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# Irrigation Frequency Requirements of 'Williams' Banana Plantlets Grown in Sphagnum Peat and Sugarcane Filter Press Mud Based Substrates

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**Sugarcane filter press mud (FPM) is a waste product of the sugar milling industry. Around the world, it is used in nurseries as a component of substrates in container nurseries. It has been used to grow bananas *Musa spp*. in various countries with contradictory results. In this experiment, 12-month pile-aged FPM or sphagnum peat (SP) was used as a substrate component for growing banana plantlets *Musa acuminata* 'Williams' (AAA) in a greenhouse in Belle Glade, FL. Substrate mixtures were either 55% or 90% FPM or SP and the complement was made of an even mixture of vermiculite and perlite. Plants were watered on 1-, 2- and 4-day intervals. At each interval, plants were watered to ensure 20% leaching. Every eight days, containers, substrate, and plants were weighed before and after irrigation to determine water usage. Plants grown in FPM had lower evapotranspiration than plants grown in an SP-based substrate. However, daily watering was required for plants in FPM-based substrate to ensure growth similar to the plants grown in SP-based substrate.**

Bananas (*Musa spp*.) are an important crop in Florida, not only for their fruit production, but also as landscape plants. Current recommendations advise growers to start with tissue culture plantlets as they are free of pests and can produce a large uniform crop (Robinson et al., 1993; Fonsah et al., 2007; Galán-Saúco and Robinson, 2010).

Irrigation of field grown bananas in plantations has been studied extensively. Shmueli (1953) found that bananas had very efficient regulation of their stomata and that there was a threshold at 66% total available moisture, where plant performance declined. The Food and Agricultural Organization of the United Nations - Evapotranspiration (FAO-ET) for bananas shows a $K_c$ of 0.5 for young plants and up to 1.2 for established plants (Allen et al., 1998). Eckstein and Robinson (1996) recommended a three-day interval between irrigations for field grown plants. Turner and Thomas (1998) found that five days after irrigation to container capacity, leaves quit emerging, stomata closed, and photosynthesis was 1/10 of the well-watered control, in 25 L pots.

Worldwide annual nursery production of tissue culture plantlets is likely in the hundreds of millions of plants per year based on worldwide acreage and requirements for planting/replanting. Despite this, there are only rudimentary data on proper irrigation of bananas during the nursery phase. Furthermore, there is a lack of information on the proper irrigation frequencies based on the type of substrate used. Robinson and Galán-Saúco (2009) recommend daily watering for light substrates and less frequent watering for heavier substrates. Silva et al. (1999) irrigated with 334 mL per 2.5 L pot twice weekly. However, Martins et al. (2011) had twice a day 1.7 cm irrigation events for the first 30 days and once a day 1.7 cm irrigation events for days 31–105. Klock-Moore and Broschat (2001) found that areca palm (*Dypsis lutescens*) and *Philodendron* produced the greatest matter in a 60% biosolid compost when irrigated daily.

Sugarcane filter press mud (FPM) is a waste product of sugar milling process that consists of soil, cane fiber, ash, and lime. Depending on the source of FPM, water holding capacity ranges from 49% to 61% by volume. The purpose of this research was to compare the growth of 'Williams' bananas grown in FPM and sphagnum peat (SP) substrates under three irrigation frequencies. The objectives of this research are to determine the effect of substrate on plant growth and water use, to determine the effect of irrigation frequency on plant growth and water use, and to determine if there is an interaction between substrate and irrigation frequency on plant growth and water use.

## Materials andMethods

Tissue culture banana plantlets 'Williams' were purchased from Sunscape Nursery in Apopka, FL. The plantlets were acclimated to greenhouse conditions under 50% shade and misting for two weeks. Plantlets were graded prior to planting to a uniform height of 4 cm and 6 leaves.

The substrate mixtures consisted of 90% and 55% FPM [12-month aged source from an Everglades Agricultural Area (EAA) sugar mill] or SP (Pro-Moss-Fine, Premier Tech Horticulture, Quakertown, PA) by volume mixed with perlite and vermiculite. The perlite (Specialty Vermiculite, Pompano Beach,

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Table 1. Physical characteristics of sugarcane filter press mud (FPM) and sphagnum peat (SP) in 90% and 55% by volume mixtures with equal parts perlite and vermiculite. The FPM was a 12-month aged sample from a sugar mill in the Everglades Agricultural Area.

| Substrate | Bulk density ($g/cm^3$) | Porosity[z] | Air-filled porosity | Water holding capacity[y] |
|---|---|---|---|---|
| FPM55 | 0.28 | 72 | 0.13 | 1.68 |
| FPM90 | 0.35 | 69 | 0.1 | 2.22 |
| SP55 | 0.15 | 83 | 0.25 | 1.65 |
| SP90 | 0.19 | 79 | 0.15 | 2.04 |

[z]Percent by volume.

[y]g $H_2O$/g substrate.

