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Comparative studies on energy balance components and their inter relations on soybean crop and bare soil in kharif season at Pune situated in semi-arid tract

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सार - इस शोध पत्र में सोयाबीन की उपज की बढ़वार के समय की विभिन्न अवस्थाओं और बिना फसल वाले खेत के विकिरण संतुलित घटकों के विषय में पुणे स्थित केन्द्रीय कृषि मौसम वैज्ञानिक वेधशाला (CAgMO) में तुलनात्मक अध्ययन किए गए हैं। वर्ष 1995 के दौरान, खरीफ के मौसम के समय उपज की बढ़वार की सभी अवस्थाओं में बिना फसल वाले खेत के साथ-साथ फसल वाले खेतों से नेट, परावर्तित और भूमंडलीय सौर विकिरणों के निरंतर माप (आँकड़े) लिए गए। बिना फसल वाले खेत की अपेक्षा, सोयाबीन की फसल के ऊपर नेट एवं परावर्तित विकिरण एल्बिडो 7, 26 और 25 प्रतिशत उच्चतर पाए गए थे। फसल के ऊपर नेट लघुतरंग (अवशोषित) विकिरण और नेट दीर्घ अवधि (निर्गमन) विकिरण से प्राप्त मूल्याकंन बिना फसल वाले खेत में क्रमशः 5 और 20 प्रतिशत कम पाए गए है।

दैनिक माध्य नेट, परावर्तित नेट लघु तरंग तथा नेट दीर्घ तरंग (निर्गमन) विकिरण क्रमशः 9.86, 3.86, 15.35 और 5.49 MJm^{-2} ओर सोयाबीन की फसल के ऊपर एल्बिडो 20 प्रतिशत पाए गए थे जबकि बिना फसल वाले खेत में ये क्रमशः 9.23, 3.07, 16.15 और 6.91 MJm^{-2} ओर 16 प्रतिशत पाए गए थे। फसल के संवर्धन के मौसम में दैनिक माध्य भूमंडलीय सौर विकिरण 19.20 MJm^{-2} था। सोयाबीन को बोने के बाद, दसवें सप्ताह में रिकार्ड किए गए उपज के उच्चतम एल्बिडो (26 प्रतिशत), सोयाबीन की फली के पकने की अवस्था में पाए गए अधिकतम एल.ए.आई. (5.9) के अनुरूप पाए गए थे।

ABSTRACT. Comparative studies of radiation balance components at different growth stages on soybean crop and bare soil were made at Central Agrometeorological Observatory (CAgMO), Pune. Continuous measurements of net, reflected and global solar radiations were made over cropped field as well as over bare soil all throughout the growth phases in kharif season of 1995. Net and reflected radiations and albedo over canopy were higher by 7, 26 and 25 per cent respectively than bare soil. The net short wave (absorbed) radiation and net long wave (out-going) radiation evaluated over the canopy were less than those over bare soil by 5 and 20 per cent respectively.

The mean daily net, reflected, net short wave and net long wave (out-going) radiation were 9.86, 3.86, 15.35 and 5.49 MJm^{-2} respectively and the albedo was 20 per cent over soybean canopy whereas for bare soil they were 9.23, 3.07, 16.15 and 6.91 MJm^{-2} and 16 per cent respectively. The mean daily global solar radiation during the crop growing season was 19.20 MJm^{-2}. The highest albedo (26 per cent) of the crop recorded in the 10th week after sowing (WAS) was in correspondence to maximum LAI (5.9) observed at pod formation stage.

Key words – Energy balance, Albedo, Soybean, Bare soil.

1. Introduction

Solar energy is the ultimate source of energy for the physical processes of plants. Plants respond to incident solar radiation throughout the life cycle and maximum values of incident radiation integrated over the growing periods influence cumulative effects such as water usage, growth and yield. However, not all in-coming radiant energy is absorbed by the vegetation even though the canopy traps most of it. Among various components of radiation balance, albedo and net radiation are of much importance in determining the radiation balance of a crop stand. Detailed information regarding the radiation balance components would be of much use in understanding the various physical and physiological processes taking place in a crop stand.

Several scientists have studied the radiation balance over field crops (Rusin, 1958, Graham and King, 1961; Stanhill *et al*., 1966; Monteith and Szeicz, 1961; Fritschen, 1967; Murthy and Rao, 1982; Kumar 1985, Chowdhury *et al*., 1993). Such studies are crop specific.

Studies on radiation balance components have also been taken up for field crops grown in semi-arid tract of India. This paper describes the radiation balance components made at Pune over bare soil and soybean canopy at different growth stages of the crop during the kharif season.

2. Materials and methods

A field experiment was conducted at the farm of Mahatma Phule Agricultural College adjacent to CAgMO, Pune (18° 32' N, 73° 51'E) during the kharif season 1995. The soybean crop (variety : MACS-124) was sown in the black cotton soil of the experimental field on July 31, 1995 with seed rate of 75kg/ha.

Continuous recording of net radiation (Rn) and reflected radiation (R_R) for the bare soil and cropped field were made from net pyrradiometers and inverted pyranometers which were mounted at a height of 1m above the ground. Continuous recording of global solar radiation (R_G) was made by a pyranometer. The distance from the effective radiating surface and the net pyrradiometer is kept constant by mounting the sensor on an adjustable mounting stand.

