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Relations between Plant Coverage and Soil Temperature beneath Film Mulch with Different Size of Planting Hole

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Abstract

The purpose of this paper was to clarify the effects of planting hole diameters of mulch film and plant coverage on soil temperature beneath mulch film. At both 6:00 and 15:00, the soil temperature in mulched zones decreased more when the plant coverage was higher and the soil temperature in the control zone (bare plot) was higher. No significant difference, however, was observed between zones with different planting hole diameters. The soil temperature differences between zones are significantly affected by air temperature, soil moisture tension and plant coverage. In vegetation zones, the daily range ratio of the soil temperature was the smallest in the zone with 3 cm diameter planting holes (Mp_3). The daily range ratio of soil temperature in all vegetation zones, except the Mp_3 zone, was affected by three factors: daily average air temperature, daily total amount of solar radiation and daily average wind speed.

Key words : Mulch, Planting hole, Soil temperature.

1. Introduction

Film mulches have many holes, where plants are planted. The effects of the planting hole size and types of the plant canopy on soil temperature beneath film mulch were already reported[1]. Ratio of daily range of soil temperature was found to increase with the present of plant and varied depending on seasons. However, in the report using imitation canopy, the plant coverage was fixed throughout the experimental period. Variation of soil temperature was depended on the plant stage because different plant stages would provide different plant coverage[2, 3]. Since canopy quantity at each plant stage was needed in the plots, imitation canopies at different stage had been used.

The purpose of this paper was to clarify the effects of the planting hole size and the plant coverage on soil temperature.

2. Experimental plots and measurement

The experiment was conducted in the experimental field of the Faculty of Agriculture, Kagawa University, from September 2, 2007 to January 26, 2008. Three rows of the plot were formed in the field, and were covered with 0.02 mm-thick black polyethylene film. The size of each row was the same as those in the report[4]. No mulch plots were also established as a control plot. In the plots with plant, a size of the imitation canopy was 22.4 cm long and 22.4 wide. A diagram of the imitation canopy was shown in the Fig. 1. The coverage of the imitation canopy was varied (0%, 20%, 30%, 60%, or 80%), and the coverage was rotated every two days. LAI of each stage was fixed at 1.0. The measurements were conducted in totally thirteen experimental plots; seven plots were

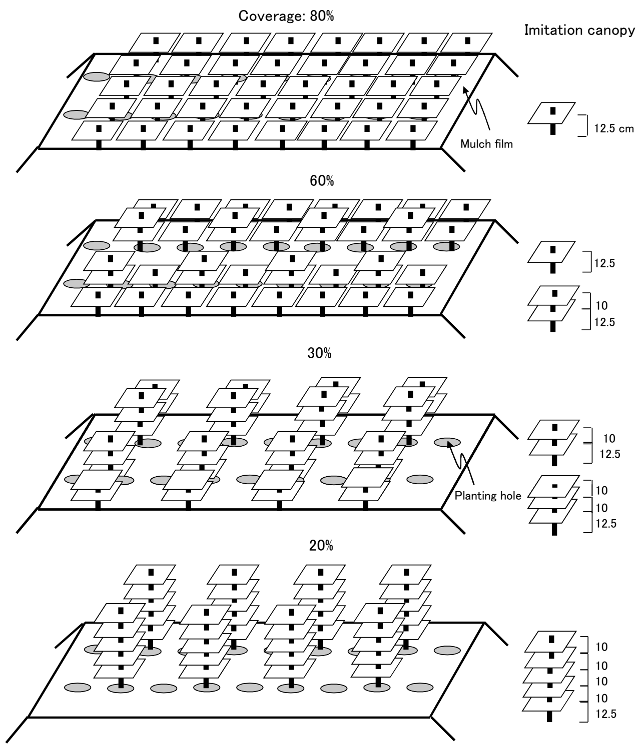

Fig. 1 Imitation canopy in each plot.

Table 1 Experimental plots.

