THE INFLUENCE OF BED COVER TYPE (GRAVEL VS PLASTIC) ON CONTAINER-GROWN PLANTS

by

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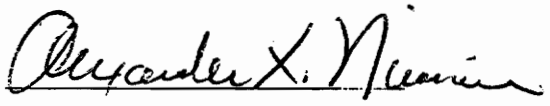

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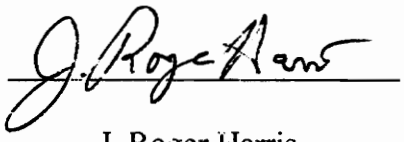

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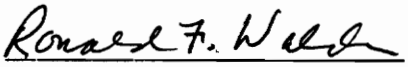

Ronald F. Walden, Co-chairman

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(ABSTRACT)

Growers report that plants on a gravel bed cover often require more frequent irrigation compared to plants on a plastic bed cover. Three experiments were conducted to determine the cause of this reported observation. The objective of Expt. 1 was to determine if bed cover type (gravel or plastic) influenced the container environment or growth of *Rhododendron* 'Girard Pleasant White' and *Ilex crenata* Thunb. 'Bennets Compacta' in 11.4 L pine bark-filled containers. Measurements included bed cover, substrate, and plant canopy temperatures; evapotranspiration, stem water potential, and plant widths were also determined. The objective of Expt. 2 and 3 was to determine the amount of water retained by the container substrate following irrigation and drainage on gravel or plastic bed covers. Pine bark-filled containers (3.8 L) on gravel or plastic beds were irrigated, allowed to drain for one h, and the amount of water retained in the container substrate was determined. In Expt. 1, bed cover temperatures (0730 to 1930

HR) and container substrate temperatures (2300 to 0400 HR) were about 2 and 1C higher, respectively, for plastic than for gravel. There were no bed cover treatment differences for other measurements. In Expt. 2, containers on plastic beds with a minimal slope retained more water than containers on gravel; water puddled at the base of containers on plastic but not on gravel. When beds were sloped so that a minimal amount of water collected at the base of containers, there was no influence of bed cover type on substrate water retention (Expt. 3). Thus, the influence of bed cover type on substrate water retention following irrigation and drainage was dependent on bed design.

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Chapter One: Literature Review

Most nurseries that produce container-grown plants use either a gravel or plastic bed cover. Bed covers improve drainage away from containers, control weeds, aid in water recapture, reduce diseases, and prevent rooting into the soil beneath containers. Bed cover type can influence container substrate temperatures, container substrate drainage, water application and use, runoff, and plant disease incidence.

Container Substrate Temperatures

High summer container substrate temperatures have been shown to reduce root growth, decrease plant quality and marketability, and increase production time (Whitcomb, 1980). Environmental factors primarily responsible for changes in container substrate temperatures are solar radiation, wind, air temperature, and absolute air humidity (Martin and Ingram, 1992). In addition to environmental factors, container substrate temperatures may also be influenced by container bed coverings. Newman and Davies (1988) found that bed covers influence substrate temperatures and ultimately affect plant growth.

Bed covers can influence substrate temperatures due to albedo or absorptive properties. White bed covers reflect more radiant energy into the plant canopy and onto the side of containers than black bed covers, thus increasing substrate temperatures (Ingram et al., 1989). Solar radiation is absorbed and re-radiated by black bed covers

(Ingram et al., 1989). Whitcomb (1980) found that substrate temperatures in black containers on a white plastic bed cover were higher than black containers on black plastic covered beds. Substrate temperatures in black pots on white clam shell beds were 5C higher than white pots on black polyethylene (Keever and Cobb, 1984).

Substrate temperature is also influenced by container compass orientation within a bed as well as compass orientation within a container and closeness to the container sidewall. Containers located on southern exposures of a bed can have temperatures 5.5 to 8.5C higher than containers in the center of the beds (Fretz, 1971). Highest substrate temperatures occur in the west container quadrant (1500 to 1900 HR) during the summer (Ingram, 1981; Keever and Cobb, 1984; Newman and Davies, 1988; Ingram et al., 1989; Martin and Ingram, 1992; Martin and Ruter, 1996) and in the south quadrant during late fall and winter (Martin and Ingram, 1988a) due to sun exposure angle.

Supraoptimal root-zone temperatures reduce growth of container-grown plants (Walden and Wright, 1995). There are two types of plant injury, direct and indirect, as a result of supraoptimal root-zone temperatures. Direct injury is caused by exposure to relatively high temperatures which cause an irreversible injury that results in cell death (Ingram et al., 1989). Indirect injury results from exposure to temperatures that do not cause cell death, but alter plant physiological processes such as photosynthesis, respiration, and hormone synthesis (Ingram et al., 1989). The lethal temperature for plants decreases linearly as exposure duration increases exponentially (Ingram, 1985).

Optimum root growth for most plants occurs between 25.5 and 29.4C (Kramer, 1949). However, container substrate temperatures in excess of 54C are common in the southeast U.S. (Ingram et al., 1989) and thus decrease root and shoot growth, yet plant responses are species specific (Martin and Ingram, 1988b; Harrison et al., 1988). Barr and Pellett (1972) and Johnson and Ingram (1984) found that decreases in root growth for numerous woody plant species occur when root-zone temperatures are above 40C. Martin and Ingram (1991) observed that root dry weight of *Magnolia grandiflora* L. 'St. Mary' at 42C was considerably less than at 38 or 34C. Martin et al. (1989) found that root and shoot dry weights of *Ilex* x *attenuata* Ashe 'East Palatka' and *Ulmus parvifolia* Jacq. 'Drake' decreased linearly with increased root-zone temperature. In a similar experiment using the same two species, Martin and Ingram (1988b) showed that shoot extension was decreased by at least 63% when grown for 12 weeks at 42C compared to 12 weeks at 28C. Root and shoot dry weights of *Ilex crenata* Thunb. 'Rotundifolia' grown at 40C for six h daily were less than plants grown at 28 or 34C for six h daily (Yeager et al., 1991). Growers should implement production practices which will prevent or minimize prolonged exposure to roots to temperatures higher than 40C in view of the deleterious effects of supraoptimal root-zone temperatures.

Growth reductions from supraoptimal root-zone temperatures are most likely a result of altered plant physiological processes such as photosynthesis and respiration. Supraoptimal root-zone temperatures decrease CO_2 fixation and increase the loss of CO_2

through increased respiration (Foster et al., 1991). Respiration rate increases initially in response to short term exposures to supraoptimal root-zone temperatures, but decreases with exposure time (Devlin and Witham, 1983). Ruter and Ingram (1991) showed that respiration rates of roots grown at 30, 34, 38, and 42C for three weeks decreased linearly with increased root-zone temperatures. Photosynthate partitioning to stem and root sinks were also affected by supraoptimal root-zone temperatures (Ruter and Ingram, 1990). Kuroyanagi and Paulsen (1988) found that chlorophyll and protein levels were decreased in shoots in response to high root-zone temperatures. Yeager et al. (1991) showed that root and shoot N accumulation decreased when root-zone temperatures were increased from 28 to 40C.

Supraoptimal or relatively high substrate temperatures may also influence substrate solution composition. Studies have shown (Niemiera and Wright, 1987; Walden and Wright, 1995) that continuous exposure to 40C decreased nitrification in a pine bark substrate, which resulted in an increased ratio of NH_4-N to NO_3-N. Such a ratio may lead to ammonium toxicity in some plant species. High substrate temperatures may also influence the release rate of temperature dependent controlled-release fertilizers, which are commonly used in container nurseries.

Substrate Drainage

The amount of water drained from a container is primarily contingent on the percentage of macropores present in a substrate. Drainage increases as the percentage of macropores increases. However, there are other factors that influence drainage in containers. Increasing the number or size of container drain holes will increase drainage and thus increase aeration within the substrate (Fare and Davis, 1994). Drain holes may also become plugged, thereby requiring container drain holes to be located on the container's side and not the bottom (Dickey et al., 1978). Work by Ruter and van de Werken (1991) demonstrated how drainage and aeration can be increased significantly in containers by using a fabric bottom on a sand bed over conventional containers. Container size and shape will affect water volume of a container (Bilderback and Fonteno, 1987). The surface beneath containers is thought to influence drainage, and will ultimately affect the height of the perched water table within the container substrate as well (Dickey et al., 1978). However, no experimental data exist describing the effect of bed cover on water saturation depth in a container.

Water Application, Use, and Runoff

Overhead irrigation is the primary irrigation method used in container nurseries in the southeastern U.S. During the growing season, growers typically irrigate daily, applying as much as 370,000 L of water per hectare per day (Bir, 1988). The container

nursery industry uses an estimated 3699 to 4932 hectare-meters of water per year (Fare et al., 1992). The reason for the large volume of water applied to container nurseries is two-fold. First, pine bark, the primary constituent of container substrate in the southeast U.S., is highly porous and therefore requires frequent irrigation to maintain adequate moisture for plant growth (Wang and Boogher, 1987). Second, growers apply water in excess of plant needs for the majority of plants because overhead irrigation application efficiency is often relatively low. For example, Beeson and Knox (1991) found application efficiency values (amount of water retained in the container and available to the plant ÷ total water applied) of 37 and 25% respectively, for plants at close spacing and at a spacing of 7.6 cm. Fare et al. (1992) reported that average water application rates in various container nurseries in Alabama, ranged from 0.8 to 3.2 cm/h. Factors that influence crop irrigation requirements include rainfall, light intensity, temperature, relative humidity, and windspeed (Knox, 1989). Plant size, growth rate, and stage of development are also important (Knox, 1989). Some production practices that enable growers to reduce irrigation amounts are grouping plants with similar water requirements and closely monitoring irrigation to prevent over watering. Another relatively new method to reduce irrigation amounts is the use of cyclic irrigation. Cyclic irrigation, in which a plant's daily water allotment is subdivided into more than one application with prescribed intervals between applications, has been shown to reduce the amount of water that drains out of containers compared to applying the same amount of water in one

continuous irrigation (Karam and Niemiera, 1994). Not only will these production practices help reduce water usage, they will also reduce the amount of water and fertilizer lost from containers.

High leaching fractions (volume of leachate collected ÷ volume of water applied to container) will cause nutrient leaching from the container and increase bed cover runoff. Thus, runoff can be the source of surface and groundwater NO_3-N pollution. Yeager et al. (1993) in a six state survey, found that production bed runoff NO_3-N levels ranged from 0.5 to 33 mg•L for nurseries using a controlled-release fertilizer and 0.1 to 135 mg•L for nurseries using a combination of controlled-release and solution fertilizers. Use of polyethylene plastic for a bed cover aids in water recapture and reuse by preventing applied water from percolating into underlying ground as would occur with gravel. Water is then channeled from beds (when properly sloped) to drainage ditches which empty into recycling ponds.

