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Energy balance study of rice using eddy covariance technique

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Abstract
Energy balance relationship over rice crop using eddy covariance and crop growth modeling was carried out during kharif crop 2016-17 at Deras, IIWM, Bhubaneswar. For the study of weather characterization, weather data were collected from eddy covariance tower at Deras, IIWM Bhubaneswar and energy balance relationship was studied over rice crop. The result of the study showed that the weekly maximum temperature was observed 32.6ºC in 41 SMW week and the minimum was 20.6ºC in 42 SMW. In highest RH was recorded 89% in 38th SMW. The total amount of rainfall during crop growth period was 380.8 mm. The maximum rainfall 92 mm received during 30th SMW. Which 42th SMW was dry. Highest SRAD value was observed 20.2 MJm^{-2}day^{-1} in 33rd SMW and lowest SRAD value 8.2 MJm^{-2}day^{-1} was observed in 31st and 35th SMW. The highest evaporation 11 mm was recorded in 41st SMW and min 0.2 mm was observed in 30th SMW. The maximum wind speed 3.9 km/h was recorded in 30th of week and minimum 1.6 km/h was recorded in 40th of week. Surface energy balance of rice was observed in every phenological stages at 8.00 h to 17.00 h. Rn was varied between 140.00 W m^{-2} to 400.26 W m^{-2} and LE was varied between 21.0 W m^{-2} to 406.69 W m^{-2}. Highest value of Rn and LE were found 400.26 W m^{-2} and 306.69 W m^{-2} were found in transplanting stage and lowest 140.0 W m^{-2} and 21.40 W m^{-2} were found in before harvesting stage. H was varied between 19.18 W m^{-2} to 53.84 W m^{-2}, where highest 53.84 W m^{-2} was found in milking stage and lowest 19.18 W m^{-2} was found in before harvesting stage. G was varied between -4.68 W m^{-2} to 5.86 W m^{-2}. G showed negative value in all phenological value except transplanting stage, It was showed positive value (5.86 W m^{-2}).

Keywords: Eddy covariance, energy balance, surface energy balance, GDD

Introduction
Rice (Oryza sativa L.) is a staple food for more than a half of the world's population and one of the most important rapidly growing food crops cultivated around the world (Simonds *et al*., 1999). Rice plays a highly significant role in the daily diet of thousands of millions of Asian's, Latin American's and African's people.

Land surface under paddy fields are covered by standing flood water for most periods of the year. This kind of land use pattern may have modified the surface energy budget, water cycle and possibly the climate of the region. Studies on the energy partitioning pattern of this kind of land surface need to be investigated. Observational and modeling studies on surface energy budget in paddy fields have been made from the 1950s (e.g. Uchijima 1961; RGE, 1967; Tomar and O'Toole, 1980; Sakuratani and Horie 1985; Harazono *et al*., 1998; Oue, 2005; Tsai *et al*., 2007; Maruyama and Kuwagata, 2008, Alberto *et al*., 2009; Maruyama and Kuwagata, 2010) [6, 1]. Most of these studies were conducted in single cropping paddy fields and focused on cropping season.

The total electromagnetic radiation (Solar spectrum) emitted by the sun is called as solar radiation. So, the sun is the ultimate source of all energy which comes to the earth's surface as short wave radiation and goes back as long wave radiations. Balance of short wave and long wave radiation is the net radiation (Rn). Energy partitioning means solar energy partitioning as Rn = H + LE + G+ EPn + ERn, where Rn is net radiation, H is sensible heat flux, G is the ground heat flux, LE is latent heat flux, EPn is energy for photosynthesis and ERn is energy for respiration, units of all components are in Wm-2. Very little energy requires for chemical reactions for photosynthesis and respiration, so there two terms generally are neglected thus energy balance equations use Rn = H + LE + G. The energy partitioning depends on various environmental factors as well as the biological characteristics of vegetation in an area (Wever *et al*., 2002; Wilson *et al*., 2002) [7]. The surface energy budget affects the microclimate of the plant canopy through parameters such as temperature, humidity, evapotranspiration and eventually plant growth.

The surface energy budget of the terrestrial ecosystem is being studied in many places using the eddy covariance technique as part of longterm, ecosystem-level measurement programmes.

