A Gravimetric Approach to Real-Time Monitoring of Substrate Wetness in Container-Grown Nursery Crops

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Abstract

Water management should be at the core of container nursery production. To increase water use efficiency, a better of understanding of how water is lost and subsequent hydration for soilless substrates is needed. Thus, the objective of this study was to monitor real-time daily substrate wetting and drying cycles as influenced by substrate and time of irrigation. To accomplish this objective a 2 (substrates) × 2 (irrigation timing) factorial study was conducted. *Cotoneaster dammeri* C.K. Schneid. 'Skogholm' (cotoneaster) was grown in two substrates consisting of aged (~1 yr) pine bark screened <1.25 cm and amended with a mineral aggregate (clay) (PBC) or coarse, washed builder's sand (PBS) at 9% (by vol.) and irrigated with one of two irrigation timings (AM cyclic application where the total daily volume to maintain a 0.2 LF was divided equally into three applications and applied at 0100, 0400, and 0700 HR, and a PM cyclic application where the total volume to maintain a 0.2 LF was divided equally and applied at 1200, 1500, and 1800 HR). Total dry weight of cotoneaster was 18% greater when grown in PBC compared to cotoneaster grown in PBS, and the weight of cotoneaster irrigated in the PM was 40% greater compared to cotoneaster grown with AM irrigation. Maximum percentage of weight at container capacity (CC; maximum weight after saturation and drainage) for PBC decreased 0.8 and 0.6% per day for AM and PM irrigation timing, respectively. Minimum percentage of weight at CC also decreased 0.9 and 1.0% per day for AM and PM, respectively for the PBC. PBS behaved similarly. With AM irrigation, the first cycle was 100% water application efficient (WAE) for both substrates and accounted for 42% of the total water gain. During the second and third cycles of irrigation an average 34 ml (96% WAE) and 238 ml (79% WAE) of water were lost, respectively, which accounted for 20% of the total water applied. With PM irrigation, the first cycle was 100% efficient resulting in a 48% increase of the total water gain. In the second cycle, water application efficiency (WAE) decreased 6% resulting in 104 ml of water leached. The WAE of the third irrigation cycle was 88% with 199 ml water lost. Leachate lost in the second and third irrigation cycle accounted for 20% of the total water applied.

INTRODUCTION

To the nursery industry, water is the 'oil' of the 21st century. Thus, water management should be at the core of container nursery production (Warren and Bilderback, 2005). Currently, leaching fraction (LF = volume leached ÷ volume applied) is the recommended method to assure adequate irrigation volume is being applied to hydrate the substrate. The current LF recommendation is ≤0.20 or ≥80% water application efficiency {WAE = [(volume applied - volume leached) ÷ volume applied] × 100} (Yeager et al., 2007).

Containerized nursery crop production is unique, in that, it most often requires daily irrigation. Currently, Best Management Practices (BMPs) suggest irrigating during early morning hours (Yeager et al., 2007). However, research in the United States has demonstrated irrigation applied during the day, particularly in the afternoon, reduces substrate temperature and plant water stress presumably by maintaining adequate available water (AW) which leads to increased growth (Beeson, 1992; Ruter, 1998). Irrigation applied at 1200, 1500, and 1800 HR resulted in 63% greater total plant dry weight compared to plants irrigated at 0300, 0500, and 0700 HR indicating containers irrigated in early morning following recommended BMPs will likely experience some level of stress on a daily basis, thus reducing growth (Warren and Bilderback, 2002). Therefore, the ideal time to irrigate is before water becomes limiting and the plant begins to experience mild water stress reducing growth. Both irrigation volume and time of application should be considered when developing a water management plan.

To increase water use efficiency a better of understanding of how water is lost and subsequent hydration for soilless substrates is needed. Thus, the objective of this study was to monitor real-time daily substrate wetting and drying cycles as influenced by substrate and time of irrigation.

