

Study of energy balance components at different growth stages of green gram grown in new alluvial zone of West Bengal

SOUMEN MONDAL, SAON BANERJEE[#], SHAON CHAKRABORTY, SALIL SAHA,
ASIS MUKHERJEE and M. K. NANDA

Department of Agricultural Meteorology and Physics

Bidhan Chandra Krishi Viswavidyalaya, (B.C.K.V.), Mohanpur – 741 252, India

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[#]e mail : sbaner2000@yahoo.com

सार – हरे चने (विग्नारदितावर सम्राट) पर विकिरण पैटर्न और उसके संतुलन का अध्ययन करने के लिए बिधान चंद्र कृषि विश्वविद्यालय, नादिया, पश्चिम बंगाल के प्रायोगिक खेत में एक प्रयोग किया गया। इसमें संवेदनशील उष्ण प्रवाह और गुप्त ऊर्जा को निर्धारित करने के लिए ब्रेब (BREB) विधि का उपयोग किया गया। यहाँ कुल विकिरण को नेट रेडियोमीटर के माध्यम से मापा गया और भू-ऊष्मा प्रवाह को मापने के लिए फूरियर के नियम का उपयोग किया गया। कुल विकिरण के दैनिक और मौसमी भिन्नता दोनों का अध्ययन किया गया। इसी प्रकार, ऊर्जा संतुलन घटकों का अध्ययन भिन्न-भिन्न फसल विकास चरणों के लिए और दैनिक आधार पर नियमित रूप से किया गया। यह देखा गया है कि शुद्ध विकिरण 6.32 Wm^{-2} से 606.43 Wm^{-2} तक बदलता रहा है। जैसा कि ऊर्जा संतुलन विभाजन द्वारा दर्शाया गया है कि सभी विकास चरणों में कुल विकिरण के 50% से अधिक योगदान गुप्त उष्मा प्रवाह का होता है। हरे चने के विकास चरणों के दौरान संवेदी उष्ण प्रवाह को कुल विकिरण के 10% से 20% में विभाजित किया गया है, जो सभी तीन ऊर्जा प्रवाह के परिमाण में सबसे कम है। इसमें बोवेन अनुपात और वाष्प दबाव में कमी (वीपीडी), बोवेन अनुपात और कैनोपी वायु तापमान अंतर (CATD) के बीच के संबंध का अध्ययन किया गया है। यह पाया गया कि बोवेन अनुपात का VPD के साथ नकारात्मक सहसंबद्ध है लेकिन CATD के साथ इसका सकारात्मक रूप से सहसंबद्ध है। यह अध्ययन संवेदनशील और भू-ऊष्ण प्रवाह के माध्यम से गुप्त उष्मा प्रवाह और सूक्ष्मजलवायविक विशेषताओं के माध्यम से ईटी पैटर्न की निगरानी करने में सक्षम बनाता है।

ABSTRACT. An experiment was conducted in the experimental farm of Bidhan Chandra Krishi Viswavidyalaya, Nadia, West Bengal to study the radiation pattern and its balance over green gram (*Vignaradiata* var. Samrat). The BREB method was used to determine the sensible heat flux and latent energy. The net radiation was measured through net radiometer and the ground heat flux was measured using Fourier's law. Both the diurnal and seasonal variation of net radiation were studied. Similarly, the energy balance components were studied regularly for different crop growth stages as well as on diurnal basis. It is observed that the net radiation varies from 6.32 Wm^{-2} to 606.43 Wm^{-2} . The latent heat flux constitutes more than 50% of the net radiation for all growth stages as depicted by energy balance partitioning. The sensible heat flux is partitioned into 10% to 20% of total net radiation throughout the growth stages of green gram, which is the lowest in magnitude among all three energy fluxes. The relationship between Bowen ratio and Vapour pressure deficit (VPD), Bowen ratio and Canopy air temperature difference (CATD) was studied. It was found that Bowen ratio is negatively correlated with VPD but positively correlated with CATD. This study enables to monitor ET pattern through latent heat flux and microclimatic characteristics through sensible and ground heat flux.

