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DETERMINATION OF IRRIGATION REQUIREMENTS AND CROP COEFFICIENTS USING WEIGHING LYSIMETERS IN PERENNIAL PLANTS

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Abstract

The increasing role of perennials in ornamental nurseries requires the elaboration of efficient and accurate irrigation control of this specific group of plants. The experiment was conducted in 2015 in Research Institute of Horticulture, in Skierniewice. The aim of the study was to determine the water requirements and designate the specific evapotranspiration crop coefficient K_c of several perennials, commonly grown in Polish ornamental nurseries. Water requirements of perennials were evaluated using weighing lysimeters. At the same time the recorded climate parameters allowed to calculate the potential evapotranspiration (ET_0). Lysimeter measurements and meteorological data allowed determine specific to each species crop coefficient (K_c). The K_c values were determined by dividing ET_c by ET_0. The obtained results showed that irrespectively of plant growth phase there is strong correlation between climate parameters and real crop evapotranspiration (ET_c) of six evaluated perennials: *Anemone hupehensis* ‚Prinz Heinrich', *Echinacea purpurea* 'Guava Ice', *Hemerocallis*, 'Sandra Elisabeth', *Salvia nemorosa* 'Mainacht' and *Veronica spicata* 'Royal Candles Glory'. The K_c coefficients of all species were changed during the growth season and increased according to plant development and percentage of ground coverage of soil in the lysimeter by leaves. The strong, positive correlation was shown for daily and hourly calculated crop evapotranspiration and potential evapotranspiration (ET_0) obtained from weather station.

Determination of crop coefficients for ornamental perennials is essential for precise calculation of water doses and irrigation controlling in the nurseries.

Keywords: ornamental nurseries, evapotranspiration, crop coefficient K_c, weighing lysimeter, automatic irrigation systems

INTRODUCTION

The area of ornamental nurseries in Poland has been developing rapidly for the past several years (Marosz 2013a). Mainly the woody plants (conifers, rhododendron, broadleaf plants) are grown in the nurseries, however the importance of perennials are increasing year by year. Nursery plants are usually grown in small containers (0.5 to 5 litres in volume) they are usually irrigated using sprinklers, while plants grown in bigger containers are watered using drippers (Burger et al. 1987, Fare et al. 1994, Grant et al. 2009, Ponder et al. 1984). Overhead irrigation is the most common method of plant watering for container production of ornamentals (Mathers et al. 2005, Radwan et al. 2010). However, perennial plants are characterized by different plant shape, speed of growth, leaf area, flowering period and thus they differ also in water requirements. Drip irrigation, commonly used for woody ornamentals cannot be applied in perennial cultivation due to rather small size of containers and dense spacing. The survey study concerned irrigation, conducted in Polish nurseries showed that the most common irrigation method is overhead irrigation (Marosz 2013b), however most of the growers do not apply any reasonable criteria for estimating plant water requirements. Ornamental perennials are rather more sensitive to excessive watering than woody plants grown in nurseries. Due to the diverse water needs of plants in nurseries, many plants during the spraying process are excessively irrigated, resulting in loss of water and fertilizer and can impose water stress (Grant et al. 2009, Incrocci et al. 2014, Schuch and Burger, 1997, Warsaw et al. 2009). Water needs of plants can be estimated based on climate parameters, recorded by weather stations, measuring soil potential or soil moisture and plant criteria (Allen et al. 1998, Beeson 2006, Incrocci et al. 2014, Lazzara and Rana 2010, Lea-Cox et al. 2004, Ley et al. 1994, Pardossi 2014, Snyder et al. 1987, Treder et al. 2010). In addition, to ensure the correct water doses to the plant in nurseries the economic and environmental aspects are also important. Incrocci et al. (2014) compared, watering of 4 common species of plant nursery: *Forsythia*, *Photinia*, *Prunus* and *Viburnum*, according to the soil criteria (tensiometers or dielectric sensors) and climate parameters (evapotranspiration) obtained lower water consumption by 21% and 40% and saving fertilizer by 39% and 79% respectively, in relation to the standard control using the controllers time. Lea-Cox and Belayneh (2014) using soil sensor controlling irrigation in *Cornus flor-*

ida and *Acer rubrum* obtained nearly three-fold increase in water use efficiency without reducing growth and quality. Capacitance sensors used for controlling irrigation of *Gaura lindheimeri* and *Phlox paniculata* resulted in higher water use efficiency and significant reduction of leachate from containers (Burnett and Iersel 2008). Controlling irrigation of nursery plants, based on soil probes to measure soil moisture is difficult due to the wide range of plant species and types of substrates as well as the size of the containers, causing large fluctuations in readings (Klamkowski and Treder 2008).

