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Radiation Interception in Field Grown Soybeans Measured by Integrated Solarimeter Films

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Abstract: Intercepted solar radiation by each leaflet in two field grown soybean communities was measured by integrated solarimeter films for two consecutive days. These solarimeters are pieces of film (70 mg, 12 mm×35 mm), and measure radiation by percentages of remaining dye after the exposure to radiation. These solarimeters were placed on every leaflet surface of two plants each of the two determinate cultivars. The experiments were done at the flowering and the young pod stages. In both experiments, the mean intercepted radiation of each layer tended to be decreased gradually toward the base of the canopy. There were several leaflets which intercepted similar radiation as compared with the global solar radiation. The portion of intercepted radiation by leaves on branches was about 60% of the total intercepted radiation at the flowering stage, and increased to about 70% at the young pod stage. Terminal leaflets intercepted more radiation ranging from 4 to 10% as compared with the side leaflets.
Key words: Canopy structure, Integrated solarimeter films, Light interception, Soybean.

簡易積算日射計によるダイズ小葉面受光量の測定：礒田昭弘・吉村登雄*・石川敏雄*・野島　博・高崎康夫（千葉大学園芸学部・*千葉大学映像隔測研究センター）

要　旨：簡易積算日射計は，フィルムに色素を展着させたもので露光により退色することから日射量を測定するもので，軽量（70 mg，12 mm×35 mm），安価，同時に多くの点で測定できる．圃場条件下で生育させた2品種のダイズ2個体の全ての小葉に簡易積算日射計を貼り付け，小葉面の受けた2日間の積算日射量を測定した．各層の平均受光量は，地面に近くなるにしたがい次第に小さくなった．全小葉のうち数枚は全天日射量と同程度の日射を受けていた．受光量のうち分枝の小葉で受光される割合は，開花期には約60%，幼莢期には約70%であった．また，頂小葉の受光量は左右小葉に比べ4−10%大きかった．
キーワード：簡易積算日射計，ダイズ，受光量，葉群構造．

Radiation interception by leaves is one of the most important factors in crop production. Usually, radiation interception in crop communities has been measured by solarimeters using silicon photovoltaic cells or thermopiles. These solarimeters, however, have some restrictions in its usage; electric source, bulkiness and cost, as well as the difficulty of measuring many points at a time. Characteristics of crop communities concerning light interception have been assumed from data based on instantaneous values or integrated values during seconds.

Yoshimura et al[15]. have developed a integrated solarimeter film (Fig. 1), which is a piece of film and measures radiation by percentages of remaining dye after the exposure to radiation. This sensor has several advantages compared with the usual measuring instruments; 1) require no electric source of power, 2) cheap and mass-production easy, 3) suitable to integrate solar radiation for a few days, 4) easy to work with out-doors, 5) easy to use on leaf surface because of small size (12 mm×35 mm) and light weight (70 mg) and 6) the possibility of measuring many points at the same time (Fig. 2).

In field grown soybeans, it has been pointed out that the leaves concentrate densely in upper layers, so that less light penetrates the lower layers of the canopy[1,3,12,14]. As mentioned above, however, intercepted radiation by crop communities in these studies were measured instantaneously, so that there is no evidence of actual light interception by leaves during a day or a few days. In this experiment, we examined the characteristics of light interception in the canopy of the field grown soybean by the use of the integrated solarimeter

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films.

Materials and Methods

1. Integrated solarimeter films

Preparation of the integrated solarimeter films is summarized as follows ; photographic triacetylcellulose film was coated with dyes (Oil Red) in acetone solution to impregnate the dyes into the film. The contact time and concentration of the dye solution were adjusted to give an optical density of the dye in the film at the peak absorption wavelength of about optical density 2. Before the experiment, the absorbance of the films were measured using a spectro-photometer (Hitachi Corp., U-1000). The details of making the integrated solarimeter film has been reported by Yoshimura et al[15]. For calibration, the integrated solarimeter films and a solar radiometer (Eko Seiki Corp., MS-42) were placed horizontally on the roof and were exposured for one day up to several days. The data for one month can be fitted quite well to a single curve, indicating that it is possible to derive the amount of integrated solar radiation from color fade ratio by using the calibration curve. This solarimeter was not effected by humidity, moisture, as well as the materials on which it was to be placed in the other experiments. Only temperature affected the dye fading rate, as such data derived from the solarimeter were corrected in terms of the relationship between the dye fading rate and temperature.