Key words – Energy balance, Heat flux, Bowen ratio, CATD, VPD.

1. Introduction

Green gram (*Vigna radiata* var. Samrat) is an important crop among the pulses. During 2015-16, green gram contributed 1.59 million ton out of total yearly pulse production of 16.47 million ton. The target of yearly green gram production in India is about 2.30 million ton. The total area covered under green gram in India was 30.41 lakh hectares in 2017-18. The coverage of the area and its production was maximum in Rajasthan (29.68%

and 25.51% of the total area and production respectively) followed by Maharashtra (Tiwari and Shivhare, 2016).

Total energy available over a crop surface and its partitioning into different components, viz., sensible heat (H), latent heat (LE) and soil heat fluxes (G) determine the crop production. The latent heat flux is essential in monitoring water resources in both large and small spatial scale. Both sensible and latent heat fluxes modulate the crop microclimate whereas ground heat flux influences the

thermal environment of the soil with greater impact. The components of energy balance are easily calculated by Bowen-ratio energy balance (BREB) method and energy balance equation (Anapalli *et al.*, 2018). Thus energy balance studies over different crops are significant to derive an array of information on crop growth and water demand pattern.

Bowen ratio energy balance (BREB) is a micrometeorological method that combines the Bowen ratio with energy balance equation of earth surface (Tanner, 1960) and assumes that under neutral stability conditions, the coefficients of heat transfer and water vapour are equal. This method has been used to estimate energy (both sensible and latent heat parts) and mass (ET) fluxes to quantify water use of crop (Cargnel *et al.*, 1996), determine crop coefficients (Malek and Bingham, 1993), evaluate crop water use models (Todd *et al.*, 2000). It is also used to measure emission of greenhouse gases like methane and nitrous oxide, etc., from soil or crop surface, determine carbon-dioxide assimilation rate in crops (Chan *et al.*, 1998) and estimate energy balance parameters above the crop surface (Mokate *et al.*, 1995). Eddy covariance technique (EC) is a standard technique for direct measurement of crop canopy ET in open environments but its use at farm level is still limited due to high cost of sensors and complexity involved in operating them. The instruments used in EC technique are also prone to high degree of uncertainties particularly in tropical humid climate. On the contrary, BREB method that does not interfere with the crop canopy is relatively cheaper and simpler to use with respect to both measurement systems and data analysis. Grain yield is the product of radiation interception, the conversion efficiency of intercepted radiation to dry matter and energy balance partitioning (Samanta *et al.*, 2019). In India, several works have been done on the effect of radiation, temperature and microclimate on crop performance (Singh *et al.*, 2007; Pandey *et al.*, 2007 and Saikia *et al.*, 2014). Considering the importance of radiation and its balance, the present research work has been carried out to partition the radiation balance components over crop surface taking green gram as test crop.

2. Materials and method

2.1. Experimental details

A field experiment was conducted in the experimental farm of Bidhan Chandra Krishi Viswavidyalaya, Kalyani, Nadia, West Bengal during Rabi season of 2017-18 on *Vigna radiata* var. Samrat. The location of experimental farm is near to the Tropic of Cancer (Latitude: 22° 57" N, Longitude: 88° 20" E and

Altitude: 9.75 m above mean sea level). The experimental farm area falls under sub-tropical climatic zone with an average annual rainfall of 1467.5 mm ranging from 1195.5 mm to 1691.9 mm. More than 80% rainfall is received from South-West monsoon during the rainy months of June to September. Crop management was done as per recommended practice. The total plot size was 4 m × 5.5 m × 18 plots, good enough to establish neutral stability condition as a pre-requisite of such energy balance study. The soil of the experimental field was alluvial in nature (Entisol) and sandy loam in texture and well drained. Date of sowing was 7th September, 2017 and the date of harvesting was 9th November, 2017.

