Pentas Water Use and Growth in Simulated Landscapes as Affected by Municipal Compost and Mined Field Clay Soil Amendments

S.M. Scheiber^{1,2}, Richard C. Beeson, Jr.³, and Sudeep Vyapari¹

University of Florida, IFAS, Environmental Horticulture Department, MREC, 2725 Binion Road, Apopka, FL 32703

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Abstract. *Pentas lanceolata* Schum. ‘New Look Red’ plants were grown in compost-amended, mined field clay-amended, or unamended sand soils in drainage lysimeters to evaluate growth, aesthetic quality, and irrigation requirements. Treatments were evaluated with irrigation controlled by tensiometers set to irrigate back to near field capacity when plant-available water in each soil declined to 50%. Compost-amended soils had greater ($P < 0.05$) mean shoot dry weight, total biomass, shoot-to-root ratios, growth indices, and landscape quality than other amendment treatments. Unamended soils and clay-amended treatments were comparable for all plant parameters. Total irrigation volumes applied were similar among treatments. Compost-amended soils yielded larger canopies, improved quality, and tended toward less cumulative irrigation. Clay amendment was not beneficial.

Frequent and excessive irrigation of landscape ornamentals can contribute to depletion of potable water supplies. Rapid population expansion and drought in parts of the United States have water management officials concerned that demands for water will exceed supply (Archer, 2002). Water consumption and corresponding percolate leaching may be significantly reduced in annual landscape beds through cultural practices such as the addition of soil amendments or use of conservative irrigation practices.

Incorporation of organic matter or compost in annual landscape beds is widely recommended to improve water and nutrient-holding capacities, particularly in sandy soils (Warren and Fonteno, 1993). However, organic matter is highly variable depending on source, can rapidly decompose, and can pose as a potential source of weed seed. An alternative soil amendment for sandy soils is clay, which possesses physical and chemical properties that increase water and nutrient-holding capacities. Calcined clays have successfully been used to reduce daily irrigation volumes in herbaceous and woody plant production (Cantliffe, 1989; Owens et al., 2003). However, calcined clays can be cost-prohibitive in the landscape environment. Mined field clay may function as a feasible economic solution for sandy soils.

Intensive management of irrigation frequency and application method can significantly decrease landscape water use. Most automated landscape irrigation is controlled by preprogrammed time clocks that use rigid scheduling without regard for available soil moisture or plant water requirements. This is especially true of residential landscapes. Furthermore, irrigation recommendations are inconsistent with application frequencies and rates varying among sources. This combination of factors often results in overirrigation in residential and commercial landscapes.

Soil moisture sensors are available that control irrigation as a function of available soil moisture. Tensiometer-regulated irrigation systems have resulted in significant reductions in irrigation volumes during production of *Rosa hybrida* L. ‘Kardinal’, *Prunus persica* (L.) Batsch ‘Cresthaven’, and *Cucumis sativus* L. without compromising quality or growth (Ells et al., 1989; Huslig et al., 1993; Oki et al., 2001). Tensiometers programmed to irrigate at 50% of plant-available water reduced irrigation volumes applied to *Petunia × hybrida* ‘Midnight’, but aesthetic quality and canopy size were compromised in simulated landscapes (Scheiber and Beeson, 2006). Qualls et al. (2001) used granular matrix soil moisture sensors to reduce average application volumes by greater than 20% in mixed residential landscapes. Dielectric probes and tensiometers reduced irrigation volumes in turfgrass without compromising growth or quality (Dukes et al., 2005; Synder et al., 1984).

Objectives of this study were to: 1) quantify irrigation requirements of an annual bedding plant in simulated landscape beds

in response to tensiometer-controlled irrigation for differently amended soils, 2) evaluate growth responses and aesthetic quality of an annual bedding plant in relation to different soil amendment practices, and 3) determine feasibility of field clay as an amendment for sandy soils to decrease irrigation requirements.

