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Surface energy fluxes in wheat (Triticum aestivum L.) under irrigated ecosystem

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ABSTRACT

The surface energy fluxes were measured over irrigated wheat during winter season. 2008-09 and 2009-10 sown on first week of November. Study revealed that the net radiation flux (Rn) varied from 420 to 693 was during 2008-09 and 328 to 926 W m-2 during 2009-10 in different growth stages. The soil heat flux was higher during initial and senescence growth stages (13 to 15 % of net radiations) as compared to peak crop growth stages (6 to 9 % of net radiations). The latent heat flux showed apparent correspondence with the growth which varied from 247 to 387 W m-2 during 2008-09 and 209 to 569 W m-2 during 2009-10 in different growth stages. Study revealed that LAI was positively related with intercepted photosynthetically active radiation (IPAR).

Key words: Energy balance, wheat, bowen ratio, net radiations, latent heat flux

Wheat (Triticum aestivum L.) is the very important and remunerative Rabi crop of North India. It is the second most important cereal crop after rice. It is grown under diverse agro-climatic conditions on 27.8 million hectares area in India with a production of 80.7 million tonnes during the season 2008-09 (Anonymous 2009). During the post-green revolution the productivity of wheat has increased but it is far below the potential yield. It is possible to increase wheat production in the country after studying energy and water balance, particularly with availability of high yielding varieties for cultivation during winter season.

Solar radiation is primary energy source that derives most of the processes of importance to soils and plants like evapotranspiration, biomass partitioning, stomatal conductance, carbon dioxide 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 (Heitman *et al*, 2010; Shen *et al*., 2004).

Sensible and evaporative heat losses are the most important processes in the regulation of energy and leaf temperature, and the ratio of two is called the Bowen ratio. The Bowen ratio energy balance (BREB) is a micrometeorological method to quantify crop water use which was used by many authors to evaluate crop water use models (Mo and Liu, 2001; Shen *et al*. 2002). 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 evapotranspiration, the energy must go into heating the soil (soil heat flux) or heating the air (sensible heat flux).

Measurements of latent (λE) and sensible (H) heat flux densities in the atmospheric boundary layer are useful for understanding processes in agriculture and meteorology and also for management applications. Several methods exist for ëE and H measurements (Dyer 1974).

The Bowen ratio energy balance (BREB) system is a ground-based system using in situ sensors to estimate the vertical fluxes of sensible and latent heat at the local surface. The Bowen ratio-energy balance has often been used with very high accuracy (Ashktorab *et al*. 1989, Nkemdirim and Haley 1973, Malek and Bingham 1993, Jegede 2002). Keeping in view the importance of energy distribution on earth surface the present study was carried out to estimate the different components of energy fluxes under irrigated ecosystem.

MATERIALS AND METHODS

Study area

The present field investigation was conducted at the experimental farm, Department of Agricultural

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Table 1: Normal as well as actual weather data during crop growth period

Parameters	Months					
	November	December	January	February	March	April
Total Rainfall (mm)						
2008-09	0.4	0.4	17.7	21.7	16.0	25.0
2009-10	5.1	00	18.4	25.0	2.0	4.4
Normal	9.4	16.9	25.4	29.9	26.1	18.3
Mean maximum air temperature (^{0}C)						
2008-09	27.6	21.2	19.6	23.1	28.9	34.1
2009-10	25.1	21.1	15.7	22.5	31.0	38.7
Normal	26.7	20.4	18.9	21.6	26.6	34.2
Mean minimum air temperature (^{0}C)						
2008-09	11.1	8.6	7.7	8.9	12.9	17.6
2009-10	10.6	6.5	6.6	9.0	14.8	20.1
Normal	10.1	6.1	5.3	7.2	11.3	16.9
Mean relative humidity (%)						
2008-09	66	78	79	73	65	41
2009-10	67	71	86	72	65	45
Normal	61	68	71	69	63	47

Meteorology, Punjab Agricultural University, Ludhiana during the Rabi season 2008-09 and 2009-10. Ludhiana is situated at 30^0-54' north latitude and 75^0-48' east longitude at a height of 247 m above the mean sea level. The climate of Ludhiana is of semi-arid with extreme winter type. The meteorological observatory nearest to the present study is located in Research farm, Department of Agricultural Meteorology, Punjab Agricultural University, Ludhiana.