The most important climatic factors influenced evapotranspiration are air temperature, solar radiation, relative humidity and wind speed. The parameter fully reflected climatic factors, defined as reference evapotranspiration (ET_0), can be calculated by many mathematical models (the most common is Penman-Monteitch equation) using the data from weather stations, describe the potential possibility of water evapotranspiration from grass area of specified plant height (8-15 cm tall) and grown at full water availability (Allen et al. 1998, Schuch and Burger 1997). The real crop evapotranspiration (ET_c) determined using weighing lysimeters and divided by ET_0 is defined as crop coefficient ($K_c = ET_c/ET_0$). A weighing lysimeter has a form of impermeable box filled with soil with plants, placed on a balance. The water layer under the soil in lysimeter is connected with "wick" with soil and allowed to free water availability to plants and soil. According to evapotranspiration process affected by climate parameters and plant growth phase water content is controlled by a balance records, and is periodically supplemented. For many agronomic and orchard crops the K_c factors are already determined and published in Food and Agricultural Organization (FAO) reports (Allen at al. 1998). The K_c factor is fluctuated during the growth season and crop vegetation phase according to plant shape and growth phase. Studies on the control of irrigation of nursery plants, based on the K_c factors are rather few and mainly related to woody plants and conifers (Burger et al. 1987, Grant et al. 2009, Incrocci et al. 2014, Irmak 2005, Niu et al. 2006, Schuch and Burger 1997). Obtained results showed that for some plants, grown in containers, the K_c values are relatively high (ranging from <1 to >5) and they can significantly exceed the K_c values determined for agricultural crops. Schuch and Burger (1997) found that water-use and crop coefficients of woody plants in containers varied considerably among species, location, and time of year. Irrigation control based on evapotranspiration models can be also used for landscape ornamentals (Kjelgren et al. 2016, Radwan et al. 2010, Shaw and Pittenger 2004, Yuan et al. 2009). Currently, the automatic irrigation systems, which allows for precise adjustment of the frequency and volume of irrigation doses to the needs of the plants, are rarely used in nurseries (Chappell et al. 2013). This is due both to the lack of objective criteria for irrigation, and the lack of appropriate controlling systems.

The main objective of this work was to calculate evapotranspiration (ET_c) using weighing lysimeters and determine the crop coefficient (K*c*) for six ornamental perennials commonly grown in nurseries.

MATERIAL AND METHODS

The study was conducted at the Institute of Horticulture, Skierniewice, during the growing season (May – October) 2015, within the IRRINURS project. Water requirements of six ornamental perennials were evaluated using weighing lysimeters. Each lysimeter (area of 1 m^2) was filled with growing medium (peat and sand 20:1 v/v). Growing plants in a lysimeter weight enables continuous recording of fluctuations in plant mass and substrate due to evapotranspiration. Chosen young perennial plants: japanese anemone (*Anemone huphensis*) ‚Prinz Heinrich', daylily (*Hemerocallis*) ‚Sandra Elisabeth', eastern purple coneflower (*Echinacea purpurea*) ‚Guava Ice', max chrysanthemum (*Leucanthemum maximum*) 'Snow Lady', silver speedwell (*Veronica spi*cata) ‚Royal Candles' and woodland sage (*Salvia nemorosa*) 'Mainacht' were planted with pots (with holes on the bottom) into the lysimeters. The early flowered perennials (*Hemerocallis*, *Echinacea* and *Veronica*) were grown from May to mid-July and late flowered (*Anemone*, *Leucanthemum*, *Salvia*) from mid-July until end of September. There were 25 plants in each lysimeter). For each pot with plants the slow release fertilizer Osmocote 8-9 M (15:9:11) was added in an amount of 2 g dm^{-3}. Around each lysimeter with perennials the pots of the same species were placed to eliminate boundary effects and those plants were watered by drippers. The lysimeters were irrigated by capillary action, providing plants with an unrestricted access to water. The water in the reservoir was refilled periodically, every few days, depending on the amount of evapotranspiration (ET_c). Fluctuations in weight lysimeters with plants placed on the scales (Radwag, Poland) were recorded automatically The water content in growing media in each treatment was monitored also using capacitance probes ECH_2O-10 (Decagon Devices, USA). The climate parameters were recorded using agro-meteorological station iMetos (Pessl Instruments, Austria) equipped with the necessary sensors to record data required for calculating ET_0: air temperature, relative humidity, solar radiation, and wind velocity. The percentage of soil shading by plants cultivated in the lysimeters was calculated using image analysis. Plants were grown up to flowering and reaching the saleable size and then the final biometric measurements were performed. Determination of the water requirements of the species (*ETc*), tested using lysimeters and the results of the ET_0 generated from the weather station allowed to calculate the crop specific parameter K_c for rested perennials. Final biometric measurements were performed after the plants from achieving commercial value, ie. the time of the full flowering of each species.