Disease

Water-borne pathogens pose a serious threat to container-grown plant production. The interaction of the container substrate composition, container bed type, and irrigation system determine the water status of the root environment and the bed beneath the containers. These factors have been related to the spread of *Phytophthera cinnamomi* Rands from diseased to healthy plants (Glasshouse Crops Research Institute, 1985).

Benson et al. (1978) found that the spread of *P. cinnamomi* between adjoining containers was significantly higher with black plastic than black plastic in combination with sawdust, pine bark or gravel. Irrigation and heavy rains cause puddling to occur on plastic, an ideal situation for spread of *P. cinnamomi* within beds. *P. cinnamomi* spread was reduced when plastic is covered with a well-drained material (Benson et al., 1978).

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Chapter Two: The Influence of Bed Cover Type (Gravel vs Plastic) on Container-grown Plants

Introduction

Most commercial nurseries in the southeastern U.S. use black polyethylene plastic or gravel bed covers in the production of container-grown plants. Growers anecdotally report that container-grown plants grown on gravel require more frequent irrigation than plants on black plastic and attribute this phenomenon to the influence bed cover type has on container environment and container drainage.

In the southern U.S., substrate temperatures may often exceed 40C which are deleterious for root growth (Walden and Wright, 1995). Martin et al. (1989) found that supraoptimal root-zone temperatures were caused in part by direct solar radiation striking container walls. Radiation reflected from bed covers also contribute to increased container substrate temperatures (Keever and Cobb, 1984). White bed covers increase container substrate temperatures more than on black bed covers (Newman and Davies, 1988; Whitcomb, 1980; Keever and Cobb, 1984). Thus, growers can minimize root-zone temperatures by bed cover selection. Bed covers may also impact canopy temperatures, thus affecting water loss from the container substrate and reducing plant growth. There are no in-depth reports in the literature on how the most prevalent bed covers, black plastic and gravel, affect the environment surrounding containers or water drainage from

containers. Therefore, the objective of this work was to determine if bed cover type affects evapotranspiration or growth of container-grown plants by influencing the environment surrounding containers or substrate water retention following irrigation and drainage.

Materials and Methods

Experiment 1

One-year-old *Ilex crenata* Thunb. 'Bennets Compacta' and *Rhododendron* 'Girard Pleasant White' plants in 11.4 L black polyethylene containers (Classic 1200, Nursery Supplies Inc., Fairless Hills, Pa.) filled with a 9.5 pine bark : 0.5 sand and 100% pine bark substrate (by volume) were grown on gravel or plastic-covered beds. Substrates were amended with 2.36 kg lime and 0.89 kg micromax per m^3. Container depth and diameter was 24 cm and 26.5 cm, respectively. There were four bottom side drain holes (1.8 cm diam) located approximately 17 cm apart and one center bottom hole (1.8 cm diam). Gravel and plastic container beds (3.0 x 3.0 m) were constructed at an outdoor site at the Hampton Roads Agricultural Research and Extension Center, Virginia Beach, Va. Each bed (sloped at 1.5%) was bound by a wooden frame. Prior to applying 0.01 cm thick black polyethylene plastic to the beds, a 9 cm layer of mineral soil was placed into frames and firmly tamped. Edges of plastic were attached to the frames. For gravel beds, 9 cm of # 57 blue stone (1.3-1.9 cm pieces), commonly used in Va. nurseries, was placed within frames. On 15 June, eight plants per species in each of eight treatment blocks were

spaced at 0.61 m (distance between container centers). The experimental design was a randomized complete block. A guard row of *Ilex crenata* Thunb. 'Helleri' (11.4 L containers) was placed on the same spacing on the perimeter of each bed. On 18 June, 50 and 30 g per pot, of Osmocote (18N-2.6P-9.9K) were applied to the substrate surface of each holly and azalea plant, respectively. This formulation of Osmocote supplies 53.3% of N as ammonium and 46.4% as nitrate. Plants were irrigated daily at 0400 HR with 1.27 cm of water via overhead impact nozzles at a rate of 0.63 cm per h.

On 6, 10 and 13 July, evapotranspiration (ET), bed cover temperature, plant canopy temperature, and humidity between plants were measured. For ET determinations, containers were weighed (two containers per bed cover treatment per block per species) at 0700 HR (one hour after irrigation completion) and at 2 h intervals thereafter until 1900 HR. Immediately following ET measurements, bed cover and canopy temperatures were measured with an infrared thermometer (Raynger PM Model, Raytek Inc., Santa Cruz, Ca.). Distance between thermometer and the subject was 30 cm; bed cover and canopy temperature measurements were made on shaded locations and centers of plant canopies, respectively. After bed and canopy temperatures were recorded, relative humidity measurements (one measurement per treatment per block) were made in the shaded location between containers with a psychrometer (Model 3312-40, Cole-Palmer Instr. Co., Chicago, Ill.).

Substrate temperatures were measured on one holly plant per treatment in each of five blocks, at five min. intervals throughout the day on 29, 30, and 31 July and 1 Aug. Copper-constantan thermocouples were placed at a depth of 10 cm in the container center and 2.5 cm from the west facing sidewall. Temperatures were recorded with a datalogger (Model CR10, Campbell Scientific, Inc., Logan, Utah).

To determine if bed cover type influenced stem water potential and drought stress, plants were last irrigated the morning of 31 July. Using a pressure chamber (Model 3005, Soil Moisture Equipment Corp., Santa Barbara, Ca.), stem water potentials for two 7.5 cm cuttings per bed cover treatment per block per species were made at 0600 HR and 1400 HR on 1 and 2 Aug. and at 0600 HR on 3 Aug. On 27 June and 15 Sept. a growth width measurement ([width A+ width B] ÷ 2) was taken for all plants. The width for 27 June was subtracted from the growth width on 15 Sept. to determine the increase in width for this time period. Substrate solution was sampled via the pour-through (PT) extraction procedure (Wright, 1986) on 7 June and 25 July for two holly plants per bed cover treatment per block and analyzed for NO_3-N.

Data for bed cover temperature, canopy temperature, stem water potential, and growth were analyzed by analysis of variance using the SAS GLM procedure (SAS Institute, 1990). A repeated measure analysis was performed for ET measurements at six 2-h time intervals per day. Substrate temperatures at the west-facing sidewall and container center were analyzed separately with time used as a regression variable (not a

classification variable) to test linear, quadratic, and cubic portions of the temperature response curve.

Experiment 2

Gravel and plastic beds were constructed on a greenhouse floor in Blacksburg, Va. Plots consisted of four 1.2 m x 1.2 m gravel beds and four 1.2 m x 1.2 m plastic-covered beds (as in Expt. 1). Although not measured, bed slope was estimated to be < 1.0 %. One *Tagetes erecta* L. 'Little Hero' per 3.8 L container (Classic 400, Nursery Supplies Inc.) was greenhouse-grown in 100% pine bark for six weeks prior to the experiment. Pine bark bulk density, airspace, and total porosity was 0.17 g/cm^3, 32.44%, and 85.08%, respectively. Container height and diameter were 18 and 19 cm, respectively; there were four side drain holes (1.8 cm diam) and one bottom center hole (1.8 cm diam). On 1, 6, and 13 Dec., plants were taken from greenhouse benches, put on respective bed covers and 500 mL of water was beaker-applied, which resulted in an approximate 20% leaching fraction (volume of leachate drained ÷ volume of water applied to the container). Irrigation was applied at 0800 HR. Immediately prior to irrigation, container weights were measured to determine amount of water retained in the substrate following irrigation. After irrigation plastic bags were immediately placed over plants to prevent ET. Forty-five min after irrigation (drainage period), plastic bags were removed and containers were weighed. The post-irrigation weight minus the pre-irrigation weight equaled the amount of water retained after irrigation and drainage. Puddles that formed beneath containers

(after irrigation and drainage) on plastic bed covers were absorbed with paper towels and weighed on the 6 and 13 Dec. trials. There were four containers per bed cover treatment in each of four blocks. The experimental design was a randomized complete block. Data for water retention were analyzed by analysis of variance using the SAS GLM procedure (SAS Institute, 1990).

Experiment 3

Simulated gravel and plastic beds were constructed with each bed constituting an experimental unit (one container per bed). For gravel beds, a five cm deep layer of # 57 blue stone was placed in a pan (38 cm diam). For plastic beds, cardboard boxes (45 cm x 35 cm x 7.5 cm; length x width x height, respectively) were filled to the top with sand and a sheet of plastic (same as Expt. 1) was placed on top of the sand and stapled to the sides of the box. Containers with and without a bottom center drain hole were used to determine if the absence of a bottom hole, analogous to a blocked center hole on a plastic bed, affected substrate water retention following irrigation. Sixteen 3.8 L containers (same as Expt. 2) with a bottom center hole and 16 without a bottom center hole were filled with 1650 g of moist 100% pine bark (565 g dry wt.). Containers were hand-irrigated for three days prior to the experiment to settle the substrate. Containers were then placed in a drying oven and dried to 1650 g, which resulted in a moisture content of 192% ([wet wt. - dry wt.] ÷ dry wt., mass basis). Eight bark-filled containers per container type were then placed on the gravel and plastic beds, in a completely randomized design. Five

hundred mL of water was then beaker-applied to each container. Containers were allowed to drain for one h and then weighed. The pre-irrigation weights were subtracted from the post-irrigation weights to determine the amount of water retained after irrigation and drainage. Puddles that formed beneath containers (after irrigation and drainage) on plastic bed covers were absorbed with paper towels and weighed. Puddle weights were added to post irrigation container weights for plastic beds since this water was in contact with the substrate via container drain holes. Least Square mean comparisons for water retention with all combinations of bed cover and container hole treatments were performed with the SAS GLM procedure (SAS Institute, 1990).

Results and Discussion

Experiment 1

Since bed cover temperature was measured from 0730 to 1930 HR on three days (6,10, and 12 July), fluctuations in cloud cover and air temperature resulted in variation in the data evidenced by three significant two way interactions (bed cover x day, bed cover x time, and day x time) (Table 1). These interactions accounted for only 0.33, 0.12, and 0.15% of variation among treatments, respectively, and therefore will be disregarded. The pattern of bed cover temperatures over time of day was similar for the three dates, thus, only data for 10 July will be presented (Fig. 1; for other dates see Appendix B Fig. 1 and 2). Bed temperatures for plastic were 1 to 2C higher than for gravel from 0730 to 0930

HR ($p \leq 0.0001$), likely due to the greater heat absorption of black plastic than on the gray colored gravel. Peak bed temperatures for both bed coverings occurred between 1330 and 1530 HR with maximum mean values ranging from 33 to 37C and 31 to 34C, respectively, for plastic and gravel on all three days. Bed cover type did not influence plant canopy temperatures; peak canopy temperatures, 29 to 32C, occurred between 1130 and 1530 HR on each of the three days monitored (data not shown). Relative humidity surrounding containers was also unaffected by bed cover type (data not shown). Apparently, the difference in bed cover temperatures between the plastic and gravel treatments was not great enough to influence plant canopy temperatures or bed humidity.