FL) and vermiculite (Specialty Vermiculite, Pompano Beach, FL) were mixed in equal parts to make up the complement of each mixture. The physical properties of bulk density, porosity, and air-filled porosity were measured using 16.5 cm × 16.5 cm containers due to their use as the container for later direct testing of bananas in an FPM-based substrate. Porosity and air-filled porosity methods were based on those outlined by Bilderback (1982). Three 2200 mL samples per substrate were placed into containers with liners, which prevented drainage. These containers were saturated and weighed to calculate a saturated weight. The liners were then punctured, which allowed the containers to drain. A drained weight was recorded four hours after the liners were punctured. The substrate was then removed from the container and oven dried at 120 °C to determine dry weight. Bulk density was determined by dividing dry weight by the volume (2200 mL). Porosity was determined by calculating the difference between saturated weight and dry weight. Air-filled porosity was determined measuring the difference between the saturated and drained weights and dividing by the total volume. Water holding capacity was determined as grams of water retained in a drained pot per gram of dry substrate in the container (Table 1). Media were prepared by mixing the components in their respective volumetric proportions in a concrete mixer. Osmocote Plus (Everris, Dublin, OH) 15N–2.6P–10K 3–4 month release was incorporated at the rate of 4.8 g fertilizer per liter of substrate. The experiment was conducted within a pad and fan cooled greenhouse at the Everglades Research and Education Center in Belle Glade, FL.

There were three irrigation frequency treatments: daily, every other day, and every 4th day. Irrigation volumes were designed to provide 20% leaching. Irrigation volumes were calculated every eight days by calculating the mass of water required to bring each pot back to container capacity. Container capacity is the amount of water held in a container substrate after drainage. The average volume of water to bring each pot back to container capacity for each treatment was then multiplied by 1.2 to determine the following week's irrigation amounts. Irrigation amounts for week one were determined by calculating daily evaporative loss from an unplanted pot.

Leaf color was measured at planting, 24 days after planting (DAP), 40 DAP, and 64 DAP with a Minolta-502 SPAD Meter [(SPAD), Minolta, Ramsey, NJ]. Stomatal conductance was measured at planting, 24 DAP, 40 DAP, and 64 DAP with a Delta-T AT4 porometer (Delta-T, Cambridge, UK). Porometer readings were made between 10:00 AM and 2:00 PM on sunny days. The SPAD readings and stomatal conductance measurements were made on the youngest fully expanded leaf approximately 1/3 of the leaf's length basad of the leaf apex. Anthocyanin-rich leaf blotches common to bananas were avoided. Leaf counts were done regularly to determine the leaf emission rate. Plant height was measured six times throughout the experiment by measuring from the plant base to the junction of the plant collar and the cigar leaf. After 64 days, the experiment was terminated and stem diameter and number of functional leaves were measured. The plants were then removed from their pots, soil cleaned from roots by washing, and dried in a drying room at 65 °C until no further weight loss occurred. Dry weights of roots and shoots were then measured to determine dry matter accumulation and root:shoot ratio.

To determine differences in evaporative water use from the substrates, a 25-day dry down was conducted in unplanted pots. Three pots were prepared with 2200 mL each of the four substrates. Irrometer MLT tensiometers (Irrometer, Riverside, CA)

Table 2. Daily evapotranspiration (ET) measured gravimetrically during 4 days from 'Williams' bananas grown in containers filled with sugarcane filter press mud (FPM) and sphagnum peat (SP) in 90% and 55% by volume mixtures with equal parts perlite and vermiculite. Plants were irrigated every 1, 2, or 4 days to container capacity with a 20% leaching fraction.

| | Irrigation interval | Day 8 | | Day 16 | | Day 24 | | Day 32 | |
|---|---|---|---|---|---|---|---|---|---|
| Substrate | (days) | ET[z] | SE[y] | ET | SE | ET | SE | ET | SE |
| FPM55 | 1 | 40 | ±7 | 46 | ±8 | 120 | ±14 a | 118 | ±13 cde |
| FPM55 | 2 | 51 | ±9 | 48 | ±8 | 88 | ±12 cde | 96 | ±13 def |
| FPM55 | 4 | 44 | ±3 | 48 | ±3 | 66 | ±5 ef | 59 | ±7 f |
| FPM90 | 1 | 25 | ±3 | 63 | ±9 | 99 | ±6 abcd | 124 | ±8 cd |
| FPM90 | 2 | 38 | ±3 | 50 | ±5 | 75 | ±7 de | 85 | ±12 ef |
| FPM90 | 4 | 30 | ±2 | 49 | ±3 | 46 | ±2 f | 66 | ±6 f |
| SP55 | 1 | 43 | ±10 | 83 | ±20 | 118 | ±21 ab | 165 | ±13 b |
| SP55 | 2 | 56 | ±10 | 77 | ±13 | 106 | ±3 abc | 218 | ±21 a |
| SP55 | 4 | 48 | ±5 | 79 | ±8 | 100 | ±1 abc | 149 | ±13 bc |
| SP90 | 1 | 58 | ±17 | 63 | ±18 | 113 | ±5 ab | 139 | ±21 bc |
| SP90 | 2 | 56 | ±10 | 63 | ±11 | 108 | ±7 abc | 132 | ±19 bcd |
| SP90 | 4 | 54 | ±10 | 63 | ±11 | 95 | ±1 bcd | 151 | ±8 bc |

[z]ET reported in mL/$H_20$ per day.

[y]Standard error.

Means in the same column followed by different letters are significantly different (Student's *t*, test, JMP 11.0; $\alpha$ =0.05).