RESULTS AND DISCUSSION

The climate conditions during the lysimeter experiments are characterized by a relatively high average daily temperature and intensive solar radiation. Temperature, radiation and wind velocity are the basic parameters taken into account models for calculating Et_0 (Snyder et al. 1987, Stanghellini et al. 1990, Treder et al. 2010). The detailed data concerning climate condition (temperature, rainfall intensity and solar radiation) during the experiment were presented in earlier paper of Treder and Treder (2016). Grown perennials differed in terms of growth, flowering period leaf surface and thus these features can influence also their water requirements (Tab. 1). The tallest plant with the highest leaf area was *Hemerocallis*, followed by *Echinacea* and then *Anemone*. These plants were characterized also by the highest growth index. Plant growth, development and appearance during the main three growth phases: beginning of cultivation in lysimeters, at vegetative growth and at full flowering are presented on photos. The early flowering perennials such as *Hemerocallis*, *Echinacea* and *Veronica* were presented at Fig. 1 and late flowering as *Anemone*, *Chrysanthemum* and *Salvia* on Fig. 2. The weighting lysimeters used in experiment allowed precisely determine actual water requirements during the growth season. As an example the changes in the lysimeter weight with *Hemerocallis*, *Echinacea* and *Veronica* and cumulative daily decrease of lysimeter weight for 12 May 2015 are presented on Fig.3. For such day the highest cumulative daily decrease in lysimeter weight was obtained for *Echinacea*, almost 5 kg and around 3.4 and 3.5 kg for *Hemerocallis* and *Veronica*. Cáceres et al. (2007) had also observed that weighing lysimeters are very useful for determining plant water requirement, especially for summer grown plants with high water demand (ET_0 3.5 – 5 l / m^2). Weight control system for irrigation which averages the measurement of a few or several plants can be very useful, especially in nurseries cultivating plants in a small volume.

Table 1. Biometric plant growth parameters at the final evaluation time

Plant name	Total fresh weight of plant, aerial part and roots [g]	Plant height [cm]	Plant diameter [cm]	Growth index*	Leaf area [cm^3]
Hemerocallis	563	83	48	65,5	1980
Veronica	111	32	23	27,5	-
Echinacea	262	75	22	48,5	1481
Anemone	259	62	36	49,5	1262
Leucanthemum	277	22	25	23,5	748
Salvia	109	43	27	35,0	541

*Growth index = (plant height + plant diameter) /2

Figure 1. The early flowering perennials, from left to right *Hemerocallis*, *Echinacea* and *Veronica*, respectively, grown in lysimeters at three growth phases. Upper row: beginning of cultivation (11 May), middle row: vegetative phase (9 Jun), bottom row: full flowering and final evaluation phase (6 Jul for *Echinacea* and *Veronica* and 27 Jul for *Hemerocallis*

The daily decrease in weight of lysimeter with *Hemerocallis* obtained for 12 May was then compared with reference evapotranspiration ET_0, calculated hourly (Fig.4). The values of daily reference evapotranspiration (ET_0), calculated using the Penman-Monteith (PM) model and daily evapotranspiration (ET_c) of *Hemerocallis*, *Echinacea* and *Veronica,* determined using weighing lysimeters are presented on Fig.5. The values of ET_c of *Echinacea* exceeded the calculated values of ET_0 for such specified day. High correlation between lysimetric measurements of ET_c of tested perennials and calculated hourly values of ET_0 was shown for 12 May, 11 Jun and 5 Jun, on Fig. 6, Fig.7 and Fig. 8, respectively. The determination coefficients (R^2) for the equations were usually higher than 0.90. However, correlation between daily crop evapotranspiration (ET_c) of *Hemerocallis*, *Echinacea*, *Veronica* and reference evapotranspiration (ET_0) obtained using Penman-Monteith model, during growth season was not so strong and the determination coefficient R^2 for *Hemerocallis*, *Echinacea* and *Veronica* were 0.62, 0.65, and 0.68 respectively (Fig. 9).