2.2. Observations

Indigenous micro-met tower was used for observation of meteorological parameters required for energy balance study. Data on net radiation by net radiometer was recorded keeping the instrument at 50 cm above the crop canopy. The air temperature and humidity was recorded at crop height and two meters above the crop using Assmann Psychrometer. All the micrometeorological data on a diurnal basis were collected at seven days interval so that all crop growth stages can be covered. Likewise the data on soil temperature at two different depths (5 and 15 cm), soil moisture (up to 60 cm), plant height, LAI, canopy temperature (by Infrared thermometer) were also collected. Data could not be recorded at 16:00 hour during flowering and at 11:00 hour during 1st pod formation stage due to rain.

2.3. Computation of Energy balance components

We know, the steady-state energy balance equation is as follows:

$LE + H = R_n - G$ (Here, LE, H and G are latent, sensible and soil heat flux respectively and R_n is the net radiation).

Dividing both sides of the equation by LE, we get:

$$1 + H/LE = (R_n - G) / LE$$

As bowen ratio (β) is defined as $\beta = H / LE$, therefore the latent heat flux can be calculated by the following formula:

$$LE = (R_n - G) / (1 + \beta)$$

Bowen ratio was calculated using the equation, $\beta = \gamma \cdot 1. dT/de$, where γ is the psychrometric constant ($0.0623 \text{ k Pa}^\circ\text{C}^{-1}$). dT and de are the temperature and

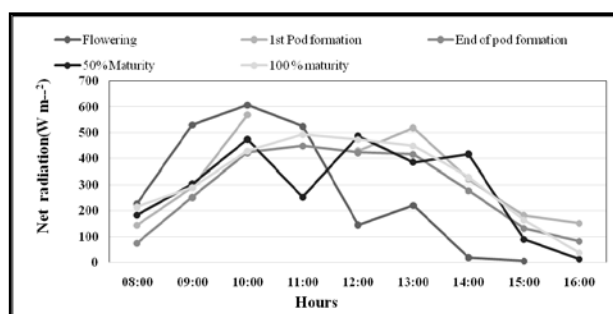


Fig. 1. Diurnal variation of Net radiation during different growth stages of green gram

vapour pressure difference between two heights above crop canopy respectively.

In the present experiment, the temperature and vapor pressure gradients were measured using two Psychrometers at two different heights (0.50 m above crop canopy and 2.0 m above crop canopy). The soil heat flux (G) was computed using Fourier's law and sensible heat flux (H) was calculated by subtracting latent and ground heat flux from net radiation.

2.4. Calculation of Evapotranspiration (ET)

We know, to evaporate 1 mm of water 2.45 MJ m⁻² latent energy is needed. To calculate the evapotranspiration (ET) on daily basis, the daily total LE (in MJ m⁻² unit) was estimated first. Then the LE was divided by the aforesaid conversion factor to obtain ET (in mm) on daily basis.

3. Result and discussion

3.1. Diurnal and seasonal variation of net radiation

The variation of net radiation depends upon climatic condition and crop status. A higher magnitude of net radiation (Rn) was observed (throughout the day as a whole) during 1st pod formation stage (Fig. 1). However the maximum net radiation value within the study period was observed during the flowering stage (606.43 Wm⁻² was recorded at 10:00 hours). The end of pod formation and 100% maturity stages follow a typically normal diurnal net radiation trend while other observations days were cloudy. In a cloudless day, the net radiation gradually increases up to 11:00 to 12:00 hours and the value reduced drastically after 13:00 hours. Similar trend was observed by Gupta and Roy (2014). During 1st pod formation stage after rain, the magnitude of net radiation from 12:00 hours was more than a cloudless day due to the presence of water droplets in the crop canopy. During morning hour (8:00 hours) the Rn ranges from 75.85 Wm² to 227.56 Wm², whereas during afternoon

