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

## II. Soybean (*Glycine max* Merr.)

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**Abstract** : The effects of the leaf movement on radiation interception were examined by a treatment which restrained the leaf movement in the upper layers of the canopy. Two determinate soybean cultivars with different canopy structures (c.v. Nanbushirome and Miyagishirome) were grown at two planting densities in the field. A pot experiment was also used to evaluate radiation interception under the conditions of no mutual shading. Intercepted radiation of every leaflet of two plants within the canopy and one plant in the pot experiment was measured by the integrated solarimeter films for two consecutive days. The amount of intercepted radiations per unit ground area in the treatments were larger than those in the controls of both cultivars and indicated the ineffectiveness of the leaf movement on radiation interception. In general, Nanbushirome intercepted larger amount of radiation in every layer of the canopy in both field and pot experiments. The differences between the control and the treatment in Nanbushirome were large as compared with Miyagishirome. The leaf temperature of the uppermost layer of the canopy in Nanbushirome was higher than the air temperature in the treatment, whereas it was at par with the air temperature in the control. The leaflets of the upper layer moved para-heliotropically to the sun rays during most of day time, it was therefore assumed that the leaf movement would regulate leaf temperature.
**Key words** : Canopy structure, Heliotropic leaf movement, Integrated solarimeter film, Leaf temperature, Radiation interception, Soybean.

**マメ科作物の葉の調位運動が受光量に及ぼす影響**　第2報　ダイズ：磯田昭弘・吉村登雄*・石川敏雄*・王培武・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抑える処理を行い，小葉の受光量を簡易積算日射計で測定した．用いた品種はナンブシロメとミヤギシロメで，30 cm（30 cm 区），40 cm（40 cm 区）の正方形に播種した．8月14日，15日に処理を行い，各区より2個体選び全小葉の2日間の受光量を測定した．同時にナンブシロメの30 cm 区の葉温を測定した．また，相互遮蔽の無い状態での受光量を推定するため，ポットで生育させた孤立個体の受光量についても測定した．両品種とも平均小葉面受光量および単位土地面積当たり受光量は処理区の方が高い値を示し，処理区間の差は30 cm 区で大きかった．ナンブシロメはミヤギシロメに比べ平均小葉面受光量が大きく，各層の受光量も大きかった．孤立個体の平均小葉面受光量は，いずれの層もミヤギシロメが小さく，孤立個体内での遮蔽も大きいものと考えられた．葉群構造は両品種とも上層に葉群が集中したが，特にミヤギシロメは葉面積指数が大きく相互遮蔽が激しかった．処理区の最上層の葉温は朝7時以降気温より高く推移したが，無処理区では気温とほぼ同様の推移を示した．以上のことからダイズの葉の調位運動は早朝と夕方遅くを除き，基本的には強い太陽光線から逃れようとする運動であり，葉温を下げる効果があるが，同時に受光量を調節して減少させる影響を持っていることがわかった．
**キーワード**：簡易積算日射計，受光量，ダイズ，調位運動，葉温，葉群構造．

In the previous paper[7], we examined the effects of the leaf movement on radiation interception in peanut by using the integrated solarimeter films. It was assumed that peanut leaves basically oriented parallel to the sun rays during midday, similar to the pattern that have been reported in cowpea[12] and kidney bean[2]. Its effectiveness for radiation interception might depend on leaf area density in the upper layer of the canopy.

Although several reports have mentioned the leaf movement in soybean[2,3,6,11,15], there are a few references to its effects on the amount of radiation interception in a community[6,9,10]. We intended to measure actual radiation interception on leaflet surfaces in field grown soybeans by the use of the integrated solarimeter films. In this experiment, we estimated the effects of the leaf movement in soybean on radiation interception by a treatment that restrained the leaf movement horizontally. Radiation interception in isolated plants was also evaluated under the conditions of no mutual shading in a pot experiment. At the same time, leaf temperature was measured in the control and the treatment of Nanbushirome.

