Performance of Satsuma Mandarin within Various Orchard Designs

by

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Abstract

Freeze protection is the most challenging aspect of commercial satsuma mandarin production in Alabama. In addition to other freeze protection methods, satsuma growers have used various orchard designs to reduce freeze damage for decades. These designs include interplanting between pecan and pine trees, and planting behind windbreaks. The goal of the first experiment was to determine the effect of different orchard designs on canopy temperature, freeze damage, fruit quality, and yield. All treatments reduced the amount of freeze damage suffered compared to the full sun orchard (control). Interplanting satsuma mandarin trees with mature pine trees resulted in warmer temperatures within the canopy. Fruit from shaded pine tree canopies had higher soluble solids content and reduced fruit weight. Heavy shading resulted in lower yields for the dense pine tree canopy treatment in 2009, when no damaging freeze occurred. Compared to other orchard designs, satsuma mandarin trees planted under pine tree canopies had greater percentages of their expected yield in 2010, when a severe freeze did occur. Dense pine tree canopies can provide an insulating effect that reduces leaf loss and subsequent yield losses when severe freezes occur, but potential maximum yields are reduced in non-freeze years compared to satsuma mandarins grown in full sun. The second study focused on the influence of different orchard designs on photosynthesis, leaf area, specific leaf area, and fruit quality. All shading treatments reduced photosynthesis. Heavy shading from dense pine tree canopy increased leaf area, specific leaf area, and reduced fruit size, and vitamin C content. There were no differences in soluble solid content (SSC) for satsuma fruit grown under dense pine tree canopy, however moderate pine tree shading increased SSC. Satsuma rind thickness was reduced with pine tree shading. There were no reductions in photosynthesis, fruit size, rind thickness, juice weight, or volume for satsuma fruit grown behind a windbreak. In years when severe temperatures are not an issue, yield may be reduced under pine tree canopies.   However, shading only negatively affected fruit size and photosynthesis.

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fw	Fresh Weight
h°	hue angle
g_s	Stomatal Conductance
LA	Leaf Area
PAR	Photosynthetic Active Radiation
Pn	Net Photosynthesis
SLA	Specific Leaf Area
SSC	Soluble Solids Content
TA	Titratable Acidity

CHAPTER ONE

Introduction and Literature Review

The satsuma mandarin (*Citrus unshiu* Marc.) belongs to the Rue family (*Rutaceae*) (Swingle and Reece, 1967). Satsumas are classified as a hesperidium, a particular type of berry. The satsuma is an easy peeling, segmented fruit that is nearly seedless. Satsumas are a type of mandarin with a characteristic loose skin and high flavor. The satsuma is the most cold hardy citrus grown commercially (Hodgson, 1967; Yelenosky, 1985). Fully acclimated mature trees with no protection have survived minimum temperatures of -9.4 °C to -7.8 °C in South Alabama and in Northern California without serious injury (Hodgson, 1967). The satsuma most likely originated in China, but became more prominent in Japan (Ferguson, 1996; Hodgson, 1967). Japan currently has the largest satsuma industry (Ferguson, 1996). In the mid-1990s, 75 % of Japan's citrus production consisted of satsumas (Iwagaki, 1997). As of 1991, Japan's satsuma acreage exceeded 50,000 hectares (ha) (Harty and Anderson, 1995).

In 1876, the first introduction of satsumas into the United States occurred when George R. Hall imported satsumas into Florida from Japan (Ferguson, 1996; Hodgson, 1967). In 1898, Samuel White from Boston, Massachusetts introduced satsumas into Baldwin County, Alabama (Winberg, 1948). Shortly after, a commercial industry was established along the coast of the Gulf of Mexico. The industry quickly expanded and by 1923 approximately 7000 ha of both bearing and non-bearing satsuma trees were planted in Alabama (Winberg, 1948). Additional acreage, totaling 650 ha, of satsumas were also planted in Florida, Mississippi, Louisiana, and Texas (Ebel et al., 2008). As a result of this expansion, producers established the Gulf Coast Citrus Exchange which handled marketing of the fruit (Winberg, 1948). The fruit was marketed as “Sugar Sweet” in 45 cities throughout the North and Midwest United States, and fruit was also exported to Canada and England. Seven packing facilities handled the acreage. At the peak of production in 1923, 700 railcar loads were shipped out of the growing region (Winberg, 1948).

The industry began losing steam due largely to the freezes that occurred in 1924, 1928, 1930, 1933, and 1940. Two hurricanes also damaged the crop in the 1920s and 1930s (Winberg, 1948). A major freeze occurred 20 Nov. 1940 killing most of the trees, which essentially eliminated the commercial industry. The freeze was extremely detrimental because temperatures dropped suddenly during a time when trees were actively growing (Winberg, 1948). Current efforts are in place to revive the satsuma industry in Alabama as well as other growing regions of Northwest Florida, Mississippi, and Louisiana.

Beginning in the late 1980s and early 1990s, farmers in Alabama began looking at alternative crops to produce. A few growers began experimenting with satsumas. As of 2005, Alabama had approximately 25.3 ha of satsumas scattered throughout the state with another 10.1 ha planned for planting (Nesbitt et al., 2008). The majority of these groves are located in Mobile and Baldwin Counties. Groves are also located in Escambia County, Houston County, and three groves are also located north of Montgomery (Nesbitt et al., 2008). The groves north of Montgomery are limited to high tunnel production. The total acreage has expanded since 2005 with additional plantings from the original growers and newcomers. As of 2011, there are approximately 50 ha of satsuma planted and more acreage expansion expected (Spiers, personal communication). New marketing efforts began in the early 2000s and the industry is quickly expanding. Commercial groves now exist in southern Mobile County and as of 2011; growers in Henry and Houston counties, Alabama will be participating in commercial sales. These commercial groves are currently supplying regional markets with Alabama grown satsumas.

The largest producer of satsumas in the United States is California. California has around 1200 ha of satsuma mandarins, Louisiana is second with 120 ha, and Alabama is the third largest producer in the United States (Fadamiro et al., 2007)**.** Florida's production of satsumas is minuscule when compared to California. Ferguson (1996) reported about 6% of Florida's citrus production consisted of mandarin type oranges such as satsumas and clementines.

Japan, South Africa, Spain, New Zealand, China, and Brazil all produce satsumas commercially. The largest producer of satsumas in the world is Japan (Ferguson, 1996). Satsumas, known as unshu mikan in Japan, consist of 75% of Japan's citrus production (Iwagaki, 1997). The majority of satsumas grown for the fresh market are consumed in the country of production. Fruit can be juiced or canned as segmented fruit. Japan has a long marketing season when compared to the United States marketing season. Japan takes advantage of numerous cultivars that start ripening in mid-September to late December (Harty and Anderson, 1995). In 1991, Japan had very early to early ripening acreage around 30,000 ha and 27,000 ha in mid-season and late season varieties (Harty and Anderson, 1995**).** Brazil has 25,000 ha of mandarins, although mostly 'Ponkan' mandarin and 'Murcott' tangerine (Cantuarias-Aviles et al., 2010).

Methods of Freeze Protection

One of the most limiting factors of satsuma production on the Gulf Coast of Alabama is the potential of hard freezes. The main priority of growers is protecting trees from damaging freezes. Citrus growers in Alabama first plant cold hardy citrus (i.e., satsumas) to minimize freeze risk potential. The most cold hardy citrus fruit grown commercially is the satsuma mandarin budded on trifoliate orange rootstock (*Poncirus trifoliata*) (Yelenosky, 1985). Satsuma growers take different steps to insure freeze damage is held to a minimum. Satsuma growers use both active and passive control measures to reduce freeze damage. Active control measures include the use of smudge pots, banking soil around the trees, and microsprinkler irrigation (Ebel et al., 2008). Although, the use of smudge pots and soil banking are no longer used due to fuel and labor cost. In addition to active control measures, satsuma growers use passive control measures such as site selection and orchard design. Different orchard designs include planting behind existing windbreaks and interplanting between pecan and pine trees.

Each orchard design is based on the preference of the grower. Some growers choose to plant behind windbreaks to reduce freeze damage. Not only does the windbreak slow the velocity of winds during an advective freezes, it reduces fruit rub. Windbreaks have been shown to protect crops from damaging freezes, where wind velocity is high, although the effectiveness of windbreaks can be quite variable (Turrell, 1973).

Technological advances in freeze protection bring hope for a sustainable satsuma industry along the Gulf Coast. Microsprinkler irrigation used for freeze protection has only been around for a couple decades. The application of microsprinkler irrigation has been shown to protect citrus trees from freezes (Bourgeois and Adams, 1987; Nesbitt et al., 2000; Parson et al., 1985). Microsprinklers are placed at the base of the tree at planting and directed to spray on the graft union (Nesbitt et al., 2008). Water recommendations are as follows, 45 L/hr during the first four years and 90 L/hr throughout the life of the tree (Nesbitt et al., 2008). A second sprinkler is placed approximately 1.2 m (4 ft) off the ground in the interior of the canopy once trees are five years and older. Scaffold branches can be protected by microsprinkler irrigation installed inside the canopy (Bourgeois and Adams, 1987). As the water freezes, it gives off heat through the process of latent heat of fusion, which helps protect the trees (Bourgeois and Adams, 1987). Foliage loss can still occur, but the main scaffolds are protected. Heat equal to 80.5˚ $kcal \cdot liter^{-1}$ is released when water is transformed to ice at 0 ˚C (Bourgeois and Adams, 1987). Bourgeois and Adams (1987) observed when temperatures reached a low of -8.9 °C, one year old satsuma 'Owari' trees could be protected with the use of microsprinkler irrigation and had a survival rate of 81.8 %. This method was demonstrated in a 1989 freeze in Louisiana when temperatures dropped as low as -11 ˚C (Nesbitt et al., 2008). Trees in Alabama were protected from a freeze of -9.4 ˚C with microsprinklers (Nesbitt et al., 2000). This protection method greatly reduces the recovery time from freeze injury to full production after severe freezes, which would normally kill unprotected trees (Ebel et al., 2005). The trunks are insulated at 0 ˚C by the layer of ice that forms around the tree. One major setback with overtree microsprinklers is the risk of limb breakage from the weight of ice (Ebel et al., 2008; Parson et al., 1991). Microsprinkler irrigation does have its faults. For example, during an advective freeze evaporative cooling could occur when water application rates are inadequate (Parsons and Wheaton, 1987). Evaporative cooling causes the plant's tissue to fall below the surrounding air temperature.

A few growers choose to double crop their orchards. Planting between both pecan trees (*Carya illinoinensis*) and pine trees is practiced. The pine species for interplanting include longleaf pine (*Pinus palustris*), loblolly pine (*Pinus taeda*) or slash pine (*Pinus elliottii*). In California, citrus have been interplanted with Deglet Noor date palms (Turrell, 1973). The citrus trees flourish, but fruit production is reduced in the shaded groves (Turrell, 1973). In Taiwan, tonkan orange (*Citrus tankan* Hayata) was interplanted between acacia (*Acacia confusa* Merr.) to reduce wind injury to fruits from typhoons (Yen and Lin, 1966). Tree spacing is typically closer in interplanted groves and more pruning is required because trees tend to be more sparsely foliated with long branches and large leaves (Nesbitt et al., 2008). However, final fruit quality is similar to that of trees in full sun groves (Nesbitt et al., 2008). It does seem that pine trees offer protection during radiational freezes, but provide little protection during the more severe advective freeze (Ebel et al., 2005).

Citrus production in protected structures is also practiced in northern areas of Alabama. These structures, or high tunnels, are usually covered with a single layer of plastic between the months of December and April (Nesbitt et al., 2008). Tree density is normally higher and size is controlled by pruning and the use of the dwarfing 'Flying Dragon'(*Poncirus trifoliata*) rootstock. Additional steps are taken by high tunnel growers to protect the trees from freezing temperatures. Some satsuma growers use black barrels filled with water within the tunnel to heat the tunnel at night. The water within the barrels retains heat during the day and release heat at night. Propane heaters and floating row covers are also used.