Figure 2. The late flowering perennials, from left to right *Anemone, Leucanthemum* and *Salvia*, respectively, grown in lysimeters at three growth phases. Upper row: beginning of cultivation (27 Jul for *Leucanthemum* and *Salvia*, 17 Aug for *Anemone*), middle row: vegetative phase (17 Aug for *Leucanthemum* and *Salvia,* 8 Sept for *Anemone*, bottom row: full flowering and final evaluation phase (21 Sept for *Salvia* and 28 Sept for *Anemone* and *Leucancthemum*)

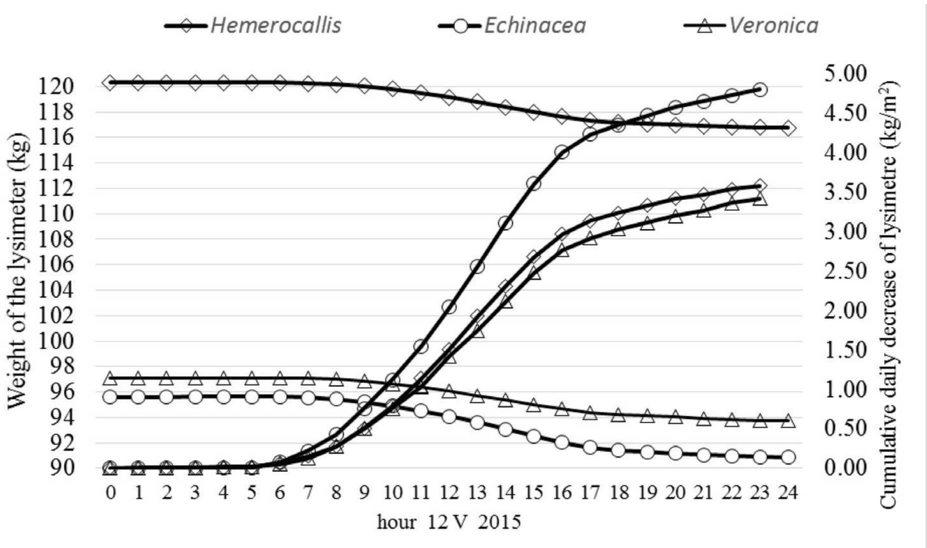

Figure 3. Changes in the lysimeter weight with plants (*Hemerocallis*, *Echinacea*, *Veronica*) and cumulative daily decrease of lysimeter weight for 12 May 2015

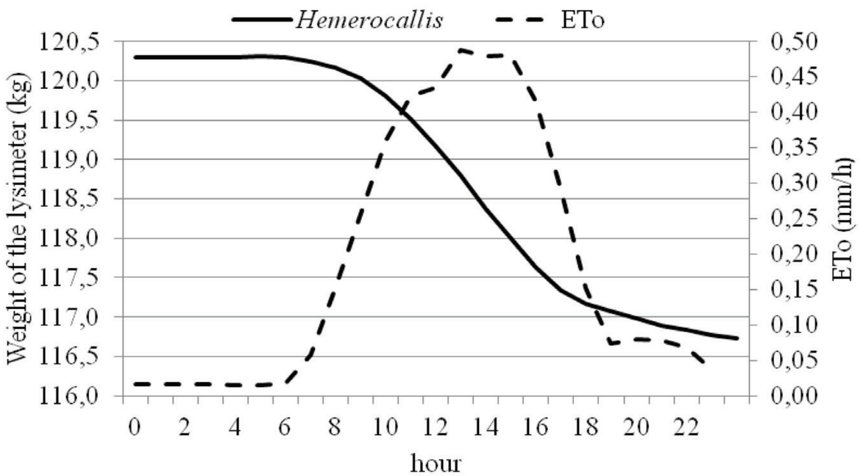

Figure 4. Changes in the lysimeter weight with *Hemerocallis* and reference evapotranspiration calculated hourly (ET_o) for 12 May 2015