Container substrate temperatures (holly) were measured on 29, 30, 31 July and 1 Aug. Only data for 29 July will be presented since the response pattern for these days was similar (for other dates see Appendix B Fig. 3, 4, 5). There were two significant cubic interactions (bed cover x time, and day x time) for substrate temperatures at the west-facing container sidewall and the container center (Table 2 and 3). These two cubic interactions only accounted for 0.16 and 0.04 % (sidewall), and 0.02 and 0.03% (center) of the variation among treatments, respectively. Therefore, these interactions will be disregarded. Substrate temperatures at both container locations exhibited a cubic pattern with peak substrate temperatures at the west-facing container sidewall occurring between 1400 and 1700 HR; maximum values ranged from 37 to 40C (Fig. 2). Substrate temperatures in the container center followed a similar pattern, however, peak

temperatures (about 35C) occurred later in the day (1800 HR), similar to results of Keever and Cobb (1984) and Martin and Ruter (1996). There was a significant bed cover treatment effect ($p \leq 0.0001$) on substrate temperature at the side and center of containers, which accounted for 0.3 and 1.3% of the variability, respectively. This difference, about 1C higher on plastic than on gravel, occurred during early evening, night, and early morning (Fig. 2). However, substrate temperatures (side and center of container) for plastic and gravel treatments were the same during sun light hours. Higher substrate temperatures on plastic than on gravel during the dark hours is likely due to higher bed cover temperatures on plastic than on gravel (Fig. 1). Bed cover temperatures were not measured during the evening hours, however, soil temperature beneath a plastic cover has been shown to be higher than the temperature of a non-mulched surface (Wilson et al., 1993). Thus, if soil under plastic was warmer than under gravel, more heat would be conducted to containers on plastic versus containers on gravel. There also might be more heat lost from the containers on gravel than on plastic due to a greater temperature gradient between the gravel-covered bed and the container substrate. This 1C substrate temperature difference between plastic and gravel treatments would probably have minimal impact on plant physiology and growth.

Evapotranspiration was measured for holly and azalea at two h intervals (0700 to 1900 HR) throughout the day on 6, 10, and 12 July. There was a significant day x bed cover x time interaction for both holly and azalea ET which can be attributed to minor

climatic differences during the days the measurements were made. Furthermore, this interaction accounted for only 4.3% and 3.5% variation among treatments for holly and azalea, respectively, and therefore this interaction will be disregarded (Table 4 and 5). Because the amounts and patterns of holly and azalea ET over time of day were similar for 6, 10, and 12 July, only data for 10 July will be presented (Fig. 3; for other dates see Appendix B Fig. 6 and 7). Evapotranspiration was unaffected by bed cover type for both holly ($p = 0.89$) and azalea ($p = 0.91$). There are no reports that show ET during the course of a day for container-grown woody plants. In this work, holly and azalea ET was at least 150 g for each two h interval from 0700 to 1700 HR. Peak ET occurred between 1100 and 1500 HR (Fig. 3). Total daily ET ranged from 870 to 1015 g and 1020 to 1220 g for holly and azalea, respectively (data not shown). Of interest is the observation that daily ET amounts exceeded the daily irrigation amount (710 mL). The ET amounts may be uncharacteristically high compared to ET amounts in a commercial nursery situation since plants in this study were at a wider spacing (0.6 m) than plants of this size and age at most commercial nurseries. A wider spacing would increase the amount of light intercepted by the plant canopy and increase the amount of air movement around the canopy compared to plants on a close spacing, thereby allowing for more transpirational water loss. Despite the lack of bed cover effect, this ET data has relevance to irrigation scheduling for container-grown plants. Grower irrigation practices are becoming more refined in terms of application efficiency, such as the use of cyclic irrigation (Karam and

Niemiera, 1994), and ET data reported here may serve as a basis for the development of a more precise irrigation regime.

Holly and azalea stem water potentials were unaffected by bed cover treatment ($p = 0.67$ and $p = 0.22$; data not shown) which, in association with ET data, indicates conditions created by bed cover type did not impose a water stress on plants. Substrate solution NO_3-N concentrations for holly were also unaffected by bed cover type (data not shown). This indicated that nitrification was relatively unaffected by the small substrate temperature difference observed between plastic and gravel treatments. There were also no bed cover treatment affects on plant widths for hollies and azaleas on gravel or plastic ($p = 0.13$ and $p = 0.67$).

Experiment 2

On two of the three measurement days (6 and 13 Dec.), the container substrate on a plastic bed cover retained more water than on gravel ($p = 0.08$ and 0.003, respectively; Table 6). A portion of the drainage water that collected beneath the containers on plastic formed a puddle at the base of the container. Puddle amounts ranged from 60 to 90 g on 6 Dec. and 60 to 100 g on 13 Dec.; puddle weights were not recorded on 1 Dec. These puddles at the base of the containers on plastic were in contact with the container drain holes and created a puddle-substrate continuum. Consequently, the higher water retention by containers on plastic than on gravel can be attributed to capillary water absorption from puddles underlying containers. The higher puddle weights on 13 Dec.

than on 6 Dec. is most likely related to the pre-irrigation substrate water content. The pre-irrigation substrate water content was an average of 104 g higher on 13 Dec. than on 6 Dec. (data not shown). Substrate water absorption has been shown to decrease as pre-irrigation substrate water content increases (Karam and Niemiera, 1994). Thus, on plastic bed covers, water at the base of containers serves as a extra-container water supply whereas containers on gravel have no such resource.

Puddle amounts are noteworthy considering that daily ET for 3.1 L container-grown holly and azaleas was found to be about 100 and 300 mL, and 150 and 300 mL, respectively, for the first and second growing seasons, respectively (Knox, 1989). Therefore, an additional 60 to 100 mL of water provided by puddles beneath containers on plastic bed covers represents a significant water supply. Since puddling beneath containers is at least partly the cause of the increased water retention on plastic beds compared to that on gravel beds, irrigation method will also have an influence on puddling at the base of containers. In this work, water was applied by hand directly into containers, however, most nurseries employ overhead irrigation for containers ($\leq$ 12 L). Overhead irrigation applies water between as well as into containers, thus this form of irrigation would increase the likelihood for puddling at the base of containers.

Experiment 3

Bed cover type did not influence substrate water retention ($p = 0.29$; data not shown). This result contradicts findings of Expt. 2 in which containers on plastic retained

more water than on gravel (in two out of three trials). The reason for this apparent contradiction is most likely related to bed slope. In Expt. 2, the slope was relatively small (visual observation) but similar to many commercial nurseries; hence water tended to puddle at the base of containers. In contrast, the slope of the simulated plastic beds of Expt. 3 was higher than in Expt. 2 (visual observation) and much less water (only about 10 g) collected at the base of containers.

To test the hypothesis that the bottom center hole of containers on plastic may be partly occluded and thereby limit drainage (increased water retention), containers with and without bottom center holes were placed on both substrate types; containers without a bottom hole were analogous to an occluded bottom center hole. If drainage from containers on plastic is limited by bottom hole occlusion, then containers without a bottom center hole on gravel should retain an amount of water similar to that retained by containers with a center hole on plastic; the amount of water retained for these two treatments was similar (Table 7), thus, bottom hole occlusion may have limited drainage and increased water retention. In three bed surface-container hole comparisons, gravel with hole vs gravel without hole, gravel with hole vs plastic without, and plastic with hole vs plastic without hole, each with-hole treatment (former treatment of each comparison), regardless of bed surface type, retained less water than the later without-hole treatment ($p \leq 0.07$) which implies that eliminating the center hole decreases drainage. This supports work by Fare and Davis (1994), who showed that reducing the amount and size of

drainage holes in 3.8 L containers reduced the amount of water drained from a 6 pine bark : 1 peat substrate (by volume). The reason for higher water retention without a center hole than with a center hole may be that the lack of a center hole slows water movement throughout the container and increases the time for water absorption by unsaturated zones within the substrate. The lack of a center hole may also increase the size of the zone of saturation (perched water table) at the bottom of the container.

Summary

Bed cover type (gravel or plastic) had a minor influence on the container environment (bed humidity, substrate temperature, plant canopy temperatures; Expt. 1). The lack of a bed surface effect on ET or growth in Expt. 1 may be related to irrigation amount. A relatively high daily amount of water (1.25 cm) was applied which resulted in a substantial substrate water content for containers on both bed cover types (personal observation). If less water was applied, plants on gravel would have less access to water than plants on plastic since water exiting containers on gravel would not collect at the base of a container as would occur on a plastic covered bed. Furthermore, overhead irrigation applies water between containers as well as in containers and the water that falls between containers can also puddle at the base of containers on plastic. To avoid puddled water, plastic covered beds must be steeply sloped to insure water removal. This situation is desirable when growing plants that are especially susceptible to water-borne pathogens. Therefore, growers must weigh the benefit of an additional water supply on

plastic covered beds with minimal slope against the increased susceptibility to water-borne pathogens. Results from Expt. 2 and 3 showed that the effect of plastic bed covers on water retention may depend on bed slope. A relatively small slope could increase the water accumulation beneath containers creating a significant additional water reservoir for plants due to the container substrate being in contact with the puddle. Results from Expt. 3 indicated that plastic bed covers may limit drainage through the bottom center drain hole of containers. The bottom center drain hole of containers on plastic may be partially blocked by the plastic seated against the bottom of the container. This would allow for higher water retention in containers on plastic covered beds following irrigation than on gravel beds in which the bottom center drain hole is allowed to drain freely.

There are other factors that growers should consider when selecting bed covers. Compared to a plastic, covering container beds with gravel requires a greater initial cost but the gravel cover is relatively long-lived. In contrast, plastic must be replaced about every two years. Deteriorated plastic is sent to a landfill which incurs a disposal fee. Plastic-covered beds have an advantage of capturing leachate from containers and water that falls between containers which can be channeled to a collection pond. On gravel-covered beds, unused water can percolate into ground water if drain tiles are not present. A plastic bed cover is also a very effective weed control mechanism and allows for easy bed cleaning in the event of container spills or pruning.

