マメ科作物の葉の調位運動が受光量に及ぼす影響(1)

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Effects of Leaf Movement on Radiation Interception in Field Grown Leguminous Crops

I. Peanut (*Arachis hypogaea* L.)*

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Abstract : The effects of leaf movement of peanut on radiation interception were examined. A peanut cultivar (c. v. Nakateyutaka) was planted at three planting densities (20 cm, 30 cm and 40 cm equidistant spacings). In the treatment plots, the upper layer of the conopy was covered horizontally with a nylon net to restrain the movement of the leaflets. Intercepted radiation of each leaflet was measured by integrated solarimeter films for two consecutive days. It was observed that the leaflets of the upper layer oriented paraheliotropically to the sun rays in midday. Intercepted radiation per unit leaf area and unit ground area of the control were larger in the 20 cm spacing, almost similar in the 30 cm spacing and smaller in the 40 cm spacing as compared with the treatment. The leaf movement of the upper layer of the canopy played a significant role in radiation interception in the 20 cm plot, no discernible effect in the 30 cm plot and a rather adverse role in the 40 cm plot. Leaf area of the 20 cm spacing was concentrated densely at the upper layer. Leaf area of the 30 cm and 40 cm spacing was larger at the middle layers. It was assumed that effectiveness of the leaf movement of the upper layer would depend mainly on spatial leaf area distribution and density.
Key words : Canopy structure, Heliotropic leaf movement, Integrated solarimeter film, Peanut, Radiation interception.

マメ科作物の葉の調位運動が受光量に及ぼす影響　第1報　ラッカセイ：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：ラッカセイの葉の調位運動が受光量に及ぼす影響を見るため，栽植密度の異なった群落を防雀網で調位運動を抑える処理を行ない，受光量を測定した．用いた品種はナカテユタカで，20 cm（20 cm 区），30 cm（30 cm 区），40 cm（40 cm 区）の正方形に播種した．8月7，8日に処理を行ない，群落中の1個体の小葉に簡易積算日射計をはり受光量を測定した．朝夕，上層の小葉は太陽光線と垂直に近い向きを示したが，昼間は立ち上がり，太陽光線と平行に近い向きを示した．平均小葉面受光量および単位土地面積当たりの受光量は，20 cm 区では無処理区が大きくなったが，30 cm 区では等しく（葉面積を同じとして計算した場合），40 cm 区では処理区の方が大きくなり，葉が立ち上がることにより疎植区では受光できずに地面に透過する光が多いことがわかった．層別受光量は，20 cm 区では無処理区は中層がもっとも大きく，処理区は上層部が大きくなり，葉の立ち上がりにより中層部の受光量が大きくなることがわかった．30 cm 区では無処理区は下層部がもっとも大きく，処理区は中層部が大きかった．40 cm 区でも無処理区は下層部が大きく，処理区は上層部が大きかった．ラッカセイの葉の調位運動が受光量に及ぼす影響は，葉群構造および葉群密度によって異なり，密植区ほど葉の立ち上がりにより過繁茂状態が緩和され中層の受光量が大きくなり，疎植区では受光量が減少することが認められた．
キーワード：簡易積算日射計，受光量，調位運動，葉群構造，ラッカセイ．

It is well known that there is orientation of the leaves of some plants during the day in response to environmental conditions[7]. In particular, several reports have been published about the leaf movement of leguminous crops, including soybean[3,8,11,12,13,19], kidney bean[2,15,18], alfalfa[17] and cowpea[16]. However, there is no description of the leaf movement in peanut (*Arachis hypogaea* L.). Peanut has two sets of a pair of leaflets constituting the compound leaf and each pair of leaflets closes during the night. After sunrise, peanut also changes the orientation of leaflets in response to radiation.

Leaf movement has two reversible aspects, paraheliotropic and diaheliotropic movements[3]. Most of the studies about this phenomenon were examined with leaf angle or

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Fig. 1. The upper leaves of the canopy with the integrated solarimeter films in the control of the 40 cm spacing around noon.

Fig. 2. The treated plants covered with the nylon net in the 40 cm spacing

leaf water potential of seedlings or individual plants[2,3,6,15,18,19]. Therefore, its effects in field conditions have not been obvious. In particular, there was no reference to its effects on the amount of radiation interception which is one of the most important factors for dry matter production. We intended to estimate the effects of the leaf movement of peanut and soybean, and their varietal differences on radiation interception in this study. The effects of the leaf movement of peanut were examined by a treatment which restrained the upper layer of the canopy covered horizontally with a nylon net in this paper. For the measurement of radiation interception, the integrated solarimeter films were used, which have several advantages (i.e., small size (10 mm × 30 mm), light weight (70 mg), massively produced and used) and can measure incoming radiation on surfaces of leaflets[9].

