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# Energy balance partitioning and evapotranspiration in Sorghum based intercropping system in western region of Tamil Nadu

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**सार** – फसलों की सतहों पर ऊर्जा संतुलन घटकों की मात्रा निर्धारित करना जल संतुलन की बेहतर समझ प्रदान करता है और पानी के किफायती उपयोग में मदद करता है। 2021 के ग्रीष्म ऋतु के दौरान तमिलनाडु कृषि विश्वविद्यालय, कोयंबटूर में ज्वार-आधारित अंतरफसल प्रणाली के प्रत्येक विकास चरण में ऊर्जा संतुलन विभाजन और वाष्पीकरण दर के परिवर्तन का अध्ययन करने के लिए एक क्षेत्र प्रयोग किया गया। बोवेन रेशियो एनर्जी बैलेंस (बीआरईबी) विधि द्वारा फसलों के ऊर्जा संतुलन के घटकों और वाष्पीकरण दर का अनुमान लगाया गया ।परिणामों से पता चला कि ऊर्जा संतुलन में विभाजन फसल विकास चरणों में भिन्न होता है। LE/Rn में भिन्नता 0.61 (अंकुरण) से 0.86 (पुष्पण) तक थी। यह भिन्नता शुद्ध विकिरण, पर्ण आवरण, मृदा की नमी की स्थिति, वाष्प दबाव की कमी पर आधारित थी। फसल अवधि के लिए कुल वाष्पोत्सर्जन 322 मिमी प्रेक्षित किया गया। वानस्पतिक अवस्था के दौरान ET की आवश्यकता सबसे अधिक थी जब कुल LE को अधिकतम पाया गया।

**ABSTRACT.** Quantifying energy balance components over crops' surfaces provides a better understanding of the water balance and helps in the economic use of water. A field experiment was conducted during summer 2021 at Tamil Nadu Agricultural University, Coimbatore, to study the change of energy balance partitioning and evapotranspiration rate at each growth stage of the sorghum-based intercropping system. The energy balance components and evapotranspiration rate of crops were estimated by Bowen Ratio Energy Balance (BREB) method. The results revealed that the energy balance partitioning varied among crop growth stages. The variation in LE/Rn was 0.61 (seedling) to 0.86 (flowering). This variation was based on net radiation, foliage cover, soil moisture condition, vapor pressure deficit. The total evapotranspiration for the crop period was observed as 318 mm. The ET requirement was the highest during the vegetative stage when the total LE was found as maximum.

**Key words** – Bowen Ratio (β), Net Radiation (Rn), Latent heat flux (LE), Sensible heat flux (H), Soil heat flux (G), Evapotranspiration (ET), Vapor pressure deficit (VPD).

## 1. Introduction

Sorghum is the most important millet crop and it is the fifth major crop in the world. It is being cultivated for various purposes such as forage, grain and biofuel. The United States is the largest sorghum producer, while India stands fifth in position. In India, sorghum covers about 4.96 million ha with production and productivity of 4.7 MT and 999 kg/ha, respectively (USDA, 2020).

Crop evapotranspiration is an essential component in determining crop performance and water use in different crop growth stages. Several methods are available to determine the *ET* of the crop, including Lysimetry (Peters *et al*., 2017; Silber *et al*., 2019), Eddy Covariance (Ortega-Farias *et al*., 2010; Prueger *et al*., 2018), Soil-Water Balance (Abdelkhalik *et al*., 2019) and Bowen Ratio-Energy Balance (Chebbi *et al*., 2018)

Bowen ratio energy balance (BREB) is a micrometeorological approach that combines the Bowen ratio with the energy balance equation of the earth's surface. It is a relatively reliable and practical method to determine the evapotranspiration of crops (Chebbi *et al*., 2018). It provides values for small-time scales with few input parameters and is more cost-effective (Hu *et al*., 2013).

The total solar energy available over crop surface and partitioning of this energy into sensible and latent heat flux determine crop production. The partitioning of available energy ($R_n$) into sensible ($H$) and latent heat flux ($LE$) depends on several factors, such as climate, topography, morphology and physiology of a given crop under specific meteorological conditions. Latent heat flux is the largest consumer of available solar energy (60-80% of net radiation), especially in irrigated conditions (Suyker & Verma, 2008). Therefore, by understanding the radiation balance over the crops' surface, it is possible to determine the evapotranspiration rate of crops in each growing stage (Mondal *et al*., 2019).To date, the study on energy balance components of sorghum intercropping is lagging.

