

Energy balance evaluation in Bengal gram (*Cicer arietinum* L.) grown in a sub-humid climate

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सारा — शीत फसल मौसम में 1990-1991 के दौरान, केन्द्रीय कृषि मौसम वेधशाला में चने की फसल पर ऊर्जा संतुलन प्राचलों के सापेक्ष योगदान के अन्वेषण के लिए किए गए प्रयोग के परिणाम इस अध्ययन में प्रस्तुत किए गए हैं।

विश्लेषण से यह प्रकट होता है कि गूल्म उष्मा ही पूर्व परिपक्व चरण तक कुल विकिरणित ऊर्जा का स्रोत होता है। फसल की परिपक्वता के पश्चात, संवेदनशील उष्मा अन्य घटकों से अधिक महत्वपूर्ण होती है।

ABSTRACT. Results of an experiment conducted at the Central Agromet Observatory on gram crop during 1990-1991 winter crop season, to investigate relative contribution of energy balance parameters, are presented in the study.

The analysis revealed that latent heat is the major source of dissipation of net radiative energy till early maturity stage. After crop attains maturity, sensible heat predominates over other components.

Key words — Sensible heat, Ground heat flux, Net radiation, Advective heat, Abscission.

1. Introduction

Growth, development and yield of field crops are largely governed by the complex interaction between the energy and water balance in the crops' immediate environment. A large fraction of the solar energy received on a cropped area is used in the evaporation from plants, heating the soil and the adjacent air, and in plant metabolism.

In order to study water use pattern of the plant in relation to its physiological age, the distribution of energy incident upon the surface must be considered and well understood. The major components of this energy are the latent heat (LE) and the sensible heat (H) and these, alongwith the soil heat flux (G) determine physiological and anatomical aspects of the plant. Magnitude of these components visually affect physiological process of plants. A prior knowledge of these parameters in the boundary layer is useful for understanding process of crop growth, for water management application, development of water balance models, assessment of type, state and status of crop through remote sensing etc. Kumar (1985) studied effect of incident shortwave radiation, net radiation and temperature on finger millet. Hourly values of incident, reflected, transmitted and utilised solar radiation for cowpea were studied by Rajegowda and Ratnam (1987). Radiation balance components in summer moong was recently studied by Surender Singh *et al.* (1991).

Not much work appears to have been done in India on the energy balance of Bengal gram as affected by surface climatic conditions.

The purpose of the study is to investigate, evaluate and discuss the size of each term of the energy balance for the entire cycle of gram.

2. The energy balance

The energy balance for a unit horizontal vegetated surface area at a height z in the crop can be written as:

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

where, R_n is the net downward radiation flux at level z , LE the latent heat flux (L is the latent heat and E is the amount of water evaporated), H is the sensible heat flux, G is the flux of heat into the soil at a depth z' below the surface, P represent energy used in photosynthesis, J is the rate of storage of sensible heat in the soil-crop-air quantum between z and z' and M , the miscellaneous exchanges not accounted by any of the above components.

R_n is positive when directed towards atmosphere-soil interface and the rest of the terms are positive when directed away from the soil surface.

The sum of P , J and M is usually smaller than the experimental error involved in the measurement of the major components and hence, can be neglected.

Eqn. (1) thus gets reduced to :

$$R_n = LE + H + G \quad (2)$$

3. The experimental detail

The experiment was conducted to evaluate the above components of energy for the entire cycle of gram at

