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# Solar Radiation Penetration and Distribution in Soybean Communities

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**Abstract**: Detailed features of solar radiation distribution and penetration in soybean communities were examined using integrated solarimeter films for 2 days. Five cultivars (c.v. Tsurukogane, Nanbushirome, Enrei, Tachinagaha and Miyagishirome) were grown under field conditions and in pots for comparison. All of these cultivars except Tsurukogane had leaf concentration in the upper layers of the canopy. Tsurukogane and Nanbushirome had smaller leaflet areas in the upper of the canopy, whereas Enrei, Tachinagaha and Miyagishirome had larger leaflets in the upper layer. The higher the intercepted radiation and the smaller the leaflet size, the larger the difference in intercepted radiation between the edge and the center of the leaflet. The mean radiation penetrating leaflet was around 1 MJ $m^{-2}$ 2 $days^{-1}$ and penetrated radiation against intercepted radiation on the leaf adaxial surface ranged from 13 to 27%. The differences were larger in the cultivars with larger leaflets and smaller in the cultivars with smaller leaflets. A canopy structure with smaller leaflets and smaller leaf area in the upper layer of the canopy may be advantageous for radiation transmission and distribution.
**Key words**: Canopy structure, Integrated solarimeter film, Penetrated radiation, Radiation distribution, Soybean

**ダイズ群落における葉身透過光と受光量の分布**：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**：ダイズ群落内の詳細な光分布を簡易積算日射計フィルムを用いて調査した．5品種（ツルコガネ，ナンブシロメ，エンレイ，タチナガハ，ミヤギシロメ）を用い，35 cm の正方形に播種し圃場条件で栽培し，小葉の中央と端の2日間の受光量そして葉身を透過した光の量を測定した．ツルコガネを除く他の4品種は葉群が上層に集中していたが，ツルコガネの上層の葉面積はそれほど大きくなかった．平均小葉面積はツルコガネ，ナンブシロメが群落上層部でも小さく，エンレイ，タチナガハ，ミヤギシロメの上層葉は大きかった．いずれの品種も受光量は小葉の端の方が中央より大きくなり，その差は小葉の小さいツルコガネ，ナンブシロメで大きかった．葉身を透過した光は平均で約1 $MJm^{-2}$　2 $days^{-1}$　で，葉表面での受光量に対して13～27％であった．群落内部への光の浸透は，上層の小葉が小さく，葉面積が上層に集中しない群落で有利であることがわかった．
**キーワード**：簡易積算日射計，群落構造，受光量，ダイズ，葉身透過光．

Radiation interception and distribution in the canopy is an important factor for crop production. Usually, models were used in such analysis for radiation interception and distribution in plant community[2,4,9,13,15]. In plant communities, however, leaf distribution and orientation change in the short-term by temporary changes of weather conditons. Leaf distribution in the long-term is effected by plant growth and climatic conditions. Thus, these models would be restricted in the usage for actual plant communities.

In the previous papers, we reported several possibilities of the usage of the integrated solarimeter films in the analysis of light intercepting characteristics in communities[6,7]. It has been pointed out that the leaves often concentrate in the upper part of the canopy in field grown soybean, restricting light penetration to the lower strata of the canopy[19,20]. In this paper, five cultivars were examined for the detail radiation interception and distribution characteristics in soybean communities to obtain some fundamental information for the improvement of light intercepting features in soybean.

## Materials and Methods

Five soybean cultivars (Tsurukogane, Nanbushirome, Enrei, Tachinagaha and Miyagishirome) were grown in 1992 in the experimental farm of Faculty of Horticulture, Chiba University. Tsurukogane is an indeterminate cultivar and grouped into Ib, and the other four cultivars are determinate type and grouped into IIc by Fukui and Arai's classification criterion of the soybean ecotype in Japan[1]. In the field experiment, the seeds were sown by hand at equidistant spacings of 35 cm between and within rows on 10 June. The seeding rate was two, which was thinned to one per stand after emergence. A combination of N, $P_2O_5$ and $K_2O$ was applied in the ratio of 30, 0 and 100 kg $ha^{-1}$ just before sowing.