Hence, the present investigation aims to study the variation of energy balance components and evapotranspiration rate with each growth stage of the sorghum-based intercropping system.

## 2. Materials and method

### 2.1. *Experimental details*

The experiment was conducted in Field No. 36 F at Tamil Nadu Agricultural University, Coimbatore, during Summer 2021. Geographically, the site is located at 11.0° N, 76.9° E falls under the western zone of Tamil Nadu with an annual rainfall of 673 mm. The experiment was laid out in Randomized Block Design. The soil of the experimental field was heavy black clay soil. The base crop is sorghum (*Sorghum bicolor*) and intercrops, *viz*., Cowpea, Greengram, Lab lab were sown and harvested during March and June, respectively. Crop management practices were done as per recommendation. In this study, the sorghum and intercrops were considered as a single unit (Jinkui *et al*., 2006). The entire growing season was divided and presented in Table 1. The energy balance components of the sorghum intercropped area were studied using the Bowen Ratio Energy Balance method.

### 2.2. *Observations recorded*

The data for net radiation was retrieved from the net radiometer using Loggernet software. The instrument measures the net radiation continuously for 24 hrs. The air temperature and vapor pressure were recorded at two levels *viz*., canopy level and 1 m above the canopy at 1hr interval from 0900 h to 1500 h daily using psychrometers (Mondal *et al*., 2019).

### 2.3. *Methodology*

The surface energy balance can be expressed as follows, based on the law of conservation of energy and gradient diffusion equation.

**TABLE 1**

**Division of growth stages**

| Crop Stage | Days | % of Total days |
|---|---|---|
| Seedling | 15 | 14 |
| Vegetative | 32 | 30 |
| Flowering | 25 | 23 |
| Maturity | 35 | 33 |
| Total Days | 107 | - |

$$R_n = LE + H + G \quad (1)$$

where, $R_n$ is net radiation (MJ/m$^2$/day), $LE$ is latent heat flux (MJ/m$^2$/day), $H$ is sensible heat flux (MJ/m$^2$/day) and $G$ is soil heat flux (MJ/m$^2$/day). The magnitude of $G$ is obtained as a fraction of $R_n$ as 5%, 20% and 25% for the fraction of tall canopy, short vegetation and bare soil respectively (Santanello and Friedl, 2003; Miralles *et al*., 2011)

The values of $LE$ and $H$ were obtained from the energy balance and the Bowen ratio concept (Bowen, 1926).

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

$$H = \frac{R_n - G}{1 + \beta^{-1}} \quad (3)$$

where, $\beta = \gamma\, \Delta T_a / \Delta\, e_a$ is called the Bowen ratio, $\gamma$ is a psychrometric constant, $\Delta T_a$, $\Delta e_a$ are vertical gradients of temperature (°C) and vapor pressure (kPa) respectively. This is applicable only when $R_n - G > 0$ if not, the method should be discarded.

### 2.4. *Estimation of evapotranspiration*

To evaporate 1mm of water 2.45 MJ m$^{-2}$ latent energy is required. The daily $LE$ (in MJ m$^{-2}$) was divided by the conversion factor to obtain the daily evapotranspiration rate (Mondal *et al*., 2019).

## 3. Results and discussion

### 3.1. *Energy Balance Partitioning*

#### 3.1.1. *Net Radiation ($R_n$)*

The daily $R_n$ varied violently and followed a zig-zag trend (Fig. 1). The variation of $R_n$ was based on climatic

