

# Monitoring Environmental Conditions and Substrate Water Content to Increase Efficiency of Irrigation in Nurseries

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**Abstract.** Competition for world water resources continues to increase due to population growth and increased agricultural and industrial water demand. This will result in a reduction in the availability of freshwater worldwide (Jury and Vaux, 2005). Efficient irrigation practices can have many benefits for both nurseries and society-at-large. Benefits for nurseries may include better control over plant quality, reduced water and fertilizer use, less power consumption (related to running pumps for irrigation), fewer problems with root pathogens, and less runoff. Benefits for society-at-large include a reduction in potential pollution from nurseries (e.g. runoff of fertilizer and pesticides), a decrease in competition for water resources, and decreases in CO<sub>2</sub> emissions.

Irrigation is necessary during the production of containerized nursery crops due to the relatively small volume of substrate that is used to produce container plants. To assure rapid growth, it is crucial to supply the plants with water and nutrients as needed. Irrespective of how the fertilizer is applied, irrigation and fertilization are closely linked, since movement of nutrients through the substrate depends on water (Majsztrik et al., 2010). Excessive irrigation leads to leaching of nutrients. This leaching constitutes an economic loss to the grower, since these nutrients are no longer available to the crop and pose a potential environmental risk, since fertilizer runoff can contribute to eutrophication of water bodies. Excessive irrigation can also produce conditions amenable to root pathogens, and thus lead to significant crop losses (Blaker and MacDonald, 1981). Finally, excessive irrigation carries a direct cost for nursery growers, since the expenses for the power to run irrigation pumps can be significant. Thus, more efficient irrigation practices can have many benefits for nurseries. At the same time, there are benefits to society-at-large when irrigation practices are

improved. A reduction in runoff, and less risk of environmental pollution, can help safeguard environmental quality and reduce the need for water treatment. Reductions in power consumption will result in a decrease in CO<sub>2</sub> emissions, and may thus contribute to slowing global climate change.

Perhaps the most significant barrier to implementation of more efficient irrigation practices is the lack of knowledge regarding when plants need to be watered and how much water needs to be applied. More sophisticated systems, such as real-time soil moisture monitoring systems, have the potential to drastically reduce the amount of water needed for irrigation by using more precise irrigation control. Soil moisture sensors monitor substrate water content, and when used in conjunction with a computer-controlled irrigation system, can be used to initiate irrigation when substrate water content drops below a user-specified set point. Here we describe the use of soil moisture sensors combined with a wireless network to remotely monitor environmental conditions, substrate water content of selected crops, and irrigation water applications. Such networks can provide growers with real-time information regarding the water status of their crops and provide valuable information regarding the efficiency of water applications. Finally, without a clear understanding of daily plant water use, it is extremely difficult to irrigate with maximum efficiency. Therefore, research is being conducted to quantify the volume of water or volumetric water content required to maintain acceptable growth rates of nursery crops, using *Hydrangea macrophylla* and *Hibiscus acetocellus* 'Panama Red' as model crops.

**Key words: production horticulture, irrigation automation, soil moisture sensor**

## Objectives & Materials and Methods

### Objective 1: Wireless Irrigation System Implementation

The objective of this project was to test a wireless sensor network in a commercial nursery, and to determine whether real-time sensor data can be used to improve irrigation practices. This work was done in collaboration with Evergreen Nurseries in Statham, GA. At this nursery, a wireless network, consisting of four dataloggers (EM50R, Decagon Devices, Pullman, WA) was installed. These dataloggers can be used to measure a wide variety of sensors. In this case, one of the dataloggers was configured as a weather station by connecting a photosynthetic photon flux sensor (Apogee Instruments, Logan UT), a relative humidity and temperature sensor (Decagon Devices), and a rain gauge (Decagon Devices). The other three dataloggers were used to monitor substrate water content in various crops, by connecting four soil moisture sensors (EC-5, Decagon Devices) to the datalogger. Later on, a rain gauge was connected to these loggers as well, with the purpose of monitoring rainfall and irrigation of

each crop. The dataloggers measured each sensor once every 20 minutes. All crops were irrigated using overhead sprinklers and grown in hoop houses covered with shade cloth. All four dataloggers communicated wirelessly with the basestation connected to a computer running DataTrac software (Decagon Devices). This software provides a simple interface to allow users to graph the data from multiple dataloggers. This allowed the grower to have easy access to all data as they were being collected. Researchers had remote access to the computer at the nursery using remote access software (TeamViewer 5.0, TeamViewer GmbH, Göppingen, Germany).

### **Objective 2: Growth of *Hibiscus acetocellus* 'Panama Red' as a function of soil volumetric water content.**

The objective of our study was to determine the effect of substrate water content on the growth of *Hibiscus acetosella* 'Panama Red' and to quantify the water requirements of this plant. On June 17, 2010 rooted cuttings of *Hibiscus acetosella* 'Panama Red', pruned to the third node above substrate level, were planted in one gallon containers filled with soilless substrate (Fafard Nursery Mix; Conrad Fafard Inc., Agawam, MA). Pots were topdressed with 24 grams of 16 month, slow release fertilizer (Graco 14-8-14 with minors; Graco Fertilizer Co., Cairo, GA) and watered in. Plants were grown in a glass-covered greenhouse throughout the study.

The irrigation system used in the experiment was based on the design described by Nemali and van Iersel, 2006, with substrate water content set points of 0.10, 0.15, 0.20, 0.25, 0.30, 0.35, 0.40, and 0.45 L·L<sup>-1</sup>. Treatments were started on June 24. The experiment was designed as a randomized complete block with eight treatments and four replications (32 total plots). Each plot contained two pots which were monitored with soil moisture sensors (EC-5, Decagon; Pullman, WA). A data logger (CR10; Campbell Scientific, Logan, UT) stored readings from the two sensors and initiated irrigation when the average of the two sensor readings dropped below the assigned substrate water content set point, providing 44.5 mL of water per irrigation event. The number of irrigation events was recorded by the datalogger, allowing for the calculation of the amount of irrigation water applied to each plant. On August 2, the experiment was ended and plant growth measurements were taken. Substrate water content was measured using a ThetaProbe soil moisture sensor (Delta-T Devices, Cambridge, UK). Shoots were cut off at the substrate surface and dry weight was determined. Data were analyzed with linear and non-linear regression using SigmaPlot (v. 11, Systat Software, San Jose, CA).