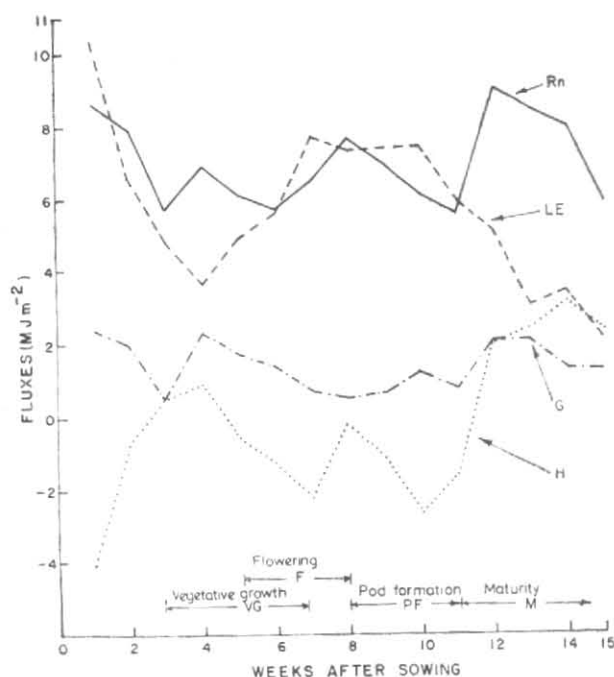


Fig. 1. Mean weekly march of energy balance parameters

Central Agrometeorological Observatory, Pune (18°32'N, 73°51'E) situated 559 m asl. Gram was grown as a winter crop in a field 7.2 hec in area during 1990-91. The soil at the experimental site is characterised by about 45% clay, 20% silt and 19% sand and bulk density in the top layer is 1.34 g cm⁻³. Because of large quantity of clay, the soil exhibits considerable swelling and shrinking as a result of wetting and drying.

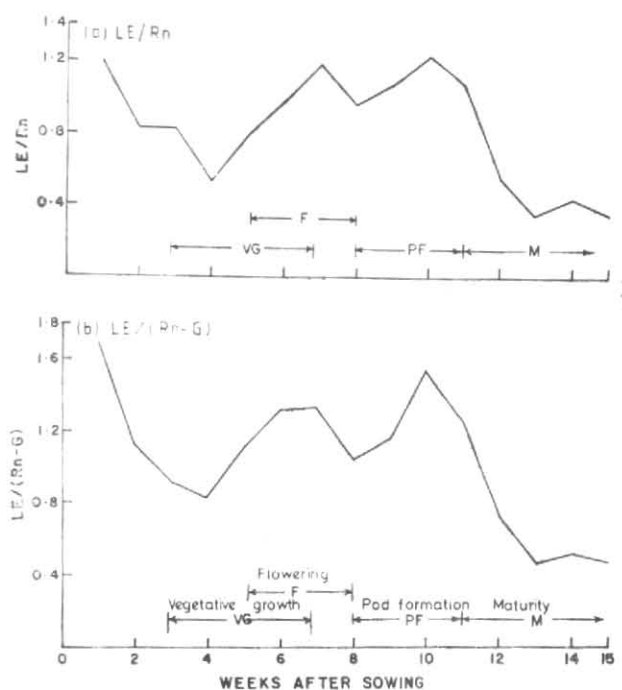
PG-05 variety of gram was sown in rows 30 cm apart on 22 November 1990 with a seed rate of 90 kg/hect, and with 86% germination. No rainfall occurred during the entire growth period of the crop. The crop, thus, survived and thrived on stored soil moisture, limited dew deposits and irrigation. Plants in the entire experimental area were irrigated once each during sowing, vegetative growth and pod formation stages. The crop was given uniform pesticide doze of 20 kg BHC/hect once during pod development stage. The plants reached a maximum height of about 45 cm.

Net radiation (R_n) was measured continuously with net pyradiometer. The net radiometers were mounted at heights of 25 and 60 cm within the crop canopy positioned between the plant rows. The output of net radiometer was received on strip chart recorder. Soil heat flux (G) was measured with soil heat flux plate buried 5 cm below the soil surface. The soil heat flux observations were taken at the eight synoptic hours, *i.e.*, at 3-hour interval.

