Mausam, (1985), 36, 4, 475-478

551.521.3

Radiative scattering in summer crop canopies

O. P. BISHNOI* and R. H. SEDGLEY

University of Westera Australia, Perth

(*Received 20 December*)

सार — फसल वितरणों के माध्यम से विकिरण का छितराव पर्णसमूह विशेषताओं के साथ रेखिक रूप से संबंधित पाया गया है, उदाहरण के तौर पर पर्णसमूह घनत्व तथा पी. ए. आर. रेंज में पर्णसमूह का आनति सूचकांक। छितराव के कार्य द्वारा दृश्य (पी. ए. आर.) दूरी की तुलना में निकटवर्ती अवरक्त (एन. आई. आर.) में उच्च संचयी मान प्रस्तुत किए गए। छितराव काफी हद तक फसल ज्यामिति पर आधारित था। जो पत्ते ऊर्ध्वाधर नीचे की ओर झुके हुए थे उनमें छितराव अधिक था और जिन फसलों में पत्ते क्षेतिज तल के समानान्तर थे या अपेक्षाकृत कम ऊर्ध्वाधर थे उनमें छितराव कम था।

ABSTRACT. Scattering of radiation through crop canopies has been found to be linearly related to the foliage characteristics such as the foliage density and inclination index of foliage in the PAR range and by second degree regression in the NIR range. The scattering function presented higher cumulative values in the near infrared (NIR) as compared to the visible (PAR) range. The scattering was highly dependent on the crop geometry with higher amount of scattering in vertical inclined leaves and progressively decreased in crops with relatively horizontal nature of leaves.

1. Introduction

Scattering of radiation through transmission and multiple reflection in crop canopies vary due to the specific differences in leaf arrangement and canopy architecture (Moldau 1965, Brandit and Tageyeva 1967, Gates *et al.* 1965, Birkebak and Birkebak 1964). The behaviour of scattering function can be used in identifying the relative differences in canopy arrangement. The radiative transfer in plant stands in very complex as it depends on the amount of leaves and other plant parts obscuring the beam, on the spatial distribution and mutual shading of the leaves, on their size and orientation etc. An attempt has been made here to understand the relationship between the scattering function of radiative transfer in crops and the canopy architecture of summer crops.

2. Radiation measurements

Radiation interception profiles were recorded with delta-T devices tube solarimeters and ISCO spectroradiometer during noon hours at maximum leaf area index (LAI) stage in maize, cowpea, mungbean, sorghum, soyabean, sunflower and maize-cowpea intercropping at the Summer Crops Irrigation Research Station, Waroona (Lat. 33 deg. S, Long. 115 deg. 48 min. E).

One tube solarimeter was sensitive to total shortwave radiation from 0.35 μm, and the other, containing a Kodak Wratten 88A gelatin folter tube, was sensitive NIR from 0.75 μm to 2.5μm. PAR from 0.35μm to 0.75μm was estimated as the difference in output of two solarimeters (Szeicz *et al.* 1984). Detector length was 85.8 cm and breadth 2.2 cm with a response time of 3 minutes for 99 per cent of radiation falling on the sensors. The tubes were mounted horizontally side by side on a sloping stand so that exposure was same, and each tube was flushed with dry air to avoid moisture condensation on their inner surface. When not in use the tube containing the gelatin filter was shielded with aluminium foil to avoid shrinkage of the filter.

Leaf area for each observation set was determined using the leaf area meter LI-3000. Stem area was computed assuming the stem to be cylinder (diameter x height). The orientation of the leaves was characterized by the mean leaf inclination which was determined as the mean of the angles between the vertical and normal to the upper side of the leaf. In case of lengthy leaves it was divided into 8 to 12 sagments.

Portable ISCO spectroradiometer fitted with a fibre optic extension cord having a 2 cm diameter flat sensor was used in recording the transmitted radiation at different foliage levels in different crops at maximum LAI stage. Sensing head acted as a cosine filter and confirmed to the Lambert's cosine law. The spectral transmission covered the range from 380 to 1550 nm with a 25 nm band pass in the PAR and 50 nm band pass in NIR range. Radiation observations were recorded during local mean time of 11.30 to 13.30 hrs.

*Present address : Department of Agricultural Meteorology, Haryana Agricultural University, Hissar—125 004, India.