	Plots[1]	Diameter[2] (cm)	Planting space[3] (cm)	Leaf canopy size[4] (cm)	LAI	Plant[5] coverage (%)
No plant	Nn	—	—	—	0	0
	Mn	—	—	—	0	0
	Mn_3	3	50[a]×25[b]	—	0	0
	Mn_{10}	10	50 ×25	—	0	0
	Mn_{16}	16	50 ×25	—	0	0
	Mn_{22}	22	50 ×25	—	0	0
	Mn_{39}	39	50 ×50	—	0	0
Plant	Np	—	50 ×25	22.4×22.4	1	
	Mp_3	3	50 ×25	22.4×22.4	1	
	Mp_{10}	10	50 ×25	22.4×22.4	1	20, 30, 60, 80
	Mp_{16}	16	50 ×25	22.4×22.4	1	
	Mp_{22}	22	50 ×25	22.4×22.4	1	
	Mp_{39}	39	50 ×50	22.4×22.4	1	

[1] Plot symbol, N: No mulch, M: Mulch, n: Noplant and p: Plant.
[2] Planting hole diameter, cm
[3] a: Interrow space, b: Intrarow spacing
[4] Size of imitation canopy, 22.4cm long and 22.4cm wide.
[5] Plant coverage of each plot was changed from 20% to 80% every two days.

without plant and the rest were with plant (Table 1).

During the experimental periods, solar radiation, albedo, heat balance, soil temperature, and soil moisture were measured. Solarimeter (Iio, S-SR2) and albedometer (Eiko, MR-21) were used for measuring the solar radiation and albedo. Net radiation in the heat balance was measured using net radiation meter (Eiko, CN-40) placed in the center of each plot at 50 cm above the row surface. Soil heat flux was measured using heat flux plates (Eiko, CN-8), which were laid below the soil surface, covered with about 2 mm of soil, in the center of each plot. Sensible and latent heat fluxes were not separated. Total of sensible and latent heat fluxes was calculated as the remainder in the heat balance.

Soil temperature sensors were made using type-T thermocouples. In each plot, ten sensors were laid underground at 10 cm depth at intervals of 30 cm in the direction of the rows. The soil temperature at 10 cm depth is used as the representative soil temperature in experiments on mulches. These measured values were recorded twice a day at 6:00 and 15:00.

For soil moisture, soil moisture tension was measured, using tensiometers (Daiki, DIK-8343) laid underground at 10 cm depth. Although tensiometers and soil temperature sensors were both laid at the same depth, they were kept at least 10 cm away from each other. The tension was measured at 6:00 and 15:00. Soil water content was also measured. As for other meteorological factors, data observed at the observation field adjoining the experimental field was used.

3. Results and discussion

3.1 Plant canopy and soil temperature

3.1.1 Temperature differences

The relations between soil temperature difference (each plot-Nn) and that in the Nn plot were shown in Fig. 2.

At 6:00, in the Mp_3-Nn, the temperature difference at 0% coverage was increased by increasing of soil temperature in the Nn plot. However, when the coverage was 20% or higher, the difference became lower as soil temperature in the Nn plot increased. When soil temperature in the Nn plot was 9 °C or larger, the temperature difference at 0% coverage was higher than any other plots. While the coverage was in a range from 20% to 80%, the temperature difference among the varied percent plant coverage was rather small. A high temperature difference in the Mp_3-Nn could be a result of heat stored in the Mp_3, while, in the Nn plot, the heat was easily radiated to the

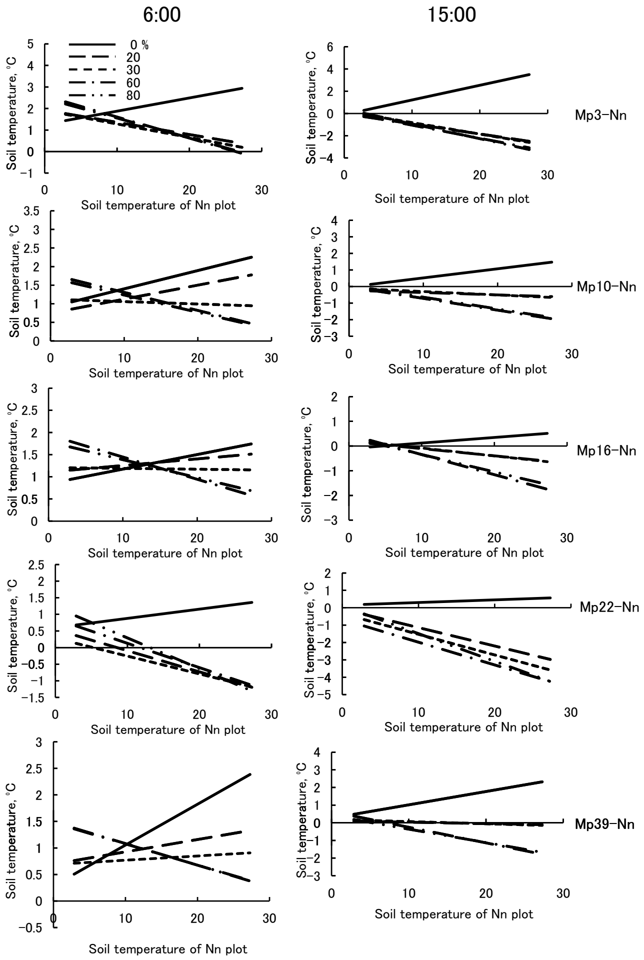

Fig. 2 Relationships of soil temperature difference (each plot-Plot Nn) and soil temperature of plot Nn at 6:00 and 15:00 from September 27 in 2007 to January 4 in 2008.

atmosphere[5].