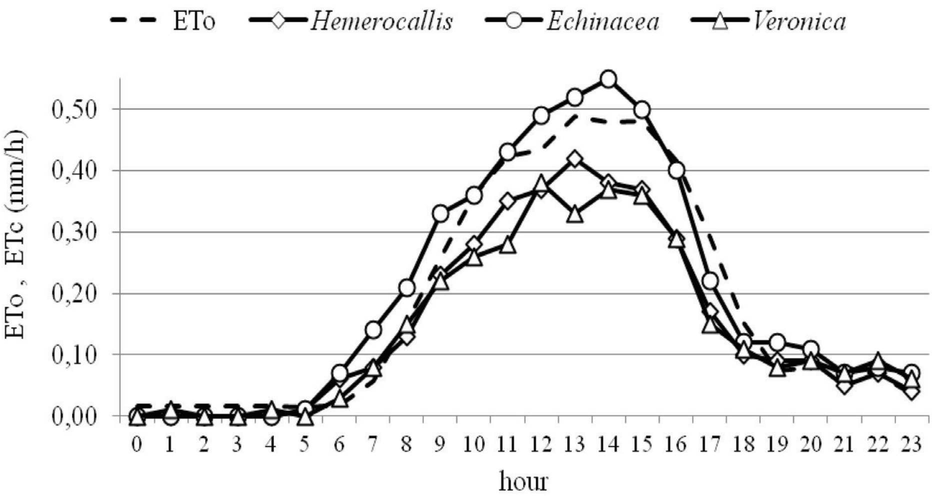

Figure 5. The values of daily reference evapotranspiration (ET_0) calculated using the Penman-Monteith (PM) model and daily evapotranspiration (ET_c) of *Hemerocallis*, *Echinacea* and *Veronica,* determined using weighing lysimeters

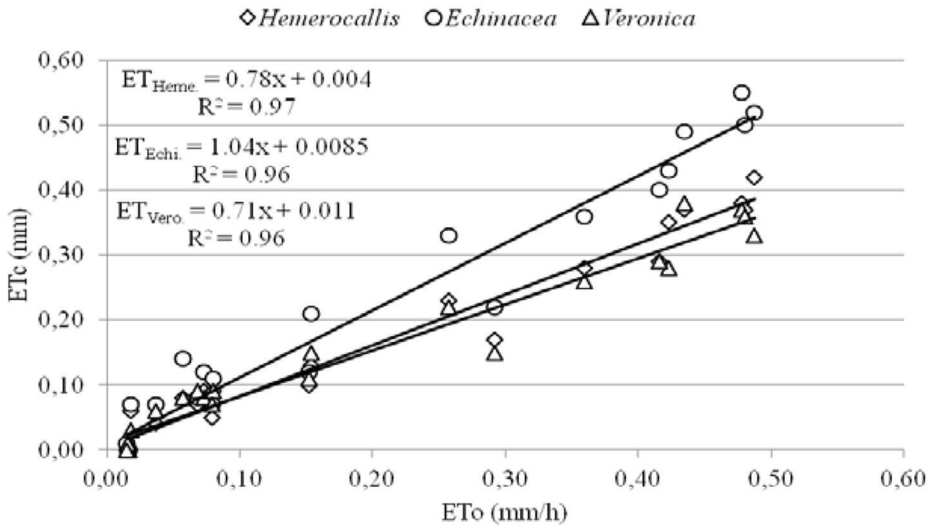

Figure 6. Correlation between crop evapotranspiration (ETc) of *Hemerocallis*, *Echinacea*, *Veronica* and reference evapotranspiration (ET_0) determined for 12 May 2015

