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Comparison of actual evapotranspiration of irrigated maize in a sub-humid region using four different canopy resistance based approaches

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ABSTRACT

The single layer *Penman-Monteith* (PM) method is widely used method for the estimation of crop evapotranspiration (ET_c). The accuracy of ET_c estimate relies upon the quality of input weather data and capacity to approach adequately canopy (r_c) and aerodynamic resistance (ra). In this study, the PM method was used to estimate daily crop evapotranspiration of irrigated maize for the years 2013 and 2014 in a sub-humid region. Four different approaches (*Monteith, Katerji-Perrier, Todorovic*, and *Jarvis*) were used to estimate canopy resistance and, then after, crop evapotranspiration by *PM* equation were evaluated. The comparison was made to daily crop evapotranspiration obtained from the soil water balance *(SWB)* and soil water content variation measured by *time domain reflectometry (TDR)*. The cumulative crop evapotranspiration of *SWB*, *Monteith, Katerji-Perrier, Todorovic* and *Jarvis* approach was respectively, 260.4, 266.8, 252.8, 263.4, 256 mm for the year 2013, and 250.5, 257.7, 240.6, 251.8, 247.6 mm for the year 2014. The comparison of results and the statistical analysis confirmed that *Todorovic* and *Jarvis* approach gave reliable values, while the *Katerji-Perrier* approach could be used as an alternative method.

1. Introduction

Water scarcity has become more acute due to air temperature rise and erratic rainfall distribution; thereby affecting agricultural production adversely (Farrea and Faci, 2008; Zhao et al., 2010). Accurate estimation of evapotranspiration (ET) from the cropped surfaces at various growth stages is critical for effective agricultural water management (Shi et al., 2008), particularly under the climate change scenario (Ferrara et al., 2010). A higher precision in the estimation of crop ET (ET_c) may result in a reduction in the loss of water resources both in planning as well as in the management of crop (Gharsallah et al., 2013). Many approaches have been developed to measure and estimate the evapotranspiration based on observations, theoretical and numerical analysis (Porporato et al., 2004).

Soil water balance models (*SWB*) are based on theoretical depictions of a finite portion of the water cycle (Campos et al., 2016) and are helpful in the determination of irrigation scheduling of a crop (Moratiel et al., 2016). The *SWB* approach requires as input soil water depletion within the crop root zone, rainfall, drainage, and irrigation (Allen et al., 1998). A major advantage of this method is its applicability while estimating the water loss from a crop field (Wilson et al., 2001). However, the major disadvantage of *SWB* method in estimating ET_c is that it does not consider canopy intercept into consideration and is typically only applicable for a smaller area (Wilson et al., 2001). Despite this, it remains as a simple method for estimating total water loss from the soil by taking into account soil water evaporation (E) and transpiration (T) as major components.

Comprehensive and periodic soil water monitoring are beneficial as they impart evaluation of soil water depletion independently, comparable to *ET* even in dry periods when irrigation, precipitation, and

Abbreviation: ASW, available soil water (mm); Eq., equation; ET, evapotranspiration (mm); ET_c, crop evapotranspiration (mm); PM, Penman-Monteith; I, net irrigation depth (mm); λ, the latent heat of vaporization of water (MJ kg^{-1}); θ_{FC}, volumetric soil moisture at field capacity (m^3 m^{-3}); θ_{Wt}, volumetric soil moisture at wilting point (m^3 m^{-3}); θ_v, volumetric soil water content (m^3 m^{-3}); ρ_g, bulk soil density; θ_g, soil water content by the gravimetric method (m^3 m^{-3}); r_c, the canopy resistance (s m^{-1}); r_a, the aerodynamic resistance (s m^{-1}); c_p, the specific heat of moist air (MJ kg − 1 °C^{-1}); A, sum of irrigation and rain (mm); ΔW, variation of soil water (mm); λ, latent heat of vaporization (2.501 MJ kg^{-1}); R_n, net radiation (W m^{-2}); G, soil heat flux (W m^{-2}); γ, psychrometric constant (kPa °C^{-1}); r*, critical resistance (s m^{-1}); r_s, stomatal resistance (s m^{-1}); LAI_{eff}, effective leaf area index; r_i, the climatologically resistance (s m^{-1}); r_c, canopy resistance; ΔT, temperature (°C); Δe_a, actual saturation vapor pressure (kPa); U_2, wind speed (ms^{-1}) at 2 m height; Δ, slope of the vapor pressure curve (kPa °C^{-1}); e_s, saturation vapor pressure (kPa); GM, gravimetric method; VPD, vapour Pressure Deficit

