Assessment of commercial fruit crop potential of selected banana (*Musa* sp.) cultivars in the subtropics of coastal Alabama

by

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Abstract

Global demand and increased adaptability of banana cultures has led to the development of a potential niche market for non-Cavendish bananas. This present work was conducted to determine the feasibility of producing banana fruit in the coastal region of Alabama, USA. In the seasons leading to fruit production, several banana cultivars demonstrated suitability for production due to vigor that was similar to banana cultivars produced in other subtropical regions. In the first season cultivars ‘Veinte Cohol’ and ‘Ice Cream’ produced significantly more leaves (39 and 38 $leaves^{-1}$ plant respectively) than all other medium height banana cultivars. Overall ‘Cardaba’ and ‘Ice Cream’ had the highest number of leaves present (NLP) and produced the highest total number of leaves (TLN). Several cultivars produced mature bunches by the end of the 2015 season: ‘Cardaba’, ‘Gold Finger’, ‘Double’, ‘Grand Nain’, and ‘Sweetheart’. Preliminary findings in cover crops studies have found no increase in soil carbon or organic matter supplied by Hairy Vetch or Crimson Clover and had no significant effect on growth of ‘Mysore’ banana plants compared to the bare ground treatment. Reflective mulch treatments resulted in yields that were consistently, numerically higher than the control treatment but these differences were not significant. Several cultivars have exhibited adaptability to the gulf coast region of Alabama and hence hold promise as being part and parcel of a banana niche market. More research must be conducted such as extended phenological studies and a precise determination of responses to critically low temperatures to assess banana cultivar’s ability to produce mature bunches before the first

frost in coastal Alabama, and the effect of innovative cultural practices to reduce inputs and increase sustainability.

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Chapter I

Introduction and Literature Review

Introduction

Bananas are imported to the US primarily from plantations in the tropics: Ecuador, the Philippines, Costa Rica, and Colombia (Kopel, 2008), but development of cold-tolerant and short-cycled banana cultivars has led to increased adaptability and expansion of banana fruit production beyond the ideal growing conditions characteristic of the tropics into the more variable climates of the subtropics (Daniells and O'Keefe, 2012; Lahav and Lowengart, 1998).

Bananas are produced in several nations in the subtropics such as Egypt, Israel, Jordan, Create, Cyprus, Turkey, Lebanon, Arabia, Yemen, Oman, Canary Islands, Madeira, Southern Taiwan, Peoples Republic of China, Asia north of 20° latitude, and Brazil south of 20° latitude (Stover and Simmonds, 1987).

Furthermore, convergence of key socio-political, economic, and environmental developments reveals the unique potential of bananas as a specialty crop in Alabama. Campaigns such as *Buy Fresh Buy Local* conducted by the Alabama Farmers Market Authority and promoted for the sake of crop diversity and increased economic sustainability of farm operations encourages production of non-traditional crops and consumption of fresh produce with health promoting qualities by consumers (Fonsah et al., 2005; Lu et al., 2000; www.fma.alabama.gov). Additionally, the Cavendish banana, a subgroup of bananas that were selected by multinational corporations as the market standard because of its resistance to Panama Disease (*Fusarium oxysporium* Cubense) dominates the banana market. This singular focus on Cavendish bananas presents opportunity for creation of a niche market for non-Cavendish bananas in coastal Alabama. Moreover the climate in coastal Alabama is mild (USDA Hardiness Zone 8b) and is conducive for banana fruit production. At the Gulf Coast Research and Extension Center (GCREC) in Fairhope, Baldwin County, AL, 30° 31' 35.018'' North, 87°53'44.473'' West) mean monthly maximum temperatures are within the cardinal temperature range for bananas for 7 months during the year (Alabama Mesonet Data 2008-2012) with mean temperatures slightly above range from mid-June to mid-August. Cardinal temperatures for bananas production fall in the range of 57° F- 88°F with optimal range of 72° F - 88° F (Robinson, 1996).

Lastly, bananas are the leading import fruit crop in the US and fourth most important crop globally. US banana import value rose from $1 billion in 2006 to nearly $2 billion in 2010 while global banana production was cited at over 100 million metric tons – a 33% increase since 2005. Moreover, bananas are an important source of food and fiber in many cultures that have a growing presence in the US creating further demand for banana specialty markets within the agricultural sector.

Bananas (*Musa* Sp.) are monocotyledonous, herbaceous, evergreen perennial plants, the fruit of which are imported to the US primarily from plantations in the Caribbean (Kopel, 2008; Lessard, 1992). However, bananas have a center of origin in southeastern Asia and the western Pacific and secondary center of origin in Africa (DeLanghe et al, 2009; Robinson, 1996). Bananas belong to the order Zingiberales and the family *Musaceae*. The family *Musaceae* is composed of only two genera *Musa* and

Ensete. *Musa* is comprised of five sections that are based on chromosome number and morphology of inflorescence (Pillay et al., 2012; Stover and Simmonds, 1987). These sections are *Eumusa* (2n= 22 chromosomes), *Rhodochlamys* (2n = 22 chromosomes), *Australimusa* (2n = 20 chromosomes), *Callimusa* (2n = 20 chromosomes), and *Ingentimusa* (2n = 14 chromosomes). Since the formation of these classes, however, technological advances in molecular biology such as amplified fragment length polymorphism (AFLP), restriction fragment length polymorphism (RFLP), and chloroplast analysis provide reason to merge *Rhodochlamys* and *Eumusa* and *Callimusa* and *Australimusa* (; Irish et al., 2014; Pillay et al., 2012). *Eumusa* is considered the most ancient and diverse section and includes desert bananas along with cooking bananas and plantains while *Australimusa* consists of the parthenocarpic and edible Fei´ bananas and *Callimusa* along with *Rhodochlamys* consist only of ornamental types (Pillay et al., 2012; Purseglove, 1972).

The genetic background of bananas which led to the development of domesticated fruit has been speculated (Simmonds, 1962) but as described by Robinson (1996) wild, diploid, subspecies of *Musa acuminata* Colla, hybridized and produced female sterile diploid (2n = 2x = 22) and triploid (2n = 3x = 33) plants, which produced parthenocarpic and edible fruit. Diploid and triploid hybrids of *M. acuminata* were transported to India and the Philippines and hybridized with a native wild banana *M. balbisiana*. This interspecific hybridization resulted in diploid and triploid crosses of *M. acuminata* x *M. balbisiana*. Because of the myriad of clones of edible bananas that have been derived from both *M. acuminata* Colla and *M. balbisiana* Colla a single scientific name cannot be given, hence , an international system was employed to avoid confusion: Bananas are first referred to by the genus *Musa* followed by the letter designations that indicate genome group (A for *acuminata* and B for *balbisiana*) and ploidy level (AAA means triploid with entire genome from *M. acuminata*) (Purseglove, 1972; Simmonds, 1987; Lessard, 1992). The major groups of bananas are AA, BB and AB (diploid); AAA, AAB, and ABB (triploid); AAAA, AAAB, AABB, and AAAB (tetraploid) (Irish et al., 2014; Ravi et al., 2014; Robinson and Galán Saúco, 2010; Stover and Simmonds, 1987). Significant variability is sometimes found among cultivars within a genomic group leading to further classification by subgroup. Genomic group is followed by subgroup (if any) which is finally followed by the cultivar name. For example, *Musa* AAA (Cavendish subgroup) 'Williams' indicates that the genome of this banana plant is 100% *Musa acuminata*, it is triploid, from the Cavendish subgroup and the cultivar name is 'Williams'. Similarly, *Musa* AAB (plantain subgroup) 'Horn' indicates that the banana plant is triploid with 2/3 of its genome from *M. acuminata* and 1/3 from *M.balbisiana* . It is from the plantain subgroup and the cultivar is 'Horn'. A banana plant with the designation of *Musa* AB 'Ney Poovan'y, means that it is diploid with 50% of its genome from *M. acuminata* and 50% from *M. balbisiana*. The cultivar name is 'Ney Poocan' y. No subgroup is given.

Notwithstanding, expansion of geographical boundaries of banana production due to increased adaptability to abiotic stresses, banana phenology depends to a large degree on both climatic and edaphic conditions which, if suboptimal, will not only result in reduced ornamental appeal but also increased cropping cycle intervals as a result of delayed flower emergence (Fonsah et al., 2004; Robinson, 1996; Surendar et al., 2013; Zhang et al., 2011). Extreme shifts in temperature and uneven rainfall distribution occur regularly in the subtropics and can affect flowering and ultimately dictate where and how banana plants can be grown (Smith et al., 1998). Environmental factors: Temperature, water supply, light, humidity, and soil structure will impact the rate of various processes in the banana plant (Turner, 1995). These conditions are consistent and conducive for year-round banana production in the tropics but some become limiting in the subtropics which typically delays flowering and forces the completion of the banana plant life cycle to span the equivalent of two growing season of the typical annual temperate crop. Flower initiation occurs without evident visual cues, but it is accepted the flower initiation typically occurs after the accrual of a critical cumulative leaf surface area that corresponds to the production of 37-46 leaves $cycle^{-1}$ (Vargas et al., 2008).

In contrast to many fruit crops in more temperate regions that exhibit predictable flowering and fruiting stages that coincide with particular seasons, banana flowering is largely unpredictable and seems to be independent of temperature and light (Robinson and Human, 1998). Added to the unpredictability of flowering is the effect of environmental conditions which impact flower initiation. Several attempts during the early and mid-20^{th} Century were made to at least describe the origin and development of the banana inflorescence but exact stimulus of flower initiation remains unknown (Fahn, 1953; Simmonds, 1959). Despite the mystery that surrounds floral initiation in bananas, certain changes in the shoot apex of bananas as they transition from vegetative to flowering stages can be observed. Pre-floral redistribution of growth takes place in the axis. The tip of the apex grows in length becoming more acute, the apex continues to rise and as it rises from ground level to a level above existing leaf bases, transition from vegetative stage to the floral stage has begun. Cells beneath the tunica-mantle of the apex, which are normally quiescent, begin to divide. Growth at the bases of previously emerged leaves decreases and floral bracts are formed in place of leaf primordia. After transition to the floral or reproductive stage is complete the extension of the axis follows the same path as developing and emerging leaves being protruded up the center of the pseudostem through the top of the plant.

Phenological and morphological responses of banana plants to changes in environmental conditions are an integration of many processes operating over time and are measures of plant vigor and hence hastening towards maturity (Turner, 1995; Vinson et at., 2015; Vuylsteke et al., 1996). Phenological and morphological assessments are therefore paramount in determining production and economic potential of bananas cultivated in the subtropics (Robinson and Galán-Saúco, 2010). Phenological studies provide insight into the developmental process of a crop so that growers can dedicate the bulk of resources when developmental rates are highest. This serves as a signal as to when to reduce inputs when development has been slowed. Phenological studies also reveal most ideal and economically significant cultivars for a region (Cruz da Silva et al., 2010; Fonsah et al., 2007; Robinson, 1996; Turner, 1995); provides knowledge concerning planting date so that harvest coincides with a particular market during a period of low crop volume (Fonsah et al., 2004); and aids in forecasting crop volume and duration of crop season according to date of flowering (Robinson, 1996). For example leaf emergence rate (LER), cumulative leaf number (CLN) produced by a plant per year and the interval between flower emergence and harvest (E-H) are factors used to determine production potential of bananas. Banana cultivar ‘Dwarf Cavendish’ a cultivar belonging to the Cavendish subgroup, was shown to produce 25 leaves prior to flower emergence and has an E-H interval of 113-212 days (Kuhne, 1980) and has demonstrated adaptability to extremes of climate (Kuhne, 1975). Comparatively, another cultivar of the Cavendish subgroup ‘Williams’ demonstrated increased yield due to the elimination of a condition known as choke throat which occurs in shorter varieties but also demonstrated an increase in “November dump”, a condition that is a result of winter time flower initiation (Fahn et al., 1961; Robinson, 1982). A comparison of ‘Dwarf Cavendish’ and ‘Williams’ revealed that increased pseudostem height by 44% in the first ratoon plants (R_1) over the original (P) plants, while pseudostem height increased by only 25% in ‘Dwarf Cavendish’(Robinson and Nel, 1985). Additionally, ‘Williams’ produced more leaves per plant, had a slower LER which combined, resulted in longer cycle times. During the life of the plant, 26-50 leaves are produced (Stover, 1979; Turner et al., 2007).

Phenological and Morphological Factors

Cumulative leaf number (CLN) range required before the emergence of the inflorescence varies and has been reported to be 37-46 leaves cycle^{-1}. Previous studies have found this number to be as low as 25 leaves and as high as 60 leaves (Turner et al., 2007; Vargas et al, 2008). In the subtropical region of Nelspruit, S.A., a comparison of LER of banana plants at various densities during the most active growing months was 1.5 – 3.5 leaves month^{-1}. Highest planting density of 2,222 plants ha^{-1} presented a range of 1.5 – 3 leaves month^{-1}, while the lowest planting density of 1,000 plants ha^{-1} presented LER of 2 – 3.5 leaves month^{-1}.

LER

Foliar phenological attributes such as leaf emergence rate (LER), leaf area (LA) and leaf area index (LAI) are the most important to consider prior to shooting and flower emergence as leaves are the primary interceptors of radiant energy from the sun. Moreover, LER is the most sensitive measure of soil water status (Kallarackal et al., 1990; Turner and Thomas, 1998). Soil water deficit of 21 kPa is sufficient to reduce LER by half while a 40 kPa soil water deficit was necessary to reduce transpiration rate by half indicating that LER is a more sensitive measure of soil water status than stomatal closure. Moreover, LER is a measure of the advancement of the plant towards maturity (Turner, 1998). In subtropical climates, banana growth rates are prolonged considerably during the winter month as evidenced in reduction in LER (Tuner, 1971). Under tropical conditions leaves emerge every 8.3 d to 12.8 d until the appearance of the inflorescence and results in the production of 37-46 leaves cycle^{-1} (Vargas et al., 2008). As the leaf emerges through the top of the plant, it is fully matured and in a vertical rolled state known as a “cigar” (Skutch, 1930; Stover and Simmonds, 1987). Management inputs such as irrigation, fertility and weed control must be adequately applied during periods of increasing LER. If management is insufficient LER will be slowed and harvest will be delayed by several weeks or months (Surendar et al., 2013).

LAI

Leaf area is used to calculate the leaf area index (LAI) which is the total leaf area of a plant or plant canopy per unit area of ground occupied by the plants. LAI indicates the capacity of a plant or plant canopy to intercept solar radiation and synthesize carbohydrates using CO_2 that is taken into the leaves through stomates. Crop yield is not correlated with amount of solar radiation received but rather it is correlated with the amount of light received by the plant canopy (Monteith, 1981). LAI varies depending several factors such as plant size, plant spacing, and season and ranges from 2-5 (Turner et al, 2007).

Number of standing leaves.

Number of standing leaves (NSL) is a measure of the amount of photosynthesizing leaf surface area maintained by the plant at any moment in time. This variable is especially important during bunch development as no more leaves are produced after flower emergence and a minimum of four leaves is required to mature a bunch (Robinson, 1996). The life span of individual leaves ranges from 71 to 281 days in the subtropics and up to 150 days in the tropics (Stover and Simmonds, 1987; Summerville, 1944). During the life of the plant, 26-50 leaves are produced and 10-14 leaves are present on the plant at single time (Stover, 1979; Turner et al., 2007).

Planting to harvest duration (PTH)

Depending on the locale and cultivar, planting to harvest duration (PTH) can last from 9 months to as long as 20 months (Fonsah et al., 2004; Robinson, 1996). Along with yield, consideration should be given to PTH as shorter maturing cultivars can enter the market sooner and provide reduced liability due to disease incidence as well as mechanical mishap and damage as a result of climate (Cruz da Silva et al., 2010; Fonsah et al., 2004). In tropical climate of Roraima, Brazil, along with other developmental parameters, PTH of several cultivars was analyzed. The cultivar ‘Nanicão’ exhibited one of the longest PTH - 296 d. ‘FHIA-2’ had one of the shortest PTH duration at 234 d. PTH duration was similar to ‘Prata Anã’ (239.7 d) and ‘Grand Nain’ (241.3 d). In the subtropical region of Florida, USA, cycle duration was decidedly longer. Banana cultivars ‘Bom’ and ‘Pelipita’, though they produced a significantly higher bunch weight

(6.8 kg and 6.5 kg respectively) than other cultivars exhibited the longest cycling times of 475 d and 500 d respectively. 'Gipungusi', demonstrated the shortest cycling time at 343 d (Ayala-Silva et al., 2008). Additionally, bunch development of cold-tolerant, sort-cycle cultivars had PTH duration of 175 days in Georgia, USA (Fonsah et al. 2007).

Pseudostem height

'Bom' exhibited the highest productivity index (100 x bunch weight/ cycling time) at 1.43 this was followed by 'Gipungusi', 'Pelipita', 'Cacambon' and 'Blue Torres Straight Island' (1.33, 1.30, 1.20, and 0.86 respectively) (Ayala-Silva et al., 2008). Plant height at 16 months after planting (Krewer et al., 2008) when measured from the base of the plant to the base of the most recently expanded leaf ranged from 1 m to 1.35 m among medium height bananas (1 m to 1.49 m) (Fonsah et al., 2004). 'Grand Nain' cultivated in this location presented with plant height of 1.06 m which is approximately that of 'Grand Nain' at flowering produced in the tropics of Roraima, Brazil (Ayala-Silva et al., 2008; Krewer et al., 2008). Shorter plants are more desirable as taller plants are more prone to lodging due to high winds or heavy crop load (Cruz da Silva et al., 2010). Method of measuring plant height at this location was not mentioned. Number of leaves present ranged from 7.5 – 14.6 during the first year and 7.0 – 14.8 the following year.

Low temperature is a major constraint for banana production in the subtropics, the type of cold weather and stage of plant development play a role (Danielles, and O'Keefe, 2012). There are many differences in response to temperature and these responses to cold vary genetically – for example optimal temperature for dry matter accumulation for 'Williams' is 20 °C while optimal temperature for LER is 30 °C (Turner, 1994). Furthermore, *Musa balbisiana* and 'Highgate' (AAA) have similar base temperatures for

LER and theoretically can be expected to perform similarly in the subtropics; however, leaves of ‘Highgate’ are more susceptible to low temperatures than *Musa balsbisiana* and as a consequence perform poorly (Turner, 1994). Leaves of FHIA-01 (‘Gold Finger’ AAAB) and FHIA-18 (‘Bananaza’ AAAB) remain green a low temperatures and have higher dry matter accumulation as a rate of higher photoassimilation rates compared to ‘Williams’ (Daniells and O’Keefe, 2012).

Banana plants established in at the University of Georgia Bamboo Farm and Coastal Gardens in Savanah, GA (USDA hardiness zone 8a) exhibited vigorous growth and 51% of the total planting flowered and set fruit four months after transplanting (Fonsah et al., 2010). Cultivars included ‘Novaria’, Blue Torres Straight Island’, ‘Cacambou’, ‘Gold Finger’, ‘Chinese Cavendish’ and ‘Veinte Cohol’. Of these cultivars ‘Veinte Cohol’ was the only cultivar to be considered short cycle because all plants of this cultivar flowered in sufficient time to reach maturity. Other cultivars ‘Chinese Cavendish’ and ‘Novaria’ also showed qualities characteristic of short cycle bananas but more research is needed for a more definitive conclusion (Fonash et al., 2010). Conversely, a study conducted in the same location revealed that an orchard established in March did not provide adequate time for fruit production during the first season as the suboptimal cultural practices, low temperatures and frost converged to delay fruiting in the initial plant crop (Fonsah et al., 2004).

A banana orchard was established at the Auburn University campus in June, 2011. All cultivars exhibited tolerance to cold temperatures. Short season cultivars 'Cacambon', ‘Praying Hands’, 'Kumunaba', 'Raja Puri', 'Belle', and 'Kandarian' were included in the study. In 2012, 'Cacambon' and 'Blue Torres Straight Island' and ‘Praying Hands’ bloomed and set fruit. The cultivar 'Cacambon' produced 10-15 fingers per hand while 'Blue Torres Straight Island' produced between 8-14 fingers per hand while ‘Praying Hands’ produced 3-4 hands with 10-17 fingers per hand. During the 2011-2012 winter seasons banana plants at the Plant Science Research Center, experienced temperatures in the mid to low 20’s (ºF). Growth of banana plants resumed the following spring. Flower initiation and fruit set occurred in nearly 60% of the plants during the second season and 86% the following season. Planting-to-harvest interval ranged from 329 d – 473 d and 405 d – 486 d during the second and third seasons respectively. In 2013, all cultivars, with the exception of ‘Raja Puri’, bloomed and set fruit. Bunch weight ranged from 3.4 – 3.6 kg. Each banana bunch contained 6 – 7 hands and each hand contained 10 – 16 fingers. Although banana plants survived freezing temperatures during winter and early spring and most set fruit, only two cultivars flowered with sufficient time to present mature bunches in the fall before frost in 2012. In Alabama the area presenting the most potential for successful banana production is along the coast as mean monthly maximum and minimum temperatures are within cardinal temperature ranges for 7 months during the year (Alabama Mesonet data 2008-2012) with mean temperatures slightly above range from mid-June to mid-August (Fig 2). Cardinal temperatures for banana production falls in the range of 57 °F -88 °F with optimal range of 72 °F – 88 °F (Robinson, 1996). Thirteen banana cultivars representing three different types were planted in the coastal region of Alabama in Fairhope on June 5, 2013 as follows: ‘Grand Nain’, ‘Dwarf Cavendish’, ‘Dwarf Red’, ‘Dwarf Green’ , and ‘Double’ (Dwarf); ‘Gold Finger’, ‘Viente Cohol’, ‘Raja Puri’, ‘Ice Cream’, and ‘Cordaba’ (medium); and ‘Pisang Ceylon’, ‘Sweetheart’, and ‘Saba’ (tall). Leaf emergence rate (LER), an important indicator of growth, among bananas were 5.0–5.5, 5.7–7.0 and 6.0–8.0 leaves month-^{1} in July, August and September respectively. The leaf emergence rates showed a steady increase and were similar to leaf emergence rates of banana plants produced in other subtropical regions around the world with climates similar to the Alabama coast.

