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Simple equation for estimating actual evapotranspiration using heat units for wheat in arid regions

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ABSTRACT

Estimation of actual evapotranspiration (ET_a) is an important part of agricultural water management in local and regional water balance studies. At the field scale, ET_a is important in irrigation planning and scheduling and is an integral part of field management decision support tools. The conventional approach of estimating actual evapotranspiration is difficult and needs more calculations and extensive data on soil-plant-atmosphere. A field experiment was conducted to simplify the measurement and calculation of actual evapotranspiration by using thermal units (heat units) for spring wheat crop under trickle irrigation system in sandy soil. Two irrigation methods were applied; the first one (A) using the crop evapotranspiration (ET_c) that depends on whether parameters, and the second (B) is the depletion from field capacity which dependent on soil parameters. Three varieties of wheat namely Sids12, Misr2 and Gemmeza10 were cultivated on sand soil and treatments arranged in complete randomized block design with three replicates.

Application of treatment (B) resulted in highly significant increase in yield production of Gemmeza10 and Misr2 as compared to treatment (A). Grain yield of different wheat varieties grown under treatment (B) could be ranked in the following descending order: Misr2 > Gemmeza10 > Sids12. While under treatment (A) it could be arranged in the following descending order: Misr2 > Sids12 > Gemmeza10. On the other hand, the overall means indicated non-significant difference between all wheat verities. The highest values of water and irrigation use efficiency as well as heat use efficiency were obtained with treatment (B). The equation used in the present study is available to estimate ET_a under arid climate with drip irrigation system.

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1. Introduction

Estimation of Actual evapotranspiration (ET_a) is of vital importance in water resources management and planning in Egypt. Crop water requirements vary during the growing season, mainly due to variation in crop canopy and climatic conditions, and are governed by crop evapotranspiration (ET_c) (Benli, Kodal, Ilbeyim, & Ustun, 2006). There are different indirect methods to estimate crop water requirements (Radiation, Blaney-Criddle, Penman–Monteith equations and Pan Evaporation) based on whether parameters, also direct information from usually one variable of the soil–water–plant system to estimate the soil water content such as the neutron probe and time-domain-reflectometry (TDR), or soil water tension in the soil by tensiometers or gypsum blocks. Nevertheless, all such devices present problems when they are used in large irrigation areas due to temporal and spatial variability of measurements and high costs of installation and management, in addition to sample alteration and low sampling volume (Ojeda-Bustamante, Sifuentes-Ibarra, Slack, & Carrillo, 2004).

Temperature is the one of the most important parameters of the climate which the potential productivity level for winter crops (Kalra et al., 2008). For most plants phonological development from seeding to maturity is related to temperature and daily accumulation of heat units. The amount of heat units required to move the plant to next development stage remains constant from year to year, however the actual amount of time (days) can vary considerably from year to year because the change of weather conditions. The temperature is a major environmental variable influencing plant growing and development, heat units are often used to predict the rate phonological development of plant species development rates increasing approximately linearly as a function of air temperature. Heat units are measured of time duration at various temperatures, therefore heat units are used to quantify phonological development (Snyder, Spano, Cesaraccio, & Duce, 1999).

Spring wheat does not require chilling for heading and it is day-neutral. However, it is also sensitive to frost. For winter and spring wheat minimum daily temperature for measurable growth is about 5 °C. Mean daily temperature for optimum growth and tillering is between 15 and 20 °C (Doorenbos & Kassam, 1979; Lallukka, Rantanen, & Mukula, 1978). The optimum post anthesis temperature for maximum kernel weight in wheat is about 15 °C (Chowdhury and Wardlaw, 1978), and each 1 °C rise in temperature above the optimum can cause a 3–5% reduction in single grain weight under both controlled environments (Wardlaw, Dawson, Munibi, & Fewster, 1989) and field conditions (Wiegand & Cuellar, 1981).

Most wheat production systems do not often exceed average daily temperatures greater than 30 °C, therefore, upper threshold temperatures, if used, are generally set to at least 30 °C, and errors in setting this upper threshold seem relatively minor for field predictions (McMaster et al., 2008). A threshold temperature refers to a value of daily mean temperature at which a detectable reduction in growth begins. A lower developmental threshold or a base temperature is one below which plant growth and development stop. Similarly, an upper developmental threshold is the temperature above which growth and development cease (Wahid, Gelani, Ashraf, & Foolad, 2007). Upper and lower developmental threshold temperatures differ for different plant species and genotypes within species. However, determining a consistent upper threshold temperature is difficult because the plant behavior may differ depending on other environmental conditions (Miller, Lanier, & Brandt, 2001).

This study presented a simple equation for estimating the actual evapotranspiration (ET_a) from weather and soil parameter by using growing degree days (GDD). This equation is easy to use and applied in arid climate. In addition, estimates yield, WUE, IWUE and HUE for wheat crop.

2. Materials and methods

2.1. Location and soil description

Filed experiment was conducted at the farm of Soil and Water Research Department, Nuclear Research Center, Atomic Energy Authority, Inshas, Egypt. It is located at 30° 24′ N latitude, 31° 35′ E longitude while the altitude is 20 m above the sea level. Soil amendment was added before cultivation at the rate of 48 m^3/h and mixed with the upper 25 cm of the soil layer. Tables 1 and 2 show some physical properties according to (Klute, 1986) and chemical properties according to (Page, 1982) of an experimental sandy soil.

2.2. Crop and irrigation treatments

Three varieties of wheat early, moderately, and late mature; Sids12, Misr2 and Gemaza10, respectively, were cultivated; under a complete block design. The varieties where cultivated in 2nd December 2012 and harvested at 11, 14 and 17 April 2013 for Sids12, Misr2 and Gemmeza10, respectively. The amount of seeds required was 150 kg ha^{-1}. The seeds planted at spacing of 15 cm between plants and 30 cm between rows.

Two treatments of irrigation water application were used, the first one treatment (A) using the crop evapotranspiration (ET_c) that was calculated by reference evapotranspiration (ET_0) and recommended crop coefficient (K_c) Eq. (1) (Doorenbos & Kassam, 1979), the Penman-Monteith equation was used to calculate reference evapotranspiration (ET_0) Eq. (2), the variables of this equation were described in FAO Irrigation and Drainage Paper No.56 (Allen, Smith, Perrier, & Pereira, 1998), and the second application treatment (B) was the quantity of soil moisture depletion has been depleted from field capacity through the root zone of soil profile as shown in Table 3 according to (Israelsen & Hansen, 1962).

$$ET_C = K_C ET_0 \quad (1)$$

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (2)$$

where:

ET_c: Crop evapotranspiration [mm d^{-1}],
K_c: Crop coefficient [–].

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