The dry and wet bulb temperatures were measured using Assman psychrometer daily at an interval of 3 hours round the clock within and above the crop canopy at surface, 50 and 100 cm heights for the computation of long-wave out-going radiation ($R_L\uparrow$) with the help of Stefan-Boltzmann's equation. The values of downward long wave radiation flux ($R_L\downarrow$) from the atmosphere were computed indirectly by using equation:

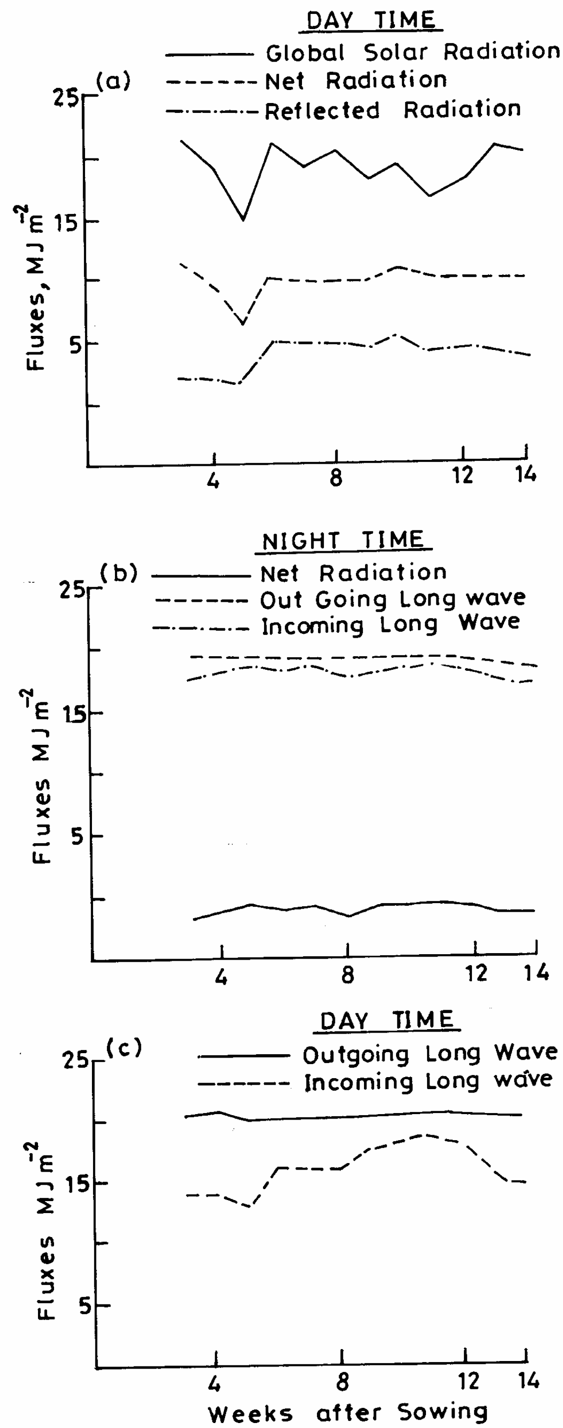
$$Rn = [(R_G - R_R) + (R_L\downarrow - R_L\uparrow)] \quad (1)$$

The energy balance on a unit horizontal surface area in the crop canopy can be expressed as:

$$Rn = LE + H + G + P \quad (2)$$

Where LE is the latent heat flux, H the sensible heat flux, G the soil heat flux and P the energy required during the process of photosynthesis.

The crop phenological observations (height, branches and leaves), leaf area index and soil moisture percentage were recorded at an interval of 7 days. The soil temperatures at surface, 10 cm and 30 cm depths were measured daily at 0730, 1430 and 1730 hrs



Figs. 1(a-c). Variation of radiation components (Day and Night) in Soybean canopy.
(a) Day-time variation of global, net and reflected radiation;
(b) Night-time variation of net, out going and incoming longwave radiation;
(c) Day-time outgoing and incoming long wave radiation.