2. Radiation interception experiment in the soybean community

Measurements of the field experiment were made in the experimental field of Faculty of Horticulture, Chiba University. Two determinate soybean cultivars, Tachinagaha (long leaflet type) and Enrei (round leaflet type), were used in this experiment. On 17 th May 1988, seeds were sown by hand in hills at equidistant spacing of 35 cm between and within rows. Each plot was 7.0 m (20 plants) in width and 22.5 m (64 plants) in length. The seeding rate was 2 or 3 seeds per hill, which was later thinned to one per hill after emergence. A combination of N, P_2O_5 and K_2O as a fertilizer was applied in the ratio of 30, 100 and 100 kg ha^{-1} just before sowing.

The experiments were done twice on 26 th and 27 th July (the flowering stage) and on 14 th and 15 th August (the young pod atage). Before placing integrated solarimeter films on leaflet surfaces, two adjacent plants of each cultivar were selected from the center of the plot. Height of the central part of leaflets for the selected plants were recorded. After sunset on 25 th July and 13 th August (the day before the experiments), integrated solarimeter films were placed at the center of every leaflet of the selected plants by double-sided binding tapes. Every solarimeter was collected at night after the exposure for the two consective days. The percentages of remaining dye on the used solarimeters were measured again by the spectro-photometer. After the removal of the solarimeters, all of the leaflet areas of the selected plants were measured by an automatic leaf area meter (Hayashi Denko Corp., AAM-5). At the same time, vertical distribution of leaf area, leaf, stem and pod

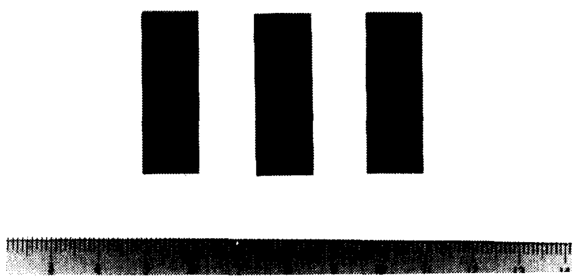

Fig. 1. The integrated solarimeter films.

Fig. 2. The integrated solarimeter films on leaflet surfaces in a soybean community.

weights were examined. The measurements were made at 10 cm height intervals of the 2 plants. Relative light intensities against the global solar radiation at the horizontal level were also recorded (30 points per 10 cm height interval) around noon using a relative light intensity photometer (Sanshin Kogyo Corp., NS-2) which is sensible within the range of 450 nm to 700 nm. Furthermore, 10 plants per cultivar were harvested for the measurement of leaf area indices.

Results

1. Intercepted radiation by crop

The growing season was very wet in 1988, and any water stress was not observed in the field. Leaf area indices (LAIs) of the crop were 4.7 and 6.0 for Tachinagaha and Enrei, respectively, in the first experiment (26 th and 27 th July; the flowering stage). The total global solar radiation during the two days was rather small, 14.1 MJm^{-2} 2 $days^{-1}$, because it was cloudy on 26 th July and partly rainy on 27 th July. The total global solar radiation was 17.4 MJm^{-2} 2 $days^{-1}$ during the second experiment (14 th and 15 th August), being higher than that in the first experiment. LAIs of the crop for Tachinagaha and Enrei were 4.6 and 5.4, respectively.

Table 1 shows the mean intercepted radiation (per unit leaf area) at 10 cm height intervals. In the first experiment, both cultivars showed a tendency of gradual decrease toward the base of the canopy. On the other hand, in the second experiment, the mean intercepted radiation by the upper three layers were rather high. However, those by the lower layers were lower than those in the first experiment in spite of the higher global solar radiation in the second experiment. This result suggests that the attenuation of light within the canopy would be enormous with age after the flowering stage, though leaf area index did not change so drastically.

