Agricultural Water Management 131 (2014) 30–40

Contents lists available at ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat

Substrate water status and evapotranspiration irrigation scheduling in heterogenous container nursery crops

Luca Incrocci[a,*], Paolo Marzialetti[b], Giorgio Incrocci[a], Andrea Di Vita[a], Jos Balendonck[c], Carlo Bibbiani[d], Serafino Spagnol[e], Alberto Pardossi[a]

[a] Department of Agriculture, Food and Environment, University of Pisa, Pisa, Italy
[b] Experimental Station for Nursery Crops (Centro Sperimentale per il Vivaismo, Ce.Spe.Vi.), Pistoia, Italy
[c] Wageningen UR Greenhouse Horticulture, Wageningen, The Netherlands
[d] Department of Veterinary Science, University of Pisa, Pisa, Italy
[e] Spagnol Greenhouse Technology Ltd., Vidor, Treviso, Italy

ARTICLE INFO

Article history:
Received 28 March 2013
Accepted 12 September 2013
Available online 5 October 2013

Keywords:
Crop coefficient
Evapotranspiration model
Hardy ornamental nursery stocks
Nutrient emission
Soil moisture sensor
Water runoff

ABSTRACT

A study was conducted to determine the effects of implementing different irrigation scheduling methods on heterogeneous container hardy ornamental nursery stocks. Four ornamental shrub species were grown in the same irrigation sector during the summer of four consecutive years (2007–2010): *Forsythia × intermedia*, *Photinia × fraseri*, *Prunus laurocerasus* L. and *Viburnum tinus* L. Automated drip irrigation based on either substrate water status (SW) or calculated crop evapotranspiration (*ET*; MODEL) was compared with "typical" timer-controlled irrigation (TIMER). In TIMER treatment, containers were irrigated based on grower management. In SW treatment, irrigation was controlled either by a water-filled tensiometer (2007) or by a dielectric soil moisture sensor (2008–2010) placed in one pot with a *Prunus* plant, the species with intermediate water need as found in preliminary work. In MODEL treatment, irrigation was controlled on the basis of the species with the greatest *ET*. Crop *ET* was calculated multiplying reference *ET* (ET_0) by a species-specific crop coefficient (K_C), which in turn was estimated from plant height. In all treatments, pre-irrigation substrate water deficit was lower than the plant available water in the container. Compared with TIMER treatment, SW and MODEL irrigation scheduling reduced considerably both water use (−21% to −40%) and nutrient emission (−39% to −74%) with no significant effect on plant growth and quality. Water saving resulted from a reduction of irrigation frequency and leaching fraction (water leached/water applied). Wireless sensor network technology and near/remote monitoring techniques can facilitate the application of plant-driven irrigation scheduling in commercial nurseries, where generally hundreds of plant taxa are cultivated in many independent irrigation sectors.

Introduction

The production of hardy ornamental nursery stocks (HONS) is an important horticultural sector in several countries, such as the United States, The Netherlands and Italy (AIPH, 2011). In Europe, one of the major production centres is located around the town of Pistoia in Tuscany (Italy), where nearly 1500 nurseries are in operation on approximately 5200 ha (Nicese and Ferrini, 2009). In this area, container cultivation has been increasingly used in the last 10–15 years as it provides many advantages, such as fast plant growth, year-round marketing and easy plantation establishment. The area covered by container crops is currently estimated to be around 1000 ha (Nicese and Ferrini, 2009).

Water and nutrients are often applied in excess to nursery crops in Pistoia, with leaching fractions (LF = water leached/water applied) ranging from 30 to 50% (Marzialetti and Pardossi, 2003). This results in water wastage and environmental pollution due to the leaching of fertilisers and plant protection products (e.g. herbicides; ARPAT, 2007). Generally, overhead sprinkler irrigation is used for containers smaller than 5–7 L, and micro-irrigation systems (drip or micro-spray irrigation) for larger containers. Crops are irrigated from May to October, when rainfall is scarce or almost negligible, like for instance in 2003 and 2012. Seasonal irrigation volume ranges from 1000 $m^3 ha^{-1}$ in soil-bound crops to 10,000–15,000 $m^3 ha^{-1}$ in container crops (Marzialetti and Pardossi, 2003). These figures are similar to those reported for

* Corresponding author at: Department of Agriculture, Food and Environment, University of Pisa, Viale delle Piagge 23, 56124 Pisa, Italy. Tel.: +39 050 2216 529; fax: +39 050 2216 524.
E-mail addresses: luca.incrocci@unipi.it, luca.incrocci69@gmail.com (L. Incrocci).

0378-3774/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.agwat.2013.09.004

nursery crops in other countries [e.g. U.K. (Grant et al., 2009) and Florida (Beeson et al., 2004)]. Annual water consumption of the whole nursery industry is estimated to be around 12 million m^3, which approximates the urban water consumption of Pistoia (Lubello et al., 2004). In the study area, groundwater is the main source of both irrigation and potable water and, in the future, the competition between domestic consumption and water necessary for nursery production is supposed to increase steadily (ARPAT, 2007).

