Journal of Arid Environments 134 (2016) 87–96

Contents lists available at ScienceDirect

Journal of Arid Environments

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

Evapotranspiration of urban lawns in a semi-arid environment: An *in situ* evaluation of microclimatic conditions and watering recommendations

Elizaveta Litvak [a,*], Diane E. Pataki [a,b]

[a] Department of Biology, University of Utah, 257 S 1400 E, Salt Lake City, UT 84112, USA
[b] Department of City & Metropolitan Planning, University of Utah, USA

ARTICLE INFO

Article history:
Received 13 April 2016
Received in revised form
27 June 2016
Accepted 29 June 2016
Available online 13 July 2016

Keywords:
Irrigation requirements
Turfgrass water use
Landscape coefficient method
Los Angeles
California
WUCOLS

ABSTRACT

As many regions worldwide are increasingly affected by water scarcity caused by unprecedented climate change and population growth, current practices of landscape irrigation need to be evaluated to develop scientifically based water-saving recommendations. We compared widely used evapotranspiration (*ET*) based guidelines of turfgrass watering requirements with *ET* from 8 irrigated turfgrass lawns (4 unshaded and 4 shaded by various degree) measured *in situ* by portable chambers in the Los Angeles Metropolitan area. *ET* from unshaded lawns was 40% higher than recommended irrigation inputs and *ET* from shaded lawns was mostly within recommended ranges. We evaluated the microclimate coefficient (k_{mc}), a factor used to adjust *ET* from reference surfaces to local microclimatic conditions. While *in situ* k_{mc} was mostly within the ranges recommended for California, (1) k_{mc} ranges for particular landscape types deviated from observations, (2) minimum and maximum k_{mc} were beyond recommended ranges, and (3) k_{mc} had clear seasonal changes overlooked by current methodology. We propose a method to quantitatively estimate the effect of shade on k_{mc} and improved categories and coefficients for applying the landscape coefficient method under realistic urban conditions.

1. Introduction

Evapotranspiration (*ET*) of turfgrass has been extensively studied for decades, primarily under controlled and agricultural conditions (Feldhake et al., 1983; Kim and Beard, 1988; Devitt et al., 1992). However, *in situ ET* of turfgrass lawns in cities is still poorly quantified (Pittenger and Shaw, 2007, 2010; Sun et al., 2012; Shields and Tague, 2012; Nouri et al., 2013b; Snyder et al., 2015). Complex urban land cover results in unique microclimates caused by the combination of small individual greenspaces and built infrastructure as well as heterogeneity of landscape composition and irrigation inputs by varying land owners. Quantifying the influence of local urban conditions on *ET* and measuring actual *ET* in complex urban terrain is particularly difficult (Feldhake et al., 1983; Grimmond et al., 1996; Grimmond and Oke, 1999; Kotani and Sugita, 2005; Offerle et al., 2006; Balogun et al., 2009; Peters et al., 2011). In the semi-arid southwestern U.S., where up to 70% of residential water is used outdoors (Gleick et al., 2003; Colby et al., 2006; St. Hilaire et al., 2008; Evans and Sadler, 2008; Sabo et al., 2010), the combination of dry air and heavy irrigation is likely to lead to very high *ET* rates (Decker et al., 1962; Kurc and Small, 2004) that are of increasing concern as the need for urban water conservation gains attention. In southern California, the worst drought on record is ongoing (2012–2016; Aghakouchak et al., 2014; Melillo et al., 2014; Diffenbaugh et al., 2015; Thompson, 2016) and further decreases in water supplies are projected due to regional climate change (Hamlet et al., 2007; Barnett et al., 2008; Hanak and Lund, 2008; MacDonald, 2010). As water scarcity increasingly affects many highly populated regions globally (Vorosmarty et al., 2000; IPCC, 2014; Schewe et al., 2014; Van Loon et al., 2016), there is a critical need to understand landscape irrigation requirements and develop efficient water management strategies under real urban conditions (Shields and Tague, 2012; Vahmani and Hogue, 2014).

Currently, *ET* of urban lawns is commonly estimated using a method developed for agriculture, which has not been directly tested in urban settings (St. Hilaire et al., 2008; Sun et al., 2012;

* Corresponding author.
E-mail addresses: elitvak@uci.edu (E. Litvak), diane.pataki@utah.edu (D.E. Pataki).

http://dx.doi.org/10.1016/j.jaridenv.2016.06.016
0140-1963/

Nouri et al., 2013b). The central concept of this method is reference *ET* (ET_0), or *ET* from vegetated surfaces that completely cover the ground and have access to non-limiting soil water. ET_0 is an essentially climatic parameter that characterizes the local atmospheric potential of driving *ET* (Allen et al., 1998). To standardize methodology, ET_0 is defined as *ET* from a vast surface of healthy turfgrass that has uniform height and completely covers the soil. ET_0 is estimated using the Penman-Monteith equation (Penman, 1948; Monteith, 1965; Eichinger et al., 1996; Pereira and Perrier, 1999) and intended to represent the maximum rate of *ET* of flat and homogenous vegetated surfaces under current meteorological conditions. To estimate *ET* from specific agricultural crops (ET_c), ET_0 is multiplied by experimentally determined coefficients (k_c):

$$ET_c = k_c ET_0. \tag{1}$$

k_c may vary from 0.15 (dry soil with no groundcover) to 1.30; values for all major crops are reported (Allen et al., 1998). Since its introduction by the Food and Agriculture Organization of the United Nations in 1977, this method has been adopted worldwide as a standard technique to estimate the water requirements of agricultural crops (Doorenbos and Pruitt, 1977; Allen et al., 1998; Fischer et al., 2011; Farg et al., 2012; Nouri et al., 2013b; Pereira et al., 2015). It has proven to be robust yet reasonably simple for practical applications (Pereira et al., 2015). In California, the Department of Water Resources maintains a set of 145 automated weather stations that measure weather parameters for calculating ET_0 (http://www.cimis.water.ca.gov/Resources.aspx). The resulting ET_0 values are reported hourly and daily, along with weather data, by the California Irrigation Management Information System (CIMIS) (http://www.cimis.water.ca.gov). ET_0 is also reported by the networks of standardized weather stations in other regions and worldwide (e.g. Arizona Meteorological Network, ag.arizona.edu/azmet; New Mexico Climate Center, weather.nmsu.edu; TexasET Network, texaset.tamu.edu; Australian Bureau of Meteorology, bom.gov.au/watl/eto).