The eddy covariance (EC) technique has been widely employed for CO_2, water vapor and heat flux measurement in various parts of the world, especially in forests, savannah and grasslands, but there are few studies on the rice ecologies. In ICAR system, many research institute like National Rice Research Institute (NRRI), Cuttack and ICAR- Indian Institute of Water Management (IIWM), Bhubaneswar installed the flux tower and measured energy fluxes on many crops. Carbon dioxide exchange and energy balance of rice paddies have been studied intensively during 1950_s and 1960_s employing conventional micrometeorological techniques, viz. Aerodynamic and Bowen ratio methods. Since 1980_s, with the development of fast-response CO_2 analyzers, CO_2 fluxes over rice canopy are measured by the Eddy Covariance method as this is a powerful tool for characterizing the gaseous carbon budget of the rice ecosystem. But, most of the conducted studies involved short-term measurements lasting for a few days to a few weeks. Over many land use system of the world, energy balance was measured using eddy covariance technique.

In Asia, notable work with EC flux measurements has been done in western Japan, China, central Japan, Bangladesh, Philippines and Taiwan to monitor seasonal, annual and inter-annual variations in CO_2 flux in irrigated, submerged (flooded) and aerobic rice fields. Rice paddies in Asia have an important role in the global budget of GHGs such as CO_2 and CH_4, yet there is considerable uncertainty in the magnitude of the net fluxes of CO_2 from these ecosystems. Globally, the rice-growing areas are predicted to increase by 4.5% at the end of 2030 (FAO, 2003) [2]. Therefore, field-level studies to measure net CO_2 fluxes and to improve understanding of the factors controlling them are needed in changed climatic scenarios.

Eddy Covariance method (EC) and Bowen-ratio energy balance (BREB) are the two primary micrometeorological systems used to measure surface fluxes. EC provides direct measurement of sensible (*H*) and latent heat fluxes (*LE*), whereas BREB is an indirect approach wherein *H* and (*LE*) are calculated from other measurements and it is derived by combining with energy balance equation of the earth's surface (Tanner, 1960). The Eddy Covariance (EC) technique is widely employed as the standard micrometeorological method to monitor fluxes of CO_2, water vapor and heat, which are necessary to determine CO_2 and heat balances of land surfaces. The EC technique has become the most important method for measuring trace gas exchange between terrestrial ecosystems and the atmosphere.

Materials and Methods

Study area: The study site is located at the research farm of ICAR-Indian Institute of Water Management, Deras, Mendhasal situated in khurdha district, Odisha. It lies between Latitude 20°17' N and, Longitude 85°41' E; 23 m above sea level. The farm is situated 30 km away from the main institute complex.

Eddy covariance Tower

Eddy covariance technique is a widely used accurate & direct method for quantifying exchange of carbon dioxide, water vapor, methane, various other gases and energy between the surface of the earth and the atmosphere. Eddy covariance provides an accounts way to measure surface atmospheric fluxes of energy and trace gas fluxes over a variety of ecosystem including agricultural and urban landscape fluxes can be measured by instruments mounted on a stationary or mobile tower. For the study energy balance. Different parameters were collected from the eddy covariance tower. These supporting data were sampled every 10 seconds using CR3000 data logger. The details of sensors are given below:

Tipping bucket

The TE525WS, manufactured by Texas Electronics, is a tipping-bucket rain gage that conforms to the National Weather Service recommendation for an 8 in. funnel. It measures rainfall in 0.01 in. increments. The unit of the rainfall is mm^{-1}.

Net Radiometer

The NR-LITE 2 is used for measuring solar and far infrared radiation balance. This balance is known as the net (total) radiation. Its upwards facing sensor measures the solar energy and far infra-red energy that is received from the entire hemisphere (180º field of view). Its downwards facing sensor measures the energy received from the surface of the soil. The two readings are automatically subtracted and the result converted to a single output signal. This output represents in watts per square meter ($w\ m^{-2}$).