The measurement of radiation interception was made on 25 and 26 August for the field experiment (at the young pod stage). Two plants of each cultivar were selected from the center of the plot in terms of equal leaf numbers. After sunset on the day before the experiment (24 August), two integrated solarimeter films[21] (their dye percentages had been already measured by a spectro-photometer (Hitachi Corp., U-1000)) were stuck on the edge and the center of all leaflet surfaces of the five cultivars. In addition, one integrated solarimeter film was coated on its surface with aluminium foil; and stuck on the abaxial surface of the terminal leaflet of Nanbushirome, Tachinagaha and Miyagishirome as shown in Fig. 1. All integrated solarimeter films were removed at night after exposure for two days. The dye remaining percentages of the integrated solarimeter films were measured by the spectro-photometer. At the same time, vertical distribution of leaf area of four plants of each cultivar was measured at 10 cm height intervals.

In the pot experiment, the seeds were sown on the same day in 1/2000 a Wagner pots with fertilizer in the ratio of 90, 300, 300 kg $ha^{-1}$ for N, $P_2O_5$ and $K_2O$, respectively. They were thinned to single plant per pot after emergence. The intercepted radiation was measured on 6 and 7 August (at the flowering

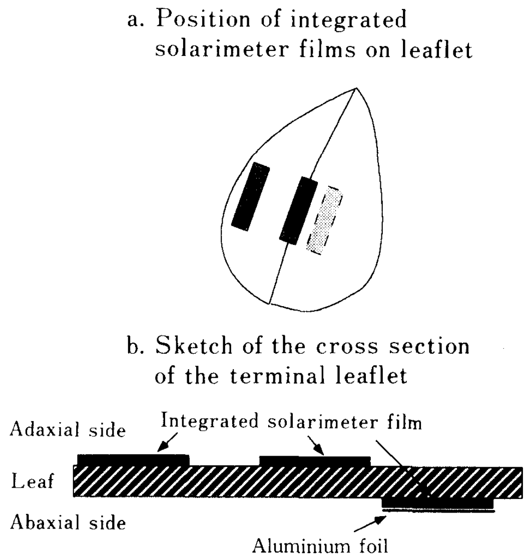


Fig. 1. Position and method of sticking integrated solarimeter films.

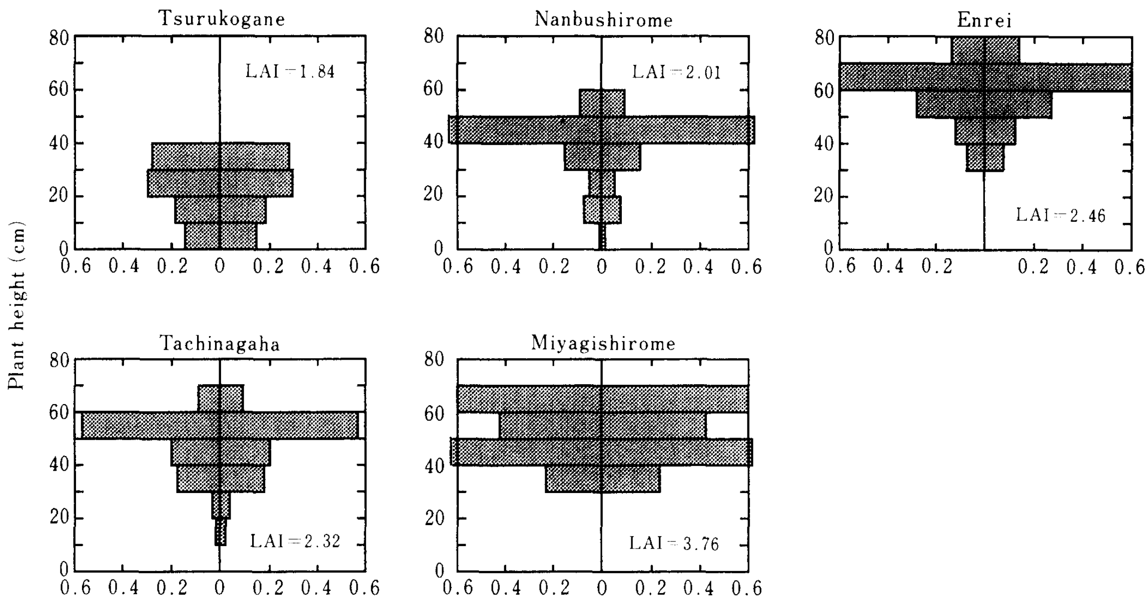


Fig. 2. Vertical distribution of leaf area index (LAI) at the young pod stage.

stage). One integrated solarimeter film was stuck on every leaflet surface of one plant per cultivar. Other methods for the measurement of intercepted radiation were the same as the field experiment.