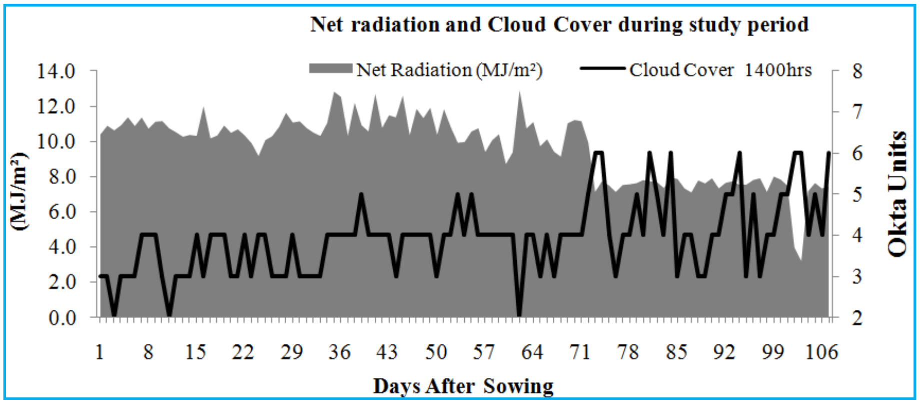


**Fig. 1.** Variation of $R_n$ and cloud cover in the crop period

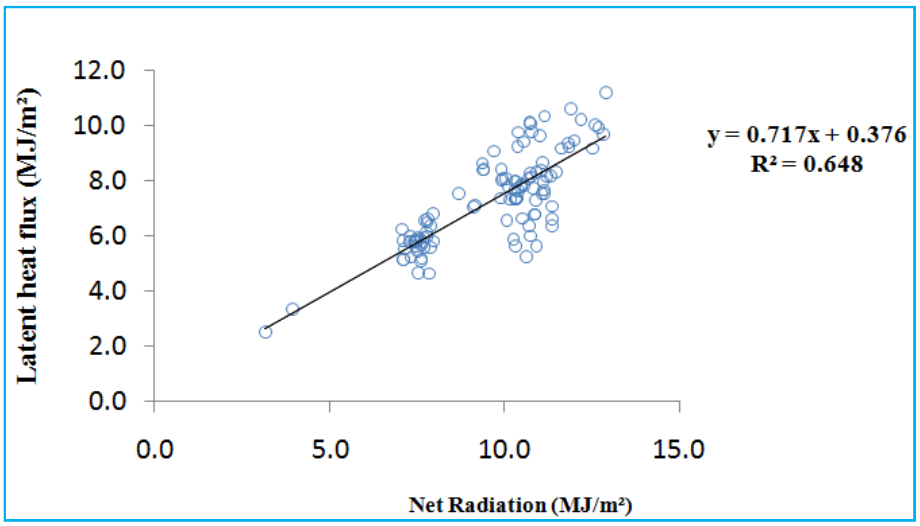


**Fig. 2.** Relationship between net radiation and latent heat flux during the crop season

conditions such as cloud cover, rain and the stage of the crop. A higher magnitude of $R_n$ was observed during the vegetative stage (352 MJ $m^{-2}$) was due to the change in albedo of cropped area from seedling to vegetative stage. The low albedo during vegetative stage may reflected less short wave radiation than seedling stage (Santos *et al.*, 2011). The maximum daily value of $R_n$ (12.9 MJ $m^{-2}$) occurred during the maturity stage. The lowest daily value of $R_n$ (3.2 MJ $m^{-2}$) during the maturity stage was due to the cloudy conditions that prevailed during the study period (Fig. 1).

3.1.2. *Latent Heat Flux (LE)*

Latent heat flux was dominant during the crop growing season. It was observed that total *LE* was maximum during the vegetative stage (261 MJ $m^{-2}$), followed by flowering (224 MJ $m^{-2}$) when the canopy cover was maximum. Total *LE* for the entire season was 780 MJ $m^{-2}$ which accounted for 74% of net radiation. There was a decreased value of *LE* during maturity (196 MJ $m^{-2}$), when the crop was almost dry, indicating a reduction in transpiration rate due to abscission of leaves (Gupta and Roy, 2014). The results clearly showed that *LE* was highly dependent on the Net radiation, soil moisture, canopy coverage and vapor pressure deficit. The maximum *LE* per day was observed as 11.2 MJ $m^{-2}$ when the $R_n$ value was high (12.9 MJ $m^{-2}$). The linear regression between $R_n$ and *LE* during the study period ($p<0.05$) (Fig. 2) showed that the relationship is positive and significant. Whenever the field was irrigated, there was a slight increase in *LE* than the previous day because of an increase in VPD and a decrease in Bowen ratio, indicating that most of $R_n$ were accounted by *LE* rather than *H*. The relationship between Latent heat flux and VPD was found to be either positive or negative (Fig. 3).