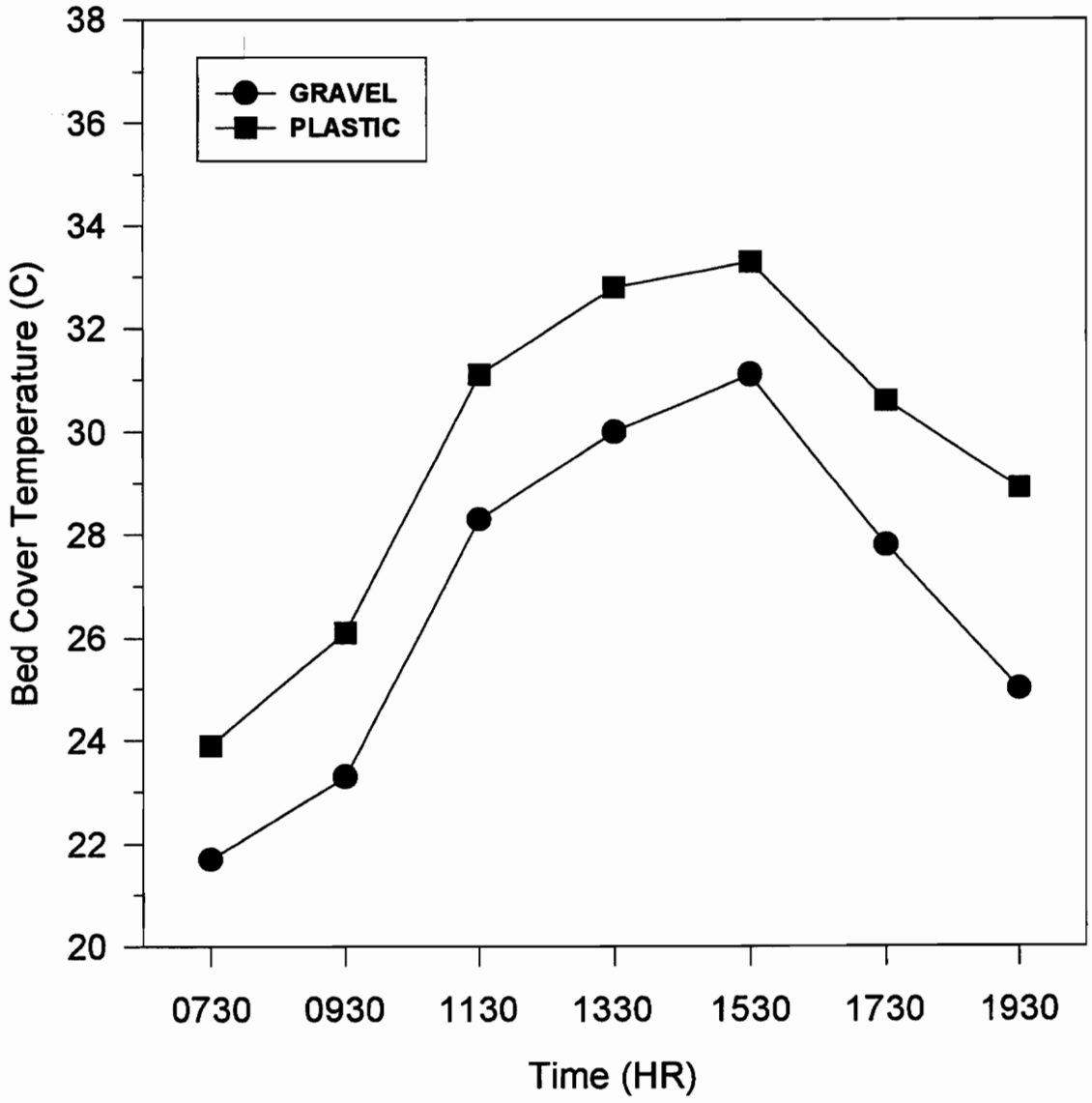

Fig. 1. Bed cover temperature (in shade of plants) measured every two h on 10 July for gravel and plastic beds (n=8 per treatment per time).

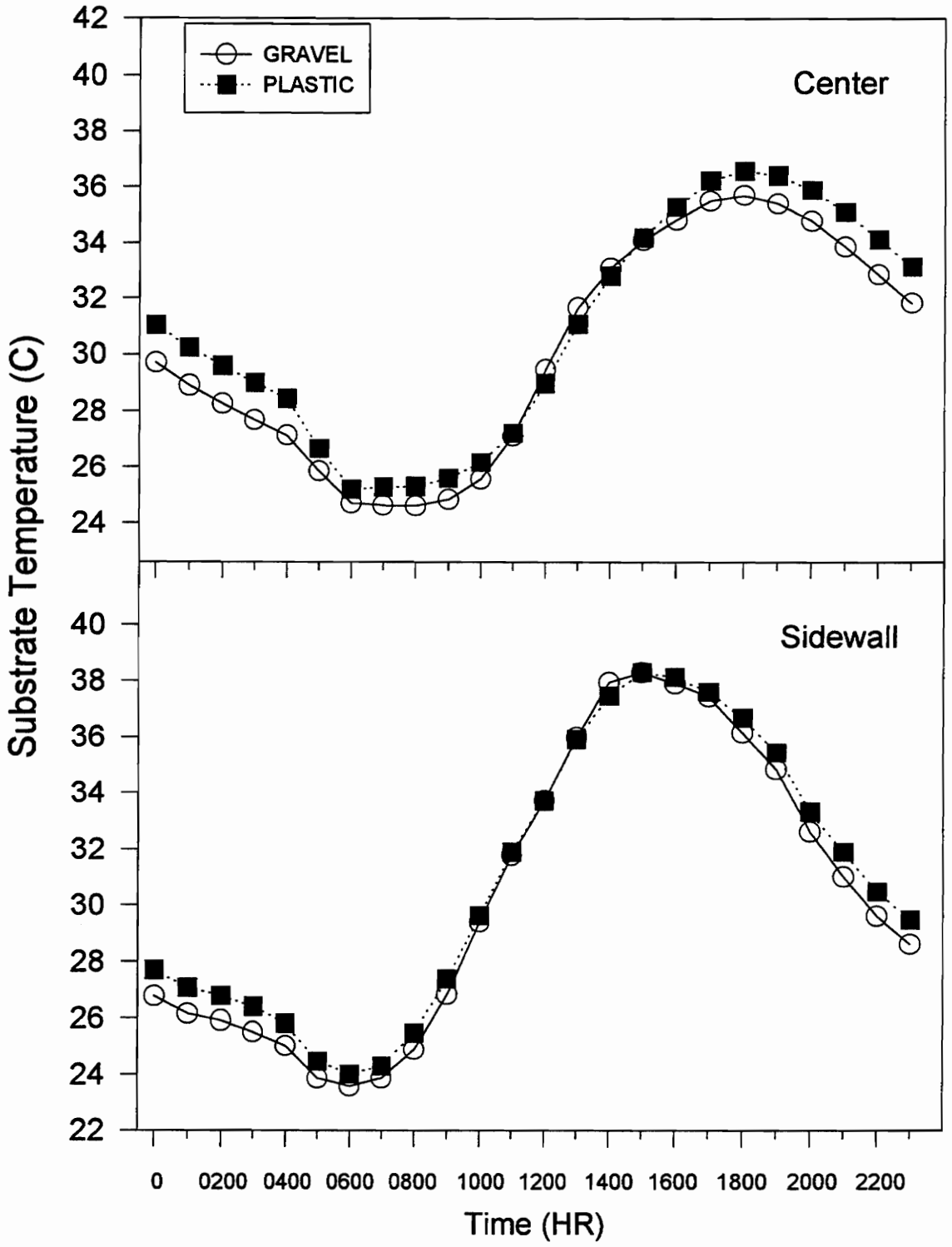

Fig. 2. Mean substrate temperature at each h, sidewall and center, on 29 July for container-grown holly on gravel or plastic bed covers (n=5 per treatment per time).

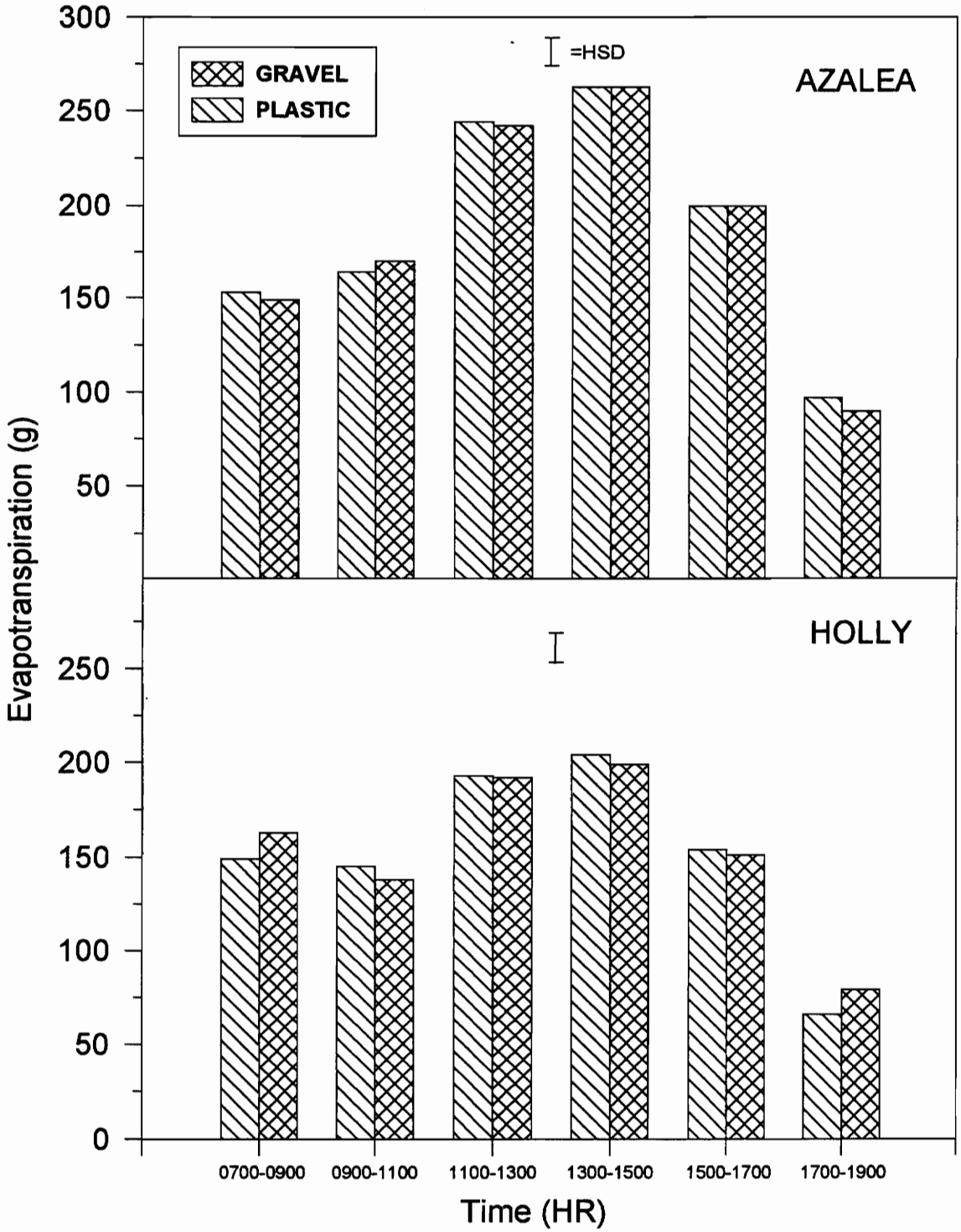

Fig. 3. Evapotranspiration every two h on 10 July, for container-grown (11.4 L) azalea and holly on gravel or plastic bed covers (n=16 per treatment per time). Bar = Tukey's HSD at 0.05 level for mean (gravel and plastic) comparison over time.