### **Objective 3. Calculating Daily Water Use of *Hydrangea macrophylla* in a Production Nursery Environment**

Our objective was to investigate the relationship between plant size, environmental factors, and water consumption of *Hydrangea macrophylla*. Data

obtained in this study may be used at a later date to develop predictive modeling software that would control irrigation frequency and duration in accordance with the needs of the plants. Our study took place at the Center for Applied Nursery Research (Dearing, GA). Sixty four rooted cuttings of two *Hydrangea macrophylla* cultivars, 32 'Fasan' and 32 'Pia' (James Greenhouses, Colbert, GA), were transplanted into 7-liter containers filled with a composted pine bark growing mix (bark, 4 lbs. lime/cu. yd., 1.5 lbs. micromax/cu. yd., 1.5 lbs gypsum/cu. yd., 2 lbs. talstar/cu. yd., 4 lbs. Osmocote Pro 18-6-12/ cu. yd.). The plants were irrigated using a custom drip irrigation system with four plants of each cultivar mounted on load cells (LSP-10, Transducer Techniques, Temecula, CA). The system was controlled using a datalogger (CR10, Campbell Scientific, Logan, UT) and multiplexer (AM25T, Campbell Scientific) and the datalogger controlled water applications and stored environmental and water use data. Light levels were monitored using a quantum sensor (QSO-sun, Apogee instruments, Logan, UT), while temperature and humidity data were collected with a temperature/humidity probe (HMP50, Vaisala, Helsinki, Finland).

The plants were watered daily at 10 pm for 30 minutes to bring the growing mix moisture level to container capacity, ensuring that water would not limit water use. Water was allowed to drain from the pots for an hour and a half before the plants were weighed at midnight, establishing a base weight for the start of each day. At 10:00 pm every night, the datalogger recorded the weights of the eight plants mounted on the load cells as the final weight for each day, before the plants were irrigated again. The datalogger then calculated the decrease in weight that occurred during that day and stored that value as the daily water use (DWU). Light levels, temperature, and relative humidity were measured every 5 minutes and compiled at 11:55 pm, at which time the datalogger calculated the daily light integral (the cumulative light integrated over the whole day). The datalogger also calculated the vapor pressure deficit from temperature and humidity measurements. Vapor pressure deficit, the additional amount of water it would take to saturate the air with water, provides the driving force for transpiration and thus likely affects plant water use. Maximum, minimum and daily average values were stored for photosynthetic photon flux, temperature, and vapor pressure deficit.

After 84 days, the plants mounted on the load cells were harvested. Total plant leaf area measurements were taken (LI 3100, Li-Cor, Lincoln, NE) to quantify the size of the plants at the end of the study. The containers, still filled with growing mix and roots, were brought to container capacity, weighed, dried, and weighed again to calculate the total water holding capacity of the pine bark growing mix. Due to poor growth of one 'Pia' and one 'Fasan' plant, only three plants of each cultivar were used in the data analysis. The effects of environmental and plant parameters on daily water use of the plants were tested using linear and multiple regression. Stepwise selection was used to eliminate non-significant factors from the model (proc REG, SAS 9.2, The SAS Institute, Cary, NC).

## Results and Discussion

### Objective 1: Wireless Irrigation System Implementation

Figure 1 is a screenshot from the DataTrac software showing the environmental conditions in the Evergreen Nursery growing production area during a one week period. Relative humidity was generally close to 95% pre-dawn and decreased to 20-30% in the afternoon. There was a clear, inverse relationship between relative humidity and temperature, which ranged from 40 to 55 °F pre-dawn to 75 to 85 °F in the early afternoon. There was only one small rain event during this period, in the morning of October 20.

The substrate water content as measured in one hoop house with both lantanas and gaillardias is shown in Fig. 2. Irrigation practices were changed during the two-week period shown here: during the first week, the crops were irrigated for 15 minutes on most days, while the crops were not irrigated on October 8 and 11. During the second week shown in this graph, the crops were irrigated twice daily, 8 minutes each time. The goal of using cyclic irrigation was to reduce leaching. The gradual increase in substrate water content following the switch to cyclic irrigation does indeed suggest that more of the applied irrigation water was retained by the substrate.

The data in Fig. 3 are from a hellebores crop during the period August 14 – September 4, 2010. These data show the average of the readings from four different sensors. As can be seen in the top graph, there was regular rain from August 13-23, and, as expected, each significant rainfall event resulted in a rapid increase in substrate water content. The rain largely stopped after August 22 and the substrate starts to dry out gradually from that time on. The substrate dries out much faster during the day than at night, presumably related to the greater vapor pressure deficit and opening of the stomates during the daylight hours. In early September, the crop was irrigated twice (as indicated by the red arrows).

The data obtained from the wireless sensor network clearly show the dynamic changes in substrate water content. However, looking at the change in substrate water content from one measurement to the next can add valuable information. To do so, we simply subtracted the current substrate water content from that measured 20 minutes earlier (Fig.4, red line). Note that only decreases in substrate water content (leaching and/or evapotranspiration) are shown. Irrigation and rainfall would appear as large negative values and are excluded for clarity.

When looking at the change in substrate water content, it is clear that each significant rain event is followed immediately by a rapid decrease in substrate water content (i.e., the spikes in the red curve). This indicates that very shortly after a rainfall event, the water drains to below where the sensor is in the

container. Given the size of the pots, that likely means that this water leached out of the pots. Such leaching events are much easier to see when looking at the change in substrate water content, rather than the substrate water content itself. This also can be seen in the data from the two irrigation events near the end of this period: the first irrigation, on September 1, apparently resulted in very light leaching, while there was a fair amount of leaching after the irrigation on September 2, as indicated by the rapid decrease in substrate water content following that irrigation.

The information that can be obtained using these wireless networks can be used to make irrigation practices more efficient. Substrate water content readings can be used to determine when irrigation is needed. By adjusting the irrigation time, and determining how much the substrate water content increases after irrigation will allow for the determination of how much water needs to be applied during an irrigation event. A rapid decrease in substrate water content is indicative of leaching.