Other Influences of Banana Plant Vigor and Flower Emergence

Water requirements and irrigation

Environmental conditions or cultural practices influence date of flowering in banana by affecting photosynthetic activity. Photosynthetic rate peaks in the morning followed by saturation deficits in the air, high leaf temperatures and partial stomatal closure during the afternoon all resulting in reduced photosynthetic rate (Eckstein and Robinson, 1995a).   Therefore, guard cells may close even if leaves are hydrated (Turner et al., 2007). In order to maintain leaf gas exchange rates soil water potential must not fall below -15 to -20 kPa range (Eckstein and Robinson, 1996). Additionally, bananas grown in the subtropics should be irrigated at intervals of one to two days depending on evaporation rates at a rate of 10 mm d^{-1} (Robinson and Bower, 1987).

Availability of water can be the most limiting abiotic factor affecting banana production in subtropical regions (Turner, 1995). In the Canary Islands in ‘Gande Naine’ (AAA Cavendish subgroup) bananas, finger length and diameter were reduced by 9% and total bunch weight was reduced by 41% from 30 to 17 kg $plant^{-1}$ when water was withheld for 63 days following flower emergence (Robinson and Nel, 1989**).** For satisfactory growth bananas require 2,000 to 2,500 mm of rainfall distributed evenly throughout the year which translates into 25 mm per week (Robinson and Galán-Saúco, 2010). Additionally, stomatal behavior, photosynthesis and transpiration were determined as physiological indicators of water deficits in bananas to determine when irrigation is necessary (Carr, 2009; Robinson and Bower, 1987). The Alabama coastal region experiences a total annual precipitation of approximately 1,600 mm of rainfall the majority occurring from rain events distributed in the active growing months (March – November) and reaching 1,252 mm. this translates into 34 mm of rain each week. Rain events tend to increase from March – August decreasing slightly from September – November with the area receiving an average of 14.6 mm rain per event. Despite the sensitivity of bananas to water deficits, there are few physiological indicators of water deficits (Carr, 2009). Considerable knowledge of water status has been gained through determination of physiological responses of plants in general to both atmospheric and soil water deficits; however, these same physiological responses are not as reliable when the unusual physiology and morphology of banana plants are considered (Turner et al., 2007). Moreover, volumetric or thermodynamic tissue water status of lactiferous plants as in the case of bananas cannot be measured using traditional methods. For example, the Scholander pressure technique is ineffective because of the inability to distinguish between sap in the xylem and latex exudates. (Turner and Thomas, 2001). Conversely measuring the refractive index of the latex exudates was found to be a reliable indicator (Milburn, 1990; Thomas and Turner, 2001). In 'Dwarf Cavendish' (AAA Cavendish subgroup) stomata experience partial closure beginning four hours before sunset, but when soil water was depleted by approximately 33% the duration of stomatal opening occurred later in the day at mid-morning with stomata on the bottom surface closing first (Shmueli, 1953). When soil water depletion reached 66% stomatal opening occurred early in the morning and the degree of opening decreased throughout the day with stomata on both top and bottom leaf surfaces behaving similarly (Shmueli, 1953). Opening of the stomatal aperture is controlled by guard cell turgor and can operate independently of leaf water status. This is due to the fact that stomata also respond to water vapor in the air. Moreover, transpiration rates are maintained even when soil water potential fall to -80 kPa when humidity is high as opposed to -20 kPa in low humidity (Robinson and Bower, 1987; Shumueli, 1953).

Several studies have been conducted to measure the response of supplemental irrigation. In New South Wales, an irrigation regime that allowed available water depletion to reach 10%, 20, 40 and 70% before re-establishing field capacity, through irrigation using under-canopy sprinkler produced the highest yield in the ratoon crops when averaged over three years (Trochoulias, 1973). This treatment yielded twice as much fruit as the rain fed control treatment. This required the addition of 8 mm of water every 3-5 days when there was no rain. Conversely, on the east coast of Australia, water regimes that ranged from 0 to 1.20 times Epan at increments of of 0.2 revealed that irrigation had little effect on yield due to ample rain lessened the need for supplemental irrigation, but water applied at a rate of 0.6 X Epan is recommended (Trochoulias and Murison, 1981).

Planting Density

Planting density for bananas is a complex integration of factors such as cultivar, soil fertility, sucker selection, management level, wind speed and topography that must be evaluated for each plantation location (Robinson and Nel, 1988). Plant density in a banana plantation is critical because it determines yield, fruit quality and cycling time and once it has been set it is not easily adjusted (Langdon et al., 2008). Also, banana in the subtropics should be spaced at a maximum to insure pseudostem temperatures remain high enough to hinder flowering (Robinson and Nel, 1985). When variations in climate are considered, the effects of planting density on bananas are more striking. One characteristic of banana plantations regardless of location is the pronounced increase in crop cycle duration in response to high planting densities. In studies conducted in the tropics harvest was delayed as long as 4 or 6 month when crop density was increased 4-fold or even doubled (Chundawat et al., 1983; Daniells et al., 1985). In the subtropics, crop cycle in the ratoon crop increased 1.5 – 3 months with 1.5 – 2.5 fold increases in planting density.

In the subtropics of Australia, 'Williams' banana (*Musa* AAA, 'Cavendish' subgroup), in response to increasing plant densities of 1000, 1250, 1666, and 2222 exhibited increased pseudostem height, leaf area, number of functional leaves at harvest and LAI from the parent crop until the second ratoon crop (Robinson and Nel 1988; Langdon et al., 2008). Increase in canopy was responsible for the extension in crop cycle from planting to R3. Bananas planted at a density of 1000 plants ha^{-1} were able to complete four crop cycles in the same period bananas planted at 2222 plants ha^{-1} completed three. LER was reduced by up to five leaves annually with an increase in plant density from 1000 to 2222 plants ha^{-1} which resulted in six more leaves produced in the 2222 plants ha^{-1} density which allowed only 14% of radiation to through the canopy beyond the recommended 10% (Turner, 1982; Robinson and Nel 1988). Yield potential should be related to the characteristics of the canopy and not necessarily crop density (Robinson and Nel, 1988). Optimal plant density was extrapolated to be from 1800-2000, but when long-term effects of crops beyond the second ratoon until are considered, a cop density of 1666 plants ha^{-1} is recommended (Robinson and Nel, 1989). Lower crop densities are desirable as increased crop densities result in increased plant height, decreased bunch weight and increased harvest cycles (Langdon et al., 2008).

Diseases and nematodes

Several devastating disease affect the Musa species. These diseases are fought by application of chemical and planting of resistant cultivars (Heslop-Harrison and Scharzacher, 2007). Disease is so severe in many regions that planting of GMO (genetically modified organism) plants are being considered despite the resistance of the public.

At the dawn of the banana trade and some years preceding, the industry became highly dependent on a single banana cultivar called ‘Gros Michel’(Musa AAA ‘Gros Michel’)(Chapman, 1997; Kopel, 2008; Stover, 1962). The cultivar was known for its ability to produce massive bunches of large fruit that were flavorful and resistant to mechanical damage (Ploetz, R.C., 2005). Large swatches of land were purchased in the tropics by Multinational corporations, deforested and replanted with monoculture of ‘Gros Michel’. The cultivar was susceptible to a condition which was known as Panama disease. Plantations began to be overtaken by the plant malady, which in response waged chemical warfare. Corporations across the tropics recorded huge losses, some total losses (Ploetz, R.C., 1992). Chemical warfare was waged against the disease sickening many plantation workers and hundreds more acres were deforested and replanted with bananas for a resistant banana, Cavendish (*Musa* AAA Cavendish), was discovered. Prior to the discovery of Cavendish bananas many predicted certain and complete ruin of the banana industry. The causal agent of Panama disease was a fungus *Fusarium oxysporum* f. sp.

Cubense which classifies Panana disease as a type of *Fusarium* Wilt. *F*. *oxysporum* f. sp. Cubense (FOC) is a vascular disease affecting the roots as well as the corm. Infection in fact originates in the roots and spreads through the corm and to the pseudostem. It causes yellowing of older leaves and heavy vascular discoloration.

Fusarium wilt has long been a problem in subtropical regions such as Australia: Initial findings were in Queensland in 1874 (Smith et al., 1998). In the subtropics subtropical race 4 (STR4) which occurs as a result of cooler temperatures and suboptimal production practices has been found in the area (Smith et al, 1998). The disease is also a significant problem in the subtropics of South Africa, Taiwan, Brazil and Canary Islands (Daniells and O'Keefe, 2012). FHIA -01 and FHIA 18 are also thought to resistant to TR4. FHIA-01 ('Gold Finger') a released to Australia in 1995, has exhibited resistance to subtropical race 4 FOC. Other cultivars thought to be resistant to TR4 and STR4 are 'Bananaza', SH-3656, and Pisang Ceylon (AAB). Since that time, many other diseases of bananas and plantains have been discovered. Some of the more economically important diseases are listed here.

In recent years, another condition is known as Black sigatoka leaf spot or black leaf streak disease caused by the fungus *Mycosphaerella fijiensis* has caused significant crop losses up to 50% (Heslop-Harrison and Scharzacher, 2007). A pale yellow or dark brown streak 1-2 mm in length appears on the lower surface of leaves. The disease progresses through several stages with increasing from minute specks to more pronounced spots along the border of a leave resulting in a streak (Stover and Simmonds, 1987). Currently the disease is controlled through harsh environmentally damaging chemicals; however, there are some Musa sp with some genetic resistance (Heslop-

Harrison and Scharzacher, 2007). FHIA-01 and FHIA-18 have exhibited resistance to this disease.

Bunchy top is caused by a luteo virus (spherical 25 nm virus particle) and it is spread via an aphid vector *Pentalonia nigronervosa*. The disease starts as dark green streaks in the petiole and leaf veins. Leaves take on an erect posture and are bunch together at the top of the plant. Cavendish varieties are susceptible but cultivars that have the ABB genome are resistant (Stover and Simmonds, 1987). Disease is controlled by removal of the entire mat of the infected plant and replanting with plants from disease-free regions.

Damage caused by burrowing nematodes (*Radopholus similis*) is caused by the secondary invasion of bacteria and fungi that has advanced to the stele as nematode invasion of the stele is rare (Pinochet and Stover, 1980). There are biological races that differ in pathogenicity and attack specific hosts (Tarte and Pinochet, 1981). Root rot caused by fungi weaken developing roots. Anchoring of the plant is consequently weakened leading to lodging of the plant which is the main reason for economic losses. Other nematode species of lesser economic importance are *Pratylenchus coffeae*, *Helicotylenchus multicinctus*, *Helicotylenchus aricanus* and members of the genera *Meloidogyne* (root knot nematode), *Rotylenchus*, *Scutellonema*, and *Hoplolaimus* (Stover and Simmonds, 1987).

Research Concepts of Reduced Inputs and Plant Cycle Duration Reduction

Cover Crop Usage Promote Sustainable Production of Banana and Plantains

Use of cover crops is one of the most important sustainable practices used in global management strategies in agricultural systems precisely because it improves soil tilth, suppresses weeds and disease, and increases yields of target crops (Lu et al, 2000; Robinson, 1996, Tixier et al., 2011). Cover crop is defined as perennial or biennial herbaceous plants used for their ability to cover soil surfaces for all year or a part of the year (Stone et al., 2005).

Before synthetic fertilizer was developed, cover crops were used to replenish soil nutrients depleted by main crops (Stone et al., 2005). Though cover crop usage in crop production is not a new technology, there has been a surge in the incorporation of cover crops in agricultural systems as it reduces inputs and suppresses pests by reintroducing biodiversity (Tixier et al. 2011). Some other benefits of cover crop usage are control of soil erosion, nitrogen fixation, and increased water holding capacity. Growing concern about the use of pesticides, soil erosion, and depletion of natural resources have prompted shifts towards more sustainable practices such as cover crop use (Lu et al 2000). A case study in the Innisfail district in coastal north Queensland, Australia presented by Bagshaw and Linday (2009) discussed concerns of government and research organizations concerning farm-sourced pollutants and their damage to natural icons such as the Great Barrier Reef and World Heritage-listed rainforest area and banana producer groups' collective intension to demonstrate good environmental stewardship. The banana group Better Banana Business Sustainability (BBBS) group identified high priority environmental areas and practices to mitigate environmental impact. One of the key practices adopted by the group was the use of cover crops. Cover crop usage provided members of BBBS reduced labor and fuel costs and preparation time. Reduced preparation time allowed growers time to manage other areas in their operations. Planting nematode (*Radophilis similis*) reduced nematicide usage and reduced sediment and pesticide transport. Intensive cultural practices used in export banana production systems are usually carried out on bare ground and therefore require large inputs such as pesticides and fertilizers and the use thereof present challenges for delicate environmental systems around the world (Bonan and Prime, 2001) Cover crops have been used in plantation and orchard production where it has mitigated soil erosion, weed infestation and nutrient leaching due to large plant spacing common to these production scenarios. Cover crops usage has increased soil organic matter which has led to increased soil productivity (Baligar et al., 2006). Use of cover crops can lower inputs even when compared synthetic mulch such as polyethylene. For example, in tomato production, hairy vetch (*Vivivia villosia*) required 250 lbs acre^{-1} less than that polyethylene mulch (Abdul-Baki and Teasdale, 1997) and provided a savings of $150 acre^{-1}. Over the course of three seasons, hairy vetch produced higher tomato yields than both polyethylene mulch and bare soil treatments. At the time of this study, return per acre was expected to exceed $44,000 compared to $22,000 and $8,000 acre^{-1} for polyethylene mulch and bare soil treatments respectively. Profitable farms strengthen rural communities allowing farmers to in turn reinvest in the community and enhance the local economy. Use a particular cover crop in an agricultural system must be considered carefully. A suitable cover should produce sufficient biomass in order to compete with weeds for resources while not competing with the main crop (Costello and Altieri, 1994; Tixier et al., 2011). In some instances, cover crops are grown before planting of a main crop. When the cover crop flowers and produces sufficient biomass it is killed and allowed to decompose. The crop residue may be incorporated in the soil or remain on the soil surface. When left on the soil surface, remaining plant residue acts as much as it provides moisture retention and weed suppression. Weed suppression is not only due to the physical barrier of cover crop but also due to allelopathic effects (Mulvaney et al., 2010). As plant residues decompose, phytotoxins are released and affect the growth of weeds and potentially the main crop (Wallace and Bellinder, 1992).

Use of cover crop systems in banana production will involve selecting the most appropriate species that presents the best trade-off between cover crop/weed systems and cover crop/main crop systems (Picard et al., 2010). Cover crops are usually evaluated in terms of yield performance of a main crop in relation to the main crop cultivated on bare ground (Tixier et al., 2010). Benefits of cover crop usage in agricultural systems are measured over several seasons and often require several years to determine. To expedite the selection process of cover crops some studies have employed the use of models to predict the performance of cover cropping systems (Rioche et al., 2012; Tixier et al., 2011). Models have been developed to predict weed populations, weed/main crop interactions, and genotype/environmental interactions (Paolini et al., 2006; Holst et al., 2007; Wang et al., 2007). A study conducted by Tixier et al. (2011) described the use of a model-based system for the selection of cover crops in banana production. The authors developed a model called SIMBA-CC which was based on radiation reception. The system was calibrated to predict the long-term performance of 11 cover crop species. The model was used to access cover crop/weed competition, cover crop/banana crop competition, and longevity of cover crop species grown under the canopy of the banana crop. In this study cover crops represented three families – Fabaceae, Poaceae, and Convolvulaceae. The authors found that the most suitable species in terms of their ability to maximize competition with weed species while minimizing completion with banana crop were *Alysicarpus ovalifolius*, *Cynodon dactylon*, and *Chamaecrista rotundifolia*.

Ripoche et al. (2012) conducted a similar study using a model called SIMBA-IC. This model simulated nitrogen and light partitioning and cover crop management at various zones in relation to banana crop placement. In the study the authors assessed banana yield and N losses in different cover management and fertilization scenarios. Zones in the banana field consisted of banana rows (BR); small inter-row (SIR) which was the area between two BRs; Inter-row (IR) which was the immediate area along the banana row but opposite the BR; and large inter-row (LIR) which was the area separated from the BR by the SIR. Cover crop treatments used in the study were *Brachiaria decumbens* (BD) and *Cynodon dactylon* (CD). A bare soil (BS) treatment was also included. The authors determined that simulation results were consistent with actual field observations and that the impact of cover crop or fertilization on agronomic and environmental performances can be realistically simulated. They concluded that in order to strike a balance between nitrogen leaching and banana yield, management practices should favor N stress in banana crop and consequently minimal reduction of yield.

Improve light penetration in lower canopy leaves

In cooler subtropical regions, the interval between late and early frosts is comparatively shorter. In order for bananas to reach maturity before the late frost, shooting and emergence of banana flowers should begin during the month of July through August in order that there is enough time for sufficient maturity to occur for the developing bunch. Studies should be conducted that investigate practices that can potentially decrease cropping cycles so that production of bananas fits within the interval of early and late frosts and conform to an annual cropping system found in crops such as peach and apple. Plastic mulch and fabrics have previously been evaluated for use in deterring insects that cause damage to plants or vector disease-causing agents such as fungi or bacteria. Improved yields of tomatoes were found as a result of colored mulches (Csizinszky et al., 1995). Aluminum mulches have been shown to repel thrips and aphids – two important disease-vector organisms (Adlers and Everett, 1968; Brown and Brown, 1992; Wolfenbarger and Moore, 1968). More recently, white reflective fabric improved light environment, increased photosynthetic activity by as much as 95% and increased yield by 18% in mature, low-density 'd' Anjou' pear orchards (Einhorn et al., 2012). Leaves 2 -5 of the banana canopy profile are the most photosynthetically active (Robinson and Galán Saúco, 2010). Rate of photosynthesis declines from leaf 6 and below.

Increased planting density improves leaf area index (LAI) of a planting (Robinson and Galán Saúco, 2010). Increased LAI in turn increases the amount of PAR banana leaves receive which leads to improved yields. However, delayed cropping cycles and increased plant height in high density plantings are the result of increased number leaves and slower leaf emergence rate (Chundawat et al., 1983; Daniells et al., 1985; Robinson and Nel, 1988; Turner, 1982). Increased light penetration reduces shading which will increase LER (Robinson, 1996). This is the reason lower density plantings (<2,000 plants ha^{-1}) are desired in the some regions in the subtropics. Increased intra canopy light interception may also decrease leaf senescence. Foliar longevity influences the number standing leaves on a plant which can shorten the cropping cycle by enhancing the amount of dry matter produced. At the time of bunch formation higher number of leaves present improves maturation of the developing bunch.

Determination of pseudostem survival of low temperatures

Banana is a tropical plant that thrives in climates where the mean annual temperature does not fall below 20°C (Damasco et al., 1997); however, mean annual temperatures in many subtropical regions fall below 9°C. This presents a significant hazard to production and indicates that low temperature (LT) is the most limiting environmental constraint in subtropical climates (Bertamini et al., 005; Boyer, 1982; Noctor et al., 2002; Zhang et al., 2011). Therefore, controlled environment studies that involve tolerance of banana plants to absolute minimum temperatures similar to those that usually occur in the coastal region of Alabama should be conducted.

Range of LT is 0-15ºC for plants that originate from temperate climates and 10-25ºC for plants of tropical and subtropical origin (Hola et al., 2008). Ideal temperature for banana production falls in the range of 14 °C -31 °C with optimal range of 22 °C – 31 °C (Robinson, 1996). Alabama's coastal region boasts potential for successful banana production owing to the fact that mean temperatures are within the acceptable range for 7 months during the year (Alabama Mesonet data 2008-2012) with mean temperatures slightly above range from mid-June to mid-August.

