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Quantifying soybean evapotranspiration using an eddy covariance approach

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ABSTRACT

Quantification of evapotranspiration (ET_c) from crops is critical in irrigation scheduling in agriculture. In a pioneering study, in the Mississippi (MS) Delta region, we quantified ET_c from soybean (*Glycine max* L.) using the eddy covariance (EC) approach (ET_e). We also monitored ET_c using a residual energy balance (EB) approach (ET_b) and compared the fluxes. The unclosed energy fluxes in the EC were post-analysis closed using the Bowen ratio (BR) and latent heat (LH) methods. The measurements were conducted in a 35-ha clay soil planted to irrigated soybean in the lower MS Delta in 2016. The crop reached physiological maturity in 126 days after emergence (DAE). Maximum LAI was 5.7 and average grain yield was 4900 kg ha^{-1}. The EC showed an energy balance closure of about 88% on a 30 min and 90% on a daily flux accumulation. The ET_e was 18.2, 6.8, and 15.9% lower than ET_b, and ET_e corrected using BR (ET_{ebr}) and LH (ET_{ele}) approaches, respectively. Average soybean seasonal ET_e, ET_b, ET_{ebr}, and ET_{ele} were 422, 499, 451, and 490 mm, respectively. Seasonal reference-crop evapotranspiration for alfalfa (ET_o) and grass (ET_r) were 470 and 547 mm, respectively. Daily ET_e, ET_b, ET_{ebr}, ET_{ele}, ET_o, and ET_r averaged across the whole season were 4.4, 5.2, 4.7, 5.1, 4.9, and 5.7 mm, respectively. For scheduling irrigations, based on grass and alfalfa reference crop ET calculated from weather data, averages of the ET_e, ET_b, ET_{ebr}, and ET_{ele} daily estimates were used in deriving crop coefficients (K_c). The K_c for grass reference varied between 0.56 and 1.29 and for alfalfa reference varied between 0.56 and 1.02. The information developed will be useful for scheduling irrigations in the MS Delta region, and the methodology developed can be adapted for generating similar information elsewhere.

1. Introduction

Overexploitation of groundwater resources for irrigation is threatening the sustainability of irrigated crop production systems across the globe (Dalin et al., 2017). The MS Delta, one of the most important agricultural production regions in the USA, relies mostly on groundwater from the MS River Valley Alluvial Aquifer for meeting its irrigation water needs. Typically, over 60% of all the crops grown in this region are irrigated. Soybean represents about 53% of the irrigated area (366,163 ha), with the remaining 47% shared between rice, corn, cotton, and aquaculture (Heatherly, 2014; Powers, 2007). Pumping water from this shallow aquifer beyond its natural recharge levels has resulted in significant aquifer depletions, threatening the future water availability opportunities for irrigation in this region (Clark and Hart, 2009). Lack of scientific research integrating crop water demands (evapotranspiration, ET_c) with available water supplies in water management decision making, has been attributed as one of the major reasons for this trend. Traditionally, field experiments for quantifying ET_c were conducted for two or more years and crop variety-specific crop coefficients (K_c) were developed for scheduling irrigations. These K_c values were used by agronomists and crop consultants to schedule crop irrigations, across locations and seasons, based on weather data normally monitored by national weather agencies at those locations (Payero and Irmak, 2013). In the agricultural scenario in the MS region, the farmers depend upon local seed companies for their seedstock requirements. The same seed variety on average is available only for 3–4 years. The crop ET_c demands change with canopy characteristics, ground surface cover, maturity group, and pest and disease susceptibilities that are crop variety specific (Irmak, 2017). So, unlike in the past, an irrigation agronomist or consultant cannot wait for collecting 2–3 years of field data to develop robust ET_c and K_c information for irrigation scheduling, for by that time the same varieties are no longer available in the region for planting. Therefore, in the current agricultural scenario in this region and in similar situations elsewhere, agronomists are required to determine rapid but robust and scientifically sound solutions for developing irrigation scheduling information