Temperature and Humidity

The HC2-S3-L measures air temperature with a pt100 RTD and relative humidity based on the Hygroclip2 technology. The HC2-S3-L has a configurable air temperature range. Each Hygroclip2 probe is 10% interchangeable and can be swapped in seconds without any loss of accuracy, eliminating the downtime typically required for the recalibration process. The HC2-S3-L housed inside motorized or passive aspirated solar radiation shield.

Soil Temperature

The 109 probe uses a thermistor to measure temperature. The 109 temperature probe can measure air/soil/water temperature. For air temperature a 41303-5 A radiation shield is used to mount the 109 probe and limit solar radiation loading. The probe can be buried in soil or submerged in water to 50ft (21 psi). Beta Therm 10K3A1 Thermistor sensor is used which measure temperature ranges from -50 to +70ºC.

Barometric Pressure sensor

The CS106 analog barometer uses Vaisala's Barocap® silicon captative pressure sensor. The Barocap sensor has been designed for accurate and stable measurement of barometric pressure. The CS106 outputs a linear 0 to 2.5 VDC signal that correspond to 500 to 1000 mb.

Soil Heat flux plate

The $HFT3_s$ are used to measure the soil heat flux at a depth of 8 cm. A TCAV averaging soil thermocouple is used to measure the temporal change in the soil layer above the HFT3.

Thermocouple

The FW05 is a type E thermocouple with a 0.0005 inch diameter. It measures atmospheric temperature gradients or fluctuations with research - grade accuracy. The FW05 consists of a type E thermocouple with connector. The connector attaches the thermocouple to a data logger via FWC-L cable.

Computation of energy balance

The energy balance was computed from the following equation (Ham *et al*., 1991)

$$R_n = H + LE + G$$

Where,

R_n = net radiation in W/m^2

H = sensible heat flux in W/m^2

LE = latent heat of vaporization in W/m^2

G = ground heat flux in W/m^2

In the above stated equation, fluxes of R_n and G towards the surface were positive and towards the atmosphere were negative, while fluxes of H and towards the atmosphere where positive and vice-versa.

Data Interpretation and Analysis

The data received at 10 second intervals from the sensors on different micrometeorological parameters from the experimental site were primarily recorded by CR3000 Data logger (Campbell Scientifics, USA). CR3000$_s$ measures electrical signal and convert the measurement to engineering units. Then the output data from the Data logger as 30 min average was stored in a storage module (CR3000, Campbell Scientifics, USA). Data tables are transferred to computer through a Compact Flash card (CR: drive) or CS mass storage media (USB: drive) to the PC. The experimental raw data at 30 min intervals were retrieved from the storage module periodically for further averaging and mathematical interpolation. After obtaining 30 min average raw data from the field, these were then averaged again for 1 hour intervals by using the "Macro" program in Microsoft Excel. Data analyses were performed using MS Excel. Graphs were also prepared by the above mentioned software. As this kind of experiment only stresses on the monitoring of the climatic variables no replication possible and trends are obtained with average data streams those were collected during the intended span of this experiment. Since the initial data were recorded as 10 sec intervals which were 30 min average, so statistical errors were to minimum and hence neglected.

Results

Energy balance components were measured at study site continuously during 2016 to understand the variation of energy fluxes in relation to climatic variable and surface conditions. It is well documented that the energy balance components are substantially influenced by surface conditions, availability of water and type of vegetation.

At tillering stage, Rn varied between 27.4 Wm^{-2} to 198.93 Wm^{-2}, at morning (8.00h) value of Rn was 72.5 Wm^{-2} lower which gradually increased highest 198.93 Wm^{-2} 13.00hr thereafter decreased 27.49 Wm^{-2} at 17.00h. LE varied between 33.89 Wm^{-2} to 194.74 Wm^{-2}. LE was highest 194.74 Wm^{-2} at 15.00h. H was varied between -3 to 53.57 Wm^{-2} where highest value 53.57 Wm^{-2} at 14.00h. G was showed always negative value which was -0.06 to -0.71 Wm^{-2} due to moist condition of the field. The graphical representation of energy balance of rice in tillering stage was represented in Figure 1.