## Materials and Methods

### 1. The field experiment

The field experiment was conducted in the experimental farm of Faculty of Horticulture, Chiba University in 1991. The two determinate cultivars, Nanbushirome (long leaflet type) and Miyagishirome (round leaflet type), were used, which are grouped into IIc by Fukui and Arai's classification criterion of the soybean ecotype in Japan[5]. The seeds were sown by hand at equidistant spacings of 30 cm and 40 cm between and within rows (11.1 and 6.3 plants $m^{-2}$, respectively) on 12th of June. The plot area was 122.4 $m^2$ and 272.0$m^2$ for the 30 cm and the 40 cm spacing, respectively. The seeding rate was 2 or 3 per stand, 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 made on 14th and 15th of August. Two plants each of the spacings were selected from the center of the plot in terms of equal leaf numbers. After sunset on the day before the experiment (13th of August), integrated solarimeter films (their dye percentages had been already measured by a spectro-photometer (Hitachi Corp., U-1000)) were stuck on every leaflet surface by double-sided binding tapes. In the treated plants, the surfaces of the canopy of 10 to 16 plants including the selected two plants were covered double with a 0.56 mesh nylon net. Consequently, leaves in about 10 cm layer from the surface of the canopy were restrained horizontally. The effect of the nylon net in reducing radiation was barely minimal. Every integrated solarimeter film was removed at night after the exposure for the two days. The dye remaining percentages of the collected integrated solarimeter films were measured again by the spectro-photometer.

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

| Plot | Leaf number ($plant^{-1}$) | Leaf area ($m^2$ $m^{-2}$) | Mean leaflet area ($cm^2$) | Mean intercepted radiation per unit leaf area (MJ $m^{-2}$ 2 $days^{-1}$) | | Intercepted radiation per unit ground area (MJ $m^{-2}$ 2 $days^{-1}$) |
|---|---|---|---|---|---|---|
| | | | | Mean | S. D. | |
| Nanbushirome | | | | | | |
| 30 cm | | | | | | |
| Control | 169 | 3.26 | 34.7 | 5.74 | 5.95 | 22.9(22.9)* |
| Treatment | 174 | 3.68 | 38.0 | 8.24 | 7.82 | 34.8(30.9) |
| 40 cm | | | | | | |
| Control | 230 | 2.16 | 30.1 | 5.90 | 5.18 | 16.0(16.0) |
| Treatment | 213 | 2.07 | 31.0 | 6.42 | 5.74 | 16.3(17.1) |
| Miyagishirome | | | | | | |
| 30 cm | | | | | | |
| Control | 157 | 6.16 | 70.6 | 3.80 | 4.85 | 27.8(27.8) |
| Treatment | 127 | 4.83 | 68.5 | 4.43 | 6.12 | 25.2(32.1) |
| 40 cm | | | | | | |
| Control | 229 | 5.27 | 73.6 | 3.44 | 4.59 | 21.0(21.0) |
| Treatment | 228 | 4.73 | 66.4 | 4.12 | 5.87 | 22.9(25.5) |

* Assumed value when leaf area of the control and the treatment would be similar.

** The global solar radiation was 30.5 MJ $m^{-2}$ 2 $days^{-1}$.

At the same time, vertical distribution of leaf area, leaf, stem and pod weights of four plants each of the spacings were examined at 10 cm height intervals.

**2. The pot experiment**

The seeds of the two cultivars were planted on 14th of June in 1/2000 a Wagner pots with fertilizer at 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 plants were grown in a greenhouse and were irrigated as and when necessary. Radiation interception was measured on 30th and 31st of July. The integrated solarimeter films were stuck on every leaflet of one plant per cultivar. The method of the measurement for radiation interception was the same as that in the field experiment.