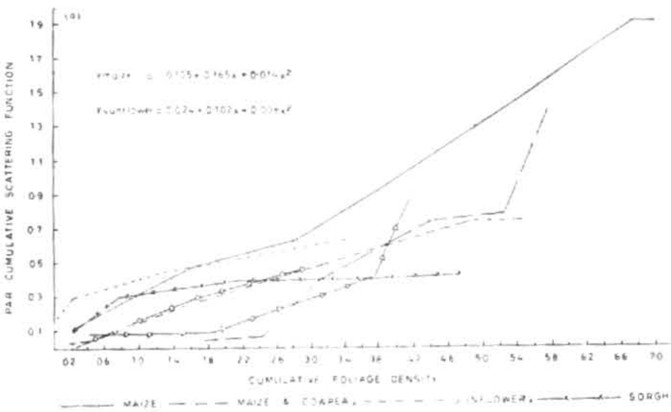

Fig. 1. Linear dependence of PAR cnmulative scattering function with foliage density distribution in different crops

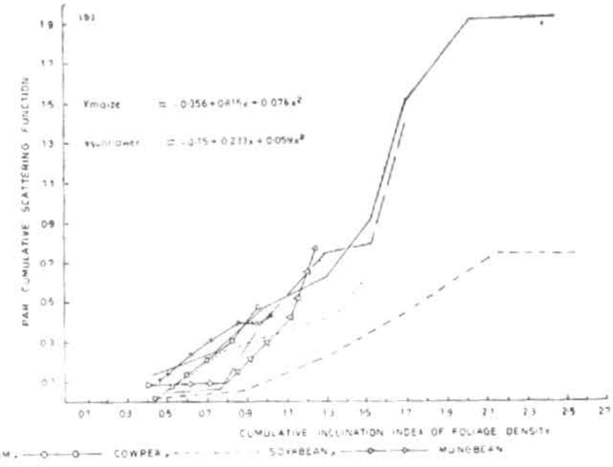

Fig. 2. Dependence of PAR scattering function on inclination index of foliage density

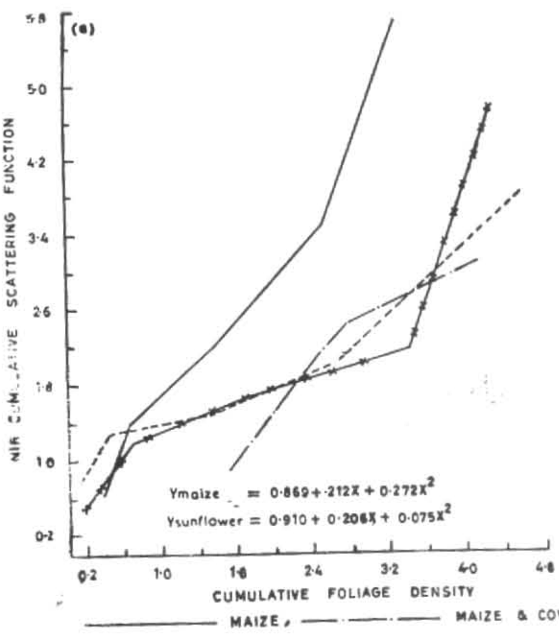

Fig. 3. Dependence of NIR cumulative scattering function on crop geometry parameters of foliage density

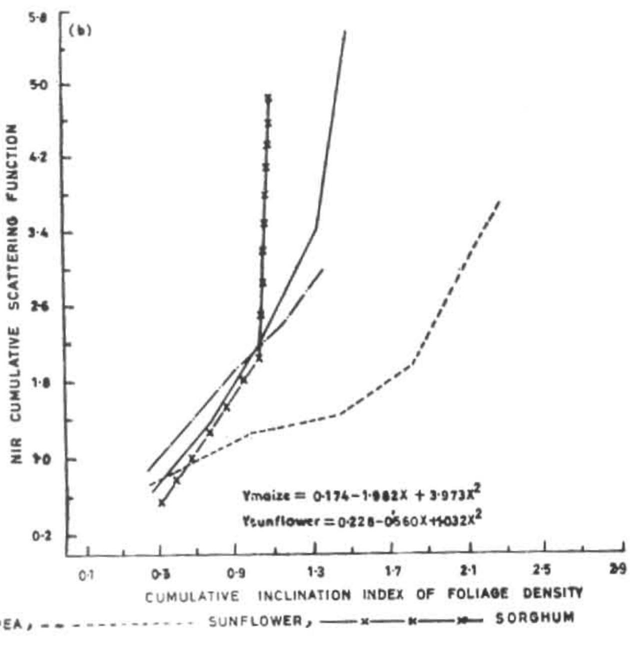

Fig. 4. Dependence of NIR cumulative scattering function on inclination index of foliage density