Table 3. Daily evapotranspiration (ET) measured gravimetrically during 4 days from 'Williams' bananas grown in containers filled with sugarcane filter press mud (FPM) and sphagnum peat (SP) in 90% and 55% by volume mixtures with equal parts perlite and vermiculite. Plants were irrigated every 1, 2, or 4 days to container capacity with a 20% leaching fraction.

| | Irrigation interval | Day 40 | | Day 48 | | Day 56 | | Day 64 | |
|---|---|---|---|---|---|---|---|---|---|
| Substrate | (days) | ET[z] | SE[y] | ET | SE | ET | SE | ET | SE |
| FPM55 | 1 | 142 | ±17 ab | 113 | ±18 cdef | 168 | ±16 ab | 149 | ±19 cd |
| FPM55 | 2 | 119 | ±9 bc | 150 | ±22 bcde | 152 | ±23 bcd | 159 | ±24 bcd |
| FPM55 | 4 | 89 | ±8 c | 82 | ±9 ef | 98 | ±9 ef | 99 | ±10 e |
| FPM90 | 1 | 153 | ±31 ab | 102 | ±25 def | 181 | ±8 ab | 150 | ±21 cd |
| FPM90 | 2 | 86 | ±11 c | 120 | ±17 cdef | 116 | ±13 de | 126 | ±16 d |
| FPM90 | 4 | 85 | ±10 c | 65 | ±6 f | 74 | ±14 f | 78 | ±11 e |
| SP55 | 1 | 158 | ±21 ab | 208 | ±40 ab | 158 | ±17 bc | 191 | ±29 ab |
| SP55 | 2 | 177 | ±3 a | 223 | ±25 a | 200 | ±10 a | 220 | ±18 a |
| SP55 | 4 | 166 | ±3 a | 163 | ±8 abcd | 171 | ±5 ab | 176 | ±7 b |
| SP90 | 1 | 119 | ±12 bc | 179 | ±19 abc | 128 | ±12 cde | 162 | ±16 bc |
| SP90 | 2 | 154 | ±11 ab | 145 | ±30 bcde | 149 | ±18 bcd | 156 | ±26 bc |
| SP90 | 4 | 166 | ±7 a | 211 | ±41 ab | 163 | ±5 abc | 195 | ±22 ab |

[z]ET reported in mL $H_20$ per day.

[y]Standard error.

Means in the same column followed by different letters are significantly different (Student's *t* test, JMP 11.0; $\alpha = 0.05$).

Table 4. Total estimated evapotranspiration (ET) measured gravimetrically from 'Williams' bananas grown in containers filled with sugarcane filter press mud (FPM) and sphagnum peat (SP) in 90% and 55% by volume mixtures with equal parts perlite and vermiculite. Plants were irrigated every 1, 2, or 4 days to container capacity with a 20% leaching fraction.[,y]

| Substrate | Irrigation interval (days) | ET[z] | SE[y] |
|---|---|---|---|
| FPM55 | 1 | 5829 | ±316 cd |
| FPM55 | 2 | 5430 | ±579 de |
| FPM55 | 4 | 3676 | ±293 f |
| FPM90 | 1 | 5941 | ±328 cd |
| FPM90 | 2 | 4414 | ±460 ef |
| FPM90 | 4 | 3193 | ±210 f |
| SP55 | 1 | 7348 | ±844 ab |
| SP55 | 2 | 8279 | ±307 a |
| SP55 | 4 | 6847 | ±189 bc |
| SP90 | 1 | 6279 | ±441 bcd |
| SP90 | 2 | 6219 | ±606 bcd |
| SP90 | 4 | 7038 | ±419 abc |

[z]ET measured in mL/$H_20$.

[y]Standard error.

Means in the same column followed by different letters are significantly different (Student's *t* test, JMP 11.0; $\alpha = 0.05$).

were installed in the containers so that the tip was 10 cm below the surface. The pots were saturated and allowed to drain free water before an initial tensiometer and mass readings were calculated.

Daily tensiometer and mass readings were taken for the first 4 days and then on days 6, 7, 10, 11, 15, 17, 22, and 25. At the end of the drying period, soil was removed from the container in order to determine dry weight. Substrate dry weight was determined by oven drying at 120 °C until no further weight loss occurred. Substrate dry mass was used to determine the remaining container capacity by subtracting the substrate dry mass and container mass from the measured masses during the experiment. These numbers were converted to percentage of total container capacity by dividing by the mass of water in the container on day 1 after drainage.

The experiment was designed as a factorial with 6 replicates of each media × irrigation treatment for a total of 72 experimental units. An experimental unit consisted of one banana plantlet in a 16.5 cm × 16.5 cm pot.

Statistical analysis was performed with JMP Pro 11.0 using a least squares model with substrate, irrigation frequency and their interaction being the effects in tests involving only one measurement. In tests involving several measurements, the multivariate analysis of variance (MANOVA) with repeated measures was used.

## Results and Discussion

Water use in FPM treatments was lower than in SP treatments. Substrate and irrigation interval affected water use. There was also a significant substrate × irrigation interval interaction for water use. From 24 DAP until the end of the experiment, highest water use in FPM treatments occurred in the daily irrigated treatments (Table 2, Table 3). For SP55, the 2-day treatment had the greatest water use from 32 DAP until the end of the experiment (Table 2, Table 3). For SP90, the 4-day treatment had the greatest water use from 32 DAP until the end of the experiment (Table 2, Table 3). Total estimated evapotranspiration (Table 4) ranged from 8279 mL in SP55-2 day to 3193 mL in the FPM90-4 day, while water use in the FPM-4 day treatments was lower than in the FPM-1 day treatments, water use in SP-4 day treatments was equal to water use in SP-1 day treatments.