Table 1. Partitioning of treatment sum of squares for bed cover temperature.

Source of Variation	df	SS	Percent of Total
Bed cover (BC)	1	1594.71 ***	9.70%
Rep (R)	7	203.32 **	1.20%
Day (D)	2	427.54 ***	2.60%
Time (T)	6	13054.79 ***	79.30%
R x BC	7	38.33 ***	0.20%
D x T	12	469.25 ***	2.90%
BC x D	2	24.77 **	0.15%
BC x T	6	54.04 ***	0.33%
BC x D x T	12	19.86 NS	0.12%
Residual	280	571.10	3.50%
Total	335	16457.70	

NS, *, **, *** Nonsignificant or significant at p = 0.05, 0.01, or 0.001 level, respectively.

Table 2. Partitioning of treatment sum of squares for substrate temperature[z] at the container sidewall.

Source of Variation	df	SS	Percent of Total
Bed cover (BC)	1	291.74 ***	0.30%
Rep (R)	4	412.60 ***	0.50%
Day (D)	3	1459.72 ***	1.60%
BC*D	3	10.80 NS	0.01%
Time (T)	1	25873.26 ***	28.00%
T x T	1	17499.92 ***	19.00%
T x T x T	1	32527.44 ***	35.30%
D x T	3	497.19 ***	0.50%
D x T x T	3	269.88 ***	0.30%
D x T x T x T	3	142.98 ***	0.20%
BC x T	1	18.63 **	0.20%
BC x T x T	1	158.71 ***	0.20%
BC x T x T x T	1	33.82 ***	0.04%
Residual	3813	11904.75	13.00%
Total	3839	92101.43	

NS, *, **, *** Nonsignificant or significant at p = 0.05, 0.01, or 0.001 level, respectively.

[z] Time used as a regression variable (not a classification variable) to test linear, quadratic, and cubic portions of the temperature response curve.

Table 3. Partitioning of treatment sum of squares for substrate temperature[z] at the container center.

Source of Variation	df	SS	Percent of Total
Bed cover (BC)	1	698.18 ***	1.30%
Rep (R)	4	262.81 ***	0.50%
Day (D)	3	1006.68 ***	1.90%
BC x D	3	17.40 **	0.03%
Time (T)	1	22297.55 ***	43.00%
T x T	1	968.78 ***	1.90%
T x T x T	1	21537.90 ***	41.20%
D x T	3	297.61 ***	0.60%
D x T x T	3	241.24 ***	0.50%
D x T x T x T	3	15.07 **	0.03%
BC x T	1	9.44 **	0.02%
BC x T x T	1	163.46 ***	0.30%
BC x T x T x T	1	7.81 **	0.02%
Residual	3813	4695.90	9.00%
Total	3839	52219.82	

NS, *, **, *** Nonsignificant or significant at p = 0.05, 0.01, or 0.001 level, respectively.

[z] Time used as a regression variable (not a classification variable) to test linear, quadratic, and cubic portions of the temperature response curve.

Table 4. Partitioning of treatment sum of squares for holly evapotranspiration.

Source of Variation	df	SS	Percent of Total
Bed cover (BC)	1	41.71 NS	0.003%
Rep (R)	7	29083.58 ***	2.10%
Day (D)	2	58093.89 ***	4.30%
Time (T)	5	1040110.45 ***	76.30%
BC x R	7	13106.19 ***	1.00%
Plant (BC x R)	23	50773.00 ***	3.72%
BC x D	2	191.30 NS	0.01%
BC x T	5	8345.47 ***	0.60%
BC x D x T	20	58297.49 ***	4.30%
Residual	510	118500.36	8.70%
Total	575	1363437.23	

NS, *, **, *** Nonsignificant or significant at p = 0.05, 0.01, or 0.001 level, respectively.

Table 5. Partitioning of treatment sum of squares for azalea evapotranspiration.

Source of Variation	df	SS	Percent of Total
Bed cover (BC)	1	24.59 NS	0.001%
Rep (R)	7	24437.96 ***	1.00%
Day (D)	2	106135.57 ***	4.80%
Time (T)	5	1854493.30 ***	83.50%
BC x R	7	18148.65 ***	0.80%
Plant (BC x R)	23	44378.68 ***	2.00%
BC x D	2	28.82 NS	0.001%
BC x T	5	2639.26 *	0.10%
BC x D x T	20	77434.03 ***	3.50%
Residual	510	112218.30	5.10%
Total	575	2221790.50	

NS, *, **, *** Nonsignificant or significant at p = 0.05, 0.01, or 0.001 level, respectively.

Table 6. Mean water retention following irrigation and drainage on gravel and plastic bed covers.

	Water retention (g)		
Bed cover type	Day 1	Day 2	Day 3
gravel	334	369	269
plastic	349	399	320
p value[z]	0.1366	0.0770	0.0031

[z] Main effect of bed covering.

Table 7. Mean water retention in 3.8 L containers with and without a bottom center drain hole following irrigation and one h of drainage on gravel and plastic bed covers.

Treatment	Water retention (g)
gravel with hole[z]	293
gravel without hole[y]	311
plastic with hole	303
plastic without hole	323
LS Mean comparison	P Value
gravel without hole vs. plastic with hole	0.4333
gravel with hole vs. plastic with hole	0.2902
gravel without hole vs. plastic without hole	0.1973
gravel with hole vs. gravel without hole	0.0715
plastic with hole vs. plastic without hole	0.0434
gravel with hole vs. plastic without hole	0.0035

[z] Container with a bottom center drain hole.
[y] Container without a bottom center drain hole.

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APPENDIX A

Experiment one

Table 1. Analysis of variance for bed cover temperature.

ANOVA

Source	df	SS	MS	F	P
Treatments	55	15886.61	288.85	141.62	0.0001
Rep (R)	7	203.32	29.05	14.24	0.0001
Bed cover (BC)	1	1594.70	1594.70	781.87	0.0105
R x BC	7	38.33	5.48	2.68	0.0001
Day (D)	2	427.54	213.77	104.81	0.0001
Time (T)	6	13054.80	2175.80	1066.76	0.0001
D x T	12	469.25	39.10	19.17	0.0001
BC x D	2	24.77	12.30	6.07	0.0026
BC x T	6	54.04	9.01	4.42	0.0003
BC x D x T	12	19.86	1.66	0.81	0.6388
Within	280	571.10	2.04		
Total	335	16457.70			

Table 2. Analysis of variance for plant canopy temperature.

ANOVA

Source	df	SS	MS	F	P
Treatments	55	7568.79	137.61	62.44	0.0001
Rep (R)	7	19.02	2.72	1.23	0.2845
Bed cover (BC)	1	0.15	0.15	0.07	0.7972
R x BC	7	19.55	2.79	1.27	0.2667
Day (D)	2	799.04	399.52	181.29	0.0001
Time (T)	6	6219.42	1036.57	470.36	0.0001
D x T	12	481.33	40.11	18.20	0.0001
BC x D	2	7.04	3.52	1.60	0.2042
BC x T	6	6.50	1.08	0.49	0.8145
BC x D x T	12	16.75	1.40	0.63	0.8132
Within	280	617.06	2.20		
Total	335	8185.85			

Table 3. Analysis of variance for holly ET with repeated measures.

ANOVA

Source	df	S S	MS	F	P
Treatments	65	1244936.88	19152.88	82.43	0.0001
Rep (R)	7	29083.58	4154.80	17.88	0.0001
Bed cover (BC)	1	41.71	41.71	0.02	0.8919
Plant (R x BC)	23	50773.00	2207.52	9.50	0.0001
Day (D)	2	58093.89	29046.94	125.01	0.0001
Time (T)	5	1040110.45	208022.09	895.25	0.0001
BC x D	2	191.30	95.65	0.41	0.6628
BC x T	5	8345.47	1669.09	7.18	0.0001
BC x D x T	20	58297.29	2914.87	12.54	0.0001
Within	510	118500.36	232.35		
Total	575	1363437.23			

Table 4. Analysis of variance for azalea ET with repeated measures .

ANOVA

Source	df	S S	MS	F	P
Treatments	65	2109572.20	32454.96	147.50	0.0001
Rep (R)	7	24437.96	3491.14	15.87	0.0001
Bed cover (BC)	1	24.59	24.59	0.01	0.9111
Plant (R x BC)	23	44378.68	1929.51	8.77	0.0001
Day (D)	2	106135.50	53067.78	241.18	0.0001
Time (T)	5	1854493.30	370898.66	1685.63	0.0001
BC x D	2	28.82	14.41	0.07	0.9366
BC x T	5	2639.26	527.85	2.40	0.0363
BC x D x T	20	77434.03	3871.70	17.60	0.0001
Within	510	112218.30	220.04		
Total	575	2221790.50			

Table 5. Analysis of variance for substrate temperature at the container sidewall. Time used as a regression variable (not a classification variable) to test linear, quadratic, and cubic portions of the temperature response curve.

ANOVA

Source	df	S S	MS	F	P
Treatments	26	80196.68	3084.49	987.94	0.0001
Day (D)	3	1459.72	486.57	155.85	0.0001
Rep (R)	4	412.60	103.15	33.04	0.0001
Bed cover (BC)	1	291.74	291.74	93.44	0.0001
BC x D	3	10.80	3.60	1.15	0.3262
Time (T)	1	25873.26	25873.26	8287.01	0.0001
T x T	1	18499.92	18499.92	5925.39	0.0001
T x T x T	1	32527.45	32527.45	10418.29	0.0001
T x D	3	497.19	165.73	53.08	0.0001
T x T x D	3	269.88	89.96	28.81	0.0001
T x T x T x D	3	142.98	47.66	15.27	0.0001
BC x T	1	18.63	18.63	5.97	0.0146
T x T x BC	1	158.71	158.71	50.83	0.0001
T x T x T x BC	1	33.82	33.82	10.83	0.0010
Within	3813	11904.75	3.12		
Total	3839	92101.43			

Table 6. Analysis of variance for substrate temperatures at the container center. Time used as a regression variable (not a classification variable) to test linear, quadratic, and cubic portions of the temperature response curve.

ANOVA

Source	df	S S	MS	F	P
Treatments	26	47523.92	1827.84	1484.18	0.0001
Day (D)	3	1006.68	335.56	272.47	0.0001
Rep (R)	4	262.81	65.70	53.35	0.0001
Bed cover (BC)	1	698.18	698.18	566.91	0.0001
BC x D	3	17.40	5.80	4.71	0.0028
Time (T)	1	22297.55	22297.55	18105.28	0.0001
T x T	1	968.78	968.78	786.63	0.0001
T x T x T	1	21537.90	21537.90	17488.45	0.0001
T x D	3	297.61	99.21	80.55	0.0001
T x T x D	3	241.24	80.42	65.30	0.0001
T x T x T x D	3	15.07	5.02	4.08	0.0067
BC x T	1	9.44	9.44	7.66	0.0057
T x T x BC	1	163.46	163.46	132.72	0.0001
T x T x T x BC	1	7.81	7.81	6.34	0.0119
Within	3813	4695.90	1.23		
Total	3839	52219.82			

Table 7. Analysis of variance for holly growth.