Wheat crop (cv. PBW 343) was sown with the row spacing of 22.5 cm on first week of November, during both the seasons 2008-09 and 2009-10. Four irrigations (7.5 cm water in each irrigation) were applied at four critical phenological stages of the crop viz., (i) CRI (ii) late tillering (iii) booting (iv) milking, which coincided with 20 to 25, 40 to 45, 70 to75, 115 to120 days after sowing, respectively in two different seasons. . Fertilizer application will given as per recommendation

Measurement of LAI

Leaf area index (LAI) of the crop was measured with Plant Canopy Analyzer (LICOR 2000) at 15 days interval starting at 30 days after sowing (DAS) during crop growth season.

Measurement of surface energy fluxes and Bowen ratio

Components of the surface fluxes of the energy balance equation were determined using a Bowen ratio energy balance (BREB). The fluxes are obtained by the energy balance Bowen ratio technique, a gradient method that uses vertical gradients of temperature and vapour pressure in combination with point measurements of net radiation and soil heat flow. The Bowen ratio (β) was measured as the ratio of air temperature and vapour pressure gradients between two fixed heights within 2 m of the surface. Net radiation (Rn) was measured using net radiometers. Soil heat flux (G) was measured with ground heat flux plates.

Measuring the temperature and vapor pressure gradients between two levels within the adjusted surface layer, β is obtained as

$$\beta = \gamma \frac{\delta T/ \delta z}{\delta e/ \delta z} = \gamma \frac{\Delta T}{\Delta e}$$

Where ΔT and Δe are the temperature and vapor pressure difference between the two measurement levels, $\gamma = cpPa/\Sigma Lv$ is the psychrometric constant, cp (1.01 kJ kg^{-1} $°C^{-1}$) the specific heat of air at constant pressure, Pa the atmospheric pressure (kPa), Σ the ratio between the molecular weights of water vapor and air (0.622), and Lv the latent heat of vaporization (kJ kg^{-1}). The convention used for the signs of the energy fluxes is Rn positive

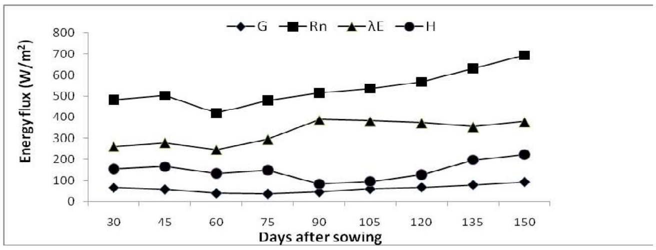

Fig 1 : Variation of energy fluxes of wheat during 2008-09

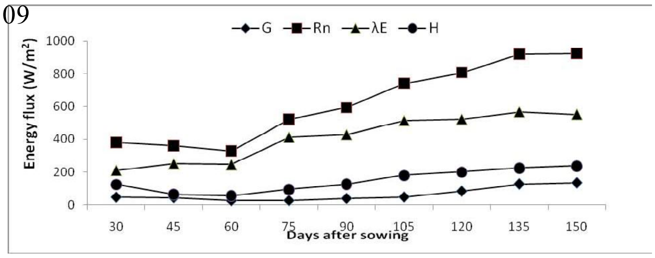

Fig 2 : Variation of energy fluxes of wheat during 2009-10

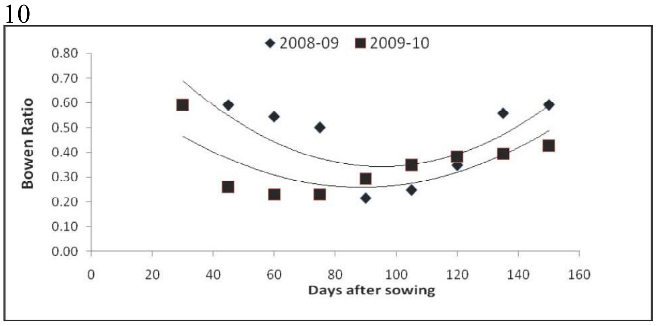

Fig 3 : Variation of Bowen Ratio of wheat

downward and G positive when it is conducted downward from the surface. Sensible and latent heat fluxes are positive upward, with a direction opposite to that of the gradients.