**3. Measurement of leaf temperature**

In the 30 cm spacing of Nanbushirome, leaf and the air temperatures were measured in both control and treated plants by thermopiles from 4 : 00 A.M. to 7 : 00 P.M. on 14th of August. Terminal leaflets were selected from the uppermost layer and at about 10 cm from the uppermost layer of the canopy. The petiole

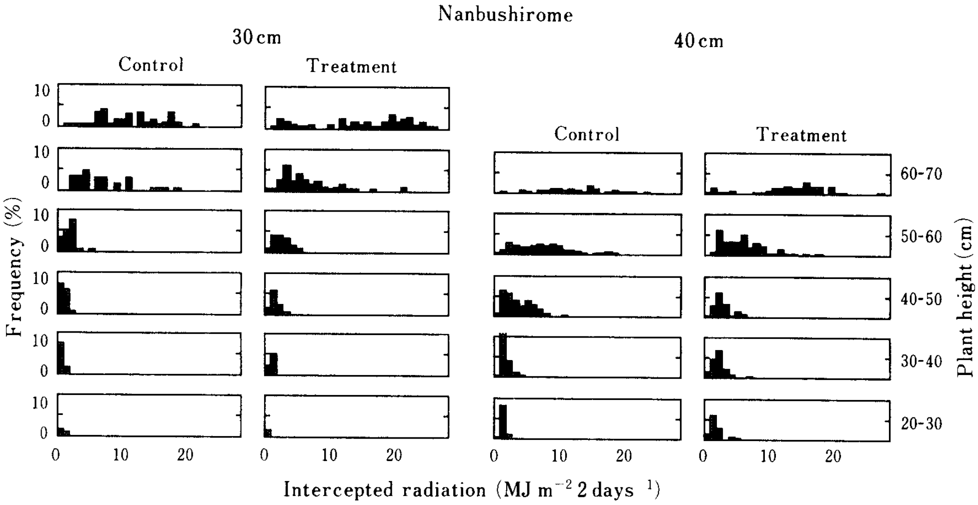


Fig. 1. Vertical frequency distribution of intercepted radiation per unit leaf area in Nanbushirome.

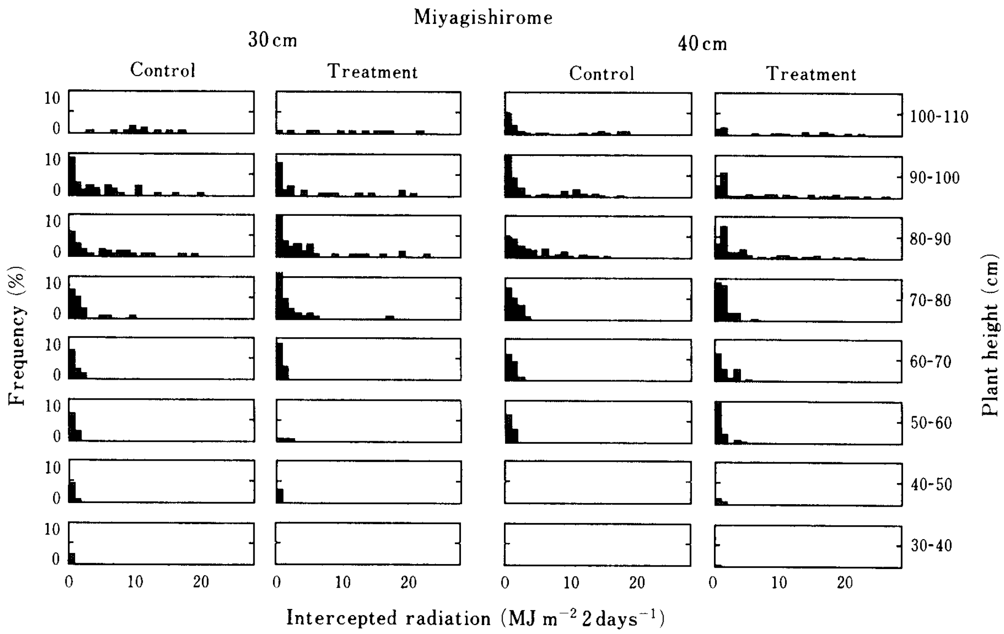


Fig. 2. Vertical frequency distribution of intercepted radiation per unit leaf area in Miyagishirome.

direction of the selected leaflets was northward (i.e., faced South when tilted upward). The thermopiles were fixed on the abaxial side of the leaflets with negligible effect of its weight on the leaflet movement. The data of the thermopiles were collected at 5 minutes' intervals by a data logger (Eto Denki Corp., Thermodac E) which was connected to a personal computer (Seiko Epson Corp., PC-286LE).