Plant height was responsive to substrate and irrigation, but differences in plant height were only measured starting 42 DAP (Table 5). Daily irrigation consistently produced the tallest plants in each treatment. However, in SP55 there were no differences in height among irrigation frequencies. This is likely due to greater root growth in this treatment, which would have allowed the plants to access more water than in other treatments. There was a positive response to irrigation for the FPM treatments, but not for the SP treatments in terms of root growth. Silva et al. (1999) found that including FPM in substrates produced smaller plants than those in a commercial mixture when irrigated twice per week. This research confirms those findings at the 4-day interval, but disputes those findings with daily irrigation. The height to stem diameter ratio does indicate some slight crowding since it was below 10:1 (Robinson and Galán-Saúco, 2009).

Table 5. Plant heights of 'Williams' bananas grown in containers filled with sugarcane filter press mud (FPM) and sphagnum peat (SP) in 90% and 55% by volume mixtures with equal parts perlite and vermiculite. Plants were irrigated every 1, 2, or 4 days to container capacity with a 20% leaching fraction.[y]

| | Irrigation interval | Day 0 | | Day 14 | | Day 28 | | Day 42 | | Day 65 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Substrate | (days) | Height[z] | SE[y] | Height | SE | Height | SE | Height | SE | Height | SE |
| FPM55 | 1 | 10 | ±0 | 24 | ±2 | 35 | ±2 | 46 | ±2 a | 50 | ±1 a |
| FPM55 | 2 | 10 | ±0 | 23 | ±2 | 31 | ±1 | 42 | ±2 ab | 47 | ±2 abc |
| FPM55 | 4 | 10 | ±0 | 21 | ±1 | 28 | ±0 | 36 | ±1 cde | 42 | ±1 def |
| FPM90 | 1 | 10 | ±0 | 22 | ±1 | 32 | ±2 | 40 | ±1 bc | 47 | ±2 abcd |
| FPM90 | 2 | 10 | ±0 | 19 | ±1 | 26 | ±1 | 39 | ±2 bcd | 43 | ±2 cdef |
| FPM90 | 4 | 10 | ±0 | 19 | ±1 | 23 | ±1 | 34 | ±1 e | 39 | ±2 f |
| SP55 | 1 | 10 | ±0 | 25 | ±1 | 35 | ±3 | 43 | ±2 ab | 49 | ±2 ab |
| SP55 | 2 | 10 | ±0 | 26 | ±1 | 35 | ±2 | 42 | ±1 ab | 45 | ±1 bcd |
| SP55 | 4 | 10 | ±0 | 23 | ±2 | 19 | ±9 | 41 | ±2 b | 46 | ±2 abcd |
| SP90 | 1 | 10 | ±0 | 24 | ±2 | 35 | ±1 | 40 | ±1 bc | 47 | ±2 abcd |
| SP90 | 2 | 10 | ±0 | 23 | ±2 | 33 | ±1 | 43 | ±2 ab | 44 | ±2 bcde |
| SP90 | 4 | 10 | ±0 | 23 | ±1 | 30 | ±0 | 35 | ±1 de | 39 | ±1 ef |

[z]Measured in centimeters (cm).

[y]Standard error.

Means in the same column followed by different letters are significantly different (Student's *t* test, JMP 11.0; $\alpha = 0.05$).

Table 6. Stem diameter, dry weights and root-shoot ration of 'Williams' bananas grown in containers filled with sugarcane filter press mud (FPM) and sphagnum peat (SP) in 90% and 55% by volume mixtures with equal parts perlite and vermiculite. Plants were irrigated every 1, 2, or 4 days to container capacity with a 20% leaching fraction.

| Substrate | Irrigation interval (days) | Stem diameter (mm) | | Shoot dry wt (g) | | Root dry wt (g) | | Total dry wt (g) | | Root:shoot ratio | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| FPM55 | 1 | 42.2 | ±2.2 ab | 29.7 | ±3.0 abc | 16.8 | ±2.1 bcd | 46.5 | ±5.0 bc | 0.6 | ±0.0 cd |
| FPM55 | 2 | 37.5 | ±2.1 bcd | 25.7 | ±3.4 cd | 12.4 | ±1.9 cdef | 38.2 | ±5.3 cde | 0.5 | ±0.0 d |
| FPM55 | 4 | 32.7 | ±1.0 ef | 20.4 | ±1.6 de | 10.7 | ±1.0 def | 31.1 | ±2.5 ef | 0.5 | ±0.0 d |
| FPM90 | 1 | 43.0 | ±2.1 a | 32.5 | ±1.3 ab | 19.4 | ±1.3 b | 52.0 | ±2.3 ab | 0.6 | ±0.0 bcd |
| FPM90 | 2 | 34.2 | ±2.0 def | 22.0 | ±2.4 de | 10.4 | ±1.6 ef | 32.5 | ±4.0 def | 0.5 | ±0.0 d |
| FPM90 | 4 | 30.2 | ±1.1 f | 16.4 | ±1.7 e | 7.6 | ±0.7 f | 24.0 | ±2.4 f | 0.5 | ±0.0 d |
| SP55 | 1 | 40.7 | ±1.7 abc | 29.5 | ±2.0 abc | 15.4 | ±2.3 bcde | 44.9 | ±4.2 bc | 0.5 | ±0.1 d |
| SP55 | 2 | 42.2 | ±0.7 ab | 34.5 | ±0.6 a | 26.8 | ±2.0 a | 61.3 | ±2.5 a | 0.8 | ±0.1 a |
| SP55 | 4 | 39.0 | ±1.2 abc | 28.2 | ±1.4 bc | 19.9 | ±3.1 b | 48.1 | ±4.1 bc | 0.7 | ±0.1 abc |
| SP90 | 1 | 39.3 | ±2.3 abc | 25.1 | ±2.6 cd | 19.2 | ±3.8 b | 44.2 | ±6.3 bc | 0.7 | ±0.1 ab |
| SP90 | 2 | 37.8 | ±2.1 bce | 25.5 | ±2.5 cd | 17.8 | ±3.0 bc | 43.3 | ±5.2 bcd | 0.7 | ±0.1 abc |
| SP90 | 4 | 37.2 | ±0.6 cde | 26.0 | ±1.0 cd | 21.1 | ±1.4 ab | 47.1 | ±2.2 bc | 0.8 | ±0.0 a |