MATERIALS AND METHODS

The experiment was a 2 (substrates) × 2 (irrigation timing) factorial in a randomized complete block design with four replications, with four plants per replication. The two substrates consisted of aged (~1 yr) pine bark screened <1.25 cm and amended with a mineral aggregate or coarse, washed builder's sand at 9% (by vol.). The mineral aggregate was a 0.25 to 0.85 mm calcined palygorsksite-bentonite (clay) from Ochlocknee, GA (Oil-Dri Corp. of America, Chicago, IL) (Moll and Goss, 1997). For simplification, pine bark amended with clay will be referred to as PBC and pine bark amended with sand as PBS. The two irrigation timings consisted of an AM cyclic application where the total daily volume to maintain a 0.2 LF was divided equally into three applications and applied at 0100, 0400, and 0700 HR and a PM cyclic application where the total volume to maintain a 0.2 LF was divided equally and applied at 1200, 1500, and 1800 HR. The experiment was conducted from 5 May to 15 Sept. 2005 at the Horticulture Field Laboratory (35°47'37" N lat; 78°41'59" W long), North Carolina State University, Raleigh.

Rooted stem cuttings of *Cotoneaster dammeri* C.K. Schneid. 'Skogholm' (cotoneaster) were potted into 14 L black plastic containers on 5 May 2005. Sixty g of 17N-2.2P-8.3K (17-5-10 six month controlled-release fertilizer, Harrell's, Lakeland, FL) was surface applied on 1 June 2005. All substrates were amended with 0.7 kg m^{-3} pulverized dolomitic limestone [$CaMg(CO_3)_2$] and 0.5 kg m^{-3} micronutrients (Micromax, The Scotts Company Inc, Maryville, OH). To monitor substrate wetting and drying, one plant was positioned on a load cell (Model RL 1042, Tedea-Huntleigh Inc, Covina, Calif.) within each treatment and replication (total of 24) which was connected to a CR23X® micrologger (Campbell Sci., Logan, Utah). Weight was recorded every 10 min. except when the irrigation was running then weight was recorded every 10 s. Weight at container capacity (CC) was determined by saturating the containers located on the load cells every 3 weeks. Saturation was achieved by placing the container into a 20 L bucket which was filled with water at sunset. When the substrate was saturated (≈2 h) (as evidenced by a glossy sheen of water at the substrate surface), the container was returned to the load cell and allowed to drain until 0400 HR the following morning. At 0400 HR weight of each of the 24 containers was recorded as container capacity. Influent and effluent from each treatment and replication were measured weekly from irrigation water that was applied via pressure compensated spray stakes (Acu-Spray Stick; Wade Mfg. Co., Fresno, Calif., 200 ml $min.^{-1}$). Based on these values, irrigation volume was adjusted weekly to maintain the 0.20 LF.

On 15 Sept. 2005 tops from two randomly chosen containers per plot (total of eight plants per treatment) were harvested. Roots were placed over a screen and washed with a high pressure water stream to remove substrate. Tops and roots were dried at 60°C until weight stabilized, and weighed. All data were subjected to analysis of variance procedures with SAS version 8.0.2 (SAS Inst., Inc., Cary, NC). All significant two-way interactions are presented in tables and figures. A polynomial curve was fitted for water loss to smooth data. Residual points were used to calculate the 1st and 2nd derivative of water loss (Kaleidagraph, Synergy Software, Reading, Penn.)

RESULTS AND DISCUSSION

Total dry weight of cotoneaster was 18% greater when grown in PBC compared to cotoneaster grown in PBS (Table 1). In addition, cotoneaster irrigated in the PM was 40% greater compared to cotoneaster grown with AM irrigation. Growth of cotoneaster was unaffected by the substrate × irrigation timing interaction. Similar results were reported by Owen (2006).

Even with a 0.2 LF maximum percentage of weight at CC for PBC decreased 0.8 and 0.6% per day for AM and PM irrigation timing, respectively (Fig. 1). Thus, it was not possible to return the substrate to 100% CC. This decreasing ability to return the substrate to 100% CC may have been due to the hysteretic effect termed the "ink bottle effect" in porous substrates (Hillel, 1998). Container capacity returned typically to 100% only during rain events with the decrease in CC occurring until the next rain event (data not presented). In lieu of a rain event, containerized substrates may require over applying of irrigation water in excess of the target LF to return to 100% CC. However, limited research has indicated it is not necessary to return to 100% CC to maintain maximum growth (Warren and Bilderback, 2005). The PBS substrate performed similarly (data not presented).

