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Diurnal energy balance studies over wheat using Bowen ratio energy balance method

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सार — सिंचित गेहूं की बढ़वार की विभिन्न अवस्थाओं पर बोवन अनुपात ऊर्जा संतुलन (बी आर ई बी) पद्धति के प्रयोग से ऊर्जा के संतुलन का अध्ययन किया गया। मेघ रहित दिनों में कुल विकिरण 517 से 694 डब्ल्यु एम$^{-2}$ के बीच रहा। संधान, पुष्पन, कोमल गुम्फावस्था और पूर्ण गुम्फावस्था में दोपहर के दौरान गुप्त ऊष्मा, कुल विकिरण के क्रमश: 89, 101, 92 और 101 प्रतिशत के लगभग रही। मृदा ऊष्मा अभिवाह (फ्लक्स) विकिरण के 6 से 13 प्रतिशत के लगभग रहा और कोमल गुम्फावस्था में ऊष्मा अभिवाह (फ्लक्स) न्यूनतम रहा। यह पाया गया कि सुग्राही ऊष्मा अभिवहन एक आम परिघटना थी जिसका कुल विकिरण में लगभग 2 से 8 प्रतिशत योगदान रहा तथा 1400 बजे के बाद सभी अवस्थाओं में उसकी तीव्रता अधिक रही।

ABSTRACT. Energy balance study was conducted over wheat crop at its various growth stages under irrigated conditions using Bowen Ratio Energy Balance (BREB) method. On clear days net radiation (R_n) ranged from 517 to 694 Wm^{-2}. The mid-day latent heat partitioning was approximately 89, 101, 92 and 101% of R_n at jointing, flowering, soft dough and hard dough stages respectively. The soil heat flux *(S)* was approximately 6 to 13% of R_n and was minimum at soft dough stage. The sensible heat advection was found to be a common phenomenon and contributed approximately 2 to 8% of R_n at mid-day and its intensity was more after 1400 hrs at all stages.

Key words — Jointing stage, Flowering stage, Soft dough stage, Hard dough stage, Latent heat flux, Sensible heat flux, Soil heat flux, Bowen ratio, Sensible heat advection.

1. Introduction

Energy balance studies help to understand the response of plant communities to environmental stress. The measurement of energy balance components and especially latent heat flux have applications in calibrating and validating crop and water balance models, validation of remote sensing assessment of crop status and water use and thus helps in water resource management.

The energy balance over wheat crop has been studied for temperate and Australian conditions (*e.g.*, Denmead and McIlroy 1970, Aese and Siddoway 1982, Brun *et al.* 1985 and Kim *et al.* 1989). However, there is very little information on the diurnal pattern of energy balance components over wheat under semi-arid regions. This region is prone to abundant heat supply and low precipitation.

The Bowen Ratio Energy Balance (BREB) (Bowen 1926) method is the simplest and most practical method for estimating latent and sensible heat fluxes. Its accuracy has been reviewed by Tanner (1960), Graham and King (1961), Fritschen (1965), Pruitt and Lawrence (1968), Denmead and McIlroy (1970), Fuchs and Tanner (1970), Blad and Rosenberg [1974 (a & b)], Sinclair *et al.* (1975), Revfeim and Jordan (1976), Spittlehouse and Black (1980), Kim *et al.* (1989) and Dugas *et al.* (1991).

In this investigation the diurnal energy balance patterns were studied over wheat crop at Pune (18° 32'N, 73°51'E, 559 m amsl), which comes under semi-arid region.

2. Material and method

The study was conducted in the post-monsoon (Rabi) season of 1991-1992 at College of Agriculture Farm, Pune. Wheat *(Triticum aestivium)* var. HD 2189 was sown on an area of approximately 3.0 hec (275 m E-W by 110 m N-S) in N-S rows 22.5 cm apart considering necessary fetch requirements for micrometeorological measurements.

In the surrounding fields also wheat was planted. The soil was deep black with clayey texture and the agronomic practices followed were as per general recommendations.