Other passive methods include selecting cold hardy rootstock. Most growers along the Gulf Coast use 'Rubidoux' (*Poncirus trifoliata*) trifoliate orange, but Louisiana growers began using 'Swingle' citrumelo (*Citrus paradisi* Macf. 'Duncan' × *P. trifoliate*) because of improved performance in salinity conditions (Nesbitt et al., 2008). 'Swingle' rootstock is potentially desirable for Alabama citrus because of its soil type adaptability, disease resistance, and cold tolerance (Nesbitt et al., 2008). A dwarf selection of trifoliate orange named 'Flying Dragon' has been in evaluation since the late 1970s. 'Flying Dragon' is a good selection for homeowners because of its landscape appeal due to the fact it only grows to 1.83 to 2.13 meters tall (Powell and Williams, 1998). Due to its size, it is preferred by high tunnel growers. Other available, but inferior, rootstocks are the sour orange (*Citrus aurantium*), Cleopatra mandarin (*Citrus reshni*), and certain citranges (cross of a trifoliate orange and a sweet orange).

Another method for reducing freeze damage is planting behind windbreaks and planting next to small bodies of water. Windbreaks will generally reduce freeze damage during a freeze, but it works best with a supplemental freeze protection method such as microsprinkler irrigation. Bodies of water located on the northwest side of orchards can result in higher temperatures and decreases in crop damage (Powell and Himelrick, 1997; Turrell, 1973). Even small ponds ranging from 0.4 to 4.04 hectares can help protect against radiational freezes if the crop is close enough (Powell and Himelrick, 1997).

Banking soil around the trunk, growing satsuma trees under pines, and the use of smudge pots were the only measures available for freeze protection in the early 20^{th}

century (Ebel et al., 2005). Banking soil protected the trunks by preserving buds, but left the majority of the canopy susceptible to freeze, which could halt production for several years (Ebel et al., 2008). Smudge pots are rarely used any longer due to the high cost of fuel and Environmental Protection Agency (EPA) regulations. Although satsuma mandarins can be protected from radiational freezes by pine trees and smudge pots, they are still vulnerable to advective freezes, which are far more severe (Ebel et al., 2005). A radiational freeze occurs on calm, clear nights when heat radiates from the surface of objects into the environment causing cold air to settle near the ground and warm air to collect above the cold air (Ingram and Yeager, 2010). This is called an inversion layer. Another type of freeze is an advective freeze that is created from cold air movement from the north/northwest that causes a sudden drop in temperatures (Ingram and Yeager, 2010; Powell and Himelrick, 1997). Advective freezes are cold, dry air masses from polar regions that generally occur in late autumn or winter. Radiation freezes are much easier to protect against as compared to an advective freezes.

Temperature variations within the orchard can be influenced by several factors. The topography of the area, manmade structures, and farming practices all contribute to microclimates (Powell and Himelrick, 1997). Microclimates are locations where temperature differences within a given area can be observed. It can be a small area or a whole county. Cold air is denser than warm air, which causes the cold air to drain downhill and settle in areas of lower elevation. Cold air dams are created by vegetation, buildings, and other structures. As a result of these air dams, cold air can back up into orchards. Farms located in lower elevations tend to be cooler than those at higher elevations, and are more susceptible to radiational freezes.

Freeze Damage

Depending on several factors including plant hardiness, the temperature and duration of the freeze event, freeze damage can result in tree death or just defoliation. In any case, the damage incurred will reduce the crop load for that year. Defoliation is known to reduce the crop load. The fruiting wood on the tree will have flowers emerge, but they will soon abscise (Ebel et al., 2000; Nesbitt et al., 2002). Flower abscission results in a loss of crop for that year. The critical temperature for wood damage to occur on satsumas varies based on how cold acclimated the tree is during the freeze. For example, a satsuma tree may suffer freeze damage -3.9 °C during early November, but may not suffer freeze damage until -6.7 °C in February. Damage to the fruit of citrus may occur at 0 °C or just below (Yelenosky, 1985).

Fruit Quality

Satsuma fruit quality is determined by fruit color, size, rind thickness, soluble solids content (SSC), titratable acidity (TA) (expressed as % citric acid), and SSC:TA ratio. A thick rind, which can indicate puffiness, is generally not accepted by consumers. There are many factors that influence fruit quality. Factors affecting juice quality range from scion and rootstock cultivar (Cantuarias-Aviles et al., 2010; Wheaton et al., 1991; Wheaton et al., 1995; Wutscher and Bowman, 1999; Wutscher and Shull, 1972), to shading (Jifon and Syvertsen, 2001; Ono and Iwagaki, 1987; Verreynne et al., 2004; and Yen and Lin, 1966), canopy position (Fallahi and Moon, 1989; Syvertsen and Albrigo, 1980; and Verreynne et al., 2004) and crop load (Syvertsen et al., 2003; Wheaton et al., 1999).

Different citrus rootstocks varieties tend to have an effect on fruit quality (Cantuarias-Aviles et al., 2010; Wheaton et al., 1991; Wheaton et al., 1995; Wutscher and Bowman, 1999; Wutscher and Shull, 1972), tree size (Cantuarias-Aviles et al., 2010; Wheaton et al., 1991; Wheaton et al., 1995; Wutscher and Bowman, 1999), and cold tolerance (Yelenosky, 1985). Cantuarias-Aviles et al. (2010) reported 'Okitsu' satsuma, budded onto 'Flying Dragon', had higher fruit quality, attributed to higher SSC, and a smaller tree size. Early ripening of fruit was induced when 'Okitsu' was budded to 'Rangpur' limes, 'Cravo Limeira' and 'Cravo FCAV' (*Citrus limonia* Osbesck), although it produced fruit with lower SSC (Cantuarias-Aviles et al., 2010). 'Okitsu' budded onto trifoliate orange varieties 'Rubidoux' and 'Flying Dragon' tend to produce fruit higher in SSC, but yield less than more vigorous rootstocks such as 'Swingle', 'Sour Orange', and 'Carrizo' (Wheaton et al., 1991). Yelenosky (1985) noted that trifoliate orange is a superior cold-hardy rootstock, while rough lemon (*C. jambhiri* Lush.) is one of the most cold-sensitive rootstocks.

Shading can also influence fruit quality in citrus. In a study which took place during one growing season, Ono and Iwagaki (1987) reported that SSC and peel coloring decreased when relative light intensities were reduced to 65 % or under. Shade treatment of 50 % during one growing season provided no difference in fruit size when crop load was at 100 %, but had larger fruit when crop load was 50 % (Syvertsen et al., 2003). There were also no differences in SSC, rind thickness, and SSC:TA ratio of 'Spring' navel orange (*Citrus sinensis* L.) fruit subjected to either full sun or 50 % shade (Syvertsen et al., 2003). In a three year study in which tonkan orange (*Citrus tankan* Hayata) was interplanted with acacia (*Acacia confusa* Merr.), Yen and Lin (1966) reported that shaded fruit tended to be more attractive in color and had thinner rind thickness. Tonkan orange fruits' SSC, SSC:TA ratio, and vitamin C content were similar when subjected to semi-shading, full shading, and full sun growing conditions (Yen and Lin, 1966). Continuous shade during one growing season has been shown to significantly reduce yields in 'Hamlin' orange (*Citrus sinensis* L.) (Jifon and Syvertsen, 2001). Continuous shade throughout the growing season resulted in reduced SSC in 'Ruby Red' grapefruit (*Citrus paradise* L.) and 'Hamlin' (Jifon and Syvertsen, 2001). Jifon and Syvertsen (2001) noted that peel color development of grapefruit was delayed by shaded treatments.

Canopy bearing position can influence certain parameters of fruit quality including, fruit color, size, SSC, TA, and SSC:TA ratio. According to Reitz and Sites (1948), the fruit from 'Valencia' oranges were shown to have higher SSC on the outer portions of the canopy and lower SSC in the inner canopy. Similar results were reported in mandarin (Fallahi and Moon, 1989; Iwagaki, 1981; Verreynne et al., 2004), grapefruit (Fallahi and Moon, 1989; Syvertsen and Albrigo, 1980), navel orange (Fallahi and Moon, 1989; Sites and Reitz, 1949), and lemon (Fallahi and Moon, 1989). The differences in fruit quality are attributed to differences in light quality and quantity (Reitz and Sites, 1948). Iwagaki (1981) reported an increase in peel color with an increase in light intensity in satsuma. In a study in the southern hemisphere, Verreynne et al. (2004) stated the north sector of satsuma, clementine, and temple canopies had significantly greener peel color than the south sector of the canopy. This difference in peel color was attributed to the observed increase in fruit temperature on the northern side of the tree, and the requirement for relatively low air temperature for fruit color to develop properly in these citrus species (Verreynne et al., 2004). Generally, a temperature of less than 13 °C is required for peel color development in citrus (Goldschmidt, 1988; Stearns and Young, 1942). Fruit size can be influenced by canopy bearing position as well. The top sector of the canopy produced larger fruit for satsuma, clementine and tangor, while the inside lower canopy produced the smallest fruit (Verreynne et al., 2004). Opposing results by Fallahi and Moon (1989) showed that fruit located in internal positions were shown to have a larger fruit weight in mandarin, grapefruit, lemon, and orange. Cohen (1988) reported the southern side of the tree produced larger fruit than the northern side in tangerine. Canopy position has also been observed to affect TA levels in citrus fruit. Verreynne et. al. (2004) reported that satsuma and clementine fruit located in internal canopy positions had the highest TA, which contributed to those fruit having the lowest SSC:TA ratio. Similar results were reported in grapefruit (Syvertsen and Albrigo, 1980) and orange (Fallahi and Moon, 1989). In contrast to these reports, Fallahi and Moon (1989) reported that mandarin fruit located in internal canopy positions were observed to have higher TA values than fruit located on the exterior of the canopy.

The effect of crop load on the quality of citrus fruit has been well-documented. Removal of 50 % of the crop increased individual fruit weight and reduced peel color development of ‘Spring’ navel (Syvertsen et al., 2003). Reducing the crop load increases fruit size and reduces the concentration of SSC in the juice (Wheaton et al., 1999). This could be attributed to the fruit size effecting the SSC and SSC:TA ratio. Large fruit tend to have less SSC and TA than smaller fruit. Larger fruit have greater juice volume, which dilutes the SSC and TA content of the fruit (Albrigo, 1977; Kesta, 1988; Sites and Camp, 1955).

Vitamin C

Vitamin C, or L-ascorbic acid, is very important nutritionally in the human body and is found in many horticultural crops. Vitamin C reportedly reduces cardiovascular diseases and arteriosclerosis (Lee and Kader, 2000), and has been mentioned as a possible cancer preventative (Block, 1991). It is required in prevention of scurvy, and aids in the reduction of inorganic iron, reducing plasma cholesterol level, and the enhancement of the immune system (Lee and Kader, 2000). Vitamin C is found in varying amounts in a number of different horticultural crops including, but not limited to, banana, blackberry, cantaloupe, citrus, kiwifruit, and strawberry (Lee and Kader, 2000). The amount of vitamin C found in mandarins is approximately 34 mg/100 g fresh weight (fw). Variation in vitamin C content can be contributed to climatic conditions such as light and temperature (Klein and Perry, 1982; Sites and Reitz, 1950) and fertilization (Lisiewska and Kmiecik, 1996; Nagy, 1980; Reitz and Koo, 1960).

Light and temperature are known to influence the chemical composition of horticultural crops (Klein and Perry, 1982). In grapefruit, higher temperatures in Arizona resulted in lower vitamin C concentration when compared to the cooler coastal climate of California (Rygg and Getty, 1955). Light interception, as a result of canopy bearing position, can influence levels of vitamin C content in citrus fruit. In ‘Dancy’ tangerine, fruit exposed to full sun were shown to be 27 % higher in vitamin C content compared to shaded fruit (Winston, 1948). Navel oranges grown in full sun were shown to have 20.9 % more vitamin C content while temple oranges had 16.7 % more vitamin C content than fruit grown in shaded conditions (Winston, 1948). Sites and Reitz (1950) reported that vitamin C content differed based on “light classes” that correlated with photosynthetic active radiation (*PAR*). Fruit from areas of the canopy that received the most light had the highest concentration of vitamin C, while fruit from the inner canopy had the lowest concentrations (Sites and Reitz, 1950).

Fertilization can also affect the concentration of vitamin C. Nitrogen fertilizers decreased vitamin C content levels in cauliflower by 7 % (Lisiewska and Kmiecik, 1996). The concentration of vitamin C in the juices of lemon, oranges, grapefruit, and mandarins was reduced when nitrogen fertilizer was increased (Nagy, 1980). Potassium fertilizer also influences vitamin C concentrations in citrus. Applying more potassium fertilizer can increase vitamin C concentrations in navel oranges (Reitz and Koo, 1960).