The currently available hardware is able to monitor substrate water content, and can help growers make decisions regarding irrigation. Planned improvements in the hardware include the incorporation of a relay, which would allow these dataloggers to open and close irrigation valves, based on grower-defined conditions. We also expect that sensors that can measure both substrate water content and electrical conductivity will soon be available. Such sensors will help to further integrate irrigation and fertilization. Measurements of electrical conductivity could be used to determine whether leaching is needed or whether additional fertilizer applications may need to be made.

### **Objective 2: Growth of *Hibiscus acetocellus* 'Panama Red' as a function of soil volumetric water content.**

The soil moisture sensor-controlled irrigation system was able to maintain soil moisture levels close to the specified set points, with set points being reached before the tenth day (Fig. 5). A strong correlation ( $r = 0.81$ ,  $p < 0.0001$ ) between ThetaProbe measurements and substrate water content set points confirmed differences in substrate water content among the treatments (Fig. 6). Plant growth, represented by shoot dry weight, was affected by water availability. This is demonstrated by the correlations between dry weight and substrate water content (Fig. 7) ( $r = 0.83$ ,  $p < 0.001$ ) as well as dry weight and total irrigation volume (Fig. 8) ( $R^2 = 0.84$ ,  $p = 0.001$ ). Total irrigation volume increased with increases in substrate water content set points ( $r = 0.82$ ,  $p < 0.001$ ) (Fig. 9).

Analysis of shoot dry weight as a function of total volume of irrigation water applied shows volume distinct non-linear response (Fig. 8). A sharp increase in growth can be observed as the irrigation volume increases from 2 to 14 L/plant, but little effect on growth is seen amongst plants receiving 22.5 L of water or more. These observations agree with van Iersel et al. (2009) and suggest that

plant growth is dependent on the amount of water applied up to a threshold, after which additional water supplied no longer significantly increases growth. This shows that plants of similar size can be obtained with differing substrate water contents, and therefore reduced irrigation volume. Our results suggest that growers using an automated irrigation system would be able to reduce total irrigation volume by approximately 20 L/plant by using a set point of  $0.35 \text{ L}\cdot\text{L}^{-1}$  instead of  $0.45 \text{ L}\cdot\text{L}^{-1}$ , while still obtaining similar size plants. Although our results are from plants grown in a controlled greenhouse setting, they suggest it is possible to achieve similar results in a nursery setting in which plants are exposed to varying environmental conditions, and our results from studies in outdoor nurseries confirm this (unpublished results).

### Objective 3. Calculating Daily Water Use of *Hydrangea macrophylla* in a Production Nursery Environment

Average DWU of both cultivars showed a gradual increase over time from 50 to 300 mL/day (Fig. 10), likely as the result of increasing plant size. There was a 12% difference in average DWU between 'Fasan' (231 mL/day) versus 'Pia' (207 mL/day). Overall, the plants only used 2.5 - 15% of the approximately 2 L of water present in the growing mix at container capacity per day, indicating that water use was never limited by water availability in the growing mix. In total, individual plants only used 17-19 L of water over the course of the 84 day experiment.

On the 48<sup>th</sup> day of the study, shade cloth was pulled over the greenhouse structure. This resulted in an immediate and sustained decrease in DWU of both cultivars (Fig. 10). DLI was the only environmental factor significantly decreased by the application of the shade cloth, while temperature and VPD remained similar (Fig. 11). There was a clear effect of DLI on DWU; on days with low light levels, DWU was low as well (e.g., day 3, 61, and 73). Surprisingly, there was no correlation between DLI and DWU (Table 1), but there were strong correlations between DWU and the interaction of DLI and plant age, as well as the three-way interaction among DLI, plant age, and leaf area. Other factors correlated with DWU include temperature, VPD, and the interaction between leaf area and plant age (Table 1).

For a more in depth analysis of those factors important in determining DWU, multiple regression was used with stepwise selection. Partial  $R^2$  values were used to quantify the effect of various factors on DWU. This regression indicated that 83.2% of day-to-day changes in DWU of 'Fasan' could be explained by the plant age, final leaf area, DLI, and their interactions combined (Table 11, Fig. 12). Although VPD and temperature were statistically significant, they only explained another 6.5% of fluctuations in DWU and were not as biologically important as plant age, leaf area, and DLI. 90.8% of fluctuations in DWU of 'Pia' could be explained by the combination of plant age, final leaf area, DLI, and their interactions (Table 1, Fig. 12), while VPD and temperature only explained an

additional 4.0%. Our finding that DLI is by far the most important environmental variable affecting plant water use is consistent with earlier findings that showed that 79% of fluctuations in daily water use of petunia could be explained based on plant age and DLI (van Iersel et al., 2010).

Our results suggest that by monitoring plant size and DLI, growers can more accurately determine the daily water requirements of hydrangea and irrigate their stock more efficiently, improving both economical and environmental aspects of ornamental plant production. Although other environmental factors, such as temperature and vapor pressure deficit also affect water use, they are much less important than light levels. We have found load cells to be an accurate and inexpensive way for growers to track plant water use to exacting tolerances, and their implementation in ornamental plant production could greatly increase irrigation efficiency.

## Conclusions

The three research objectives reported above demonstrate successful monitoring of real-time soil moisture and environmental data, actual plant water use requirements of two genera and the effects of various environmental conditions on plant daily water use. In objective 1, implementation of a wireless monitoring system afforded Evergreen Nursery the ability to change irrigation practices based on real-time data to make irrigation practices more efficient. Substrate water content readings were used to determine when irrigation was needed. Irrigation practices were changed during the two-week period this study was in place. During the first week, crops were irrigated for 15 minutes on most days. During the second week, crops were irrigated twice daily, 8 minutes each time. This change to cyclic irrigation was implemented to reduce leaching. The gradual increase in substrate water content following the switch to cyclic irrigation suggests that more of the applied irrigation water was retained by the substrate. The currently available hardware is able to monitor substrate water content, and can help growers make decisions regarding irrigation. Planned improvements in the hardware include the incorporation of a relay, which would allow these dataloggers to open and close irrigation valves, based on grower-defined conditions. We also expect that sensors that can measure both substrate water content and electrical conductivity will soon be available. Such sensors will help to further integrate irrigation and fertilization. Measurements of electrical conductivity could be used to determine whether leaching is needed or whether additional fertilizer applications may need to be made.

