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ScienceDirect
Agricultural and Forest Meteorology 146 (2007) 94–106
AGRICULTURAL AND FOREST METEOROLOGY
www.elsevier.com/locate/agrformet

Surface energy fluxes and crop water stress index in groundnut under irrigated ecosystem

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Received 6 July 2006; received in revised form 18 January 2007; accepted 20 May 2007

Abstract

Reliable estimation of surface sensible and latent heat flux is the most important process to appraise energy and mass exchanges among atmosphere, hydrosphere and biosphere. In this study the surface energy fluxes were measured over irrigated groundnut during winter (dry) season using Bowen ratio (β) micrometeorological method in a representative groundnut growing areas of eastern India, i.e. Dhenkanal, Orissa. The crop was grown with four irrigations based on phenological stages *viz*., (i) branching, (ii) pegging, (iii) pod development and (iv) seed filling and assessed what the crop stress was at those times to see if irrigation scheduling cold be optimized further. Study revealed that the net radiation (R_n) varied from 393–437 to 555–612 W m^{-2} during two crop seasons (2004–2005 and 2005–2006). The soil heat flux (G) was higher (37–68 W m^{-2}) during initial and senescence growth stages as compared to peak crop growth stages (1.3–17.9 W m^{-2}). The latent heat flux (LE) showed apparent correspondence with the growth which varied between 250 and 434 W m^{-2} in different growth stages. The diurnal variation of Bowen ratio (β) revealed that there was a peak in the morning (9.00–10.00 a.m.) followed by a sharp fall with the mean values varied between 0.24 and 0.28. The intercepted photosysnthetic photon flux density or photosysntehtically active radiation (IPAR) by the crop was also measured and relationship between IPAR and leaf area index (LAI) was established with days after sowing. This relationship will be useful in developing algorithm of crop simulation model for predicting LAI or IPAR.

The stressed and non-stressed base lines were also developed by establishing relationship between canopy temperature and vapour pressure deficit (VPD). With the help of base line equation, [$(T_c - T_a) = -1.32\text{VPD} + 2.513$], crop water stress index (CWSI) was derived on canopy-air temperature data collected frequently throughout the growing season. The soil moisture depletion was measured throughout the crop growing period and plotted with CWSI at different stages. The values of CWSI (varied between 0.45 and 0.64) were noted just before the irrigations were applied based on phenological stages. Study revealed that at two stages (branching and pegging), CWSI were much lower (0.46–0.49) than that of recommended CWSI (0.60) for irrigation scheduling. Therefore, more research is required to optimize the phenology based irrigation scheduling further in the region, which method is using now by local producers.

Keywords: Energy balance; Bowen ratio; Leaf area index; Groundnut; Crop water stress index

1. Introduction

Groundnut is the dominant oilseed crop in Orissa, eastern India (Latitude 17°22′–22°45′N and Longitude 81°45′–87°50′E), covering an area of 250.46 thousand ha, which is mostly grown without irrigation during rainy season or with carry-over residual soil moisture

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doi:10.1016/j.agrformet.2007.05.008

during dry/winter season. But growing of groundnut with irrigation is gaining popularity in the state during winter season (November–December to February–March) when rainfall is limited. It is possible to increase groundnut production in the state after studying energy and water balance, particularly with availability of high yielding varieties for cultivation during winter season.

Solar radiation is the primary energy source that drives most of the processes of importance to soils and plants like evapotranspiration, biomass partitioning, stomatal conductance, carbon exchange and water use efficiency (Figuerola and Berlinger, 2006; Brown and Halweil, 1998; Kar, 2005). The studies of surface energy fluxes, radiation utilization and crop water stress of important crops of any region are of paramount importance to understand the different factors and their influence on plant growth and development (Shen et al., 2004).

Sensible and evaporative heat loss are the most important processes in the regulation of energy and leaf temperature, and the ratio of the two is called the Bowen ratio. The Bowen Ratio Energy Balance (BREB) is a micrometeorological method to quantity crop water use which was used by many authors to evaluate crop water use models (Cargo and Brutsaert, 1996; Grelle et al., 1999; Perez et al., 1999; Mo and Liu, 2001; Nicholas and Cuenca, 1993; Shen et al., 2002, 2004). Generally where water does not limit transpiration and when soil is wet, latent heat flux consumes most of the energy from net radiation. As the soil dries and water becomes less available for evapotransportion, the energy must go into heating the soil (soil heat flux) or heating the air (sensible heat flux).

Jackson et al. (1981) presents the theory behind the energy balance that separates net radiation from the sun into sensible heat which heats the air and latent heat that is used for transpiration. As the crop undergoes water stress due to non-availability of soil moisture the stomata closes and transpiration decreases, as a result leaf temperature increases. The crop water stress is indicated by the crop water stress index (CWSI) which is the measure of the relative transpiration rate occurring from a plant (using a measure of plant temperature).

Number of studies were carried out in different parts of the world based on micrometeorological measurements for energy balance computation (Reginato and Howe, 1985; Zhang and Lemeur, 1995; Rana and Katerji, 2000; Zhang et al., 2002). The CWSI for monitoring water status and irrigation scheduling of different crops was studied by many earlier workers (Idso et al., 1981; Azam et al., 1986; Sammis et al., 1988; Hatfield, 1990; Moran et al., 1994; Nielsen and Gardner, 1989; Grelle et al., 1999; Calvet, 2000; Irmak et al., 2000; Orta et al., 2002). There is still a need for a better understanding of the process controlling evapotranspiration and energy partitioning of the important crops like groundnut in eastern India where farmers' traditional practice is to irrigate the crop based on phenological stages. Earlier studies on groundnut in the region (Kar et al., 2006) revealed that four irrigations were required to provide optimum yield and based on this recommendation local producers schedule irrigation for growing the crop. But there is a need to assess the stress (in terms of CWSI) at the time of irrigation at different growth stages to investigate if this procedure could be optimized further. Keeping the importance of above aspects in view, in this research work we have attempted to study distribution of surface energy fluxes and crop water stress index (CWSI) with application of irrigation at different growth stages. The values of CWSI were particularly noted just before application of irrigations.

2. Material and methods

2.1. Study area

The study was conducted at Dhenkanal district, Orissa, India (Latitude 20°50′ to 20°55′; Longitude 85°45′ to 85°50′; 139 m above m.s.l.) during two winter/dry seasons (2004–2005 to 2005–2006). The region belongs to sub-humid subtropical agro-ecological zone where average annual rainfall is 1440 mm and 80% of that received during rainy season (June–September) due to southwest monsoon. The mean monthly maximum temperature ranges from 46.2 °C in May to 29.4 °C in December. On the other hand, mean monthly minimum temperature varies between 24.6 °C in July and 9.0 °C in December. Generally in the region, the winter season is dry, as a result cropping system is mainly confined to rainy season, dominated by rice. But now groundnut is getting popular in the region as an important oilseed crop during dry/winter season with the help of carry-over residual soil moisture and supplemental irrigations from harvested rainwater of rainy season.

2.2. Weather during crop growth period

The normal as well as prevailing weather conditions during two crop growth seasons (2004–2005 and 2005–2006) are given in Table 1. The study revealed that the