Foliar damage to bananas occurs when night temperatures are 0 °C – 6 °C and results in yellow leaves caused by chlorophyll destruction, while the simultaneous cessations of LER and plant growth occurs when mean monthly minimum temperature falls to 9 °C or when mean monthly temperature falls to 14 °C (Robinson and Galán Saúco, 2010). Additionally, flower initiation that occurs during periods of LT result in malformed bunches that are reduced in size. This phenomenon was demonstrated in a study conducted in South Africa. Bunch mass and number of hands per bunch were reduced by 35% and 23% respectively when flower initiation occurred during the winter in ‘Williams’ (AAA) (). Low temperature reduces photosynthetic capacity through photoinhibition - a broad term that can suggest a protective, regulatory mechanism in the phototsystem II (PS2) centers or photo damage to photosynthetic cellular machinery, and it is a result of photon energy absorbed in excess of the capacity of the electron transport systems in leaves (Bertamini et al., 2005; Huner et al., 1998). Photoinhibition increases with decreasing temperatures and increased photon irradiance (Zhang et al., 2011). Classified among the first symptoms of LT are extensive damage to plants at the cellular and sub-cellular levels such as damage to key proteins, rupturing of thylakoid membranes and consequently disruption of photochemical activity through change in the ultra-structure of chloroplasts (Hola et al., 2008; Zhang et al., 2011). These phenomena that occur during periods of LT can also result in production of damaging reactive oxygen species. Reactive oxygen species (ROS) are produced during normal physiological processes as byproducts of aerobic metabolism (Apel and Hirt, 2004). During long-term exposure to LT, however, high levels of ROS accumulate in cells in plant leaves (Zhang et al., 2012). ROS such as peroxide, superoxide, hydroxyl radicals and singlet oxygen are extremely toxic to plants and react with DNA, proteins, carbohydrates, and lipids and cause cell death (Zhang et al., 2011).

Plants are able to counter the effects of ROS by both enzymatic and nonenzymatic scavenging mechanisms; nevertheless, once balance between production and scavenging of ROS is disturbed by either biotic or abiotic phenomenon, ROS levels rise within cells which can cause irreversible damage that lead to tissue necrosis and ultimately to plant death (Apel and Hirt, 2004; Rebeitz et al.,1988). Some plant species such as grape (*Vitis vinifera*) and spinach (*Spinacia oleracea*) have shown some resiliency to LT-induced photoinhibition. The D1 protein center within PS2 complex, often damaged by photo irradiation, is replaced regularly and it was hypothesized that plants capable of sustaining adequate replacement rates are able to maintain photosynthetic levels (Andersson and Aro 2001; Zhang et al., 2011). Likewise, plantain cultivars such as ‘Cachaco’ (*Musa paradisiaca* ABB cv. Dajiao) have exhibited tolerance to LT when compared to a dessert banana such as ‘Williams’ (*Musa acuminata* AAA cv. Williams) which is susceptible to LT, (Zhang et al., 2011). When grown in day and night temperature as low as 7ºC, DPPH scavenging activity was lowered by LT in ‘Williams’ but was unchanged in ‘Cachaco’ (Zhang et al., 2011).

In subtropical regions where mild climatic conditions allow banana production to continue throughout winter, banana leaf production may simply be slowed or stopped altogether. However, as a consequence of more marginal climatic conditions in other regions of the subtropics, wintertime banana production does not occur, as sub-freezing temperatures render leaf destruction complete and the leaf sheaths, compressed to form the pseudostem are left to protect the remaining developing leaves within the axis of the pseudostem as well as subterranean leaf primordia and apical meristem. Banana production will, therefore, depend on cold tolerance of the pseudostem as new leaves will be regenerated when environmental conditions become more conducive for banana production.

Formation of ice crystal in the apoplasts of and between cells is a dehydrative process because as ice crystals form in the apoplast, water is drawn out of the cytosol. For example, as much as 90% of osmotically active water is drawn out of cell when temperatures reach -10 °C (Thomashow, 1999). However, the primary reason for plant death as a result of LT is injury to plasma membranes as a result of expansion-induced lysis (Smallwood and Bowles, 2002) complicated further by perturbations in electrical potential or loss of osmotic behavior upon thawing of plant tissues (Thomashow, 1999; Steponkus, 1984). Plant survival of sub-freezing conditions will depend on the tendency of plant tissues to tolerate or avoid freezing. Freeze tolerance occurs when ice crystals are allowed to form in the apoplast. Formation of ice crystals in the apoplast will draw water out of the cytosol and prevent the formation of ice crystal in this region of the cell, but sections of membrane must be deleted through vesiculation or conserved through invaginations to accommodate changing cell volume and return to pre-freeze configurations as ice thaws (Smallwood and Bowles, 2002). Freeze avoidance prevents formation of ice crystals in the cytosol through supercooling; however, this strategy is effective when exposure to subfreezing temperatures is brief as nucleators - initiators of ice crystal formation, in the environment are abundant (Smallwood and Bowles, 2002). Certain plant species that have been acclimated to draught conditions have subsequently exhibited cold tolerance (Serrano et al., 2005; Wong et al., 2005). Changes that occur at the cellular level as a result of water deficit occur also as a result of exposure to LT (Medeiros and Pockman, 2011). This is significant because banana cultivars that have *balbisiana* as part of their genetic make-up tend to have tolerance to draught and many factors associated with LT are shared with other abiotic stresses such as draught and salinity and it has been suggested that expression of cold tolerance may involve several parallel pathways that can lead to activation of a 'suite' of genes involved in tolerance to LT (Smallwood and Bowles, 2002; Xin and Browse, 2000). Additionally, ABA, if applied exogenously can impart tolerance to LT in several plant species (Chen et al., 1983). Studies show that ABA levels increase as a response to LT and increases tolerance to LT (Chen et al. 1983). Also, some studies in LT seem to suggest that calcium plays a role in cold acclimation. Initially, after expose to LT there is an influx of calcium ions to the cytosol from the apoplast (Knight et al., 1991; Smallwood and Bowles, 2002). It has been shown that calcium is necessary for the full complement of cold tolerance gene expression in *Arabidopsis* (Kaye et al., 1998).

As part of the assessment of banana production along the coast of Alabama, cold studies that involve pseudostem tolerance to subzero temperatures should be conducted. Difference in responses to LT may be found among different banana cultivars. A study revealed that a clone of 'Williams' banana cultivar, W811 exhibited the smallest decrease in photosynthetic rate and stomatal conductance when compared to three other clones of the same cultivar after exposure to LT for 48 and 72 h signifying greater tolerance to LT (Zhang et al., 2012). Therefore greater differences among cultivars from diverse genetic backgrounds are expected. In relation to LT, plant responses can be categorized in two ways: Adaptation or acclimation. As previously defined (Huner et al., 1998) adaptation to LT is the result of genotypic response to long-term exposure and genotypic alterations as a result of LT are stable and persist in a population throughout subsequent generations. Conversely, acclimation is a phenotypic response to an environmental factor that doesn't result in genetic change initially but, long-term can lead to adaptation. Cold acclimation, exposure to LT above 0 °C has historically been known to increase tolerance of LT below 0 °C. Previous studies have shown that plants at the cellular level respond less to absolute temperature and more to changes in temperatures (Minorsky and Spanswick, 1989).

Conclusions

Bananas possess unique potential as a specialty crop for Alabama because they are the leading import fruit crop in the US and they are intrinsic to many cultures which, through increased immigration, have a growing presence in the US creating further demand and greater potential for banana specialty markets within the agricultural sector (Ayala-Silva et al. 2008; Cruz da Silva, 2010; Fonsah et al., 2007). Moreover, Alabama's climate along the gulf coast is favorable for production of bananas which have some measure of cold tolerance and shorter production cycles in comparison to banana cultivars that are cultivated in the tropics. Alabama and the Southeastern region of the United States in general have historically been proving ground for several specialty or exotic crops such as Satsuma mandarin which was introduced to the state in 1898 from Japan (Ebel et al., 2008) and Kiwifruit, a native of China, commercially produced in California since the late 1960's is being tested to determine feasibility for production (Bernie et al., 2009). Subsequently, kiwi varieties AU Golden Dragon and AU Golden Sunshine were developed and released through a joint venture between Auburn University Department of Horticulture and the Fruit and Tea Institute of Hubei Provence, China. Other crops include Chinese chestnut (*Castanea mollissima*), Asian pear (*Pyrus pyrifolia*), Oriental persimmon (*Diospyros kaki*), pomegranate (*Punica granatum*), Mayhaw (*Crataegus* Sp), pineapple guava (*Acca sellowiana*), white mulberry - (*Morus alba*) food source for the silkworm moth (*Bombyx mori*) for production of silk, sisal (*Agave sisalana*), cotton (*Gossypium hirsutum*), and wine grape (*Vitis vinifera*) (Lamberts, 1993; Pauly, 2007; Walker et al., 2014). Production of these exotic crops in the variable and extreme climate of the subtropics encountered varying degrees of success and failure. Banana crops themselves are fraught with innate challenges such as plant responses to crop density, unique developmental responses to a given climate and varietal non-conformity over flower initiation which is apparently initiated by an unknown elicitor without regard to light quantity and temperature. As was with previously introduced exotic crops, navigating these formidable challenges in the subtropics will be critical to successful banana production along the coast of Alabama.

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Chapter II

Exploring the Use of Cold-Tolerant Short-Cycle Banana Cultivars for Fruit Production in Coastal Alabama

A phenological study was designed to determine the feasibility for producing bananas in the subtropical region of Coast of Alabama. Thirteen Cavendish and non-Cavendish banana cultivars planted at a 2.4 m x 3 m spacing. Cultivars were separated according to vigor as dwarf, medium and tall and treated as separate experiments. The study followed a completely randomized design with 6 single-plant replication. Pseudostems among dwarf cultivars increased over 100% between 34 days from planting (DFP) and 59 DFP and by 62% between 59 DFP and 95 DFP. The mean number of leaves sustained by dwarf cultivars ranged from 5 at 60 DFM to 14 at 208 DFM. Phyllochron, as measured by LER, ranged from 5 leaves month^{-1} during the warmest parts of the season to 1 leaf month^{-1} when temperatures were cooler. Medium cultivar 'Cardaba' consistently produced among the tallest pseudostems while 'Gold Finger' produced among the shortest pseudostems. 'Gold Finger' typically produced the lowest height: circumference ratio (HCR) which indicated a stronger pseudostem. Cultivars were able to support a similar number of leaves (NSL) and a sufficient number of leaves emerged while 'Raja Puri' produced the fewest leaves at each sampling. 'Saba' bananas were theoretically able to intercept more light radiation than 'Pisang Ceylon' and 'Sweetheart' as indicated by LAI. Pseudostem length of 'Saba' bananas was statistically longer than 'Pisang Ceylon' and 'Sweetheart' for most of the season. Tall bananas were able to support fewer leaves after mid-season as NSL decreased after this point. Morphological and phenological characteristics were determined at the time of flower emergence. Pseudostem length of ‘Grand Nain’ in the current study were 58% shorter than ‘Grand Nain’ cultivated in the subtropics of the Canary Islands but were 41% taller than ‘Grand Nain’ bananas cultivated in the subtropical region of coastal Georgia, USA (Savannah) which is in the same USDA hardiness zone . Both cultivars flowered after a CLN of 26.2 and 24.4 leaves plant^{-1} for ‘Double’ and ‘Grand Nain’ respectively. Flower emergence occurred 15 d earlier in ‘Double (160) than in ‘Grand Nain’ (175). Flower emergence occurred earliest in ‘Cardaba’ followed by ‘Gold Finger’ (145 d and 166 d respectively ‘Grand Nain’ had an 83% survival rate while ‘Dwarf Red’ had a 50% survival rate by the end of 2014. Several cultivars demonstrate potential for fruit production in coastal Alabama but phenology is notably lacking in the current study compared to the same cultivars produced in other regions of the subtropics. More phenological studies are necessary to determine cultivars with the greatest adaptability an experience floral initiation and bunch maturity prior to early frost in coastal Alabama.

Introduction

Global production of bananas has been cited at over 100 million metric tons since 2005 making it the 4th most important crop in the world (FAOSTAT, 2013). Bananas are intrinsic to many cultures as they are an important source of food and income and vital to the economies of developing nations serving a variety of functions such as a source of starch, dessert fruit, substrate for beer production, livestock forage, shade, roofing and medicinal purposes (Ayala-Silva et al. 2008; Cruz da Silva, 2010; Ouma, et al. 2010). Leaves and ancillary portions of the inflorescence are sold at African and Chinese markets in the US (Fonsah et al., 2004). See Figure 2. 1. and 2. 2. for anatomical descriptions of the banana plant.

Bananas are monocotyledonous, herbaceous, evergreen perennial plants with a center of origin in southeastern Asia and the western Pacific and secondary center of origin in Africa (DeLanghe et al, 2009; Lessard, 1992; Robinson, 1996); however, bananas are imported to the US primarily from plantations in other nations within the topics such as Ecuador, the Philippines, Costa Rica, and Colombia at low prices (Kopel, 2008). Moreover, development of cold-tolerant and short-cycled banana cultivars has led to increased adaptability and expansion of banana fruit production into the variable climates of the subtropics (Lahav and Lowengart, 1998). In the subtropics, bananas are produced in several nations such as Egypt, Israel, Jordan, Crete, Cyprus, Turkey, Lebanon, Arabia, Yemen, Oman, Canary Islands, Madeira, southern Taiwan, People's Republic of China, Asia north of 20º latitude, and Brazil south of 20º latitude (Stover and Simmonds, 1987).

Regions of banana fruit production in the subtropics are largely situated between 20° and 30° north and south of the Equator, but production of bananas is met with the challenges presented by variations between day and night temperature as well as extremes in seasonal temperatures and uneven rainfall distribution (Smith et al., 1998; Robinson, 1996). However, banana studies conducted in the subtropics whether they target commercial banana fruit production, ornamental appeal, optimal plant spacing and arrangement or cultivar performance, continue to demonstrate potential for banana production in the subtropics and their marketability in both local and international venues

(Denger et al., 1997; Fonsah et al. 2007; Langdon et al., 2008; Lessard, 1992; Robinson et al., 1996).

Production of Banana Fruit in Alabama

Potential for banana fruit production as a specialty crop in Alabama lies in global demand, favorable climatic conditions, the need for crop diversity to provide sustainability to farm operations and significant health benefit supplied to consumers. Hawaii is the only state in the US that produces Cavendish bananas on a commercial scale, but non-Cavendish banana fruit has been successfully produced in the southeastern US in Georgia, Florida and Texas (Fonsah et al., 2004; Krewer et al., 2008;). In fact, non-Cavendish bananas have been produced in Florida for more than a century (Fonsah et al., 2004; Ploetz et al., 1999). The banana market in Florida has previously generated $ 2.5 million annually (Fonsah et al., 2007). In the subtropical region of Florida, cycle duration was decidedly longer. Banana cultivars ‘Bom’ and ‘Pelipita’, though they produced a significantly higher bunch weight (6.8 kg and 6.5 kg respectively) than other cultivars exhibited the longest cycling times of 475 d and 500 d respectively. ‘Gipungusi’, demonstrated the shortest cycling time at 343 d (Ayala-Silva et al., 2008). Additionally, in Georgia, there is high demand for banana nursery stock and several banana cultivars demonstrated relative high production of suckers producing 5-6 suckers per plant. Suckers are separated from the mother plant, containerized and retailed for approximately $ 15 each. A spacing of 6 m^2 $plant^{-1}$ therefore could potentially earn $ 133,000 - $ 160,000 ha^{-1} for containerized banana plantlets (Krewer et al., 2008). In Georgia, cold-tolerant, sort-cycle cultivars began producing bunches 25 weeks after planting (Fonsah et al. 2007).

Bananas are the leading import fruit crop in the US where import value rose from $1 billion in 2006 to nearly $2 billion in 2010. Additionally, the influx of immigrants into the U.S. and into the state of Alabama specifically helps to create further demand and greater potential for a banana specialty market within the agricultural sector (Fonsah et al. 2007).

Cavendish bananas were selected as the sole commercial banana due to their resistance to Panama Disease (*Fusarium oxysporum* Cubense) and yield potential by large, Multinational Corporations such as Dole, Chiquita Brands International and United Fruit (Chapman, 2007; Kopel, 2008). This singular focus on Cavendish bananas creates niche market potential for non-Cavendish bananas seldom exploited. There is precedence for the sale of other banana varieties on the market. In the 1880's, for example, U.S. banana markets consisted of a number of cultivars other than 'Gros Michel'- a former industry standard replaced due to its susceptibility to Panama Disease - that were apparently known by name as they were referenced in recipes found in turn-of-the-century cookbooks and magazines (Danielles andO'Keefe, 2012; Soluri, 2002; Stover and Simmonds, 1987).

The climate in coastal Alabama is considered subtropical and is relatively mild compared to other regions and parts of the southeastern US. At the Gulf Coast Research and Extension Center (GCREC) in Fairhope, Baldwin County, AL (30°31'35.018" North, 87°53'44.473" West) mean monthly maximum and minimum temperatures are within cardinal temperature ranges for 7 months during the year (Alabama Mesonet data 2008-2012; Robinson and Galán-Saúco, 2010a) with mean temperatures slightly above range from mid-June to mid-August (Figure 2. 3.). Cardinal temperatures for banana production fall in the range of 57 °F to 88 °F with optimal range of 72 °F to 88 °F (Robinson, 1996). For satisfactory growth bananas require 2,000 to 2,500 mm of rainfall distributed evenly throughout the year which translates into 25 mm per week (Robinson and Galán-Saúco, 2010a). The GCREC site rests on a Malbis sandy Loam. The region also experiences a total annual precipitation of approximately 1,600 mm of rainfall the majority occurring from rain events distributed in the active growing months (March – November) and reaching 1,252 mm. this translates into 34 mm of rain each week. Rain events tend to increase from March – August decreasing slightly from September – November with the area receiving an average of 14.6 mm rain per event.

Health Benefits of Banana Fruit

Fresh bananas provide significant health benefits to consumers. In the US, high incidences of diet-related chronic diseases such as cancer, stroke, hypertension and heart disease persist. Increasing fruit consumption is a strategy of increasing consumption of phenolics and antioxidants which work to counter the damaging and disease-causing effects of free radicals that are generated during normal chemical processes occurring within the human body (CDC, 2013). Current USDA guidelines suggest that fruits and vegetables should make up 50% of meals consumed because of their content of bioactive compounds (Patil et al., 2014). Consumption of fruit, vegetables and grains as part of a regular diet can lead to positive health outcomes (Bellavia et al., 2013). In fact, the World Health Organization (WHO) has promoted the consumption of fruits and vegetables as a means to reduce diet-related health issues (Goldman, 2014). Bananas are not only an excellent source of vitamin B_6 and contain moderate levels of Vitamin C, Manganese, and potassium but they are also a suitable source of phenolics and anthocyanins. Total phenolics of *Musa Cavendish* was found to exist more abundantly in the peel (907 mg 100 g dry wt. $^{-1}$) than the pulp (232 mg 100 g dry wt.$^{-1}$) (Someya et al., 2002).

Many fruit crops exhibit predictable flowering and fruiting stages that coincide with particular seasons; however, banana flowering seems to be independent of temperature and light (Robinson and Human, 1988). The elicitor of floral initiation in bananas is unknown as bananas flower throughout the season without regard for temperature or light. Several attempts during the early and mid-20th century were made to describe origin and development of the banana inflorescence (Fahn, 1953; Simmonds 1959).

Nevertheless, inflorescence is formed without externally evident visual cues. It is accepted however that flowering has occurs after a banana plant has reached a critical cumulative leaf surface area that corresponds to the production of 37-46 leaves cycle^{-1} (Vargas et al., 2008). Flower emergence is said to have occurred when the proximal floral bract opens to reveal the initial female hand on the hanging banana bunch (Robinson, 1996) (Figure 2. 4.). Bunch weight can be affected by the season in which flower emergence takes place. Flowers initiated during periods when temperatures are in excess of the optimal mean temperature of 22 °C produced bunches of correspondingly reduced weight (Stover and Simmonds, 1987). Monitoring LER, number of standing leaves (NSL), and cumulative leaf number (CLN) helps predict fruit production. Abiotic factors such as temperature, irrigation/rainfall and plant spacing affect LER and rate of photosynthesis and will ultimately affect flower initiation and time of harvest.

However, though bananas have wide adaptability and can tolerate abiotic stresses, they respond acutely to their environment and sub-optimal conditions will manifest slow growth, delayed fruit production, reduced quality of fruit and ornamental appeal (Fonsah et al., 2004; Robinson, 1996; Surendar et al., 2013; Zhang et al., 2011). Drastic shifts in environmental conditions such as temperature and rainfall occur regularly in the subtropics and this will impose several constraints on banana markets. Several areas of concern in banana production in the subtropics need to be addressed – the most critical of which are banana phenological responses to a given geographical area. Phenology of bananas is even more difficult to study in the subtropics due to wider variations in temperature than in the tropics so detailed studies become more important where conditions are variable and extreme (Robinson, 1996). The purpose of this project is to determine the best suited cultivars for fruit production and landscape potential of cold-hardy, short-cycled, non-Cavendish bananas in coastal Alabama by evaluating phenological responses and measuring fruit quality through both physiochemical and pomological analyses.

Materials and Methods

Thirteen banana cultivars derived from tissue culture were supplied by Agri-Starts Whole Sale Nursery (Apopka, FL). The cultivars are as follows: ‘Gold Finger’ (AAAB), ‘Saba’ (ABB), ‘Dwarf Cavendish’ (AAA), ‘Pisang Ceylon’ (AAB), ‘Double’ (AAA), ‘Dwarf Green’ (AAA), ‘Dwarf Red’(AAA), ‘Raja Puri’(AAB), ‘Grand Naine’(AAA), ‘Cardaba’(ABB), ‘Viente Cohol’(AA), ‘Sweet Heart’(AABB), and ‘Ice Cream’(ABB). Banana plants were at the 3 to 8 leaf stage upon shipment and were potted in 8-inch containers on 12 April 2013 using Promix plant media (Premier Tech Horticulture, Quakertown, PA). Bananas received a top dress of 15 g of Osmocote 14-14-14 on April 12. Bananas received an additional 100 ml of 20-10-20 at a concentration of 250 ppm $week^{-1}$ beginning April 22.