<u>Leaf Physiology</u>

Shading can affect many leaf characteristics including net photosynthesis (Pn), leaf area (LA), and specific leaf area (SLA). Light intensities related to *PAR* can influence photosynthesis (Bjorkman and Holmgren, 1966; Boardman, 1977). Plants grown in shaded conditions have lower photosynthetic rates and they perform efficiently at low light intensities (Boardman, 1977). It has been shown in citrus that trees grown under moderate shade can have higher midday photosynthesis when compared to trees grown in full sun (Jifon and Syvertsen, 2001; Syvertsen, 1984). This is due to reduced stress in the form of lower leaf temperatures during the midday and the low irradiance required (600-700 µmol m^{-2} s^{-1}) to saturate citrus leaves (Jifon and Syvertsen, 2001; Syvertsen, 1984). However, in these studies trees were only shaded for a portion of the growing season and not the entire life of the tree.

Sun and shade grown leaves also differ in leaf area and leaf thickness. Compared to leaves in full sun, shaded leaves are typically broader and thinner, i.e., have higher

SLA. Leaf thickness plays a partial role in the amount of light absorbed by a leaf and the diffusion pathway of CO_2 through its tissues (Agusti et al., 1994; Syvertsen et al., 1995). The thinner shaded leaves have larger chloroplasts and are richer in chlorophyll than the leaves from full sun (Boardman, 1977). Shade leaves have large grana stacks that have an irregular orientation within the chloroplast, which likely contribute to greater efficiency for the collection of weak, diffuse radiation present in shaded situations (Boardman, 1977). Leaves grown in full sun have a stronger development of the palisade and spongy mesophyll regions, which accounts for the thicker leaves (Boardman, 1977). These adjustments made by sun and shade leaf structure aid in the increase in photosynthesis.

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CHAPTER TWO

Orchard Design Influences Fruit Quality, Canopy Temperature, and Yield of Satsuma Mandarin (*Citrus unshiu* 'Owari')

Abstract

Freeze protection is the most challenging aspect of commercial satsuma mandarin production in Alabama. Satsuma growers have used various orchard designs to reduce freeze damage for decades. These designs include interplanting between pecan and pine trees, and planting behind windbreaks. The goal of this research was to determine the effect of different orchard designs on orchard temperature, freeze damage, fruit quality, and yield. All treatments reduced the amount of freeze damage suffered compared to full sun orchard treatment (control). Only interplanting satsuma mandarin trees with mature pine trees resulted in warmer temperatures within the canopy. Fruit from satsuma trees grown under shaded pine tree canopies had higher soluble solids content and reduced fruit weight. Heavy shading resulted in a significantly lower yield for the dense pine tree canopy treatment in 2009, in the absence of a severe freeze. Compared to other orchard designs, satsuma mandarin trees interplanted with pine trees had greater percentages of their expected yield in 2010, when a severe freeze did occur. Dense pine tree canopies can provide an insulating effect that reduces leaf loss and subsequent yield losses when severe freezes occur, but potential maximum yields are reduced in non-freeze years compared to satsuma mandarins grown in full sun.

Introduction

The satsuma mandarin (*Citrus unshiu* Marc.) is an easy peeling, segmented fruit that is nearly seedless. Satsumas are a type of mandarin with a characteristic loose skin and high flavor that originated in China (Ferguson, 1996; Hodgson, 1967). Satsumas are one of the most cold hardy citrus grown commercially (Hodgson, 1967; Yelenosky, 1985). Fully hardened satsuma mandarins budded onto trifoliate orange rootstock (*Poncirus trifoliata* L.) are cold tolerant to -10 °C (Yelenosky, 1985). The cold hardiness of the satsuma allows for production in the northernmost areas of the citrus growing region in the southeastern U.S. (Ebel et al., 2004). Satsumas have been grown in south Alabama since the early 20th century. Acreage once exceeded 7500 ha, but severe freezes in the 1930s and 1940s devastated commercial production (Winberg, 1948). This led to integrating various orchard designs to help mitigate damage caused by severe freezes.

One limiting factor of satsuma production on the Gulf Coast of Alabama is the potential of hard freezes. A hard freeze destroys vegetation and leads to ice formation in standing water. Satsuma growers use both active and passive control measures to reduce freeze damage. Active control measures include the use of smudge pots, banking soil around the trees, and microsprinkler irrigation (Ebel et al., 2008). Although, the use of smudge pots and soil banking are no longer used due to fuel and labor cost. In addition to active control measures, satsuma growers use passive control measures such as site selection and orchard design (Powell and Himelrick, 2000). Different orchard designs include planting behind existing windbreaks, interplanting between pecan trees, or interplanting between pine trees (Nesbit et al., 2008).

The effectiveness of currently used satsuma orchard designs for added freeze protection is unknown and likely variable. Some satsuma growers choose to plant behind windbreaks in combination with microsprinkler irrigation to reduce freeze damage. Not only does the windbreak slow the velocity of winds during advective freezes, it may reduce fruit rub during the active growing season. Windbreaks have been shown to protect crops from damaging freezes, although the effectiveness is dependent on the type of windbreak, its height, width and orientation (Turrell, 1973).

Planting between both pecan trees (*Carya illinoinensis*) and pine trees is practiced in south Alabama. The pine species for interplanting include longleaf pine (*Pinus palustris*), loblolly pine (*Pinus taeda*) or slash pine (*Pinus elliottii*). In California, citrus has been interplanted with Deglet Noor date palms (Turrell, 1973). Citrus trees interplanted with Deglet Noor date palms flourish, but fruit production is reduced in the shaded groves (Turrell, 1973). In Taiwan, where typhoons can severely damage fruit, wind damage to tonkan orange (*Citrus tankan* Hayata) fruit is reduced when interplanted between acacia (*Acacia confusa* Merr.) (Yen and Lin, 1966). More pruning is required in interplanted satsuma groves due to the trees being more sparsely foliated with long branches and large leaves (Nesbitt et al., 2008). Compared to satsumas grown in full sun, fruit ripening is generally delayed when interplanted with pine trees; however, final fruit quality is similar to that of trees in full sun groves (Nesbitt et al., 2008). It does seem that pine trees offer protection during radiational freezes, but provide little protection during more severe advective freezes (Ebel et al., 2005).

Depending on the severity of the freeze event and the freeze protection strategies utilized, freeze damage can be severe enough to kill the tree or just cause defoliation. In any case, the damage incurred will reduce the crop load for that growing season. Fruiting wood on a defoliated tree will have flowers, however they will abscise (Ebel et al., 2000; Nesbitt et al., 2002). Flower abscission results in loss of crop for that year.

Satsuma fruit quality is determined by fruit color, size, rind thickness, soluble solids content (SSC), titratable acidity (TA) (expressed as % citric acid), and SSC:TA ratio. Shading has been reported to influence fruit quality of several citrus species (Jifon and Syvertsen, 2001; Ono and Iwagaki, 1987; Verreynne et al., 2004; Yen and Lin, 1966). Ono and Iwagaki (1987) reported that SSC and peel color decreased when relative light intensities (RLA) were reduced to 65 % or less during one growing season. 50 % shade treatment during one growing season did not affect fruit size when crop load was 100 %, but resulted in larger fruit when crop load was reduced to 50 % (Syvertsen et al., 2003). The effects on shading citrus for subsequent seasons were not reported. There were also no differences in SSC and SSC:TA ratio of ‘Spring’ navel orange (*Citrus sinensis* L.) fruit subjected to either full sun or 50 % shade (Syvertsen et al., 2003). In a three year study in which tonkan orange trees were interplanted with acacia, Yen and Lin (1966) reported that shaded fruit tended to be more attractive in color and had thinner rind thickness. There were no differences for SSC, SSC:TA ratio, and vitamin C content when trees were subjected to semi-shading, full shading, and full sun (Yen and Lin, 1966). Continuous shade throughout one growing season was shown to reduce fruit SSC concentrations and yields in ‘Hamlin’ orange (*Citrus sinensis* L.) (Jifon and Syvertsen, 2001). SSC was reduced in ‘Ruby Red’ grapefruit (*Citrus paradise* L.) due to continuous shade throughout the growing season (Jifon and Syvertsen, 2001). Interestingly, fruit weight of grapefruit was increased by continuous shade, whereas fruit weight of orange was reduced by continuous shade (Jifon and Syvertsen, 2001). Only continuous shading throughout the growing season resulted in less yield (Jifon and Syvertsen, 2001). Jifon and Syvertsen (2001) noted that peel color development of grapefruit was delayed by shaded treatments. In these studies, the trees were only shaded for one to three years and not continuously throughout the life of tree. Although different orchard designs are being used in Alabama satsuma production, their effect on yield and fruit quality is unknown.

The risk of freeze damage is a major concern for satsuma growers in south Alabama and although the actual effectiveness has not been previously determined, many growers utilize various orchard designs to protect against freeze damage. Interplanting citrus among various species of plants or behind a windbreak can offer protection during freezes (Turrell, 1973), but it can also affect plant growth, fruit quality and yield (Jifon and Syvertsen, 2001; Ono and Iwagaki, 1987; Turrell, 1973; Verreynne et al., 2004; Yen and Lin, 1966). A detailed study to determine the effect of these orchard designs will assist current and future satsuma growers. The objectives of this study are to determine the effects of currently used orchard designs on satsuma fruit quality, yield, and canopy temperature.

Materials and Methods

Satsuma (*Citrus unshiu* Marc.) trees planted in Grand Bay, AL (lat. 32° 28’ N, long. 88° 20’ W) and Irvington, AL (lat. 30° 26’ N, long. 88° 12’ W), USDA Hardiness Zone 9, were utilized in this experiment. The cultivar evaluated was ‘Owari’ budded onto trifoliate orange (*Poncirus trifoliata*) ‘Rubidoux’ rootstock. Trees were fertilized using current recommendations for citrus production in South Alabama (Powell and

Williams, 1998). The experimental design was a completely randomized design with 4 single tree replications.

Treatments include five different orchard designs: 1) 5 year old trees interplanted with Loblolly pine (*Pinus taeda*) (40 – 60 % shade) (pine tree 1 [Pi1]), 2) 13 year old satsumas planted behind a living windbreak (Wb), 3) 7 year old trees planted in full sun (control), 4) 4 year old trees interplanted with pecan trees (*Carya illinoinensis*) (Pe), and 5) 19 year old trees interplanted with loblolly pine (*Pinus taeda*) (70 – 90 % shade) (pine tree 2 [Pi2]). The windbreak used for treatment 2 is a living screen made mostly of oak trees (*Quercus sp.*) and underbrush. Tree ages listed are ages as of the beginning of the experiment (2009). In treatment 4, trees are shaded by 40-60% during the pecan trees' active growing season. The percent shade was determined by measuring the light interception inside and outside the orchard, then dividing the light interception inside the orchard by the light interception outside the orchard. In each of the orchard designs, four randomly selected trees were tagged and used for data collection.

The experiment was initiated in the fall of 2009. Fruit were harvested on December 1-3, 2009. Ten fruit per tree were randomly picked to measure weight, length, width, titratable acidity (TA), pH, soluble solids content (SSC), SSC:TA ratio, and external color from each of the four trees. Fruit were immediately transported to the Auburn University Horticulture lab for fruit quality measurements. Each individual fruit weight was recorded using an A&D EJ-610 scale (A & D Engineering, San Jose, CA, USA). Fruit length and width were taken using a digital caliper (Mitutoyo U.S.A., Aurora, IL, USA). Yield was recorded on a per tree basis. Yield was then compared to the expected yield based on the tree age (Lindsey et al., 2009).