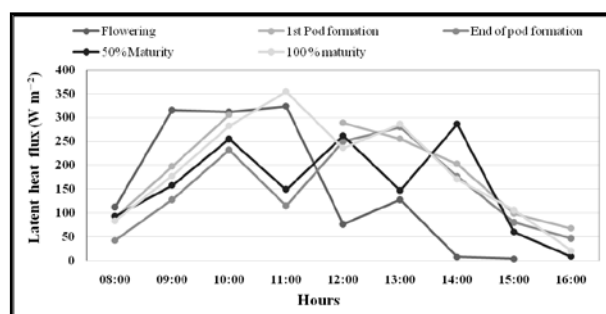


Fig. 2. Diurnal variation of latent heat flux during different growth stages of green gram

hours (16:00 hours) the value varied from 12.64 Wm⁻² to 151.71 Wm⁻² for various growth stages of the crop. The pattern of diurnal variation of Rn follows the solar inclination as well as the variation of global solar radiation. The value of net radiation varied from the lower limit of 6.32 Wm⁻² to 606.43 Wm⁻².

3.2. Latent energy variation

The average latent heat flux during the growth stages follows almost a similar trend like net radiation. The results depict a clear indication that net radiation is one of the major factors behind the latent heat flux. It also depends upon the soil moisture content, VPD, canopy coverage, etc. During the morning hours (8:00 hours) LE varied from 42.76 Wm⁻² to 112.28 Wm⁻². During afternoon hours (16:00 hours) LE varies from 8.47 Wm⁻² to 67.53 Wm⁻². The LE value reaches a maximum during the 100 % maturity stage 353.76 Wm⁻² at 11:00 hours and reaches the lowest value 4.14 Wm⁻² during flowering at 15:00 hours (Rn value was also lowest during the same time). The mean LE during the growth stages was maximum during 100% maturity stage due to less foliage and more exposure of the soil as compared to the other stages and also for high VPD value. Lower mean LE value at the end of pod formation was due to less net radiation because of cloud cover. The most irregular trend was found during 50% maturity stage. Bowen ratio also acts as an indicator of latent heat flux. Greater the value of Bowen ratio, greater is the sensible heat flux with lesser latent heat flux. In wet condition the latent heat flux increases, after a shower during 11:00 hours at 1st pod formation stage, when the value of latent heat flux was more in later hours as compared to other stages. In wet soil, latent heat flux increases with increasing VPD and *vice versa*. The diurnal variation of latent heat flux in different growth stages is shown in Fig. 2.

3.3. Soil heat flux

The diurnal variation of soil temperature at 5 cm and 15 cm depth and soil heat flux related to net radiation was

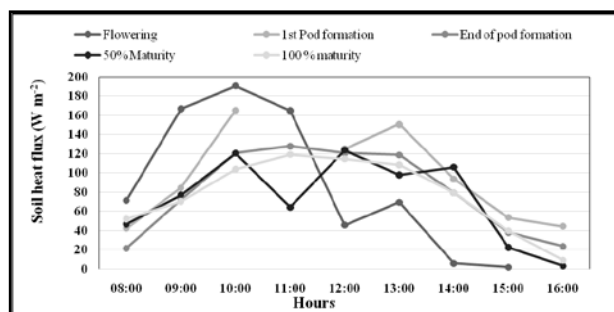


Fig. 3. Diurnal variation of soil heat flux at different growth stages of green gram

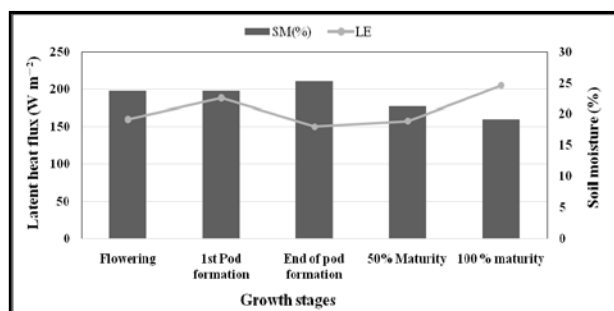


Fig. 4. Variation of LE along with prevailing soil moisture at different growth stages