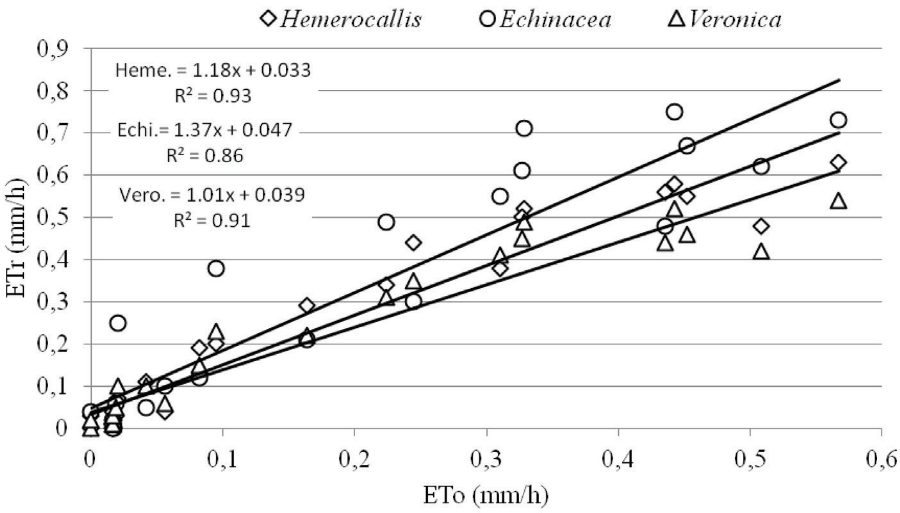

Figure 7. Correlation between crop evapotranspiration (ET_r) of *Hemerocallis*, *Echinacea*, *Veronica* and reference evapotranspiration ET_0) determined for 11 June 2015

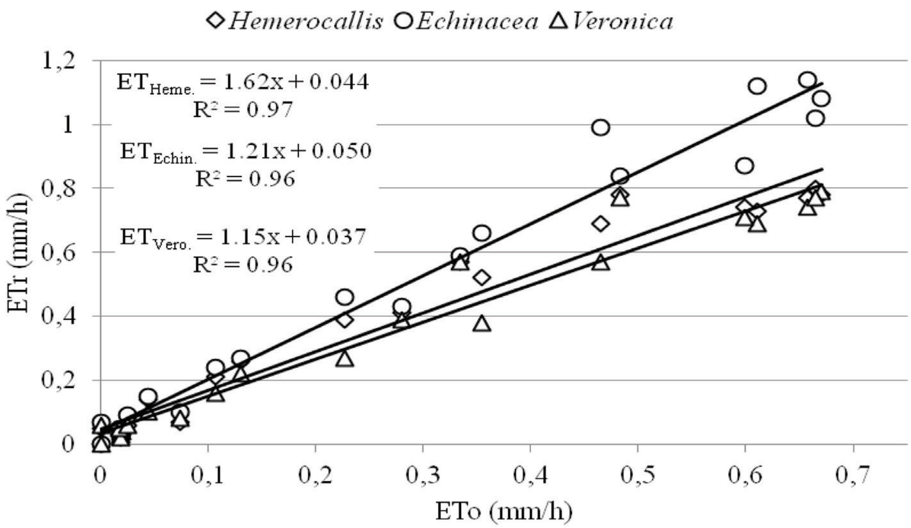

Figure 8. Correlation between hourly crop evapotranspiration (ET_r) of *Hemerocallis*, *Echinacea*, *Veronica* and reference evapotranspiration ET_0) determined for 5 July 2015

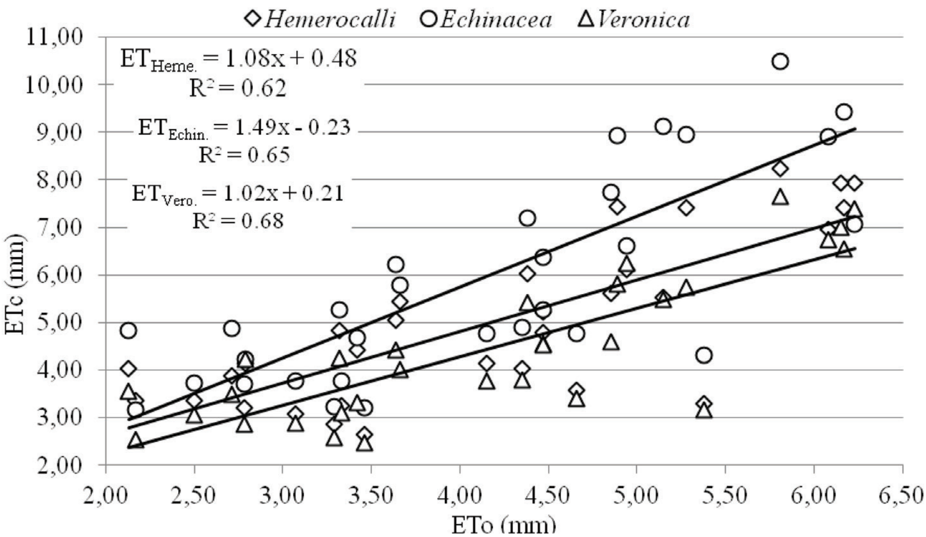

Figure 9. Correlation between daily crop evapotranspiration (ETc) of *Hemerocallis*, *Echinacea*, *Veronica* and reference evapotranspiration (ET_0) obtained during growth season

