4333.3	a	136.7	ab	35.8	ab	1.6	a
Soil	172.8	b	0.30	a	1722.4	b	1608.6	b	81.8	b	24.0	b	8.1	a
EAST SIDE														
Incorporated	337.6	a	0.31	a	3877.8	a	3674.7	a	153.9	a	44.6	a	4.7	a
Incorporated +Mulch	345.2	a	0.32	a	3932.9	a	3729.0	a	147.2	a	48.5	a	8.3	ab
Bed	354.5	a	0.30	a	4045.7	a	3846.5	a	144.3	a	46.2	a	8.7	ab
Soil	5.2	b	0.27	a	46.3	b	45.0	b	1.4	b	0.0	b	0.0	b
WEST SIDE														
Incorporated	403.9	a	0.32	a	4802.2	a	4572.0	a	172.3	a	53.2	a	4.7	a
Incorporated +Mulch	295.6	ab	0.33	a	3529.2	ab	3359.1	ab	124.0	ab	42.4	ab	3.6	a
Bed	440.9	a	0.30	a	5174.7	a	4938.6	a	182.6	a	46.8	ab	6.6	a
Soil	115.7	b	0.28	a	1215.9	b	1147.5	b	53.3	b	12.5	b	2.7	a

[z] Means followed by the same letters within a column indicate no significant differences, Duncan's test, α=0.05.

Table A-15. Root density (root length/dm^3 soil and root surface area/dm^3 soil) and average root diameter by center, east and west sides of row middles and upper, middle and lower soil depths for southern highbush blueberry in all four soil treatments, Summer 2010 (Chapter 4)^z.

Treatments	Total Root Surface Area (cm^2/dm^3 soil)		Average Root Diameter (mm)		Total Root Length (cm/dm^3 soil)		Length of Roots by Diameter (cm/dm^3 soil)							
							0 to 1 mm		1 to 2 mm		2 to 4.5 mm		> 4.5 mm	
CENTER SIDE														
Upper	429.6	a	0.31	a	5083.7	a	4845.6	a	177.3	a	52.2	a	8.4	a
Middle	387.6	a	0.32	a	4332.6	a	4095.0	a	179.1	a	50.3	a	8.3	a
Lower	149.2	b	0.32	a	1730.3	b	1650.8	b	53.9	b	19.6	b	6.0	a
EAST SIDE														
Upper	449.5	a	0.31	a	5292.7	a	5046.1	a	182.6	a	56.2	a	7.6	a
Middle	361.4	a	0.33	a	4208.1	a	4003.8	a	155.9	a	43.9	ab	4.5	a
Lower	131.1	b	0.29	a	1540.6	b	1462.7	b	60.6	b	16.1	b	1.2	a
WEST SIDE														
Upper	357.7	a	0.31	a	4147.5	a	3950.5	a	145.6	a	43.5	a	8.0	a
Middle	308.0	a	0.34	a	3418.6	a	3225.1	a	139.8	a	47.2	a	6.6	a
Lower	116.1	b	0.25	a	1361.0	b	1295.9	b	49.7	b	13.8	b	1.6	b

^{z} Means followed by the same letters within a column indicate no significant differences, Duncan's test, α=0.05.

Table A-16. Root density (root length/dm^3 soil and root surface area/dm^3 soil) and average root diameter by upper+middle and lower soil depths of southern highbush blueberry in amended and non-amended soils, Summer 2010 (Chapter 4)[z].

Treatments	Total Root Surface Area (cm^2/dm^3 soil)		Average Root Diameter (mm)		Total Root Length (cm/dm^3 soil)		Length of Roots by Diameter (cm/dm^3 soil)							
							0 to 1 mm		1 to 2 mm		2 to 4.5 mm		> 4.5 mm	
UPPER AND MIDDLE LAYERS (0 to 18 cm)														
Incorporated	545.1	a	0.34	a	6108.8	a	5780.9	a	242.6	a	74.9	a	10.3	a
Incorporated +Mulch	397.3	a	0.33	a	4694.1	a	4467.8	a	167.1	a	52.5	a	6.7	a
Bed	452.4	a	0.30	a	5504.1	a	5264.8	a	181.2	a	51.3	a	6.8	a
Soil	134.4	b	0.30	a	1348.5	b	1264.0	b	62.7	b	16.8	b	5.0	a
LOWER LAYER (19 to 27 cm)														
Incorporated	213.8	ab	0.31	a	1114.4	ab	1055.9	ab	41.5	ab	15.2	a	1.8	a
Incorporated +Mulch	372.2	ab	0.30	a	2054.2	ab	1961.4	ab	65.1	ab	21.8	a	5.9	a
Bed	507.9	a	0.28	a	2719.5	a	2588.7	a	101.3	a	26.2	a	3.2	a
Soil	54.1	b	0.24	a	287.8	b	272.9	b	11.1	b	2.8	a	0.9	a

[z] Means followed by the same letters within a column indicate no significant differences, Duncan’s test, α=0.05.

