Agricultural Water Management 212 (2019) 78–87

Contents lists available at ScienceDirect

Agricultural Water Management

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

Effects of various irrigation regimes on water use efficiency and visual quality of some ornamental herbaceous plants in the field

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ARTICLE INFO

Keywords:
Herbaceous spices
Drought
Irrigation management
Water use efficiency

ABSTRACT

Efficient use of water by selection of appropriate plant species is becoming increasingly important in semi-arid and arid regions to save scarce water resources. In this study, the effects of water deficit irrigation on physiological responses, water-use efficiency (WUE) and visual quality of four herbaceous ornamental species (*Malva sylvestris, Althea rosea, Callistephus chinensis* and *Rudbeckia hirta*) were investigated. The experiment was a split-plot treatment based on a randomized complete block design experiment with four irrigation levels (25%, 50%, 75%, and 100% reference evapotranspiration (ET0)) and four replications. *Althaea rosea* and *Rudbeckia hirta* showed dehydration avoidance by modifying their leaf shape, decreasing stomatal conductance and increasing Water Use Efficiency (WUE_{i}). The lowest specific leaf area and highest root/shoot ratio were seen in *Althaea rosea* at 25% and 50% ET0, respectively. *Malva sylvestris* used a drought escape strategy by early flowering. In terms of landscape aesthetic values, *Malva sylvestris* performed well with a minimum of 75% ET0. *Althaea rosea* and *Rudbeckia hirta* were well-maintained with 25%–50 % ET0 irrigation levels. However, for an acceptable aesthetic landscape appearance, the minimum level of irrigation for *Callistephus chinensis* was 50% ET0. These results suggest that use of drought-tolerant spices such as *Althaea rosea* and *Rudbeckia hirta* can improve irrigation management and conserve aesthetic performance in urban landscapes.

1. Introduction

Increased industrialization, rising population, and climate change have resulted in water conflicts especially in urban environments (Lea-Cox and Ross, 2001). In many urban communities, irrigation of urban landscapes is a considerable fraction of urban water consumption (between 40% and 70%) (Lockett et al., 2002). The absence of a perceptible association between landscape performance and resources such as water makes water conservation difficult. Water management is difficult when there are wide fields of expectations and end users (Kjelgren et al., 2000). Species diversity and their water need characteristics (Kjelgren et al., 2000), differences in regions, management practices, and landscape types make a determination of irrigation requirements more complex (Hilaire et al., 2008). To mitigate demand problems, water managers are looking to achieve significant long and short-term water saving strategies (Brown et al., 2004). Therefore, some conservation strategies are implemented such as using precision landscape irrigation (Kjelgren et al., 2000), using alternative water sources (Hilaire et al., 2008), using native and drought tolerant plant species (Lockett et al., 2002), applying deficit irrigation strategies (Hilaire et al., 2008; Mansour et al., 2017) and identifying the varying water needs in the developmental stages (Stabler and Martin, 2000). Studies to define the minimum irrigation need for maintenance of plants with acceptable aesthetics display are surprising possibilities for water conservation in landscaping. For example, many non-turf landscape plants can sustain acceptable aesthetics under some levels of water deficit protocols (Kjelgren et al., 2000). Investigations on irrigation of enera landscape groundcovers showed several species had acceptable performance at 20% or 50% of reference evapotranspiration (ET0) (Staats and Klett, 1995; Pittenger et al., 2001). A study showed 11 and 14 shrub species maintained acceptable aesthetic appearance at irrigation amounts equal to 0% and 18% of ET0, respectively (Shaw and Pittenger, 2004). For example, the species such as Workwood, *Feathery cassia*, Orchid spot rockrose, Pride of madeira, Bush snapdragon, *Noell grevillea*, Toyon, 'Green Cloud' texas ranger, *Prostrate myoporum* and 'Santa Cruz' firethorn, Goldmoss had acceptable appearance in no irrigation. Costello et al. (2005) reported no difference among irrigation at 0%, 25%, or 50% ET0 in the growth of 2- year oaks. Furthermore, the results from studies on water use of some landscape trees illustrated that increases of water use are associated with plant species type, plant size and/or soil moisture content (Devitt et al., 1994, 1995; Vrecenak and Herrington, 1984). Based on Stabler and Martin (2000, 2004),

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https://doi.org/10.1016/j.agwat.2018.08.012
Received 24 January 2018; Received in revised form 11 June 2018; Accepted 9 August 2018

water use efficiency (WUE) for established *Cercidium floridum, Nerium oleander,* and *Leucophyllum frutescens* could be optimized by deficit irrigation regimens.