Materials and Methods

Pentas lanceolata Schum. ‘New Look Red’ were obtained from a commercial nursery in 0.72-L containers and transplanted on 3 Sept. 2003 into 12 drainage lysimeters made from 246-L polyethylene containers (Lerio Corp., Kissimmee, FL.) with a diameter of 0.89 m and a depth of 0.44 m. Each lysimeter was located in an open-sided clear polyethylene-covered shelter and contained three plants. Three plants were planted in an equilateral triangular pattern, 30 cm apart, and mulched with shredded hardwood bark to a depth of 5 cm uniformly over the soil surface. Lysimeters were backfilled with native top soil (Apopka fine sand) to simulate landscape conditions. Treatments evaluated were unamended top soil (Apopka fine sand series; control) and soil amended with either composted yard waste (Orange County Solid Waste Management, Orange County, FL.) (9% greater than 2 mm, 49% between 2 mm and 0.42 mm, and 42% greater than 0.42 mm) (50% by volume) or mined local field clay (Kaolite; 93.9 sand:5.6 clay:0.5 silt, by volume) (50% by volume) in the top 15 cm. Clay was chosen as representative of the base soil foundation used in new home construction in Central Florida and is commonly found in urban soils of residential landscapes. Subsamples taken from each amended soil and the unamended control soil were analyzed for nutrient content by a commercial soil testing laboratory (Agro Services International, Orange City, FL) before planting.

To minimize impact of solar radiation on root temperatures, exteriors of containers were coated with white exterior latex flat house paint (Enterprise Paint Co., Wheeling, IL). Controlled-release fertilizer was uniformly broadcast with a standard nitrogen rate of 1.678 kg/100 m² of 18N–2.6P–9.9K Osmocote (Scotts Co., Marysville, OH) in each lysimeter immediately after transplanting as recommended in Best Management Practices for Florida landscapes (Black and Gilman, 1998).

Each lysimeter was irrigated 9.2 mm daily for 21 d after transplanting. Irrigation of each lysimeter was controlled as a separate zone using an automated irrigation time clock (model Sterling 12; Superior Controls Co., Valencia, CA). Irrigations always began at 0500 hr and were completed by 0600 hr each day. Irrigation was applied within each lysimeter from three microirrigation spray stakes equipped with a half-circle spreader (model Stake 31, Spreader Red 180; Dan Sprinklers, Kibbutz Dan, Israel) situated in a triangular pattern with each emitter 46 cm apart and mounted 7.6 cm aboveground level.

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¹Assistant Professor.

²To whom reprint requests should be addressed; e-mail scheiber@ufl.edu.

³Associate Professor.

The combined flow rate was 2.86 L·min⁻¹ (4.6 mm·min⁻¹). The Christiansen Uniformity Coefficient was a minimum of 0.99 before planting (Haman et al., 1996). Mechanical flow meters (model C700TP; ABS, Ocala, FL.) were installed for each lysimeter with irrigation volumes recorded Monday through Friday. Tipping bucket rain gauges (Davis Instruments, Hayward, CA) were placed underneath each lysimeter and connected to a data logger (CR10) and control module (SDM-SW8A; Campbell Scientific, Logan, UT) to measure percolate volume.

Beginning 22 d after transplanting, irrigation frequency and rate were regulated with tensiometers equipped with microswitches (model LTA-12, Irrometer Company, Inc., Riverside, CA) wired in series with the electric water valve. One tensiometer was installed in each lysimeter between southeastern and southwestern plants, equidistance (15 cm) from the transplanted plants, such that the bottom of its porous cup was at the same depth as the bottom of a root ball (10 cm below the soil surface) per manufacturer's specifications (Irrometer Co., 2007) and as described by Evans et al. (2005) and Hensley and Deputy (1999). Irrigation was initiated when current was supplied by the irrigation controller and the microswitch on the tensiometer was closed as a result of decreases in soil matric potential below the set point. Irrigation ran until sufficient water infiltrated to the depth of the porous cup to increase matric potential sufficiently to open the microswitch, closing the electric water valve.

Plant-available water (PAW) was calculated for each soil type from soil water dehydration curves (Klute, 1986). After amendments were incorporated and lysimeters well irrigated to settle the soil, one core sample was randomly taken from each of the four lysimeter replications for each treatment. Cores were 5 cm in height and recovered from a depth of 7 to 12 cm below the soil surface using a 10-cm core sampler (model 0200; Soilmoisture Equipment, Inc., Santa Barbara, CA). Cores were saturated under vacuum before initiating dehydration using a pressure plate system (model 1500; Soilmoisture Equipment). Soil moisture was recorded at 0, 1, 2.5, 5, 10, 20, 40, and 100 kPa with a final determination at 1.5 MPa. Air porosity was calculated as the difference in mass between saturated and mass after equilibrium at 1 kPa. Plant-available water was calculated at each balance pressure as the difference between mass at each balance pressure and the mass at 1.0 kPa. Based on dehydration curves, microswitches on the tensiometers were set at 7, 8, and 5 kPa for the control, compost, and clay-amended soils, respectively, to trigger irrigation when PAW (between 1 kPa and 40 kPa) declined to 50% of field capacity. Lysimeters were subsequently irrigated back to near field capacity to at least the depth of the original root ball.