The BREB method is based upon the principle of conservation of energy, *i.e.*, the energy entering the

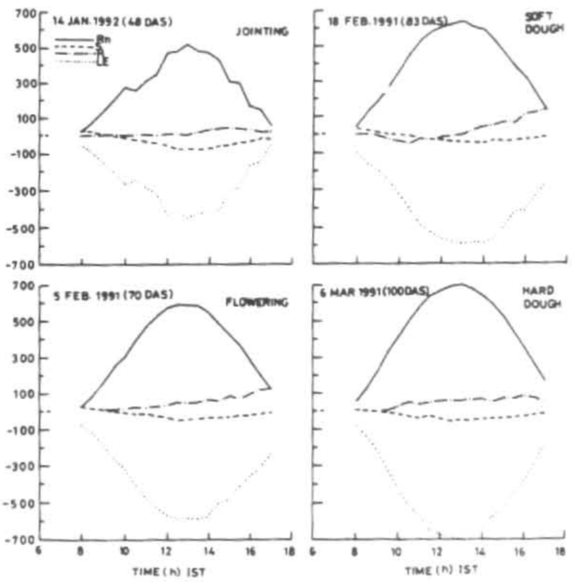

Fig. 1. Diurnal patterns of energy balance components at jointing. flowering. soft dough and hard dough stages in wheat crop

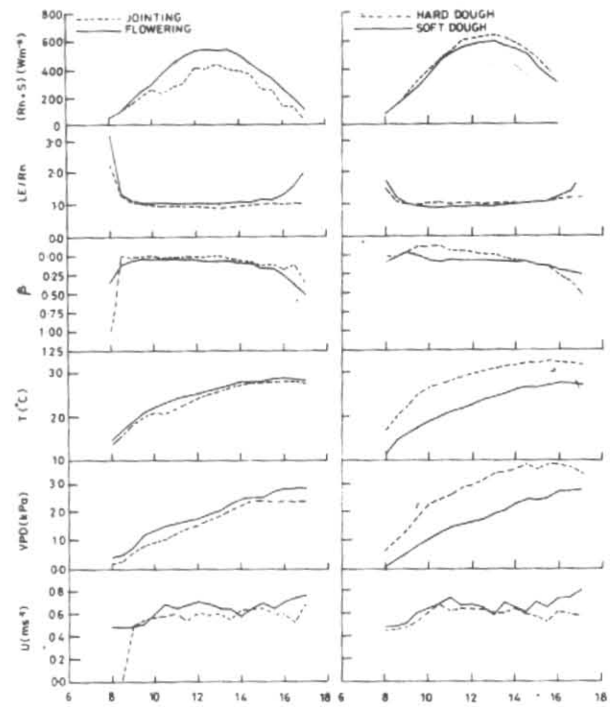

Fig. 2. Diurnal patterns of (R_n + S). LE/R_n. Bowen ratio, temperature. vapour pressure deficit (VPD) and wind speech (U) of jointing. flowering soft dough and hard dough stages

surface is equal to the energy leaving that surface. The energy budget for a crop surface is:

$$R_n+H+LE+S+PS+M=0 \quad (1)$$

where. R_n is net radiation. H is sensible heat flux, LE is latent heat flux and S is surface soil heat flux. all expressed in Wm^{-2}. PS and M are energy fixed in plants by photosynthesis and energy involved in respiration respectively, which are assumed negligible due to their minor contribution (about 1-2% of R_n). The sign convention followed was that the flux densities are assigned positive sign if they are towards the surface and negative sign if they are away from the surface.

The R_n was measured by net radiometer (REBS Inc., Seattle, U.S.A.) at 2.0 m height above ground. The soil heat flux at 5 cm depth was measured with two sets of soil heat flux plates (REBS Inc., Seattle, U.S.A.). One plate was installed within the row and the other between the rows. The averaging soil thermocouples (Copper-Constantan) were also buried at 1 cm and 4 cm depths. The surface soil heat flux (S) was estimated employing combination method (Tanner 1960).