3. Method

Ross and Nilson's (1963,1965) scattering function $f(w)$, was determined using the radiation profile measurements in different crops as

$$I/I_0 = f(w) + e^{-KF} \quad (1)$$

Where, I and I_0 are the radiant flux densities at a given foliage index F below the crop canopy and above the canopy, and K is the foliage extinction coefficient. With random distribution of foliage angles, θ_L, the scattering function $f(w)$ related to the scattering coefficient (w) of the foliage as (Ross and Nilson 1965).

$$f(w) = \frac{w}{3} \left(\frac{1}{1 + 2 \sin \beta} \right) \quad (2)$$

Where β is the angle which incident radiation makes with the horizontal. An average value of $\beta = 70°$ was used for noon hour observations.

Extinction coefficients, K, were determined for PAR and NIR radiation from the slopes of regression between ln I/Io and cumulative leaf area index F from the top of the canopy. Scattering coefficient of the foliage, w, was determined for each crop canopy layer. The cumulative scattering function values were related with the crop geometry parameters like, vertical distribution of foliage area commonly represented by the normalized foliage are density $\bar{a}(\bar{z})$ (Ross and Ross 1969 a) and the inclination index of the foliage area X_L (Ross and Ross 1969 b) given by the following expressions.

$$\bar{a}(\bar{Z}) = h_L \, a(Z)/L_0 \quad (3)$$

$$X_L = \int_0^{\pi/2} \left| 1 - g(\theta_L) \right| \sin(\theta_L) \, d\theta_L \quad (4)$$

where, $\bar{Z} = Z/h_L$ is the relative height,

L = height above the ground surface,

h_L = height of crop with leaf area index L,

L_0 = Leaf area index of leaves within a vertical cylinder of unit cross-section and height h_L,

$a(Z)$ = foliage are density function which determines the foliage area in a unit space volume at height Z,

θ_L = mean leaf inclination which is the angle between the vertical and normal to the upper side of the leaf,

$g(\theta_L)$ = distribution function of foliage area orientation defined as the part of the foliage area oriented with an inclination θ_L assuming that there is no preferred azimuth orientation determined from the boundary satisfying condition that

$$\int_0^{\pi/2} g(\theta_L) \sin\theta_L \, d\theta_L = 1.$$

The foliage area orientation depends on species and has vertical and seasonal changes (Warren Wilson *1959*, *1965*, de Wit *1965*, Ross and Nilson 1967, Ross and Ross 1969a). The radiation and crop geometry parameters have been presented here to understand their dependence.

TABLE 1

Foliage attenuation and scattering coefficients in PAR and NIR radiation

Crop	Attenuation coefficient		Cumulative scattering coefficient	
	PAR	NIR	PAR	NIR
Maize	0.75	0.31	1.91	5.56
Sorghum	0.47	0.35	0.74	3.73
Soybean	0.51	0.28	0.82	4.05
Maize+Cowpea	0.53	0.35	1.39	3.92
Sunflower	0.84	0.35	0.74	3.73
Cowpea	0.65	0.39	0.86	4.21
Mungbean	0.56	0.22	0.87	4.18

4. Results and discussions

Table 1 presents the radiation transmission characteristics in different crops due to even distribution of foliage density through the crop height. The decrease of K values in the wavelength bands from PAR and NIR presents that there is preferential transmission of NIR through the foliage. The difference between K values in PAR and NIR was smaller in sorghum, soybean, maize + cowpea intercropping and cowpea canopies, but increased for open canopies like maize and sunflower. This appears to be related to foliage density. In dense or bush canopies of soybean and cowpea crops the leaves tend to be crowded together and take up multipositions, whereas in open canopies like maize, sunflower, the leaves assumed easy or changing posture with depth during the growing season. Scattering coefficient being higher in NIR range as compared to PAR leads to deeper penetration of NIR radiation through the foliage.