In the first experiment, the total intercepted radiation by the individual plant (the summation of intercepted radiation per unit leaf area (MJm^{-2} 2 day^{-1}) and leaflet area (m^2)) were 3.0 $MJpl.^{-1}$ 2 $days^{-1}$ and 3.3 $MJpl.^{-1}$ 2 $days^{-1}$ for Tachinagaha and Enrei, respectively. While the intercepted radiation per unit ground area was 24.6 MJm^{-2} 2 $days^{-1}$ for Tachinagaha and 27.0 MJm^{-2} 2 $days^{-1}$ for Enrei. In the second experiment, the total amount of intercepted radiation per plant were 2.7 $MJpl.^{-1}$ 2 $days^{-1}$ and 3.7 $MJpl.^{-1}$ 2 $days^{-1}$ for Tachinagaha and Enrei, respectively, which gave 22.2 MJm^{-2} 2 $days^{-1}$ and 30.5 MJm^{-2} 2 $days^{-1}$ per unit growing area.

2. Frequency distribution of intercepted radiation with height

Fig. 3 shows the frequency distribution of intercepted radiation on leaflet surfaces (per unit leaf area) at 10 cm height intervals. In both experiments, the distribution pattern of the two cultivars were similar. The upper four layers had large deviations and high maximum values. The maximum of these layers

Table 1. Mean intercepted radiation at 10cm height intervals.

	Tachinagaha						Enrei					
	26, 27th July			14, 15th Aug.			26, 27th July			14, 15th Aug.		
Height (cm)	n	Mean (MJ m^{-2}2$days^{-1}$)	S.D.	n	Mean (MJ m^{-2}2$days^{-1}$)	S.D.	n	Mean (MJ m^{-2}2$days^{-1}$)	S.D.	n	Mean (MJ m^{-2}2$days^{-1}$)	S.D.
90—100	9	7.64	1.99	20	10.87	4.55	3	10.24	1.48	32	12.15	3.54
80—90	36	7.69	3.14	26	9.23	2.63	24	7.03	3.09	42	6.81	3.58
70—80	35	5.12	2.42	22	6.34	3.69	43	5.95	2.90	41	3.23	2.26
60—70	30	4.12	1.61	28	2.99	0.67	27	4.99	2.48	26	2.01	0.56
50—60	36	2.42	0.33	35	2.60	0.87	30	2.86	0.50	34	1.87	0.46
40—50	39	2.18	0.29	20	2.17	0.70	45	2.42	0.35	6	1.70	0.39
30—40	14	1.96	0.26	3	2.25	0.20	12	2.27	0.27	3	1.76	0.10
20—30	3	1.64	0.20	0	—	—	0	—	—	0	—	—
10—20	0	—	—	0	—	—	0	—	—	0	—	—
0—10	0	—	—	0	—	—	0	—	—	0	—	—
Total or Mean	202	4.22	2.81	154	5.34	4.09	184	4.41	2.79	184	5.10	4.48

were quite similar to the value of the global solar radiation. In the first experiment, the maximum value of all the leaflets for Tachinagaha and Enrei was 13.0 MJm^{-2} 2 $days^{-1}$ and 14.0 MJm^{-2} 2 $days^{-1}$, which were 92% and 99% respectively of the global solar radiation. The minimum values except the uppermost layer were not so different among each layer, and were below 3.0 MJm^{-2} 2 $days^{-1}$.

In the second experiment, ranges of distribution were wider at the upper three layers as compared with the first experiment, because of higher global solar radiation. The maximum values of the upper four layers were also higher than those in the first experiment, which were similar to the value of the global solar radiation. The highest value of all the leaflets was 16.7 MJm^{-2} 2 $days^{-1}$ for Tachinagaha and 18.7 MJm^{-2} 2 $days^{-1}$ for Enrei, which was 96% and 107% respectively of the value of the global solar radiation.