Growth indices and biomass. Measurements of average canopy height, widest canopy width, and the width perpendicular to the

widest width were recorded to calculate growth indices as volume (growth index = height × width 1 × width 2). All plants were measured immediately after transplanting and at final harvest on 12 Dec. 2003. The experiment was conducted for 100 d. To calculate shoot-to-root ratios, shoots were severed at the soil line and dried at 65 °C until constant dry weight was obtained. To obtain root dry weight, each lysimeter was subsampled such that the southeastern one-third of the soil volume spanning the depth of the lysimeter was removed. Total root mass was calculated by multiplying measured root mass by 3.

Aesthetic quality. Overall plant quality, plant density, and flower coverage, based on aesthetic appearance, were rated on a scale of 1 (dead) to 5 (mounded, proportional form; dense; complete coverage). Aesthetic quality was evaluated by three observers and conducted at the end of data collection. Although quality standards differ, ratings of 1 and 2 would be unacceptable, a rating of 3 would be marginally acceptable, and ratings of 4 and 5 would be acceptable in most professionally maintained landscape situations.

Data analysis. The experiment was conducted as a randomized complete block design with four blocks of single-lysimeter soil amendment replicates. Each block contained all three amendments for a total of 12 lysimeters. A malfunction in the irrigation control for one compost replicate resulted in excessive irrigation on two occasions. Data from this replicate were discarded and included in the statistical analysis as missing data. Growth data, consisting of growth index, height, shoot dry weight, root dry weight, total biomass, and shoot-to-root ratios, were analyzed using GLM. Cumulative irrigation was similarly analyzed using GLM. Overall plant quality, plant density, and flower coverage were analyzed by NPAR1WAY Wilcoxon Kruskal-Wallis. Where differences in aesthetic quality were indicated, means separation was by Wilcoxon two-sample test (Howell, 2004). Soil dehydration curves were also analyzed using GLM. Aeration and PAW at each equilibrium point were analyzed separately with three replications for the clay and control soils and four replications for the compost amendment. For both the clay and control samples, one replication was determined to be an outlier ($P < 0.05$) based on W.J. Dixon's criterion (Snedecor and Cochran, 1980). Where sig-

nificant differences were indicated, mean separation was by Fisher's protected least significance differences (F-protected LSD, Snedecor and Cochran, 1980). All analyses were conducted using SAS (version 9.1.3; SAS Institute, Cary, NC).

Results and Discussion

Biomass and aesthetic quality. Lysimeters amended with compost had greater ($P < 0.05$) mean shoot dry weight, total biomass, shoot-to-root ratios, and growth indices than other amendment treatments (Table 1). Only final plant height (40.1, 37.4, and 35 cm) and root dry weight (23.1, 24.1, and 27.1 g for compost, control, and clay, respectively) were similar among treatments. Control and clay amendments were similar for all parameters and produced ≈86 g less shoot dry weight compared with compost-amended lysimeters. Higher total biomass accumulation of compost-amended soils (Table 1) was attributed solely to greater shoot dry weight ($P < 0.05$). This greater shoot mass resulted in shoot-to-root ratios of compost-amended lysimeters being 1.9× and 1.6× larger ($P < 0.05$), respectively, than control and clay treatments (Table 1). Compared with control and clay treatments, compost amendment also increased ($P < 0.05$) canopy size by 1.4-fold and 1.6-fold, respectively (growth index, Table 1). Similar increases in shoot growth in response to incorporation of organic matter have been reported in *Hordeum vulgare* L. and *Lactuca sativa* L. (Al-Redhaiman et al., 2003; Liang et al., 2005).

Compost-amended soil had greater floral displays and plant density ($P < 0.05$) than the control (Table 2). Values for both of these characters were intermediate for plants in the clay-amended soils. When judged for overall quality, there were no differences ($P > 0.05$) among treatments. However, overall quality of plants in the control treatment was a little over half that of plants in compost-amended soils. In two of the four control replications, some shoot dieback was observed at harvest.

Irrigation applications and volumes. Before induction of tensiometer-controlled irrigation, all treatments received approximately the recommended volume of 10.6 L of irrigation daily (Trenholm et al., 2002). Once tensiometer control was imposed, cumulative irrigation volumes for all treatments over the last 70 d ranged from 18.5 L to 107.1 L per lysimeter. Actual volumes applied were only

Table 1. Growth measurements for pentas grown in simulated landscapes with three soil amendments (no amendment—control, municipal compost, field clay) over a 100-d period during Fall 2003 in central Florida.