Bananas were planted at the Gulf Coast Research and Extension Center in Fairhope, AL, USA (30°31'35.018" North, 87°53'44.473" West) on June 6, 2013 after pseudostem length reach a minimum of 61 cm on a Malbis sandy loam (Figure 2. 5.). Bananas were separated by height class: Dwarf (1.5 m -2.5 m); Medium (2.5 m- 4.2 m); and Tall (3.6 m – 7.6 m) and followed an experimental design that consisted of six single-plant replications arranged in a completely randomized design (CRD) with cultivar and days-from-planting (DFP) in a factorial arrangement in 2013. The region of the gulf coast of Alabama experienced uncharacteristic and extremely low temperatures in late December, 2013 and early January 2014 (Figure 2. 6.) Absolute low temperature in the field reached -10 °C. The PC crop succumbed to the low temperatures; however, rhizomes of the PC crop survived and ratoon plants (suckers) were successfully generated from the lateral meristems of the rhizomes and resulted in vigorous plants for the following season (Fig 2. 7.).

In 2014 phenological data was measured from days from mature leaf (DFM) in place of DFP. Mature leaf or F_{10} leaf indicates transition from juvenile stage to vegetative stage and is characterized as having a width at the widest expanse of 10 cm or greater. This occurred on 18 March 2014. Bananas were planted on raised beds 0.9 m and 0.3 m high. Irrigation was supplied through drip tubing (Irrigation Mart, Rushton, LA) that had an emitter spacing of 61 cm. Bananas received irrigation at a rate of 50 mm $week^{-1}$. Bananas were planted at an in-row spacing of 2.4 m and a 3 m spacing between rows. Weeds were controlled by application of Finale® herbicide (Bayer Environmental Sciences, Research Triangle Park, NC) at a rate of (118 $ml \cdot L^{-1} \cdot ha^{-1}$) at 2 application $month^{-1}$.

Lateral meristems were allowed to persist on the corm which necessitated monthly management of suckers. Pseudostems of suckers were cut at soil level and were covered with soil to prevent microbial invasion (Fonsah and Chidebelu, 1995; Robinson and Gálan-Saúco, 2010b).

Phenological data collection consisted of leaf emergence rate (LER), pseudostem height as measured from the ground to the bifurcation formed by the petiole bases of the top two leaves, pseudostem circumference taken at 30 cm, of pseudostem at flowering, DFM to flower emergence (exposure of first flower set of the inflorescence), number of suckers produced, laminal length and width of the third positioned leaf, leaf area index (LAI), number of standing leaves (NSL), ambient and soil temperatures, cumulative leaf production (CLP) . Watchdog dataloggers (Spectrum Technologies, Aurora, IL) were installed on both exterior rows and a center row to measure ambient and soil temperature. Dataloggers were placed at opposing ends of a row as well as at row center. Dataloggers were programed to collect ambient and soil temperature at 30- minute intervals.

Statistics

Data was analyzed using SAS statistical analysis program (Cary, NC). Anova was performed on all growth parameter responses using PROC GLIMMIX. Data were analyzed separately for each year and cultivar size group combination. The experimental design was a completely randomized design (CRD) with a factorial arrangement of cultivars and DFP or DFM. Non-normal counts were analyzed using either the Poisson or negative binomial distribution. Differences among cultivars were determined using Shaffer Simulated method or T-test.

Results and Discussion

Dwarf cultivars were represented by triploid banana plants of the species acuminata (AAA) and all belonged to the Cavendish subgroup therefore there was very little genetic variability (Figure 2. 8.). However, phenological differences were found. In 2013, there was no interaction between the main effects DFP and cultivar in pseudostem height (Table 2. 1. and 2.2). The pseudostem of ‘Dwarf Red was significantly taller than ‘Dwarf Cavendish’ and ‘Double’ with mean pseudostem lengths of 103.6 cm, 85.4 cm, and 85.3 cm respectively. Pseudostems increased over 100% between 34 DFP and 59 DFP and by 62% between 59 DFP and 95 DFP. Pseudostem height increases were less dramatic as temperatures became cooler resulting in an increase of only 8% between 124 DFP and 150 DFP.

There was a significant interaction between DFP and cultivar in pseudostem circumference (Table 2. 3.). Of the five dwarf cultivars ‘Dwarf Cavendish’ followed a significant linear trend between 34 DFP and 150 DFP while the remaining four cultivars followed a quadratic trend. Differences were found among cultivars at 124 DFP and 150 DFP. Pseudostem circumference of ‘Dwarf Red’ was significantly larger than ‘Dwarf Cavendish’ and ‘Grand Nain’ at 50 cm, 42 cm and 40.2 cm respectively at 124 DFP. These differences between ‘Dwarf Red’ and the remaining cultivars expanded to include all with the exception of ‘Dwarf Green’. There were no significant differences in the main effects in the HCR which followed a quadratic trend between 34 DFP and 150 DFP (Table 2.4.).

In NSL, ‘Dwarf Red’ was able to sustain significantly fewer leaves (10.8) than ‘Dwarf Cavendish’ (12.2), ‘Double’ (12.8), and ‘Grand Nain’ (12.3) throughout the growing season (Table 2. 5.). Mean NSL increased by approximately one leaf at four of the five samplings. This suggests that leaf emergence was approximately equal to leaf total senescence.

There was a difference between the main effects of cultivar and DFP in 2013 (Table 2. 6.). Laminal length of ‘Dwarf Red’, and ‘Grand Nain’ followed a significant linear trend while ‘Dwarf Cavendish’, ‘Dwarf Green’ and ‘Grand Nain’ followed a quadratic trend. The largest increase was 91% which occurred between 59 DFP and 94 DFP in ‘Grand Nain.

Laminal width does not change considerably relative to length. Therefore there were few differences demonstrated (Table 2. 6.). Laminal width of ‘Dwarf Cavendish’, ‘Dwarf Red’ and ‘Double’ followed a linear trend while ‘Dwarf Green’ followed a quadratic trend. Few differences were found at 124 DFP and 150 DFP. Width of ‘Dwarf Red’ was significantly larger than ‘Double’ at 124 DFP. This difference expanded to include the remainder of the cultivars by 150 DFP. Lamina exhibited characteristic shredding in response to high winds (Figure 2. 9.).

Leaf area index (LAI) was significantly affected by the main effects cultivar and DFP (Table 2. 7.). LAI increased linearly from 34 to 150 DFP in ‘Dwarf Red’ and ‘Double’ but followed a quadratic trend in the remaining cultivars. Differences were found among cultivars at 124 DFP and 150 DFP. There was a difference between ‘Dwarf Red’ (1.59) and ‘Double’ (0.83) at 124 DFP so was theoretically able to intercept more light radiation. By the end of the season ‘Dwarf Red’ had also had a greater potential than ‘Dwarf Cavendish’ and ‘Grand Nain’ to intercept light radiation.

Phyllochron, as measured by LER, ranged from 5 leaves to 1 leaf month^{-1} when temperatures were cooler (Table 2. 8.). This led to a mean total leaf number that ranged from 18-35 leaves. There was a significant interaction between the main effects once again. ‘Dwarf Cavendish’ produced significantly more leaves during the season than ‘Dwarf Green’ and ‘Dwarf Red’ (Table 2. 9.).

Contrary to results found in 2013 where the interaction between cultivar and DFP were not significant, there was a significant interaction between cultivar and DFM in both pseudostem length and pseudostem circumference in 2014 (Table 2. 10.). Both followed a linear trend. Data were collected on 60, 90, 117, 160, 185, and 208 DFM. HCR increased linearly from 60 DFM to 208 DFM (Table 2. 11.).

There was not an interaction between DFP and cultivar in NSL (Table 2. 12.). All cultivars were able to sustain a significantly higher number of leaves than ‘Dwarf Red’ in 2014 with the exception of ‘Dwarf Green’. The mean number of leaves sustained by dwarf cultivars ranged from 5 at 60 DFM to 14 at 208 DFM.

There was no interaction between DFM and cultivar in laminal length (table 2. 13.). The largest increase in mean laminal length in all cultivars was 67% which occurred between 60 and 90 DFP. There was an interaction between DFM and cultivar in Laminal width. Each cultivar demonstrated a linear increase in laminal width. Differences among cultivars did not occur until 185 DFM and 208 DFM. LAI increased in quadratic fashion and it ranged from a mean of 0.03 to 1.61 indicating that the ability to intercept light increased (Table 2. 14.).

As in 2013, the interaction between DFM and cultivar was not significant in LER. The phyllochron increased from 4 to 6 leaves between 60 DFM to 160 DFM. ‘Double’ and ‘Dwarf Cavendish’ followed a quadratic trend while ‘Dwarf Green’, Dwarf Red’ and ‘Grand Nain’ followed a linear trend in CLN (Table 2. 15.). ‘Dwarf Green’ and ‘Dwarf Red’ produced significantly fewer leaves than all other cultivars by the end of the season.

Phenological data was collected periodically from initiation of the vegetative stage in banana which as indicated by the production of the F_{10} leaf (Robinson and Galán Saúco, 2010c) which measures at the widest point at 10 cm or greater. Banana reached this stage on approximately 18 March 2014. Phenological data were collected 60, 117, 160, 185, and 208 d from the production of the first mature leaf (DFM).

Pseudostem length was affected by an interaction between cultivar and DFM (Table 2. 16.). The cultivars ‘Cardaba’ and ‘Gold Finger’ followed a linear trend while ‘Raja Puri’ and ‘Ice Cream’ followed a quadratic trend. At each DFM ‘Cardaba’ consistently had the tallest pseudostems but were similar to ‘Raja Puri’ and ‘Ice Cream’ at 60 DFM and similar only to ‘Ice Cream’ at 90 DFM and at each sampling thereafter. ‘Gold Finger’ produced the shortest pseudostems which were similar only to ‘Raja Puri’ at each DFM. Pseudostem circumference was also affected by an interaction between cultivar and DFM. Consistent with findings in pseudostem length, ‘Caradaba’ and ‘Ice Cream’ exhibited significantly longer circumferences at most samplings throughout the season.

HCR was not significant during mid-season (117 DFM) or late season (208 DFM) (Table 2. 17.). Most cultivars followed a linear trend with the exception of ‘Ice Cream’ which followed a quadratic trend. ‘Gold Finger’ produced the lowest HCR which indicated a stronger pseudostem; however, HCR of “Gold Finger’ was similar to those of ‘Ice Cream’ and ‘Raja Puri’ late in the season.

Cultivars were able to support a similar number of leaves (NSL) at each DFM. All cultivars followed a quadratic trend as NSL increased at each sampling (Table 2. 18.). Leaves of ‘Gold Finger’ were the smallest as indicated by laminal length and width (Table 2. 19. and 2. 20.). LAI was affected by an interaction between cultivar and DFM and each cultivar followed a linear trend (Table 2. 21.). LAI of ‘Cardaba’ and ‘Ice Cream’ were consistently larger numerically at each sampling and could theoretically intercept more light but LAI of ‘Cardaba’ was statistically similar to most other cultivars throughout the season.

A sufficient number of leaves emerged (Table 2. 22.) at each DFM during the warmer months and decreased as temperatures became cooler. There was an interaction between cultivar and DFM in CLN and all followed a quadratic trend (Table 2. 23.). ‘Raja Puri’ produced the fewest leaves at each sampling.

In 2013, pseudostem length of ‘Saba bananas was statistically higher than both ‘Pisang Ceylon’ and ‘Sweetheart’ for most of the season (Table 2. 24.). Pseudostem circumference of ‘Pisang Ceylon’ bananas was statistically smaller than ‘Saba’ and ‘Sweetheart’ at each DFM. This translated to a statistically higher HCR for ‘Pisang Ceylon’ indicating a weaker pseudostem (Table 2. 25.).

‘Saba’ bananas were able to support a larger number of leaves during the latter half of the season (Table 2. 26.) and exhibited lamina that were statistically of greater length and width than ‘Pisang Ceylon’ and ‘Sweetheart’ for much of the season (Table 2. 27.). Surprisingly, LAI was not significant until 208 DFM (Table 2. 28.). ‘Pisang Ceylon’ had the fewest leaves to emerge (Table 2. 29.) than ‘Saba’ and ‘Sweetheart’ but CLN was similar to ‘Saba’ and statistically smaller than ‘Sweetheart (Table 2. 30.).

In 2014, the pseudostem of ‘Saba’ was statistically taller longer than both ‘Pisang Ceylon’ and ‘Sweetheart’ at each DFM (Table 2. 31.). Both ‘Saba’ and ‘Sweetheart’ followed a linear trend while ‘Pisang Ceylon’ followed a quadratic trend. Pseudostem circumference of ‘Saba’ bananas was statistically the largest. Pseudostem circumference of ‘Pisang Ceylon’ and ‘Sweetheart’ were similar until 160 DFM (Table 2. 31.). Thereafter, circumference of ‘Pisang Ceylon’ pseudostems were the smallest statistically. Smaller circumferences of ‘Pisang Ceylon’ pseudostems resulted in higher HCR and were theoretically more vulnerable to lodging. By the end of the season pseudostems of ‘Sweetheart’ bananas were strongest statistically and less prone to lodging due to high winds or heavy crop load (Table 2. 32.).

Tall bananas were able to support fewer leaves after mid-season as NSL decreased after this point (Table 2. 33.). ‘Saba’ produced the leaves in the largest surface areas of the tall banana as laminal length and width of ‘Saba’ statistically higher than those of ‘Pisang Ceylon’ and ‘Sweetheart’ at each DFM (Table 2. 34. And 2.35.). As expected due to comparatively larger leaf surface area, ‘Saba’ bananas were theoretically able to intercept more light radiation than ‘Pisang Ceylon’ and ‘Sweetheart’ as indicated by LAI (Table 2. 36.).

Floral initiation, yield, and bunch characteristics of the R_3 crop

Sporadic flowering occurred in October, 2014 which did not allow sufficient time for bunch development nor efficient representation from cultivars for statistical analysis. In 2015 in the R3 crop flower emergence began on 28 July. Morphological and phenological characteristics were determined at the time of flower emergence (Table 2. 37.). Among the dwarf bananas, flower emergence occurred in two of the five cultivars – ‘Double’ and ‘Grand Nain’. At the time of flower emergence ‘Double supported a significantly higher number of leaves than ‘Grand Nain’ but both cultivars had a sufficient number of leaves to carry the developing bunch to maturity (Table 2. 38.). Pseudostem length of ‘Double’ was 156.64 cm while ‘Grand Nain’ pseudostems were 149.81 cm. There were no statistical differences found between these two cultivars. Pseudostem length of ‘Grand Nain’ cultivated in the subtropics of the Canary Islands was 58% taller than pseudostems of ‘Grand Nain’ bananas in the current study comparing plants of the same ratoon. ‘Grand Nain’ bananas in the current study were 41% taller than bananas cultivated in the subtropical region of coastal Georgia, USA (Savannah) which is in the same USDA hardiness zone (Galán-Saúco et al., 1992; Krewer et al., 2008).

Both cultivars produces leaves well below the 38-50 leaves expected prior to flower emergence – 26.2 and 24.4 leaves plant^{-1} for ‘Double’ (Figure 2. 10.) and ‘Grand Nain’ (Figure 2. 11.) respectively. Flower emergence occurred 15 d earlier in ‘Double (160) than in ‘Grand Nain’ (175). Bunch weight of ‘Double’ bananas was significantly higher (11.86 kg) than ‘Grand Nain’ (5.76 kg). Bunches of ‘Grand Nain’ bananas cultivated in the Canary Islands were 35 kg on average from 1993 and 1994 production seasons (Cabrera et al., 1998). The number of hands per bunch was similar for ‘Double’ and ‘Grand Nain’, 8.7 and 8.3 respectively. Hand number of both cultivars was decidedly lower in the current study than in bananas cultivated in the Canary Islands (12 hands bunch^{-1}).

Among the medium height bananas all four of the remaining cultivars reached flower emergence. At flower emergence, ‘Ice Cream’ and ‘Cardaba’ retained approximately 13 leaves which was significantly higher than the number of leaves retained by ‘Gold Finger’ and ‘RajaPuri’ at 9.2 and 8.8 leaves respectively. Pseudostem length of ‘Ice Cream’ and ‘Cardaba’ at flower emergence differed significantly from ‘Gold Finger’ but was similar to ‘Raja Puri’. ‘Cardaba’ and ‘Raja Puri’ produced significantly fewer leaves than ‘Ice Cream’ but produced a CLN similar to ‘Gold Finger’. Flower emergence occurred earliest in ‘Cardaba’ which was similar to ‘Gold Finger’ (145 d and 166 d respectively). ‘Ice Cream’ and ‘Raja Puri’ required 58-79 d longer than ‘Cardaba’ for flower emergence to occur. Of the four remaining medium height banana cultivars flower emergence occurred in ‘Gold Finger’ and ‘Cardaba’ such that there was sufficient for bunches to ripen before early frost. Bunch weight of ‘Cardaba’ (7.22 kg) (Figure 2. 12.) was numerically higher than the bunch weight of ‘Gold Finger’ (Figure 2. 13.). ‘Gold Finger’ and ‘Ice Cream’ demonstrated a significantly higher number of hands bunch-1 than ‘Cardaba’ and ‘Raja Puri’.

Of the three tall cultivars, flower emergence occurred in ‘Sweetheart’ and ‘Pisang Ceylon’ but not in ’Saba’. ‘Sweetheart’ (Figure 2. 14.) was the only cultivar to produce mature bunches prior to early frost; however, bunch characteristics of ‘Pisang Ceylon’ and ‘Sweetheart were compared and there were no significant difference found in number of hands bunch^{-1}, total finger number bunch^{-1} or finger number hand^{-1}.

Survivability

Dwarf bananas experienced the most plant mortality in comparison to the other types (Table 2. 39.). Between the parent crop (PC) and R_1 in 2013 and 2014, 83% of

‘Grand Nain’ mats survived while only 50% ‘Dwarf Red’ bananas survived. By the end of 2015, ‘Dwarf Green’ maintained 100% survival. Bananas of the Cavendish subgroup have 100% of their genome derived from *Musa acuminata*, therefore clones of this type tend to be less cold hardy and succumb to low temperatures. It is not surprising that most of the mortality was demonstrated among the dwarf bananas since they were all members of the Cavendish subgroup. Among medium height bananas, low survivability was demonstrated in ‘Veinte Cohol’. Similarly, the genome of ‘Veinte Cohol’ is 100% derived from *Musa acuminata*. Additionally, ‘Veinte Cohol’ is diploid which are known to be less cold hardy than bananas with higher ploidy.

Conclusions

Dwarf banana cultivars responded similarly in phenology to the conditions of the gulf coast of Alabama. This is the result of a lack of genetic variability considering all of the selected dwarf cultivars belong to the Cavendish subgroup and as characteristic of this group, they were all triploid and 100% acuminate which makes them cold sensitive. Moreover, cultivars ‘Dwarf Red’, ‘Dwarf Green’ and ‘Double’ are sports of ‘Dwarf Cavendish’ (Personal communication). The most important cultivars of this group are ‘Dwarf Cavendish’ and ‘Grand Nain’ because of the reliance of Multinational companies on these two Cavendish varieties. The variety ‘Dwarf Green’ had the highest survival rate (100%); however, this variety is considered a banana for home cultivation and has not be considered as suited for commercial production.

Medium height bananas selected for this study demonstrated the most diversity and the most potential as components of a banana niche market for coastal Alabama. ‘Cardaba’ and ‘Ice Cream’ were the most vigorous in terms of pseudostem length and circumference and the number of leaves the plants were able to maintain. All medium height bananas flowered, but only two of the five medium height cultivars developed mature bunches before the early frost. ‘Gold Finger’ was not considered the most vigorous banana in this study but this cultivar along with ‘Cardaba’ was able to produce mature bunches during in both the R_1 crop (data not shown) and the R_2 crop.

Of the tall bananas, floral initiation occurred in ‘Sweetheart’ and mature bunches were produced by the end of the season. ‘Pisang Ceylon’ flowered later in the season and as a consequence, did not produce mature bunches, while ‘Saba’ did not flower in this study.

Diseases such as tropical race 4 Panama Disease (TR4) and black Sigatoka are considered among the most economically important in the industry. The cultivar ‘Gold Finger’ and ‘Sweetheart’ are reported to have resistance to these two diseases. Moreover, they are tetraploids and as a result have more tolerance to cold than cultivars of lower ploidy levels. These qualities along with a demonstrated reliability in fruit set in this study may lead to their selection in Alabama niche market.

Conversely, ‘Veinte Cohol’ is a diploid plant (AA) and is cold sensitive. It was noted by the end of the PC crop (2013) floral initiation had occurred in all ‘Veinte Cohol’ bananas. This observation was made when pseudostems damaged by the severe winter of 2013-14 were cut and removed from the field. When pseudostems of ‘Veinte Cohol’ were cut creating a cross section of the pseudostem, the “true stem” which bares the inflorescence was discovered which confirmed floral ignition had taken place. Moreover the only surviving ‘Veinte Cohol’ plant in the study flowered during the R_2 crop and produced a mature bunch before fall.