The evaporation heat flux E was measured as depletion of soil moisture in a 60 cm soil profile during a 7-day interval by using the following formula (*cf.* Islam 1991).

$$E = 10 H \sigma (S_0 - S_1) + I + P \quad (3)$$

where, E is the evaporative loss (cm) in a week, H the root depth (m), σ , the bulk density of the soil (g cm⁻³), S_0 and S_1 are soil moisture content (%) at the beginning and end of the week, I , the amount of irrigation (mm)



Figs. 2(a & b). Mean values of : (a) LE/R_n , and (b) $LE/(R_n - G)$

and P , precipitation (mm). The soil moisture was measured by gravimetric method, once in a week.

The soil evaporation E in the cropped field is thus obtained from Eqn. (3) and is considered as evaporative loss from plants and soil together, *i.e.*, evapotranspiration. This is multiplied by L , the latent heat and then converted into energy terms per unit time (*i.e.*, week) per unit area.

4. Bowen ratio

Sensible heat flux (H), was computed indirectly through Bowen's ratio β . For this purpose dry and wet bulb temperatures were measured at 3-hour interval with the help of Assman fan aspirated psychrometer at 25 and 60 cm heights. The Bowen's ratio is the ratio of sensible and evaporative flux, *i.e.*,

$$\beta = H/LE \quad (4)$$

β is calculated from the transport equation for convective and latent heat flow

$$\beta = \frac{\rho c_p K_H \Delta T / \Delta z}{\rho L K_W \Delta q / \Delta z} \quad (5)$$

where, ρ is the density of air, c_p is the specific heat of air, L is the latent heat of evaporation, K_H is the transport coefficient for heat, and K_W the transport coefficient for water.

ΔT and Δq are the difference in air temperature and specific humidity respectively between the vertical distance Δz . The ratio K_H/K_W is generally regarded as unity. Thus, knowing β and LE , H the sensible heat flux is calculated by using Eqn. (4).

5. Results and discussion

5.1. Energy balance components

Daily average of the energy balance components during the gram growing season (winter) for different Weeks After Sowing (WAS) is given in Table 1 and also depicted in Fig. 1.

TABLE 1

Daily averages of energy balance components (MJm^{-2})

Weeks after sowing	R_n	LE	H	G	LE/R_n	$LE/R_n - G$
1	8.64	10.40	-4.16	2.40	1.20	1.66
2	7.87	6.52	-0.65	2.00	0.83	1.11
3	5.73	4.77	0.48	0.48	0.83	0.91
4	6.90	3.75	0.93	2.32	0.54	0.82
5	6.15	4.95	-0.49	1.71	0.79	1.11
6	5.73	5.61	-1.29	1.41	0.98	1.30
7	6.53	7.71	-2.20	0.75	1.18	1.33
8	7.58	7.26	-0.22	0.54	0.96	1.03
9	6.90	7.39	-1.11	0.62	1.07	1.17
10	6.05	7.41	-2.59	1.23	1.22	1.53
11	5.48	5.88	-0.59	0.81	1.07	1.25
12	9.01	4.96	1.98	2.07	0.55	0.71
13	8.40	2.96	2.37	2.07	0.35	0.46
14	7.86	3.43	3.09	1.34	0.43	0.52
15	5.77	2.12	2.33	1.32	0.36	0.47

It is seen from Table 1 and Fig. 1 that in the initial growth phase there is a decrease in latent heat flux (LE) from a maxima of 10.4 MJm^{-2} during the first week. Irrigation during the first week caused LE to be almost equal to R_n . During the period of maximum growth (4-7 WAS) when crop canopy gets gradually developed, LE rates tend to increase. The value of LE exceeds 7 MJm^{-2} during flowering and pod formation (7-10 WAS). Irrigation during sowing and pod formation period (10-11 WAS) caused LE to be invariably more than R_n . Another factor which contributes to higher LE during these phases is higher atmospheric demand. The mean maximum temperature was 31.8°C (7-10 WAS) while during immediately preceding week it was 29.7°C .