ANOVA

Source	df	S S	MS	F	P
Treatments	15	22.74	1.52	0.67	0.8022
Rep (R)	7	8.11	1.16	0.51	0.8224
Bed cover (BC)	1	5.29	5.29	2.33	0.1336
R x BC	7	9.34	1.33	0.59	0.7628
Within	48	109.03	2.27		
Total	63	131.77			

Table 8. Analysis of variance for azalea growth.

ANOVA

Source	df	SS	MS	F	P
Treatments	15	76.68	5.11	2.53	0.0076
Rep (R)	7	33.00	4.72	2.33	0.0393
Bed cover (BC)	1	0.38	0.38	0.19	0.6686
R x BC	7	43.30	6.19	3.06	0.0096
Within	48	97.06	2.02		
Total	63	173.74			

Table 9. Analysis of variance for holly stem water potential.

ANOVA

Source	df	SS	MS	F	P
Treatments	27	2504.31	92.75	118.78	0.0001
Rep (R)	4	4.76	1.19	1.52	0.2044
Bed cover (BC)	1	0.14	0.14	0.18	0.6685
Plant (R x BC)	14	21.18	1.51	1.94	0.0361
Time (T)	4	2472.69	618.17	791.66	0.0001
BC x T	4	5.54	1.30	1.77	0.1435
Within	72	56.22	0.78		
Total	99	2560.54			

Table 10. Analysis of variance for azalea stem water potential.

ANOVA

Source	df	S S	MS	F	P
Treatments	27	3252.82	120.48	58.59	0.0001
Rep (R)	4	10.87	2.72	1.32	0.2702
Bed cover (BC)	1	3.21	3.21	1.56	0.2153
Plant (R x BC)	14	20.83	1.49	0.72	0.7441
Time (T)	4	3215.04	803.76	390.91	0.0001
BC x T	4	2.87	0.72	0.35	0.8442
Within	72	145.99	2.06		
Total	99	3398.80			

Experiment two

Table 11. Analysis of variance for water retention on gravel and plastic beds following irrigation and drainage on 1 Dec.

ANOVA

Source	df	S S	MS	F	P
Treatments	7	3280.38	468.63	0.59	0.7591
Rep (R)	3	380.63	126.88	0.16	0.9227
Bed cover (BC)	1	1819.13	1891.13	2.37	0.1366
R x BC	3	1008.63	336.21	0.42	0.7390
Within	24	19129.50	797.06		
Total	31	22409.88			

Table 12. Analysis of variance for water retention on gravel and plastic beds following irrigation and drainage on 6 Dec.

ANOVA

Source	df	S S	MS	F	P
Treatments	7	14397.00	2056.71	0.95	0.4872
Rep (R)	3	4376.25	1458.75	0.67	0.5760
Bed cover (BC)	1	7381.13	7381.13	3.41	0.0770
R x BC	3	2639.63	879.88	0.41	0.7494
Within	24	51887.00	2161.96		
Total	31	66284.00			

Table 13. Analysis of variance for water retention on gravel and plastic beds following irrigation and drainage on 13 Dec.

ANOVA

Source	df	S S	MS	F	P
Treatments	7	29316.50	4188.07	2.12	0.0806
Rep (R)	3	6843.25	2281.08	1.15	0.3477
Bed cover (BC)	1	21321.13	21321.13	10.79	0.0031
R x BC	3	1152.13	384.04	0.19	0.8992
Within	24	47433.00	1976.38		
Total	31	76749.50			

Table 14. Analysis of variance for water retention on gravel and plastic beds following irrigation and drainage in containers with and without a bottom center drain hole.

ANOVA

Source	df	S S	MS	F	P
Treatments	3	3738.25	1246.08	3.62	0.0252
Bed cover (BC)	1	990.13	990.13	2.88	0.1010
Hole treatment (HT)	1	2738.00	2738.00	7.95	0.0087
BC x HT	1	10.13	10.13	0.03	0.8651
Within	28	9637.25	344.19		
Total	31	13375.50			

APPENDIX B

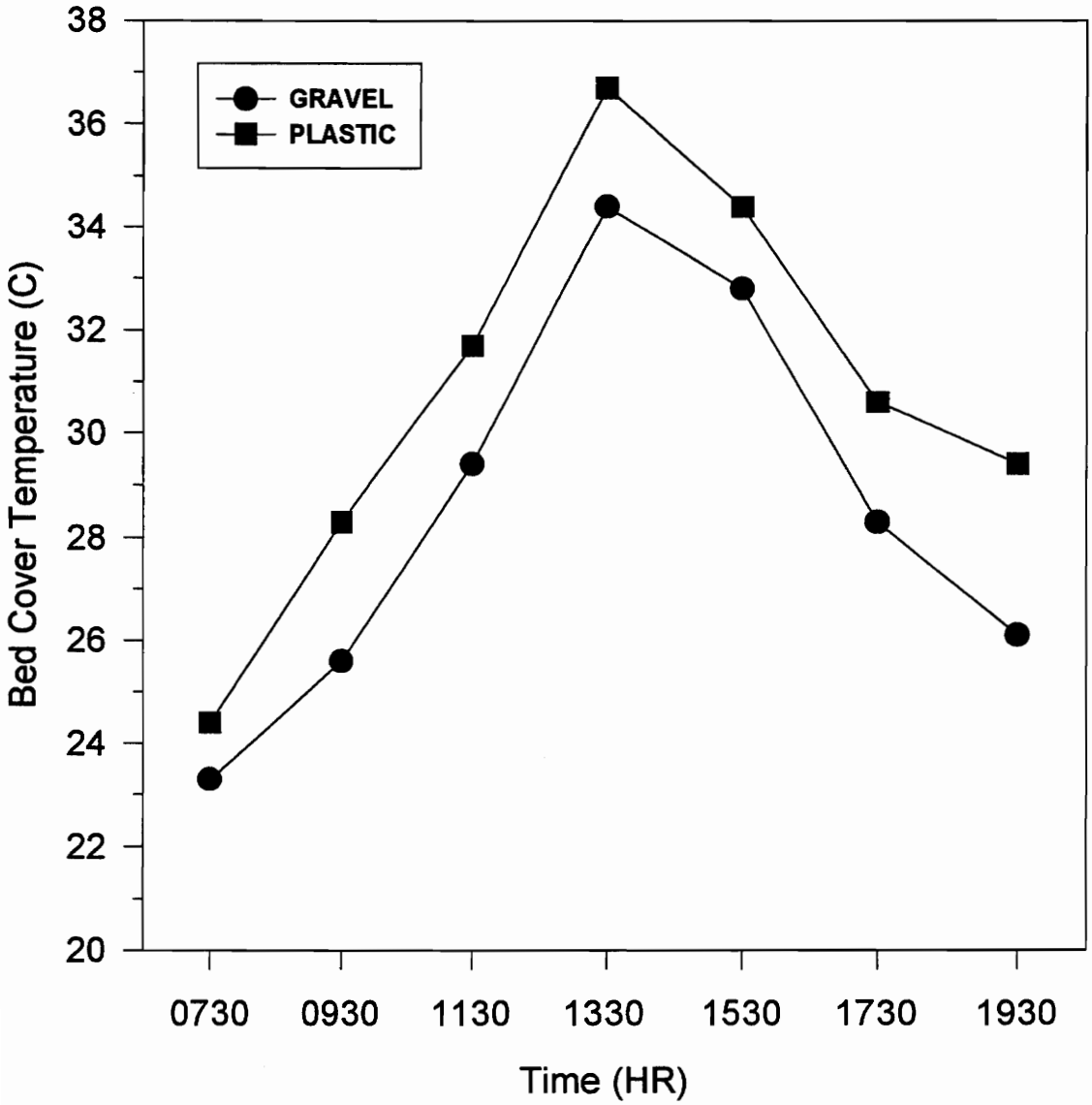

Fig. 1. Bed cover temperature (in shade of plants) measured every two h on 6 July for gravel and plastic beds (n=8 per treatment per time).

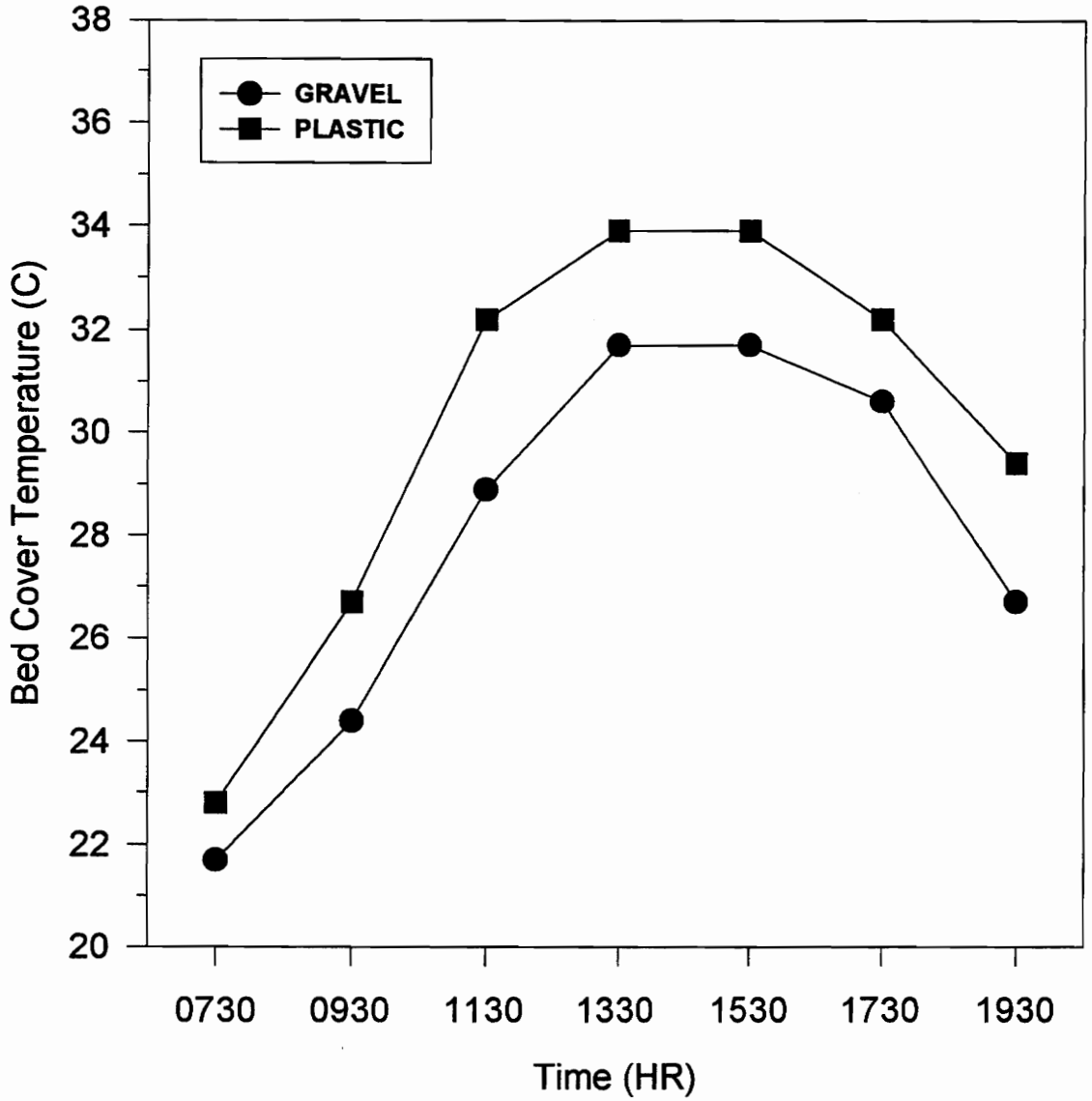

Fig. 2. Bed cover temperature (in shade of plants) measured every two h on 12 July for gravel and plastic beds (n=8 per treatment per time).