[z]Means in the same column followed by different letters are significantly different (Student's *t* test, JMP 11.0; $\alpha = 0.05$).

Leaf emission rates have been identified as the most sensitive indicator of soil water deficit (Turner et al., 2007)). In this study, differences that appeared were fairly small, and only appeared 39 DAP (Table 7, Table 8). At 64 DAP, the only treatment that showed any difference between daily irrigation and longer intervals was FPM90, where the 1-day treatment differed from the 2-day and 4-day treatments. Some research indicates that drought stress induces leaf yellowing and early leaf senescence (Ke, 1979). However, the current research found no differences in the number of functional leaves 64 DAP. The SPAD readings (Table 9) consistently showed no differences between irrigation frequencies in the SP treatments. In the FPM treatments, which had lower SPAD readings than SP, there was a trend toward lower SPAD readings with increasing intervals between irrigation events, which agreed with the findings of Ke (1979). The lower SPAD readings could also be indicative of a more intense iron deficiency due to precipitation of iron in dryer substrates.

Dry matter production (Table 6) and evapotranspiration (Table 10) relate well to porometer readings (Table 10) because they are indicative of stomatal aperture, which controls the rate of carbon assimilation and transpiration. Highest water use was found in the largest plants in SP55-2 day, while the smallest plants were produced in the lowest water use treatment, FPM90-4 day. Stomatal conductance has been shown to be an indicator of drought stress by several researchers (Shmueli, 1953; Ke, 1979; Turner and Thomas, 1998; Turner et al., 2007). Drought stress, indicated by stomatal closure, was shown during the 24 DAP and 40 DAP measurement in all 4 day treatments except SP90. Surprisingly, no stress in any treatment was found 64 DAP. This could be a result of greater rooting that allowed the plants to access additional water. Under a 25-day unplanted dry down, FPM-based substrates had higher soil moisture and higher water potentials at the end of 25 days (Figs. 1 and 2). This finding indicates that evaporation from the SP-based substrates was higher than in the FPM-based substrates. Given the lack of difference between substrates in terms

Table 7. Leaf production of 'Williams' bananas grown in containers filled with sugarcane filter press mud (FPM) and sphagnum peat (SP) in 90% and 55% by volume mixtures with equal parts perlite and vermiculite. Plants were irrigated every 1, 2, or 4 days to container capacity with a 20% leaching fraction.

| | Irrigation interval | Day 0 | | Day 12 | | Day 20 | | Day 28 | |
|---|---|---|---|---|---|---|---|---|---|
| Substrate | (days) | Leaves | SE[z] | Leaves | SE | Leaves | SE | Leaves | SE |
| FPM55 | 1 | 6 | ±0.0 | 8.2 | ±0.2 | 9.2 | ±0.2 | 10.8 | ±0.2 |
| FPM55 | 2 | 6 | ±0.0 | 8 | ±0.0 | 9 | ±0.0 | 10 | ±0.0 |
| FPM55 | 4 | 6 | ±0.0 | 8.7 | ±0.4 | 9.7 | ±0.4 | 10.7 | ±0.4 |
| FPM90 | 1 | 6 | ±0.0 | 8.3 | ±0.3 | 9.3 | ±0.3 | 10.3 | ±0.3 |
| FPM90 | 2 | 6 | ±0.0 | 7.8 | ±0.5 | 8.8 | ±0.5 | 9.8 | ±0.5 |
| FPM90 | 4 | 6 | ±0.0 | 8.3 | ±0.3 | 9.3 | ±0.3 | 10 | ±0.4 |
| SP55 | 1 | 6 | ±0.0 | 8.5 | ±0.3 | 9.5 | ±0.3 | 10.8 | ±0.3 |
| SP55 | 2 | 6 | ±0.0 | 8.3 | ±0.3 | 9.3 | ±0.3 | 10.5 | ±0.3 |
| SP55 | 4 | 6 | ±0.0 | 8.7 | ±0.3 | 9.7 | ±0.3 | 10.8 | ±0.4 |
| SP90 | 1 | 6 | ±0.0 | 8.5 | ±0.2 | 9.5 | ±0.2 | 10.5 | ±0.2 |
| SP90 | 2 | 6 | ±0.0 | 8.7 | ±0.2 | 9.7 | ±0.2 | 11.2 | ±0.3 |
| SP90 | 4 | 6 | ±0.0 | 8.5 | ±0.2 | 9.5 | ±0.2 | 11 | ±0.4 |

[z]Standard error.