Materials and Methods

Peanut was grown in the field of the experimental farm of Faculty of Horticulture, Chiba University in 1990. Nakateyutaka, which is a bunch type derived from the multiple crossing between the cultivars of Spanish and Virginia types, was used in this experiment. The seeds were sown by hand at equidistant spacings of 20 cm, 30 cm and 40 cm between and within rows (25.0, 11.1, 6.3 plants m^{-2}, respectively) on 16th of May. The plot area was 20 m^2, 60 m^2 and 76.8 m^2 for 20 cm, 30 cm and 40 cm plot, respectively. The seeding rate was 2 or 3 per hill, 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, 100 and 100 kg ha^{-1} just before sowing.

The measurement of radiation interception was done on 7th and 8th of August. One plant each of the spacings was selected from the center of the plot. After sunset on the day before the experiment (6th of August), integrated solarimeter films (its dye percentages had been already measured by a spectro-photometer (Hitachi Corp., U-1000)) were stuck on every leaf of the selected plants. Two integrated solarimeter films per compound leaf were put on surfaces of the right and left leaflet of the upper and the lower pairs by double-sided binding tape, respectively (Fig. 1, peanut community around noon). For the calculation of total intercepted radiation per unit ground area (Σ (intercepted radiation per unit leaf area x leaflet area)/growing area), the intercepted radiation per unit leaf area of the left leaflet of the upper pair and the leaflet area of the right leaflet of the lower pair were regarded to be similar to the values of their counterparts. In the treatment plots, the surfaces of the canopy of 10 to 16 plants including the selected plant were covered double with a 0.56 mesh nylon net. Consequently, leaves in about 5 cm layer from the surface of the canopy were restrained horizontally (Fig. 2). The effect of the nylon net in reducing radiation was minimal. Every integrated solarimeter film was removed at night after the exposure for the two days. The dye remaining percentages of the collected inte-

Table 1. Leaf area and intercepted radiation per unit leaf area and per unit ground area.

Planting spacing	Leaf area (cm^2 $plant^{-1}$)		LAI (m^2 m^{-2})		Mean intercepted radiation per unit leaf area (MJ m^{-2} 2 $days^{-1}$)		Amount of intercepted radiation per unit ground area (MJ m^{-2} 2 $days^{-1}$)	
	Control	Treatment	Control	Treatment	Control	Treatment	Control	Treatment
20 cm	1870	1784	4.68	4.46	4.65	3.99	24.2	19.7(20.7)*
30 cm	2174	2729	2.42	3.03	5.88	5.63	16.0	19.6(15.7)
40 cm	3012	3199	1.88	2.00	6.69	7.08	14.5	17.8(16.8)

* Assumed value when leaf area of the control and the treatment would be similar.
** The global solar radiation was 30.7 MJ m^{-2} 2 $days^{-1}$ during the experiment.

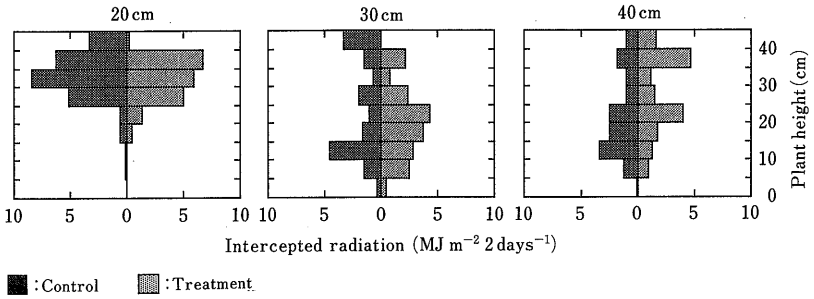

Fig. 3. Vertical distribution of amount of intercepted radiation per unit ground area.

grated solarimeter films were measured again by the spectro-photometer. At the same time, vertical distribution of leaf area, leaf and stem weights of four plants in the controls of the three spacings were examined at 5 cm height intervals. Relative light intensities were also measured for 20 points per 5 cm height interval around noon using a relative light intensity photometer (Sanshin Kogyo Corp., NS-2).

The experimental days were clear, and the global solar radiation for the two days was 30.7 MJ m^{-2} 2 $days^{-1}$. Mean air temperature during day time (4 : 00 A.M. to 7 : 00 P.M.) was 32.3°C and 31.4°C for 7th and 8th of August, respectively. The experimental field was very dry, since the amount of precipitation during one month before the experiment was only 4.5 mm.