## Results

### 1. Radiation interception in the field experiment

The growing season was very wet. The amount of precipitation during two weeks before the field experiment was 84.5 mm. The experimental days (14th and 15th of August) were clear. The global solar radiaton was 30.5 MJ $m^{-2}$ 2 $days^{-1}$, and mean air temperature during day time (4 : 00 A.M. to 7 : 00 P.M.) was 25.7°C.

Mean intercepted radiation per unit leaf area was higher in both cultivars and spacings of the treated plants (Table 1). The value of the treated plants of Nanbushirome was larger than that of the control in the 30 cm spacing (significant at the level of $P=0.025$ of t test) and in the 40 cm spacing (significant at the level of $P=0.4$). The treated plants of Miyagishirome also had larger values than the control in the 30 cm spacing (significant at the level of $P=0.4$) and in the 40 cm spacing (significant at the level of $P=0.2$). Intercepted radiation per unit ground area in the treated plants was also larger than that in the control (the value of the treatment in the 30 cm spacing of Miyagishirome was larger than that of the control, when it was assumed that leaf area of the control and the treatment would be similar). The difference between the control and the treatment was larger in the 30 cm spacing of both cultivars as compared with the 40 cm spacing.

In Nanbushirome, the distribution pattern of intercepted radiation per unit leaf area was different between the control and the treatment in the 30 cm spacing, i.e., there were many leaflets in the treated plants that intercepted more than 15 MJ $m^{-2}$ 2 $days^{-1}$ as compared with the control (Fig. 1). In the 40 cm spacing, however, there was no marked difference between the control and the treatment, although there were a few leaflets that intercepted more radiation in the second and the third layers of the control and in the uppermost layer of the treatment. Miyagishirome also had larger values in the upper three layers of the treated plants in both spacings (Fig. 2). In general, however, Miyagishirome intercepted smaller radiation in every layer and the differences between the control and the treatment were not large as compared with Nanbushirome.

Fig. 3 shows vertical distribution of amount

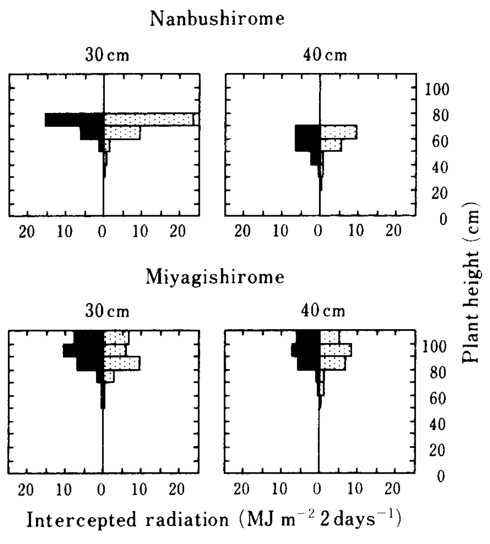


Fig. 3. Vertical distribution of amount of intercepted radiation per unit ground area.

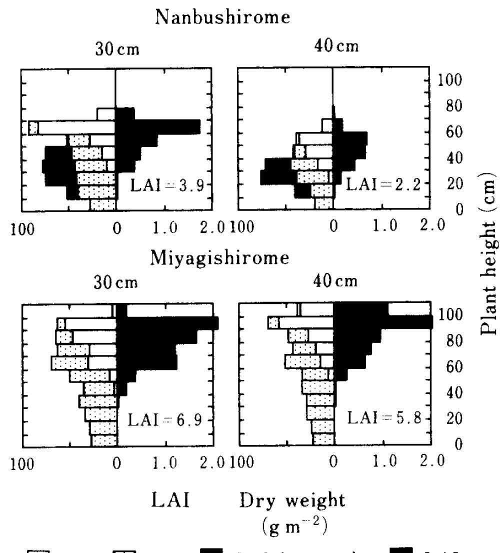


Fig. 4. Vertical distribution of dry weights and leaf area index (LAI).