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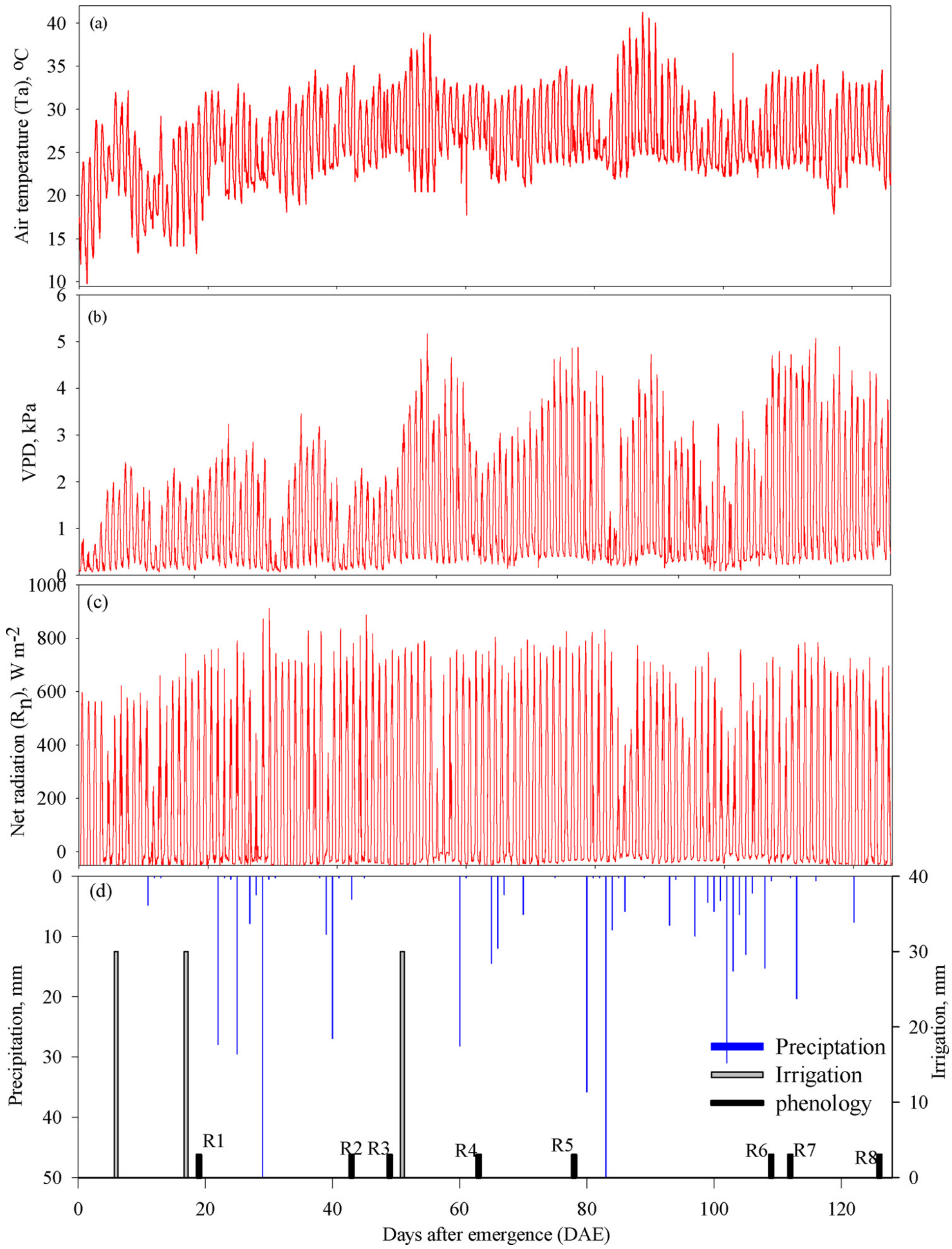

Fig. 1. Observed (a) air temperature, (b) vapor pressure deficit (VPD), (c) net radiation, and (d) precipitation, irrigation, and soybean crop phenology during the 2016 growing season (R1, R2… R8).

for conserving the limited water resources available for irrigation. The study presented here is an example in this direction.

In the search for an ideal method for quantifying ET from cropping systems, many methods of varying complexity have been reported in the literature, including soil water balance, residual energy balance (EB), and Bowen ratio (BR) modeling; field lysimeters; sap flow measurements; and eddy covariance (EC) (Shi et al., 2008; Wilson et al., 2001). Among these methods, EC and EB have emerged as two scientifically sound and easy to install and operate methods for collection of accurate ET_c data in the crop field for irrigation water management applications (Baldocchi, 2003; Foken and Wichura, 1996; Parent and Anctil, 2012; Shurpali et al., 2013; Tallec et al., 2013; Uddin et al., 2013; Zhao et al., 2007).

The inability of EC measurements in balancing the energy inputs with the energy outputs from cropping systems, known as energy balance non-closure problem (EBC), continue to haunt this method, hindering its applications in irrigation water management (Foken et al., 2011; Foken, 2006; Gao et al., 2017; Leuning et al., 2012; Liu et al., 2017; Mauder et al., 2007; Oncley et al., 2007). As no universal solution has emerged to resolve the EBC, a few methods have been proposed for post-analysis forcing of a closure in the computed fluxes by making some assumptions about energy dynamics in cropping systems. One of the methods is based on the Bowen ratio (BR), which assumes that the BR of the unclosed energy fluxes has the same BR as the measured fluxes (Blanken et al., 1997; Ingwersen et al., 2011; Twine et al., 2000). Another method is to fully assign the unclosed energies to the latent energy (LE) flux (LH method; Twine et al., 2000). In another method, the whole unclosed energies were added the sensible heat fluxes (H) (Ingwersen et al., 2011). Payero and Irmak (2013) used the LH method to account for the unclosed energies in their EC measurements of soybean ET_c in Nebraska, USA.

Ground-based continuous, intensive, quantitative monitoring of energy balance components in cropping fields provides an alternative method for quantifying ET_c based on a residual energy balance (EB)