Fig. 1 presents the linear dependance of PAR cumulative scattering function with the foliage density distribution in different crops. The linear increase was observed to be rapid in open and relatively vertical leaved canopies (maize, sorghum etc) than the densely packed and relatively horizontal canopies. It was also observed that scattering was slow in top foliage layer, but increased rapidly as the radiation penetrated in the lower foliage layers probably due to differences in the foliage density through the crop height. The spread of scattering was recorded over a band bounded between scattering behaviour in maize and sunflower/beans. The slow increase in maize in the beginning was due to the horizontal nature of the two top leaves, but increased rapidly because of the inclined leaves in the lower foliage layers. Similarly PAR scattering function presented a better dependence on the inclination index of foliage density. (Fig. 2) than the distribution of foliage density through the height (Fig. 1). The continuous increase in scattering function from the top towards the lower crop foliage layers was due to the multireflections taking place due to inclined leaves. The comulative scattering behaviour attains a saturation level as the transmitted radiation reached the lower foliage layers. The spread of scattering function was again recorded between maize and sunflower leaves. The saturation indicates that at the bottom there is practically negligible increase in the transmitted radiation and therefore the lower leaves suffer due to non-availability of sufficient PAR radiation.

The NIR cumulative scattering function too depends strongly on the crop geometry parameters the distribution of foliage density (Fig. 3) and inclination index of the foliage density (Fig 4). The spread of NIR scattering was recorded over a band bounded between scattering due to maize/sorghum and sunflower geometries. It appears that multiple scattering increases as the NIR penetrates through the foliage layers and has the potentiality of reaching the lower layers more effectively than PAR. There may be a number of other photomorphogenic parameters affecting the scattering function, but the crop geometry parameters-foliage density distribution and inclination index of the foliage density layers appear to be the most effective parameters. The regression equations shown in the diagrams presents a second degree dependance in NIR as compared to linear dependence in the PAR scattering. The scattering function presented in these diagrams, amounts to different cumulative values in different crops depending on their canopy architecture therefore can function as an index of multiple scattering in relative to crop geometry.

References

Birkebak, R. and Birkebak, R., 1964, *Ecology*, **45**, 646-649.

Brandt, A.B. and Tageyeva, S.V., 1967, *Optical Parameters of plant organisms*, Nanka, Moscow (Russian).

De Wit, C.T., 1965, Photosynthesis of leaf canopies, Agric. Rep. No. 663, Wageningen.

Gates, D.M., Kergin, H.J., Schleter, J.C. and Weidner, V.R., 1965, *Appl. Optics*, **4**, 11-20.

Moldan, H., 1967, Phytoactinometric Investigations of Plant Canopy, Valgns, Tallinn, 89-109.

Ross, Yu.k. and Nilson, T., 1963, K. teoric radiofs ionnogo rezhima rastitel nogo pokrova. Iss led Fig. Atmos., *Akad. Nauk. Eston,* S.S.R., **11**, 55-80.

Ross, Yu. K. and Nilson, T., 1965, Propeskanye pyramoi radiatric solrtsa seskokosya istvemymi posevami. Iss led. Fiz., *Atmos, Akad, Nauk. Eston,* S.S.R., **11**, 5-54.

Ross , J. and Nilson, T., 1967, *In photosynthesis of productive system*, Ed. A. Nichi. Porevsch., Jerusalem., 56-99.

Ross, J. and Ross, V., 1969 (a), In photosynthetic productivity of plant stand, Institute of physics and Astronomy, *Academy of Sciences of the Eston,* S.S.R., pp. 44-59.

Ross, J. and Ross, V., 1969 (b), In photosynthetic productivity of plant stands, *Academy of Sciences of the Eston,* S.S.R., 60-82.

Szeicz, G., Monteith, J.L. and Dos Santos, J.M., 1964, *J. appl. Ecol.*, **1**, 169-174.

Warren Wilson, J., 1959, *In the Measurement of Grassland Productivity*, Ed. J. D. Ivins, London, 51-61.

Warren Wilson, J., 1965, *J. appl. Ecol.*, **2**, 383-390.