Individual fruit were cut in half and juiced for the SSC, pH, and TA measurements. The fruit was juiced using a Black and Decker citrus juicer model CJ630 (Stanley Black and Decker, New Britain, CT, USA). Freshly prepared juice was filtered through grade 50 cheesecloth to separate pulp from juice. 1 mL of juice, at room temperature, was placed on a Leica Mark II Abbe Refractometer (Kernco Instruments, El Paso, TX, USA) for SSC reading. 5 mL of the remaining juice was placed in 100 mL beakers and 25 mL of double-distilled water having an electrical conductivity of 18.2 $M\Omega/cm^2$ obtained through a Millipore Direct-Q™ 5 filter system (Millipore Corp., Bedford, MA, USA) was added to bring the final volume to 30 mL. TA and pH were measured using an automated titrimeter (Metrohm Titrino Model 751 and Metrohm Sample Changer; Metrohm Corp., Herisau, Switzerland) and associated software (Brinkmann Titrino Workcell 4.4 Software; Brinkmann Corp., Westbury, NY, USA). The automatic titrimeter was housed in a Fisher Scientific refrigerated chromatography chamber maintained at 10 °C (Model Isotemp Laboratory Refrigerator; Fisher Scientific, Raleigh, NC, USA). 0.1 M solution of NaOH was titrated to the endpoint of pH 8.1 and the results were expressed in citric acid equivalent using the formula: [(mL NaOH × 0.1N × 0.064 $meq \cdot g^{-1}$ of juice) × 100]. SSC:TA ratio was calculated by dividing SSC by TA. External peel color was determined, for each individual fruit, visually using the following rating scale: 1) pre-color break (completely green fruit), 2) initial color break (predominantly green with few areas of isolated yellowing, 3) significant yellow mottling (fruit has multiple areas of yellow with no orange, 4) market-ready color (predominantly yellow to orange with few areas of green remain), 5) final coloration (predominantly orange fruit or yellow to orange transition with no green remaining). The experiment was repeated in 2010. Fruit were harvested on November 16, 2010 and the same procedures were used to determine yield and fruit quality.

Temperature within the orchard was recorded beginning in October 2009. Temperature data loggers (Spectrum Technologies, Inc., model 100 Watchdog Data Logger, Plainfield, Illinois, USA) were placed approximately 1.5 m high in the outer canopy of the north facing side of the tree. An additional data logger was placed in an adjacent open field on a post at a height of 1.5 m. Air temperature was measured every 30 minutes to observe differences in temperature from within the canopy and outside the orchard, in order to determine whether or not the orchard designs were effective in providing an insulating effect during freezing temperatures. After a severe freeze event, an estimation of freeze damage was completed by visually estimating the percentage of leaf loss a tree suffered.

All experimental data were analyzed using the GLIMMIX procedure in SAS 9.2 (SAS Institute, Inc., Cary, NC, USA). Single degree of freedom contrasts were used to examine simple effects in an interaction.

Results and Discussion

During the winter of 2009-2010, a severe freeze event occurred on January 1-13, 2010 in Alabama in which nighttime temperatures fell below freezing for 13 continuous days. Temperatures were observed to be as low as -11 °C outside the orchards on January 11, 2010. Only dense pine tree canopies (Pi2) created an insulating effect that resulted in warmer temperatures within the canopy (-8.35 °C) when compared to the temperature outside of the orchard in an open field (-11 °C) (Figure 1; Table 1). The following spring, trees were evaluated for symptoms of freeze damage by estimating the percentage leaf loss. Satsumas interplanted with pine trees (Pi1 and Pi2) sustained the least amount of freeze damage, with estimated leaf loss at 1 % and 2 % respectively, when compared to the full sun orchard (30 % leaf loss) (Table 2). Satsumas planted behind a windbreak (Wb) and satsumas interplanted with pecans (Pe) sustained more freeze damage, with 10 % and 11.25 % respectively, than the satsumas interplanted with pine trees. However, all orchard designs treatments experienced less damage than satsuma trees planted in the full sun orchard (control) (Table 2).

In 2009, in the absence of freeze damage, only the satsuma trees interplanted with dense pine trees (Pi2) had reduced yields compared to the expected yield for satsuma trees of that age growing in full sun (Table 3). Satsuma yield for the dense pine tree canopy treatment was 72.2 kg/tree versus the expected yield of 181.4 kg/tree based on the tree age of 19 years. The severe shading experienced for satsuma interplanted with dense pine tree canopy (Pi2) treatment appeared to reduce yields by 40%, which is consistent with results from Jifon and Syvertsen (2001). The following year, satsuma tree yield was reduced severely due to a severe freeze event that took place in January 2010. All treatments resulted in yields that were significantly less than the expected yields (Table 3). However, the yields for satsuma trees planted under the two pine tree canopy treatments did have a greater percentage of expected yield compared to the other treatments (Table 4), which is likely attributable to the lower percent leaf loss caused by the winter freeze event in January 2010 (Table 2).

In 2009, fruit from the satsumas interplanted with dense pine trees treatment (Pi2) and satsumas interplanted with pecans (Pe) had reduced fruit weight compared to fruit grown in the full sun orchard (Table 5). In 2010, satsuma fruit weight followed a similar pattern, as fruit weight (Table 5) was reduced under pine tree canopies (Pi1 and Pi2). In 2009, the satsuma fruit size in relation to length and width was smaller when grown under dense pine tree canopy (Pi2) (Table 5). In 2010, the length and width of fruit grown under pine tree canopies were smaller than the control and windbreak treatments. The reduction of fruit weight is consistent with results reported in continuous shading of navel orange, but contradictory to what was reported for grapefruit (Jifon and Syvertsen, 2001).

In both 2009 and 2010, satsumas under shaded pine tree treatments (Pi1 and Pi2) had higher SSC than that of the fruit grown in full sun (control) (Table 5). These results are contradictory to what was reported by Ono and Iwagaki (1987) in which shaded satsumas had lower SSC than trees grown in full sun. The results are also contradictory to what was reported for grapefruit and navel orange under continuous shade (Jifon and Syvertsen, 2001). In the studies conducted by Ono and Iwagaki (1987), and Jifon and Syvertsen (2001) the trees were only shaded for one to three years and not continuously throughout the life of tree. Whereas in our study, the satsumas and either the pines or pecans were planted at the same time. The treatment effect of the increase of SSC in the present study may be attributed to the smaller fruit size. Smaller citrus fruit tend to have higher SSC (Albrigo, 1977; Kesta, 1988; Sites and Camp, 1955). In 2009, fruit from the pecan tree interplanting treatment (Pe) had higher SSC when compared to the control, but they were not different in 2010. In 2009, there were no treatment effects on satsuma fruit TA, pH, or SSC:TA ratio (Table 5). These results confirmed what was reported in previous studies with navel and tonkan orange (Syvertsen et al., 2003; Yen and Lin, 1966). However in 2010, orchard design appeared to influence satsuma fruit TA, pH, and SSC:TA ratio. Satsumas planted behind a windbreak (Wb) had higher TA and lower SSC:TA ratio than all other treatments (Table 5). Satsumas interplanted with pine trees (Pi1and Pi2), and satsumas grown in the full sun orchard (control) had the highest SSC:TA ratios. Satsumas interplanted with pecan (Pe) had the highest pH and the lowest TA (Table 5). There were no differences in pH with satsumas interplanted with pine tree (Pi1 and Pi2), planted behind the windbreak (Wb), or the full sun orchard (control). The treatment effect on pH, TA, and the SSC:TA ratio could have been influenced more by the reduced crop load than the actual treatments. Fruit quality, in terms of higher SSC, was enhanced under pine tree canopy treatments. In 2010, the fruit grown in the full sun orchard (control) and satsumas grown behind the windbreak (Wb) were much larger and tended to have a puffier peel than satsumas grown under pine tree canopy treatments.

In 2009, satsuma external peel color was greater in the orchard planted behind the windbreak (Wb) treatment compared to the orchards interplanted with pecan or pine tree treatments, but external fruit color was not different than the satsumas grown in full sun orchard (control) (Table 5). There were no differences in external peel color between the satsumas grown in the full sun orchard (control) and satsumas grown under pecan and pine tree canopies (Pe, Pi1, Pi2) in 2009. In 2010, satsumas grown under moderate pine tree canopy (Pi1) had greater peel color than the other treatments. Peel color of satsumas grown under dense pine tree canopy (Pi2) were not different from satsumas grown behind the windbreak (Wb) or the satsumas grown in the full sun orchard (control) (Table 4). Previous studies determined that shading reduced the peel color of satsuma (Ono and

Iwagaki, 1987) and grapefruit (Jifon and Syvertsen, 2001). Shading did not appear to affect external peel color in this study.

Conclusions

Satsumas grown under pine tree canopies (Pi1 and Pi2) provided an insulating effect during a severe freeze event resulting in minimal freeze damage. During the freeze event, the satsumas grown under pine tree canopies (Pi1 and Pi2) provided more protection than the satsumas grown behind the windbreak (Wb) and the satsumas interplanted with pecan (Pe), but all treatments had less damage than the satsumas grown in the full sun orchard (control). Fruit grown under shaded pine tree canopies had higher SSC, which may have resulted from the smaller fruit weight and size. Shading did not reduce satsuma fruit quality. Satsumas grown under dense pine tree canopy (Pi2) had lower yields due to the heavy shading in 2009. Satsumas grown under dense pine canopy moderated temperature during the severe freeze event in 2010, which resulted in higher yields compared to the other orchard designs. However, potential maximum yields are significantly reduced in years when freeze damage is not experienced.

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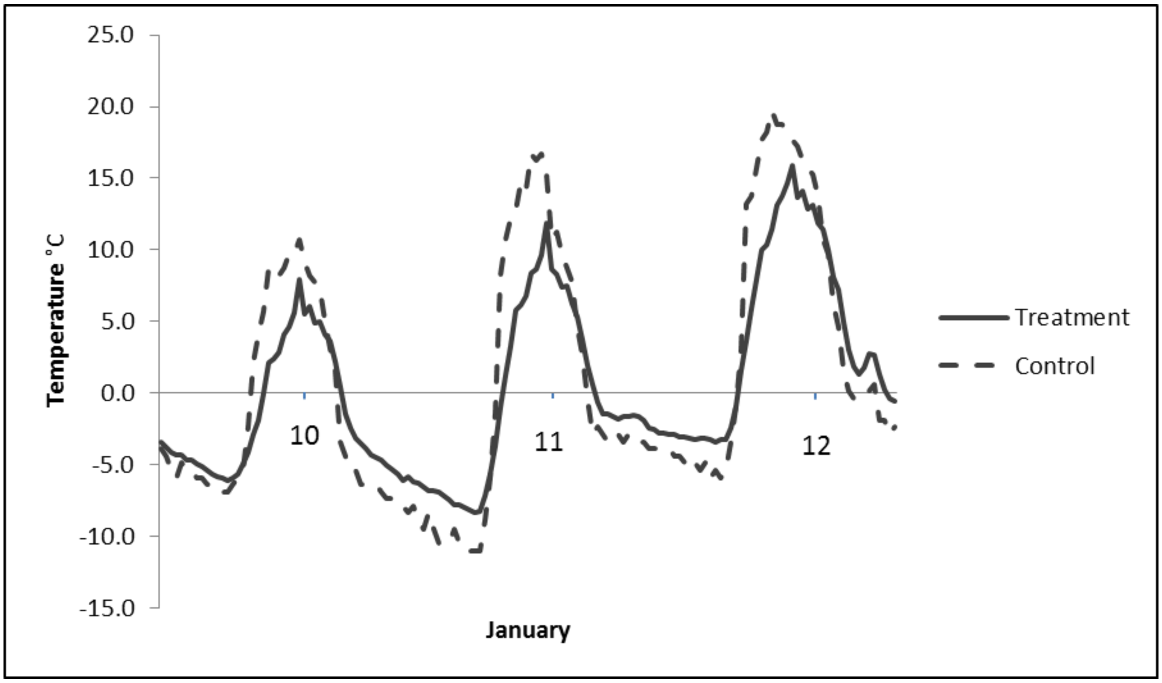

Fig. 1. Effect of dense pine tree canopy orchard design on satsuma mandarin (*Citrus unshiu* 'Owari') canopy temperature during a severe freeze event (January 10-12, 2010), south Mobile County, Alabama. Data based on 4 data loggers placed approximately 1.5 m high in experimental trees and control treatment is based on 1 data logger placed approximately 1.5 m high in adjacent open field.

Table 1. Effect of satsuma mandarin (*Citrus unshiu* 'Owari') orchard designs on the minimum canopy temperature during a severe freeze event (January 10-12, 2010), south Mobile County, Alabama.