‘Veinte Cohol’ is known in the industry to have a short production cycle. Some banana producing regions use an annual planting system where ‘Veinte Cohol’ is planted and is able to flower in a single season reliably. The banana mats are removed and the field is replanted with ‘Veinte Cohol’ the following season. Additionally, ‘Veinte Cohol’ could be used in protective horticulture such high tunnels or greenhouses.

Results to date show promise for banana niche mark in coastal Alabama; however, when phenology and physiology of bananas used in this study are compared with those of the same cultivars produced in other subtropical regions, plant vigor and yield are notably lower in bananas produced in coastal Alabama. Reduced vigor may cause a delay in floral imitation and a corresponding reduction in yield. More phenological studies are necessary to arrive at a more precise determination in the selected banana cultivars adaptability to the region and reliability as a source of bananas for a new and developing banana niche market.

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Table 2. 1 P-values of interaction terms of dwarf, medium, and tall banana cultivars

Variable	**Cultivar* DFP^z 2013**	**Cultivar*DFM^y 2014**
	Dwarf	
Pseudostem Height (cm)	0.1672	0.1271
Pseudostem Circumference (cm)	0.0042	0.5778
Height: Circumference Ratio	0.6210	0.8012
Number of Standing Leaves (NSL)	0.3575	0.4515
Cumulative Leaf Number (CLN)	0.9999	0.0020
Leaf Area Index (LAI)	0.9999	0.9998
Leaf Emergence Rate (LER)	0.2348	0.0020
	Medium	
Pseudostem Height (cm)	<0.0001	0.0042
Pseudostem Circumference (cm)	<0.0001	0.0130
Height: Circumference Ratio	0.2738	0.2386
Number of Standing Leaves (NSL)	0.0027	0.0004
Cumulative Leaf Number (CLN)	0.0308	<0.0001
Leaf Area Index (LAI)	0.0021	0.0088
Leaf Emergence Rate (LER)	0.2348	0.0020
	Tall	
Pseudostem Height (cm)	<0.0001	<0.0001
Pseudostem Circumference (cm)	<0.0001	<0.0001
Height: Circumference Ratio	0.2321	<0.0001
Number of Standing Leaves (NSL)	0.0020	0.0283
Cumulative Leaf Number (CLN)	0.0014	0.9688
Leaf Area Index (LAI)	<0.0001	<0.0001
Leaf Emergence Rate (LER)	0.8731	0.9949

^{z}DFP = Days from planting. Used as a variable in 2013

^{y}DFM = Days from mature leaf used as a variable in 2014

Table 2. 2. Pseudostem length (cm) of dwarf (*Musa* AAA (Cavendish subgroup)) bananas cultivated at the Gulf Coast Rec, Fairhope, AL – parent crop 2013.

Cultivar[z]	Pseudostem Height (cm)	**DFP**[z]	Pseudostem Height (cm)
Dwarf Cavendish	85.4 b[y]	34	30.5
Dwarf Green	94.5 ab	59	64.0
Dwarf Red	103.6 a	95	103.6
Double	85.3 b	125	125.0
Grand Nain	88.4 ab	150	131.0
Sign. [x]			Q***

[z]The Cultivar and DFP main effects were significant
[y]Any two means within a row not followed by the same letter are significantly different at $P \leq 0.05$.
[x]Indicates a significant quadratic effect

Table 2. 3. Pseudostem circumference (cm) of dwarf (*Musa* AAA (Cavendish subgroup)) bananas cultivated at the Gulf Coast REC, Fairhope, AL – parent crop 2013.

Cultivar^{z}	**Days from Planting**^{z}					
	34	**59**	**95**	**124**	**150**	**Sign.**^{x}
D. Cavendish	14.6 ns	22.0 ns	30.6 ns	41.2 b^{y}	42.1 bc	L***
Dwarf Green	13.4	24.8	35.4	46.0 ab	46.0 ab	Q***
Dwarf Red	14.3	25.8	36.4	50.0 a	50.0 a	Q**
Double	13.4	22.0	32.5	39.2 ab	40.2 c	Q**
Grand Nain	12.6	24.0	30.6	42.1 c	40.2 c	Q**

^{z}The Cultivar and DFP main effects were significant

^{y}Any two means within a row not followed by the same letter are significantly different at $P \leq 0.05$.

^{x}Indicates a significant quadratic or linear effect

Table 2. 4. Height: circumference ratio of dwarf (*Musa* AAA (Cavendish subgroup)) bananas cultivated at the Gulf Coast REC, Fairhope, AL – parent crop 2013.

	Days from Planting[z]					
	34	**59**	**95**	**124**	**150**	Sign.[y]
HCR	2.2	2.7	3.2	2.9	3.0	Q***

[z]The DFP main effect was significant.
[y]Indicates a significant quadratic effect

Table 2. 5. Pseudostem circumference (cm) of dwarf (*Musa* AAA (Cavendish subgroup)) bananas cultivated at the Gulf Coast REC, Fairhope, AL – parent crop 2013.

Cultivar[z]	NLP	**DFP**[z]	NLP
Dwarf Cavendish	12.2 a[y]	0	10.1
Dwarf Green	10.8 b	30	11.8
Dwarf Red	10.7 b	66	12.4
Double	12.8 a	95	13.2
Grand Nain	12.3 a	121	11.4
Significance[x]			Q***

[z]The Cultivar and DFP main effects were significant

[y]Any two means within a row not followed by the same letter are significantly different at $P \leq 0.05$.

[x]Indicates a significant quadratic effect

Table 2. 6. Length and width (cm) of the third-position lamina of dwarf(*Musa* AAA (Cavendish subgroup)) bananas cultivated at the Gulf Coast REC, Fairhope, AL – parent crop 2013.

			DFP^{z}			
	34	**59**	**95**	**124**	**150**	**Sign.**^{x}
Cultivar^{z}			Length (cm)			
Dwarf Cavendish	41.1 ab	65.0 bc	112.5 ns	127.7 ab^{y}	125.4 bc	Q***
Dwarf Green	41.4 a	75.2 a	125.7	122.6 ab	126.2 ab	Q**
Dwarf Red	42.2 a	76.2 ab	115.0	135.3 a	149.4 a	L***
Double	40.1 b	66.3 c	100.0	104.0 b	117.8 c	L***
Grand Nain	38.1 b	65.5 c	125.0	117.0 b	120.7 c	Q***
			Width (cm)			
Dwarf Cavendish	21.0 ns	34.0 ns	52.5 ns	62.2 ab	63.0 b	L**
Dwarf Green	23.1	43.1	64.5	67.0 ab	72.6 b	Q***
Dwarf Red	24.3	41.4	56.6	81.2 a	78.2 a	L***
Double	18.3	31.0	48.5	50.3 b	58.4 b	L***
Grand Nain	17.7	31.75	58.6	53.3 ab	56.4 b	Q***

^{z}The Cultivar and DFP main effects were significant

^{y}Any two means within a row not followed by the same letter are significantly different at $P \leq 0.05$.

^{x}Indicates a significant quadratic or linear effect

Table 2. 7. Leaf area index (LAI) of dwarf (*Musa* AAA (Cavendish subgroup)) bananas cultivated at the Gulf Coast REC, Fairhope, AL – parent crop 2013.

	DFP[z]					
Cultivar[z]	**34**	**59**	**95**	**124**	**150**	**Sign.**[x]
Dwarf Cavendish	0.11 ns	0.28 ns	0.84 ns	1.32 ab[y]	1.00 c	Q**
Dwarf Green	0.10	0.42	0.97	1.07 ab	1.08 ab	Q**
Dwarf Red	0.10	0.37	0.88	1.59 a	1.43 a	L***
Double	0.09	0.30	0.73	0.83 b	1.02 bc	L***
Grand Nain	0.08	0.30	1.11	0.97 ab	0.86 c	Q***

[z]The Cultivar and DFP main effects were significant

[y]Any two means within a row not followed by the same letter are significantly different at $P \leq 0.05$.

[x]Indicates a significant quadratic or linear effect

Table 2. 8. Leaf emergence rate (LER) of dwarf (*Musa* AAA (Cavendish subgroup)) bananas cultivated at the Gulf Coast REC, Fairhope, AL – Parent Crop 2013.

	DFP[z]					
	34	**59**	**95**	**124**	**150**	**Sign.**[y]
LER	5	6	6	4	1	Q***

[z]The DFP main effects were significant

[y]Indicates a significant quadratic effect

Table 2. 9. Cumulative leaf number (CLN) of dwarf (*Musa* AAA (Cavendish subgroup)) bananas cultivated at the Gulf Coast REC, Fairhope, AL – parent crop 2013.

Cultivar[z]	TLN	**DFP**[z]	TLN
Dwarf Cavendish	30 a[y]	34	18
Dwarf Green	26 b	59	24
Dwarf Red	26 b	95	30
Double	29 ab	124	34
Grand Nain	28 ab	150	35
Sign.[x]			Q***

[z]The Cultivar and DFP main effects were significant
[y]Any two means within a row not followed by the same letter are significantly different at P≤ 0.05.
[x]Indicates a significant quadratic effect

Table 2. 10. Pseudostem length and circumference at each sampling period of dwarf (*Musa* AAA (Cavendish subgroup)) bananas cultivated at the Gulf Coast REC, Fairhope, AL, R_1 crop, 2014.

	DFP[z]						
	60	**90**	**117**	**160**	**185**	**208**	**Sign.[y]**
Length (cm)	24.4	48.7	76.2	91.4	140.2	158	L**
Circumference (cm)	11.5	19.1	26.0	32.5	46.0	47.0	L***

[z]The DFP main effects were significant

[y]Indicates a significant linear effect

Table 2. 11. Mean height:circumference at each sampling period of dwarf (*Musa* AAA (Cavendish subgroup)) bananas cultivated at the Gulf Coast REC, Fairhope, AL – R_1 crop 2014.

	DFP[z]						
	60	**90**	**117**	**160**	**185**	**208**	**Sign.[y]**
HCR	2.1	2.6	3.0	3.0	3.1	3.4	L***

[z]The DFP main effects were significant

[y]Indicates a significant linear effect

Table 2. 12. Mean number of standing leaves (NSL) of dwarf (*Musa* AAA (Cavendish subgroup)) bananas cultivated at the Gulf Coast REC, Fairhope, AL – R_1 crop 2014.

Cultivar[z]	NSL	**DFP**[z]	NSL
Dwarf Cavendish	11 a[y]	60	5
Dwarf Green	10 ab	90	7
Dwarf Red	9 b	117	10
Double	11 a	160	11
Grand Nain	1 1a	185	14
		208	14
Sign.[x]			L***

[z]The Cultivar and DFP main effects were significant

[y]Any two means within a row not followed by the same letter are significantly different at P≤ 0.05.

[x]Indicates a significant linear effect

Table 2. 13. Mean laminal length and width at each sampling of dwarf (*Musa* AAA (Cavendish Subgroup)) bananas cultivated at the Gulf Coast REC, Fairhope, AL – R_1 crop 2014.

	DFP[zy]						
	60	90	117	160	185	208	Sign.[w]
Length (cm)	30.0	48.5	81.0	112.3	131.0	143.0	L***
				Width (cm)			
Cultivar[y]							
Dwarf Cavendish	17.5 ns	25.6 ns	43.2 ns	66.8 ns	65.0 ab[x]	70.4 ab	L***
Dwarf Green	18.0.1	26.1	44.5	47.7	69.0 ab	73.0 ab	L***
Dwarf Red	18.2	27.1	67.0	58.6	76.2 a	81.5 a	L***
Double	15.4	26.4	48.0	51.5	58.7 b	60.0 b	L***
Grand Nain	15.7	24.4	58.6	55.3	64.7 ab	68.0 ab	L***

[z]The DFP main effect was significant (length).
[y]The Cultivar and DFP main effects were significant (width)
[x]Any two means within a row not followed by the same letter are significantly different at $P \leq 0.05$.
[w]Indicates a significant linear effect

Table 2. 14. Leaf area index (LAI) and LER each sampling of dwarf (*Musa* AAA (Cavendish subgroup)) bananas cultivated at the Gulf Coast REC, Fairhope, AL – R_1 crop 2014.

				DFP[z]			
	60	**90**	**117**	**160**	**185**	**208**	**Sign.**[y]
LAI	0.03	0.12	0.41	0.86	1.34	1.61	Q***
LER	4	5	5	6	4	2	Q**

[z]The DFP main effect was significant (LAI and LER)
[y]Indicates a significant quadratic effect

Table 2. 15. Cumulative leaf number (CLN) of dwarf (*Musa* AAA (Cavendish subgroup)) bananas cultivated at the Gulf Coast REC, Fairhope, AL – R_1 crop 2014.

	DFP[z]						
Cultivar[z]	60	90	117	160	185	208	Sign.[x]
Dwarf Cavendish	5 ns	11 a[y]	16 a	22 a	26 a	29 a	Q**
Dwar Green	4	8 ab	13 ab	18 ab	22 b	24 b	L***
Dwarf Red	3	8 ab	12 b	15 b	21 b	23 b	L***
Double	5	11 a	16 a	22 a	26 a	29 a	Q***
Grand Nain	5	9 ab	15 a	21 a	26 a	28 a	L***

[z]The Cultivar and DFP main effects were significant (width)

[y]Any two means within a row not followed by the same letter are significantly different at $P \leq 0.05$.

[x]Indicates a significant quadratic or linear effect

Table 2. 16. Pseudostem length (cm) and circumference (cm) of medium height non-Cavendish (*Musa* sp.) bananas cultivated at the Gulf Coast REC, Fairhope, AL – R_1 crop 2014.

	DFP[z]						
	60	90	117	160	185	208	Sign.[x]
				Length (cm)			
Cultivar[z]							
Cardaba	67.1 a[y]	115.8 a	177 a	204.2 a	274.3 a	287.0 a	L***
Gold Finger	45.7 b	70. 1b	122 b	146.3 c	195.1 b	204.2 c	L***
Ice Cream	70.1 a	119.0 a	174 a	195.0 ab	253.0 a	256.0 ab	Q**
Raja Puri	52.0 ab	88.4 b	143.2 b	170.6 bc	204.2 b	213.4 bc	Q**
				Circumference (cm)			
Cardaba	20.1 ns	36.4 a	50.0 a	60.3 a	68.0 a	71.7 a	Q***
Gold Finger	16.3	30.0 ab	37.3 b	51.0 b	59.3 b	60.2 ab	L***
Ice Cream	19.1	35.4 a	53.0 a	65.1 a	74.0 a	72.7 a	Q***
Raja Puri	16.3	27.0 b	40.2 b	47.0 b	56.4 b	55.5 b	Q***

[z]The Cultivar by DFP interaction was significant (Length and Circumference).
[y]Any two means within a row not followed by the same letter are significantly different at $P \leq 0.05$.
[x]Indicates a significant quadratic or linear effect

Table 2.17. Height:circumference ratio of medium height non-Cavendish (*Musa* sp.) bananas cultivated at the Gulf Coast REC, Fairhope, AL – R_1 crop 2014.

	DFP[z]						
Cultivar[z]	60	90	117	160	185	208	Sign.[x]
Cardaba	3.3 a[y]	3.2 a	3.6 ns	3.4 a	4.1 a	4.0 ns	L**
Gold Finger	2.7 b	2.4 b	3.2	2.9 b	3.3 b	3.3	L**
Ice Cream	3.4 a	3.4 a	3.3	3.0 b	3.4 b	3.6	Q*
Raja Puri	3.3 a	3.3 a	3.6	3.6 a	3.6 ab	3.8	L*

The Cultivar by DFP interaction was significant.

[z]The Cultivar by DFP interaction was significant.

[y]Any two means within a row not followed by the same letter are significantly different at $P \leq 0.05$.

[x]Indicates a significant quadratic or linear effect

Table 2. 18. Number of standing leaves of medium height non-Cavendish (*Musa* sp.) bananas cultivated at the Gulf Coast REC, Fairhope, AL – R_1 crop 2014.

	DFP[z]						
Cultivar[z]	60	90	117	160	185	208	Sign.[y]
Cardaba	5	9	11	15	16	16	Q***
Gold Finger	6	9	12	14	14	15	Q***
Ice Cream	4	9	10	15	16	16	Q**
Raja Puri	5	8	10	12	12	12	Q***

[z]The Cultivar by DFP interaction was significant.
[y]Indicates a significant quadratic effect

Table 2. 19. Laminal length of medium height non-Cavendish (*Musa* sp.) bananas cultivated at the Gulf Coast REC, Fairhope, AL – R1 crop 2014.

Cultivar[z]	Length(cm)	**DFP**[z]	Length(cm)
Cordaba	141.2a[y]	60	57.6
Gold Finger	114.0b	90	85.5
Ice Cream	140.4a	117	129.5
Raja Puri	133.0a	160	161.5
		185	177.0
		208	182.0
Sign.[x]			Q***

[z]The Cultivar by DFP interaction was significant.
[y]Any two means within a row not followed by the same letter are significantly different at $P \leq 0.05$.
[x]Indicates a significant quadratic effect

Table 2. 20. Laminal width of medium height non-Cavendish (*Musa* sp.) bananas cultivated at the Gulf Coast REC, Fairhope, AL – R_1 crop 2014.

Cultivar[z]	Width (cm)	**DFP**[z]	Width (cm)
Cardaba	58.2a[y]	60	28.4
Gold Finger	48.7c	90	41.0
Ice Cream	54.6ab	117	54.6
Raja Puri	50.8bc	160	62.0
		185	64.0
		208	68.5
Sign.[x]			Q***

The Cultivar and DFP main effects were significant

[z]The Cultivar by DFP interaction was significant.

[y]Any two means within a row not followed by the same letter are significantly different at $P \leq 0.05$.

[x]Indicates a significant quadratic effect

Table 2. 21. Leaf area index (LAI) of medium height non-Cavendish (*Musa* sp.) bananas cultivated at the Gulf Coast REC, Fairhope, AL – R_1 crop 2014.

	DFP[z]						
Cultivar[z]	60	90	117	160	185	208	Sign.[x]
Cardaba	0.13 a[y]	0.45 a	1.10 ns	1.78 ns	2.23 a	2.41 a	L***
Gold Finger	0.07 b	0.23 b	0.76	1.26	1.61 ab	1.80 ab	L***
Ice Cream	0.09 ab	0.41 a	0.89	1.84	2.17 a	2.41 a	L***
Raja Puri	0.08 ab	0.32 ab	0.74	1.41	1.46 b	1.57 b	L***

[z]The Cultivar by DFP interaction was significant.
[y]Any two means within a row not followed by the same letter are significantly different at $P \leq 0.05$.
[x]Indicates a significant linear effect

Table 2. 22. Leaf Emergence Rate (LER) of Medium Height non-Cavendish (*Musa* sp.) Bananas Cultivated at the Gulf Coast REC, Fairhope, AL – R_1 Crop 2014.

	DFP[z]						
	60	**90**	**117**	**160**	**185**	**208**	**Sign.**[x]
LER	5	5	5	6	3	2	Q**

[z]The DFP interaction was significant.
[x]Indicates a significant quadratic effect

Table 2. 23. Cumulative leaf number (CLN) of medium height non-Cavendish (*Musa* sp.) bananas cultivated at the Gulf Coast REC, Fairhope, AL – R1 crop 2014.

	DFP[z]						
Cultivar[z]	60	90	117	160	185	208	Sign.[x]
Cardaba	5 ns	9 ns	15 a[y]	21 a	24 a	26 a	Q***
Gold Finger	6	10	15 a	22 a	26 a	28 a	Q***
Ice Cream	4	9	15 a	22 a	26 a	27 a	Q***
Raja Puri	5	9	14 b	19 b	21 b	23 b	Q***

[z]The Cultivar by DFP interaction was significant.
[y]Any two means within a row not followed by the same letter are significantly different at $P \leq 0.05$.
[x]Indicates a significant quadratic effect

Table 2. 24. Pseudostem length and circumference of tall non-Cavendish (*Musa* sp.) bananas cultivated at the Gulf Coast REC, Fairhope, AL – parent crop 2013.

	DFP[z]					
Cultivar[z]	**34**	**59**	**95**	**124**	**150**	**Sign.**[x]
			Length (cm)			
Pisang Ceylon	36.5 ns	76.2 b[y]	131.0 c	164.5 c	173.7	Q***
Saba	40.0	97.5 a	168.0 a	207.2 a	222.5	Q***
Sweetheart	43.0	88.3 b	146.0 b	183.0 b	189.0	Q***
			Circumference (cm)			
Pisang Ceylon	12.4 b	23.0 b	34.4 c	45.0 b	46.0 b	Q***
Saba	18.2 a	32.5 a	49.0 a	64.1 a	66.0 a	Q***
Sweetheart	17.2 a	30.0 a	45.0 b	61.2 a	62.2 a	Q***

[z]The Cultivar by DFP interaction was significant (Length and Circumference).
[y]Any two means within a row not followed by the same letter are significantly different at $P \leq 0.05$.
[x]Indicates a significant quadratic effect

Table 2. 25. Height: circumference ratio of tall non-Cavendish (*Musa* sp.) bananas cultivated at the Gulf Coast REC, Fairhope, AL – parent crop 2013.

Cultivar[z]	HCR	**DFP**[z]	HCR
Pisang Ceylon	3.5a	34	2.5
Saba	3.1b	59	3.2
Sweetheart	3.0b	95	3.5
		124	3.3
		150	3.4
Sign.[x]			Q***

[z]The Cultivar by DFP interaction was significant.