The experimental days were very clear. The global solar radiation and the mean air temperature were 35.6 MJ $m^{-2}$ 2 $days^{-1}$ and 35.4 MJ $m^{-2}$ 2 $days^{-1}$, and 28.6°C and 29.5°C for 6, 7 of August and 25, 26 of August, respectively.

## Results

### 1. Canopy structure of the field experiment

Fig. 2 shows vertical distribution of leaf area index. The leaf area index was smaller in Tsurukogane with relative smaller leaf areas in the upper layers of the canopy. The other four cultivars had larger amount of leaf area in the upper layers, showing typical table type. In particular, as a result of mutual shading, leaves in the lower layers of Enrei and Miyagishirome had already defoliated. Tsurukogane and Nanbushirome had smaller leaflet areas in the upper layer of the canopy. Enrei and Miyagishirome had large leaflets in the upper layer. Tachinagaha had large leaflets in the upper layers and smaller ones at the base of the canopy (Fig. 3).

### 2. Differences in radiation interception between the center and the edge of the leaflet

The intercepted radiation per unit leaf area at the edge of the leaflet was significantly larger than that at the center in Tsurukogane and Nanbushirome (P=0.05 level). The other three cultivars were also larger at the edge of the leaflet though insignificant (Table 1). The mean intercepted radiation at every layer of the cultivars was also larger at the edge with the exception of the upper two layers of Tachinagaha. The upper layers tended to have larger differences. In particular, the uppermost layer of Tsurukogane had a significantly larger value at the edge.

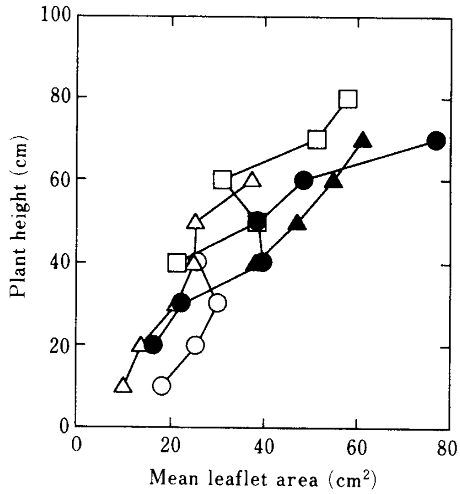


Fig. 3. Vertical distribution of mean leaflet area.
—○— Tsurukogane —●— Tachinagaha
—△— Nanbushirome —▲— Miyagishirome
—□— Enrei

Table 1. Mean value of the difference in intercepted radiation per unit leaf area between the center and the edge of leaflet.

| Height (cm) | Tsurukogane | Nanbushirome | Enrei (MJ $m^{-2}$ 2$days^{-1}$) | Tachinagaha | Miyagishirome |
|---|---|---|---|---|---|
| 70～80 | | | 0.304 | | |
| 60～70 | | | 0.157 | −0.148 | 1.061 |
| 50～60 | | 1.028 | 0.332 | −0.055 | 0.556 |
| 40～50 | | 0.453 | 0.419 | 0.767 | 0.052 |
| 30～40 | 1.288* | 0.825 | 0.372 | 1.105 | 0.184 |
| 20～30 | 1.238 | 0.052 | | 0.418 | |
| 10～20 | 0.394 | 0.606 | | 0.299 | |
| 0～10 | 0.098 | | | | |
| Total | 0.837* | 0.511* | 0.149 | 0.331 | 0.352 |
| P value | 0.003 | 0.017 | 0.536 | 0.218 | 0.213 |

* Significant at 5% level of T test.

** Positive value implies that the value on the edge is larger than that on the center.

Table 2. Radiation penetrating leaflet per unit leaf area.

| Cultivar | Number | Penetrated radiation ($MJ\ m^{-2}\ 2days^{-1}$) | | Intercepted radiation on leaf surface ($MJ\ m^{-2}\ 2days^{-1}$) | | Percentage of penetrated radiation* (%) | |
|---|---|---|---|---|---|---|---|
| | | Mean | S.D. | Mean | S.D. | Mean | S.D. |
| Nanbushirome | 32 | 1.04 | 0.31 | 9.36 | 4.28 | 13.2 | 6.4 |
| Tachinagaha | 20 | 0.99 | 0.38 | 7.93 | 8.22 | 27.1 | 25.0 |
| Miyagishirome | 26 | 1.20 | 0.25 | 10.15 | 7.07 | 25.9 | 26.4 |
| Significance | | ns | | ns | | ns | |

* Against intercepted radiation on leaf surface.