Table A-17. Spearman's correlation coefficient for soil pH, pine bark used per plant, total root length and total root surface area for southern highbush blueberry in all four soil management treatments (Chapter 4).

		Pine Bark Used per Plant	Soil pH	Total Root Length	Total Root Surface Area
Pine Bark Used per Plant	***r***[z]	1	-0.50869	0.47971	0.28704
	α[y]		0.0132	0.0704	0.2996
	n[z]	23	23	15	15
Soil pH	***r***	-0.50869	1	-0.2561	-0.26692
	α	0.0132		0.3569	0.3362
	n	23	23	15	15
Total Root Length	***r***	0.47971	-0.2561	1	0.94118
	α	0.0704	0.3569		<.0001
	n	15	15	16	16
Total Root Surface Area	***r***	0.28704	-0.26692	0.94118	1
	α	0.2996	0.3362	<.0001	
	n	15	15	16	16

[z] r (spearman's correlation coefficient)
[y] α (probability > |r| under H_0: Rh_o=0)
[x] n (number of observations)

B) FIGURES

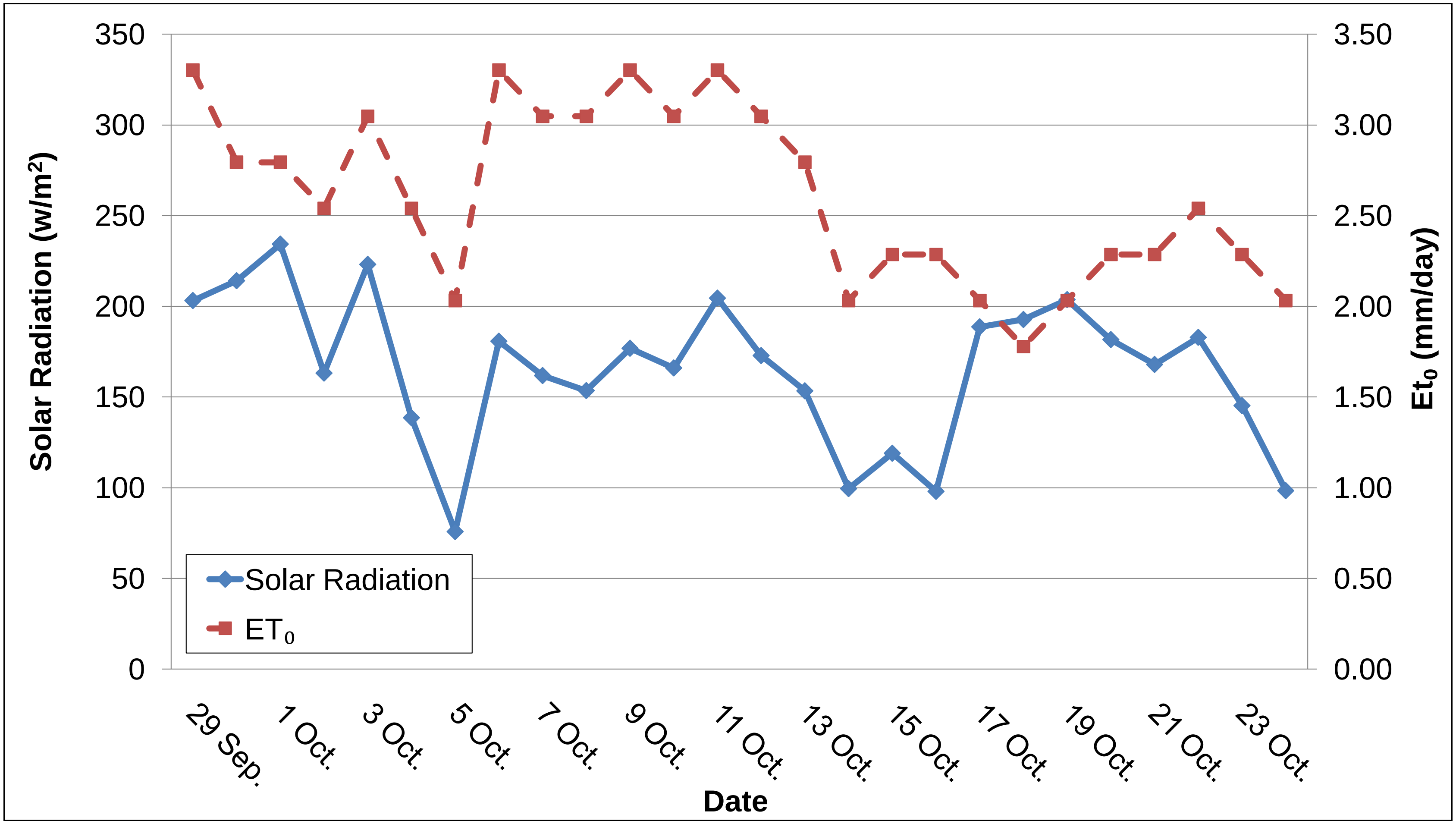

Figure A-1. Solar Radiation and reference crop evapotranspiration (ET_0) during pressure chamber readings of shoots of southern highbush blueberry in Fall 2009 (29 Sept. to 24 Oct.) (Chapter 4).