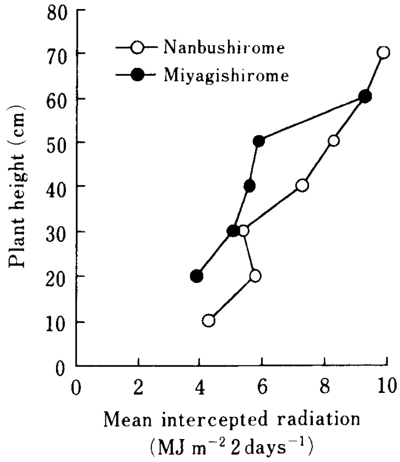


Fig. 5. Mean intercepted radiation per unit leaf area in the individual plants grown in pots.

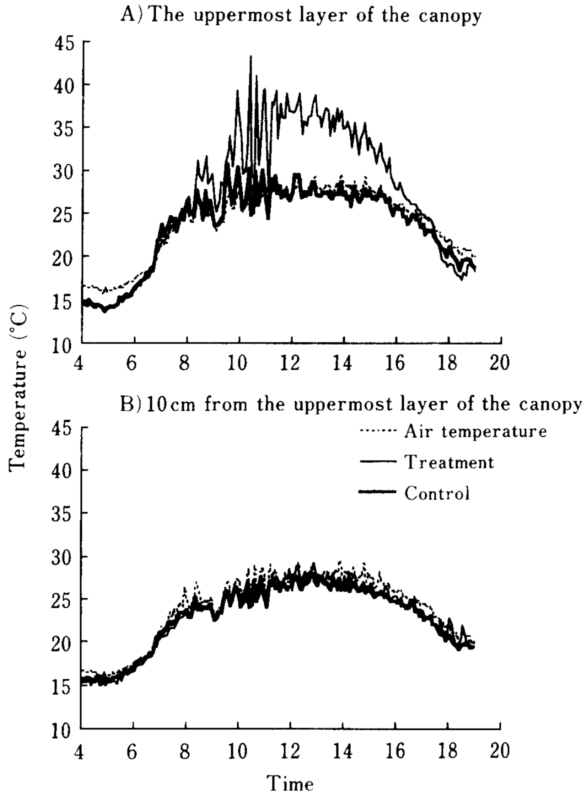


Fig. 6. Changes with time in leaf and air temperature in Nanbushirome

of intercepted radiation per unit ground area. Nanbushirome had the largest amount in the uppermost layer at each spacing, and its value of the treatment was larger than that of the control. In the 40 cm spacing, the difference between the control and the treatment was not large, although the value of the uppermost layer of the treatment was slightly large. On the other hand, Miyagishirome generally had a smaller value of intercepted radiation in every layer in spite of having larger leaf area, and small differences between the control and the treated plants as compared with Nanbushirome. The second layer from the top was the largest in both spacings except the treatment in the 30 cm spacing.

**2. Canopy structure in the control**

Nanbushirome had a short canopy height and smaller leaf area indices in most of the layers being less than 1.0 in both spacings (Fig. 4). There was the highest leaf area density at the second layer in the 30 cm spacing, and at the middle layers in the 40 cm spacing. Miyagishirome had larger leaf area indices than Nanbushirome in both spacings. Its canopy shape was a typical table type, so that the lower leaves had already defoliated. Miyagishirome had produced no pod at this stage.

**3. Radiation interception in the pot experiment**

The global solar radiation was 24.3 MJ $m^{-2}$ 2 $days^{-1}$ during the experimental days. In the uppermost layer, mean intercepted radiation per unit leaf area was not so different in Nanbushirome and Miyagishirome (Fig. 5). However, Nanbushirome had larger values in the other layers. In particular, the values of the three layers below the uppermost were rather high as compared with Miyagishirome.

**4. Leaf temperature**

Fig. 6 shows leaf temperatures in the uppermost layer and at about 10 cm from the uppermost layer of the canopy of the 30 cm spacing in Nanbushirome. The leaf temperatures of the control and the treated plants were lower just before 7 A.M., then rose to equilibrate till 8 A.M. when compared with the air temperature. In the treated plants, the leaf temperature became rather high and fluctuated largely after 8 A.M. due to the sun rays. The maximum temperature recorded was 43°C at 10 A.M., that was higher than the air temperature by 15°C. The leaf temperature of the control was at par with the air temperature, although it was slightly higher from 6 : 55 A.M. to 11 : 00 A.M. and was lower during afternoon. The control had lower leaf temperature than the treatment during most part of the day. However, it was higher than that of the treatment during the periods from 5 : 15 A.M. to 7 : 40 A.M. and after 5 : 25 P.M. At about 10 cm below the uppermost, the leaf temperatures in both the control and the treatment were lower than the air temperature during the day. The leaf temperature of the treatment was not different from that of the control until noon, thereafter it became a little higher during the afternoon.