In field trials utilizing soil moisture probes, the soil moisture sensor-controlled irrigation system was able to maintain soil moisture levels close to specified set points. *Hibiscus acetocellus* 'Panama Red' plant growth, represented by shoot dry weight, was affected by water availability. This is demonstrated by the



correlations between dry weight and substrate water content as well as dry weight and total irrigation volume. A sharp increase in growth can be observed as the irrigation volume increases from 2 to 14 L/plant, but little effect on growth is seen amongst plants receiving 22.5 L of water or more. This shows that plants of similar size can be obtained with differing substrate water contents. Our results suggest that growers using an automated irrigation system would be able to reduce total irrigation volume by approximately 20 L/plant by using a set point of 0.35 L·L<sup>-1</sup> instead of 0.45 L·L<sup>-1</sup>, while still obtaining similar size plants.

In another genera/species, *Hydrangea macrophylla*, average daily water use of both cultivars showed a gradual increase over time, likely the result of increasing plant size. Overall, the plants only used 2.5 - 15% of the approximately 2 L of water present in the growing mix at container capacity per day, indicating that water use was never limited by water availability in the growing mix. When correlating environmental factors with daily water use, daily light integral was the only environmental factor significantly decreased by the application of shade cloth, while temperature and VPD remained similar. There was a clear effect of daily light integral and plant size on daily water use. These results suggest that by monitoring plant size and DLI, growers can more accurately determine the daily water requirements of hibiscus and hydrangea and irrigate their stock more efficiently, improving both economical and environmental aspects of ornamental plant production.

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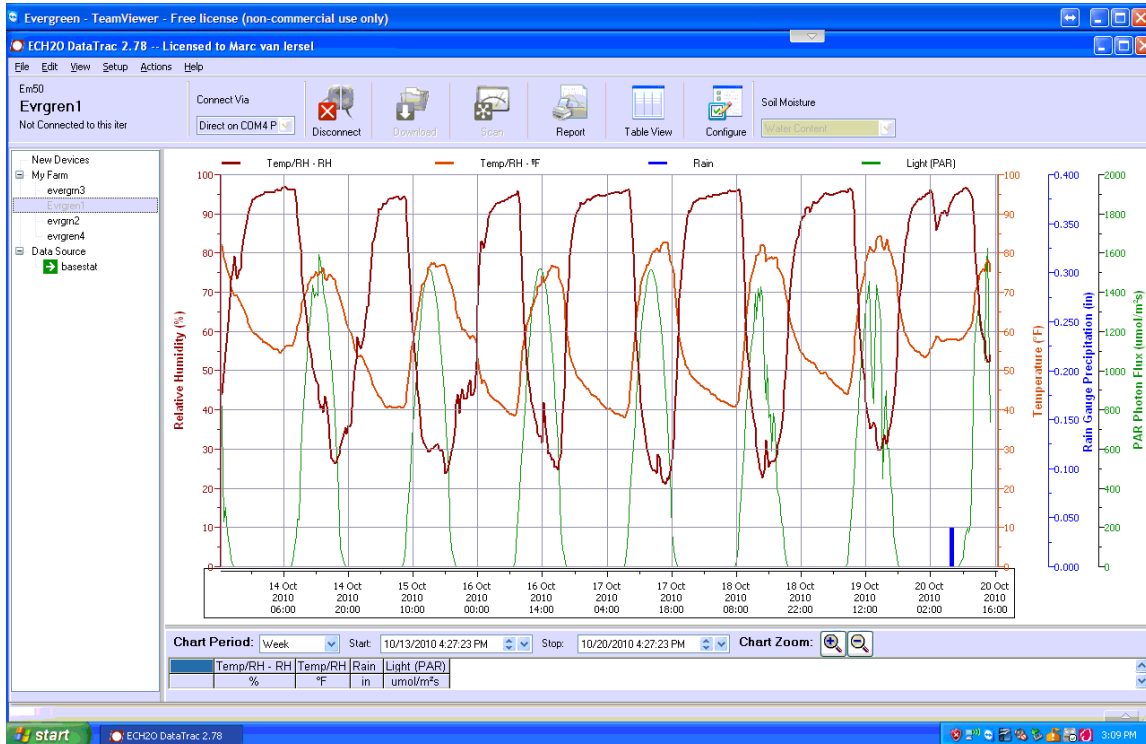


Figure 1. Screenshot of the DataTrac graphic user interface showing environmental conditions in a nursery during a one week period. Data include temperature, light intensity, relative humidity, and rainfall.



Figure 2. Screenshot showing the DataTrac graphic user interface. The four lines show substrate water content of two containerized lantana (green and black, plants in #2 containers)) and two gaillardia plants (purple and blue, #1 containers). Pink bars indicate rainfall or irrigation events. Irrigation was changed from once daily to twice daily on October 14.