	Minimum Temperature (°C)			
Orchard Design	Treatment [z]	Control [y]	P Value	Significance
Pine Trees 1	-7.75	-8.5	0.1935	NS
Windbreak	-9.48	-9.0	0.4022	NS
Control	-9.97	-11.0	0.0825	NS
Pecans	-9.98	-10.5	0.3557	NS
Pine Trees 2	-8.35 b	-11.0 a	0.0002	**

[z]Based on 1 data logger placed approximately 1.5 m high in the canopy of 4 trees.
[y]Based on 1 data logger placed approximately 1.5 m high in an adjacent open field.
Least square means comparison among treatment and controls (lower case) in rows using paired contrast at $\alpha = 0.05$.
NS, *, **, ***, Indicates nonsignificant and significant differences at $P \leq 0.05$, 0.01, 0.001 respectively.

Table 2. Effect of orchard design on percent leaf loss of satsuma trees caused by low winter temperature in January 2010, south Mobile County, Alabama[z].

Treatment	% Leaf Loss
Pine Trees 1	1.0 d
Windbreak	10.0 bc
Control	30.0 a
Pecans	11.3 b
Pine Trees 2	2.0 d
P-value	<0.0001
Significance	***

[z]Based on visual estimation of percent leaf loss.

Least square means comparison among treatments (lower case) in columns using paired contrast at $\alpha = 0.05$.

N.S., *, **, ***, Indicates nonsignificant and significant differences at $P \leq 0.05$, 0.01, 0.001 respectively.

Table 3. Effect of orchard design on satsuma mandarin (*Citrus unshiu* 'Owari') yield in south Mobile County, Alabama, 2009-2010. Yields (n = 4) are compared to the expected yield for trees of the same age planted in full sun[z].

Orchard Design	Yield (kg/tree)	Expected Yield (kg/tree)	P-value	Significance
	2009			
Pine Trees 1	49.1	86.2	0.3527	NS
Windbreak	115.5	181.4	0.1082	NS
Control	119.1	158.8	0.3205	NS
Pecans	32.7	54.4	0.5813	NS
Pine Trees 2	72.2 b	181.4 a	<0.0001	***
	2010			
Pine Trees 1	35.0 b	113.4 a	<0.0001	***
Windbreak	8.8 b	181.4 a	<0.0001	***
Control	20.2 b	181.4 a	<0.0001	***
Pecans	6.0 b	86.2 a	<0.0001	***
Pine Trees 2	46.8 b	181.4 a	<0.0001	***

[z]Lindsey et al., 2009.

Least square means comparison among treatment yield and expected yield (lower case) in rows using paired contrast at $\alpha = 0.05$.

NS, *, **, ***, Indicates nonsignificant and significant differences at $P \leq 0.05$, 0.01, 0.001 respectively.

Table 4. Effect of orchard design on percentage of expected yield (based on tree age[z]) of satsuma mandarin (*Citrus unshiu* ‘Owari’), south Mobile County, Alabama, 2009-2010 (n = 4).

Orchard Design	% Expected Yield (kg/tree)	
	2009	2010
Pine Trees 1	57.0	31.0 a
Windbreak	63.7	4.9 b
Control	75.0	11.1 b
Pecans	60.0	6.9 b
Pine Trees 2	39.8	25.8 a
P-value	0.2958	<0.0001
Significance	NS	***

[z]Lindsey et al., 2009.

Least square means comparison among treatments (lower case) in columns using paired contrast at $\alpha = 0.05$.

NS, *, **, ***, Indicates nonsignificant and significant differences at $P \leq 0.05$, 0.01, 0.001 respectively.

Table 5. Effect of orchard design on satsuma mandarin (*Citrus unshiu* 'Owari') fruit weight, length, width, external color, pH, soluble solid content (SSC), % titratable acidity (TA), and SSC:TA ratio harvested on December 1-3, 2009 and November 16, 2010, south Mobile County, Alabama, 2009-2010[z].

Treatment	Weight (g)	Length (mm)	Width (mm)	External Color[y]	pH	SSC (%)	Titratable Acidity[x] (%)	SSC:TA
				2009				
Pine Trees 1	129.57abc	51.6 abcd	68.9 abc	4.88 ab	3.89	9.7 ab	0.738	13.1
Windbreak	146.76 a	55.8 a	72.4 ab	5.00 a	3.96	9.5 abc	0.705	13.9
Control	139.12 ab	54.2 ab	72.7 a	4.80 abc	3.98	8.6 d	0.750	11.9
Pecans	121.56 cd	54.1 abc	68.9 bc	4.63 bc	3.93	9.4 bc	0.745	12.7
Pine Trees 2	106.64 d	47.9 d	64.3 d	4.58 c	3.84	10.2 a	0.743	13.9
P-value	0.05	0.0035	0.0285	0.0018	0.338	0.0012	0.9883	0.6077
Significance	*	**	*	**	NS	**	NS	NS
				2010				
Pine Trees 1	117.8 c	49.7 c	64.5 c	4.58 a	3.79 ab	10.2 a	0.95 b	10.9 ab
Windbreak	162.1 ab	57.2 b	71.1 ab	3.88 b	3.77 bc	10.0 ab	1.09 a	9.30 d
Control	180.5 a	62.3 a	73.6 a	4.05 b	3.78 bc	8.9 d	0.85 bcd	10.6abc
Pecans	141.7 b	57.4 b	67.3 bc	3.38 c	3.89 a	8.3 d	0.84 d	10.0 bc
Pine Trees 2	108.7 c	49.1 c	62.4 c	4.18 b	3.73 bcd	9.9 bc	0.91 bc	11.0 a
P-value	<0.0001	<0.0001	<0.0001	<0.0001	0.0348	<0.0001	0.0001	0.0023
Significance	***	***	***	***	*	***	***	**

[z]Based on 10 fruit sample.
[y]External color was determined by rating each fruit (1 to 5, 1 = completely green, 5 = completely orange).
[x]Titratable acidity is expressed as citric acid.
Least square means comparison among treatments (lower case) in columns using paired contrast at $\alpha = 0.05$.
NS, *, **, ***, Indicates nonsignificant and significant differences at $P \leq 0.05, 0.01, 0.001$ respectively.

CHAPTER THREE

Influence of Orchard Design on Satsuma Mandarin (*Citrus unshiu* 'Owari') Fruit Quality, Physiology, and Productivity

Abstract

Satsuma mandarin growers in Alabama try to mitigate freeze damage by using various orchard designs. These designs include interplanting between pecan and pine trees, and planting behind windbreaks. The goal of this research was to determine the influence of different orchard designs on canopy temperature, photosynthesis, leaf area, specific leaf area, and fruit quality. Satsuma canopy temperature under dense pine tree canopy was warmer than control trees in grown in full sun. All shading treatments reduced photosynthesis. Trees grown under pine tree and pecan tree canopies had greater leaf area, and tended to have thinner leaves (greater specific leaf area) compared to trees grown in full sun. Fruit from trees grown under dense pine tree canopies had reduced fruit weight and size, rind thickness, and vitamin C content. There were no differences in SSC due to the dense pine tree canopy treatment, however moderate pine tree shading resulted in increased SSC. There were no reductions in photosynthesis, fruit size, rind thickness, juice weight, or volume for trees planted behind a windbreak. In addition to freeze protection, the effects on photosynthesis and fruit quality should also be considered when selecting an orchard design for satsuma mandarin production.

Introduction

Though the satsuma mandarin (*Citrus unshiu*) is the most cold hardy citrus grown commercially (Hodgson, 1967; Yelenosky, 1985), freeze damage is the most limiting factor in satsuma mandarin production in south Alabama. To alleviate freeze damage, satsuma growers use different orchard designs including planting behind existing windbreaks, and interplanting between pecan and pine trees. These orchard designs offer variable freeze protection, but also likely affect plant growth, physiology, and fruit quality. Windbreaks have been shown to protect crops from damaging freezes when wind velocity is high, although the effectiveness of windbreaks can be quite variable (Turrell, 1973).

Shading can have an effect on many leaf characteristics including net photosynthesis (Pn), leaf area (LA), and specific leaf area (SLA). Light intensities related to *PAR* can influence photosynthesis (Bjorkman and Holmgren, 1966; Boardman, 1977). Plants grown in shaded conditions have lower photosynthetic rates and they perform efficiently at low light intensities (Boardman, 1977). In a one year study with 'Ruby Red' grapefruit (*Citrus paradisi* L.) and 'Hamlin' sweet orange (*Citrus sinensis* L.), trees grown under moderate shade had higher midday photosynthesis when compared to trees grown in full sun (Jifon and Syvertsen, 2001). This is due to reduced stress in the form of lower leaf temperatures and leaf-to-air vapor pressure during the midday, and the low irradiance required (600-700 µmol m^{-2} s^{-1}) to saturate citrus leaves (Jifon and Syvertsen, 2001; Syvertsen, 1984). Sun and shade leaves differ in leaf area and leaf thickness. Leaves grown in shaded conditions are typically broader and thinner, i.e. have greater SLA when compared to leaves grown in full sun. Leaf thickness plays a partial role in the amount of light absorbed by a leaf and the diffusion pathway of CO_2 through its tissues (Agusti et al., 1994; Syvertsen et al., 1995). Thinner, shaded leaves have larger chloroplasts and are richer in chlorophyll than the leaves from full sun (Boardman, 1977).

In California, citrus has been interplanted with Deglet Noor date palms (*Phoenix dactylifera*). Citrus trees flourish, but fruit production is reduced in shaded groves (Turrell, 1973). More pruning is required in interplanted groves due to the trees being more sparsely foliated with long branches and large leaves (Nesbitt et al., 2008). Satsuma fruit quality is determined by peel color, fruit size, rind thickness, soluble solids content (SSC), titratable acidity (TA) (expressed as % citric acid), and SSC:TA ratio. There are many factors that influence fruit quality including shading (Jifon and Syvertsen, 2001; Ono and Iwagaki, 1987; Verreynne et al., 2004; Yen and Lin, 1966) and canopy position (Fallahi and Moon, 1989; Syvertsen and Albrigo, 1980; Verreynne et al., 2004). Ono and Iwagaki (1987) reported that SSC and peel color decreased when relative light intensities (RLA) were reduced to 65 % or less during one growing season. 50 % shade did not affect fruit size when crop load was 100 %, but resulted in larger fruit when crop load was reduced to 50 % (Syvertsen et al., 2003). There were also no differences between full sun and 50 % shade in regards to SSC, rind thickness, and SS:TA ratio of 'Spring' (*Citrus sinensis* L.) navel orange (Syvertsen et al., 2003). In a three year study in which tonkan orange (*Citrus tankan* Hayata) was interplanted with acacia (*Acacia confusa* Merr.), Yen and Lin (1966) reported that shaded fruit tended to be more attractive in color and had thinner rind thickness. There were no differences between semi-shading, full shading, and full sun in regards to SSC and SSC:TA ratio (Yen and Lin, 1966). Continuous shade has been shown to reduce yields in 'Hamlin' orange (*Citrus sinensis*

L.) and ‘Ruby Red’ grapefruit (*Citrus paradise* L.) (Jifon and Syvertsen, 2001). In contrast to seasonal or short-term shade, continuous shade resulted in reduced SSC in grapefruit and ‘Hamlin’ (Jifon and Syvertsen, 2001). Fruit weight of grapefruit was increased by continuous shade, but fruit weight of orange was reduced by continuous shade (Jifon and Syvertsen, 2001). Jifon and Syvertsen (2001) noted that peel color development of grapefruit was delayed by shade treatments.

There are also pronounced differences in fruit quality related to canopy bearing position. According to Reitz and Sites (1948), fruit from ‘Valencia’ oranges (*Citrus sinensis* L.) were shown to have higher SSC on the outer portions of the canopy and lower SSC within the canopy. Similar results were reported in mandarin (Fallahi and Moon, 1989; Iwagaki, 1981; Verreynne et al., 2004), grapefruit (Fallahi and Moon, 1989; Syvertsen and Albrigo, 1980), navel orange (Fallahi and Moon, 1989; Sites and Reitz, 1949), and lemon (Fallahi and Moon, 1989). The differences in fruit quality were attributed to light quality and quantity, related to photosynthetic active radiation (*PAR*) (Reitz and Sites, 1948). Peel color development can also be contributed to canopy bearing position. Iwagaki (1981) reported an increase in peel color with an increase in light intensity in satsuma. In a study in the southern hemisphere, Verreynne et al. (2004) stated the north sector of satsuma, clementine, and temple canopies had significantly greener peel color than the south sector of the canopy.