Treatment	Shoot dry wt ^a (g)	Biomass (g)	Shoot:Root (g)	Growth index ^b (m ³)
Control	172.4 b ^c	196.5 b	7.46 b	0.079 b
Field clay	164.8 b	191.8 b	6.22 b	0.070 b
Municipal compost	260.2 a ^w	283.3 a	11.69 a	0.110 a
<i>P</i> value	0.0099	0.0301	0.0114	0.0060

^aMeans representative of four lysimeter replicates.

^bGrowth index = height × width 1 × width 2 based on individual plant canopy.

^cMean separations within columns using Fisher's protected least significant difference, $P = 0.05$.

^wMeans representative of three lysimeter replicates.

Table 2. Overall plant quality, plant density, and flower coverage ratings for pentas grown in nonamended topsoil (control) or soil amended with either municipal compost or mined field clay.^z

Treatment	Quality	Density	Flower coverage
Control	2.50 a ^x	2.41 b	2.50 b
Field clay	3.08 a	2.75 ab	2.91 ab
Municipal compost	4.44 a ^w	4.33 a	4.33 a
χ^2 value	6.72	6.36	6.07
<i>P</i> value	>0.05	0.0417	0.0480

^zScores ranged from 1, a dead plant; to 5, a plant of optimum size, density, and flower coverage.

^xMeans representative of four lysimeter replicates.

^yMean separations within columns using Wilcoxon two-sample test, *P* = 0.05.

^wMeans representative of three lysimeter replicates.

2.5% to 14.4% of the current recommended rate. Number of irrigation events per lysimeter over this time period ranged from three to eight, instead of the 70 recommended, and were similar among treatments (*P* > 0.05). Control soils averaged 5.25 events, whereas clay and compost-amended soils averaged 5.75 and 6.33 events, respectively. Mean cumulative irrigation volume applied per treatment (65.7, 63.5, and 51.5 L for control, clay, and compost soils, respectively) and mean volume per event were similar (*P* > 0.05) among treatments, although the volume per event to control plants was two- to three-fold higher than that applied to amended soils (20.9, 10.5, and 7.5 L for control, clay, and compost soils, respectively).

Compost-amended treatments accumulated greater (*P* < 0.01) shoot dry weight per liter of irrigation water applied than other treatments tested. Mean ratios ranged from 0.49 g·L⁻¹ and 0.51 g·L⁻¹ for clay and control treatments, respectively, to 0.73 g·L⁻¹ shoot accumulation for compost. Similar results were found for total biomass accumulation per liter of irrigation water applied with compost-amended lysimeters producing 0.80 g·L⁻¹ compared with 0.57 g·L⁻¹ accumulated by both clay and control treatments. Clay and control treatments were similar for both parameters. Root dry weight production per liter of irrigation water applied was similar (*P* > 0.05) among amendments with a mean value of 0.074 g·L⁻¹ across all treatments.

Greater shoot growth in compost soils compared with other treatments is difficult to explain. Shoots from compost soils were largest, but mean cumulative irrigation volume was 20% less than the unamended control soil. Lower volume was likely a result of the higher macropore space in compost-amended soils allowing more rapid percolation of irrigation water to the porous cup, shutting off an irrigation event more quickly. This also likely accounts for the trend toward higher frequency. Dehydration curves indicated aeration varied (*P* < 0.01) between compost-amended soil (12.7%) and the control (3.7%) and clay-amended (1.4%) soils. Aeration and PAW water content were similar between unamended and clay-amended

soils over the range of dehydration curves (Fig. 1). However, both had greater (*P* < 0.01) PAW at 1 and 2.5 kPa than compost-amended soils (Fig. 1). Above 2.5 kPa, there were no differences (*P* > 0.05) in PAW among soil treatments. However, between field capacity (1 kPa) and 40 kPa, both the control (20.6 g/100 cc soil) and clay amendment (24.8 g/100 cc) soil held more available water than the compost-amended soil (17.0 g/100 cc soil).

Although PAW at high matric potentials was 50% less in compost-amended soils, at trigger points for irrigation, soil volumes of PAW varied by ≈28%. Thus, the extra water available at high matric potentials appears to have had minimum impact given the infrequent irrigation. Uniform mulching of all soil surfaces should have negated any differences in hydraulic conductivity related to surface evaporation among soil treatments.