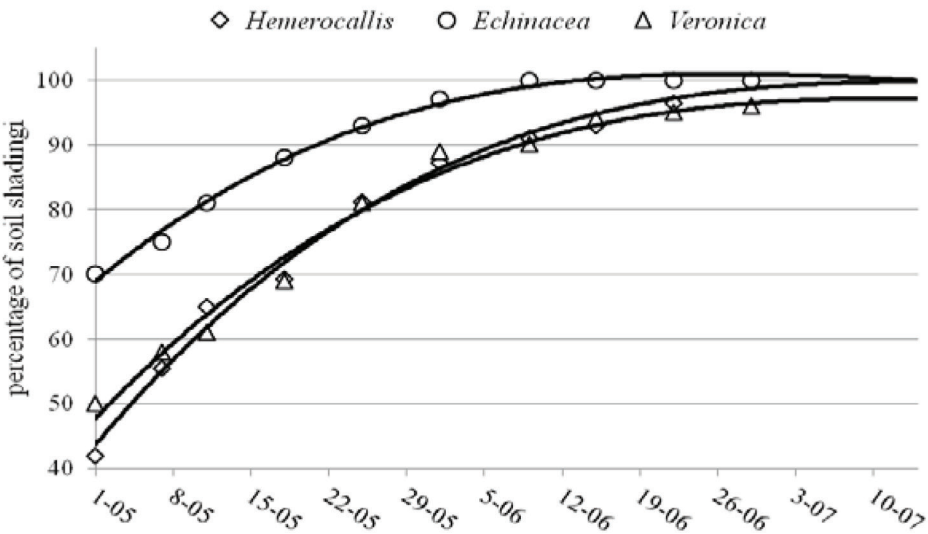

Figure 10. Percentage of soil shading by plants cultivated in the lysimeters (%) during the growth season for *Hemerocallis*, *Echinacea*, *Veronica*

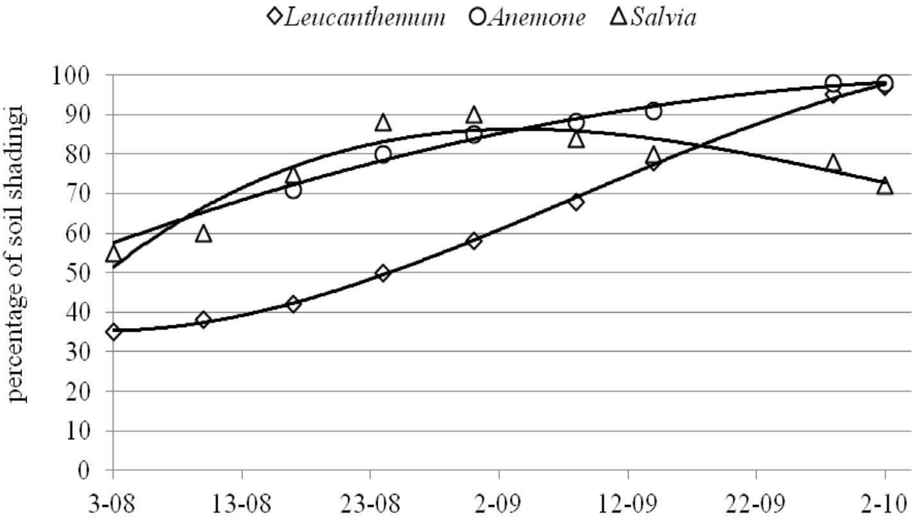

Figure 11. Percentage of soil shading (%) by plants cultivated in the lysimeters during the growth season for *Leucanthemum*, *Anemone* and *Salvia*