Figure 2 depicted that Rn varied between 68.21 Wm^{-2} to 476.02 Wm^{-2}. LE varied between 75.17 Wm^{-2} to 314.55 Wm^{-2} at panicle stage. H was varied between -11.32 to 63.29 Wm^{-2}. G was varied between -3.23 to 0.94 Wm^{-2}. The maximum value of R_n, *L*E, H and G showed 476.02 Wm^{-2}, 314.55 Wm^{-2}, 83.97 Wm^{-2} and 0.94 Wm^{-2} in hr. 12.00, 14.00, 10.00 and 17.00hr respectively and lowest value 68.21, 75.17, -11.32 and -3.23 Wm^{-2} in hr 17.00 h, 08.00, 17.00 and 08.00h respectively. Rn, LE, H showed lowest value during morning and evening time.

At milking stage Rn varied between -10.58 Wm^{-2} to 494.77 Wm^{-2}, at morning (8.00h) value of Rn was 108.37 Wm^{-2} lower which gradually increased highest 494.77 Wm^{-2} 12.00h thereafter decreased -10.58 Wm^{-2} at 17.00h. LE varied between 20.69 Wm^{-2} to 234.97 Wm^{-2}. LE was highest 234.97 Wm^{-2} at 11.00h. H was varied between 14.04 to 107.57 Wm^{-2} where highest value 107.57 Wm^{-2} at 10.00h. G was varied between -4.74 to 0.46 Wm^{-2} due to moist condition of the field. The graphical representation of energy balance of rice at milking stage was represented in Figure 3.

Figure 4 showed that Rn varied between 7.42 Wm^{-2} to 413.00 Wm^{-2}, at morning (8.00h) value of Rn was 140.95 Wm^{-2} which gradually increased highest 413.0 Wm^{-2} 12.00h thereafter decreased 7.42 Wm^{-2} at 17.00h at dough stage. LE varied between 33.79 Wm^{-2} to 185.75 Wm^{-2}. LE was highest 185.75 Wm^{-2} at 12.00h. H was varied between 6.40 to 65.99 Wm^{-2} where highest value 65.99 Wm^{-2} at 12.00h. G was varied between -3.46 to 0.27 Wm^{-2}.

Study revealed that sensible heat flux *(H)* and latent heat flux *(LE)* followed the pattern of global radiation throughout the day. In the rice field latent heat flux *(LE)* was the governing form of water loss and consumed most of the energy of the net radiation *(R_n)*. The sensible heat *(H)* in the rice field showed a slight fluctuation indicating that the vegetative fields acted as a factor for heat transfer towards the atmosphere. During the daytime the ground heat flux (*G*) was positive signifying that the soil absorbed heat from the atmosphere.

In the previous studies (e.g. RGE, 1967; Harazono *et al*., 1998; Gao *et al*., 2003; Oue, 2005; Tsai *et al*., 2007) [6] also found the *LE* was larger in the afternoon than in the morning under the same magnitude. H was a minor component and its magnitude was similar to that of G in the *Aman* rice periods.

