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

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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, Ase 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.


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 AESTIVUM) var. HD 2189 was sown on an area of approximately 3.0 hectar (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
surface is equal to the energy leaving that surface. The energy budget for a crop surface is:

\[ R_n + H + LE + S + PS + M = 0 \]  \( (1) \)

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 W m\(^{-2}\). \( PS \) 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:

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

where $\beta$ is expressed as:

$$\beta = \frac{H}{LE} = \frac{\rho \, c_p \, K_H \left(dT/dz\right)}{\frac{\rho}{} \, L_e \, K_W \left(de/dz\right)} \quad (3)$$

where $H$ and $LE$ are in Wm$^{-2}$, $L_e$ - latent heat of vapourization for water (kJkg$^{-1}$), $c_p$ - specific heat of dry air at constant pressure (kJkg$^{-1}$ K$^{-1}$), $\rho$ - density of air, $e$ - 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

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

where, $c_p P/LE$ is the psychrometric constant ($\gamma$) (0.0623 kPa°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$^2$s$^{-1}$).

3. Results and discussion

3.1. Diurnal patterns

Fig. 1 shows the typical diurnal energy balance components for joining, flowering, soft dough and hard dough stages of wheat. The day of observation during joining stage was slightly cloudy during the early part of the day resulting in low $R_n$. At joining 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 joining, 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 joining, 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 joining, 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 joining, 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 joining 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 joining 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 joining and 1100 hr at the flowering stage till 1330 hr the $LE/R_n$ ratio followed usual pattern.

The Bowen ratio ($\beta$) was negative almost through the day at joining, flowering and hard dough stage due to consistent SHA. $\beta$ was positive around 0.04 to 0.12 from 0900 to 1300 hr at soft dough stage. From 1400 hr onwards the $\beta$ ranged from ~0.04 to ~0.53 due to advection. The $\beta$ at maximum $R_n$ and $LE$ at joining, 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 joining 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.

References