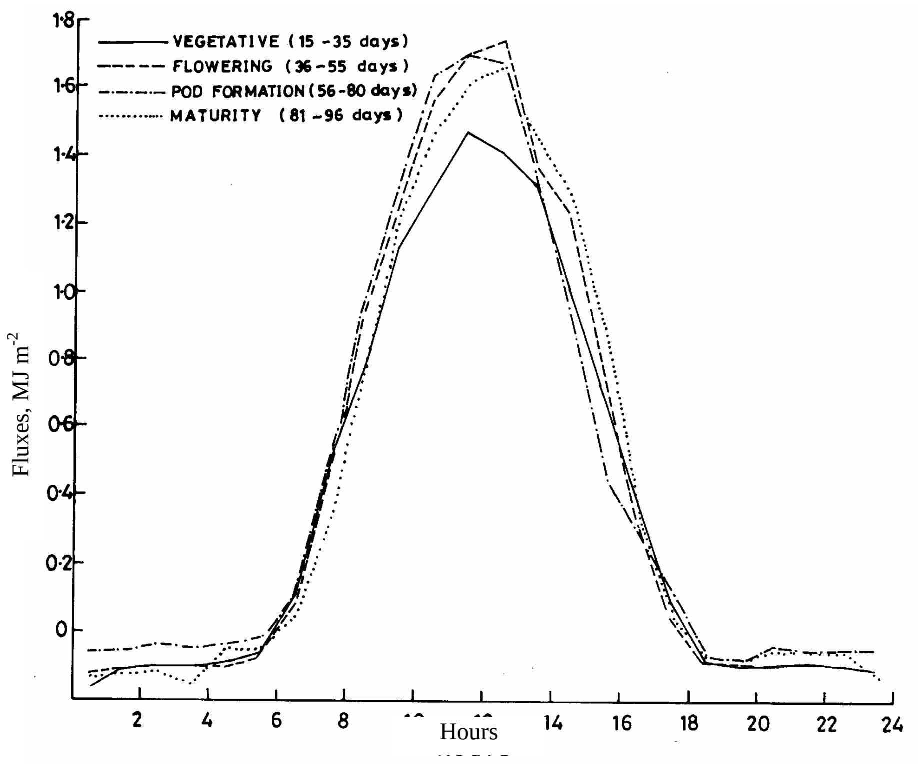


Fig. 2. Diurnal variation of net radiation at different stages of crop growth

IST throughout the crop growing period for computation of soil heat flux (G) from:

$$G = -K\,dT/dZ = -K\,(T_2 - T_1) / (Z_2 - Z_1)$$

Where K is the thermal conductivity of the soil (0.21 $MJm^{-1}\,h^{-1}c^{-1}$), T_1 and T_2 are the temperatures of soil at the depths Z_1 and Z_2 respectively.

The data were analysed for the energy balance equations (1) and (2) and for Bowen's ratio method. The H/LE ratio is obtained from measurements of dry and wet bulb temperatures difference in the air between the two levels above the crop.

3. Result and discussion

3.1. *Radiation balance components*

The different components of net radiation vary differently depending on the season, conditions of the sky, soil and the vegetations. As mentioned the measurements were carried out during August-October 1995. Care was taken to keep the reference field bare of all vegetations. Regular recordings were started only from third week after sowing the seeds.

Fig.1 gives the variations in the different energy balance components during the 14 week period of the crop growth stages. During this period the mean value of global solar radiation R_G was 19.01 MJm^{-2}. Due to the prevailing seasonal heavy clouding R_G values are generally low, values varying between 14.73 and 21.31 MJm^{-2}. The lower values are generally associated with the prevailing clouds of the monsoon season. The reflected radiation R_R from the canopy shows some interesting features. The daily values were steady and low at around 2.5 MJm^{-2} upto 5 WAS; there after they increase by more than 100 per cent to nearly 5 MJm^{-2} and then remained nearly steady. This is obviously due to the increased reflection from the canopy at flowering, pod formation and maturity stages. This is inspite of larger variations in the daily global solar radiation. Naturally the values of albedo also shows similar variations, with a 9 per cent value at seedling stage and this abruptly increased to 24 per cent at flowering stage. It increased marginally to 27 per cent at pod stage and subsequently decreased to 18 per cent when the plant reached maturity stage. The average value of albedo during the entire cropping period is 20 per cent.

The downward terrestrial (long wave) radiation $R_L\downarrow$ is always lower than the upward radiation $R_L\uparrow$ in the,

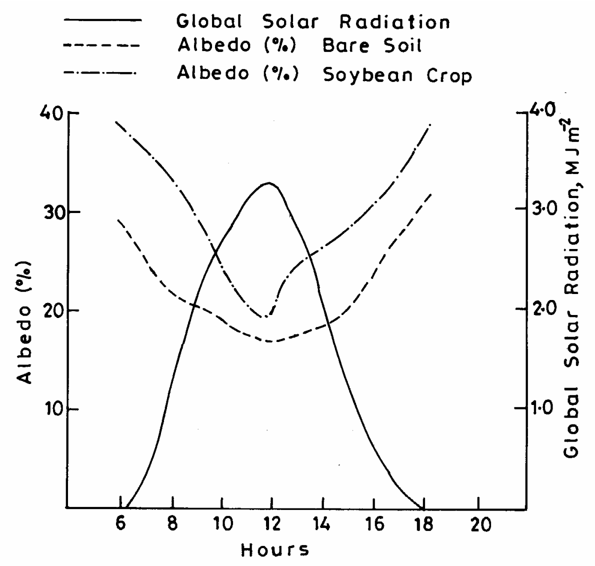


Fig. 3. Diurnal march of global radiation and albedo (%) of bare soil and soybean crop during pod formation stage

same wave lengths, giving rise to a net upward radiant flux which by convention is given a negative sign. While the upward radiation $R_L\uparrow$ during night times shows a monotonous trend slightly decreasing from 19.45 MJm^{-2} to 18.14 MJm^{-2} as the crop advanced from seedling to maturity stages. These values were marginally higher during the daytime though maintaining the decreasing trend. The downward flux however shows larger variations as they are more closely dictated by the varying cloudy conditions. $R_L\downarrow$ values changed from 18.14 MJm^{-2} to 19.45 MJm^{-2} during the nights. These values were in the range 19.90 to 20.46 MJm^{-2} during the day. While the changes in $R_L\downarrow$ are very small in the night, they are larger during the daytime being controlled by the clouds and the reflected solar radiations from the changing canopy conditions.