[y]Any two means within a row not followed by the same letter are significantly different at $P \leq 0.05$.

[x]Indicates a significant quadratic effect.

Table 2. 26. Number of leaves present of tall non-Cavendish (*Musa* sp.) bananas cultivated at the Gulf Coast REC, Fairhope, AL – parent crop 2013.

	DFP[z]					
Cultivar[z]	**34**	**59**	**95**	**124**	**150**	**Sign.**[x]
Pisang Ceylon	8 ns	12 ns	11 b[y]	13 b	12 ab	Q**
Saba	9	10	13 a	16 a	13 a	Q***
Sweetheart	10	11	12 b	14 b	11 b	Q***

[z]The cultivar by DFP interaction was significant.
[y]Any two means within a row not followed by the same letter are significantly different at $P \leq 0.05$.
[x]Indicates a significant quadratic effect

Table 2. 27. Laminal length (cm) and width (cm) of tall non-Cavendish (*Musa* sp.) bananas cultivated at the Gulf Coast REC, Fairhope, AL – parent crop 2013.

Length (cm)					
	DFP[z]				
Cultivar[z]	34	59	95	124	Sign.[x]
Pisang Ceylon	45.2 b[y]	74.0 c	133.6 ns	136.1 b	Q***
Saba	55.3 a	94.0 a	126.2	201.4 a	L***
Sweetheart	52.0 a	86.0 b	133.0	178.0 a	L***
Width (cm)					
Pisang Ceylon	22.6 b	37.0 b	64.2 ns	67.3 b	Q***
Saba	30.0 a	49.0 a	60.0	80.0 a	L***
Sweetheart	25.0 b	39.0 b	54.3	64.0 c	Q**

[z]The Cultivar by DFP interaction was significant (length and width).
[y]Any two means within a row not followed by the same letter are significantly different at P≤ 0.05.
[x]Indicates a significant quadratic or linear effect

Table 2. 28. Leaf area index (LAI) of tall non-Cavendish (*Musa* sp.)bananas cultivated at the Gulf Coast REC, Fairhope, AL – parent crop 2013.

		DFP^{z}			
Cultivar^{z}	34	59	95	124	Sign.^{x}
Pisang Ceylon	0.09ns	0.36ns	1.02ns	1.21b^{y}	Q**
Saba	0.17	0.48	1.13	2.33a	Q**
Sweetheart	0.14	0.41	0.96	1.43b	L***

^{z}The Cultivar by DFP interaction was significant.

^{y}Any two means within a row not followed by the same letter are significantly different at P≤ 0.05.

^{x}Indicates a significant quadratic or linear effect

Table 2. 29. Leaf emergence rate (LER) of tall non-Cavendish (*Musa* sp.) bananas cultivated at the Gulf Coast REC, Fairhope, AL – parent crop 2013.

Cultivar[z]	LER	**DFP**[z]	LER
Pisang Ceylon	4 c[y]	34	5
Saba	5 b	59	6
Sweetheart	5 a	95	6
		124	4
		150	2
Sign.[x]			Q***

[z]The Cultivar by DFP interaction was significant.
[y]Any two means within a row not followed by the same letter are significantly different at $P \leq 0.05$.
[x]Indicates a significant quadratic effect

Table 2. 30. Cumulative leaf number (CLN) of tall non-Cavendish (*Musa* sp.) bananas cultivated at the Gulf Coast REC, Fairhope, AL – parent crop 2013.

	DFP[z]					
Cultivar[z]	34	59	95	124	150	Sign.[x]
Pisang Ceylon	16 b[y]	22 b	27 b	31 b	32 b	Q***
Saba	16 b	21 b	28 b	32 b	34 b	Q***
Sweetheart	18 a	24 a	31 a	35 a	37 a	Q***

[z]The Cultivar by DFP interaction was significant.
[y]Any two means within a row not followed by the same letter are significantly different at $P \leq 0.05$.
[x]Indicates a significant quadratic effect

Table 2. 31. Pseudostem length (cm) and circumference (cm) of tall non-Cavendish (*Musa* sp.) bananas cultivated at the Gulf Coast REC, Fairhope, AL – R1 crop 2014.

	DFP[z]						
Cultivar[z]	60	90	117	160	185	208	Sign.[x]
				Length (cm)			
Pisang Ceylon	52.0 b[y]	91.4 b	140.2 b	167.4 b	213.4 b	213.3 b	Q**
Saba	82.3 a	128.0 a	192.0 a	222.5 a	304.8 a	335.3 a	L***
Sweetheart	48.7 b	94.4 b	143.2 b	164.5 b	219.4 b	238.0 b	L***
				Circumference (cm)			
Pisang Ceylon	17.2 b	28.7 b	36.4 b	44.0 c	51.6 c	52.6 c	Q**
Saba	25.0 a	41.1 a	61.3 a	79.4 a	89.0 a	94.0 a	Q***
Sweetheart	17.2 b	32.0 b	45.0 b	61.2 b	71.0 b	80.4 b	L***

[z]The Cultivar by DFP interaction was significant (Length and cirfumference).
[y]Any two means within a row not followed by the same letter are significantly different at P$\leq$ 0.05.
[x]Indicates a significant quadratic or linear effect

Table 2. 32. Height: circumference ratio of tall non-Cavendish (*Musa* sp.) bananas cultivated at the Gulf Coast REC, Fairhope, AL – R1 crop 2014.

	DFP[z]						
Cultivar[z]	60	90	117	160	185	208	Sign.[x]
Pisang Ceylon	3.0 ns	3.2 ns	3.8 a[y]	3.8 a	4.1 a	4.3 a	L***
Saba	3.3	3.1	3.2 b	2.8 b	3.4 b	3.5 b	Q***
Sweetheart	2.8	3.0	3.2 b	2.7 b	3.1 c	3.0 c	NS

[z]The Cultivar by DFP interaction was significant.
[y]Any two means within a row not followed by the same letter are significantly different at P≤ 0.05.
[x]Indicates a significant quadratic or linear effect

Table 2. 33. Number of standing leaves (NSL) of tall non-Cavendish (*Musa* sp.) bananas cultivated at the Gulf Coast REC, Fairhope, AL – R1 crop 2014.

			DFP[z]				
Cultivar[z]	60	90	117	160	185	208	Sign.[x]
Pisang Ceylon	6 ns	9 ns	10 b[y]	14 ns	11 ns	11 ns	Q***
Saba	5	8	12 a	15	13	11	Q***
Sweetheart	5	8	11 ab	13	12	13	Q***

[z]The Cultivar by DFP interaction was significant.

[y]Any two means within a row not followed by the same letter are significantly different at P≤ 0.05.

[x]Indicates a significant quadratic effect

Table 2. 34. Laminal Length (cm) of tall non-Cavendish (*Musa* sp.) bananas cultivated at the Gulf Coast REC, Fairhope, AL – R1 crop 2014.

			DFP[z]				
Cultivar[z]	60	29	57	100	125	148	Sign.[x]
Pisang Ceylon	55.1 b[y]	79.0 b	121.0 b	136.4 b	174.4 c	183.0 b	L***
Saba	81.3 a	125.0 a	184.4 a	231.1 a	249.4 a	266.0 a	L***
Sweetheart	53.0 b	82.0 b	128.0 b	165.6 b	198.2 b	176.2 b	L***

[z]The Cultivar by DFP interaction was significant.
[y]Any two means within a row not followed by the same letter are significantly different at $P \leq 0.05$.
[x]Indicates a significant linear effect

Table 2. 35. Laminal width (cm) of tall non-Cavendish (*Musa* sp.) Bananas cultivated at the Gulf Coast REC, Fairhope, AL – R1 crop 2014.

Cultivar[z]	Width(cm)	**DFP**[z]	Width (cm)
Pisang Ceylon	56.0 b[y]	0	33.0
Saba	68.0 a	29	46.2
Sweetheart	55.1 b	57	61.0
		100	61.2
		125	81.0
		148	76.0
Sign.[x]			Q***

[z]The Cultivar by DFP interaction was significant.
[y]Any two means within a row not followed by the same letter are significantly different at $P \leq 0.05$.
[x]Indicates a significant quadratic effect

Table 2. 36. Leaf area index (LAI) of tall non-Cavendish (*Musa* sp.) bananas cultivated at the Gulf Coast REC, Fairhope, AL – R1 crop 2014.

	DFP[z]						
Cultivar[z]	0	29	57	100	125	148	Sign.[x]
Pisang Ceylon	0.12 ab[y]	0.37 ab	0.80 b	1.11 b	1.75 b	1.57 b	L***
Saba	0.19 a	0.63 a	1.86 a	2.75 a	2.88 a	2.76 a	Q***
Sweetheart	0.09 b	0.30 b	0.79 b	1.45 b	2.11 b	1.80 b	L***

[z]The Cultivar by DFP interaction was significant.
[y]Any two means within a row not followed by the same letter are significantly different at $P \leq 0.05$.
[x]Indicates a significant quadratic or linear effect

Table 2. 37. Phenological comparisons at flower emergence (TLN) of dwarf, medium and tall Cavendish and non-Cavendish (*Musa* sp.) bananas cultivated at the Gulf Coast REC, Fairhope, AL – R2 crop 2015.

Cultivar	**NLP at Flowering**	**Psuedostem Height (cm) at Flowering**	**Total Leaf # at Flowering**	**Days to Flower Emergence**	**Yield Bunch^{-1} (kg)**
		Dwarf			
Double	10.8 a[z]	156.64	26.2	160	11.86 a
Grand Nain	9.75 b	149.81	24.4	175	5.76 b
P value	*0.5856*	*0.6226*	*0.2635*	*0.0023*	*0.045*
		Medium			
Ice Cream	13 a	308.86 a	28.2 a	223 a	7.22
Cardaba	12.8 a	365.32 b	24.0 b	145 b	5.63
Gold Finger	9.2 b	195.07 c	25.2 ab	166 b	.
Raja Puri	8.8 b	229.34 cb	22 b	224 a	.
P value	*0.0001*	*0.0001*	*0.0021*	*0.0040*	*0.6088*
		Tall			
Sweetheart	9.5 a	204.22 b	26.6	179 b	.
Pisang Ceylon	6.8 b	247.90 a	27.5	217 a	.
P value	*0.0132*	*0.012*	*0.6236*	*0.0023*	.

[z]Any two means within a row not followed by the same letter are significantly different at $P \leq 0.05$.

Table 2. 38. Comparison of bunch characteristics of dwarf, medium height and tall Cavendish and non-Cavendish (*Musa* sp.) bananas cultivated at the Gulf Coast REC, Fairhope, AL – R2 crop 2015.

Cultivar	**Total Hand No. /Bunch**	**Total Finger No./Bunch**	**Fingers Per Hand**
Dwarf			
Double	8.7	129	17.3
Grand Nain	8.3	136	17.0
P-Value	*0.068*	*0.7076*	*0.9560*
Medium			
Gold Finger	9.5 a[z]	138.0 a	17.6 a
Ice Cream	8.2 a	136.0 a	16.2 a
Cardaba	6.3 b	74.0 b	11.7 b
Raja Puri	6.0 b	88.4 b	17.6 a
P-Value	*0.0058*	*0.0059*	*0.0500*
Tall			
Sweetheart	8.6	134	18.0
Pisang Ceylon	8.5	117	16.0
P-Value	*0.8000*	*0.1556*	*0.8033*

[z]Any two means within a row not followed by the same letter are significantly different at $P \leq 0.05$.

Table. 2. 39. Mean survivability (%) of dwarf, medium and tall Cavendish and non-Cavendish bananas cultivated at GREC, Fairhope, AL

	Mean Survivability (%)	
	2013-2014	2014-2015
Cultivar		
Dwarf		
Double	100	83
Dwarf Cavendish	100	83
Dwarf Green	100	100
Grand Nain	83	83
Dwarf Red	50	50
Medium		
Cardaba	100	100
Gold Finger	100	100
Ice Cream	100	100
Raja Puri	100	100
Veinte Cohol	16	16
Tall		
Pisang Ceylon	100	100
Saba	100	100
Sweetheart	100	100

Figure 2. 1. Anatomy of aerial vegetative portions of a banana plant

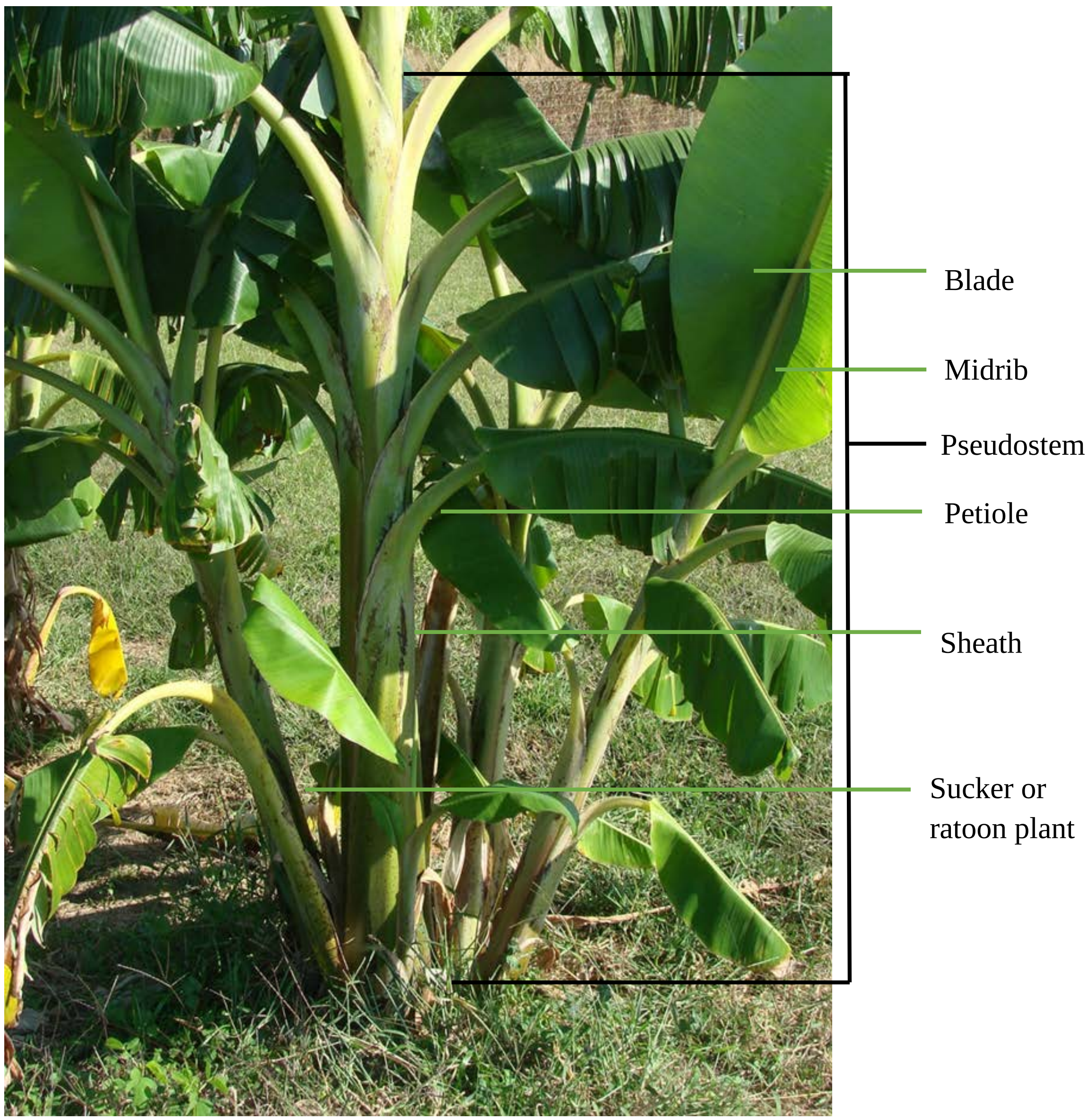

Figure 2. 2. Anatomy of a banana bunch without the bell or male bud

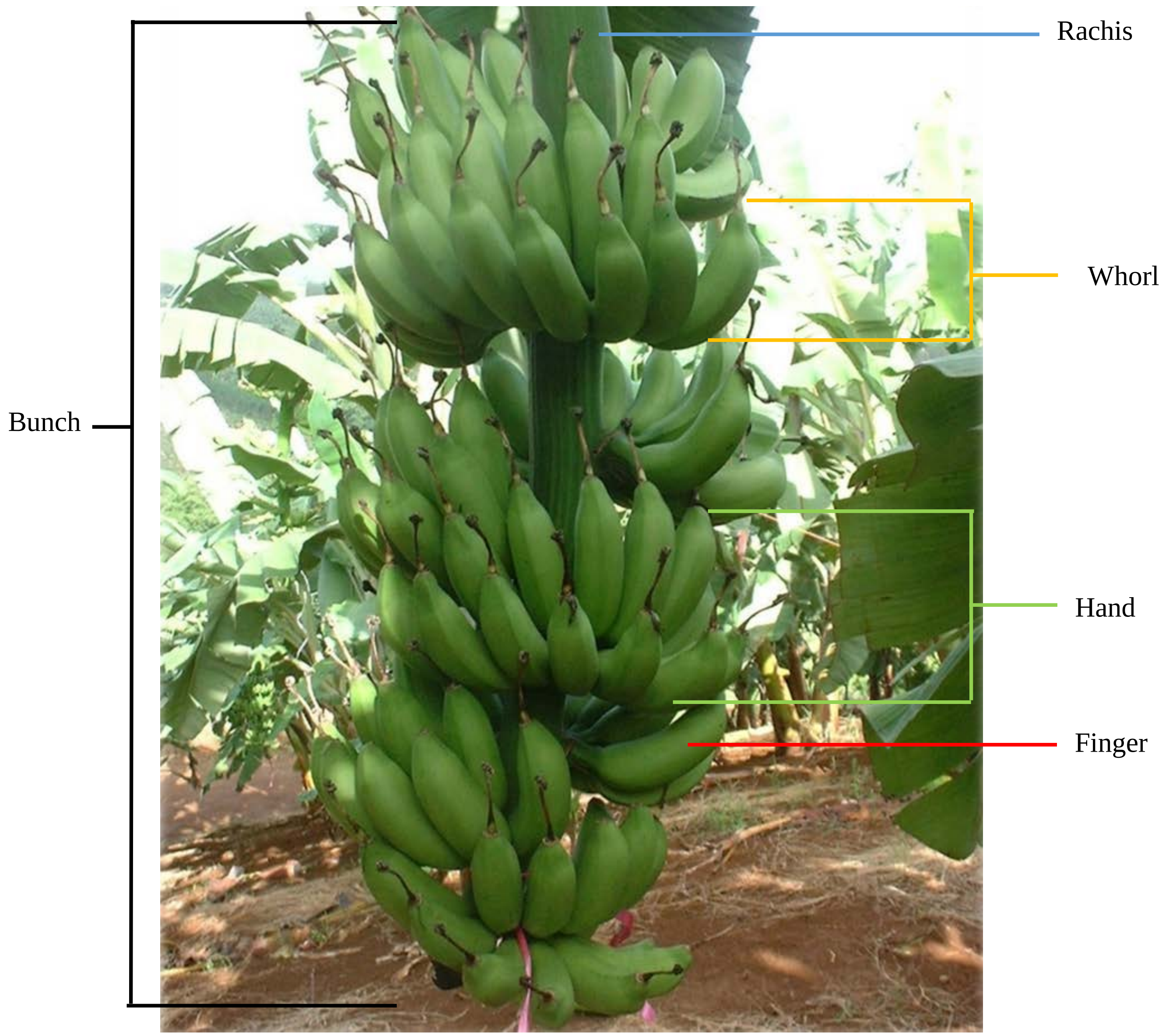

Figure 2. 3. Long-Term Mean Monthly Maximum and Minimum Temperatures in Fairhope, AL, USA

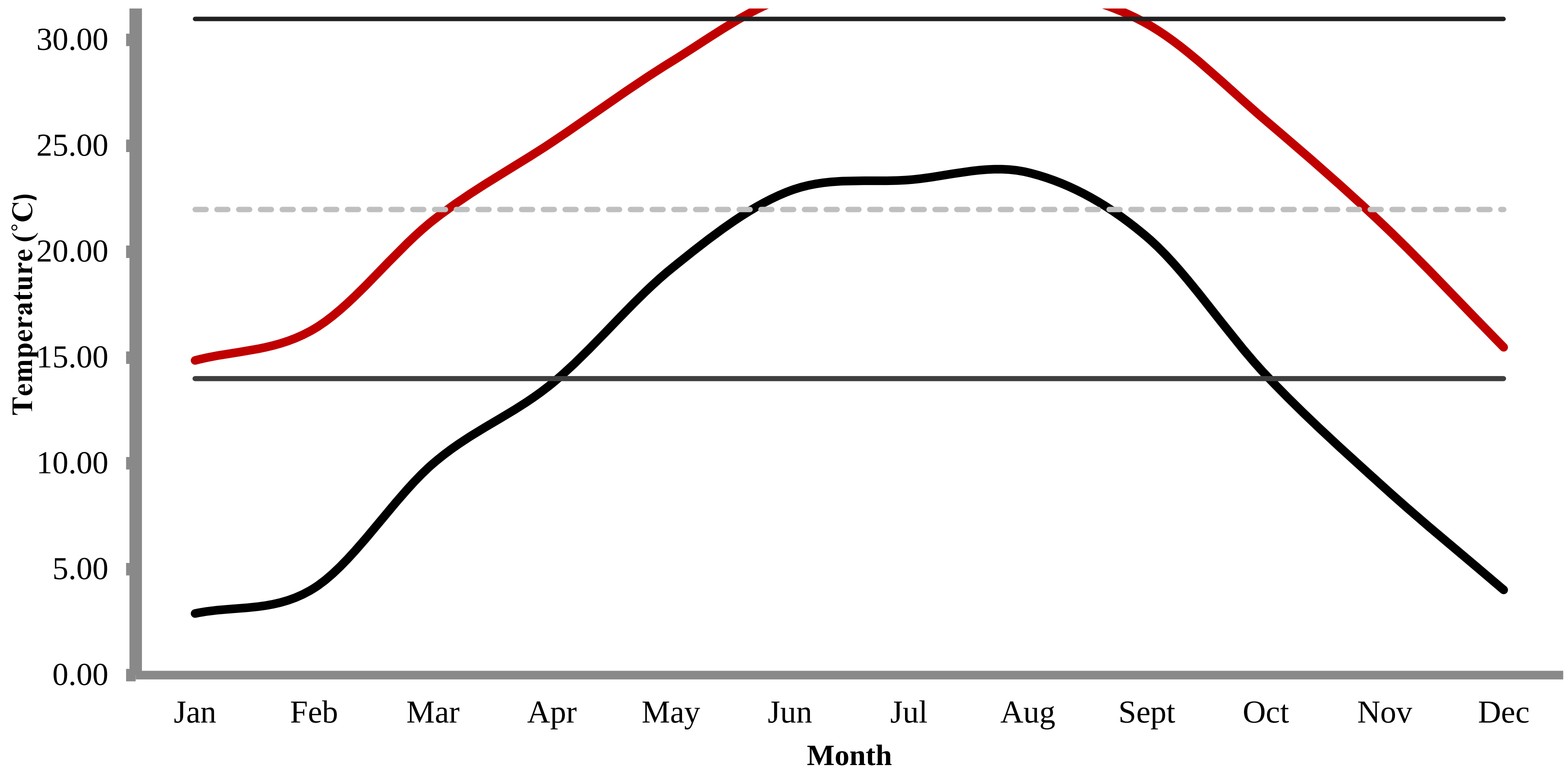

Figure 2. 4. Emerged flowers of inflorescence of banana cultivated at the Gulf Coast Research and Extension Center, Fairhope, AL.