Minimum percentage of weight at CC also decreased 0.9 and 1.0% per day for AM and PM, respectively for the PBC (Fig. 1). Thus, a similar quantity of water was lost each day to evapotranspiration even though CC was not returned to 100%. For the entire study, neither substrate irrigated in the AM decreased below 84% (loss of ~1600 ml) of weight at CC, whereas substrates irrigated in the PM never decreased below 87% (loss of ~1300 ml) (data not presented). Thus, regardless of irrigation timing neither substrate decreased below 68% of weight at CC where AW would be depleted based on physical properties reported by Owen (2006). However, even though theoretical AW was never depleted growth data herein indicated water stress may have reduced plant growth when irrigated in the AM.

Hydration of substrates with AM irrigation occurred commonly as illustrated by data from 25 to 28 August (Fig. 2). The first irrigation cycle was 100% WAE for both substrates and accounted for 42% increase in the total water gain (data not presented). During the second and third cycles of irrigation an average 34 ml (96% WAE) and 238 ml (79% WAE) of water were lost, respectively, which accounted for 20% of the total water applied dictated by the 0.2 LF. Similarly, decreasing WAE was observed with cyclically applied overhead- (Karam and Niemera, 1994) and micro-irrigation (Lamack et al., 1993) and was attributed to a “water-threshold point” that when exceeded resulted in decreased water retention. With either substrate, WAE was maximized (100%) when applied irrigation volume returned the system to ≤95% CC (data not presented). Attempting to achieve greater CC or applying greater amounts of water within a cycle resulted in a large decrease in WAE.

Hydration of substrates with PM irrigation occurred concurrently with evapotranspiration (Fig. 3). However, a similar trend in WAE occurred with the AM irrigation regime. The first water application was 100% efficient resulting in a 48% increase in the total water gain. In the second irrigation cycle WAE decreased 6% resulting in 104 ml of water leached (data not presented). The WAE of the third irrigation cycle was 88% with 199 ml water lost (data not presented). Leachate lost in the second and third irrigation cycle accounted for 20% of the total water applied dictated by the 0.2 LF. The third irrigation cycle in PM irrigation was 10% more efficient that the AM irrigation probably because hydration occurred concurrently with evapotranspiration resulting in replacement of water lost between irrigation cycles.

Water loss was affected by both substrate, irrigation timing, and the interaction. During 24 to 27 Aug 2005 cotoneaster grown in PBC used an average 1087±68 ml and 1302±73 ml per day when irrigated with AM or PM irrigation, respectively, whereas cotoneaster grown in PBS used an average of 945±60 ml and 1086±65 ml when irrigated with AM or PM irrigation, respectively (data not presented). This trend in daily water use is believed to be illustrative of the increased water buffering capacity available in a PBC versus PBS substrates (Owen, 2006). Water loss via evapotranspiration occurred at a rate of 1.7 and 1.5 ml $min.^{-1}$ for a clay versus sand amended substrate, respectively, when irrigated in the AM, whereas water loss during active evapotranspiration occurred at a average rate of 2.9 and 3.0 ml $min.^{-1}$ for a clay versus sand amended substrate, respectively, when irrigated in the PM (data not presented). This reduced daily water loss of cotoneaster when irrigated in the AM may be a function of plant stress memory in which repeated, induced stresses related to the edaphic environment may lead to a decline of stomatal conductance (g_s) as a protective mechanism against further drought induced stress (Goh et al., 2003). Chaves et al. (2002; and references therein) further explained the phenomenon as an induced stomatal closure, primarily as a result of low soil moisture, that decreases net photosynthesis (P_n) as a stress protection mechanism which may lead to a long term decrease in photosynthetic capacity resulting in reduced plant growth. Thus, even minor episodes of water stress may lead to long term growth reductions.

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Tables

Table 1. Total plant dry weight (g) of Skogholm cotoneaster grown in pine bark substrates amended (by vol.) with 9% sand or 9% 0.85 mm - 0.25 mm Georgiana bentonite-palygorksite mineral aggregate (clay) irrigated cyclically in the AM or PM.

Main effects	Total plant dry weight[z]
Substrate	
Clay	205 ± 20[y]
Sand	173 ± 16
Irrigation application timing[x]	
AM	142 ± 7
PM	236 ± 10
Substrate (S)	0.001[v]
Irrigation (I)	0.001
S × I	0.09

[z]Total dry weight = root dry weight (g) + top dry weight (g); [y]Data are means ± SE based of eight observations; [x]AM = irrigation applied at 0100, 0400, and 0700 HR; PM = irrigation applied at 1200, 1500, and 1800 [v]*P* value.