Fruit weight, size, and TA can be influenced by canopy bearing position. Fully exposed fruit of satsuma, clementine and tangor produced larger fruit while fruit within the canopy produced smaller fruit (Verreynne et al., 2004). Conflicting results by Fallahi and Moon (1989) reported internally located fruit had larger fruit weight in mandarin, grapefruit, lemon, and orange. In a study in the northern hemisphere, Cohen (1988) reported the southern side of the tree produced larger fruit than the northern side in tangerine. Verreynne et al (2004) reported fruit produced within the canopy had higher TA, which contributed to the lower SSC:TA ratio. Similar results were reported in grapefruit (Syvertsen and Albrigo, 1980) and orange (Fallahi and Moon, 1989). However, mandarin (*Citrus reticulate* 'Blanco') fruit from the interior canopy reportedly had reduced TA (Fallahi and Moon, 1989).

Vitamin C, or L-ascorbic acid, is very important nutritionally in the human body and is found in many horticultural crops. Vitamin C is found in varying amounts in a number of different horticultural crops including but not limited to banana, blackberry, cantaloupe, citrus, kiwifruit, and strawberry (Lee and Kader, 2000). The amount of vitamin C found in mandarins is approximately 34 mg/100 g fresh weight (fw). Variation in vitamin C content is attributed to climatic conditions such as light and temperature (Klein and Perry, 1982; Sites and Reitz, 1950).

In grapefruit, higher temperatures in Arizona resulted in lower vitamin C concentration when compared to the cooler coastal climate of California (Rygg and Getty, 1955). Light interception as a result of canopy bearing position can influence levels of vitamin C in citrus fruit. Sites and Reitz (1950) reported vitamin C content differed based on "light classes" which correlates with *PAR*. Fruit from areas of the canopy that received the most light exposure were higher in vitamin C concentration, while fruit from the inner canopy had lower concentrations (Sites and Reitz, 1950). In 'Dancy' tangerine, fruit exposed to full sun were 27 % higher in vitamin C content when compared to fruit from shaded areas (Winston, 1948). Navel oranges grown in full sun were shown to have 20.9 % more vitamin C content, while Temple oranges had 16.7 % more vitamin C content than fruit grown in shaded conditions (Winston, 1948).

The purpose of this study is to evaluate the effects of various orchard designs and canopy positions on satsuma mandarin physiology and fruit quality. The orchard designs used in this study were implemented primarily to enhance freeze protection by influencing canopy temperature. These orchard designs provide shading to the trees thus altering growth habits. Shading can reduce photosynthesis and other aspects of leaf physiology that may influence fruit quality. Canopy bearing position does affect fruit quality and it is important to know these differences when sampling for crop maturity. By using a science-based method to evaluate these differences, the differences in leaf architecture, physiology, and fruit quality can be determined in comparison satsumas grown in full sun orchards.

Materials and Methods

Satsuma (*Citrus unshiu* Marc.) trees planted in Grand Bay, AL (lat. 32° 28’ N, long. 88° 20’ W) and Irvington, AL (lat. 30° 26’ N, long. 88° 12’ W), USDA Hardiness Zone 9, were utilized in this experiment. The cultivar evaluated was ‘Owari’ budded onto trifoliate orange (*Poncirus trifoliata*) ‘Rubidoux’ rootstock. Trees were fertilized based on Citrus for Southern and Coastal Alabama (Powell and Williams, 1998). The experimental design is a split-split plot design with orchard design in the whole plot factor, date in the subplot factor, and direction in the sub-subplot factor.

Each orchard design is compared to full sun trees at its location. Treatments include four different orchard designs and control trees planted in adjacent full sun orchards for each treatment: 1) 6 year old trees interplanted with loblolly pine (*Pinus taeda*) (40 – 60 % shade) with 8 year old control trees, 2) 14 year old satsumas planted behind a living windbreak with 8 year old control trees, 3) 5 year old trees interplanted with pecan trees (*Carya illinoinensis*) with 8 year old control trees, and 4) 20 year old trees interplanted with Loblolly pine (*Pinus taeda*) (70 – 90 % shade) with 10 year old control trees. The windbreak used for treatment 2 is a living screen made mostly of oak trees (*Quercus sp.*) and underbrush. In treatment 3, the trees are shaded by 40-60% during the pecans active growing season. In each of the orchard designs and control orchards, four randomly selected trees were tagged and used for data collection. The percent shade was determined by measuring the light interception inside and outside the orchard, then dividing the light interception inside the orchard by the light interception outside the orchard. The experiment was completed in the fall of 2010. The fruit were harvested on November 16, 2010. Trees were separated into four quadrants for data collection. The four quadrants were related to north, south, east, and west direction.

<u>Leaf Physiology</u>

In the summer of 2010, photosynthesis (Pn), leaf area (LA), specific leaf area (SLA), and leaf chlorophyll concentration (expressed as SPAD) were measured. Photosynthesis was measured using a LI-COR 6400 (Model 1000, LI-COR Biosciences, Inc., Lincoln, Nebraska, USA) in May, July, and September. Pn measurements were taken on the sun-sky setting on the LI-COR 6400. Satsuma trees were separated into four quadrants based on north, south, east, and west directions. Treatment trees and control trees were measured within a 1.5 h. One leaf per quadrant was measured. The leaves were the fourth to sixth leaf from the terminal leaf. Measurements were taken on full sun days with no cloud cover. Pn was measured based on the amount of photosynthetic active radiation (*PAR*) each leaf received. *PAR* was measured using a portable light meter (Apogee Instruments model QMSS, Logan, Utah, USA). Leaf chlorophyll concentration was measured using a Konica Minolta chlorophyll meter (model SPAD-502, Konica Minolta Sensing Americas, Inc., Ramsey, New Jersey, USA) on the same leaves that were used for Pn. Leaves were then placed in ziploc bags and brought back to the lab for LA and SLA measurements. Leaf area was measured using a LI-COR 3100 leaf area meter (LI-COR Biosciences, Inc., Lincoln, Nebraska, USA). Specific leaf area was determined using the formula ($LA \times DM^{-1}$) where DM is dry mass of the leaves.

<u>Fruit Quality</u>

The experiment was completed in the fall of 2010. Fruit were harvested once fruit maturity reached a SSC:TA ratio of 10:1. Fruit weight, length, width, juice weight, volume, internal color, and external color were measured using four single fruit replications/quadrant/tree (n=16). Fruit were transported to the Auburn University Horticulture lab for quality measurements. Each individual fruit weight was determined using an A&D EJ-610 scale (A & D Engineering, San Jose, CA, USA). Fruit length and width were measured using a digital caliper (Mitutoyo U.S.A., Aurora, IL, USA).

SSC, TA, SSC:TA ratio, and pH were determined using a freshly prepared composite juice sample that consisted of four fruit/quadrant/tree (n = 4). Fruit were cut in half and juice was extracted for juice weight, volume, SSC, pH, and TA measurements. Fruit samples were juiced using a Black and Decker citrus juicer model CJ630 (Stanley Black and Decker, New Britain, CT, USA). Extracted juice samples were transferred into graduated cylinders and juice weight and volume were measured. Juice samples were filtered through grade 50 cheesecloth to separate pulp from juice. SSC was measured by placing 1 mL of juice on a Leica Mark II Abbe Refractometer (Kernco Instruments, El Paso, TX, USA). 5 mL of the remaining strained juice was placed in 100 mL beakers and 25 mL of double-distilled water having an electrical conductivity of 18.2 $M\Omega/cm^2$ obtained through a Millipore Direct-Q™ 5 filter system (Millipore Corp., Bedford, MA, USA) was added to bring the final volume to 30 mL. TA and pH was measured using an automated titrimeter (Metrohm Titrino Model 751 and Metrohm Sample Changer; Metrohm Corp., Herisau, Switzerland) and software (Brinkmann Titrino Workcell 4.4 Software; Brinkmann Corp., Westbury, NY, USA). The automatic titrimeter was housed in a Fisher Scientific refrigerated chromatography chamber maintained at 10 °C (Model Isotemp Laboratory Refrigerator; Fisher Scientific, Raleigh, NC, USA). A 0.1 M solution of NaOH was titrated to the endpoint of pH 8.1 and the results were expressed in citric acid equivalent using the formula: $[(\text{mL NaOH} \times 0.1\text{N} \times 0.064\ \text{meq}\cdot\text{g}^{-1}\ \text{of juice}) \times 100]$. SSC:TA ratio was calculated by dividing SSC by TA.

Four single fruit reps/quadrant/tree (n = 16) were used to determine external peel color and internal color. External peel color was determined according to Jifon and Syvertsen (2001) in which four measurements along the equator of the fruit were measured. Internal fruit color was determined by cutting the fruit in half along the equator and recording a single measurement of a halved segment. A Minolta CM-700d spectrophotometer (Konica Minolta Sensing Americas, Inc., Ramsey, New Jersey, USA) using CIELAB color space coordinates (L*, a*, b*, C, h°) was utilized to measure peel and internal segment color, while only h° will be used. Hue angle (h°) can be visualized on a 360° color wheel where red-purple corresponds to 0°, yellow corresponds to 90°, bluish-green corresponds to 180°, and blue corresponds to 270° (McGuire, 1992). Calibration was achieved by using a white calibration tile. Data was recorded using SpectraMagic™ NX CM-S100w software (Konica Minolta Sensing Americas, Inc., Ramsey, New Jersey, USA).

Vitamin C

Experimental tree canopies were divided into four quadrants based on north, south, east, and west directions for fruit sampling. Four single fruit replications/quadrant/tree (n = 16) were harvested on November 16, 2010. Four random sample replicates consisting of approximately 10 g of frozen fruit sample were homogenized in 15 mL of cold m-phosphoric acid-acetic acid solution (30 g MPA, 0.5 g ethylenediamine tetraacetic acid, EDTA; and 80 mL glacial acetic acid diluted to 1 L with Mili-Q water) using Omni International GLH homogenizer (Omni International, Kennesaw, Georgia, USA) and a Omni International model G10-95 saw tooth probe (Omni International, Kennesaw, Georgia, USA). Samples were transferred to 50 mL centrifuge tubes, followed by a 10 min sonication run (Branson model 5510, Branson Ultrasonic Corporation, Danbury, Connecticut, USA). Sonicated samples were clarified by centrifugation (Beckman Centrifuge model J2-21, San Antonio, Texas, USA) at 13,000 g_n for 15 min at 4 °C and filtered with Miracloth (EMD Millipore, Darmstadt, Germany). The contents were transferred to 2 mL micro-centrifuge tubes (Eppendorf, Hauppauge, New York, USA). Samples were stored at -80 °C to run at a later date.

Vitamin C was determined according to Gossett et al. (1994) with minor modifications (Hodges et al., 1996) that allow for adaptations for micro-plate determinations. For vitamin C determination, a 2.0-mL micro-centrifuge tubes containing 50 µL of Milli-Q water, 100 µL of appropriately diluted clarified crude extract was added to 250 µL of KH_2PO_4 (150mM, pH 7.4 and 5 mM EDTA), followed by a 10 min room temperature incubation to which 50 µL of Milli-Q water was added. A subsequent series of reagents consisting of 200 µL trichloroacetic acid (TCA), 200 µL of O-phosphoric acid, 200 µL of 4% (w/v) 2, 2-dipryridyl dissolved in 70% HPLC grade ethanol, and 100 µL of 3% (w/v) $FeCl_3$ was added to complete the reaction mixture. Generation of a standard curve was achieved by measuring six different concentrations of L-ascorbic acid (0, 20, 40, 60, 80, and 100 µM) in parallel with appropriate diluted samples. Micro-centrifuge tubes were capped, vortexed (Fisher Scientific Genie 2, Pittsburg, Pennsylvania, USA), inserted into floating micro-centrifuge tube racks, and incubated in a water bath (Fisher Scientific model ISOTEMP 210, Pittsburg, Pennsylvania, USA) maintained at 40°C for 60 min. Samples were clarified by centrifugation (Thermo, Micromax Centrifuge, Milford, Massachusetts, USA) at 10,000 g_n for 15 min at 4°C. Samples were immediately transferred to multichannel pipette reservoir and 200 µL were pipetted into a 96 well flat bottom plate (Costar cat # 3370, Corning, Inc., Corning, New York, USA). The absorbance was read at 525 nm using a microplate reader (Synergy HT, BIO-TEK Instruments, Inc., Winooski, Vermont) maintained at 25°C. Results were expressed as vitamin C mg/100 g fw.