Water conservation can also be achieved using such strategies as Water Sensitive Urban Design (Kazemi et al., 2009, 2011) while, keeping landscape aesthetic values at the same time is still a challenge (Hurd et al., 2006). Several research works have been conducted in this area which focuses on how to create low maintenance and attractive meadows in urban landscapes (Hitchmough et al., 2004; Dunnett and Hitchmough, 2007). Due to the beauty of flowering herbaceous species, it is hard to convince people to eliminate them from urban landscaping (Rutgers Master Gardeners, 2016). These plants are the first group which shows symptoms of water deficiency. Therefore, to optimize landscape aesthetic performances of water-wise landscaping (Sun et al., 2012), studies have been focused on drought effects on herbaceous flowering plants (Moosavi et al., 2014). Due to morphological and physiological adaptations, using native plants is as a way to maintain acceptable landscape appearance (Starman and Lombardini, 2006) and support local wildlife (Ober and Knox, 2017). However, the complexities of urban microclimates have resulted in not adapting of some native plants to a harsh new habitat (Wade et al., 2010). To obtain an exceptional landscape performance, a mix of adapted exotics and native plant species should be applied in municipal landscaping. The whole-plant characters (Blum, 2005) and atmospheric demand for moisture have effects on plant water needs (Kjelgren et al., 2000). Plants adjust their water demand by dehydration avoidance characters such as creating more trichomes (Ehleringer et al., 1976), reducing lower specific leaf area (Fonseca et al., 2000), increase their rooting depth (Kjelgren et al., 2009) and changing their stomatal size and density (Masle et al., 2005). Native plants obtain accommodation mainly by dehydration escape and dehydration avoidance rather than dehydration tolerance (Blum, 2005). However, having drought tolerance potential, plants experience some degree of wilting, leaf burn, reduction in growth, flower size, number of flowers and quality (Zollinger et al., 2006). Therefore, understanding the minimum water needs for desirable plant quality (Henson et al., 2006) and the varying degree of adaptation and water use efficiency may assist in keeping landscape visual quality to an acceptable level (Cameron et al., 2006; Andrew et al., 2013).

In the current study, the effect of water deficit irrigation on physio-morphological and landscape performance of two native herbaceous species, *Althaea rosea*, *Malva sylvestris,* and two adapted exotic plant species to Iran, *Rudbeckia hirta* and *Callistephus chinensis* were examined. The main aim was to provide knowledge on the lowest watering level for acceptable maintenance, which may help to design future water management framework for a mix of native and non-native urban landscaping.

2. Material and methods

2.1. Plant materials and experimental design

This field study was conducted in Mashhad Botanic Garden (Longitude: E59° 36', Latitude: N36° 15' and 985 m above sea level, average rainfall per year: 233.8 mm) located in south part of the city of Mashhad, Iran during 2016. Physical and chemical characteristics of the soil of the experimental site are listed in Table 1.

The experimental design was a split-plot treatment based on a randomized complete block design with four replications. The irrigation treatments were in four levels including 25%, 50%, 75% and 100% of the reference evapotranspiration (ET0) (required to optimize growth of *Poa pratensis* (Kentucky bluegrass). The hourly weather data (air temperature, relative humidity, solar radiation, wind speed and rainfall) were achieved from local weather station records. Local reference evapotranspiration (ET0) was obtained from weather data using Penman–Montieth equation (Allen et al., 2000).

The study examined four herbaceous flowering plant species including *Rudbeckia hirta, Callistephus chinensis, Althaea rosea, Malva sylvestris*. The size of each of the 64 plots was 1 m × 1.5 m and they were separated by a 1-meter distance. The plots o*f Althaea rosea, Malva sylvestris, Rudbeckia hirta and Callistephus chinensis* species we consisted of 6–12 plants, respectively. *Althaea rosea, Malva sylvestris and rudbeckia hirta, Callistephus chinensis* species were spaced a minimum of 0.5, 0.3 m apart, (4 and 8 plants per square meter) respectively.

In April 2016, the seeds were sown in plastic trays and uniform seedlings (6 to 8-leaf stage) were transplanted approximately one month after planting the seeds. The plants were allowed to establish one month prior to the treatment initiation. The weeds were removed using a hand removal. Then the plants were treated with four irrigation levels until the end of the season. Rainfall per day was subtracted from the amount of each treatment. The total Available moisture content in the soil was 14.9% (Table 1). Pure Irrigation Depth (PID) which is dependent on the root depth of the experimental species, was calculated 4.47 cm or 44 mm. The maximum irrigation interval (4 days) was calculated as the ratio of PID to maximum water requirement at the maximum growth stage which was 10 mm/day. In this research, irrigation intervals were considered every second days. The total amount of water taken up by the plants in each plot was calculated in all the treatments during the period of the experiment to measure water use efficiency.

2.2. Measurements

At the end of the study period, landscape impact, floral impact and appearance impact of the studied species were assessed applying a modified method of Rozum (2014). Appearance impact rating was evaluated base on a 1–5 Likert- type scale. Complete death of plants and leaves was scored 1 = dead, 2 = visible witling, firing and green leaf < 50%, 3 = slow growth, green leaves = 50%, 4 = good growth, green leaves = 75% and 5 = exceptional growth.

Floral impact rating was based on how much plant's appearance is improved by flowering. It was rated on a scale of 1–5 where 1 = no flowering; 2 = 25% impact; 3 = 50% impact; 4 = 75% impact and 5 = 95% impact, very showy inflorescence. Landscape impact rating was assessed based on how the general appearance of the plants, their flowering and their insect and disease symptoms impacted on the landscape quality. The gradations of the scales were as follows: 1 = having a weak growth in the landscape, sparse flowering or without ornamental value; 5 = having a pleasurable landscape appearance. *Althea rosea* displayed a degree of leaf rolling, which was rated on a scale of 1–5: 1 = no rolling; 5 = full leaf rolling. After conducting a visual rating, the plants were harvested, their roots were washed, and then the fresh weight of the roots and shoots were measured. To measure the dry mass (DM) and root/shoot ratio, the plants were placed

Table 1
Characteristic of the soil in the experimental field.

pH	Organic C %	N	P ppm	K	Sand %	Silt	Clay	Soil texture	BD g/cm^3	FC v/v%	PWP
7.80	0.5	0.04	14.3	210	38.8	36	c	loam	1.45	25.2	10.2

Field capacity (FC)- Permanent Wilting Point (PWP)- Bulk Density (BD).