Due to over-irrigation, huge quantities of water are being used in nurseries, in particular for container crops that consume 75–80% of the total water demand of HONS industry (Marzialetti and Pardossi, 2003). Inaccurate scheduling is the main cause of excessive irrigation. Growers generally estimate crop water need based on personal experience and use simple timers for automated irrigation. The practice to lay out different plant species in the same irrigation plot, which is typical of HONS production (Grant et al., 2009), also results in over-irrigation, as growers tend to control irrigation based on the most water-demanding species. Recycling runoff water can help to conserve water and reduce fertiliser leaching in HONS systems (Marzialetti and Pardossi, 2003). However, application of closed irrigation systems is scarce in the Pistoia area, as these are more difficult to manage and increase the risk of root diseases.

Both current legislation on water resources (e.g. European Water Framework Directive and European Nitrate Directive) and competition for water with other users will affect the future development of HONS industry around Pistoia. Actually, water scarcity is one of the main reasons that restrict the application of container cultivation in many nurseries and have forced some growers to move their production far from Pistoia. Without doubt, irrigation efficiency in nurseries must be substantially improved to allow them to keep their current profitable location and to minimize environmental impact. The same considerations can be applied to the HONS industry in other countries (e.g. Beeson and Brooks, 2008; Grant et al., 2009; Harris et al., 2007). In Florida, for instance, because of strong competition with the drinking water market, consumption of irrigation water has been restricted for nurseries located in areas close to urban centres (Beeson and Brooks, 2008).

An approach to efficient irrigation management in containerized HONS entails the regulation of frequency and, possibly, water dose based on either water potential (or tension) or volumetric water content (θ) of the growing medium, which can be measured with soil moisture sensors (SMS; Pardossi et al., 2009; Pardossi and Incrocci, 2011; van Iersel et al., 2011). The appliance of SMS to schedule irrigation in mono-crop systems, either in soil or in soilless substrate, has been documented by many authors (Pardossi et al., 2009; Pardossi and Incrocci, 2011; van Iersel et al., 2011). However, much less attention has been paid to the use of SMS for automated irrigation of mixed container nursery crops.

Another method for scheduling irrigation in containerized HONS is based on the determination of crop evapotranspiration (ET; Bacci et al., 2008; Grant et al., 2012). Crop ET can be calculated from reference ET (ET_0) and a crop coefficient (K_C) that defines the relationship between the two (Allen et al., 1998):

$$ET = ET_0 \cdot K_C. \tag{1}$$

Reference ET can be easily calculated from weather data with for instance the Penman–Monteith (Allen et al., 1998) or the CIMIS equation (California Irrigation Management Information System, 2009). Alternatively, ET_0 can be determined using an evaporation pan or special devices such as an "Evaposensor" (Grant et al., 2012).

In container culture, irrigation can be controlled automatically by a weighing lysimeter, which measures crop ET directly over short time intervals (hourly or less). This system is widely applied in greenhouse crops (de Graaf et al., 2004) and was also proposed for outdoor nursery crops (Beeson, 2011).

In this work, several irrigation systems for heterogeneous container nursery crops using soil moisture probes or a crop model control were compared with standard grower practices using timing control.

Materials and methods

Experimental site

The study was carried out in Pistoia, Italy (latitude: 43°55′9″N; longitude: 10°54′27″E) between 2007 and 2010. Mean values of daily air temperature, global solar radiation and ET_0 were similar in all seasons and differences in season-cumulated ET_0 were principally due to the different duration of each trial (Table 1 and Fig. 1). Long-term (1951–2012) average rainfall and air temperature recorded between May and September are 323 mm and 21.1 °C, respectively (*source*: www.cespevi.it/meteost.htm).

Plant material and growing technique

Four ornamental shrub species were selected for their commercial importance and to include plants with different habit and water need: *Forsythia* × *intermedia* (border forsythia), *Photinia* × *fraseri* (redtip photinia), *Prunus laurocerasus* L. (cherry or English laurel) and *Viburnum tinus* L. (lauristinus). In preliminary work, *Forsythia* daily ET was 1.6–2.5 times greater than in *Viburnum*, with *Photinia* and *Prunus* exhibiting intermediate ET.

One-year old rooted cuttings of the selected species, which had been grown in 1.8-L plastic pots, were transplanted at the end of April and cultivated outdoor in 9.6-L black plastic cylinder containers until October of four consecutive years (2007–2010; Table 1). Each container hosted one plant and crop density was 2.4 plant m^{-2}. Plants were grown according to the standard practice in Pistoia; for instance, they were pruned in July to promote bottom branching.

Substrate was a peat–pumice mixture (1:1, v:v), which is recommended for its good aeration and quick water percolation and is quite common in the nurseries around Pistoia. Bulk density, porosity and water retention curve of the substrate were determined by

Table 1
Basic information on the irrigation study conducted with container nursery crops in Pistoia (Italy) between 2007 and 2010.

Year	2007	2008	2009	2010
Planting date	16 April	28 April	20 April	29 April
Period of observations	12 May–11 October	10 June–9 October	18 May–7 October	25 June–5 October
Days of observations	153	122	143	103
Mean daily air temperature (°C)	21.2	22.3	23.4	22.5
Mean daily global radiation (MJ m^{-2})	21.5	19.8	20.0	19.6
Mean daily reference evapotranspiration (ET_0; mm day^{-1})	3.82	3.62	3.73	3.42
Season-cumulated reference evapotranspiration (ET_0; mm day^{-1})	584.5	441.0	533.3	352.3
Season-cumulated rainfall (mm)	350.8	55.6	159.3	238.4