The net solar (short wave) radiation R_{sn} is a very important parameter which is absorbed by the earth surface and by the leaves for photosynthesis activities. R_{sn} was found to vary from 12.24 to 19.48 MJm^{-2}. The factors that seriously affect R_{sn} are the clouds and albedo of the surface and the canopy. The net terrestrial (long wave) radiant energy flux R_{Ln} is generally higher during the day than in the night and is always negative *i.e.* it is energy loss from the earth surface and canopy. During the day times the values of R_{Ln} varied from 1.73 MJm^{-2} to 6.60 MJm^{-2}. The variations are obviously over a quite smaller range from 0.44 MJm^{-2} to 1.65 MJm^{-2} during the night.

On an average the net radiation over the crop canopy was 10.81 MJm^{-2}. The values show large fluctuations ranging from 6.23 to 13.05 MJm^{-2}. They were lowest during the 5th week after sowing at the time of flowering. The highest was in the 3rd week when the seedlings appeared but it was nearly a bare soil during this period.

Fig. 2 shows the diurnal variations in the net radiations over the different stages of growth. It is interesting to note that the net radiation becomes 0 about 30 minutes after sunrise and about 30 minutes before sunset. The values are negative during the night time as the canopy loses terrestrial (long wave) radiation in the form of radiative heat. It is seen that the peaking of the flux occurs at around 1130 hrs during vegetative and pod formation stages and it is at about 1300 hrs during flowering and maturity stages. The net radiation is higher in the forenoons in the pod formation stage while it is higher in the afternoons in the flowering stages. During maturity stage Rn is the least of the three stages during the forenoons. It is highest in the afternoon. This performance may have to be more critically measured and energy economics worked out.

3.2. *A comparison with the measurements over the bare soil*

The regular measurements of reflected solar radiation and the net radiation are made in the near by network radiation station. The soil below both the inverted pyranometer and the net pyrradiometer are always kept free of any vegetation to ensure a reference base values for these parameters.

3.2.1. *Albedo* (α)

The noon time values of albedo of the black cotton soil of Pune is around 12 percent where as the daily mean value is 16 per cent. Under vegetation, that of soybean crop this value increases to 20 per cent. A comparative values of the parameter over the vegetated soil and the bare soil are given in Table l. These are the mean daily values for each stage of the crop.

It is interesting to note that the albedo of the cultivated soil is hardly 10 per cent while it is 17 per cent over bare soil during the vegetative stage when the cultivated soil is watered and remains moist. The reflection from the irrigated soil is lower than that of bare but dry soil. The values of α over canopy overshoots those over bare soil once the crop starts growing into different stages. This albedo is not that of the leaves

TABLE 1

Radiation balance component over soybean crop and bare soil at different phenophases

Phenophases	Soybean crop						Bare soil					Ratio of Rn over bare soil (%)	Ratio of RLn over bare soil (%)
	R_G MJm^{2}	Rn MJm^{-2}	R_R MJm^{-2}	α (%)	Rsn MJm^{-2}	R_{Ln} MJm^{-2}	Rn MJm^{-2}	R_R MJm^{-2}	α (%)	Rsn MJm^{-2}	R_{Ln} MJm^{-2}		
Seedling (15 days)	-	-	-	-	-	-	-	-	-	-	-	-	-
Vegetative (16-35 days)	18.48	8.87	1.93	10	16.55 (90%)	–7.68	9.66	3.23	17	15.25 (83%)	–5.59	+8	–37
Flowering (36-55 days)	20.15	10.16	4.78	24	15.37 (76%)	–5.21	9.96	3.22	16	16.96 (84%)	–7.24	–5	+28
Pod formation (56-80 days)	17.88	10.29	4.58	26	13.30 (74%)	–3.01	9.21	3.01	17	14.87 (83%)	–5.66	–12	+14
Maturity (81-96 days)	20.33	10.13	4.15	20	16.18 (80%)	–6.05	8.36	2.80	14	17.52 (86%)	–9.16	–21	+34
Mean	19.21	9.86	3.86	20	15.35 (80%)	–5.49	9.23	3.07	16	16.15 (84%)	–6.91	–7	+21

NB : 1) Values in parentheses are percent values of absorption of R_G. 2) Negative signs show long-wave effective outgoing radiation

alone but includes the under surface (soil) as well. The albedo over the canopy reaches maximum (26 per cent) during the pod formation stage. As the crop matures, the albedo also decrease (20 per cent) gradually.

Fig. 3 shows the diurnal variations in albedo over the cultivated land and the bare soil during the pod stage. Though the variations show similar pattern, the changes are steep in the case of the values of crop canopy as compared to the gradual and symmetrical changes over the bare soil.