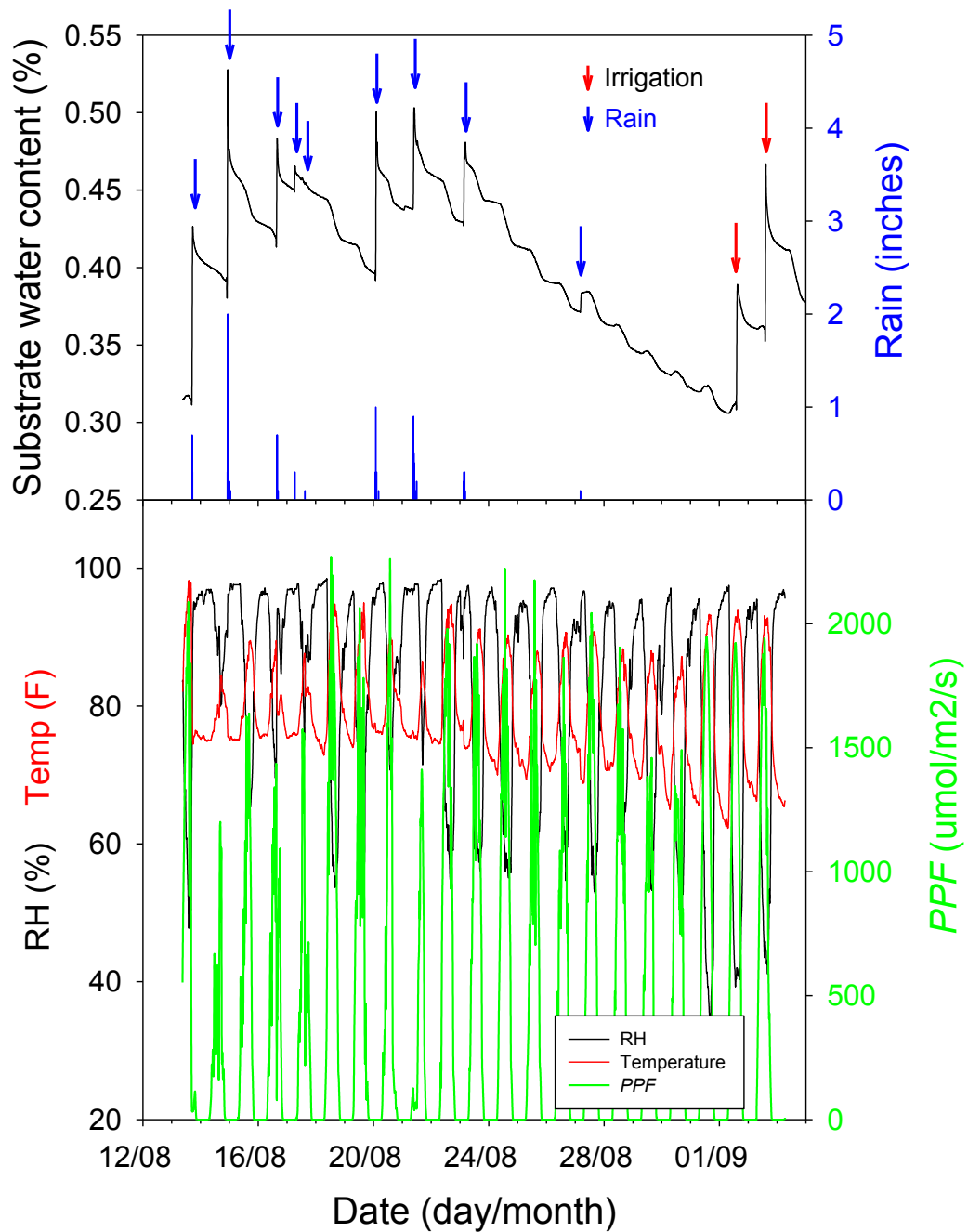


Figure 3. Substrate water content of a *Hellebores* crop (top, average of four sensors) and environmental conditions (rain, top and RH, temperature and photosynthetic photon flux, bottom) in a commercial nursery. Plants were grown in #1 containers.

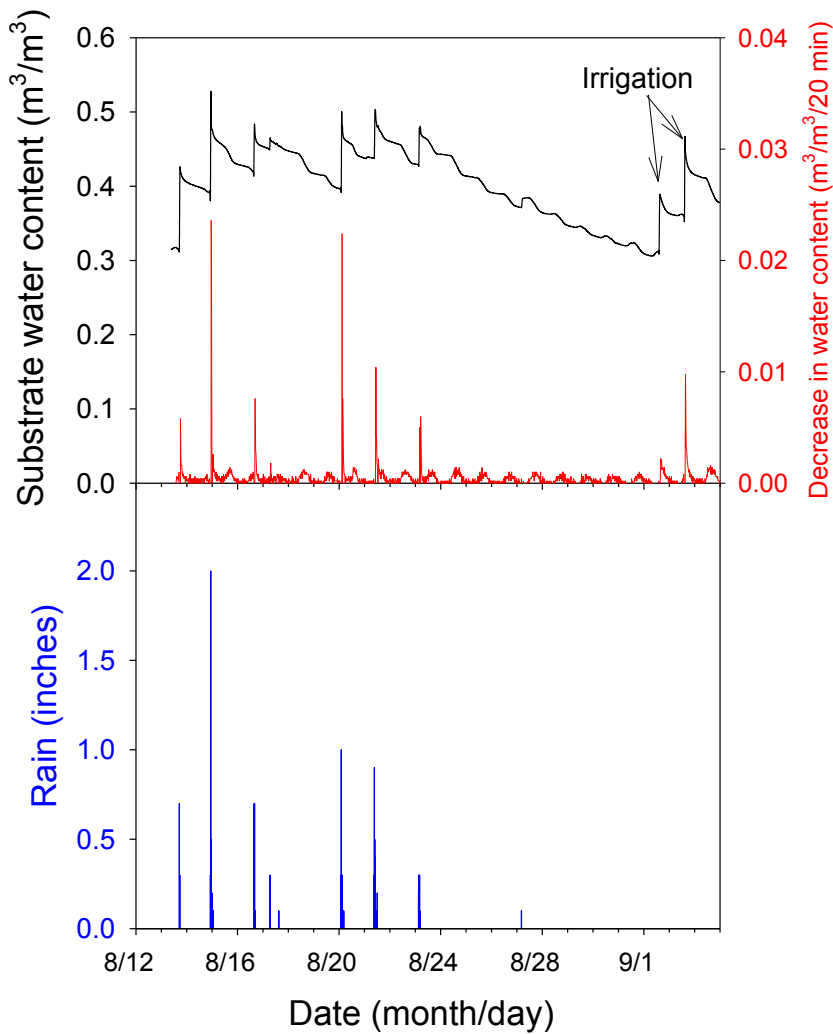


Figure 4. Substrate water content of a hellebores crop (top, black line) and the change in substrate water content in a 20 minute period (top (red line)). Note that there is a rapid decrease in substrate water content following each significant rainfall event (blue bars, bottom). This is indicative of leaching. Plants were grown in #1 containers.