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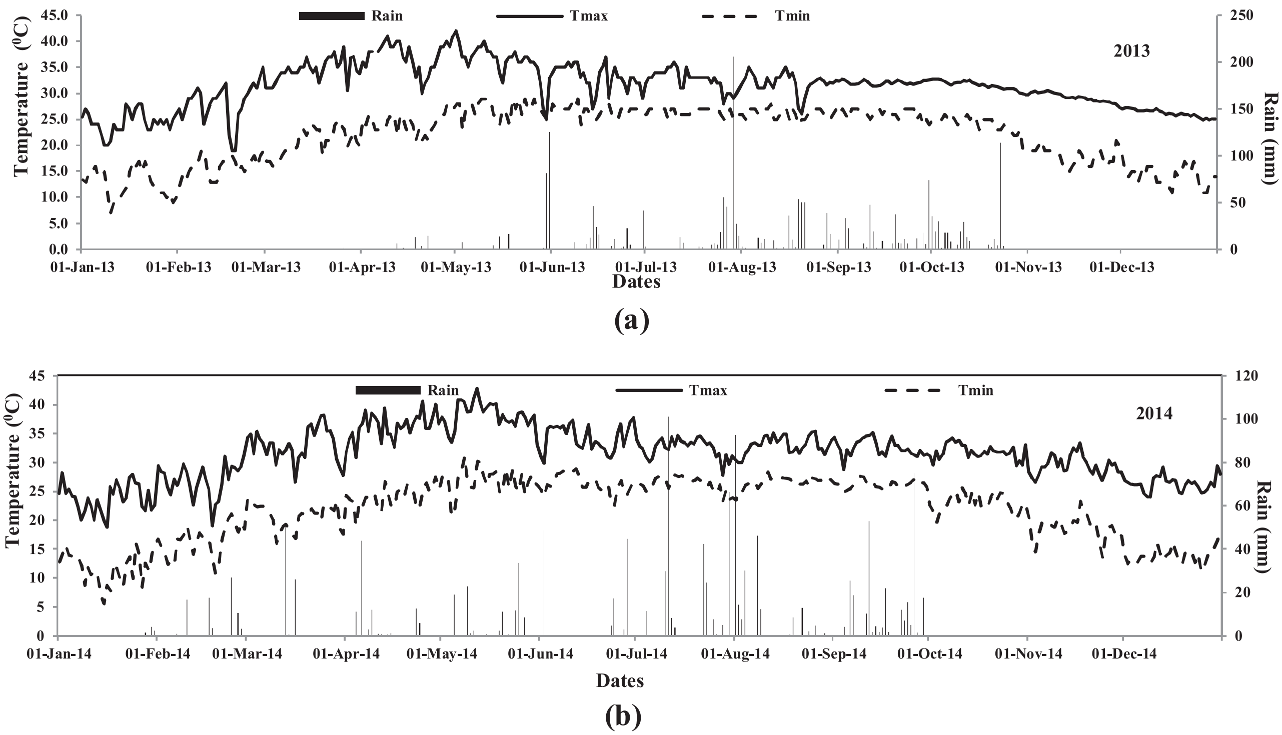

Fig. 1. Temporal variation of rain (mm), Temperature (maximum and minimum) at Kharagpur study area for the year a) 2013 and b) 2014 respectively.

drainage are negligible. The precision in soil water balance confides on space and time scales of actual measurement of soil water. The Time Domain Reflectometry (*TDR*) is a method that can be used to estimate ET for irrigation management. With the application of the *TDR* probes it is feasible to obtain a soil water balance at hourly, and plot scales (Rana and Katerji, 2000; Schelde et al., 2011; Topp et al., 1994). As *TDR* method is capable of giving daily soil moisture content so instead of calculating the evapotranspiration for a 7-day week period, the evapotranspiration was calculated on a daily basis. Thus, the cumulative evapotranspiration obtained on a daily basis would yield more precise results in comparison to weekly period in which fluctuations corresponding to soil moisture would be more.

