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Basal crop coefficients for vine and erect crops with plastic mulch in a sub-tropical region

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ABSTRACT

Dual crop coefficient approach of partitioning evapotranspiration (ET_c) into transpiration (T) and evaporation (E) has been used extensively for applications ranging from estimating crop water allocations to irrigation scheduling. Although the basal crop coefficient (K_{cb}) provides an improved estimate of T, variations in K_{cb} are still possible due to variations in climate and management practices necessitating the development of regional K_{cb}. Large drainage lysimeters (4.87 m × 3.65 m × 1.37 m) were used to develop K_{cb} for drip irrigated bell pepper and watermelon with plastic mulch in sub-tropical Florida using four and three seasons of data, respectively. The average K_{cb} values for the initial, mid-season, and late stages were 0.12, 0.68, and 0.77, respectively, for bell pepper, and 0.05, 0.96, and 0.66 for watermelon. The K_{cb} values for pepper from this study were statistically lower ($p = 0.047$) than the generic FAO-56 values (adjusted for mulch and plant density) and improved the estimates of T and E by 27.3 and 7%, respectively. Although lysimeter K_{cb} values for watermelon were numerically lower than FAO-56, no statistical difference was detected. However, FAO-56 overestimated watermelon E by 52%. The lysimeter-based K_{cb} improved the ET_c estimate and this improvement was 26 and 51% of the respective seasonal rainfall for pepper and watermelon. When extrapolated to all drip irrigated pepper acreage in Florida, the K_{cb} from this study could potentially reduce the applied water by some 6.9 million m^3 of water compared to using FAO-56 K_{cb}, highlighting the importance of accurate estimation of ET_c for the irrigation management. The improved K_{cb} will help customize the irrigation management and reduce nutrient leaching as well as improve simulations of ET_c within the hydrologic models for similar environment

1. Introduction

Water demand is increasing at the global scale due to rapid population growth and is causing stress on the available water resources. In Florida, agriculture is the largest user of water resources accounting for nearly 40% of total freshwater withdrawals (Marella, 2008). Due to high population growth (32%) in the last decade and increased industrial activities, water demand in Florida has been on rise and is expected to be 31 million m^3 per day in 2030, a 30% increase compared to 2005 (FDEP, 2011). Existing water resources in the state are not likely to meet 2030 demand (FDEP, 2011). Water conservation, including the improved irrigation scheduling of crops, is one of the solutions targeted by the state agencies to meet the shortfall. This necessitates the precise estimation of crop evapotranspiration (ET_c).

Dual crop coefficient method is recommended when the precise estimates of ET_c are desired for a variety of applications including irrigation scheduling using drip or sprinklers (Allen et al., 1998). In dual crop coefficient method, a single crop coefficient (K_c) is separated into two components: a basal crop coefficient (K_{cb}) for crop transpiration (T) and soil evaporation coefficient (K_e) for evaporation from soil (E). Crop transpiration affects plant growth and yield (Steduto et al., 2009), while E is considered as an unproductive component. One of the key advantages of K_{cb} is its use in the precise scheduling of drip irrigation which can result in significant water savings. The K_{cb} is less impacted by the surface condition of the field and the type of surface wetting which makes them more robust and transferable (Irmak et al., 2013).

The K_{cb} values reported in FAO-56 are intended for standard crop densities and optimum agronomic and water management practices in the arid to sub-humid climate. These values may change with the production method (e.g. plastic mulch, high initial wetting), management, and climate. Florida's sub-tropical climate is different from rest of the US, requiring development of the regional

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crop coefficients to improve water allocation plans. Bell pepper (pepper) and watermelon are two major crops of Florida and are typically grown on the sandy soils (>95% sand) with the raised soil beds covered with plastic mulch. The presence of impermeable plastic mulch affects the fluxes and may change crop water use compared to the open-field conditions (Allen et al., 1998; Amayreh and Al-Abed, 2005; Lovelli et al., 2005) resulting in deviation of the crop coefficients from literature values.

Plastic mulch works as a moisture barrier which does not allow the soil moisture to escape from the bed suppressing *E*. Improved water use efficiency of 10–20% is possible by reducing soil evaporation (Deng et al., 2006). Limiting rainfall entry into the mulched beds also reduces leaching of nutrients. The decreased *E* reduces the accumulation of salt in the root zone that would require frequent flushing to flush the salts out of the root zone. Mulch also prevents weeds and reduces insect and other related disease which can increase yield to make it an economically feasible practice. Opaque mulch acts as a thermal insulator, damping the diurnal waves of soil temperature (Shinde et al., 2001). The presence of plastic mulch at the soil surface with an accompanying air-gap increases contact resistance resulting in smaller temperature amplitude in the soil beds. Almost 12 million ha of land worldwide were under the plastic mulch as of 1999 (Miles et al., 2005), a number which must have increased considerably by now.

The recommended adjustment for mulch in FAO-56 is only approximate to account for the effects of partial reflection of solar radiation, micro-advection of heat from mulch to soil, and insulation. These adjustment factors can vary widely (Allen et al., 1998). Therefore, development of the regional K_{cb} is encouraged to more adequately reflect the crop water use under local environmental conditions (Allen et al., 1998). Developing regional dual crop coefficients in Florida for pepper and watermelon for better irrigation scheduling can be an important step toward the conservation of freshwater resources as well as reducing environmental losses of the nutrients.