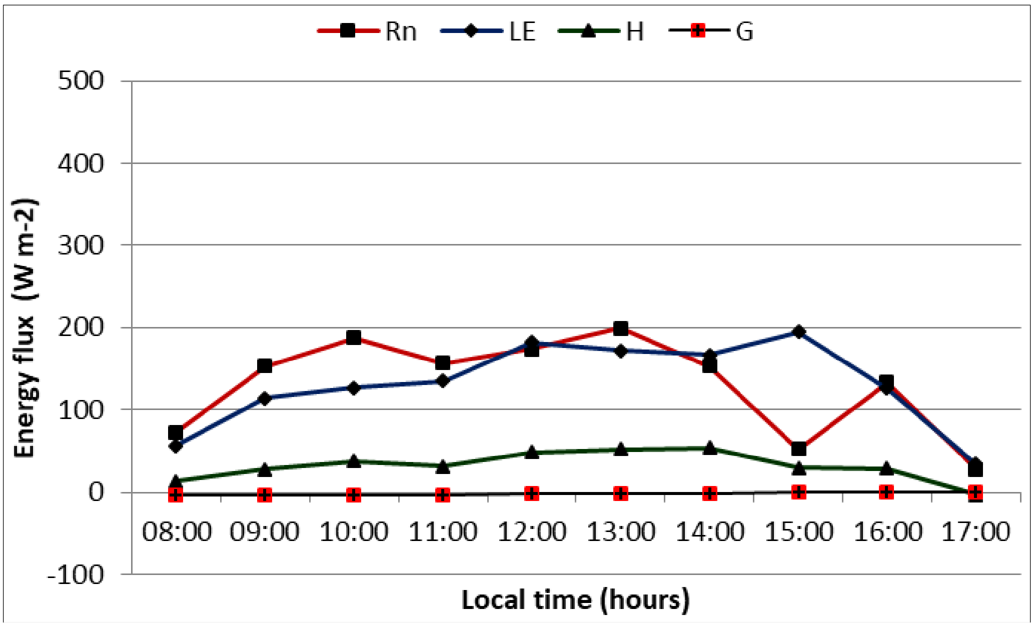

Fig 1: Diurnal pattern of energy balance at tillering stage of rice crop

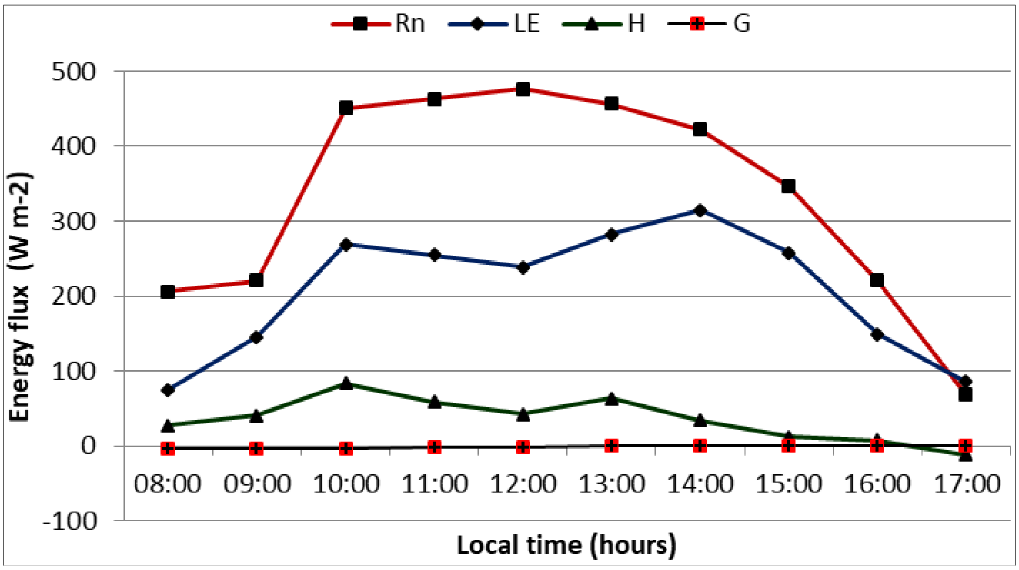

Fig 2: Diurnal pattern of energy balance at panicle initiation stage of rice crop