The process based single layer *Penman–Monteith* (*PM*) (Irmak and Muttibwa, 2010; Monteith et al., 1965) is one of the most widely acceptable and used method for the evaluation of evapotranspiration (Allen et al., 1998, 2005; Katerji and Rana, 2006; Katerji et al., 2011; Gharsallah et al., 2013). The *PM* method calculates ET_c without an intermedial computation for a reference surface (Rana and Katerji, 2008, 2009) and is derived from the principles of energy conservation and air diffusion (Li et al., 2014). The single layer *PM* method uses the aerodynamic resistance (r_a) and canopy resistance (r_c) with the stomatal conductance and the effective leaf area index (Allen et al., 1998). However, the *PM* model requires values of r_c which is crop-specific and varies with respect to microclimatic attributes of the boundary layer above the crop (Irmak and Muttibwa 2010; Rana and Katerji, 2009).

The r_c is a physiological as well as aerodynamic parameter in the ET process, and is a function water potential, and meteorological variables (Alves et al., 1998; Alves and Pereira, 2000; Lecina et al., 2003; Perrier, 1975). Many approaches have been developed to calculate r_c using microclimatic variables and plant or soil water status as inputs (Ershadi et al., 2015; Irmak and Muttibwa, 2010; Li et al., 2014; Stewart, 1988). The ET_c estimated on the basis of soil moisture balance and meteorological variables are not so accurate, since the error is high due to fluctuation in weather variables. However, in case of canopy resistance approach, which relies on the leaf area index and stomatal conductance, can help in estimation of ETc with higher accuracy level (Gharsallah et al., 2013).

Maize (*Zea mays*) is a major crop after rice and wheat that can grow in different soils and climatic conditions; however, it is sensitive to water stress (Panda et al., 2004; Zhao et al., 2010). The most critical growth stage of maize is flowering, which affects its biomass, grain yield and plant height (Farréa and Faci, 2008; Pandey et al., 2000). Several studies have been conducted to assess the water requirement of maize (Djaman and Irmak, 2013; a and Faci, 2006, 2008;). The primary objective of this study was to compare four different canopy resistance (*rc*) approaches using the standard PM method to calculate ETc for irrigated maize in a sub-humid region. The four approaches considered were: (a) *Monteith* (Monteith et al., 1965), (b) *Katerji and Perrier* (Katerji and Perrier, 1983), (c) *Todorovic* (Todorovic, 1999), and (d) *Jarvis* (Jarvis, 1976) approaches. These values of ET_c approaches were then compared on a daily basis with ET_c estimated using SWB and measured soil water content variations. The best approach to estimate the irrigated maize ETc was selected on the basis of statistical analysis comparing the values estimated by different models and those obtained from the SWB method.

2. Materials and methodology

2.1. Experimental site

Two field experiments were conducted on irrigated maize at the experimental farm of Department of Agricultural and Food Engineering, Indian Institute of Technology, Kharagpur, West Bengal, India (22.33° N latitude, 87.33° E longitude, and altitude 48 *m*) in the year 2013 and 2014 (Srivastava et al., 2017a, 2017b). The texture of the soil is sandy loam; and classified as an 'Alfisol' (Halder et al., 2016, 2017) with a field capacity of 23%, and a wilting point of 10% and an effective root depth of 0.6 m (Srivastava et al., 2017a).

2.2. Meteorological conditions

Kharagpur climate is classified as sub-humid with an average temperature range of 21–41 °C, with an average rainfall of 1200–1500 mm annually (Srivastava et al., 2017a, 2017b). The weather data was