However, turfgrass lawns within cities differ from commercial crops in several important ways, which may limit the applicability of the crop coefficient method to cities. Unlike crop fields, lawns are often non-uniform (contain more than one species and/or do not completely cover the ground), have a relatively small size (with edge effects that can significantly influence *ET*) and are commonly shaded by landscape trees and structures (Snyder et al., 2015). As a result, available values of k_c are not likely to be applicable to urban lawns. In addition, because k_c was developed for deducing irrigation requirements of agricultural crops, the values are optimized for high crop yields. In urban settings, recreational and aesthetic functions of lawns are more valued than rapid growth (St. Hilaire et al., 2008; Sun et al., 2012). For these reasons, instead of k_c, CIMIS uses another set of coefficients to estimate *ET* of urban landscapes (Costello and Jones, 1994; Costello et al., 2000):

$$ET = k_L ET_0 = k_d k_s k_{mc} ET_0, \tag{2}$$

where k_L is a landscape coefficient defined as a product of k_d, a density factor, k_S, a species-specific factor, and k_{mc}, a microclimate factor. This method is called the landscape coefficient method (LCM).

k_d characterizes the density of plantings: $k_d = 1$ when turfgrass completely covers the ground and $0 < k_d < 1$ when it does not. k_s represents minimum watering requirements for growing unstressed, aesthetically acceptable turfgrass for recreational purposes. Even though k_s exhibits prominent seasonal variations (Pittenger and Shaw, 2004), the California Department of Water Resources reference guide recommends using annually averaged k_s (0.6 for warm-season grass, such as Bermudagrass and St. Augustine grass, and 0.8 for cool-season grass, such as tall fescue; Costello et al., 2000). The most uncertain factor in determining turfgrass *ET* in urban settings is k_{mc}. Because of the paucity of urban landscape *ET* measurements, it is currently estimated based on common sense and "subjective assessments" in the absence of empirical data (Costello et al., 2000). Thus, LCM recommends observation-based, arbitrarily assigned values of k_{mc}: from 0.5 to 0.9 ("low") for shaded locations sheltered from wind, 1.0 ("average") for conditions similar to reference, and from 1.1 to 1.4 ("high") for plots subjected to advection and/or strong winds. Because this method is explicitly subjective, it inevitably introduces errors in *ET* estimates. However, it is utilized in the California Code of Regulations and in other regions nationally and internationally to determine efficient irrigation amounts for urban turfgrass as the best method currently available (California Department of Water Resources, 2009; City of Los Angeles Department of City Planning, 2011; University of Arizona, 2005; Salvador et al., 2011; Al-kofahi et al., 2012; Nouri et al., 2013b). In general, a widely applicable method is needed to provide irrigation recommendations for urban arid and semi-arid environments.

The goal of this study is to quantify urban microclimatic conditions and actual *ET* based on *in situ* measurements at actual urban lawns, define k_{mc} more precisely, and develop research-based watering recommendations. We used a dataset of *ET* from 8 urban lawns measured *in situ* by portable chambers in the Los Angeles metropolitan area (Litvak et al., 2014). We asked the questions: (1) What is actual k_{mc} of typical urban lawns in Los Angeles area? (2) Is actual k_{mc} in agreement with values recommended by LCM? (3) Based on this analysis, can more accurate recommendations that are easily applicable by landscape managers be developed? In particular, *in situ ET* measurements have shown that shading may dramatically decrease *ET* of urban turfgrass lawns (Litvak et al., 2014). As a result, we expect that k_{mc} of shaded turfgrass lawns can be adjusted to more realistically represent common urban conditions and make water recommendations more precise.

2. Methods

2.1. The dataset of turfgrass ET

We utilized measurements of *ET* from 8 irrigated turfgrass lawns in the Los Angeles metropolitan area (Litvak et al., 2014). The lawns were located at the campus of the University of California ("Irvine"), the California State University Fullerton Arboretum ("Fullerton"), and the Los Angeles County Arboretum and Botanic Garden ("LA Arboretum") (Fig. 1). Most lawns were dominated by Bermuda grass (*Cynodon dactylon*, Table 1) and regularly mowed and maintained according to common practices in southern California. All the lawns were equipped with irrigation sprinklers that were controlled automatically in Irvine and manually by landscape managers in Fullerton and LA Arboretum. Usually, the lawns received irrigation once a day in Irvine and Fullerton and once a week in LA Arboretum.

Four lawns were not shaded; one of them (U-F2) had palm trees at the edge, but they cast shade largely away from the lawn (Table 1). The other four lawns received shade from trees. The lawn S-I2 was also significantly shaded by a nearby building (Table 1). For all shaded lawns except S-I2, tree canopies were the major source of turfgrass shading.

ET of turfgrass was measured with portable chambers made of clear PVC during a series of field campaigns in the summer of 2010 and winter of 2011. *ET* was calculated from rapid temperature and humidity changes that were recorded by small dataloggers placed inside the chambers, and daily sums of *ET* (mm d^{-1}) were