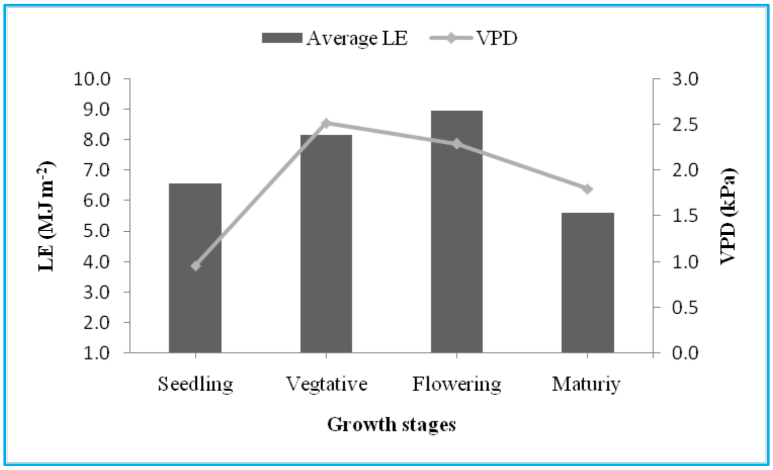


**Fig. 3.** Variation of Latent Heat Flux and Vapor pressure deficit in the growing season

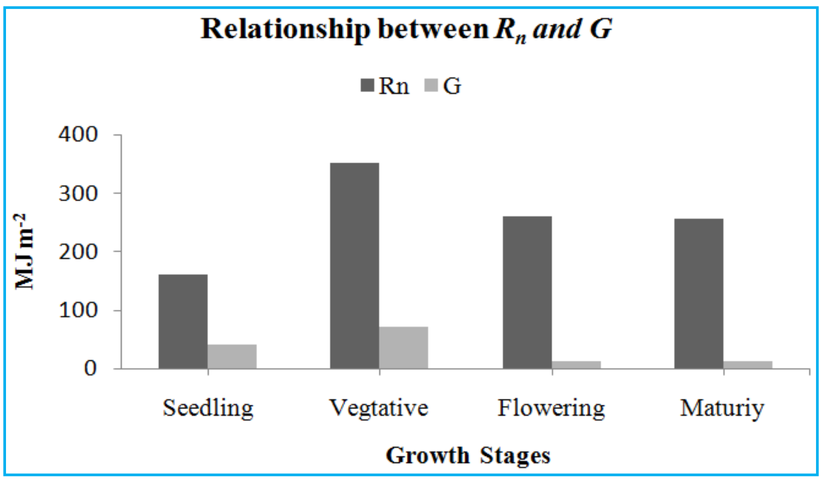


**Fig. 4.** Relationship between net radiation and soil heat flux during the crop season

The increase in VPD increased *LE* (positive) still, sometimes higher VPD affects the stomatal conductance (negative), thereby restricted the transpiration rate in crops resulting in less latent heat flux (Yuan *et al.*, 2017). This negative relationship was prominent in the mid and late stage of the crop (Fig. 3).

3.1.3. *Sensible heat flux (H)*

The $H$ was maximum during the seedling stage with an average of 1.5 MJ $m^{-2}$. The total $H$ during the entire growing season was 131.4 MJ $m^{-2}$ which accounted for 13.75 % of total $R_n$. The average sensible heat flux was minimum during the vegetative stage when there was active foliage cover when most of $R_n$ was diverted to latent heat flux (Table 2).

3.1.4 *Ground heat flux (G)*

The variation of ground heat flux is highly dependent on net radiation. The average soil heat flux almost followed the same trend as net radiation. A maximum $G$ (70.4 MJ $m^{-2}$) was observed during the vegetative stage when the total net radiation was found to be maximum (352 MJ $m^{-2}$). There was a sharp decrease in $G$ with crop growth. The average value of $G$ during the entire crop season was 34 MJ $m^{-2}$, which was 14% of $R_n$. The relationship between $R_n$ and $G$ was depicted in Fig. 4.