3.2.2. *Reflected solar radiation (R_R)*

The actual amount of energy absorbed depends on the reflectivity of the surface. Thus variations in the actual energy gives an important insight into the energy budget studies. Over the two sets of sites, soybean vegetation with irrigation facilities and the bare soil, the amount of reflected solar radiation is higher over the bare soil. It is 3.23 MJm^{-2} over bare soil as compared to 1.93 MJm^{-2} over the moist soil for the same value of incident irradiances of mean 18.48 MJm^{-2} (Table 1). The sharp increase in R_R values over the canopy is striking while the values remain nearly constant over the bare soil. Though the global solar irradiances decreased by 11 per cent to 17.88 MJm^{-2} during pod stage, the values of R_R remain remarkably high at 4.58 MJm^{-2}, just a fall of 4 per cent. The corresponding reduction is a higher 7 per cent over bare soil. By the time the crop matured the reflected radiation has reduced by 9 per cent despite an increase of 14 per cent in the mean daily global radiation. It is 7 per cent fall over bare soil, mainly due to the hardening of the soil due to lack of moisture.

Fig. 4 shows the diurnal variations in the reflected radiations. The reflected radiation values are very low during the seedling and vegetative stages due to high moisture in the cropped field. The slight asymmetry seen around the noon in the case of the later stages is entirely due to orientation of the leafy surfaces to the incident radiation. The diurnal variations over the bare soil are uniform and nearly the same over the entire period except during the pod formation stage when higher number of cloudy days has caused lower reflected radiation.

3.2.3. *Net solar radiation (R_{sn})*

Though global solar radiation dictates the changes in R_{sn}, it is seen (from Table 1) that R_{sn} has reduced by 7 per cent from vegetative to flowering stage where as it increased by 11 per cent over the bare soil. Thereafter the changes are nearly in tandem; the reduction is by about 12 per cent to pod stage and the increase by nearly 20 per cent during the weeks when the crop matured.

3.2.4. *Net Radiation (Rn)*

On an average the net radiation fluxes over bare soil are 9.23 MJm^{-2} and they are 9.86 MJm^{-2} over soybean