observed during various crop growth stages. It was observed that during flowering stage the G reaches the maximum value (among all observations) which was 190.46 Wm^{-2} during around 10:00 hours (Fig. 3). At 11:00 hours it sharply decreases due to cloud cover and reaches all-time lowest value 1.98 Wm^{-2} at 15:00 hours. During this phase, the soil heat flux consumed the maximum amount of net radiation among the growth stages (31%) due to less absorption by crop canopy and less consumption of radiation by LE. During morning hours (8:00 hours) the G value varied from 21.61 Wm^{-2} to 71.42 Wm^{-2} and during afternoon hours (16:00 hours) the G value varied from 3.21 Wm^{-2} to 44.60 Wm^{-2} . A positive correlation was found between Rn and G and between G and ST as the ST and Rn increases with the increase of G. In a cloud-free day (100% maturity) the G attains maximum value during 11:00 hours when the net radiation was maximum. During an overcast (50% maturity) day the G value reaches maximum at 12:00 hours.

3.4. Energy balance partitioning

In the whole crop growing period it was observed that the magnitude of LE was higher than G and H. The magnitude differs from stage to stage but LE was always higher than G and H. The LE consumes from 53% (end of pod formation) to 64% (100% maturity) of net radiation. During 100% maturity, it reaches maximum due to less

TABLE 1

Energy balance partitioning at different growth stages of green gram

Growth Stages	LE/Rn	G/Rn	H/Rn
Flowering	0.56	0.31	0.13
1 st pod formation	0.58	0.29	0.13
End of pod formation	0.53	0.28	0.18
50% maturity	0.54	0.25	0.20
100% maturity	0.64	0.24	0.12
Average	0.57	0.27	0.15

vegetation and high VPD (Table 1). On an average LE consumes 57% of net radiation. The partitioned soil heat flux varied from 24% (100% maturity) to 31% (flowering) and on an average 27% of net radiation was contributed to G. It was noticed that when the partitioned of Rn to LE was minimum, G was maximum. The radiation energy converted to S was lowest among the energy flux components ranges from 12% (100% maturity) to 20% (50% maturity). During morning hours (8:00 hours) the value of sensible heat flux ranges from 11.48 Wm^{-2} (end of pod formation) to 79.25 Wm^{-2} (100% maturity) and during afternoon hours (16:00 hours) it ranges from 0.96 Wm^{-2} (50% maturity) to 40.11 Wm^{-2} (1st pod formation). The lowest value of H is 0.20 Wm^{-2} during 15:00 hours during flowering stage because of less radiation and the highest value was 141.33 Wm^{-2} (50% maturity) due to less soil heat flux. As it was raining at 11:00 hours rain the values of LE was high due to vaporization of water present in leaves and eventually sensible heat flux was less. During the end of pod formation and 50% maturity stage the magnitude of values was less due to cloud cover and less amount of radiation. Moreover, in all the stages of the green gram crop, most of the energy was utilized for vaporizing the moisture present in soil and plant system by means of evapotranspiration. Wind speed also plays an important role in energy balance partitioning. Bezerra *et al.* (2014) in their study found LE/Rn varied from 58 to 81%, H/Rn varied from 11 to 29% and G/Rn varied from 6 to 15% which are in concurrence with our study result.

3.5. Variation of latent energy flux with soil moisture

In our study, it was observed that the value of LE during the crop growing period was affected by soil moisture status (Fig. 4). The LE was increased from flowering to 1st pod formation stage due to increasing soil moisture percent and also the net radiation. During the end