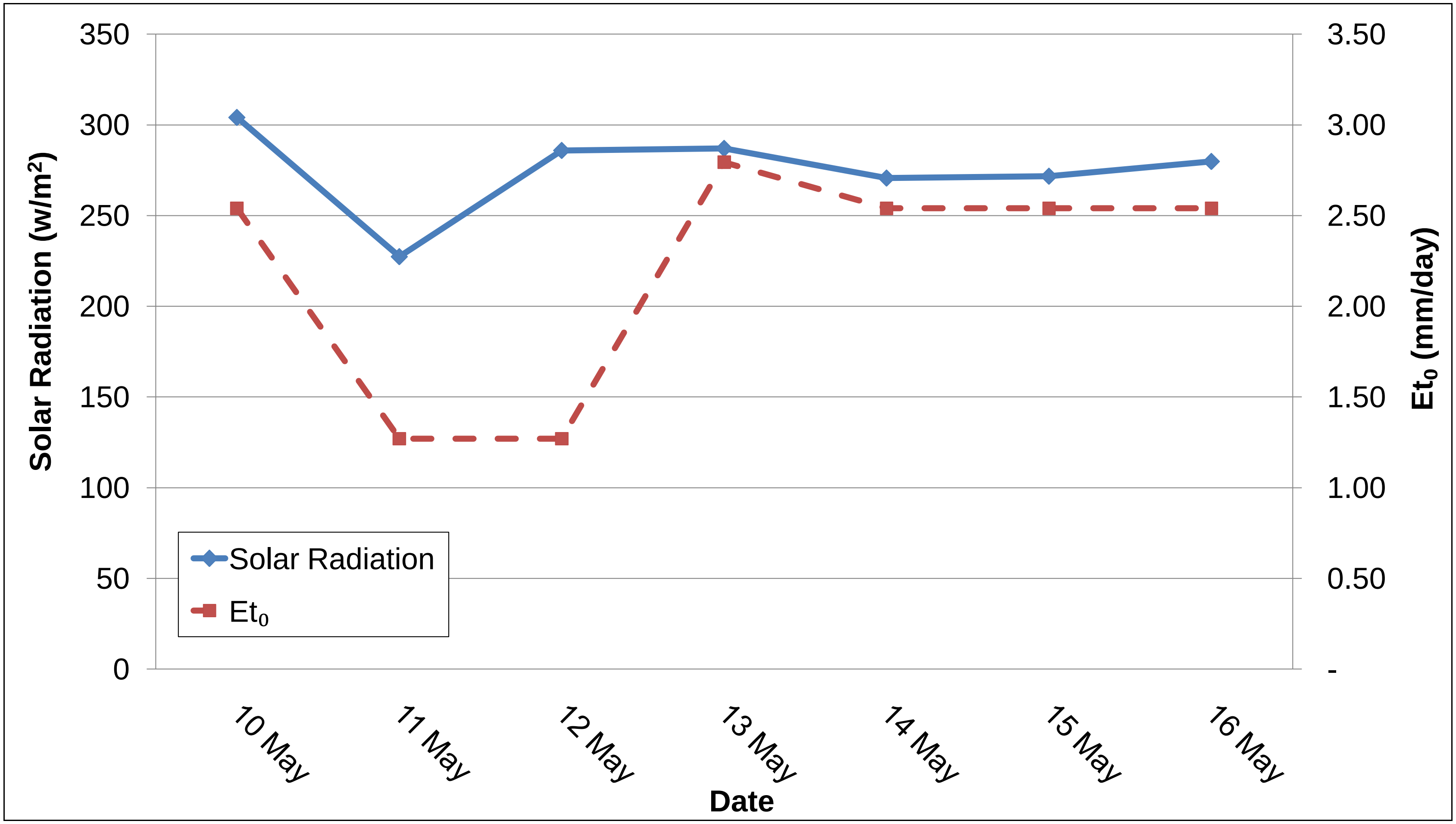

Figure A-2. Solar Radiation and reference crop evapotranspiration (ET_0) during pressure chamber readings of shoots of southern highbush blueberry in Spring 2010 (10 May to 16 May) (Chapter 4).

LIST OF REFERENCES

Bender, F. 1968. Bark utilization: A continuing problem. Department of Forestry and Rural Development, Forestry Branch Departmental Publication 1248. Ottawa, Canada.

Billeaud, L.A. and J.M. Zajicek. 1989. Influence of Mulches on Weed Control, Soil pH, Soil Nitrogen Content, and Growth of Ligustrum japonicum. J. Environ. Hort. 7(4):155-157.

Brady, N.C. and R.R. Weil. 2002. The nature and properties of soils. 13th ed. Prentice Hall, Upper Saddle River, N.J.

Bryla, D.R., A.D. Shireman, and R.M.A. Machado. 2010. Effects of Method and Level of Nitrogen Fertilizer Application on Soil pH, Electrical Conductivity, and Availability of Ammonium and Nitrate in Blueberry. Acta Hort. 868:95-102. <http://hdl.handle.net/10113/46473>.

Collins, M.E. 2009. Key to soil orders in Florida. University of Florida Cooperative Extension Service, Institute of Food and Agriculture Sciences, EDIS. Univ. of Fla., Gainesville, Fla.

Coville, F.V. and United States. Bureau of Plant Industry. 1910. Experiments in blueberry culture. G.P.O., Washington. USDA. Bul. 193.

Cregg, B.M. and R. Schutzki. 2009. Weed Control and Organic Mulches Affect Physiology and Growth of Landscape Shrubs. HortScience 44(5):1419-1424.