Figures

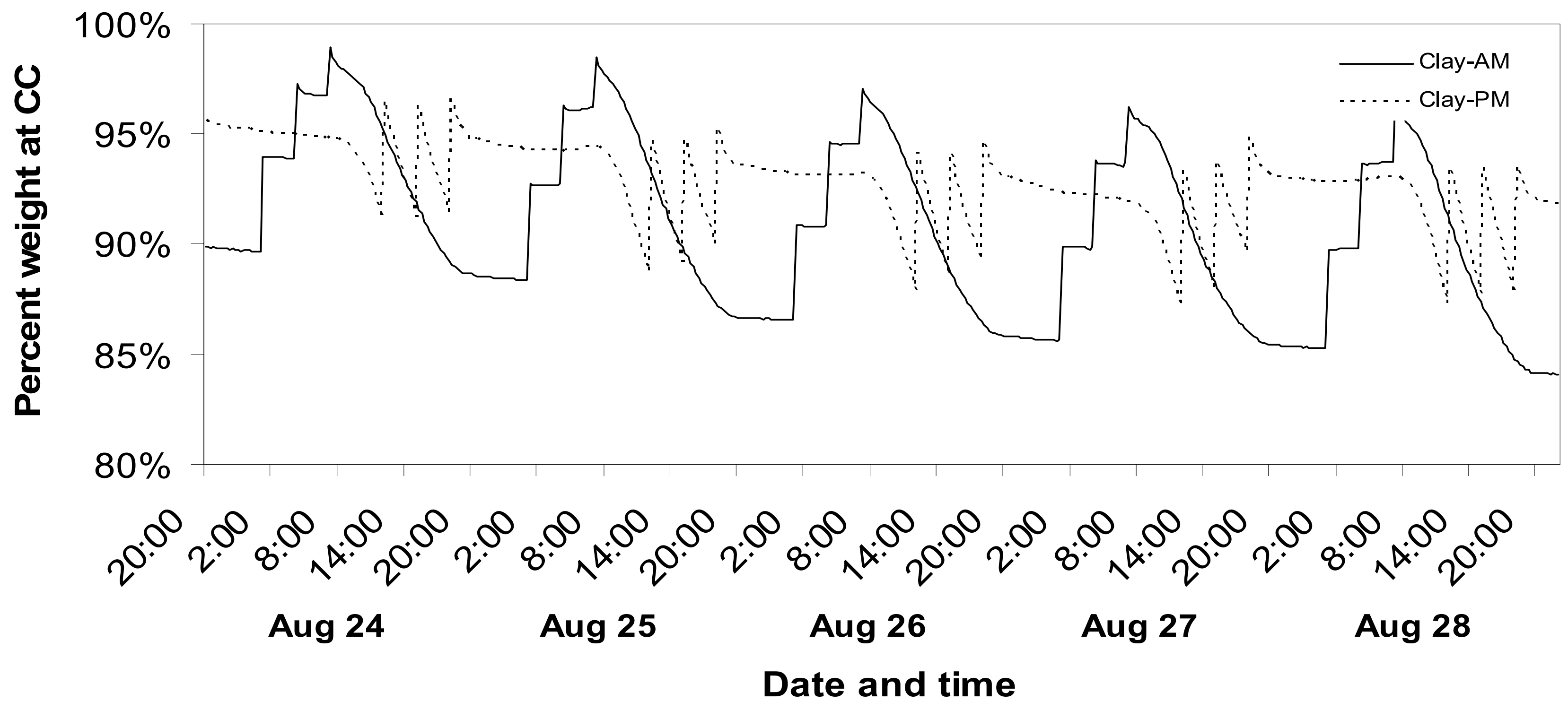

Fig. 1. Diurnal flux of weight at container capacity (CC) for Skogholm cotoneaster grown in a pine bark substrate amended with 9% (by vol.) 0.25 to 0.85 mm Georgiana bentonite-palygorksite mineral aggregate (clay) or 9% (by vol.) sand cyclically irrigated in the AM (0100, 0400, and 0700 HR) or PM (1200, 1500, 1600 HR) with a target leaching fraction of 0.20.