Aspirated psychrometers with Automatic Exchange Mechanism (AEM) was used for reversing the psychrometer position to remove any instrumental bias. The dry and wet bulb temperatures were measured above the crop canopy with Chromel-Constantan thermocouples which were enclosed in a highly polished insulated radiation shield. The two psychrometers were calibrated prior to each growth stage in the field by bringing them at same level. Aerodynamic uniform ceramic wicks having consistent porosity were used to record wet bulb temperature. These wicks were attached to a positive head of distilled water supply which maintained the shining wet appearance needed to get full wet bulb depression. The two psychrometers were separated by 1 m distance and the position of lower psychrometer was always maintained~25 cm above the canopy so that both the psychrometers lie in the fully adjusted boundary layer. The mean wind speed was recorded at 2.0 m above ground with a three cup anemometer (014 Met One Inc., U.S.A.) and wind direction using wind vane (024 Met One Inc., U.S.A.). The signals from these micrometeorological sensors were recorded with 21X micrologger (Campbell Inc., U.S.A.). The 21X was programmed to switch the AEM every 15 min and record average data after the end of 15 min. After switching, the data from the psychrometers were not recorded for initial 3 min to allow the temperature sensors to attain equilibrium at the new position and check for real time data. The H and LE were computed using BREB technique. LE (the energy flux density associated with the latent heat of evaporation) was estimated as :

$$LE = \frac{-(R_n + S)}{1 + (\beta)} \quad (2)$$

where, β is expressed as :

$$\beta = \frac{H}{LE} = \frac{\rho\, c_p\, K_H\, (dT/dz)}{\frac{L\varepsilon\rho}{P}\, K_W\, (de/dz)} \quad (3)$$

where, H and LE are in Wm^{-2}, L — latent heat of vapourization for water ($kJkg^{-1}$), c_p — specific heat of dry air at constant pressure ($Jkg^{-1}\,{}^\circ K^{-1}$), ρ — density of air, ε — ratio of the molecular weight of water to that of air (0.622), P — atmospheric pressure at the site (kPa), dT/dz and de/dz are temperature and vapour pressure gradients respectively, over 1 m height. After simplifying

$$\beta = \frac{c_p P\, K_H\, dT}{L\, \varepsilon\, K_W\, de} = \gamma\, \frac{dT}{de} \quad (4)$$

where, $c_pP/L\varepsilon$ is the psychrometric constant (γ) (0.0623 $kPa\,{}^\circ C^{-1}$) and this approach is further simplified with the assumption of equality of the turbulent transfer coefficients for heat and water vapour (K_H and K_W in m^2s^{-1}).

3. Results and discussion

3.1. *Diurnal patterns*

Fig. 1 shows the typical diurnal energy balance components for jointing, flowering, soft dough and hard dough stages of wheat. The day of observation during jointing stage was slightly cloudy during the early part of the day resulting in low R_n. At jointing stage the R_n, S and LE were maximum at 1300 hr and were 518, —77 and —443 Wm^{-2} respectively. On day of observation during flowering stage the sky was clear and R_n followed a normal inverted parabolic curve reaching its maximum value of 588 Wm^{-2}, at 1230 hr. At the same time S and LE were −50 and −586 Wm^{-2} respectively. At soft dough stage R_n reached its maximum of 641 Wm^{-2} at 1300 hr and its partitioned components, *viz.*, S, H, LE were −44, −5 and −592 Wm^{-2} respectively, while at hard dough stage R_n reached its maxima of 694 Wm^{-2}, at 1300 hr and S and LE were −53 and −695 Wm^{-2} respectively. At this time Sensible Heat Advection (SHA) was to the tune of 54 Wm^{-2}. At jointing, during mid-day (1100 to 1400 hr)~89% of R_n was consumed in LE and ~13% in S. At flowering~101% of R_n was consumed in LE and 6% by S. About 7% of energy was added by SHA. Kim *et al.* (1989) in an experiment conducted in U.S.A. reported that during anthesis stage in wheat the maximum R_n was~640 Wm^{-2} and LE was~91% of R_n. He found sensible heat advection to begin in the late afternoon and ranged from 80 to 210 Wm^{-2}. Brun *et al.* (1985) showed that with favourable soil moisture ET from spring wheat was 92% of R_n. At soft dough stage, during mid-day~92% of R_n was consumed by LE.~6% by S and ~2% by H while at hard dough stage~101% of R_n was consumed in LE and~7% in S. Here too SHA contributed~8% to the energy balance.