Current Results Nexus. 2010. Average yearly rainfall in Florida. Smithers BC, Canada. 28 February 2011. <http://www.currentresults.com/Weather/Florida/yearly-florida-rainfall.php>.

Daniels, W.L. and R.D. Wright. 1988. Cation exchange properties of pine bark growing media as influenced by pH, particle size, and cation species. J. Am. Soc. Hort. Sci. 113(4):557-560.

Dourte, D.R. 2007. Crop water requirements and irrigation management of southern highbush blueberries. Univ. of Fla., Gainesville, Fla., M.S. Thesis, <http://purl.fcla.edu/fcla/etd/UFE0021504>.

FAOSTAT. 2010. Agricultural crops price statistics. Food and Agriculture Organization of the United Nations Statistics Division. Rome, Italy. 15 October 2010. <http://faostat.fao.org/site/567/default.aspx#ancor>.

Florida Dept. of Agriculture. 1945. Blueberries with special reference to Florida culture. Florida State Dept. of Agriculture, Tallahassee Fla. Fla. Dept. of Agr. Bul. 33. <http://ufdc.ufl.edu/UF00014994>.

Gough, R.E. 1994. The highbush blueberry and its management. Food Products Press Inc., Binghamton N. Y.

Guedes de Carvalho, R.A., C.G. González Beça, M.N. Sampaio, O. Neves, M.C. Sol Pereira, and A. Macedo. 1984. Use of pine bark for preparation of activated carbon and as a soil conditioner. Agricultural Wastes 9(3):231-238.

Hanson, A., J.R. Harris, R. Wright, A. Niemiera, and N. Persaud. 2004. Water Content of a Pine-bark Growing Substrate in a Drying Mineral Soil. HortScience 39(3):591-594.