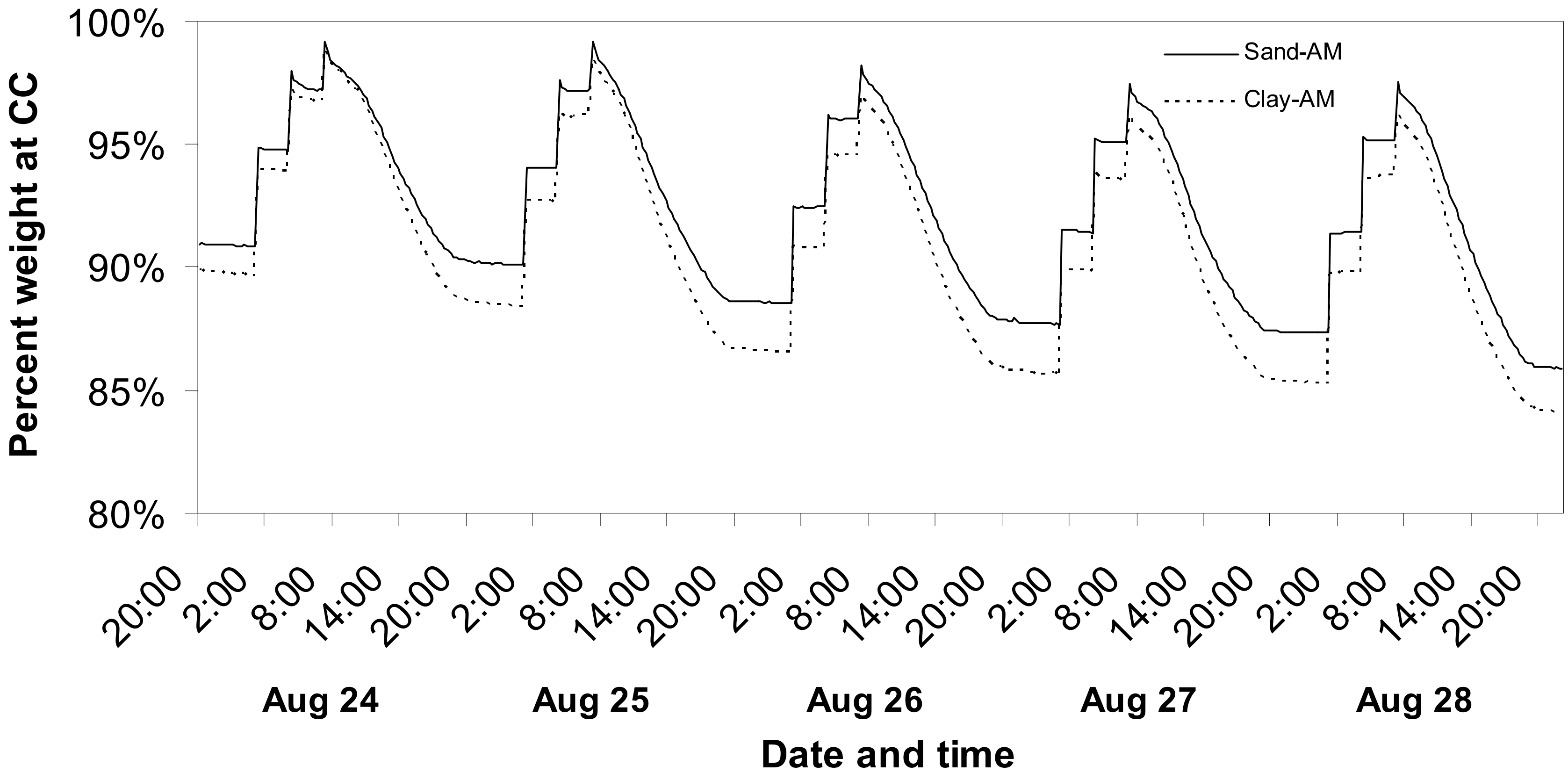

Fig. 2. Diurnal flux of weight at container capacity (CC) for Skogholm cotoneaster grown in a pine bark substrate amended with 9% (by vol.) 0.25 to 0.85 mm Georgiana bentonite-palygorksite mineral aggregate (clay) or 9% (by vol.) sand cyclically irrigated in the AM (0100, 0400, and 0700 HR) with a target leaching fraction of 0.20.