Table 8. Leaf production of 'Williams' bananas grown in containers filled with sugarcane filter press mud (FPM) and sphagnum peat (SP) in 90% and 55% by volume mixtures with equal parts perlite and vermiculite. Plants were irrigated every 1, 2, or 4 days to container capacity with a 20% leaching fraction.[z]

| | Irrigation interval | Day 39 | | Day 47 | | Day 64 | |
|---|---|---|---|---|---|---|---|
| Substrate | (days) | Leaves | SE[z] | Leaves | SE | Leaves | SE |
| FPM55 | 1 | 11.8 | ±0.2 abc | 12.8 | ±0.2 abcde | 14.2 | ±0.3 ab |
| FPM55 | 2 | 11.2 | ±0.2 c | 12.2 | ±0.2 cde | 13.5 | ±0.2 b |
| FPM55 | 4 | 11.5 | ±0.6 bc | 12.5 | ±0.4 bcde | 14.0 | ±0.3 ab |
| FPM90 | 1 | 12.0 | ±0.4 abc | 12.8 | ±0.3 abcde | 14.3 | ±0.2 a |
| FPM90 | 2 | 11.2 | ±0.7 c | 12.0 | ±0.6 de | 13.5 | ±0.7 b |
| FPM90 | 4 | 11.5 | ±0.2 bc | 11.8 | ±0.4 e | 13.5 | ±0.2 b |
| SP55 | 1 | 12.5 | ±0.4 ab | 13.3 | ±0.3 ab | 14.8 | ±0.4 a |
| SP55 | 2 | 12.2 | ±0.3 abc | 12.8 | ±0.4 abcde | 14.5 | ±0.3 a |
| SP55 | 4 | 12.7 | ±0.3 a | 13.2 | ±0.5 abc | 14.7 | ±0.3 a |
| SP90 | 1 | 12.3 | ±0.2 ab | 13.0 | ±0.3 abcd | 14.2 | ±0.3 ab |
| SP90 | 2 | 12.8 | ±0.2 a | 13.7 | ±0.3 a | 14.8 | ±0.2 a |
| SP90 | 4 | 12.8 | ±0.3 a | 13.3 | ±0.3 ab | 14.7 | ±0.3a |

[z]Standard error.
Means in the same column followed by different letters are significantly different (Student's *t* test, JMP 11.0; $\alpha = 0.05$).

Table 9. Leaf color measures were taken using a Minolta-502 SPAD Meter (SPAD). The SPAD readings from 'Williams' bananas grown in containers filled with sugarcane filter press mud (FPM) and sphagnum peat (SP) in 90% and 55% by volume mixtures with equal parts perlite and vermiculite. Plants were irrigated every 1, 2, or 4 days to container capacity with a 20% leaching fraction.

| | Irrigation interval | Day 0 | | Day 24 | | Day 40 | | Day 64 | |
|---|---|---|---|---|---|---|---|---|---|
| Substrate | (days) | SPAD | | SPAD | | SPAD | | SPAD | |
| FPM55 | 1 | 41.8 | ±3.5 | 37.1 | ±2.7 abcde | 42.2 | ±2.8 d | 44.5 | ±2.3 bc |
| FPM55 | 2 | 44.9 | ±3.2 | 29.1 | ±2.7 e | 48.2 | ±1.3 bc | 42.4 | ±1.8 cd |
| FPM55 | 4 | 42.3 | ±2.3 | 32.1 | ±3.3 bcde | 43.7 | ±1.2 cd | 41.5 | ±1.2 cd |
| FPM90 | 1 | 47.2 | ±1.8 | 31.7 | ±3.3 cde | 44.4 | ±1.2 cd | 44.4 | ±2.1 bc |
| FPM90 | 2 | 39.9 | ±3.8 | 39.8 | ±3.4 abc | 38.8 | ±2.7 d | 38.0 | ±2.1 d |
| FPM90 | 4 | 45.2 | ±2.3 | 30.7 | ±2.3 de | 38.9 | ±2.6 d | 31.9 | ±1.5 e |
| SP55 | 1 | 39.9 | ±3.8 | 40.1 | ±3.3 ab | 53.2 | ±2.2 ab | 48.6 | ±1.0 ab |
| SP55 | 2 | 45.2 | ±2.3 | 42.0 | ±4.0 a | 53.3 | ±2.1 ab | 45.1 | ±1.9 abc |
| SP55 | 4 | 45.3 | ±2.9 | 39.9 | ±3.9 abc | 54.3 | ±2.3 a | 47.7 | ±1.4 ab |
| SP90 | 1 | 39.6 | ±3.6 | 38.9 | ±2.2 abcd | 53.6 | ±2.0 ab | 46.7 | ±1.6 abc |
| SP90 | 2 | 46.7 | ±2.1 | 39.1 | ±2.0 abc | 53.5 | ±1.9 ab | 50.4 | ±3.2 a |
| SP90 | 4 | 43.1 | ±2.8 | 38.5 | ±1.5 abcd | 54.2 | ±1.9 a | 45.6 | ±1.4 abc |

Means in the same column followed by different letters are significantly different (Student's *t* test, JMP 11.0; $\alpha = 0.05$).