## Discussion

Leaf movement has two reversible aspects, i. e., paraheliotropism and diaheliotropism[4]. In this experiment, the leaves might orient diaheliotropically during the early morning and just before sunset, since the leaf temperature of the control was higher than that of the treatment during these periods. During most part of the day, however, the leaves in the control appeared to orient paraheliotropically to the sun rays, since the leaf temperature of the control being at par with the air temperature during this period and the leaves intercepted less radiation as compared with the treated plants. Hirata[6] has reported that the leaf movement served as an avoidance mechanism of photoinhibition of photosynthesis under extremely high sun light conditions. The leaf temperature of the treated plants was very high in the midday. The photosynthesis of the leaves might therefore be inhibited.

It has been reported that leaf movement, in particular, paraheliotropic movement, would be related to the water conditions of the plants[1,11,12]. We had much rain in the summer of 1991, so that the soybean field was sufficiently wet during the experimental period. The leaf movement in this experiment therefore demonstrates that leaves could orient paraheliotropically during most of the day time even under well watered conditions. Tazaki et al.[13] reported that water stress in midday reduced photosynthesis of rice grown even in paddy field. It may be assumed that the water supply in soybean also could not meet the water demand for transpiration and subsequent reduction of leaf temperature at such day time of fine weather. More detailed research will be needed to evaluate the relation of the leaf movement to water conditions and leaf temperature.

It was found that leaf movement played a significant role in the reduction of mutual shading and in the increase of radiation interception in the dense leaf canopy of peanut[7]. In soybean, however, we could not find the effectiveness of the leaf movement on radiation interception. Although the different results may be caused by differences betweeen the crops in their physiological reactions to radiation and water, some presumptions may be conceived from the obtained results ; Nanbushirome did not have a dense leaf area as the peanut canopy, so that the tilting up of the upper leaves might increase unintercepted radiation. On the other hand, Miyagishirome also did not show a significant effect of the leaf movement on radiation interception in spite of having large leaf area. The leaf movement in Miyagishirome seems to be smaller owing to its large leaflet size, since the difference between the control and the treated plants was smaller in mean intercepted radiation per unit leaf area as compared with the 30 cm spacing of Nanbushirome. In addition, serious mutual shading might overshadow the effect of leaf movement. The values of mean intercepted radiation per unit leaf area in both treatment and control were rather low as compared with Nanbushirome. For the isolated individuals grown in the pots, the value in mean intercepted radiation for Miyagishirome was not so different from that for Nanbushirome in the uppermost layer, while the values in the middle and the lower layers were smaller than those for Nanbushirome. This result may be interpreted as existence of self shading due to its large leaflet even in the isolated plant. Mutual shading must therefore be serious in the community of Miyagishirome. Consequently, the intercepted radiation per unit leaf area might become smaller.

The leaf movement in soybean seemed to be similar to that in peanut essentially, i.e., paraheliotropically to the sun rays during almost day time of fine days. As mentioned above, however, the effectiveness of the leaf movement on radiation interception was different between the crops. This result might be affected largely by their morphological characteristics such as leaflet size, leaf thickness and leaf area density, in addition to the physiological reactions to radiation and water.

There was a large difference between Nanbusirome and Miyagishirome in leaf orientation. It has been also reported that soybean would have rather large varietal differences in leaf movement[15]. It is therefore necessary to survey varietal differences in leaf orientation from the viewpoint of radiation interception to obtain the information necessary for the improvement of canopy structure in soybean. In addition, the leaf orientation may be one of the useful criteria in breeding for the arid conditions after the evaluation of the relationship between leaf movement and water conditions.

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