Intercepted photosynthetically active radiation (IPAR)

Quantum sensor meter (LQM70-10) was used to measure the intercepted photosynthetically active radiation (IPAR) by the whole canopy. IPAR was computed as per the following relationship.

IPAR by whole canopy= incident radiation on the canopy-reflected radiation by the canopy-transmitted radiation+ reflected radiation from the ground.

$$\text{IPAR (\%)} = \frac{\text{PAR received at any height } (\mu Es^{-1}\ m^{-2})}{\text{PAR incident above the crop canopy} (\mu Es^{-1}\ m^{-2})} \text{ X } 100$$

The reflected radiation was obtained by keeping the sensor inverted 0.5 m above the canopy and the sensor was kept on the ground across the rows diagonally to get transmitted radiation at the ground. To get the reflected PAR from the ground, the sensor was held in the inverse position at 0.05 m above the ground. The measurement was made at regular interval on clear days between 11.00 and 12.00 hrs IST when disturbances due to leaf shading and leaf curling were minimum.

RESULTS AND DISCUSSION

Variation of surface energy fluxes during crop growth period

The seasonal variation of surface energy fluxes over wheat during crop growth seasons revealed that net radiation (Rn), over the crop varied from 420 to 693 Wm^{-2} during 2008-09 and 328 to 926 Wm^{-2} during 2009-10 from December to April of crop growth season. The midday value of latent heat flux (on clear day) varies from 247 to 387 Wm^{-2} during 2008-09 and 209 to 569 Wm^{-2} during 2009-10 at different growth stages.

The seasonal course of soil heat flux (G) shows the peak value during early crop growth period when crop coverage was minimum and at harvest maturity stage of wheat crop. Midday G value ranged from 35 to 92 Wm^{-2} and 28 to 135 Wm^{-2} in wheat crop. The ratio of G/Rn from maximum LAI to senescence stage was found 6 to 13 per cent over the crop.

Bowen ratio was higher during early and senescence stages of crop growth which was due to higher sensible heat flux and lower latent heat flux during those periods (Fig. 3). The Bowen ratio started to decline from 30 DAS and minimum value of 0.22 was reached at 90 DAS during 2008-09 and 0.23 at 75 DAS during 2009-10 and there was a sharp fall of Bowen ratio during peak growth stage when leaf area index (LAI) was maximum. The higher LAI led to greater transpiration therefore latent heat flux density was higher during that period.

Diurnal variation of energy balance

Since diurnal variation of energy balance of both the crop growing season 2008-09 and 2009-10 shows more or less same trend, three crop growth stages (tillering, flowering and physiological maturity stages) of both the seasons were taken (Fig. 4 & 5) Net radiation (Rn) was the highest from 12.00 to 13.00 hrs with the values being 498, 505, 630 Wm^{-2} during 2008-09 and 398, 354, 813 W m^{-2} during 2009-10 in three respective crop growth stages (Fig. 4 & 5). Hourly λE was also highest during 12.00 to 13.00 hrs.