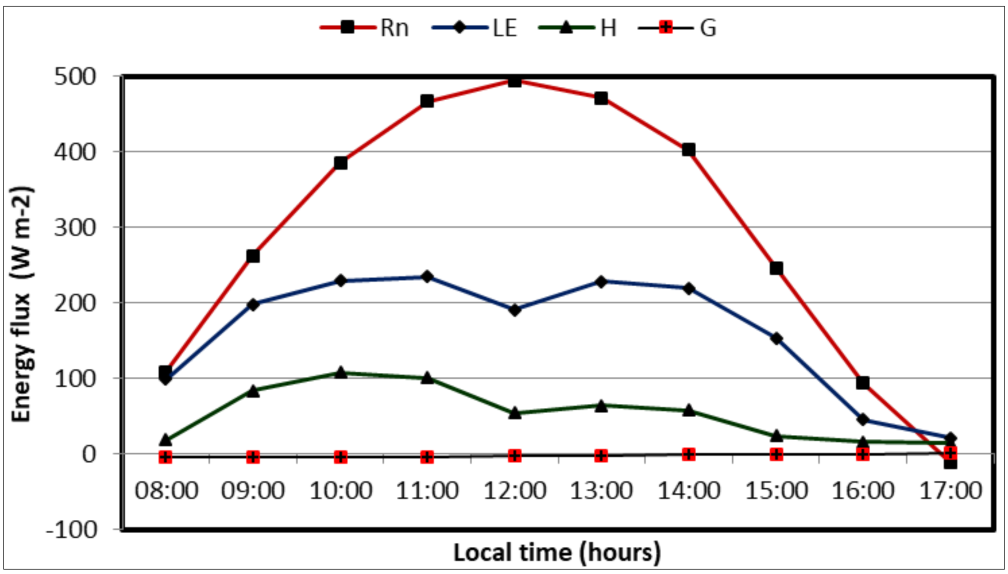

Fig 3: Diurnal pattern of energy balance at milking stage of rice crop

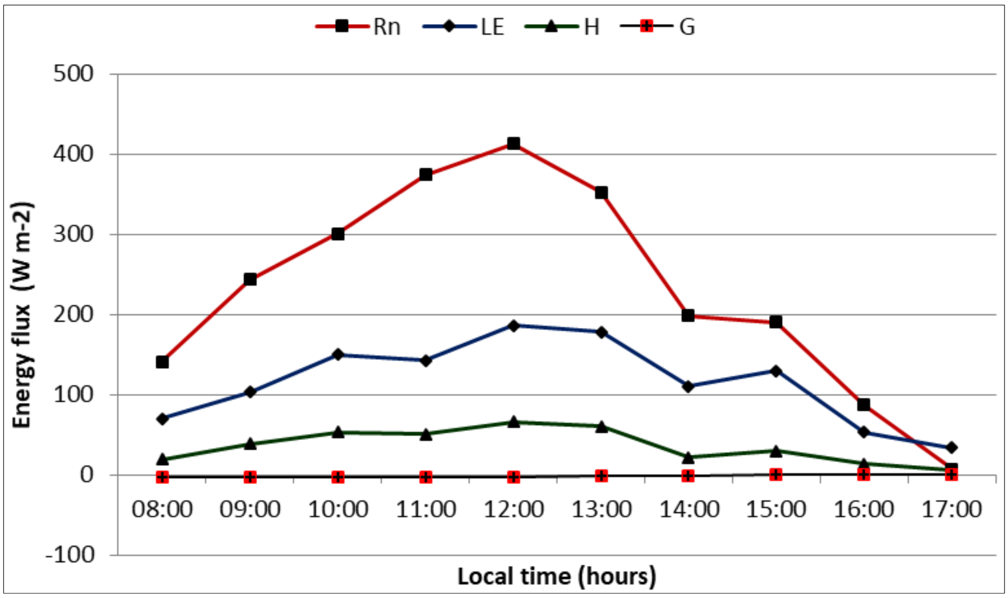

Fig 4: Diurnal pattern of energy balance of dough stage of rice crop

Discussion

Surface study energy balance of rice was observed in every phenological stages at 8.00 h to 17.00 h. Rn was varied between 140.00 W m^{-2} to 400.26 W m^{-2} where highest 400.26 W m^{-2} was found in transplanting stage and lowest 140.0 W m^{-2} was found in before harvesting stage. LE was varied between 21.0 W m^{-2} to 406.69 W m^{-2}, where highest 306.69 W m^{-2} was found in transplanting stage and lowest 21.40 was found in before harvesting stage. H was varied between 19.18 W m^{-2} to 53.84 W m^{-2}, where highest 53.84 W m^{-2} was found in milking stage and lowest 19.18 W m^{-2} was found in before harvesting stage. G was varied between -4.68 W m^{-2} to 5.86 W m^{-2}, where only transplanting stage positive value which was 5.86 W m^{-2} and remaining all stage showed negative values. All through the cropping season differences in water and energy fluxes were attributed by the availability of sunlight and abundance of water at the site as well as differences in solar radiation during crop season. Rainfall kharif rice had substantial influence on the seasonal and inter annually variability of energy partitioning at rice field.

Conclusion

The highest value of Rn and LE was observed at the time of transplanting and lowest was observed before harvesting. The highest value of Sensible heat was recorded during flowering to milking stage. The ground heat flux showed positive value at the time of transplanting, means soil absorbed energy at the time of transplanting.

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