3. Intercepted radiation by the main stem and branches, and by each leaflet

In the first experiment, the leaves on the main stem intercepted about 60% of the total intercepted radiation for both Tachinagaha and Enrei as shown in Fig. 4. The portion of intercepted radiation by leaves on branches became larger with age, about 70% of the total intercepted radiation was intercepted by leaves on branches in the second experiment. However, only the upper two or three layers of branches increased their values, while the other layers of the main stem and branches had decreased values.

Table 2 indicates percentages of leaflet areas and intercepted radiation by each leaflet (terminal, right and left side). In both experiments, there were differences between the cultivars in leaflet area, largely due to the sizes of selected plants. The terminal leaflet areas were larger by about 10% than each of the right and left leaflet of the two cultivars in both experiments. Mean values of intercepted radiation by the terminal leaflets were significantly larger by over 10% than each of the right and left leaflets except for the values of Tachinagaha in the first experiment. Consequently, intercepted radiation by terminal leaflets per plant increased by 4 to 10% over those of side leaflets.

4. Canopy structure

Fig. 5 shows vertical distribution of leaf area, dry matter weights, relative light intensities within the canopy around noon and

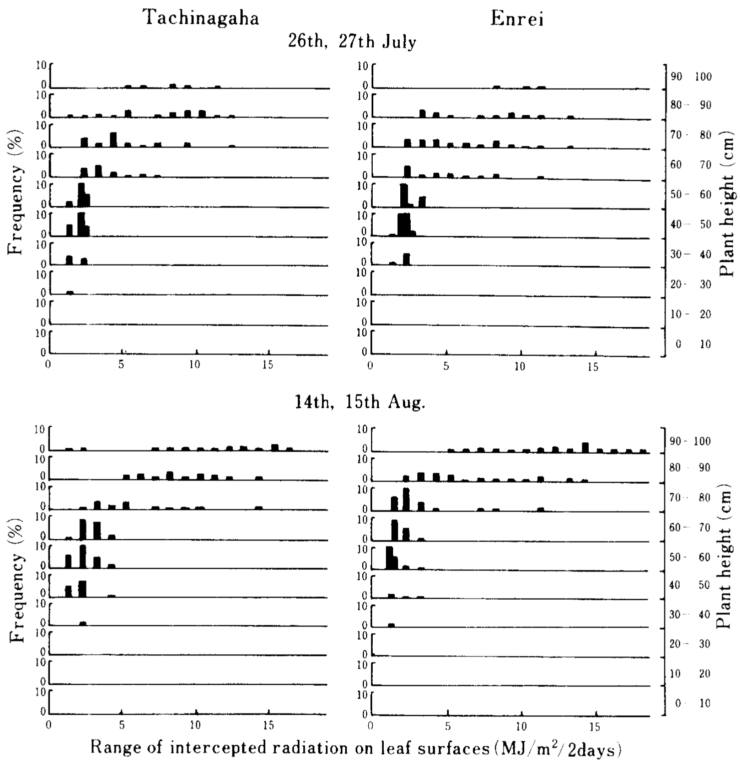

Fig. 3. Frequency distribution of intercepted radiation on leaflet surfaces at 10 cm height intervals.

percentages of intercepted radiation against the global solar radiation. Both cultivars had a high concentration of leaves in the upper part of the canopy in both experiments. Enrei was just earlier than Tachinagaha, producing larger shoot and pod weights at the young pod stage. In both experiments, the light intensities in the upper layers were high, but the light penetration decreased toward the middle and basal layers around noon. As compared with light intensities around noon, percentages of intercepted radiation against the global solar radiation during the two days were larger in the middle and the lower layers. This result suggests that the lower leaves could intercept radiation coming from the sun at lower altitudes (i.e. in the morning and in the evening.)