<u>Canopy temperature</u>

Canopy temperature was measured beginning in May 2010. Temperature data loggers (Spectrum Technologies, Inc., model 100 Watchdog Data Logger, Plainfield, Illinois, USA) were placed approximately 1.5 m high in the outer canopy of the north facing side of the tree. Additional data loggers were placed approximately 1.5 m high in the outer canopy of the north facing side of control trees in an adjacent full sun orchard for comparison. Canopy temperature was recorded every 30 minutes to observe differences among treatment and control trees. After a severe freeze event, temperatures were compared to assess differences among treatments and their respective controls.

Analysis of variance was performed using PROC GLIMMIX in SAS version 9.2 (SAS Institute, Cary, NC). The normality assumption for ANOVA was tested using the tests for normality statistics in PROC UNIVARIATE. Data were considered non-normal when the Shapiro-Wilk, the Kolmogorov-Smirnov, the Anderson-Darling, and the Cramér-von Mises tests were all significant. Data were analyzed as a split-split plot design with orchard design in the whole plot factor, date in the subplot factor, and direction in the sub-subplot factor. Appropriate steps were taken to correct within-group correlation and heterogeneous variance to minimize the Akaike information criterion (AIC) goodness of fit values when compared to no corrective steps. Paired contrasts were used to compare least squares means among directions and between locations and the controls. Linear and quadratic orthogonal contrasts were applied over months. All tests were considered significant at $P \leq 0.05$.

Results and Discussion

The influence of orchard design on leaf architecture was notable for the shaded orchards. In the summer of 2010, leaf area (LA) was much larger under dense pine tree canopy (Pi2) when compared to its respective control during the 3 different months (Table 1). LA from Pi2 (45.1, 45.0, and 47.1 cm^2) was approximately 1.5 × larger than leaves from trees grown in full sun (26.5, 22.8, and 29.1 cm^2) during each of the three months. Leaves from Pi2 also had greater specific leaf area (SLA; i.e. thinner leaves) than the control trees in May and July. This illustrates how greatly shaded trees from Pi2 are throughout the year. The effect of pine tree canopy 1 (Pi1) on leaf architecture was less pronounced. Pi1 treatment was less densely shaded, which is reflected in the leaf architecture. The LA was greater in leaves collected in May, but there were no differences in LA in July and September. Similar to Pi2, the SLA was greater in leaves from Pi1 in May and July. There was no difference in SLA for any of the observed treatments in September, as the leaf samples were extremely variable in SLA. Trees grown behind a windbreak (Wb) had greater LA for all months tested when compared to its control. This increase in LA may be due to afternoon shading provided by the oak tree borders. However, specific leaf area (SLA) for Wb (135.1, 85.8, and 82.3 $cm^2 \cdot g^{-1}$) was not different from its control (127.6, 76.2, and 78.9 $cm^2 \cdot g^{-1}$) (Table 1). This indicates that even though there are differences with the LA, the leaves are just as thick as the leaves from trees grown in full sun. There was no effect on LA due to the pecan tree canopy (Pe), though in July the SLA was higher for Pe than the control. SPAD measurements did not exhibit any specific trend for shaded or non-shaded treatments (Table 1).

Shaded orchards experienced reductions in light interception and photosynthesis. Photosynthesis (Table 2) and leaf temperature (Table 3) of satsumas grown under dense pine tree canopy (Pi2) was greatly reduced due to shading. The reduction in photosynthesis contradicts results reported for other citrus varieties in which shaded treatments had higher midday photosynthesis due to the decrease in leaf temperature (Syvertsen, 1984). However, leaves of Pi2 did not reach the suggested light saturation point for citrus leaves at 600-700 µmol m^{-2} s^{-1} (Jifon and Syvertsen, 2001; Syvertsen, 1984). Hence, Pi2 was more severely shaded than the treatment used in the experiment conducted by Syvertsen (1984). However, the photosynthesis of the orchard interplanted with pecans (Pe) was significantly less than the control, even though its leaves reached the light saturation point reported by Syvertsen (1984). The same was true for Pi1 for the month of May (Table 3). Trees were only shaded for one growing season in the study by Syverten (1984), whereas the shaded treatments in the present study have been shaded throughout the life of the orchards. Photosynthesis was reduced in Pi1 in May and July (Table 2), but not in September when light interception was similar for Pi1 and control trees when measurements were taken (Table 3). There were no differences in photosynthesis for Wb, which received equal light interception as the control (Table 2; Table 3). There were observed differences in photosynthesis among direction for Pe and Wb, which may result from different light levels among direction (Table 2; Table 3). There were no specific trends observed in the differences for stomatal conductance (Table 2).

Canopy temperature was affected by only one orchard design (Table 4). During a severe freeze event that occurred during December 27-29, 2010, only Pi2 provided some insulation from cold temperatures (Table 4). Pi2 had higher canopy temperatures within its orchard compared to the full sun orchard (control). No other orchard provided an insulating effect on temperature during this particular freeze.

Fruit quality was also affected by orchard design treatments. Fruit weight was reduced for Pe and Pi2 (Table 5). Heavy shading under dense pine tree canopy greatly affected fruit weight and the fruit size in relation to length and width. Fruit weight for Pi2 was 108.2 g compared to 159.4 g of the control. The reduction in fruit weight was similar to what was reported for orange, but in contrast to results reported for grapefruit when fruit were heavily shaded (Jifon and Syvertsen, 2001). Shade from both pine tree canopy treatments resulted in fruit with thinner rind thickness (Table 5), which is a desirable characteristic. Rind thickness for Pi2 and its control was 2.2 mm and 3.6 mm, respectively. Results for rind thickness were consistent with results reported by Yen and Lin (1966). Juice weight and volume were reduced only for Pe and Pi2 (Table 5). This was anticipated due to both treatments having a smaller fruit weight. There were no differences in external peel color due to shading provided by either pine tree canopy treatment (Table 6). This contradicts what has been reported previously with shading of satsuma (Ono and Iwagaki, 1987) and grapefruit (Jifon and Syvertsen, 2001). However, Wb and Pe did affect external peel color when compared to their respective controls (Table 6). There were no differences due to canopy orientation (quadrant) for the fruit quality measurements except internal fruit color (Table 3; Table 6). The fruit from the north quadrant were darker orange than the other quadrants (Table 3; Table 6). Internal fruit color from fruit interplanted with pine tree (Pi1 and Pi2) had lower hue values than their respective controls (Table 6). Windbreak control had higher hue values than the windbreak treatment. Dense pine tree canopy (Pi2) did not affect SSC, while Pi1 had higher SSC (10.2%) versus the control with 9.8% (Table 7). These results are in contrast to results reported previously for ‘Ruby Red’ grapefruit and ‘Hamlin’ orange, in which shaded fruit had lower SSC than fruit grown in full sun (Jifon and Syvertsen, 2001). Windbreak had higher SSC than its control with 10% and 9.1%, respectively. Fruit from satsuma interplanted with dense pine tree treatment (Pi2) were more mature (i.e., had higher SSC:TA ratio) than its respective control treatment. Fruit from satsuma interplanted with dense pine tree canopy treatment (Pi2) had reduced vitamin C content (Table 7). These results correlate with previous results reported (Winston, 1948) in which fruit grown in shade have lower concentrations of vitamin C. In contrast, there was an increase in vitamin C content in orchards protected by windbreak (Table 7).

Conclusion

Orchard designs used for freeze protection affected plant physiology, leaf architecture, and fruit quality as a result of shading. Photosynthesis and production may be enhanced with short-term shade (Jifon and Syvertsen, 2001; Syvertsen and Albrigo, 1980), but long-term shading reduces photosynthesis and alters leaf architecture (i.e. leaf area and specific leaf area). Fruit quality i.e., reduced rind thickness, increased fruit weight, and soluble solid content were enhanced with shaded orchard designs. In the present study, only canopy temperature for satsumas interplanted with dense pine tree canopy (Pi2) was warmer when compared to control trees planted in an adjacent full sun orchard. Warmer temperatures experienced under dense pine tree canopies may result in reduced freeze damage and allow damaged trees to recover faster than others. However, the effects on physiology, leaf architecture, fruit quality, and yield should also be considered when choosing an orchard design.

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Table 1. Influence of orchard design on satsuma mandarin (*Citrus unshiu* 'Owari') leaf chlorophyll concentration (SPAD), leaf area (LA), and specific leaf area (SLA) for pine tree canopy (Pi1), windbreak (Wb), interplanted pecans (Pe), and dense pine tree canopy (Pi2) treatments compared to their respective controls, south Mobile County, AL, 2010.[z]

	SPAD						
	Date				Control		
Treatment	May	July	Sept.	Sign.[y]	May	July	Sept.
Pi1	47.3	73.9	81.0 a[x]	Q***	51.7	78.1	77.0 b
Wb	46.3	71.9	74.9	Q***	50.9	69.2	73.3
Pe	43.2	77.4 a	80.6	Q***	47.0	70.7 b	77.1
Pi2	42.3 b	76.3	76.8	Q***	47.7 a	74.8	75.0
	LA (cm^2)						
	Date				Control		
	May	July	Sept.	Sign.	May	July	Sept.
Pi1	27.3 a	25.4	24.7	NS	20.6 b	25.3	21.8
Wb	25.9 a	20.6 a	26.1 a	Q**	21.4 b	15.7 b	18.8 b
Pe	26.7	20.8	24.9	Q**	28.6	21.3	25.4
Pi2	45.1 a	45.0 a	47.1 a	NS	26.5 b	22.8 b	29.1 b
	SLA ($cm^2 \cdot g^{-1}$)						
	Date				Control		
	May	July	Sept.	Sign.	May	July	Sept.
Pi1	135.4 a	85.8 a	82.3	Q***	119.4 b	72.0 b	76.6
Wb	135.1	76.7	79.8	Q***	127.6	76.2	78.9
Pe	155.3	85.5 a	83.1	Q***	149.8	74.7 b	80.1
Pi2	145.2 a	88.7 a	95.9	Q***	125.0 b	77.5 b	83.8

[z]Based on 16 leaf samples.

[y]NS, *, **, ***, indicates nonsignificant and significant differences at $P \leq 0.05$, 0.01, and 0.001.

[x]Least squares means comparison among treatments and controls (lower case) in rows using paired contrasts at $\alpha = 0.05$.

Table 2. Influence of orchard design on satsuma mandarin (*Citrus unshiu* 'Owari') photosynthesis and stomatal conductance for treatments versus their respective controls, south Mobile County, AL, 2010.[z]

	Net Photosynthesis (µmol $m^{-2}s^{-1}$)							
	Date				Direction[y]			
Treatment	May	July	Sept.	Significance	East	North	South	West
Pine Trees 1	8.68 b	4.29 b	12.12	Q**	7.99 b	8.62	8.44 b	8.40 b
Control	11.80 a	8.76 a	12.59		11.46 a	9.82	11.40 a	11.52 a
Windbreak	10.55	10.9	9.45	Q**	10.82 A	10.59 A	10.46 A	9.37 bB
Control	9.95	10.81	9.99		9.89	10.45	9.68	10.99 a
Pecans	7.98 b	13.04 b	11.29	NS	7.88 bB	10.77 bA	12.13 A	12.30 A
Control	12.41 a	14.11 a	12.83		12.83 a	13.04 a	13.23	13.37
Pine Trees 2	5.64 b	8.97 b	5.31 b	Q*	6.98 b	5.86 b	6.11 b	7.59 b
Control	11.02 a	14.98 a	10.90 a		12.40 a	12.18 a	12.84 a	11.76 a

	Stomatal Conductance (mmol $m^{-2}s^{-1}$)							
	Date				Direction			
Treatment	May	July	Sept.	Significance	East	North	South	West
Pine Trees 1	0.12 b	0.16	0.24	L***	0.18 b	0.18	0.17 b	0.16 b
Control	0.16 a	0.27	0.27		0.23 a	0.20	0.23 a	0.28 a
Windbreak	0.09	0.14	0.14	Q**	0.14 aA	0.13 A	0.13 A	0.09 B
Control	0.11	0.13	0.10		0.08 b	0.13	0.11	0.13
Pecans	0.13	0.24	0.24 a	NS	0.22 a	0.19	0.21	0.20 a
Control	0.14	0.20	0.15 b		0.15 b	0.18	0.17	0.16 b
Pine Trees 2	0.09	0.13	0.14	L***	0.14 A	0.09 B	0.11 bA	0.14 A
Control	0.10	0.17	0.14		0.14	0.13	0.15 a	0.11

[z]Based on 16 leaf samples from each date.
[y]Based on 4 leaf samples per each direction.
The location by date and the location by direction interactions were significant at $\alpha = 0.05$.
Least square means comparison among directions (upper case) in rows using paired contrasts at $\alpha = 0.05$.
Least square means comparison between locations and controls (lower case) in columns using paired contrast at $\alpha = 0.05$.
Not significant (NS) or significant linear (L) or quadratic (Q) trend over dates using contrasts at $\alpha = 0.05$ (*), 0.01 (**), or 0.001 (***).