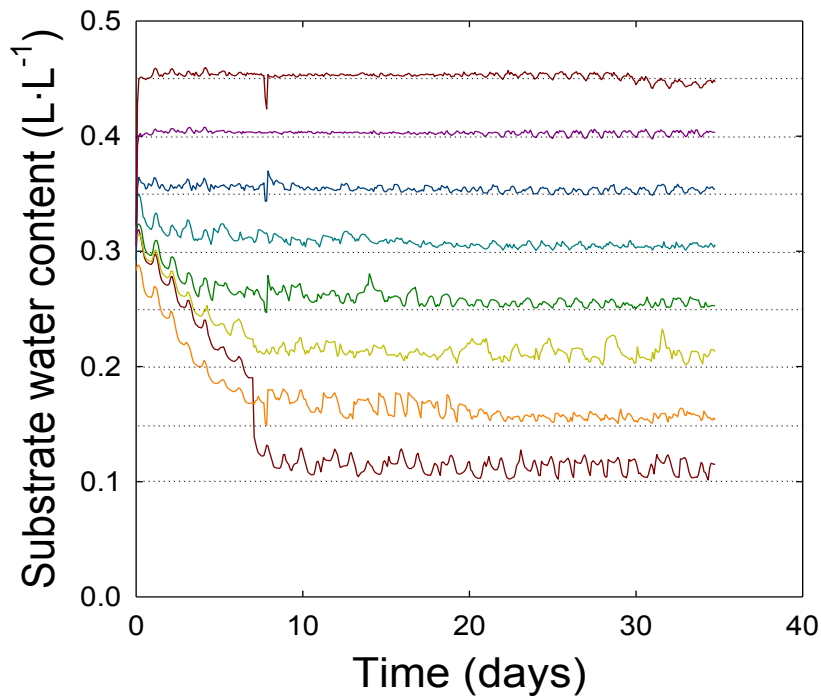


Figure 5. Substrate water content over the length of the experiment. Dashed lines indicate set points for irrigation.

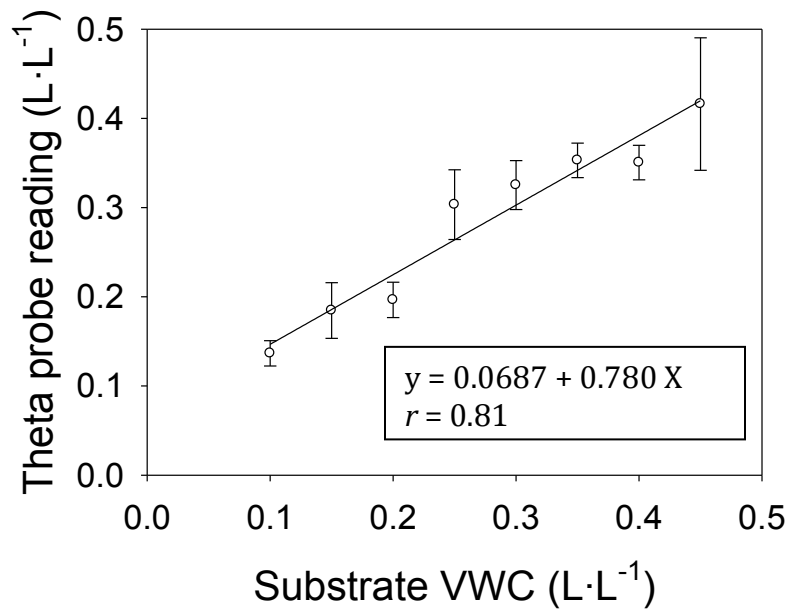


Figure 6. Theta Probe readings of substrate moisture content versus substrate water content set points of the automated irrigation system. Symbols represent means with standard errors for each treatment ( $n=4$ ).

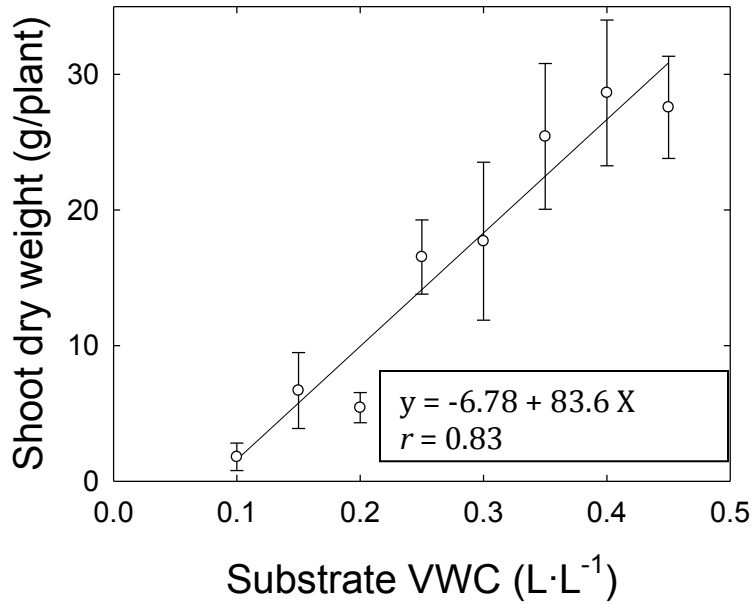


Figure 7. Shoot dry weight of hibiscus ‘Panama Red’ as affected by substrate water content set point at which the plants were irrigated. Symbols represent means with standard errors for each treatment (n=4).

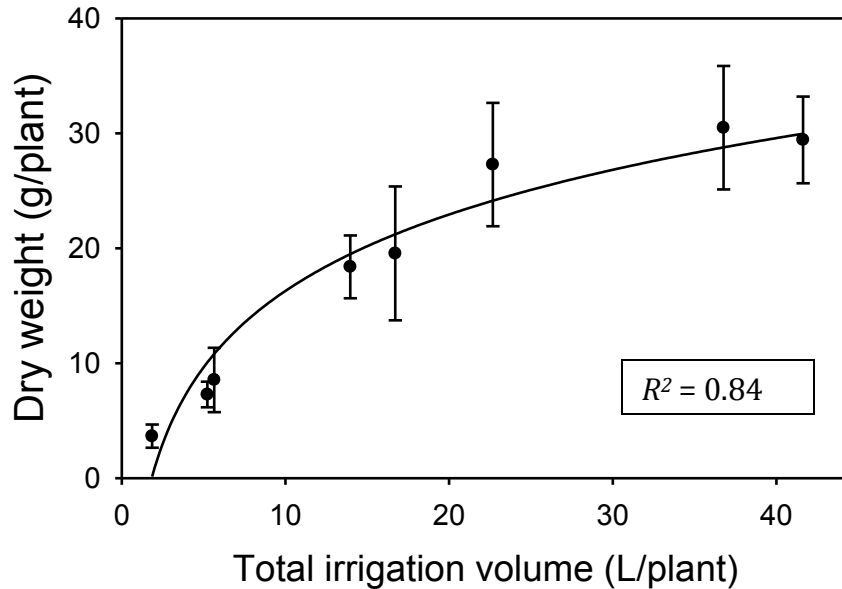


Figure 8. Shoot dry weight of hibiscus ‘Panama Red’ as a function of the total amount of water the plants received during the experiment. Symbols represent means with standard errors for each treatment (n=4).