Greater shoot growth in compost soils was associated with higher soil aeration in the upper third of the soil column. Comparable effects of aeration were found with varying percentages of compost during container production, in which higher aeration correlated with greater shoot growth (Beeson, 1996). Greater growth of *Rhododendron indica* 'Mrs. G.G. Gerbing' in compost-amended compared with unamended sandy landscape soils with consistent irrigation have also previously been reported (Beeson and Keller, 2001). In both these examples, experiments extended to 18 months and were associated with greater root growth. For the 70 d of the pentas' growth, total root mass was similar among treatments but was not separated between amended and unamended soil depths. However, root systems within all treatments were observed primarily within the upper 15 cm of the soil volume where the tensiometer cups were placed. Our observations of root distribution concur with the findings of Knoop and Walker (1985) who reported that root density of herbaceous vegetation in a southern African savanna was concentrated in the upper 10 cm. Similar results were found for vegetables and turfgrass. Opena and Porter (1999) found root volume of *Solanum tuberosum* L. was two-fold greater at depths less than 15 cm than below 15 cm. Bowman et al. (1998) reported that 98% of the root length density of *Agrostis palustris* Huds. occurred in the upper 12.5 cm. Thus, irrigation control by the tensiometers most likely was based on the PAW of the majority of the root systems.

Higher nutrient availability derived from compost decomposition may also have attributed to greater shoot mass from compost soils. Before transplant, nitrogen content of compost-amended (7 µg·cm³) and unamended soils (5.8 µg·cm³) were similar (*P* > 0.05). Clay-amended soils (10 µg·cm³) had greater (*P* < 0.05) nitrogen content than other amendment treatments. Phosphorus and potassium content, electrical conductivity, and pH were similar among treatments (data not shown; *P* > 0.05). All lysimeters were fertilized equally with a controlled-release fertilizer under the mulch, so plants should not have been nutri-

Fig. 1. Moisture dehydration curves of the three soil treatments. For the control and clay soils, each point represents three replications. Each point on the compost curve represents four replications.

tionally impaired, although nutrient release may have been impeded by the low irrigation frequency. Mean total percolate volumes accumulated from 30 days after transplant (DAT) until termination of the experiment 70 d later were similar (*P* > 0.05) among treatments and ranged from 6.046 L for clay-amended lysimeters to 0.007 L for compost to a complete lack of percolate from the control treatment; thus, nutrient leaching was not a factor. However, neither tissue nor soil nutrient analysis was conducted at the end of the experiment.

Incorporation of clay provided no improvement in plant growth, aesthetic qualities, PAW, or irrigation requirements relative to the unamended control soil. Reductions in irrigation application volumes through the integration of calcined clays in production substrates have been reported (Owens et al., 2003). However, in a related study, growth declined when percent by volume of clay exceeded 12% (Owens et al., 2004). In the present study, native field clay was incorporated at a rate of 50% by volume in the upper one-third of the soil depth, yet the field clay consisted of only 5.6% clay particles and 0.5% silt. Further research is needed to determine if altering the percentage or using a source with higher clay content will yield improved growth.

In conclusion, compost-amended soil combined with tensiometer-controlled irrigation produced aesthetically pleasing canopies of adequate size while exhibiting substantial conservation of irrigation compared with current recommendations for daily irrigation of unamended sand soil. Similar tensiometer-controlled irrigation of unamended or field clay-amended sands produced smaller canopies (growth index) with reduced floral displays and plant density within the control treatment. Thus, incorporation of native field clay was of limited benefit. Previously Oki et al. (2001) reported a 66% increase in harvestable stems of *Rosa hybrida* L. 'Kardinal' while reducing application volumes 26% using tensiometers. Zhang et al. (2005) reported comparable results for *Triticum aestivum* L., and Battilini (2000) reported yield and quality of *Vitis vinifera* irrigated at 50% crop evapotranspiration were not

reduced compared with well-watered plants. In contrast, Kirnak et al. (2001) reported irrigation applications at 40% PAW reduced dry matter production by 43% as well as overall quality of *Solanum melongena* L. 'Teorem F1'. Similar results were found by Silber et al. (2006) for *Leucadendron* L. 'Safari Sunset' at 40% PAW. In outdoor landscapes, irrigation based on soil moisture could reduce volumes applied compared with common timeclock-based systems while supporting aesthetically pleasing quality, because tensiometers would integrate hydration of the soil volume by rainfall.

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