Harris, W.G., M. Chrysostome, T.A. Obreza, and V.D. Nair. 2010. Soil Properties Pertinent to Horticulture in Florida. HortTechnology 20(1):10-18.

Hart, J.M., B. Strik, L.White, and W. Yang. 2006. Nutrient management for blueberries in Oregon. Extension Service, Or. State Univ., Corvallis, Or.

Hornsby, A.G., T.M. Buttle, T.E. Crocker, R.F. Mizell III, R.A. Dunn, and G.W. Simone. 1991. Blueberries. Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, EDIS. Univ. of Fla., Gainesville, Fla.

Jackson, B.E., R.D. Wright, and J.R. Seiler. 2009. Changes in Chemical and Physical Properties of Pine Tree Substrate and Pine Bark During Long-term Nursery Crop Production. HortScience 44(3):791-799.

Lemaire, F. 1995. Physical, chemical and biological properties of growing medium. Acta Hort. 396:273-284.

Lyrene, P.M. 1997. Value of various taxa in breeding tetraploid blueberries in Florida. Euphytica 94:15-22.

Lyrene, P.M. and T.E. Crocker. 1984. Florida blueberry handbook. Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences. Univ. of Fla., Gainesville, Fla. <http://purl.fcla.edu/fcla/tc/feol/UF00014476.pdf>.

Lyrene, P.M. and W.B. Sherman. 1979. The Rabbiteye Blueberry Industry in Florida-1887 to 1930: With Notes on the Current Status of Abandoned Plantations. Econ. Bot. 33(2):pp. 237-243. <http://www.jstor.org/stable/4254053>.

Lyrene, P.M. and J.G. Williamson. 2004. Protecting blueberries from freezes in Florida. University of Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, EDIS. Univ. of Fla., Gainesville, Fla.

Merhaut, D.J. and R.L. Darnell. 1995. Ammonium and Nitrate Accumulation in Containerized Southern Highbush Blueberry Plants. HortScience 30(7):1378-1381.

Naasz, R., J.C. Michel, and S. Charpentier. 2005. Measuring hysteretic hydraulic properties of peat and pine bark using a transient method. Soil Sci. Soc. Am. J. 69(1):13-22.

Niemiera, A.X., T.E. Bilderback, and C.E. Leda. 1994. Pine Bark Physical Characteristics Influence Pour-through Nitrogen Concentrations. HortScience 29(7):789-791.

Norden, D.E. 1989. Comparison of pine bark mulch and polypropylene fabric ground cover in blueberries. Proc. Fla. State Hort. Soc. 102:206-208.

Obreza, T.A., and M.E. Collins. 2009. Common soils used for citrus production in Florida. University of Florida Cooperative Extension Service, Institute of Food and Agriculture Sciences, EDIS. Univ. of Fla., Gainesville, Fla.

Odneal, M.B. and M.L. Kaps. 1990. Fresh and Aged Pine Bark as Soil Amendments for Establishment of Highbush Blueberry. HortScience 25(10):1228-1229.

Owen, J.S.J., S.L. Warren, T.E. Bilderback, J.P. Albano, and D.K. Cassel. 2008. Physical properties of pine bark substrate amended with industrial mineral aggregate. Acta Hort. 779:131-138. <http://hdl.handle.net/10113/39998>.

Spiers, J.M. 1998. Establishment and Early Growth and Yield of `Gulfcoast' Southern Highbush Blueberry. HortScience 33(7):1138-1140.

Spiers, J.M. 2000. Influence of cultural practices on root distribution of 'Gulfcoast' blueberry. Acta Hort. 513:247-252.

Takamizo, T. and N. Sugiyama. 1991. Growth responses to N forms in rabbiteye and highbush blueberries. J. Japan. Soc. Hort. Sci. 60(1):41-45.

Thorne, M.S., Q.D. Skinner, M.A. Smith, J.D. Rodgers, W.A. Laycock, and S.A. Cerekci. 2002. Evaluation of a Technique for Measuring Canopy Volume of Shrubs. J. Range Manage. 55(3):235-241. <http://www.jstor.org/stable/4003129>.

Throop, P.A. and E.J. Hanson. 1998. Nitrification and utilization of fertilizer nitrogen by highbush blueberry. J. Plant Nutr. 21(8):1731-1742.

Turner, J.C. and O.E. Liburd. 2007. Insect Management in Blueberries in the Eastern United States. University of Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, EDIS. Univ. of Fla., Gainesville, Fla.