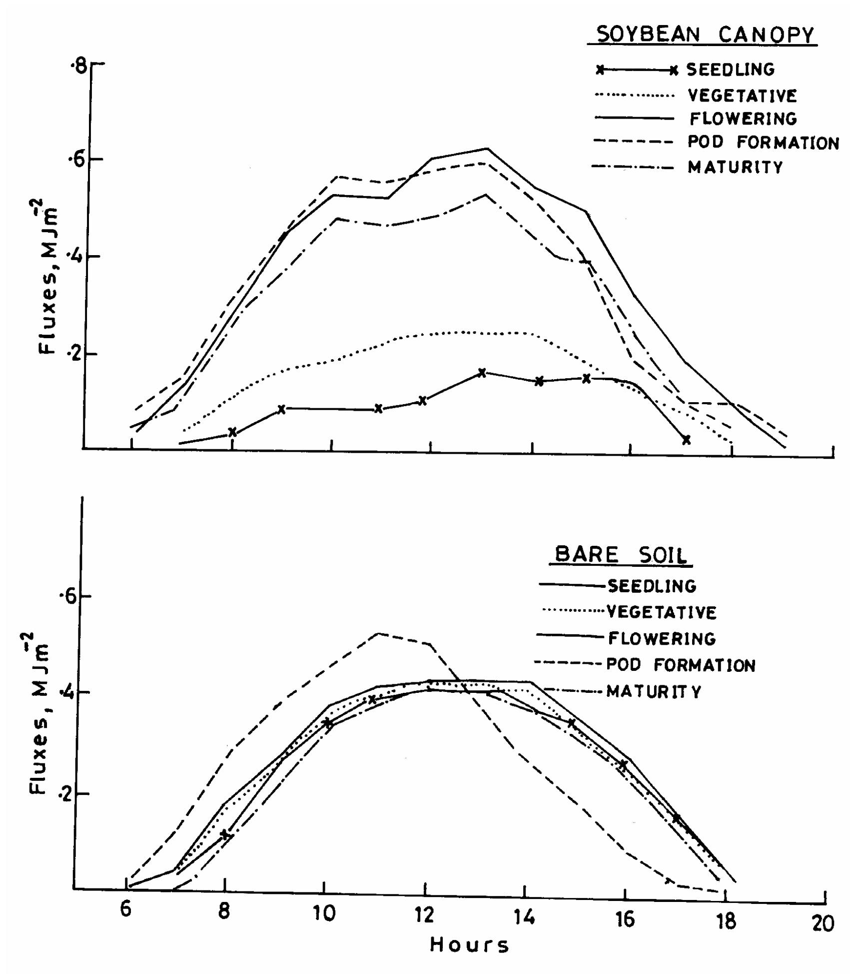


Fig. 4. Diurnal variation of reflected radiation over surface and bare soil

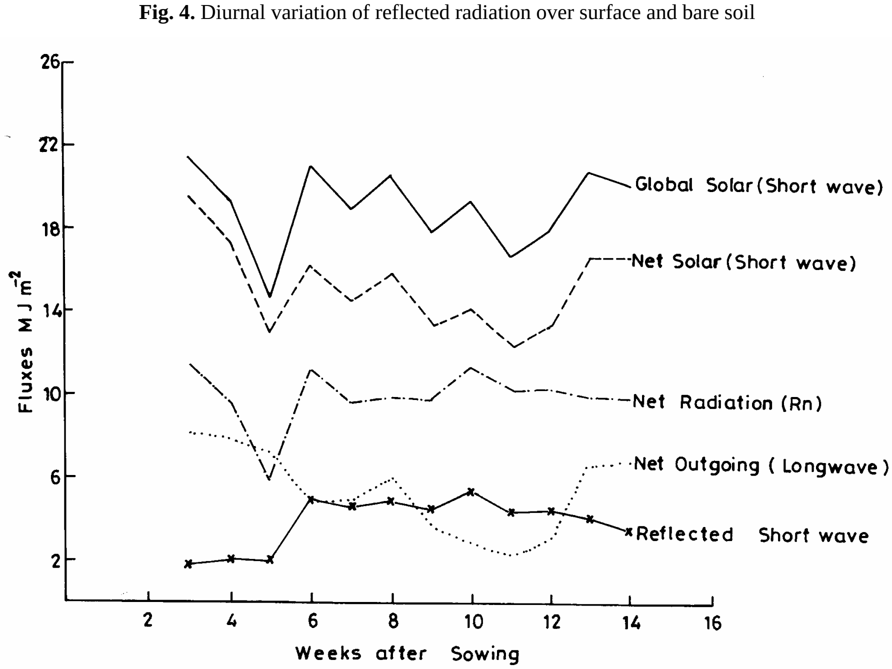


Fig. 5. Patterns of global, net (short wave), net (long wave), net radiation and reflected radiation on soybean canopy

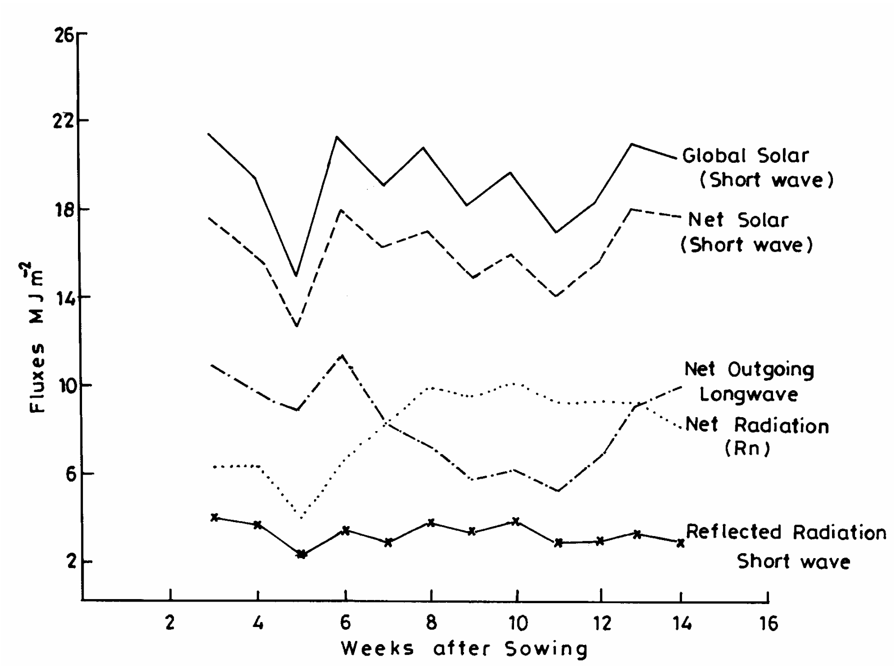


Fig. 6. Patterns of global, net short wave, net long wave, net radiation and reflected radiation on bare soil

canopy, about 7 per cent higher than the bare soil (Table 1). This is to ascribe to the lower emisivity of the leaves when compared to the high emisivity of the bare black soil. The values of net radiation are nearly the same around 10.20 MJm^{-2} possibly controlled by the higher moisture content over the leaves and the higher temperatures near the leaves when compared to the conditions obtainable over the bare soil. The difference between the fluxes over the two sites is least at 5 per cent during the flowering stage. The difference increases as the crop stage advances into pod formation (12 per cent) and it becomes 21 per cent during the maturity stage. Though these values are only mean over the controls that are involved in net radiation field and their interactions are complex. Similar feature has already been seen in Fig. 2. Net radiative fluxes form more than 50 per cent of global radiation over the soybean field. The maximum is 58 per cent during the pod stage.

The performance of various parameters of radiation balance are presented in Figs. 5 and 6 for soybean canopy and bare field respectively. The net solar radiation march closely follows that of global solar radiation over the bare soil and it is so in the case of soybean as well except for the larger magnitude in the differences. A comparison between the two figures shows that the net long wave radiation, R_{Ln} over the canopy is consistently lower by more than 20 per cent than that of over the bare soil. R_{Ln} however is higher by over 35 per cent in the initial seedling and vegetative stages as the soil had been irrigated during these stages. Having absorbed more solar radiation the soil radiates more. The maximum between R_{Ln} values over the two surfaces is again during the pod stage being above 47 percent. It is just –3.01 MJm^{-2} during the pod formation stage.

3.2.5. *Latent heat (LE), sensible heat (H) and soil heat (G) fluxes*

LE varied from 5.0 MJm^{-2} day^{-1} at 5 WAS to 11.17 MJm^{-2} day^{-1} at 10 WAS (Table 2). LE was more or less steady during 6 to 9 WAS and was slightly higher than Rn at 9 and 10 WAS. LE was maximum (11.17 MJm^{-2} day^{-1}) at 10 WAS. It is interesting to note that LE was slightly higher at flowering and pod formation stages (8 to 12 WAS). It decreased gradually to 8.47 MJm^{-2} at the last week during the maturity stage. The average daily LE for soybean crop was 8.99 MJm^{-2} (92 per cent of Rn).