Figure 2. 5. Dwarf banana cultivars 12 weeks after DFM at the Gulf Coast Research and Extension Center, Fairhope, AL

Figure 2. 6. Ambient and soil temperatures in banana field From July, 2013 through November, 2014 at the Gulf Coast Research and Extension Center, Fairhope, AL

Figure 2. 7. Bananas regenerated from the rhizome in May, 2015 after uncharacteristically low temperatures in late December, 2013 and early January, 2014 at the Gulf Coast Research and Extension Center, Fairhope, AL.

Figure 2. 8. Banana cultivars which belong to the Cavendish subgroup cultivated at the Gulf Coast Research and Extension Center, Fairhope, AL

Figure 2. 9. Laminal leaf shredding due to high winds of banana cultivated at the Gulf Coast Research and Extension Center, Fairhope, AL

Figure 2. 10. Developing bunch from Double (AAA) dwarf banana cultivars cultivated at the Gulf Coast Research and Extension Center, Fairhope, AL

Figure 2. 11. Harvest banana bunch from Grand Nain (AAA) banana cultivated at the Gulf Coast Research and Extension Center, Fairhope, AL

Figure 2. 12. Developing Cardaba banana bunch prior to harvest in December, 2015 at the Gulf Coast Research and Extension Center, Fairhope, AL

Figure 2. 13. Developing bunch from a Gold Finger (AAAB) exhibiting symptoms of chill damage prior to harvest in December, 2015 at the Gulf Coast Research and Extension Center, Fairhope, AL

Figure 2. 14. Developing bunch from Sweetheart (AABB) cultivar prior to harvest in December, 2015 at the Gulf Coast Research and Extension Center, Fairhope, AL

Chapter III

Concepts to Improve Sustainability of non-Cavendish bananas cultivated in the subtropics of Coastal Alabama

Bananas possess unique potential as a specialty crop to enhance sustainability of farm operations because of their global demand and the development of cultivars that are more cold tolerant and have shorter production cycles. In the global market bananas are known to require considerable inputs making their production cost prohibitive for smaller farm operations. To mitigate these demands, innovative production practices must be sought. Reflective mulches have been used to enhance lighting in production systems to improve yield and quality of fruit crops and cover crops have been used in rotations to increase crop diversity, improve soil quality, moisture retention and a source of organic matter and nutrients. Reflective mulches and cover crops were selected and their effects on banana phenology were determined in two experiments. In experiment one; white polyethylene fabric and silver reflective film panels were installed on opposing sides of a group of three banana plants to form an experimental unit. A control treatment which received no reflective mulch was included in the study. The study followed a randomized complete block design and contained six replications. In experiment two, hairy vetch and Crimson clover along with a natural cover control formed the basis of a second study. Bananas bunches of the white reflective mulch treatment were 27% and 15% heavier in the reflective mulch treatments compared to bananas bunches of the control and were produced on pseudostems that were 12% and 3% taller respectively than bananas of the control treatment. Leaf area of silver and white mulch treatments were increased by 8% and 16% respectively than the control. Light radiation was enhanced in the lower canopy of banana plants of the reflective mulch treatments. Flower emergence in the white fabric mulch treatment occurred 5 d earlier than the control whereas flower emergence in the silver mulch treatment was delayed by 26 d when compared to the control. Crimson clover and hairy vetch produced bananas with pseudostems that were 20% and 8% taller respectively than those of the control. Banana leaf area was 24% greater in the Crimson clover treatment compared to the control while leaf area of the hairy vetch treatment was 10% larger. Reflective mulches and cover crops provided small gains in increasing sustainability of niche market bananas. Reflective mulches resulted in earlier floral emergence. Though banana plant vigor was slightly increased by cover crop usage, more time is needed for cover crops to affect change to physical structure of the soil.

Introduction

Farmland in Alabama is being traded for development as many farmers are no longer able to sustain their operations (Farmers Market Authority; Lu et al., 2000; Nickerson et al., 2012). This not only necessitates crop importation from perhaps thousands of miles and the use of fossil fuels it also presents a challenge to rural communities because farmers are increasingly unable to reinvest in the community to enhance the local economy. Crop diversity is a means to increase economic sustainability of farm operations (Farmers Market Authority). Bananas offer a potential source for crop diversity as banana fruit as well as containerized banana plants may be cultivated and retailed by farmers as an alternative commodity to increase the economic sustainability of their operations. The "*Buy Fresh, Buy Local*" campaign conducted by the Alabama

Farmers Market Authority allows farmers to plant a diversity of crops and sell them at farmers markets and grocers, while encouraging consumers to purchase fresher, better tasting produce that also provides significant health benefits. A diverse crop planting creates niche markets by allowing growers to produce crops locally that have traditionally been imported. Banana fruit production is a new technology in the Southeast region that offers a potential source for crop diversity because 1) Demand for the crop. Bananas are the number one import fruit crop in the US with import value rising from $ 1 billion in 2006 to nearly $ 2 billion in 2010. Global banana production in 2011 was estimated at 106,058,470 metric tons and has increased 33% since 2005 making bananas the fourth most important crop worldwide (Foastat, 2016). In many countries, bananas and plantains (*Musa* sp.) are an important staple, as both a food source and critical source of income and they are vital to the economies of developing nations (Abdul-Baki et al. 1997; Fonsah et al, 2004; Surendar et al., 2007). 2) The climate along the gulf coast of Alabama is conducive for banana plant development. Temperatures in the region remain within the cardinal temperature range for banana production for approximately 7 months. During the times when temperatures fall below this range conditions are not usually lethal to the plant. 3) Banana cultivation has expanded beyond tropical boundaries due largely to the development of cold-tolerant, short-cycle cultivars (Lahav and Lowengart, 1998).

In large scale commercial production, banana crops require copious amounts of inputs such as fertilizer, irrigation, and pest control. However, there has been conflicting reports as to whether bananas require such high levels of resources (Turner et al., 2007).

Notwithstanding, innovative production practices can be investigated to preserve the sustainability that niche market bananas offer.

Innovation one: Reflective Mulch

In order that bananas reach maturity before the late frost, flower emergence should begin during the month of July through August to provide sufficient time for maturity of the developing bunch. The use of innovative production practices can be investigated for their potential to decrease cropping cycles to encourage harvesting within the interval of early and late frosts and conform to an annual cropping system found in crops such as peach and apple. Plastic mulch and fabrics have previously been evaluated for use in deterring insects that cause damage to plants or vector disease-causing agents such as fungi or bacteria. Improved yields of tomatoes were found as a result of colored mulches (Csizinszky et al., 1995). Aluminum mulches have been shown to repel thrips and aphids – two important disease-vector organisms (Adlerz and Everett, 1968; Brown and Brown, 1992; Wolfenbarger and Moore, 1968). More recently, white reflective fabric improved light environment, increased photosynthetic activity by as much as 95% and increased yield by 18% in mature, low-density 'd' Anjou' pear orchards (Einhorn et al., 2012).

Theoretically, increased planting density increases light interception by a corresponding increase in leaf area index (LAI) which leads to improved yield (Robinson and Galán Saúco, 2010; Robinson and Nel, 1989). However, delayed cropping cycles and increased plant height in high density plantings are the result slower LER and an increased number of leaves cycle^{-1} (Chundawat et al., 1983; Daniells et al., 1985; Robinson and Nel, 1989; Turner, 1982). Increased light penetration reduces shading which will increase LER (Robinson, 1996). This is the reason lower density plantings (<2,000 plants ha^{-}

^{1}) are desired in some regions in the subtropics (Robinson and Nel, 1989). Additionally, researchers have stated that decreased photosynthetic activity observed in leaves below the fifth position on the banana leaf profile is due to aging of the photosynthetic apparatus. Leaves in positions 2 -5 are the most recent of the banana canopy profile and are the most photosynthetically active (Robinson and Galán Saúco, 2010). Rate of photosynthesis begins to decline at leaf 6 and below. It is possible that increased senescence could be the result of shading (Khan et al., 2000). Chlorophyll a and b in shade plants often increases but photosynthesizing efficiency is lowered (Baldi et al., 2012). Leaf senescence, a largely genetic factor (Yoshida, 1962), is characterized by leaf yellowing as a result of chlorophyll degradation (Schelbert et. Al. 2009). Components of the degraded chlorophyll are redistributed and used elsewhere in the plant (Masclaux-Daubresse et al., 2008). In densely populated monocultures such as found in banana production, leaves of the upper canopy receive full sun while lower profile leaves receive partial shade due to blocking of solar radiation by leaves in the upper canopy. Shaded leaves adjust to increasing shade so that a positive carbon balance is maintained, but as more leaves are added in the upper canopy shade is increased and leaves cannot adequately compensate for reduced solar radiation and subsequently, leaf senescence is induced (Brouwer et al., 2012). Foliar longevity influences NSL which can shorten the cropping cycle by enhancing the amount of dry matter produced if values are optimal. At the time of bunch formation higher NSL improves maturation of the developing bunch. Bananas require a minimum of 4 leaves to affect full maturity of a developing bunch.

Innovation two: Cover Crop Usage

Cover crops usage is one of the most important sustainable practices used in global management strategies in agricultural systems and leads to improved soils, increased organic matter, and increased yield of target crops (Baligar et al 2006; JC Robinson, 1996; Lu et al, 2000; Tixier et al 2011). Though cover crop usage in crop production is not a new technology, there has been a surge in the incorporation of cover crops in agricultural systems as it reduces inputs and suppresses pests by reintroducing biodiversity (Tixier et al. 2011) and, in some cases eliminates the use of pesticides, controls soil erosion, and reduces depletion of natural resources (Lu et al 2000).

Intensive cultural practices used in export banana production systems are usually carried out on bare ground and therefore require large inputs such as pesticides and fertilizers and the use thereof present challenges for delicate environmental systems around the world (Bonan and Prime, 2001). Use of cover crops increases sustainability by lowering inputs more effectively than some conventional cultural practices such as the use of polyethylene mulch. Hairy vetch (*Vivivia villosia*) reduced N usage by 250 lbs acre^{-1} less than that polyethylene mulch (Abdul-Baki and Teasdale, 1997) and saved $150 acre^{-1} in inputs.

A suitable cover crop should produce sufficient biomass in order to compete with weeds for resources while not competing with the main crop and are usually evaluated in terms of yield performance of a main crop in relation to the main crop cultivated on bare ground (Costello and Altieri, 1994; Picard et al., 2010; Tixier et al., 2010).

The objective of this study is to determine the effects of reflective mulch treatments and cover crop usage on the phenology/physiology of developing banana plants. The hypothesis is that both main crop (bananas) and secondary crop (cover crop) can be mutually cultivated without creating adverse effects on the phenology of the main crop.

Materials and Methods

Reflective mulch

Musa AAB (Mysore subgroup) 'Mysore' bananas obtained from tissue culture (Agri-Starts Inc, Apopka, FL) were planted on raised beds 0.9 m wide and 0.15 m high. Bananas were set at a within row spacing of 2.4 m on 10 July, 2014. Experimental plots consisted of three banana plants. Silver reflective high density polyethylene film (Wilson Orchard and Vineyard Supply Yakima, WA) with a thickness of 1 mil and white woven polypropylene ground cover fabric at thickness of 0.1 $kg \cdot m^{-1}$ were used to form panels with length of 7.3 m and width of 2 m. To improve durability of the silver metallic mulch, white, woven polypropylene fabric was attached to the underside. Mulch panels were installed on 20 April 2015. Panels were placed parallel to and on both sides of the raised beds 0.6 m from the base of the pseudostem of the central plant and fastened in place using metal stakes (Figures 3. 1. and 3. 2.). As the control, centipede sod was allowed to persist uncovered by a mulch treatment and growth was controlled with periodic applications of herbicide (Figure 3. 3.). A randomized complete block design was used. A block was 30 m in length and contained three experimental units that were spaced 4.3 m apart. Blocks (rows) were set on 6 m centers. Spacing was selected to prevent influence of one treatment over another. Bananas received approximately 50 mm water $week^{-1}$. Bananas were fertilized according to the recommendations of the Agricultural and Environmental Services Laboratories of the University of Georgia, USA.

The parent crop (PC) which are bananas that were planted in the first season succumbed to low temperatures of the winter. Absolute minimum temperature fell to -10

°C in January, 2014. Ratoon plants however. (R_1) or suckers were generated from the PC rhizome. Winter-damaged Pseudostems of the PC were cut to a height of 0.5 m and suckers were selected to replace the PC on 20 April 2015. All banana plants reached the mature vegetative stage which is indicated by the production of mature leaves or the first F_{10} leaf (leaf 10 cm in width) by 18 March 2015. Phenotypical data were collected on 55, 93, 135, 163, and 219 days from emergence of mature leaf (DFM) and consisted of Pseudostem height (measured from base of the plant to the bifurcation formed by the top two leaf petiole bases), pseudostem circumference at 30 cm above the ground, laminal length and width (widest portion) of the third leaf of the plant profile, phyllochron or leaf emergence rate (LER) as measured by the number of fully expanded leaves generated $month^{-1}$, number of standing leaves present, leaf area index (LAI) calculated from equation 1. Soil temperature and soil moisture data were collected using an external temperature sensor and a WaterScout SM 100 sensor interfaced with a WatchDog 1200 Microstation datalogger (Spectrum Technologies, Aurora, IL) at each experimental plot. Both temperature and moisture probes were set at a depth of 20 cm.

Equation 1: $l \times w \times 0.83/ (UGA)$ where l is laminal length and w is laminal width multiplied by correction divided by UGA which is the unit ground area. Other phenotypical data that were collected upon flowering are: days to flower emergence (DFE) (emergence occurs when the first set of flowers of the inflorescence has been exposed), pseudostem height at flower emergence, pseudostem circumference at flower emergence.

Light measurements and photosynthetic activity were collected using a TPS-2 photosynthesis analyzer (PP systems, Amherst, MA). Light measurements were taken at the central plant at 55 days from mature leaf (DFM). Light and reflectance were measured at 60 cm above ground and approximately 60 cm from the pseudostem facing south. This series of measurements was repeated on the opposite side of the plant. A PLC4 broad leaf cuvette was used to measure photosynthetic activity from a leaf area of 2.5 cm^2. Readings were taken from the second, fourth and bottom leaves (leaves 7 or 8) of the profile from the central plant.

Temperature of the plants was taken from the pseudostem of the central plant 1 m above ground on 28 August 2015 at 10:00 am using an infrared temperature meter (Spectrum Technologies, Inc. Aurora, IL). With a SPAD meter, chlorophyll readings were taken from leaves 3 and 5 from both laminal halves on all three plants in the plot. This resulted in 12 SPAD readings $plot^{-1}$.

Cover crop

An on-farm study to determine the effects of two cover crops on the phenology of *Musa* ABB 'Dwarf Orinoco' bananas was established at the Oak Hill Tree Farm in Grand Bay, AL, (30° 31' 56.3952" Latitude and -88° 20' 29.9862" Longitude). The designated area was formerly pasture land and the soil type was a Heidel sandy loam. Crimson clover (*Trifolium incarnatum*) and hairy vetch (*Vivivia villosia*) cover crop treatments were seeded at recommended rates in 6 m × 7.3 m experimental plots and the experimental plots were arranged in a completely randomized design. A control experimental plot consisted of the natural, pre-established cover that was ~ 60% bahiagrass (*Paspalum notatum*). Soil samples were collected prior to seeding to determine initial organic matter content, soil fertility and lime requirements. Another soil sample was taken near the end of the season. Biomass samples were collected after cover crops reach full bloom by clipping plants near soil surface in two 0.1 m^2 quadrangle area dimensions in each experimental plot. Biomass samples were oven-dried to determine C and N content. Cover crops were allowed to persist and decompose on the soil surface. Each experimental plot contained 5 plants. A single banana plant was set in the center of each plot. On opposing sides of the central plant a row consisting of 2 bananas was established at a distance of 3 m. Banana pants in the row were set at a 2.4 m within row spacing and were equidistant from the central plant. This resulted in a spacing of 7 $m^2 \cdot plant^{-1}$. Drip irrigation consisted of 16 mm polyethylene tubing with two manually-installed emitters at a spacing of 2.4 m for delivery at each plant. Emitters were design to deliver 7.6 $L \cdot h^{-1}$. Bananas received 25 mm water $week^{-1}$. Fertility was supplied by hand following recommendations of the Agricultural and Environmental Services Laboratories of the University of Georgia, USA. Ambient and soil temperatures were monitored using WatchDog A-Series Dataloggers (Spectrum Technologies, Aurora, IL). Cover crop and control experimental plots were mowed on four occasions after cover crop biomass had completely senesced and the previously established Bahia grass and other weed species became dominant. Mowed plant material was allowed to remain on the surface of each plot for the benefit of nutrient recycling and moisture retention. Foliar sampling consisted of extracting 3 leaf sections 2.5 cm in width form the widest portion of the lamina beginning at the midrib to the laminal edge. Sections were taken from the 2^{nd} and 3^{rd} positioned leaves of each plant in a plot and resulted in 15 leaf sections $plot^{-1}$. Banana growth data were collected from the centermost plant in each experimental plot and consisted of growth parameter data such as pseudostem length, pseudostem circumference, leaf area, and leaf emergence rate.

Statistics

An analysis of variance was performed on all responses using PROC GLIMMIX in SAS version 9.4 (SAS Institute, Cary, NC). The experimental design was a completely randomized design with a factorial arrangement of cultivar and days after mature leaf emergence. Days after emergence of mature leaves were analyzed as repeated measures. Where residual plots and a significant COVTEST statement using the HOMOGENEITY option indicated heterogeneous variance among treatments, a RANDOM statement with the GROUP option was used to correct heterogeneity. For counted responses, the normality assumption for ANOVA was tested using studentized residuals and the tests for normality statistics in PROC UNIVARIATY. Data were considered non-normal when the Shapiro-Wilk, the Kolmogorov-Smirnov, the Anderson-Darling, and the Cramér-von Mises tests were all significant. Non-normal counts were analyzed using either the Poisson or negative binomial distribution depending on which distribution resulted in a Pearson Chi-Square / DF value closest to value of 1.0. Differences among treatments were determined using the Shaffer Simulated method.

Results and Discussion

Reflective Mulch

Reflective mulch treatments had no significant effect on bunch weight or total hand weight though values of reflective mulch treatments were consistently higher numerically than the control (Table 3. 1.). Bananas cultivated using silver and white reflective mulches produced bunches that were 27% and 15% heavier respectively than bananas in the control treatment. Total hand weight of bananas from the silver and white reflective mulches were 24% and 20% heavier respectively than the control while production efficiency was higher in bananas of the silver reflective treatment. Bananas of the control treatment had 33% higher production efficiency than bananas of the white reflective mulch treatment. Both bunch weight (0.9398 kg) and total hand weight (0.8375 kg) were strongly correlated to soil moisture. The weight of individual hands were 21% higher in bananas from the white reflective fabric treatments then from bananas of the control treatment while hands from the silver reflective treatment were 12% higher than hands of the control treatment (Table 3. 2.). There were only slight differences in finger length and width among treatments though values of reflective mulches were numerically higher than the control. Soil moisture was moderately or strongly correlated to average hand number, finger length and width while soil temperature was weakly or moderately correlated to these variables.