### 3. Radiation penetrating leaflet

The mean penetrated radiation per unit leaf area was largest in Miyagishirome and smallest in Tachinagaha, which was similarly related to the intercepted radiation on the leaf surface although there was no significant difference (Table 2). Nanbushirome had a smaller mean and standard deviation of penetrated radiation against intercepted radiation on the adaxial surface. The values of Tachinagaha and Miyagishirome were similar for the mean and the standard deviation.

Fig. 4 shows the vertical distribution of percentages of radiation penetrating leaflets against intercepted raidation on the adaxial leaf surface. The values in the uppermost layer of Tachinagaha and Miyagishirome were small and their mean intercepted radiation on the adaxial surface were rather large. On the contrary, the percentages of penetrated radiation in the second layer were large, whereas the mean values of intercepted radiation were small. In Nanbushirome, the percentages of penetrated radiation in the second and the third layers, besides the uppermost layer, were also smaller compared to the other two cultivars. Intercepted radiation on the adaxial surface was also smaller. The values in the lower layers of each cultivar except Nanbushirome tended to be large, since intercepted radiation on the adaxial surface was smaller as compared to the upper layers.

Fig. 5 showed the relationship between intercepted radiation on the adaxial surface and the percentage of radiation penetrating leaflet. The values fitted well to the equation of power series, i.e., the larger the values of intercepted radiation on the adaxial surface, the lower the values and a smaller deviation of the percentage of penetration. Using these equations, the values of radiation penetrating leaflets were estimated for all the leaflets of the three cultivars. Estimated total radiation penetrating leaflets per unit ground area were 1.97 $MJ\ m^{-2}\ 2\ days^{-1}$, 1.97 $MJ\ m^{-2}\ 2\ days^{-1}$ and 4.38 $MJ\ m^{-2}\ 2\ days^{-1}$ for Nanbushirome, Tachinagaha and Miyagishirome, respectively.

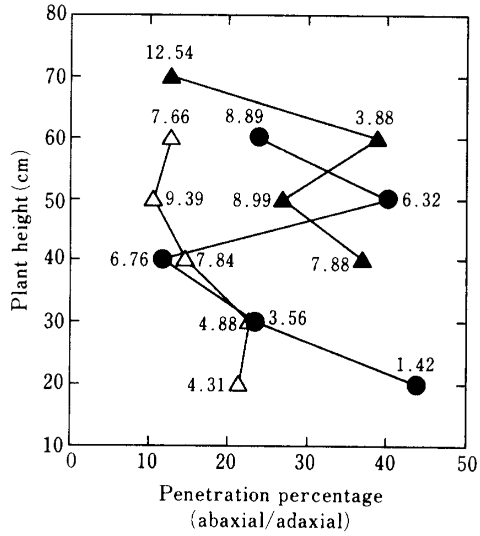


Fig. 4. Percentage of radiation penetrating leaflet.
Figures indicate mean values of intercepted radiation on the leaf surface per unit leaf area ($MJ\ m^{-2}\ 2\ days^{-1}$).
—△— Nanbushirome —▲— Miyagishirome
—●— Tachinagaha

### 4. Vertical distribution of intercepted radiation in the pot and the field experiments

Intercepted radiation in every layer of the pot experiment were larger than that in the field experiment, although the global solar radiation on both experimental days was quite

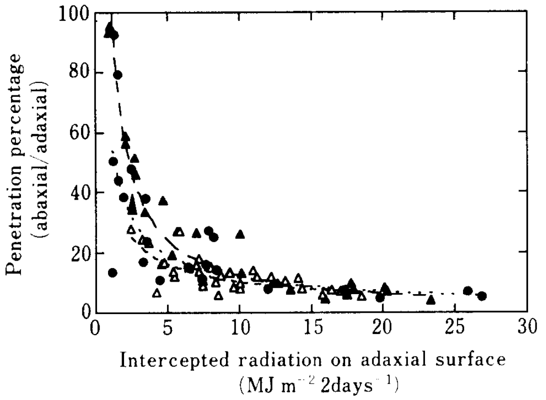


Fig. 5. Relationship between penetration percentage and intercepted radiation on adaxial surface.