The sensible heat flux (H) was positive during the seedling, vegetative and maturity stages. It was negative at flowering and pod formation stages (week no. 8 to 12). This indicates that the amount of energy was extracted from the surrounding air when the crop canopy was fully developed by advection of energy. During this period LE was equal to Rn. The lowest negative value of H for the cropped canopy is obviously the advected energy adding to LE. Since the net radiation is used for various

TABLE 2

Energy balance components at different weeks after sowing

Week after sowing	Rn MJm^{-2}	LE MJm^{-2}	H MJm^{-2}	G MJm^{-2}	Rn-G	H / LE	LE / Rn	LE /Rn-G
3	11.40	10.09	0.08	0.51	10.89	0.08	0.89	0.93
4	9.50	7.05	1.15	1.30	8.20	0.16	0.74	0.86
5	5.77	5.00	0.26	0.51	5.26	0.05	0.87	0.95
6	10.10	8.95	0.35	0.80	9.30	0.04	0.89	0.96
7	9.59	8.86	0.19	0.51	9.05	0.02	0.93	0.98
8	9.83	9.75	–0.12	0.20	9.63	–0.01	0.99	1.01
9	9.78	9.83	–0.16	0.11	9.67	–0.02	1.01	1.02
10	11.16	11.17	–0.12	0.11	11.05	–0.01	1.00	1.01
11	10.07	10.05	–0.09	0.11	9.96	–0.01	1.00	1.01
12	10.17	10.11	–0.05	0.11	10.06	–0.01	0.99	1.01
13	9.93	8.54	0.59	0.80	9.13	0.07	0.86	0.93
14	9.98	8.47	1.00	0.51	9.47	0.12	0.85	0.89
Mean	9.77	8.99	0.32	0.47	9.31	0.04	0.92	0.96
percentage of Rn		(92%)	(3%)	(5%)	(95%)			

Rn : Net Radiation, LE : Latent heat flux, H : Sensible heat flux, G : Soil heat flux

purposes like heating up the air and evaporation, the LE can not be derived only from Rn. The needed energy to equalize LE with Rn has to be advected from the surrounding environment was found to be 0.16 MJm^{-2} day^{-1} when LE was about 2 percent higher than Rn. H was found to be –0.57 and –0.3 MJm^{-2} over corn (Rosenberg, 1969. Sumayao, *et al*., 1980).

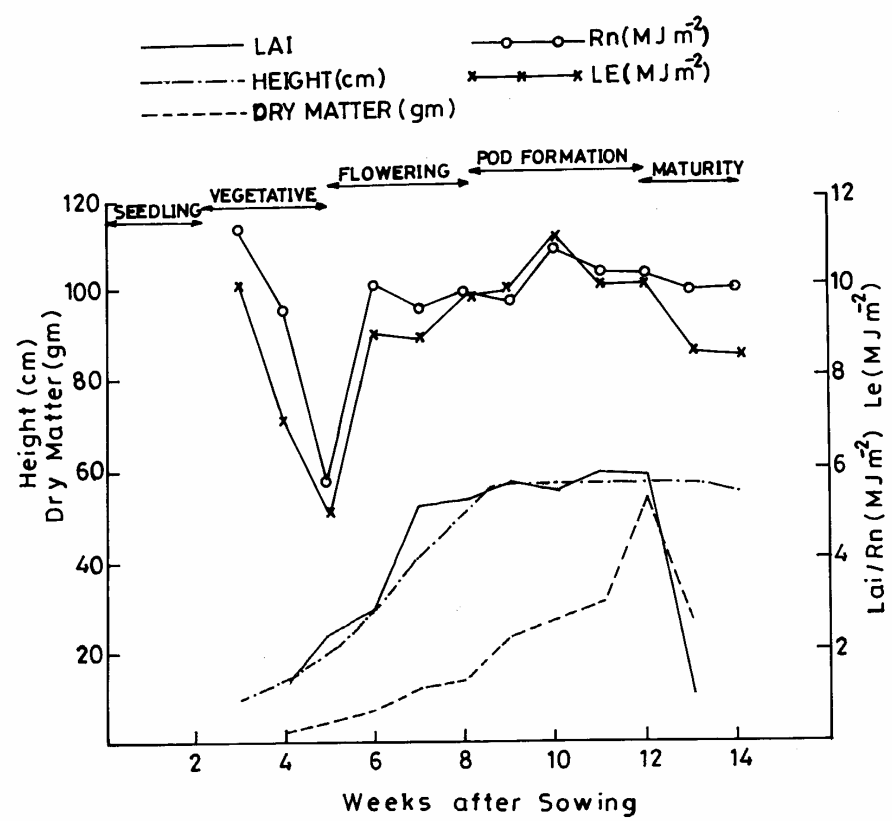
The soil heat flux (G) from 8 to 12 WAS was very small as the soil was fully covered with crop canopy. The mean daily value of G for soybean crop was 0.47 MJm^{-2} day^{-1} (5 per cent of Rn). Higher soil heat fluxes during vegetative, early flowering (till 7 WAS) and maturity stages (13 and 14 WAS) were observed in soybean field (Table 2). This is due to the lowest albedo of the surfaces during the relevant periods.