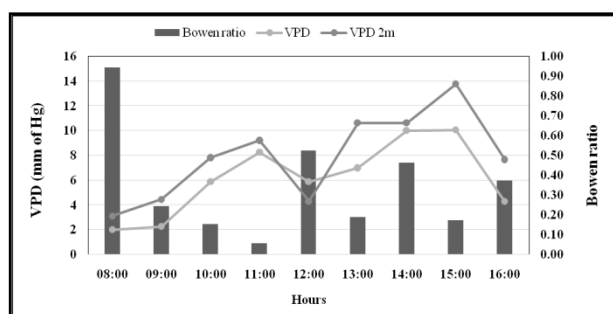


Fig. 5. Relationship between Bowen ratio and VPD

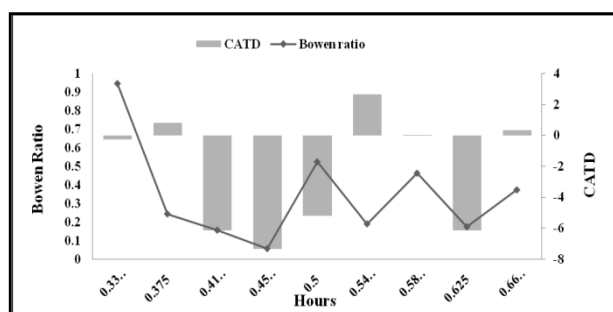


Fig. 6. Relationship between Bowen ratio and CATD

of pod formation stage inspite of the higher value of soil moisture, LE decreased due to low net radiation as a result of cloud cover. At the 100% maturity stage, the LE value was high due to exposed soil to the sun because of less foliage.

3.6. Variation of Bowen ratio over crop growth stages

Bowen ratio is the ratio of sensible heat flux and latent heat flux. The calculated Bowen ratio is closely related with LE and VPD. It was found that Bowen ratio is negatively correlated with VPD and LE (Fig. 5), i.e., if VPD and LE increases then the value of Bowen ratio decreases. Net radiation is also a controlling factor of Bowen ratio. If the net radiation is low, Bowen ratio decreases. It was found that the Bowen ratio decreased rapidly with increasing soil moisture when soil was initially dry. Bowen ratio was insensitive to change in soil moisture when the soil is wet (Yuan *et al.*, 2017). It was found that during most of the time Bowen ratio decreases with increasing VPD. VPD at 2 m above crop height was more than the VPD at 0.5 m above crop height.

It was found that maximum negative magnitude of CATD coincided with the low value of Bowen ratio (Fig. 6), which might be due to cooling of leaf surface by transpiration that affects LE and finally Bowen ratio. A positive relationship was found between the Bowen ratio

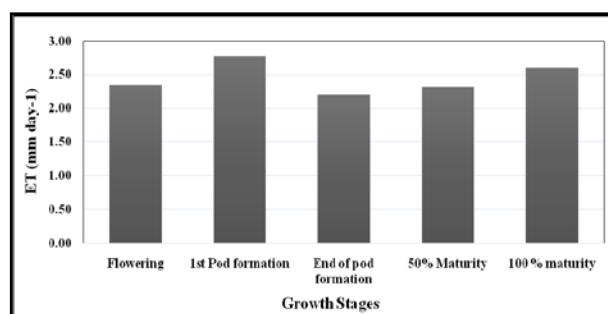


Fig. 7. Seasonal variation of ET during different growth stages

and CATD. Thus, the Bowen ratio can be used as an indicator of the available energy partitioning. Notably, the soil moisture, net radiation and VPD are influencing each other during the energy partitioning process.

3.7. Estimation of ET from latent energy

As mentioned, hourly LE values were calculated by using BREB method and the values of LE and its variation indicates the amount of water that is evaporated from the crop and soil. The amounts of ET during crop stages were almost nearer to each other (Fig. 7). The value of ET ranges from 2.20 mm day⁻¹ to 2.77 mm day⁻¹. The peak value of ET was observed at 1st pod formation stage when the LE value is high and lowest value of ET was observed when the net radiation value was lowest.

4. Conclusions

It can be concluded that there is a large variation in the magnitude of net radiation (6.32 Wm⁻² to 606.43 Wm⁻²) depending upon the cloud cover. In a cloudless day, the net radiation follows a particular trend increasing from morning hours, reaching maximum value during 11:00 to 12:00 hours, then declining in the afternoon hours. The value of Bowen ratio varied from 0.05 to 0.96 and LE, which is the most dominant component of energy balance partitioning varied from 42.76 Wm⁻² to 112.28 Wm⁻². The sensible heat flux constitutes about 27% of total net radiation, whereas the share of ground heat flux ranges is lowest (15%). The evaporative fraction was maximum during afternoon hours. It was observed that the Bowen ratio is negatively correlated with VPD and higher negative magnitude of CATD coincided with a low value of Bowen ratio.

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