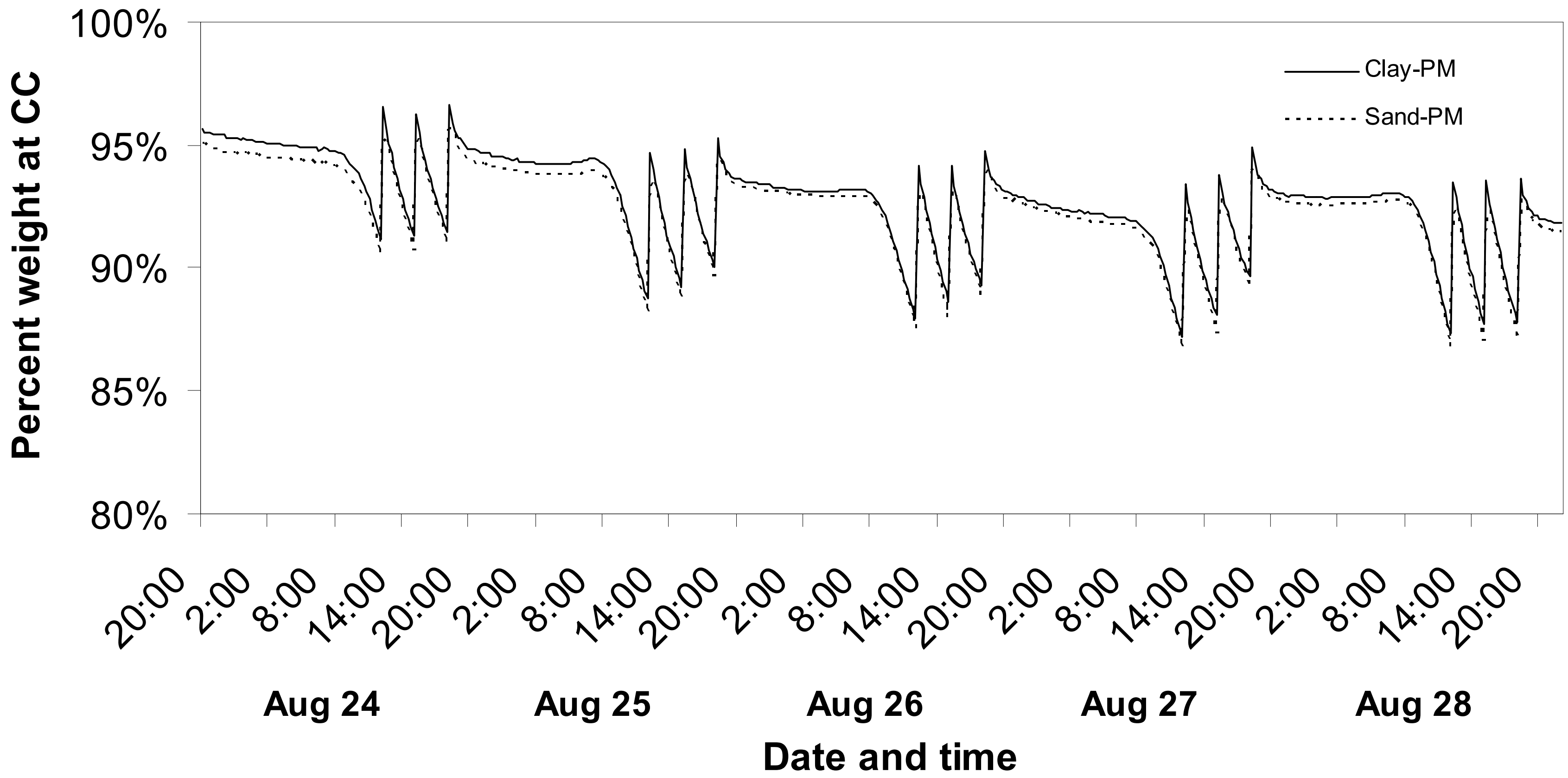

Fig. 3. Diurnal flux of weight at container capacity (CC) for Skogholm cotoneaster grown in a pine bark substrate amended with 9% (by vol.) 0.25 to 0.85 mm Georgiana bentonite-palygorksite mineral aggregate (clay) or 9% (by vol.) sand cyclically irrigated in the PM (1200, 1500, 1600 HR) with a target leaching fraction of 0.20.