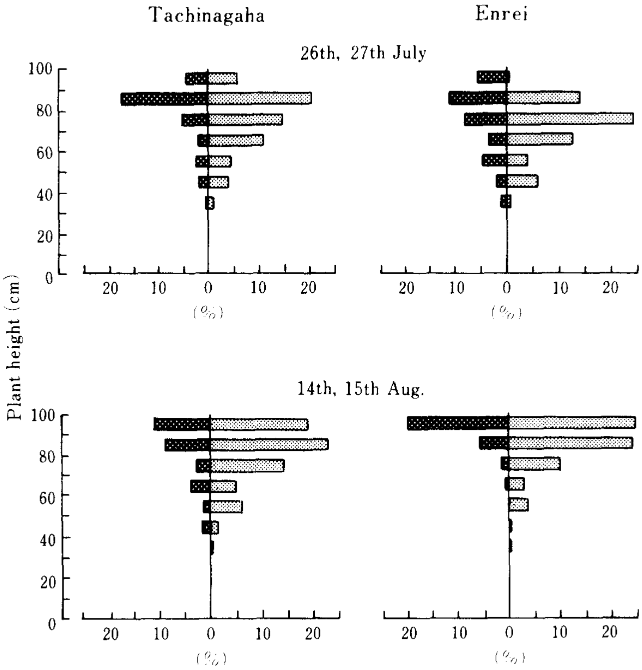

Fig. 4. Vertical distribution of percentages of intercepted radiation by leaves on the main stem and branches.
▩ : the main stem, ▨ : branches.

Discussion

Although the two cultivars that were used in this experiment had different leaflet shapes (round and long ones), no marked difference was found between them in terms of light interception. The two cultivars were similar in canopy structures (canopy size, leaf area and dry matter distribution), leaflet area and maturity, and were different only in leaflet shape. In such a case, leaflet shape would not be so important for light interception. It can therefore be assumed that size and thickness of leaflets or spatial distribution of leaves would largely affect light interception and transmission.

It was found that leaves concentrated densely in upper layers and a large part of incoming radiation was intercepted by the upper 20—30 cm layers. With increasing age, light interception by lower layers became worse, while the percentages of light interception by leaves on branches increased. It has been reported that artificial treatments of the canopy structures or the supplement of light increased assimila-

Table 2. Leaflet area and intercepted radiation of each leaflet (terminal, right side and left side)

Leaflet	Leaflet area (cm²pl.$^{-1}$)		Intercepted radiation per unit leaf area (MJm^{-2}2days^{-1})		Amount of intercepted radiation (MJpl.$^{-1}$2days^{-1})	
	Tachinagaha	Enrei	Tachinagaha	Enrei	Tachinagaha	Enrei
26th, 27th July						
Terminal	2191	2297	4.32	4.63	1.10 (36.6)*	1.22 (37.0)
Right side	2050	2083	4.15	4.45	0.96 (32.0)	1.07 (32.3)
Left side	1991	2118	4.19	4.16	0.94 (31.3)	1.01 (30.7)
Significance	***	***	NS	***	***	***
14th, 15th August						
Terminal	1552	2205	5.89	5.56	1.07 (39.5)	1.47 (39.4)
Right side	1427	1972	4.82	4.81	0.78 (28.8)	1.14 (30.6)
Left side	1429	1921	5.34	4.92	0.86 (31.7)	1.12 (30.1)
Significance	***	***	***	***	***	***

* ; Percentages against the total intercepted radiation by the plant.
*** ; 0.1% level of significance, NS ; No significance.