Table 3. Influence of orchard design on satsuma mandarin (*Citrus unshiu* 'Owari') leaf temperature and light interception for treatments versus their respective controls, south Mobile County, AL, 2010.[z]

	Leaf Temperature (°C)							
	Date				Direction[y]			
Treatment	May	July	Sept.	Significance	East	North	South	West
Pine Trees 1	36.09 b	30.18 b	37.49	Q***	34.39 b	34.54 b	34.83 b	34.58 b
Control	38.86 a	33.50 a	37.67		36.82 a	36.42 a	36.80 a	36.69 a
Windbreak	41.41	39.18	38.91	Q***	39.57 B	39.58 B	39.85 B	40.35 A
Control	40.21	39.58	40.35		40.43	40.01	39.99	39.74
Pecans	38.05 b	37.37	36.05 b	Q*	35.47 bC	37.34 bB	37.98 bA	37.85 bAB
Control	41.13 a	37.85	41.50 a		40.20 a	39.92 a	40.14 a	40.38 a
Pine Trees 2	34.11 b	35.83 b	33.69 b	NS	34.66 b	34.39 b	34.31 b	34.81 b
Control	40.20 a	40.56 a	40.52 a		40.16 a	40.21 a	40.38 a	40.97 a

	Light Interception (μmol $m^{-2}s^{-1}$)							
	Date				Direction			
Treatment	May	July	Sept.	Significance	East	North	South	West
Pine Trees 1	1165.62 b	115.75 b	1174.50	Q***	768.75 b	836.92 b	891.83 b	777.00 b
Control	1949.25 a	712.87 a	1423.94		1372.67 a	1393.17 a	1362.50 a	1319.75 a
Windbreak	918.62	1266.69	1359.69	Q***	1196.42 AB	1279.17 A	1257.75 AB	993.33 B
Control	941.25	1286.00	1232.94		1154.00	1205.75	1161.50	1092.33
Pecans	854.19 b	910.94 b	1016.44 b	NS	314.50 bC	893.67 bB	1346.67 bA	1153.92 A
Control	1341.69 a	1627.50 a	1642.25 a		1550.75 a	1565.92 a	1583.92 a	1448.00
Pine Trees 2	365.19 b	215.06 b	171.69 b	NS	291.92 bA	98.08 bB	80.92 bB	531.67 bA
Control	1656.75 a	1545.56 a	1772.94 a		1622.75 a	1703.5 a	1658.17 a	1649.25 a

[z]Based on 16 leaf samples from each date.
[y]Based on 4 leaf samples per each direction.
The location by date and the location by direction interactions were significant at α = 0.05.
Least square means comparison among directions (upper case) in rows using paired contrasts at α = 0.05.
Least square means comparison between locations and controls (lower case) in columns using paired contrast at α = 0.05.
Not significant (NS) or significant linear (L) or quadratic (Q) trend over dates using contrasts at α = 0.05 (*), 0.01 (**), or 0.001 (***).

Table 4. Influence of various satsuma mandarin (*Citrus unshiu* 'Owari') orchard designs on the minimum canopy temperature versus their respective controls during a severe freeze event, December 27-29, 2010.

	Minimum Temperature (°C)			
Orchard Design	Treatment [z]	Control [y]	P-value	Significance
Pine Trees 1	-6.17	-6.29	0.6936	NS
Windbreak	-6.01	-5.56	0.1578	NS
Pecans	-6.29	-6.04	0.3983	NS
Pine Trees 2	-5.42 b	-6.60 a	0.0005	**

[z]Based on 1 data loggers placed approximately 1.5 m high in the canopy of 4 trees.
[y]Based on 1 data loggers placed approximately 1.5 m high in an adjacent open field orchard.
Least square means comparison among treatment and controls (lower case) in rows using paired contrast at $\alpha = 0.05$.
NS, *, **, ***, Indicates nonsignificant and significant differences at $P \leq 0.05$, 0.01, 0.001 respectively.

Table 5. Influence of orchard design on satsuma mandarin (*Citrus unshiu* 'Owari') weight, length, width, rind thickness, juice volume, and juice weight for treatments versus their respective controls, south Mobile County, AL, 2010.[z]

Treatment	Weight (g)	Length (mm)	Width (mm)	Rind Thickness (mm)	Juice Volume (mL)	Juice Weight (g)
Pine Trees 1	117.8	49.7 b	64.6	3.0 b	45.6	46.4
Control	137.8	55.8 a	68.0	3.8 a	48.6	49.3
Windbreak	162.1	57.2	71.2	3.2	68.9	70.3
Control	150.8	57.2	68.6	3.1	60.7	62.6
Pecans	141.7 b	57.4	67.3 b	3.7	47.8 b	48.7 b
Control	197.6 a	59.7	74.7 a	3.1	73.6 a	75.4 a
Pine Trees 2	108.2 b	49.0 b	62.3 b	2.2 b	47.6 b	48.4 b
Control	159.4 a	59.7 a	70.2 a	3.6 a	59.7 a	60.7 a

[z]Based on 16 fruit sample.
Only location was significant at $\alpha = 0.05$.
Least square means comparison between locations and controls (lower case) in columns using paired contrast at $\alpha = 0.05$.

Table 6. Influence of orchard design on satsuma mandarin (*Citrus unshiu* ‘Owari’) external hue (h°) and internal hue (h°) angles for treatments versus their respective controls, south Mobile County, AL, 2010.[zy]

External h°				
Treatment		Control	Direction[x]	
Pine Trees1	65.8	65.9	East	74.84 NS
Windbreak	79.8 b	87.6 a	North	73.81
Pecans	83.0 a	70.2 b	South	75.83
Pine Trees2	74.5	73.0	West	75.39
Internal h°				
Treatment		Control	Direction	
Pine Trees1	61.1 b	66.1 a	East	63.0 B
Windbreak	66.6 a	62.6 b	North	62.8 C
Pecans	64.9	64.6	South	64.2 A
Pine Trees2	59.4 b	62.5 a	West	63.7 AB

[z]Based on 16 fruit sample.

[y]Measured in CIELAB. h° = hue angle (0° = red-purple, 90° = yellow, 180° = bluish-green, 270°= blue).

[x]Based on 4 fruit samples per direction.

Least square means comparison between locations and controls (lower case) in rows using paired contrast at $\alpha = 0.05$.

Least square means comparison among directions (upper case) in columns using paired contrasts at $\alpha = 0.05$. N.S. is not significant.

Table 7. Influence of orchard design on satsuma mandarin (*Citrus unshiu* ‘Owari’) soluble solids content (SSC), titratable acidity (TA), SSC:TA, pH, and vitamin C content for treatments versus their respective controls, south Mobile County, AL, 2010.[z]

Treatment	SSC (%)	Titratable Acidity (%)[y]	SSC:TA	pH	vitamin C (mg/100 gfw)
Pine Trees 1	10.2 a	0.95	10.9	3.8	23.22
Control	9.8 b	0.95	10.4	3.8	24.22
Windbreak	10.0 a	1.09 a	9.3	3.8	24.47 a
Control	9.1 b	0.98 b	9.4	3.8	20.78 b
Pecans	8.3 b	0.84 b	10.0	3.9 a	22.07
Control	9.3 a	0.93 a	10.1	3.7 b	23.04
Pine Trees 2	9.9	0.91	11.0 a	3.7 b	23.07 b
Control	9.7	0.96	10.2 b	3.9 a	26.10 a

[z]Based on 16 fruit sample.
[y]Titratable acidity is expressed as citric acid.
Only location was significant at $\alpha = 0.05$.
Least square means comparison between locations and controls (lower case) in columns using paired contrast at $\alpha = 0.05$.

CHAPTER FOUR

Final Discussion

Satsuma mandarins (*Citrus unshiu* Marc.) have been grown in Alabama since the early 20th century. Acreage once exceeded 7000 ha, but a series of severe freezes along with other factors devastated the industry (Winberg, 1948). As of 2005, the industry had approximately 25.3 ha of both bearing and non-bearing satsumas (Nesbitt et al., 2008). The main priority for these satsuma growers is the protection against damaging freezes. Satsuma growers utilize a variety of orchard designs to minimize freeze damage. These orchard designs include planting behind existing windbreaks and interplanting between pecan and pine trees. Shade reportedly effects fruit quality, yield, and photosynthesis of citrus (Jifon and Syvertsen, 2001; Ono and Iwagaki, 1987; Syvertsen, 1984; Verreynne et al., 2004; and Yen and Lin, 1966). However, limited research has been conducted in Alabama utilizing these satsuma mandarin orchard designs.

In 2009, five different orchards were chosen based on their design in south Mobile County, AL. Four trees were randomly selected within each treatment. Treatments included satsumas planted behind a living windbreak, interplanted with pecan trees (*Carya illinoinensis*), a full sun orchard (control), and two orchards in which satsumas were interplanted with loblolly pine (*Pinus taeda*). Canopy temperature, total yield, fruit weight, length, width, titratable acidity, pH, soluble solids content, SSC:TA ratio, and external color were determined.

Pine tree canopies provided an insulating effect during a severe freeze which resulted in minimal freeze damage. However, all treatments suffered reduced freeze damage than the control. Shading from pine tree canopies resulted in higher soluble solid content, although this may have been due to the observed smaller fruit weight and size. Heavy shading from dense pine tree canopy resulted in lower fruit yield. However, during a year following a severe freeze event, trees interplanted with pine trees had a higher percentage of expected yields than other treatments.

In the second experiment, four different orchards were chosen based on their design and compared to control trees planted in adjacent full sun orchards in south Mobile County, AL. Four trees were randomly selected within each orchard. Treatments included satsumas planted behind a living windbreak, interplanted with pecan trees (*Carya illinoinensis*), and two orchards in which satsumas were interplanted with loblolly pine (*Pinus taeda*). Satsuma fruit were harvested based on quadrant to determine possible influences of canopy position. Photosynthesis, leaf area, specific leaf area, and leaf chlorophyll concentration (expressed as SPAD) were measured three times throughout the summer. At harvest, total yield, fruit weight, length, width, soluble solids content, titratable acidity, pH, SSC:TA ratio, external and internal color, vitamin C content, rind thickness, juice weight, and volume were determined.

Canopy position effected internal fruit color, photosynthesis, and stomatal conductance. Reduced photosynthesis and stomatal conductance can be attributed to the amount of light intensity. Severe shading provided by dense pine tree canopy reduced photosynthesis, fruit size, rind thickness, juice weight, volume, and vitamin C content. Shading of the trees increased leaf area and specific leaf area. However, the soluble solid content for dense pine tree canopy did not differ from its control. Satsumas interplanted with pecans had reduced photosynthesis, fruit weight and width, external peel color, soluble solid content, juice weight, and juice volume. However, there were no observed differences with the SSC:TA ratio or vitamin C content. Satsumas grown under a moderate pine tree canopy had reduced photosynthesis when light intensity was reduced. Fruit weight was not affected by moderate pine tree canopy, however fruit length and rind thickness were reduced. Soluble solid content was higher in satsumas interplanted with moderate pine tree canopy than its control. There were no reductions in photosynthesis, fruit size, rind thickness, juice weight, or volume for satsuma trees planted behind a windbreak. Heavy shading did reduce fruit size, but it did not reduce soluble solid content. Photosynthesis was reduced with all shading treatments.

Satsumas have been grown in Alabama since the early 20th century (Winberg, 1948). Severe freezes wiped out early attempts at producing satsumas for commercial markets. Recently, growers in Mobile County, Alabama have utilized various orchard designs to help mitigate freeze damage. However, satsuma canopy temperature was only reduced when planted interplanted with dense pine tree canopy. These various orchard designs affect the growth of satsumas in terms of physiological and reproductive traits. Shading provided by orchard designs utilized in this study may not negatively affect fruit quality, but potential yields in years without freeze damage are significantly reduced.

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