3.3. *Relationship between LE and Rn*

At the early stages of crop growth when plant foliage was small, the LE/Rn was dependent on the wetness of soil surface. As the crop gradually developed, LE/Rn progressively increased indicating increase in proportion of transpiration and decrease in soil evaporation. Between flowering and pod formation stages when crop growth was maximum, LE/Rn was nearly 1.0. Thus under the potential evaporation condition LE for soybean crop lies in the near limits of Rn (Table 2). LE/Rn was about 1.0 from 8 to 12 WAS as the warm air advected the crop canopy and evaporating surface was cooler due to the transpiration loss under continuous moisture supply from the soil. Gerber and Decker (1960) also showed that ET/Rn ratio was lower when the soil was dry as compared to when it was wet. For soybean crop mean value of LE / Rn was found 0.92 (92 %).

3.4. *Relationship between LAI and LE*

LAI attained the maximum (5.95) at 11 WAS and suddenly dropped during 13 WAS, at maturity stage of the crop due to senescence. LE gradually increased with the increasing LAI. The highest LE (11.17 MJm^{-2} day^{-1}) was attained at 10 WAS, just one week before, when maximum LAI was attained. It is interesting to note that as the LAI and dry matter of crop increased with the advancement of the growth stages, LE also increased till it attained maxima (Fig. 7). LAI increased almost in tandem with the height of the crop. It is also significant that the albedo values also increased during this period when LAI curve became flat after 8 weeks. It is during this period that H and G became stable. With LAI



suddenly decreasing once the maturity stage in, H and G show sudden increase as the global radiation can penetrate inside the crop to heat the soil. Again this results in sudden increase in the weight of the dry matter with the advancement of growth stages of the crop.

4. Conclusion

(*i*) The albedo of the cultivated site highly depends on the moisture condition and the leaf area index. The albedo was highest during the pod formation stage. It is about 26 per cent when compared to 16 per cent of bare soil.

(*ii*) The albedo value dropped to 10 per cent when the soil was irrigated with water and seeds were sown.

(*iii*) Reflected radiation was 4.58 MJm^{-2} during pod formation stage despite an 11 per cent decrease in global solar radiation. The reflected radiation was highest at 4.78 MJm^{-2} during flowering stage.

(*iv*) Net radiation flux was on an average 7 per cent more over the soybean canopy when compared with bare soil. It was highest with 10.29 MJm^{-2} during pod formation stage, though the maximum ratio between the two surfaces occurred during maturity stage.

(*v*) The diurnal variation in net radiation shows that maximum flux is achieved at around 1130 hrs during vegetative and pod formation stages. The maximum epoch is delayed by an hour beyond the noon in the cases of flowering and maturity stages.

(*vi*) Net out-going terrestrial (long wave) radiation is considerably lower over the canopy by more than 20 per cent excepting during the early stage when it was higher by more than 35 per cent.

(*vii*) Net radiation was comparable to integrated latent heat of evaporation during the entire crop season. 95 per cent of Rn was used for evapotranspiration and 3 per cent for sensible heat purposes.

(*viii*) LE/Rn was about 1.0 (100 per cent of Rn) at pod formation stage and for remaining growth stages it was about 0.85.

(*ix*) As the LAI increased with the advancement of crop growth stages LE also increased till LAI attained maxima (5.95).

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References

Chowdhury, A., Das, H. P. and Chivate, V. R., 1993, "Energy balance evaluation in Bengal gram (*Cicer arietinum* L) grown in a sub-humid climate", *Mausam*, **44**, 3, 277-280.

Fritschen, L. J., 1967, "Net and solar radiation relations over irrigated field crops", *Agric. Meteorol*., **4**, 1, 55-62.

Gerber, J. F. and Decker, W. L., 1960, "Evapotranspiration and heat budget of corn field", *Agron. J*., **53**, 259-261.

Graham, W. G. and King, K. M., 1961, "Short wave reflection coefficient for a field of maize", *Q.J.R. Met. Soc*., **87**, 425-428.

Kumar, K. K., 1985, "Radiation balance components in a finger-millet crop", *Mausam*, **36**, 2, 233-234.

Monteith, J.L. and Szeicz, G., 1961, "Radiation balance of bare soil and vegetation", *Q. J. R. Met. Soc*., **87**, 159-170.

Murthy, B.S. and Rao, K.S., 1982, "Short wave albedo of soil and Jowar crop", *Mausam*, **33**, 2, 217-220.

Rosenberg, N., 1969, "Advective contribution of energy utilised in evapotranpiration by alfalfa in the east central plains", *Agric. Meteorol*., **6**, 179-184.

Rusin, N. P., 1958, "Radiation balance of a grain field", Glavnaia Geofizicheskara observatoria, Trudy, **77**, 43-56.

Stanhill, G., Hofstede, G. J. and Kalima, J. D., 1966, "Radiation balance of natural and agricultural vegetation", *Q. J. R. Met. Soc*., **92**, 391, 128-140.

Sumayao, C. R., Kanemasu, E. T. and Brakke, T.W., 1980, "Using leaf temperature to asses evapotranspiration and advection", *Agric. Meteorol*., **22**, 153-166.