After pod formation (10-11 WAS) moisture shortage, physiological age and senescence retards any further crop development thus lowering LE which become significantly lower than R_n . However, for the entire crop season, R_n for gram was usually as great as LE . Integrated values of LE for the crop season was found 85.12 MJm^{-2} , about 20% less than the cumulative R_n . This can be attributed to the fact that gram canopy was never fully developed with the LAI attaining a maximum values of 3.8 only.

The sensible heat flux (H) was mostly negative from latter part of vegetative growth to the beginning of maturity (Table 1 : Fig. 1) indicating that the largest amount of energy was probably extracted from the surrounding air from vegetative to early maturity phase.

Rosenberg (1969) observed negative value of H as high as 157 Wm^{-2} (0.57 MJm^{-2}) for corn. Rosenberg and Verma (1978) gave estimates of H as -249 Wm^{-2} (0.90 MJm^{-2}) for the same crop. Sumayao *et al.* (1980) found negative value of H as 89.9 Wm^{-2} (0.3 MJm^{-2}) for corn. The largest negative value of H was 4.16 MJm^{-2} found for gram in the present study. The negative values of H were usually associated with air temperatures in the $29-30^\circ\text{C}$ range. H was found positive during initial growth period and the soil heat flux (G) was positive throughout the crop season.

TABLE 2

Energy balance components (MJ m^{-2}) at various phytophases

Phytophases	R_n	LE	H	G
Vegetative (3-6 WAS)	24.51	19.8 (78)	-0.37 (-0.01)	5.79 (24)
Flowering (5-7 WAS)	18.41	18.27 (99)	-3.98 (-22)	3.87 (21)
Pod formation (8-10 WAS)	20.53	22.06 (107)	-3.92 (-19)	2.39 (12)
Maturity (11-13 WAS)	22.89	13.80 (60)	3.76 (16)	4.95 (22)

Figures in the parenthesis represent percentage with regards to net radiation

Gram canopy never develops fully to cover the underlying soil surface completely probably resulting in higher values of G after maturity. The values of H and R_n have also become larger; however, LE is reduced after maturity.

The energy utilised by different components, out of the net energy impinging on the crop surface is shown in Table 2 for different phytophases. It is seen that LE is nearly 75% of the net radiation during vegetative growth. Suresnder Singh *et al.* (1991) found, *albeit* for a summer crop, that about 75% of the net energy is utilised by the plant for evapotranspiration in vegetative growth, flowering and pod formation in moong. During flowering and pod formation it exceeds net radiation, the extra amount has probably been supplied through advection and ground. During maturity, due to withering, only 60% of the net energy has been used by the plant. The sensible heat also contributed significantly during maturity since soil dryness did not provide necessary energy. During all phenophases G contributed substantially to the energy balance.

5.2. LE : Net radiation relationship

The mean values of LE/R_n for different weeks is shown in Fig. 2(a). At the start of the crop season, plant foliage is small and LE/R_n values are highly dependent on the wetness of the soil surface due to natural rainfall, irrigation or dew deposits. The irrigation provided higher LE/R_n in the initial few weeks of the plant growth. The ratio subsequently falls rapidly till start of vegetative phase. As the crop gradually develops, LE/R_n progressively increases. Between flowering and early maturity, when vegetative growth is maximum, LE/R_n is nearly 1.0.

During flowering and 9-11 WAS, LE/R_n exceeded 1.0. Such large values clearly indicate that some amount of sensible heat was locally advected. This advected energy contributed to 10-35% of LE during the period.

After attaining peak value, LE/R_n decreased sharply, suggesting reduction of actual evapotranspiration due to lack of available soil moisture and withering of plant.

5.3. LE : ($R_n - G$) relationship

($R_n - G$) indicates available energy to crops. Among other factors it depends largely on whether energy from surrounding gets advected into the cropped field. Weekly ratio of $LE/(R_n - G)$ is shown in Fig. 2 (b).