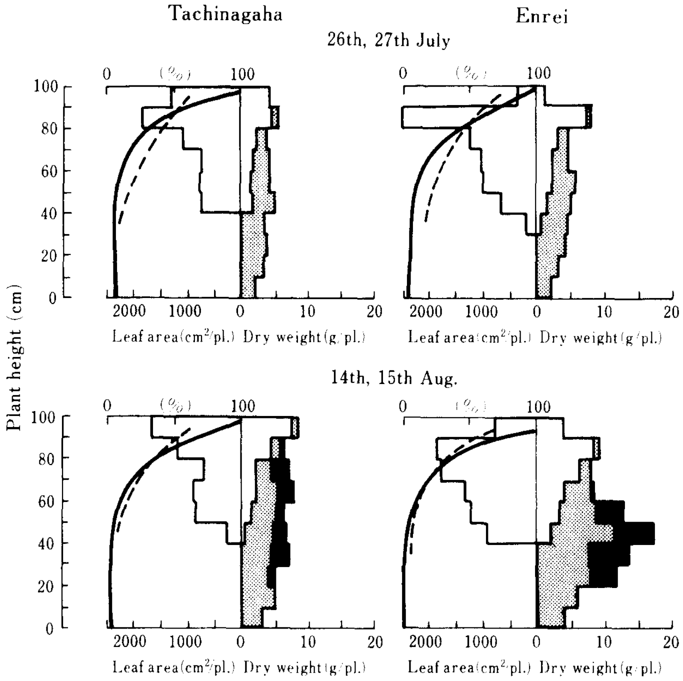

Fig. 5. Vertical distribution of leaf area, dry matter weights, relative light intensities within the canopy around noon and percentages of intercepted radiation against the global solar radiation.
□ : leaf, ▩ : stem, ■ : pod dry weight, —— : relative light intensity within the canopy around noon, - - - : percentages of intercepted radiation against the global solar radiation.

tion rates or seed yields in soybean[3,6,10,13]. These results indicate that improvement of light penetration in a soybean canopy is one of the important problems in increasing yield. Nakaseko et al.[9] observed that active leaf adjusting movement allowed light to penetrate within the canopy in a high-yielding soybean field. Kawashima[4,5] suggested that soybean leaves might move spatially and temporarily to adjust light illuminance evenly on leaf blades. In rice plant (*Oryza sativa* L.), the highest value of intercepted radiation on a leaf surface measured by the integrated solarimeter films was only 61% of the global solar radiation[2]. In this experiment, several leaflets in the upper layers intercepted similar or higher radiation as compared with the global solar radiation, indicating the effects of leaflets tilting upward to intercept the sun light.

Kumura[7] pointed out difficulties in the measurement of light interception in field conditions, i.e. variation in light intensity during the measurement. In this experiment, we could measure the integrated light interception by leaflets without effects of temporary variation of climatic conditions (light intensity, wind and rain) and found the detailed distribution of intercepted light in the crop community. An important problem however, is coming up with the use of the integrated solarimeter films ; it was found that the sum of intercepted radiation by leaflets were 30—90% larger than global solar radiation. It was not likely that the size of the measured plants would be larger as compared with other plants in the crop community, since their leaf area indices were not so different from those of the community. Some reasons may be ascribed to an overestimation. One factor may be due to the site on which solarimeters were placed. The central part of leaflets would be able to intercept more radiation than the marginal part of leaflets, since the marginal part of leaflets overlapped each other as compared with the central parts on which the solarimeters were placed. In addition, the solarimeters might also measure the light that had once permeated other leaflets as reported by

Monteith[8]. Another cause would be the reflection of light from other leaf surfaces. The solarimeters measured the light that had once (twice or several times) been reflected from other leaflets. A leaflet surface would receive the reflection of light from many other leaflets, as such an integrated value of these reflections would be a substantial portion of the whole plant's intercepted radiation. In order to reduce such overestimation, it may be needed to measure the albedo over the canopy surface. It was reported that the maximum value of the albedo over the canopy surface of a potato field was 21% of the incoming radiation in closed canopy[11]. The albedo over the soybean canopy may not be so different from that over the potato canopy, since the plant heights and the canopy structures are not so different. Absorbed radiation by the canopy would therefore be smaller than the intercepted radiation measured by the integrated solarimeter film. The integrated solarimeter film is very effective to measure integrated light interception without effects of temporary changing of climatic conditions, although there exists some problems to solve immediately as discussed above. We have been developing also the use of other solarimeter films which can measure radiation during longer or shorter periods. These solarimeters will be worthwhile to measure the effect of leaf adjusting movement or varietal differences in light interception.

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