Table 10. Porometer readings from 'Williams' bananas grown in containers filled with sugarcane filter press mud (FPM) and sphagnum peat (SP) in 90% and 55% by volume mixtures with equal parts perlite and vermiculite. Plants were irrigated every 1, 2, or 4 days to container capacity with a 20% leaching fraction.

| Substrate | Irrigation interval (days) | Day 0 s/cm | | Day 24 s/cm | | Day 40 s/cm | | Day 64 s/cm | |
|---|---|---|---|---|---|---|---|---|---|
| FPM55 | 1 | 0.6 | ±0.1 | 0.1 | ±0.0 c | 1.0 | ±0.1 c | 0.4 | ±0.2 |
| FPM55 | 2 | 0.3 | ±0.1 | 1.0 | ±0.3 bc | 1.3 | ±0.1 c | 0.4 | ±0.1 |
| FPM55 | 4 | 0.3 | ±0.0 | 3.3 | ±0.6 b | 7.2 | ±1.4 a | 1.1 | ±0.5 |
| FPM90 | 1 | 0.5 | ±0.1 | 0.3 | ±0.1 c | 1.4 | ±0.3 c | 0.4 | ±0.2 |
| FPM90 | 2 | 0.4 | ±0.1 | 0.5 | ±0.2 bc | 1.3 | ±0.3 c | 1.6 | ±1.0 |
| FPM90 | 4 | 0.4 | ±0.1 | 2.1 | ±0.7 bc | 9.0 | ±3.9 a | 0.7 | ±0.3 |
| SP55 | 1 | 0.5 | ±0.1 | 0.2 | ±0.1 c | 1.2 | ±0.3 c | 0.2 | ±0.1 |
| SP55 | 2 | 0.3 | ±0.1 | 1.4 | ±0.4 bc | 0.6 | ±0.1 c | 0.9 | ±0.2 |
| SP55 | 4 | 0.3 | ±0.0 | 6.5 | ±3.3 a | 6.2 | ±1.9 ab | 0.6 | ±0.4 |
| SP90 | 1 | 0.5 | ±0.1 | 0.3 | ±0.1 c | 1.4 | ±0.3 c | 0.5 | ±0.2 |
| SP90 | 2 | 0.3 | ±0.1 | 0.3 | ±0.1 c | 0.7 | ±0.1 c | 0.8 | ±0.5 |
| SP90 | 4 | 0.4 | ±0.1 | 1.8 | ±0.8 bc | 2.5 | ±0.3 bc | 0.2 | ±0.1 |

Means in the same column followed by different letters are significantly different (Student's *t* test, JMP 11.0; $\alpha$ =0.05).

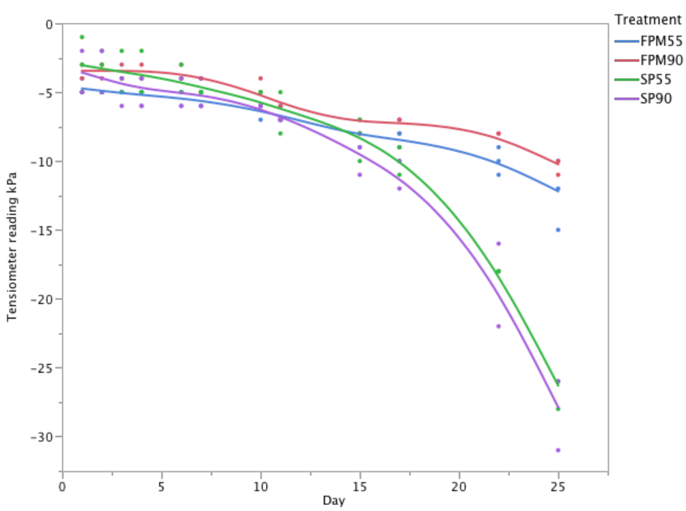


Fig. 1. Tensiometer readings from containers filled with sugarcane filter press mud (FPM) and sphagnum peat (SP) in 90% and 55% by volume mixtures with equal parts perlite and vermiculite. Containers were filled to container capacity and allowed to dry down over 25 days.

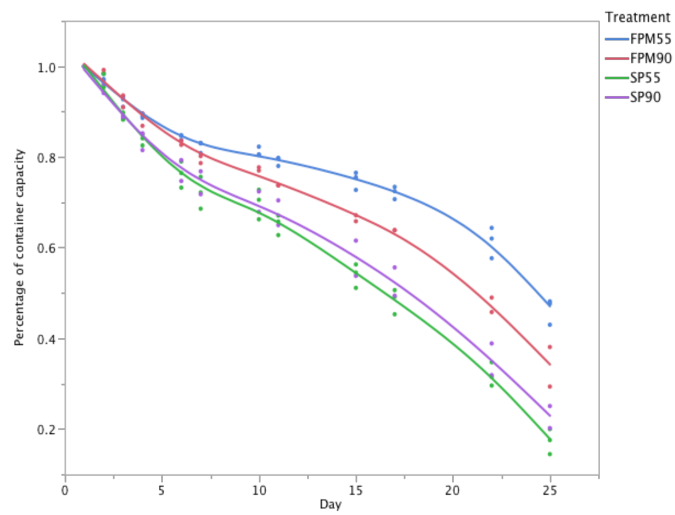


Fig. 2. Percentage of container capacity remaining from containers filled with sugarcane filter press mud (FPM) and sphagnum peat (SP) in 90% and 55% by volume mixtures with equal parts perlite and vermiculite. Containers were filled to container capacity and allowed to dry down over 25 days.

of stomatal conductance, the differences in water use are likely driven by differences in evaporation from the substrate surface.