Intercepted photosynthetically active radiation (IPAR)

The variation of intercepted photosynthetically active radiation (IPAR) (Fig. 6). Shows maximum

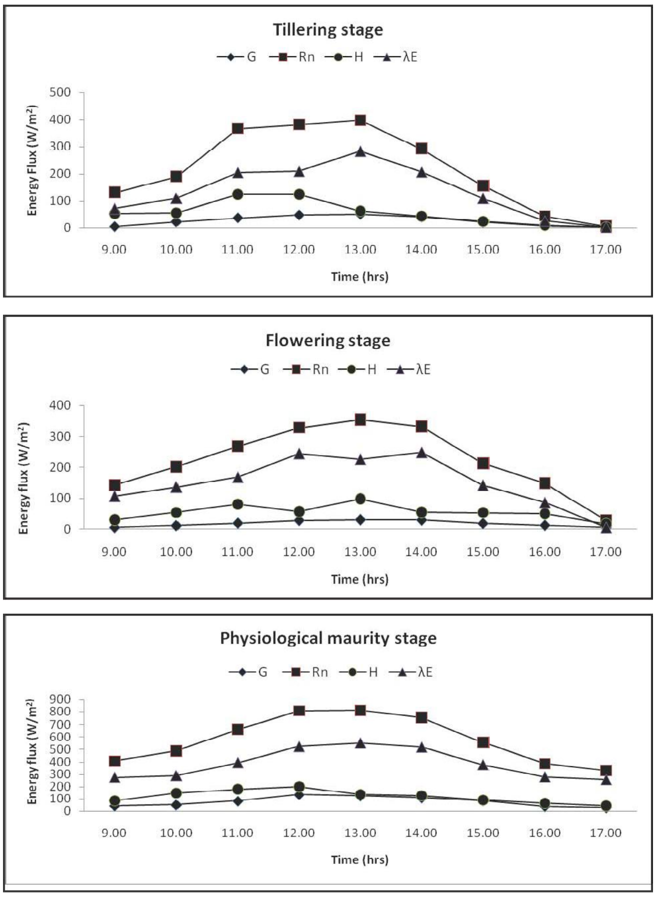

Fig 4 : Diurnal variation of energy balance of wheat at different growth stages during 2008-09