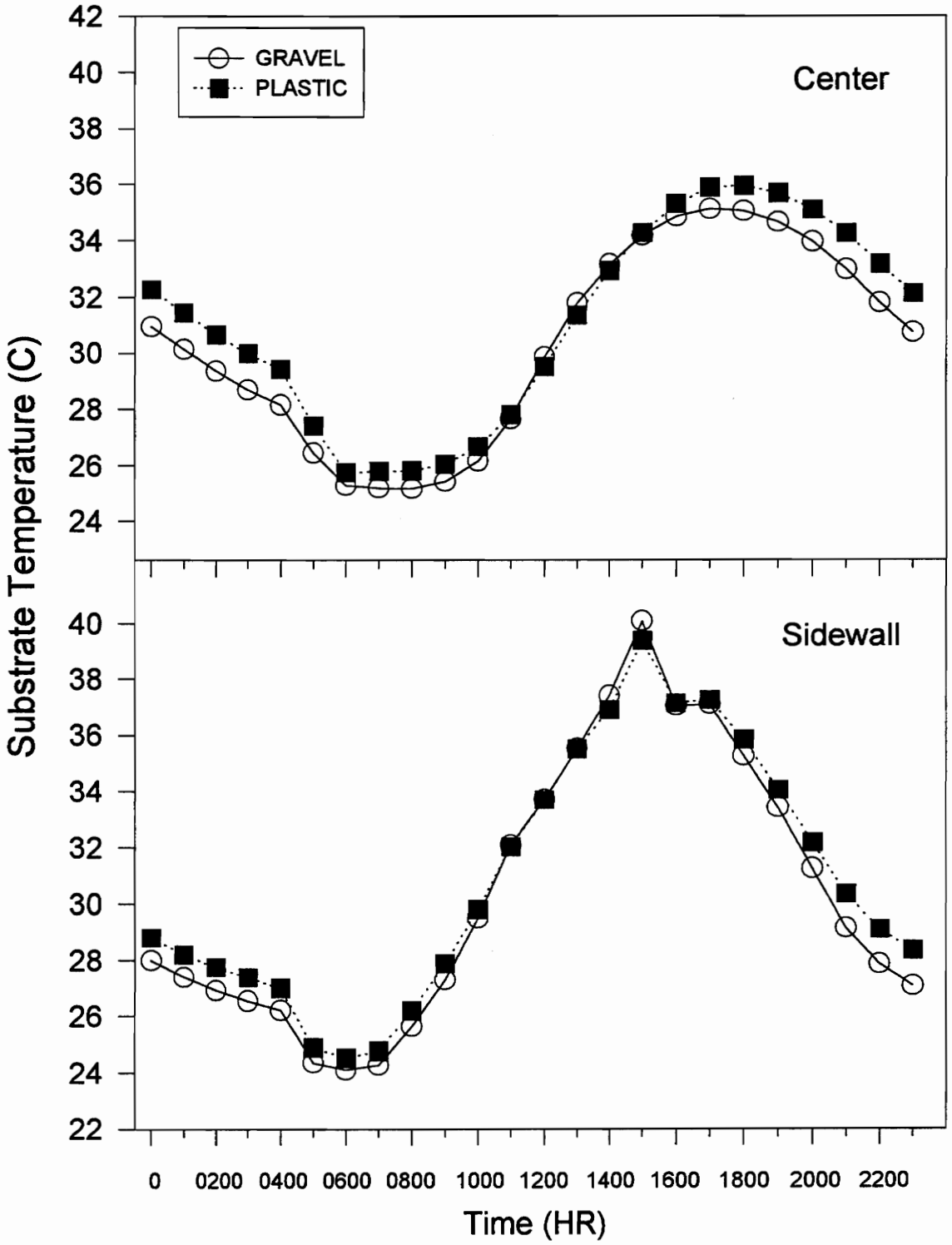

Fig. 3. Mean substrate temperature at each h, sidewall and center, on 30 July for container-grown holly on gravel and plastic bed covers (n=5 per treatment per time).

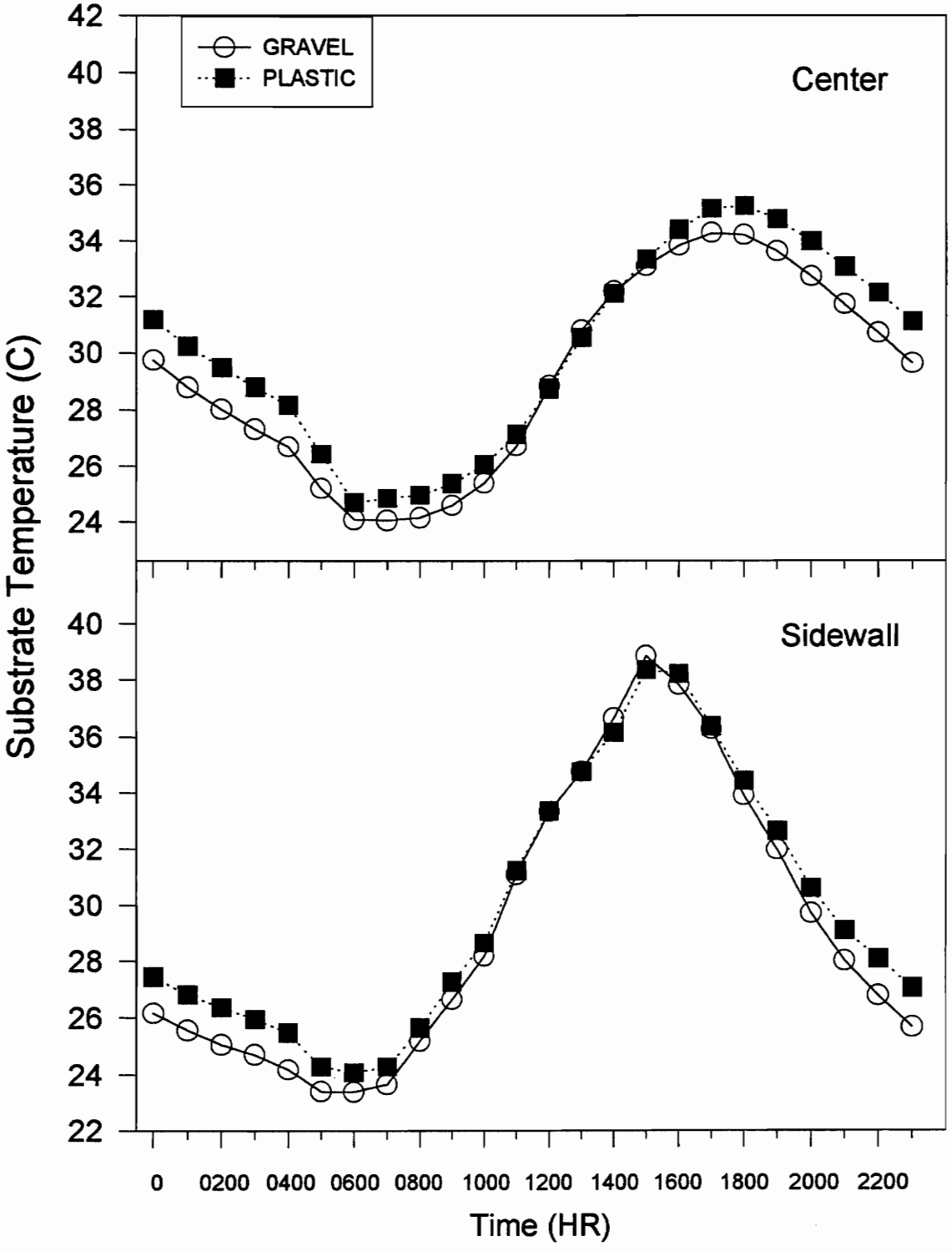

Fig. 4. Mean substrate temperature at each h, sidewall and center, on 31 July for container-grown holly on gravel or plastic bed covers (n=5 per treatment per time).