Despite using less water, the plants grown in FPM seemed to be more sensitive to longer intervals between irrigation. Rather than being an indication of water in FPM being held at higher tension, as is suggested by Gallego et al. (2008), these findings point to the possibility that less frequent irrigation caused deleterious salt accumulation. Biernbaum (1992) noted that extensive leaching was required to maintain electrical conductivity levels in commercially available substrates. Levels of $NO_3$ in an adjoining leaching study were frequently in excess of 100 mg/L and K levels were frequently in excess of 50 mg/L. Decreasing root weights also point to salt accumulation as a possible reason for increased sensitivity to longer irrigation intervals. As moisture decreased, these concentrations would increase to potentially harmful levels. Interestingly, the proportion of FPM in the mixture did not visibly affect plant quality, so a grower would have some latitude in the proportion of perlite and vermiculite incorporated into the substrate.

In conclusion, plant growth and water use are affected by substrate and irrigation frequency. There is also an interaction between substrate and irrigation frequency. Plants grown in FPM based substrates are more sensitive to decreased irrigation frequency. This is likely due to salt accumulation. Daily-irrigated FPM plants were equivalent in size and color to those grown in SP based substrates. These plants were able to reach marketable size and color while using ≈ 70% of the water used in the sphagnum peat based substrates.

## Literature Cited


Allen, R.G., L.S. Pereira, D. Raes, and M. Smith. 1998. Crop Evapotranspiration, FAO. Irrigation and Drainage Paper No. 56, United Nations Food and Agriculture Organisation, Rome, Italy.

Biernbaum, J.A. 1992. Root-zone management of greenhouse container-grown crops to control water and fertilizer. HortTechnology 2:127–132.

Bilderback, T.E. 1982. Container Soils and Soilless Media. NCAES, Nursery Crops Production Manual, Raleigh, NC.

Eckstein, K. and J.C Robinson. 1996. Physiological responses of banana (*Musa* AAA; Cavendish sub-group) in the subtropics. VI. Seasonal responses of leaf gas exchange to short-term water stress. J. Hort. Sci. 71:679–692.

Fonsah, E.G., C.A. Adamu, B.N. Okole, and B.G. Mullinix. 2007. Field evaluation of Cavendish banana cultivars propagated either by suckers of by tissue culture, over six crop cycles in the tropics. Fruits. 62:205–212.

Gallego, R.O., A.M. Martorell, M. Díaz, M.O. Sosa, and A. Cruz. 2008. Propiedades físicas de sustratos, base de los sistemas agrícolas urbanos. Revista Agrotecnia de Cuba. 32.

Gálan-Sáuco, V. and J.C. Robinson. 2010. Field establishment of in vitro-produced banana plants. Fruits. 65:43–51.

Ke, L.S. 1979. Studies on the physiological characteristics of bananas in Taiwan II. Effects of soil moisture on some physiological functions and yield of the banana plant. J. Agr. Assn. China. 108:11–23.

Klock-Moore, K.A. and T.K. Broschat. 2001. Effect of four growing substrates on growth of ornamental plants in two irrigation systems. HortTech. 11:456–460.

Martins, A.N., L.D. Poz, E. Suguino, N.M. Silvestre Dias, and M.J. Perdoná. 2011. Aclimatação de mudas micropropagadas de bananeira 'Nanicão Williams' em diferentes substratos e fontes de nutrientes. Revista Brasileira de Ciencias Agrarias. 6:65–72.

Robinson, J.C., C. Fraser, and K. Eckstein. 1993. A field comparison of conventional suckers with tissue-culture banana planting material over three crop cycles. J. Hort. Sci. 68: 831-836.

Robinson, J.C. and V. Galán Sáuco. 2009. Nursery hardening of in vitro-produced banana plants. Fruits. 64:383–392.

Shmueli, E. 1953. Irrigation studies in the Jordan Valley. 1. Physiological activity of the banana in relation to soil moisture. Bull Res. Council Israel. 3D:228–247.

Silva, G.D., A.A. Fernandes, M.C. Toledo Pereira, C.H. Bruckner, and D.L. de Siqueira. 1999. Aclimatação de mudas de bananeira (*Musa* spp.) 'Prata' (AAB) em diferentes substratos. Revista Ceres 46:543–554.

Turner, D.W., J.A. Fontescue, and D.S. Thomas. 2007. Environmental physiology of the bananas (*Musa* spp.). Braz. J. Plant Phys. 19:463–484.

Turner, D.W., and D.S. Thomas. 1998. Measurements of plant and soil water status and their association with leaf gas exchange in banana (*Musa* spp.): A laticiferous plant. Scientia Hort. 77:177–193.