Results

1. The amount of intercepted radiation per unit ground area

Table 1 shows leaf area of the measured plants, intercepted radiation per unit leaf area and per unit ground area. Leaf areas of the 20 cm and the 40 cm spacings were not so different between the control and the treatment. In the 30 cm spacing, however, leaf area of the treated plant was larger than that of the control. There was a tendency of mean intercepted radiation per unit leaf area to be different among the planting populations. The mean value of the control was larger in the 20 cm spacing (significant at the level of $P=0.20$ of the t test), almost similar in the 30 cm spacing (significant at the level of $P=0.50$) and smaller in the 40 cm spacing (significant at the level of $P=0.30$) as compared with the treatment. Total intercepted radiation per unit ground area depended mainly on mean intercepted radiation per unit leaf area, i.e., the control was larger in the 20 cm spacing, similar in the 30 cm spacing (when it was assumed that leaf area of the control and the treatment would be similar) and smaller in the 40 cm spacing.

The amount of intercepted radiation per unit ground area showed quite different vertical distribution between the controls and the treatments of the 20 cm and 40 cm spacings

(Fig. 3). The control of the 20 cm spacing had the largest intercepted radiation in the third layer from the top, while the amount of intercepted radiation of the treated plant was largest in the second layer and decreased toward the base of the canopy. In the 40 cm spacing, the control had the largest amount in the lower layer, while the upper layer was the largest in the treatment. The upper layers were larger in both control and treatment of the 30 cm spacing and the largest amount was intercepted by the lower layer in the control and by the middle layer in the treatment. This result indicates that the leaf movement of the upper layers would allow the light to penetrate toward the middle and lower layers.

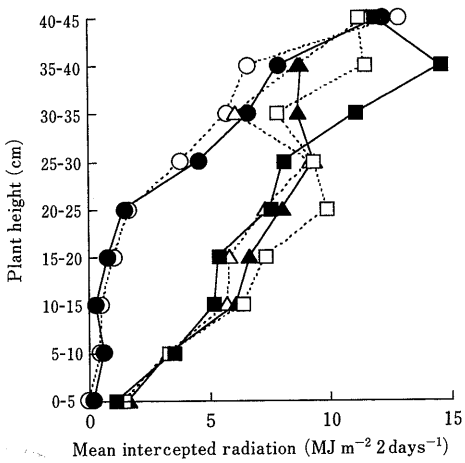

Fig. 4. Mean intercepted radiation per unit leaf area with plant height.
···○··· 20 cm Control, ···△··· 30 cm Control, ···□··· 40 cm Control, —●— 20 cm Treatment, —▲— 30 cm Treatment, —■— 40 cm Treatment.

2. Distribution of intercepted radiation with plant height

Fig. 4 shows the vertical distribution of mean intercepted radiation per unit leaf area. The 20 cm spacing had quite lower values in the lower and the middle layers as compared with the other plots. The values were not so different between the control and the treatment. In the 30 cm spacing, the values of the control were similar in the lower and the middle layers and lower in the upper layers as compared with those of the treated plants. The control had higher values in the lower and the middle layers and lower values in the upper layers than the treatment.

Frequency distribution of intercepted radiation per unit leaf area differed among the planting populations and between the control and the treatment (Fig. 5). In the 20 cm spacing, there was no leaflet that intercepted more than 10 MJ m^{-2} 2 days^{-1} in the lower five layers of both control and treatment. Although there was no obvious difference between the control and the treatment, the control had several leaflets which intercepted rather large amount of radiation in 25-30 cm and 30-35 cm layers. The maximum values of the treatment were larger in the upper two layers and smaller in the next two layers as compared with the control. The frequency distribution of the 30 cm spacing was not so different between the treatment and the control, although there were a few leaflets which

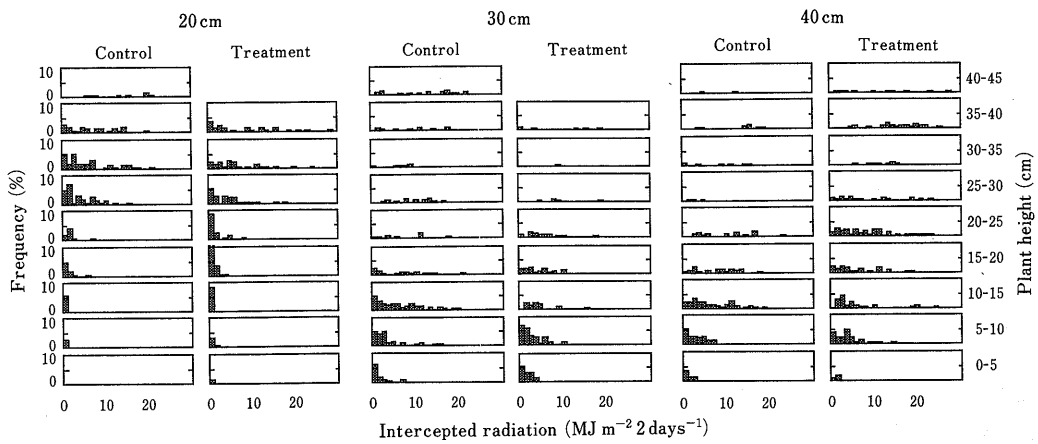

Fig. 5. Frequency distribution of intercepted radiation per unit leaf area.