—▲— Miyagishirome $y=112.0x^{-0.953}$ r=0.97

--△-- Nanbushirome $y=45.8x^{-0.649}$ r=0.73

···●··· Tachinagaha $y=60.8^{-0.717}$ r=0.73

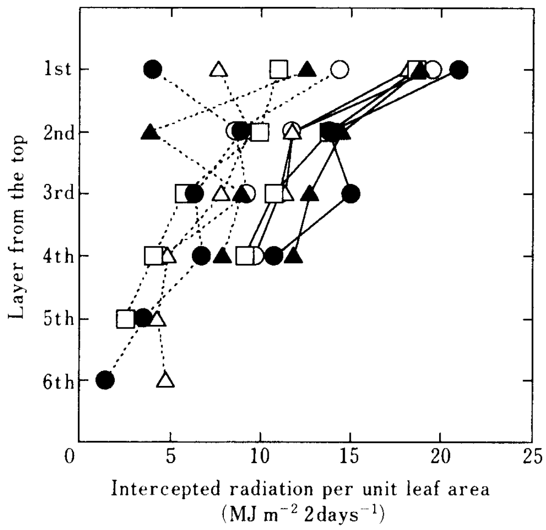


Fig. 6. Vertical distribution of intercepted radiation at 10 cm intervals from the top of the canopy in the pot and the field experiments.

○ : Tsurukogane △ : Nanbushirome

□ : Enrei ● : Tachinagaha

▲ : Miyagishirome

—— : Pot ---- : Field

similar (Fig. 6). There was no large difference in the uppermost layer but rather a large difference occurred in the third layer in the pot experiment. The values were larger in Tachinagaha and Miyagishirome and smaller in Tsurukogane and Nanbushirome. In the field experiment, there was a large difference in the upper layers. Tsurukogane and Enrei had larger values, and Tachinagaha and Nanbushirome had smaller values in the upper layers of the canopy. In the lower layers, however, Enrei showed smaller values. The differences between the pot and the field experiments tended to be larger in Tachinagaha and Miyagishirome with larger leaflets and smaller in Tsurukogane and Nanbushirome with smaller leaflets.

## Discussion

We reported that the sum of intercepted radiation by leaflets was 30～90% larger than the global solar radiation, and assumed such large values[7]. Hirota et al.[3] estimated that absorbed solar radiation would be about 70 to 75% at the maximum LAI stage, with a reflectance percentage of about 25 to 30%. In addition, the total radiation penetrating leaflets was about 10～20% of the global solar radiation. The percentage of the penetrated radiation against the global solar radiation would increase under cloudy conditons, since the penetrated radiation was around 1 MJ $m^{-2}$ 2 $days^{-1}$ even where leaflets intercepted low radiation. The amount of radiation absorbed by the canopy may therefore be rather small as compared to the total intercepted radiation measured by the integrated solarimeter films.

The radiation that has penetrated the canopy once, for example, would be 1 MJ $m^{-2}$ $2days^{-1}$, its light intensity could be approximately less than 6 klux, which is very low irradiance for photosynthesis according to the light-photosynthesis relation by Kumura[12]. This estimation indicates that the once penetrated radiation of leaflet may not be so effective for photosynthesis as has been pointed out in rice by Matsushima et al.[14].

Difference between the edge and the center of leaflet in radiation interception was observed. The higher the intercepted radiation and the smaller the leaflet size, the larger the difference. Although the reason in not obvious, smaller leaflets may be able to intercept reflected radiation from other leaflets under high light conditions. For Tsurukogane which had smaller leaflet sizes and the largest differences between the edge and the center of leaflets in intercepted radiation, the extent of decrease in mean intercepted radiation in the field as compared with the individual plant was smallest. Nakaseko[18] reported that canopy with the leaves and petioles that was made smaller by mechanical stimulation showed the improvement of light penetration of the canopy. Thus, a canopy structure with smaller leaflets in the upper layer of the canopy may be advantageous for light transmission. In addition, leaf area distribution might also affect the effectiveness of light penetration of the canopy. In the potato plant, the canopy structure with uniform distribution of leaf area had advantages for light penetration as compared with the table type canopy which concentrated leaves in the upper layers[5]. In soybean, most of the reports which referred to vertical distribution of leaf area indicated the table type[6,11,16,17]. However, Tsurukogane was the only cultivar which did not have leaf concentration in the upper layers of the canopy in this experiment, although its LAI was rather small. In addition being only the indeterminate type among the cultivars used in this experiment, Tsurukogane is one of recommended cultivars in the higher latitudes of Japan (Hokkaido). In a relatively different environment as in Chiba prefecture in Kanto area, it became dwarf and matured earlier. This result suggests a new possibility of canopy structure for light utilization and the evaluation of the yield traits will be worthy of consideration in future research. Finally, the leaf movement may affect radiation interception largely in field conditions[8,10,17]. This problem will be discussed in detail in a subsequent paper.

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