USDA ESMIS. 2010. U.S. Blueberry Industry. Economics, Statistics and Market Information System of the United States Department of Agriculture. Cornell Univ. 25 February 2011. <http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1765>.

USDA NASS. 2011. Noncitrus Fruits and Nuts 2010 Preliminary Summary. United States Department of Agriculture. National Agricultural Statistics Service. Cornell Univ. 25 February 2011. <http://usda.mannlib.cornell.edu/usda/current/NoncFruiNu/NoncFruiNu-01-21-2011.pdf>.

USDA NRCS. 2010. Web Soil Survey. United States Department of Agriculture. Natural Resource Conservation Service. 20 February 2011. <http://websoilsurvey.nrcs.usda.gov/>.

Williamson, J.G. 2007. Weed management in blueberries. University of Florida Cooperative Extension Service, Institute of Food and Agriculture Sciences, EDIS. Univ. of Fla., Gainesville, Fla.

Williamson, J.G., G. Krewer, B.E. Maust, and E.P. Miller. 2002. Hydrogen cyanamide accelerates vegetative budbreak and shortens fruit development period of blueberry. HortScience 37(3):539-542.

Williamson, J.G., G. Krewer, G. Pavlis, and C.M. Mainland. 2006. Blueberry soil management, nutrition and irrigation, p. 60–74. In: N.F. Childers and P.M. Lyrene (eds.). Blueberries: For growers, gardeners and promoters. N.F. Childers Horticultural Publications, Gainesville, Fla.

Williamson, J.G., P.M. Lyrene, and E.P. Miller. 2003. Early and Mid-fall Defoliation Reduces Flower Bud Number and Yield of Southern Highbush Blueberry. Proc. Fla. State Hort. Soc. 116:25-27.

Williamson, J.G. and E.P. Miller. 2009. Effects of Fertilizer Rate and Form on Vegetative Growth and Yield of Southern Highbush Blueberry in Pine Bark Culture. HortTechnology 19(1):152-157.

Williamson, J.G. and J.H. Crane. 2010. Best Management Practices for Temperate and Tropical/Subtropical Fruit Crops in Florida: Current Practices and Future Challenges. HortTechnology 20(1):111-119.

Williamson, J.G., F.S. Davies , and P.M. Lyrene. 2004. Pruning blueberry plants in Florida. Institute of Food and Agricultural Sciences, EDIS. Univ. of Fla., Gainesville, Fla.

Williamson, J.G., P.F. Harmon, and O.E. Liburd. 2008. Florida Blueberry Integrated Pest Management Guide. University of Florida Cooperative Extension Service, Institute of Food and Agriculture Sciences, EDIS. Univ. of Fla., Gainesville, Fla.

Williamson, J.G. and P.M. Lyrene. 1995. Commercial blueberry production in Florida. Institute of Food and Agricultural Sciences. EDIS. Univ. of Fla., Gainesville, Fla.

Williamson, J.G. and P.M. Lyrene. 2004. Blueberry gardener's guide. University of Florida Cooperative Extension Service, Institute of Food and Agriculture Sciences, EDIS. Univ. of Fla., Gainesville, Fla.

Wright, A. and P. Harmon. 2010. Identification of Species in the Botryosphaeriaceae Family Causing Stem Blight on Southern Highbush Blueberry in Florida. Plant Dis. 94(8):966-971.

BIOGRAPHICAL SKETCH

Luis Eduardo Mejia was born in the lowlands of Colombia in Tierralta, Cordoba, but was raised in the highlands in a little town called La Unión, Antioquia. He is the oldest son of Daniel Mejia and Luz Dary Cardona, farmers by heritage. In 2004, he graduated with a Bachelor of Science in agribusiness from Zamorano University in Honduras. From December 2004 to July 2007, he gained work experience in Colombia, Florida, and Michigan prior to starting graduate school. In the lowlands of Colombia, he worked during a year with his family scouting plantain, papaya, field corn and pastures. In Florida, he worked during a year in Glades Crop Care Inc. in three different production areas of south Florida (Immokalee, Homestead and Belle Glade) scouting greenhouses and over 30 different field crops. In Michigan, he worked during half a year with Agri-Business Consultants in Montcalm County scouting potatoes and cucumbers. Since August 2007, Luis started working with Dr. Jeffrey Williamson to obtain a Master of Science in horticultural science at the University of Florida. Luis plans to go back to the lowlands of Colombia and work with his family and the small farmers of his homeland.