Some factors and indicators of energy balance are shown in Fig. 2. The mid-day mean air temperature (T) ranged from 22 to 27°C at jointing, 24 to 28°C at flowering, 21 to 26°C at soft dough stage and 28 to 32°C at hard dough stage (Fig. 2).

Similarly, the corresponding mid-day mean VPD ranged from 1.2 to 2.2 kPa at jointing, 1.6 to 2.5 kPa at flowering, 1.4 to 2.3 kPa at soft dough stage and 2.6 to 3.5 kPa at hard dough stage. This indicates a high atmospheric demand at hard dough stage which resulted in highest recorded ET during crop growth period. The mean mid-day wind speeds did not show large variations. They were around 0.60, 0.65, 0.66 and 0.63 mm^{-1} at jointing, flowering, soft dough stage and hard dough stage respectively.

The LE/R_n (relative amount of R_n consumed as LE) ratio was above 1 from 0800 to 0930 hr at jointing stage and also above 1 from 0800 to 1100 hr at flowering stage (Fig. 2). It resulted because S was towards surface during early morning. At the jointing and flowering stage for 1330 hr onwards till late evening the LE/R_n ratio was 0.9 and 0.9 to 1.5 respectively. The LE/R_n ratio above 1 is attributed to SHA. From 0930 hr at the jointing and 1100 hr at the flowering stage till 1330 hr the LE/R_n ratio followed usual pattern.

The Bowen ratio (β) was negative almost through the day at jointing, flowering and hard dough stage due to consistent SHA. β was positive around 0.04 to 0.12 from 0900 to 1300 hr at soft dough stage. From 1400 hr onwards the β ranged from −0.04 to −0.53 due to advection. The β at maximum R_n and LE at jointing, flowering, soft dough and hard dough stages was −0.01, −0.08, 0.01, and −0.08 respectively. Later in the afternoon it became further negative due to SHA.

3.2. *Sensible heat advection (SHA)*

At jointing and flowering stage H was positive through the day and ranged from 1 to 42 Wm^{-2} and 10 to 127 Wm^{-2} respectively (Fig. 1). At jointing stage the *LE* was slightly less than R_n but at flowering stage *LE* was more than R_n from 1330 hr onwards which suggest a definite case of SHA (Fig. 2).

At soft dough stage H was positive from 1330 hr onwards in the range of 21 to 137 Wm^{-2} while at hard dough stage H was positive in the range of 20 to 81 Wm^{-2} but *LE* was more than R_n from 1000 hr onwards which shows occurrence of SHA (Fig. 2).

4. Conclusion

Under irrigated conditions in semi-arid regions the sensible heat advection is a normal phenomenon rather than an abnormal condition. It ranged from 1 to 42 Wm^{-2} at jointing, 10 to 127 Wm^{-2} at flowering, 21 to 137 Wm^{-2} at soft dough and 25 to 81 Wm^{-2} at hard dough stage. The duration and intensity of SHA are significant. The maximum R_n ranged from 518 to 694 Wm^{-2} from jointing to hard dough stage. The mid-day *LE* ranged from 6 to 13% depending on crop stage. The additional energy was contributed by SHA which was around 2 to 8% of R_n. The temperature and VPD over the crop were good indicators of atmospheric status but energy balance depends on crop and soil factors too.

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