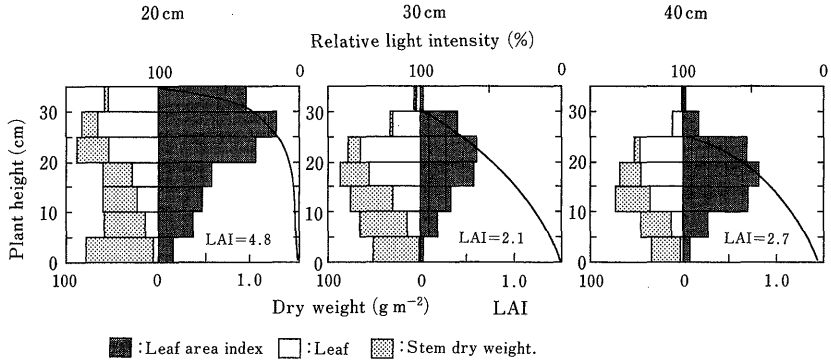

Fig. 6. Vertical distribution of dry weights and leaf area index.

intercepted larger amount of radiation in the upper and the lower layers of the control. On the other hand, the treatment of the 40 cm spacing had higher maximum values in the upper two layers as compared with the control, since the leaflets of the upper layer were settled perpendicular to incoming radiation around noon. The leaflets of the lower layers in the control could intercept relatively larger amount of radiation because of the leaf movement of the upper layer.

3. Canopy structure

The leaf area of the 20 cm plot concentrated in the upper layers in the control (Fig. 6). The light scarcely penetrated the middle and the lower layers. The total leaf area index was more than 4.5. The treated plants covered with the net might therefore have serious mutual shading. The leaf area of the 30 cm and 40 cm plots were distributed largely in the middle layers. The light penetrated gradually towards the base of the canopy. It was therefore presumed that the treatment would not affect the radiation interception in the middle layers where the largest leaf area occurred in these plots, although only the uppermost layer would be affected by net covering.

Discussion

In this experiment, it was found that the leaf movement played a significant role in radiation interception in the 20 cm spacing, no discernible effect in the 30 cm spacing and a rather adverse in the 40 cm spacing. We observed a shift from diaheliotropic to paraheliotropic leaf orientation, i.e., leaves oriented to face the sun rays in the early morning and just before sunset, while reduction of radiation interception occurred in the midday as similar to the pattern that have been reported in cowpea[16] and kidney bean[2]. In particular, active light avoidance of leaflets was observed around noon (Fig. 1). In the 40 cm spacing with small leaf area index in the upper layers, the portion of penetrated radiation without interception would therefore increase because of the paraheliotropic leaf movement of the upper layer of the canopy. While in the 20 cm spacing with dense leaf area at the upper layers, the light avoidance of the leaflets of the upper layer would increase radiation interception in the middle and the lower leaves. Consequently, the total intercepted radiation by the whole canopy increased. In the 30 cm spacing, the gain of intercepted radiation by the leaflets of the lower layers might be similar to the loss of unintercepted radiation. Peanut has generally very dense leaf area distribution. It is common that leaf area indices exceeded more than 4 or 5[4,5,10,14]. A low canopy with such a large leaf area index may have serious mutual shading. In the conditions with serious mutual shading such as the case of the 20 cm spacing, the paraheliotropic leaf movement may therefore be effective to reduce mutual shading, to increase intercepted radiation of the canopy and to increase canopy photosynthetic rate. On the other hand, Hirata et al.[8] reported that the paraheliotropic leaf movement of soybean was a function to avoid photoinhibition when the leaves were irradiated with extremely high intensity for a long time. Although the paraheliotropic leaf movement in peanut was not effective on radiation interception in the lower population density, it may also have an effect on the reduction of leaf temperature and the prevention of a decline in photosynthesis of the upper layer of the can-

opy.

Peanut plants were growing under water stressed conditions in this experiment. It has been reported that the heliotropic leaf movement would be closely related to leaf water potential[2,3,13]. In well watered conditions, the shift from diaheliotropic to paraheliotropic leaf movement might be delayed. The amount of intercepted radiation might therefore increased even in the control of the lower planting density. Wofford and Allen[19] reported that varietal differences in soybean existed in leaf orientation. In peanut, Aboagye et al.[1] also observed that there were large varietal defferences in radiation interception per unit leaf area measured by the integrated solarimeter films. It is assumed that peanut would have rather large varietal differences in the leaf movement and the reaction to water conditions. Adequate evaluation of these relationships will require other trials such as a varietal experiment or experiments including water treatment and monitoring of water conditions.

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