At final sampling (219 DFM) neither pseudostem length, pseudostem circumference, nor HCR were significantly affected by reflective treatments (Table 3. 3.). Banana plants of the reflective mulch treatments were larger than the control according to pseudostem length and width but values were not significantly affected. Silver reflective mulch produced bananas with a 12% greater length than the control while white reflective mulch produced bananas plants with pseudostems that were 3% longer than banana pseudostems of the control. Statistical similarities in both pseudostem length and circumference resulted in no statistical difference in height: circumference (HCR).

There was only an 8% increase in leaf area in the bananas of the silver reflective mulch treatment over bananas of the control while bananas of the control treatment produced leaves with a 16% greater leaf area than bananas of the white fabric (Table 3. 4.). CLN and LER values were virtually the same among treatments.

At 55 DFM (Table 3. 5.), light reflectance and interception were significantly increased in the reflective mulch treatments over the control treatment when measured between 1200 h and 1230 h. Light reflected in the white fabric treatment was increased by 3 fold compared to the control while light interception was increased by 57% compared to the control. Additionally, there was a 3.3-fold increase in reflected light compared to the control and a 60% increase in light interception.

Rate of photosynthesis (Table 3. 6.) at 55 DFM of the reflective mulch treatments was not significantly increased in the 2nd, 4th or 8th lamina above those of the control. As expected, overall rate of net photosynthesis ($\mu mol \cdot m^{-2} \cdot s^{-1}$) decreased from the 2nd to the 8th lamina; however, there was a 2-fold increase in photosynthetic rate over the control. Values of Chlorophyll content taken at 93 DFM, as expressed in SPAD values, was numerically higher in the reflective mulch treatments compared to the control but differences among treatments were not significant. There was a 1.4% increase in temperature of pseudostems while white fabric created < 1°C increase.

Flower emergence occurred significantly earlier in the white reflective treatment than the silver reflective treatment or the control (Table 3. 7.). Flower emergence occurred 5 d sooner in the white reflective treatments compared to the control while flower emergence in the silver mulch treatment occurred 26 d later than in the control treatments.

Discussion

Phenological/physiological measurements of bananas of the reflective mulch treatments were often numerically higher when compared to the control but differences among treatments were often not significant. In a previous study, reflective fabrics did not cause ‘d’ Anjou’ pear trees to be physiologically more advanced than the control which received no reflective fabric (Einhorn et al., 2012).

These slight increases in growth in bananas of the reflective mulch treatments over the control may be responsible for earlier flower emergence found in white mulch treatments over the control though only a 5 d difference. According to Table 3.6., light reflectance and light interception were significantly increased above those of the control; however, silver reflective mulch did not hasten flower emergence but resulted in a delay of 26 d. This could have been the result of bananas leaves receiving incident light radiation in excess of their photosynthesizing capacity resulting in damage directly to the photosynthetic apparatus leading to photoinhibition, which might ultimately lead to delayed flower emergence. (Baroli and Melis, 1998; Powles, 1984). When light radiation is excessive, bananas will execute a light-avoidance response of leaf folding, but this response was circumvented in a sense due to light radiation coming from opposing sources.

Cover Crop Experiment

Hairy vetch (Table 3. 8.) had the highest fresh weight (177.18 g) but this did not result in hairy vetch having the highest dry weight which was found in Crimson Clover treatment (131.2 g). The control cover treatment that consisted of ~ 60% bahiagrass had a fresh and dry weight of 49.7 g and 23.8 g respectively. Hairy vetch treatment contributed the highest percentage of N at 3.15% followed by Crimson Clover (1.88%) and natural (control) cover (1.6%). There was no significant difference in percent C among the treatments but C:N ratio of hairy vetch treatment was lower than crimson clover (21:1) and the control cover treatment (20:1). Low C:N ratio of hairy vetch resulted in faster decomposition and less residence time on the soil surface. Hairy vetch was expected to supply significantly more N (143 kg·ha^{-1}) compared to Crimson Clover (121 kg·ha^{-1}) and natural cover control (41 kg·ha^{-1}).

Soil samples collected prior to cover crop application revealed that soil pH (Table 3. 9.) was similar in all plots (~ 5.5). There was no significant difference in soil macro nutrients phosphorus, potassium, or magnesium. Calcium was significantly lower in soil samples collected from the hairy vetch treatment than the control but similar to Crimson Clover treatments.

Percent soil organic matter was slightly higher numerically in hairy vetch treatment compared to natural cover (1.64) and Crimson Clover (1.62). Additionally, there were no significantly differences found in percent soil C or percent soil N among all treatments.

A second soil analysis taken in November, 2014 revealed a significant decrease in pH (5.1) in the hairy vetch treatment (Table 3. 10.). Increased soil acidity might have caused a corresponding decrease in Mg as this nutrient is made less available as soil pH decreases.

Foliar nutrient content of the banana plants was compared among treatments though no sufficiency ranges are available for sampling that occurs at bunch formation (Table 3. 11.). No significant differences were found in foliar nutrient content due to a cover crop treatment. Range of foliar Mn (404.4-566.2) Na (259.8 – 447.2), and Mg (0.144-0.172) were the broadest of the foliar nutrients.

Growth parameters were not significantly affected by cover crop treatments compared to the control treatments; however, bananas of the cover crop treatments were consistently larger numerically than bananas of the control treatment (Table 3. 12.). Leaf area of bananas cultivated Crimson Clover treatments was 24% greater than bananas of the control while bananas of the hairy vetch treatment were 10% larger than the bananas of the control treatment. Crimson clover and hairy vetch also produced taller bananas (20% and 8% respectively) than the control, while pseudostem circumference of bananas of the Crimson Clover and hairy vetch treatments were 20 % and 12 % greater than bananas of the control treatment.

Number of standing leaves , LER and total leaves produced were similar for all treatments (Table 3. 12.).

Discussion

It is not surprising to see no significant differences among treatments. Benefits of cover crop usage in agricultural systems are measured over several seasons and often require several years to determine. To expedite the selection process of cover crops some studies have employed the use of models to predict the performance of cover cropping systems (Rioche et al., 2012; Tixier et al., 2010). Models have been developed to predict weed populations, weed/main crop interactions, and genotype/environmental interactions (Holst et al., 2007; Paolini et al., 2006). A study conducted by Tixier et al. (2010) described the use of a model-based system for the selection of cover crops in banana production. The authors developed a model called SIMBA-CC which was based on radiation reception. The authors determined that the most suitable species in terms of their ability to maximize competition with weed species while minimizing completion with banana crop were *Alysicarpus ovalifolius*, *Cynodon dactylon*, and *Chamaecrista rotundifolia*.

Models use for prediction of how bananas in a banana-cover crop production system can be useful, but the more definitive method is actual field trials. More experimentation will be needed to determine the effects of Crimson Clover and Hairy Vetch on the growth and yield of banana plants.

Cover crop usage as a sustainable practice is also used in natural or organic production. An added premium can be placed on bananas that are certified organic or are grown naturally. Integration of organic or natural cultural practices were thought not to provide enough nutrients for commercial banana production but integration of natural resources in banana production at various stages of banana plant development could actually result in higher yield while enhancing soil quality (Manivannan and Selvamani, 2014). More recently studies confirmed banana production using 100% organic inputs can achieve sufficient yield of high quality fruit that can command premium prices in the market (Manivannon and Selvamani, 2014). Records of trade volume are sparse but the USDA was able to estimate total value of organic bananas imported to the US as $214.5 million in 2013. In the US organic production has increased by 34% since 2000. Organic production of bananas is increasing globally. Ecuador (Table 3. 13.) is the leading producer of organic bananas at over 20,000 ha devoted to production.

Organic banana production is thought to be good for the overall health of agrosystems and people specifically, but they must understandably follow strict guidelines as found in the guidelines for production, processing, labelling, and marketing of organically produced foods (FAO). Third party certification systems in agriculture have proliferated. Third party certification was marketed on the premise that consumers in wealthy, first world nations will pay extra for a product that is produced in ways that reflect their values. This is a segment of consumers that make purchases that are in keeping with deeply held values or beliefs. Currently, organic and fair trade certified bananas are set at a premium price and are presented as high-end. In 2011, production in this market was 55,000 MT per year or 11% of the total EU market (Van der Waal and Moss, 2011). Rainforest certification carried by Chiquita Brands International bananas are high-end and account for 15% of the market share. In the 1990's Chiquita formed an alliance with Sustainable Agricultural Network (SAN). Out of this collaboration was formed the Rainforest Alliance – an American, non-governmental agency concerned with promotion of sustainable practices. This greatly enhanced their brand as the Chiquita – Rainforest Alliance was considered one of the most strategic environmental plans (Etsy and Winston, 2009; Van der Waals and Moss, 2011).

Conclusions

The two innovations discussed reveal marginal potential in increasing sustainability of subtropical production of non-Cavendish bananas for a niche market. Reflective mulches were ineffective in increasing banana plant vigor, increasing leaf surface area, leaf longevity (NSL), or LER which hastens arrival at a CLN range predictive of flower emergence. White mulch decreased DTE significantly compared to the no cover control and silver mulch treatment. DTE was significantly increased in the silver mulch treatments compared to the white mulch or control. Effects of reflective mulch treatments in decreasing or increasing DTE may have more to do with soil moisture and soil temperature than increased light radiation in the under canopy of bananas. Reflective mulch usage in bananas may be more impactful where cultivars with exceptionally brief production cycles such as 'Veinte Cohol' are being grown.

Cover crop usage in banana production has been strongly encouraged. It has the potential of lowering inputs such as irrigation, fertility, and pests such as weeds, insects and disease. Benefits of cover crop usage may not be realized in large commercial plantations were Cavendish is being produced because nutrients would not be made available at the rates required by the industry. These operations require excessive amount of irrigation and fertilizer –especially K and N. However, studies have shown that banana production using 100% organic inputs like cover crop usage produced comparable yields to a system utilizing conventional production methods. Nevertheless, small farmer operation could benefit from cover crop usage because bunch yield would be necessarily smaller would not demand the level nutrient (N) supply that bananas require for the Cavendish market.

Cover crops in this single-year study did not affect soil composition or structure to the point of increasing plant vigor. Use of cover crops is a paradigm shift for many farm managers and appreciable benefits to the soil will be realized after long-term practice, but demand for naturally or organically grown products continues to increase. Bananas that meet the requirements of a particular certification can receive a premium price.

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Table 3. 1. Effect of Silver Reflective Mulch and White Reflective Mulch on Yield and Production Efficiency of Musa (AAB) ‘Mysore’ Bananas at the Gulf Coast REC Fairhope, AL. 2013.

Treatment	**Bunch Weight (kg)**	**Total Hand Weight (kg)**	**Production Efficiency (bunch wt./Rachis wt)**
No Cover	5.4ns	4.6ns	6.0ns
Silver Reflective	6.9	5.7	7.5
White Reflective	6.2	5.5	4.5
Correlation			
Soil Temperature	0.3415	0.3769	0.0234
Soil Moisture	0.9398	0.8375	0.851

Table 3. 2. Effect Silver Reflective and White Reflective Mulch on Bunch Characteristics of Musa (AAB) 'Mysore' Bananas at the Gulf Coast REC, Fairhope, AL. 2013.

Treatment	**Number of Hands**	**Avg Hand Weight (g)**	**Finger Length (mm)**	**Finger Width (mm)**
No Cover	9ns	510.5ns	77.6ns	21.6ns
Silver Reflective	9.0	570.2	83.5	22.1
White Reflective	8	620.2	88.8	22.0
Correlation				
Soil Temperature	0.5836	0.5042	0.4393	0.483
Soil Moisture	0.0303	0.8803	0.7807	0.5966

Table 3. 3. The Effects of Silver Reflective Film and White Reflective Mulch on Pseudostem Length, Pseudostem Circumference,and Height: Circumference Ratio on Musa sp. (AAB) 'Mysore'Banana at the Gulf Coast REC, Fairhope, AL.

Treatment	**Pseudo-stem Length (cm)**	**Pseudo-stem Circum. (cm)**	**Height: Circum. Ratio**
Silver Film	260.60	59.0	4.44
White Fabric	239.80	53.0	4.52
No Cover	232.66	51.2	4.48
P-Value	0.3634	0.1931	0.9550

Table 3. 4. The Effects of Silver Reflective Film and White Reflective Mulch on Leaf Area, Number of Leaves Present, Cumulative Leaf Number and Leaf Emergence Rate on Musa sp. (AAB) ‘Mysore’ Banana at the Gulf Coast REC, Fairhope, AL.

Treatment	**3rd Pos-ition Leaf Area (cm^2)**	**Number Leaves Present**	**Cumulative Leaf Number**	**Leaf Emergence Rate (Leaves $month^{-1}$)**
Silver Film	12,590	13.60	33.33	4.33
White Fabrice	10,027	13.60	33.67	4.00
No Cover	11,665	13.00	32.20	4.00
P-Value	0.1263	0.8945	0.2975	0.1439

Table 3. 5. Light Reflectance of white fabric and silver film as measure by photosynthetically active radiation (*PAR*). Gulf Coast REC, Fairhope, AL.

Trt	**Temp °C**	**East Reflect. (µmol·m^{-2}·s^{-1})**	**West Reflect. (µmol·m^{-2}·s^{-1})**	**East Intercept (µmol·m^{-2}·s^{-1})**	**West Intercept (µmol·m^{-2}·s^{-1})**
White Fabric	29.97	388.67 a[z]	419.17 a	728.2	1379.8 a
Silver Film	29.50	507.33 a	381.83 a	840	1316.2 a
No Cover	28.60	104.00 b	101.50 b	738.0	606.3 b
P-Value	0.8279	0.0006	0.0015	0.9082	0.0148

[z]Any two means within a row not followed by the same letter are significantly different at P< 0.05 according to Shaffer Simulated method.

Table 3. 6. Spad Reading and Net Photosynthesis of the 2nd, 4th , and 8th Lamina of *Musa* sp. (AAB) 'Mysore' Banana at the Gulf Coast REC, Fairhope, AL.

Treatment	**Spad Reading**[y]	**Net Photo-synthesis**[x] **2nd Lamina ($\mu mol \cdot m^{-2} \cdot s^{-1}$)**	**Net Photo-synthesis 4th Lamina ($\mu mol \cdot m^{-2} \cdot s^{-1}$)**	**Net Photo-synthesis 8th Lamina ($\mu mol \cdot m^{-2} \cdot s^{-1}$)**	**Mean Net Photo-synthesis ($\mu mol \cdot m^{-2} \cdot s^{-1}$)**
No Cover	52.32	19.0	16.55	12.63	16.5
White Fabric	53.36	21.35	14.52	30.95	26.2
Silver Film	53.52	20.74	12.7	9.88	13.98
P-Value	0.5951	0.7847	0.7435	0.2544	0.1080

[y]Spad readings were taken at 135 DFM
[x]Photosynthesis was measured at 55 DFM

Table 3. 7. Effect of Silver Reflective and White Reflective Mulches on Timing of Flower Emergence of Musa (AAB) 'Mysore' Bananas at the Gulf Coast REC, Fairhope, AL. 2013.

Treatment	**Days to Emergence (DTE)**
Bare Ground	221b[z]
Silver Reflective	247a
White Reflective	216c
Correlation	Pr > F
Temperature	<.0001
Moisture	0.0409

[z]Any two means within a row not followed by the same letter are significantly different at $P< 0.05$ according to Shaffer Simulated method.

Table 3. 8. Fresh weight, dry weight, %N and %C of crimson clover (CC), hairy vetch (HV), and Bahia grass (BG)sod control plots at the Oak Hill Tree Farm, Grand Bay, AL, May, 2015.

Cover Crop Treatment	**Fresh Weight (g)**	**Dry Weight (g)**	**Nitrogen (%)**	**Carbon (%)**	**Nitrogen kg ha^{-1}**
HV	177.2 a[z]	41.1 b	3.2 a	42.0	143 a
CC	131.3 b	61.5 a	1.9 b	39.3	121 a
BG	49.7 c	23.9 c	1.6 b	31.5	41 b
P-Value	0.0004	0.0021	0.0021	0.057	0.0013

[z]Any two means within a row not followed by the same letter are significantly different at P< 0.05 according to Shaffer Simulated method.

Table 3. 9. First analysis of elemental soil nutrient composition of experimental plots containing Crimson Clover (CC), Hairy Vetch (HV), and Bahia grass (BG) control treatments at the Oak Hill Tree Farm, Grand Bay, AL, November, 2013.

Cover Crop Trt	**pH**	**P**	**K**	**Mg**	**Ca**	**Al**
BG	5.7	119.4	128.2	63	703.6 a[z]	205.2
CC	5.5	126.6	125.4	58.4	615.2 ab	212.6
HV	5.5	134.8	113.4	54.2	597.4 b	215.8
Sig.	0.1163	0.7723	0.2865	0.0573	0.0341	0.5571
	B	**Cu**	**Fe**	**Mn**	**Na**	**Zn**
BG	0.1	1.02	17.6	15.6	37.2	1.18
CC	0.1	1.22	20.6	16.4	36.6	1.12
HV	0.12	1.12	20.0	12.6	34.4	1.20
Sig.	0.4096	0.7089	0.0509	0.2648	0.3403	0.9366

[z]Any two means within a row not followed by the same letter are significantly different at $P < 0.05$ according to Shaffer Simulated method.

Table 3. 10. Second analysis of elemental soil nutrient composition of experimental plots containing Crimson Clover (CC), Hairy Vetch (HV), and Bahia grass (BG) control treatments at the Oak Hill Tree Farm, Grand Bay, AL,– November, 2014.

Cover Crop Treatment	**pH**	**P**	**K**	**Mg**	**Ca**
BG	5.62 a	134.2	176.6	70.4 a[z]	709.4
CC	5.5 a	155.6	164	72.4 a	616.8
HV	5.18 b	145.2	152.6	50.20 b	510.2
Sig.	0.0025	0.7575	0.4412	0.0394	0.1906

	Carbon (%)	**Nitrogen** (%)	**Organic Matter** (%)	**C:N Ratio**
HV	1	0.08	1.72	13:1
BG	0.964	0.082	1.64	12:1
CC	0.946	0.076	1.62	12:1
Sig.	0.4438	0.547	0.3895	.

[z]Any two means within a row not followed by the same letter are significantly different at $P < 0.05$ according to Shaffer Simulated method.

Table 3. 11. Foliar nutrient composition of bananas cultivated in Crimson Clover (CC), Hairy Vetch (HV), and Bahia grass (BG) sod control treatment at the Oak Hill Tree Farm, Grand Bay, AL, 2014.

Cover Crop Trt	**Ca**	**K**	**Mg**	**P**	**Al**	**B**
BG	0.382	3.204	0.158	0.202	10.8	6.59
CC	0.390	3.140	0.172	0.200	12.2	7.39
HV	0.406	3.120	0.144	0.200	10.8	6.99
Sig.	0.8309	0.8811	0.132	0.9801	0.9018	0.8935

	Cu	**Fe**	**Mn**	**Na**	**Zn**
BG	13.8	41.0	404.4	259.8	25.4
CC	13.8	42.4	537.4	447.2	24.4
HV	16.4	41.2	566.2	339.0	23.4
Sig.	0.219	0.8688	0.056	0.1121	0.9663

Table 3. 12. Effect of Crimson Clover and Hairy Vetch Treatments on growth parameters of 'Dwarf Orinoco' Bananas in Grand Bay, AL, 2014.

Cover Crop	**Pseudo-stem Length (cm)**	**Pseudo-stem Circum (cm)**	**Leaf Laminal Length (cm)**	**Laminal Width (cm)**
Bahai grass Control	49.30	13.14	49.75	24.10
Crimson Clover	58.02	15.25	54.81	26.87
Hairy Vetch	53.60	14.26	52.98	25.32
Significance				
Cover Crop	0.068	0.1155	0.2217	0.2394
DFP	<.0001	<.0001	<.0001	0.0015
Cover x DFP	0.8061	0.6703	0.6258	0.5117
	Leaf Area(cm^2)	**Number Standing Leaves**	**LER**	**Cumulative Leaf Number**
Bahai grass Control	1238.70	6.12	3.28	10.20
Crimson Clover	1590.44	6.76	3.31	10.36
Hairy Vetch	1362.90	6.36	3.36	10.20
Cover Crop	0.223	0.1597	0.9911	0.8392
DFP	<.0001	<.0001	0.476	<.0001
Cover x DFP	0.5349	0.0703	0.9926	0.9413

Table 3. 13. [1]Production Area of Organically Produced Bananas of Leading Countries in Latin America and the Caribbean.

Country	**Total Area (Hectares)**
Ecuador	20,033
Dominican Rep.	14,953
Peru	5,092
Costa Rica	3,409
Mexico	238
Guatemala	72
Panama	22
Jamaica	7

[1]Statistics provided by The World of Organic Agriculture and Trends 2010.

Figure 3. 1. White reflective mulch used to increase light interception of lower canopy leaves

Figure 3. 2. Silver reflective mulch used to increase light interception of lower canopy leaves.

Figure 3. 3. Control treatment with no reflective fabric or film cover.