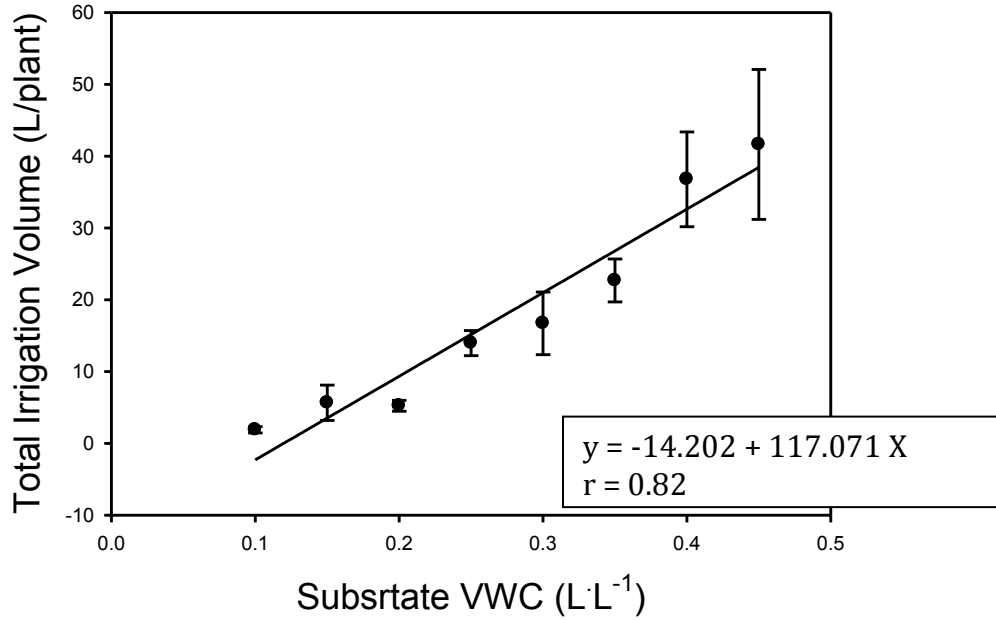


Figure 9. Total irrigation volume as affected by substrate water content set point at which the plants were irrigated. Symbols represent means with standard errors for each treatment (n=4).



Table 1. The relationship between daily water use and various parameters used to explain day to day changes in water use of two hydrangea cultivars as indicated by Pearson's correlation coefficients (*r*) and significance (*P*). DLI = daily light integral, VPD = vapor pressure deficit.

Cultivar	---- 'Fasan' ----		----- 'Pia' -----	
	<i>r</i>	<i>P</i>	<i>r</i>	<i>P</i>
Day	0.646	<.0001	0.581	<.0001
DLI	0.064	0.3186	0.077	0.2338
Temperature	0.806	<.0001	0.719	<.0001
VPD	0.750	<.0001	0.690	<.0001
Leaf area	-0.169	0.0085	0.413	<.0001
Day * DLI	0.885	<.0001	0.804	<.0001
Day * leaf area	0.582	<.0001	0.721	<.0001
DLI * leaf area	0.012	0.8526	0.234	0.0002
DLI * leaf area * day	0.812	<.0001	0.923	<.0001

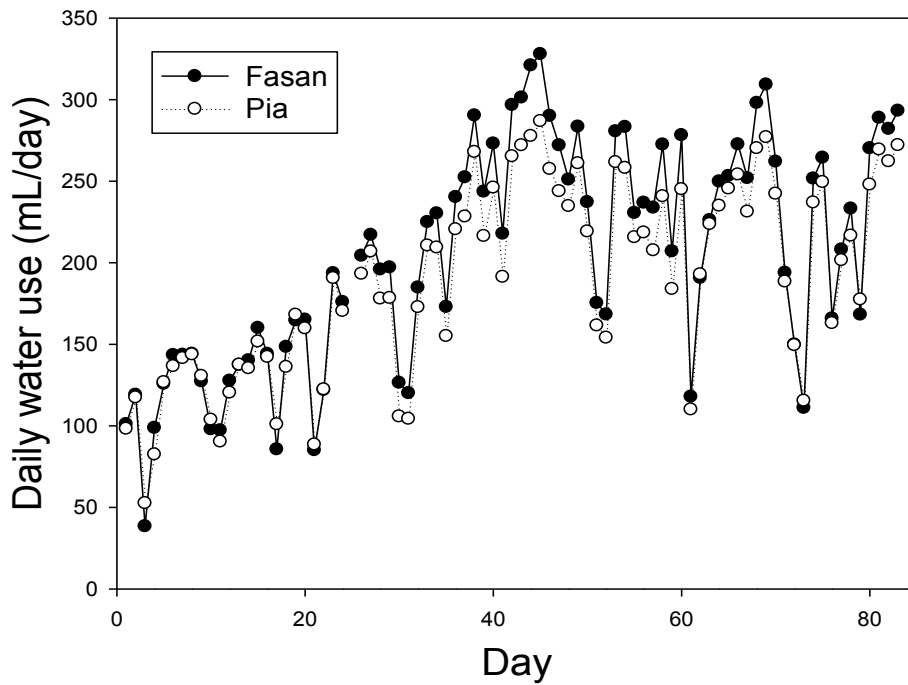


Fig. 10. Daily water use of *Hydrangea macrophylla* cultivars 'Fasan' and 'Pia' from May 01, 2010 to July 21, 2010 in Dearing, GA. Data points are the mean of three plants.