3.1.5. *Bowen Ratio (β)*

Bowen ratio is the ratio of sensible and latent heat flux. The value of $\beta$ of crop season was in the range

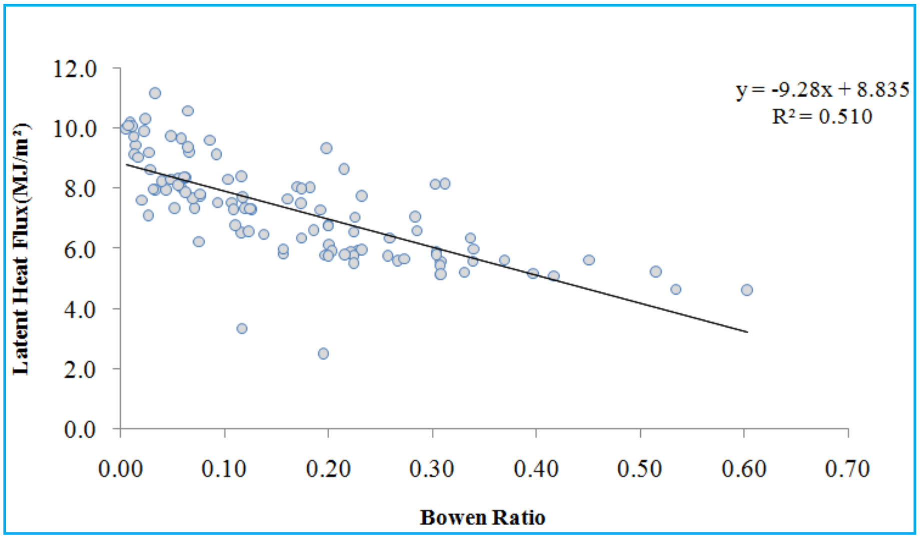


**Fig. 5.** Relationship between Bowen ratio and latent heat flux during the crop season

**TABLE 2**

**Total Net radiation ($R_n$), Average Bowen ratio ($\beta$), Sensible heat flux (*H*), Latent heat flux (*LE*), Soil heat flux (*G*) Energy Balance partitioning and Evapotranspiration rate in each growth stage of the crop**

| Crop Stage | $R_n$ | β | H | LE | G | $LE/R_n$ | $H/R_n$ | $G/R_n$ | ET (mm) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | (MJ $m^{-2}$) | | | | | |
| Seedling | 161.4 | 0.24 | 22.5 | 98.5 | 40.3 | 0.61 | 0.14 | 0.25 | 40.2 |
| Vegetative | 352.3 | 0.08 | 20.6 | 261.2 | 70.5 | 0.74 | 0.06 | 0.20 | 106.6 |
| Flowering | 260.7 | 0.11 | 23.7 | 224.0 | 13.0 | 0.86 | 0.09 | 0.05 | 91.4 |
| Maturity | 256.2 | 0.25 | 47.4 | 196.0 | 12.8 | 0.77 | 0.18 | 0.05 | 80.0 |
| Total Evapotraspiration | | | | | | | | | 318 |

of 0.08-0.25. The average value of *β* was minimum during the vegetative stage and was high during the maturity stage. It was observed that *β* was negatively correlated with latent heat flux, *i.e*., β increases with a decrease in *LE* (Fig. 5) Like *LE*, *β* was also greatly influenced by irrigation. Whenever the field was irrigated, there was a slight decrease in *β* than the previous day, which was due to enhanced *LE* and decrease of *H*. The linear regression between *β* and *LE* during the study period showed that the relationship is negative and significant ($p<0.05$). The energy balance partitioning in each growing period is depicted in Table 2.

### 3.2. *Evapotranspiration (mm)*

The variation in *LE* indicates the amount of water that can be evaporated from the surface. The total *ET* of the cropped area was 318 mm. The *ET* was maximum during the vegetative stage (107 mm) followed by flowering (91 mm) when the *LE* was found to be maximum. The rate of *ET* at various growth stages is presented in Table 2.

## 4. Conclusions

The energy balance partitioning and evapotranspiration rate of each growth stage was estimated. The variation of energy balance components in the growth stage was revealed that, in the entire season, $LE/R_n$ was dominant and consumed about 74% of $R_n$. The values of *LE* varied with net radiation, canopy spread and soil moisture. The *ET* rate was the highest (106.6 mm) during the vegetative stage when the total value of *LE* was a maximum of 261 MJ $m^{-2}$. A disadvantage of the BREB method is that it requires continuous measurement of weather variables and is restricted to daytime.

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