Lysimeters have been considered as the standard method for development of crop coefficients for several decades (Howell et al., 1991) for various crops (Devitt et al., 1992; Clark et al., 1996; Haman et al., 1997; Bethune et al., 2001; Bryla et al., 2010; Shukla et al., 2012, 2014a,b). The accuracy of lysimeter depends on its design, vegetation characteristics in the fetch area (Farahani et al., 2007), replication in space and time (Shukla et al., 2012), and the accuracy of the water balance components measurements (drainage lysimeters).

To date, the K_{cb} values for the watermelon and pepper grown on the plastic mulch in sub-tropical Florida and elsewhere have not been reported. The objectives of this study are to: (1) develop K_{cb} for drip-irrigated pepper and watermelon grown on the raised soil beds covered with the plastic mulch in sub-tropical Florida using drainage lysimeters; and (2) compare *E* and *T* from this study with the FAO-56 using dual crop coefficient approach.

2. Material and methods

2.1. Study area

The study was conducted in spring 2003, 2004, and 2005 growing seasons for watermelon and fall 2003, 2006, 2007, and 2008 seasons for pepper at the Southwest Florida Research and Education Center (SWFREC), University of Florida, Immokalee, Florida (26.41° N, 81.41° W). The region has a sub-tropical climate with the mean monthly maximum and minimum temperatures of 29 and 17 °C, respectively, with the mean annual rainfall of 1260 mm (1970–2009 data, Southeast Regional Climate Center 2010). Climatically, the region can be divided into wet (June–October) and dry (November–May) seasons with 70% of annual rainfall occurring during the wet season. The first six weeks of pepper growing season occurs in the wet season while watermelon is grown completely in the dry season.

2.2. Lysimeters and field layout

Four drainage lysimeters (4.85 m × 3.65 m × 1.35 m) were used to quantify ET_c and develop K_{cb} and K_e for drip-irrigated pepper and watermelon. Each lysimeter had two raised soil beds with bed-to-bed (b-b) spacing of 2.2 m (Fig. 1). The crops were planted in the lysimeters to mimic the actual field conditions for both crops. For pepper, each lysimeter contained 40 plants (20 plants per bed) with both plant-to-plant (p-p) and row-to-row (r-r) spacing of 0.25 m in each bed. For watermelon, each lysimeter contained six plants (three plants per bed). The beds were covered with the plastic mulch while the remaining surface area consisted of the row-middle bare soil that would be present in a typical field. A picture of an experimental site is shown in Fig. 2. The native soil from the research farm was used to rebuild the soil profile inside the lysimeter. A detailed description of the lysimeter design, components, installation, and operation is presented in Shukla et al. (2006).

2.3. Monitoring systems

The irrigation, drainage, and runoff were measured using flowmeters (Model DLJ S50; accuracy 95% or greater, DLJ Company, Hackensack, NJ) connected to a datalogger. Soil moisture measurements were taken in the bed (bed soil moisture) and between the ditch and the bed (row-middle soil moisture) at 0.10 m increment from 0 to 0.7 m depth using the soil moisture sensors (Diviner 2000, Sentek Sensor Technologies, Australia). The accuracy of the soil moisture measurement probe was evaluated comparing 24 observations in the field with the gravimetric soil moisture values (Pandey and Shukla, unpublished data). The soil moisture data for 0.1–0.3 m depth from the gravimetric method and soil sensors were not statistically different ($p = 0.27$). The mean absolute error (MAE) and root mean square error (RMSE) values were 1.26 and 1.52%, respectively. The error affected ET_c calculations by less than 1%. Rainfall, air temperature, wind speed, relative humidity, and solar radiation were measured at the Florida Automated Weather Network (FAWN) weather station, installed in an open ground with well-watered grass in the fetch area, located 50 m to the north of the lysimeters.

2.4. Development of K_{cb}

The lysimeter based K_c's were developed using the volumetric water balance (Eq. (1)) which consisted of measuring inflows and outflows to and from the lysimeter, and the change in soil water storage over a stipulated period of time:

$$ET_c = K_c \times ET_0 = P + I - D - R - \Delta S \quad (1)$$

where *P* is precipitation (mm), *I* is irrigation (mm), *D* is drainage (mm), *R* is runoff (mm), and ΔS (mm) is change in soil moisture.

The K_c is computed as a ratio of ET_c to ET_0. The crop coefficient values were developed for four stages: initial stage (0–10% of ground cover), development stage (10% ground cover to effective full cover), mid-season stage (effective full cover to start of maturity), and late stage (maturity to harvest) (Allen et al., 1998). Day after transplant (DAT) 0–20, 21–48, 49–83, and 84–97 were used as the initial, development, mid-season, and late stages for the pepper, while respective values for watermelon were DAT 0–13, 14–48, 49–69, and 70–83.

The single K_c was separated into K_{cb} and K_e (Eq. (2)) using the method outlined in Allen et al. (1998). This method provides a