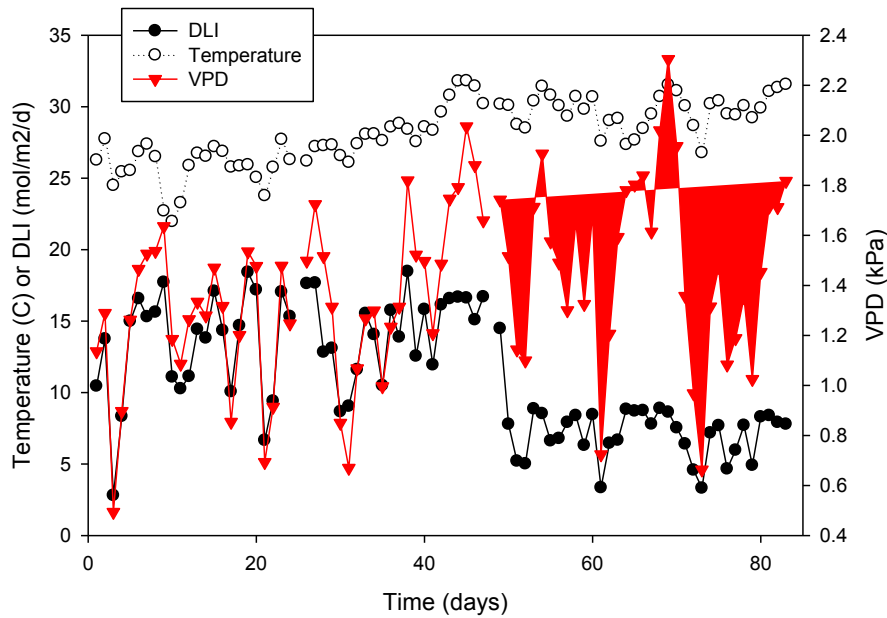


Fig. 11. Daily light integral (DLI), temperature, and vapor pressure deficit (VPD) from May 1, 2010 to July 21, 2010 in Dearing, GA.

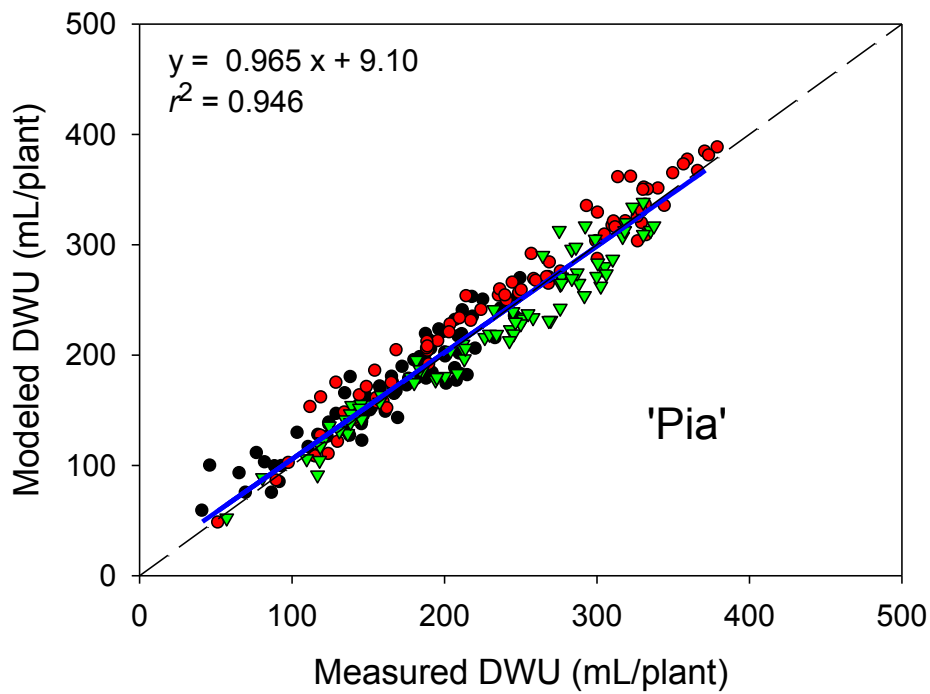
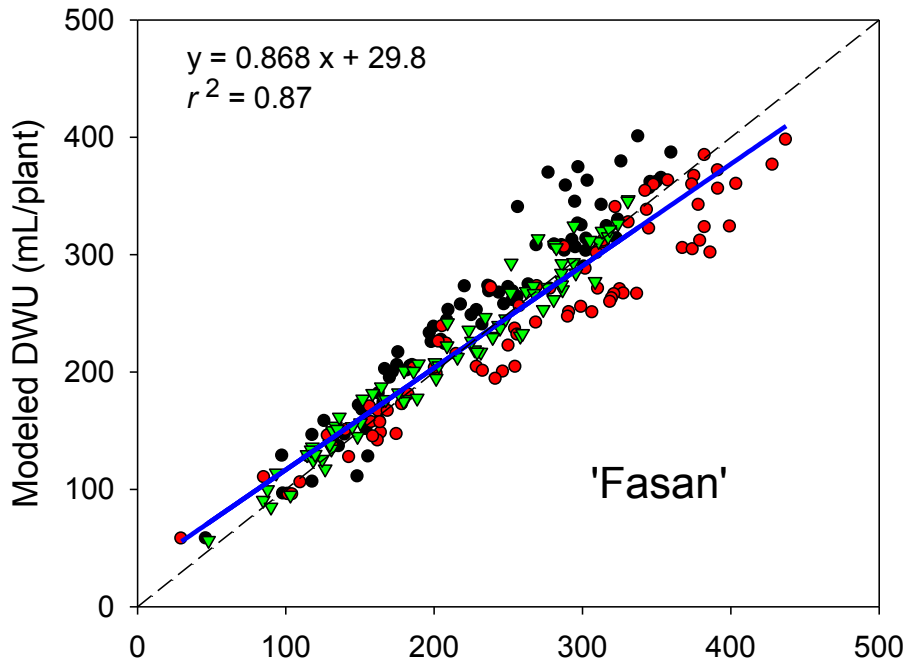


Fig. 12. Measured daily water use (DWU) values versus modeled DWU of *Hydrangea macrophylla* 'Fasan' (top) and 'Pia' (bottom). Different symbols represent different plants. Blue lines indicate regression lines