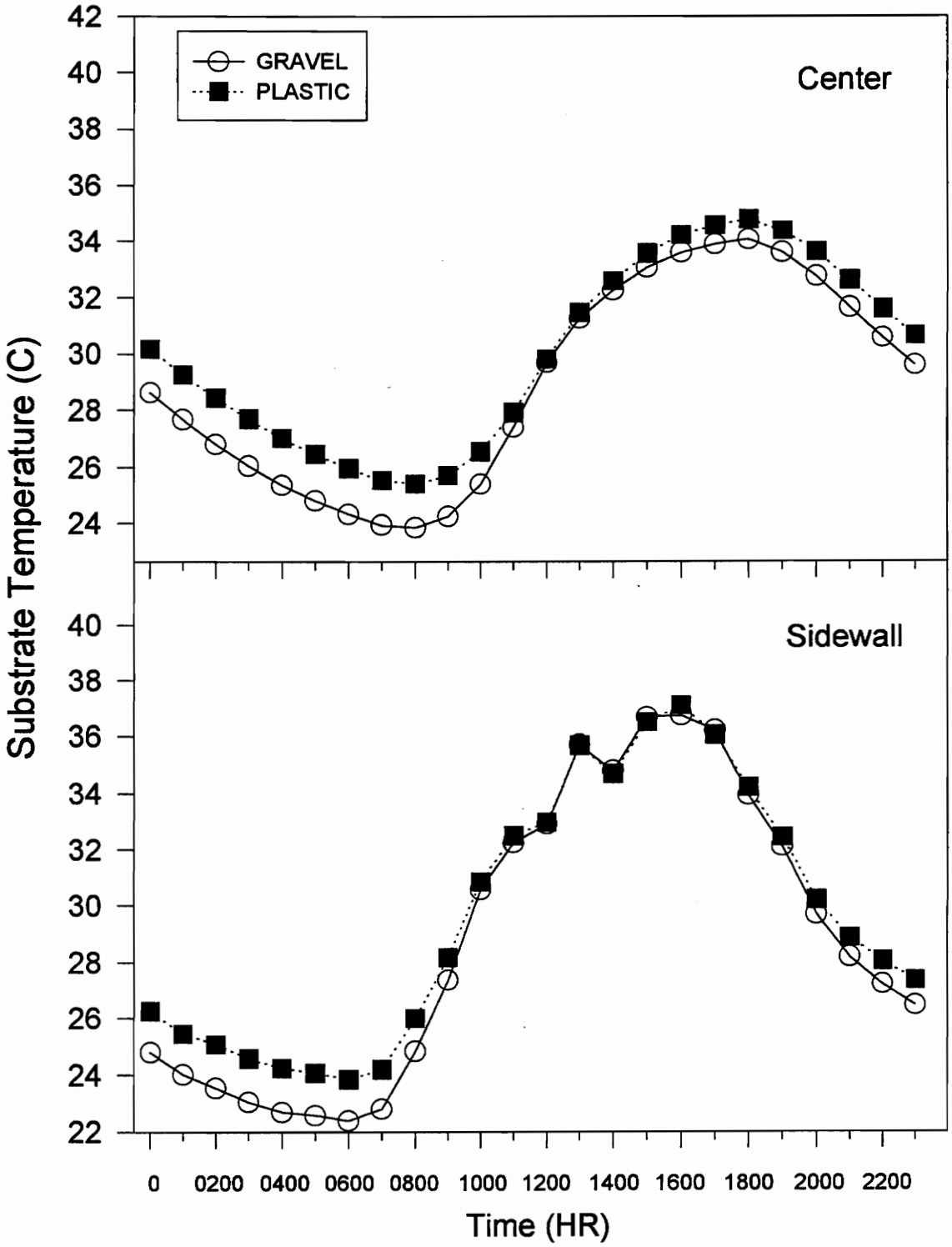

Fig. 5. Mean substrate temperature at each h, sidewall and center, on 1 Aug. for container-grown holly on gravel or plastic bed covers (n=5 per treatment per time).

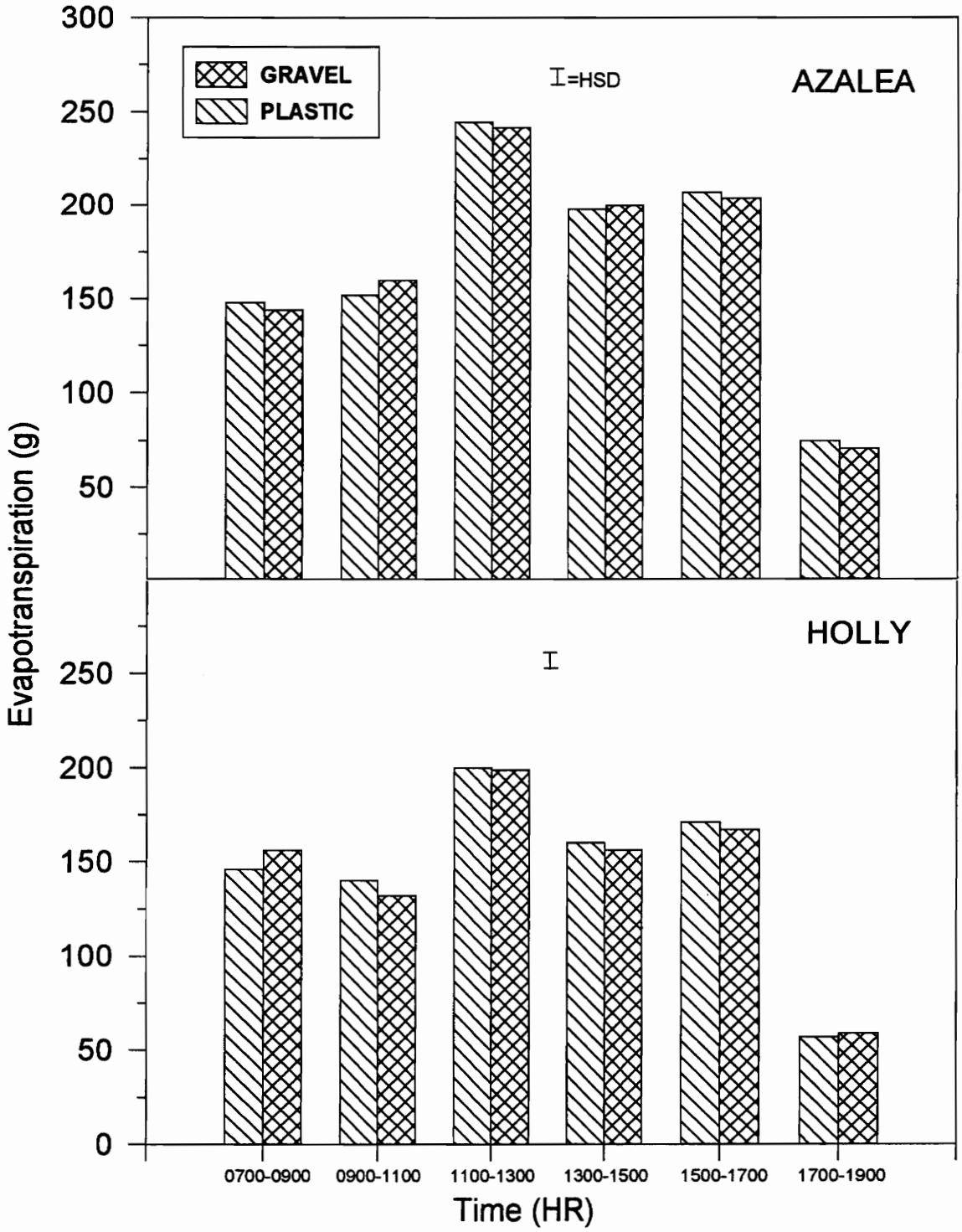

Fig. 6. Evapotranspiration every two h on 6 July, for container-grown (11.4 L) azalea and holly on gravel or plastic bed covers (n=16 per treatment per time). Bar = Tukey's HSD at 0.05 level for mean (gravel and plastic) comparison over time.

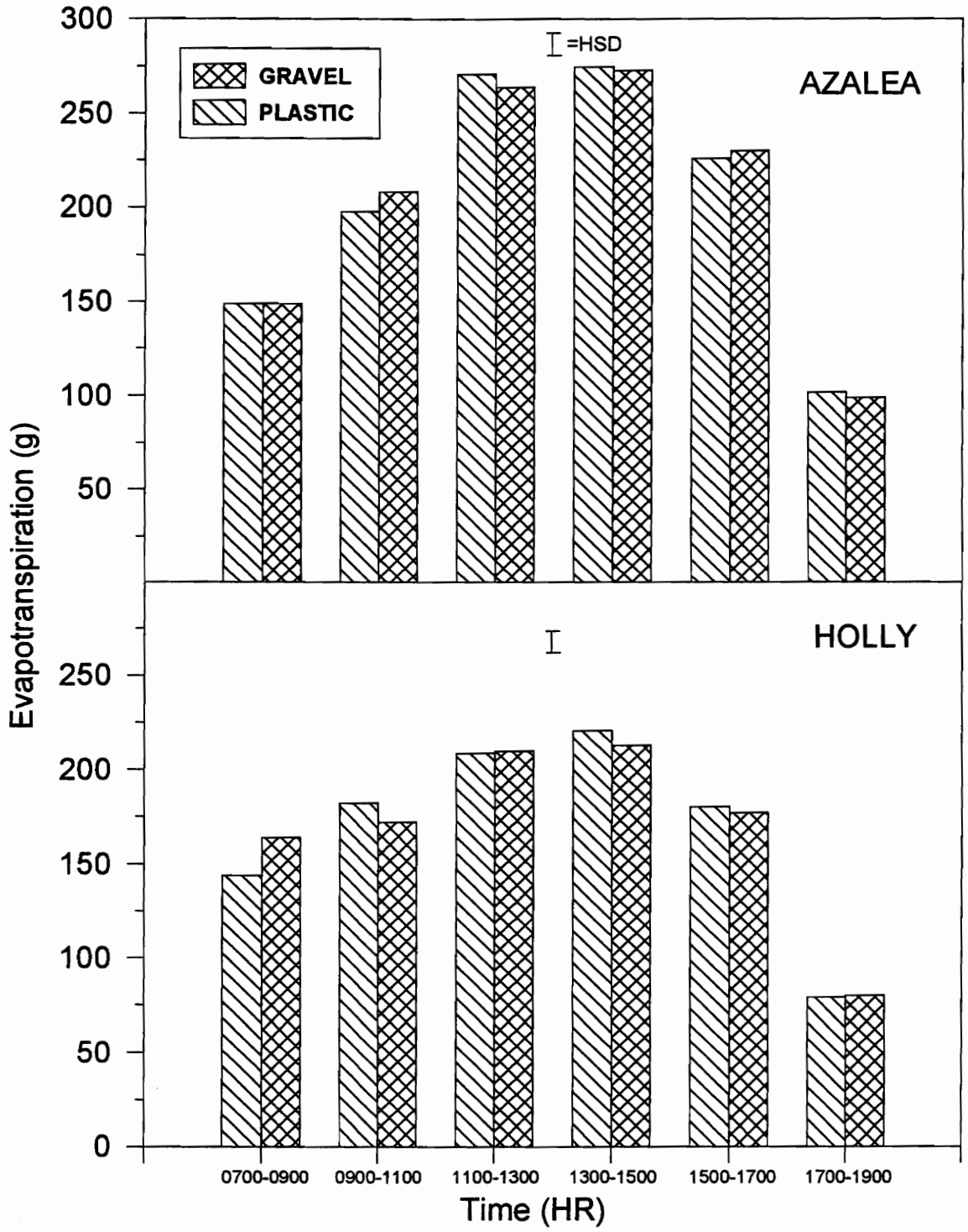

Fig. 7. Evapotranspiration every two h on 12 July, for container-grown (11.4 L) azalea and holly on gravel or plastic bed covers (n=16 per treatment per time). Bar = Tukey's HSD at 0.05 level for mean (gravel and plastic) comparison over time.

Vita

Marion James Packett was born on January 21, 1972 in Richmond, Virginia. He grew up in Warsaw, VA, attending Richmond County Public schools. In 1990 Marion graduated from Rappahannock High School and attended Virginia Polytechnic Institute and State University that fall. In May 1994, he received a B.S. in Horticulture from Virginia Polytechnic Institute and State University. During summer vacations while attending college, Marion was employed at Red Oak Nurseries and focused his career goals toward the nursery industry. In August 1994, he began graduate studies in the M.S. program of the Department of Horticulture at Virginia Polytechnic Institute and State University, Blacksburg, VA.