Apart from the initial growth phase, when this ratio is greater than 1.0, $LE/(R_n-G)$ exceeds 1.0 during flowering and commencement of maturity. Large values of the ratio during initial crop growth are due to higher R_n which in turn decreases (R_n-G). The mean weekly value for the season as a whole was 1.02. Peterschmitt and Perrier (1991) found mean value of this ratio as 1.00 for rice in southeast coastal India. Due to drying up of soil after maturity, *i.e.*, after 11 WAS, low values of $LE/(R_n-G)$ appear. The difference between accumulated LE and (R_n-G) was 1.09 MJm^{-2} , *i.e.*, less than 2% of LE . In the study, gram which was not much irrigated and which did not get any rainfall, the seasonal (R_n-G) underestimated LE by just 1.8%. Hence at least till commencement of maturity when LE/R_n-G was > 1.0 , R_n-G also could be a dependable tool to assess LE .

When LE/R_n-G is more than 1.0, such situations warrant energy supply from air to crop through advective heat transfer. This is precisely what has been observed between 5-11 WAS.

5.4. Advection of energy

Some amount of energy is often advected from the adjoining barren fields into the cropped field. This happens when the latent heat energy LE exceeds R_n-G . The magnitude of the advected energy could be substantial in semi-arid regions. The advected energy E_a is rather difficult to measure and is calculated as the difference between equilibrium evapotranspirative energy E_e , and the latent heat energy LE , *i.e.*,

$$E_a = LE - E_e \quad (6)$$

A number of methods are available to compute equilibrium evapotranspirative energy. Lang *et al.* (1974) defines equilibrium evapotranspirative energy.

$$E_e = \frac{\delta}{\delta + \gamma} \frac{R_n - G}{L} \quad (7)$$

where, δ is the slope of saturation vapour pressure ($\text{mb}/^\circ\text{C}$), γ is the psychrometric constant ($\text{mb}/^\circ\text{C}$) and $\delta/\delta + \gamma$ is a function of wet bulb temperature.

Tomar and O'Toole (1979) have multiplied the right hand side of Eqn. (7) by 1.26 to get E_e . Perrier *et al.* (1980) obtained E_e as LE/C where C is a factor dependent on crop type, its stomatal resistance and canopy architecture. Recently Steiner *et al.* (1991) determined equilibrium evapotranspiration for different ranges of minimum temperature.

In the present study advection of energy was observed for two weeks after germination of gram and during active vegetative and flowering stages, totalling 9 weeks out of 15 weeks of the crop season. For these cases, the equilibrium evapotranspirative energy flux was calculated using Tomar and O'Toole (1979) method and then using Eqn. (7), the advective energy was obtained.

The results are shown in Table 3. The advective energy ranged from 33 to 58% of the latent evaporative energy with a mean value of 45%. It means that the energy whenever transported from surrounding area into the crop field during rabi season, could be at least one-third of the total evaporative energy of the system. Evans (1971) concluded that for all practical purposes, the advective energy does not exceed 60% of the total latent heat energy.

TABLE 3

Equilibrium and advective energy

S. No.	Equilibrium evaporative (MJ m^{-2})	Advective energy (MJ m^{-2})	Advective energy/total energy (%)
1	4.18	5.87	58
2	3.72	2.55	41
3	2.93	1.84	39
4	2.89	2.53	47
5	3.86	3.58	48
6	4.72	2.29	33
7	4.20	2.93	41
8	3.22	3.94	55
9	3.13	2.55	45

6. Conclusions

(i) Due to irrigation, the latent heat flux (LE), could be as large as, or even greater than net radiation.

(ii) Sensible heat becomes predominant over other components after maturity and contributes nearly a third of the latent heat.

(iii) Maximum energy is extracted by the gram plant during vegetative phase.

(iv) Cumulatively, the latent heat flux (LE) could be about 20%, less than the net radiation energy and so can serve as a useful tool for estimating plant moisture loss.

(v) The energy transported from surrounding area into the crop field could be at least one-third of the total evaporative energy of the system.

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