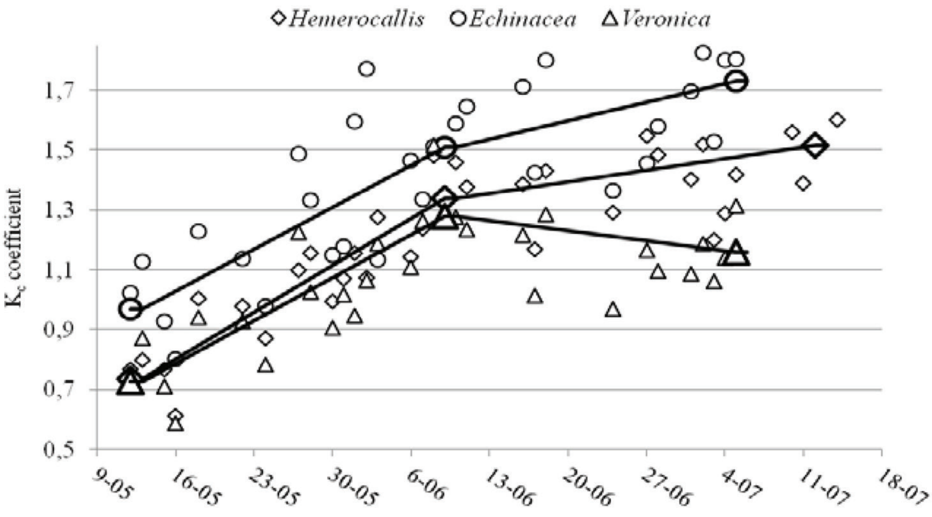

Figure 12. The K_c coefficient determined using weighing lysimeters for *Hemerocallis*, *Echinacea*, *Veronica* during the growth season

Percentage of soil shading (%) by plants cultivated in the lysimeters during the growth season for *Hemerocallis*, *Echinacea* and *Veronica* was shown on Fig.

10 and for *Leucanthemum*, *Anemone* and *Salvia* on Fig.11. Summer flowering perennials as *Hemerocallis*, *Echinacea* and *Veronica* almost completely covered soil in the lysimeters. Autumn flowering perennials had lower leaf area, especially *Salvia*, and thus the percentage of soil shading for this plant was lower. According to expectation K_c coefficients increased during the growth season and tall perennials, with higher leaf area as *Echinacea* and *Hemerocallis* had higher and K_c coefficients (Fig. 12) than low perennials like *Leucanthemum* and *Salvia* (Fig. 13). The values of these coefficients have changed with plant growth and entering to the next growth phase. At the end of flowering time the K_c of *Veronica* and *Salvia* were lower than during the full vegetative phase. According to those results the irrigation control programs should consider that water requirements are decreasing at the end of flowering time. These findings are consistent with the data published by Garcia-Navarro et al (2004), Niu et al. (2006), Radwan et al. (2010) Shaw and Pittenger (2004), and Yuan et al. (2009) for perennials.

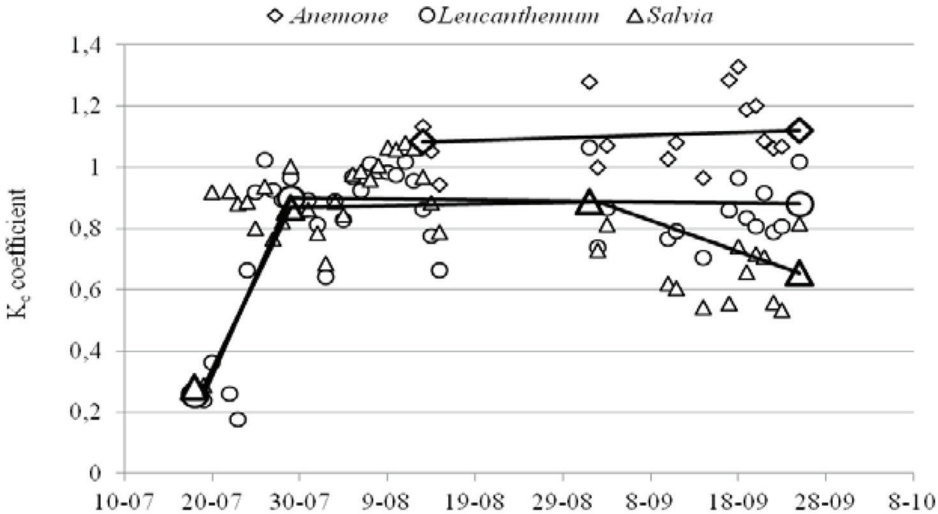

Figure 13. The K_c coefficient determined using weighing lysimeters for *Anemone*, *Leucanthemum* and *Salvia*, during the growth season

CONCLUSIONS

The obtained results showed that weighting lysimeters can be very useful for controlling irrigation system of perennials, especially in nurseries cultivating plants in small containers. The strong correlation was shown between hourly calculated crop (ET_c) and reference (ET_0) evapotranspiration for all tested perennials, which suggest that this information should be included into irrigation programs. Plants differing in leaf area, plant shapes and flowering time should be separately collected in the benches for better irrigation controlling. The determined K_c coefficients can be very useful for precise irrigation of these perennials based on climatic data, generated from weather station located in the nursery.

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