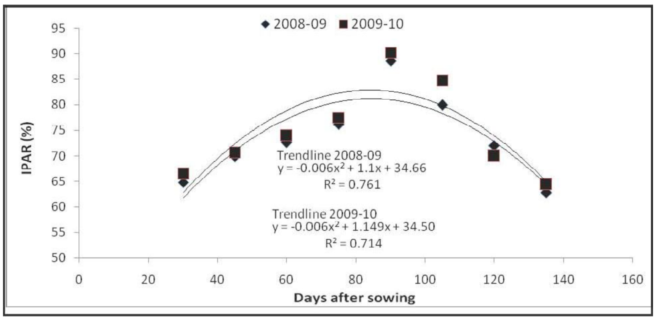

Fig 6 : Variation of IPAR with days after sowing (DAS) in wheat

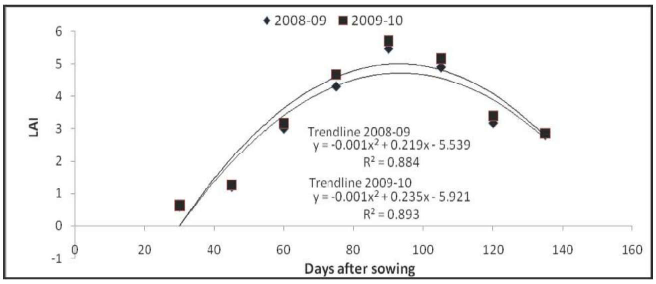

Fig 7 : Variation of LAI with days after sowing (DAS) in wheat

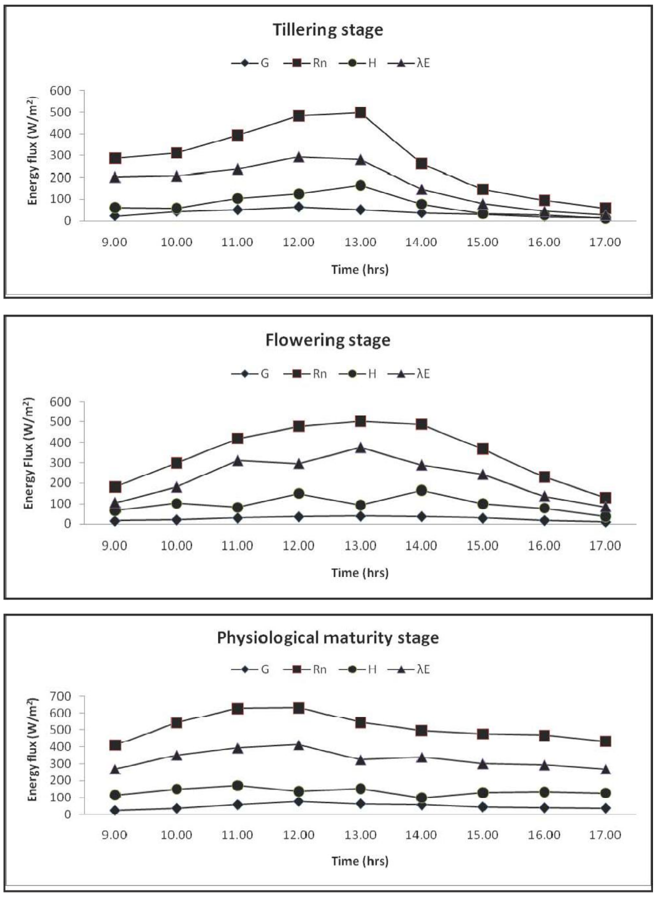

Fig 5: Diurnal variation of energy balance of wheat at different growth stages during 2009-10

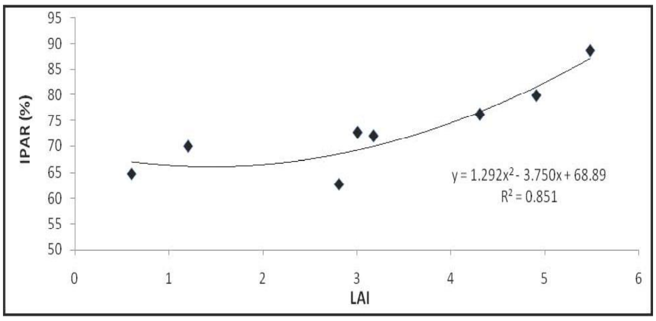

Fig 8 : Relationship between IPAR and LAI in wheat during 2008-09

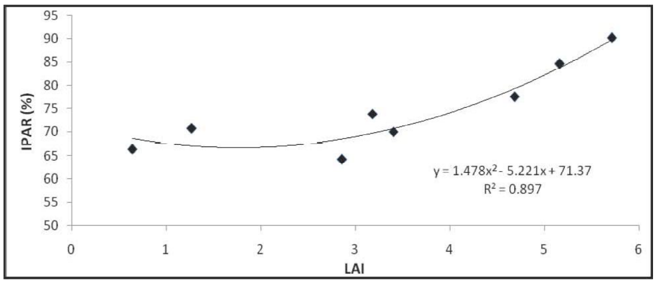

Fig 9 : Relationship between IPAR and LAI in wheat during 2009-10 interception of 88.6 and 90.2 per cent at 90 DAS during 2008-09 and 2009-10 respectively. The relationship between IPAR (%) and days after sowing (DAS) was established and a polynomial equation of second order (best fit) was derived to compute IPAR. The highest LAI of 5.48 and 5.71 were observed in 2008-09 and 2009-10, respectively (Fig. 7). A polynomial equation of second order was derived to compute LAI at different days after sowing (DAS). The relationship between IPAR and LAI was also established and equations were developed to predict IPAR of wheat with LAI data during both the seasons (Fig. 8 and 9). Study revealed that LAI was positively related with intercepted photosynthetically active radiation (IPAR). During the peak growth period, the soil heat flux (G) and Bowen ratio was less due to existence of highest leaf area index (LAI). The developed relationship of IPAR with DAS and LAI will be useful for development of algorithm of crop simulation model for prediction LAI and vice versa (Fig. 8 and 9). With the help of predicted LAI or IPAR, soil heat flux (G) can be derived.

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