In the Mp_{10}-Nn, the relations between temperature difference and soil temperature in the Nn plot at each percentage of plant coverage showed the same tendency as those in the Mp_3-Nn, except for the 20% coverage. When the temperature in the Nn plot was 18 °C or higher, the temperature difference for each coverage could be ranked as follow: 0% > 20% > 30% > 60% > 80%. Hence, the temperature difference decreased with an increasing of the plant coverage, because during the daytime larger plant coverage can reduce the amount of solar radiation reach to the ground. Therefore, the stored heat in the plots with the larger plant coverage caused the lowering temperature difference[6].

In the Mp_{16}-Nn and the Mp_{39}-Nn, at 0%, 20% and 30% coverage, the temperature differences increased with the increasing of soil temperature in the Nn plot. However, when the plant coverage was larger than 30%, the temperature difference became lower as the temperature in the Nn plot was increased. When soil temperature in the Nn plot was larger than 14 °C and 10 °C in the Mp_{16} and the Mp_{39}, respectively, the order of temperature difference at each plant coverage was 0% > 20% > 30% > 60% > 80%. In the Mp_{22}-Nn, the temperature difference showed the same tendency as found in the Mp_3-Nn.

At 15:00, in the Mp_3-Nn, the temperature difference at 0% coverage increased as same as the increasing of soil temperature in Nn plot. On the other hand, when the plant coverage was 20% or larger, the temperature difference decreased with the increasing of soil temperature in the Nn plot. When the planting hole was larger than 3 cm (Mp_{10}, Mp_{16}, Mp_{22} and Mp_{39}), the relationship between temperature difference and soil temperature in the Nn plot for each of the plant coverage showed the same tendency as observed in the Mp_3-Nn. Furthermore, order of the temperature differences at each plant coverage was 0% > 20% > 30% > 60% > 80%.

The temperature difference was reported to decrease with the raising of a shade[7-9] because the shade by canopy could decrease both of the solar radiation and the net radiation beneath the canopy up to 75% during the daytime[10].

Both of 6:00 and 15:00, soil temperature difference was found to increase with a higher soil temperature in the Nn plot. This tendency was observed when the plant coverage was larger than 30% regardless of the planting hole diameter. Furthermore, the temperature difference reduced with the increasing of the plant coverage.

3.1.2 Temperature difference and meteorological factors

In order to clarify the relation between the temperature difference and the meteorological factors, multiple regression analysis was used (Table 2). The criterion variable was the temperature difference, and the explanatory variables were

Table 2 Standard partial regression coefficients in the multiple regression between soil temperature difference at 10cm depth under imitation canopy and meteorological factors from Sep. in 2007 to Jan. in 2008.

Temperature difference[1]		Meteorological factor[2]							Multiple[3] regression coefficient, r
		Te	Pr	Ia	Um	SmA	SmB	Pc	
6:00	Np[4]	−0.578				−0.518	0.458	0.495	0.791
	Mp_3	−0.548		0.102		−0.470	0.309	−0.267	0.669
	Mp_{10}					0.163	−0.225	−0.370	0.415
	Mp_{16}	−0.271				−0.215		−0.154	0.305
	Mp_{22}	−0.498				0.265	−0.202	−0.262	0.629
	Mp_{39}	0.106				0.453	−0.496	−0.287	0.358
15:00	Np	−0.526		−0.086		0.714	−0.644	−0.383	0.871
	Mp_3	−0.334			0.068	−0.471	0.315	−0.514	0.716
	Mp_{10}	−0.168		−0.083		0.151	−0.247	−0.652	0.724
	Mp_{16}	−0.415		−0.180		−0.208		−0.542	0.717
	Mp_{22}	−0.500		−0.100			−0.056	−0.586	0.805
	Mp_{39}	−0.161				0.235	−0.304	−0.711	0.741

1) Criterion variables.
2) Explanatory variables.
Notation: Te = daily mean air temp. (℃); Pr = amount of precipitation (mm); Ia = amount of insolation ($MJm^{-2}day^{-1}$); Um = daily mean wind velocity (ms^{-1}); Pc = plant coverage (%); SmA = soil moisture suction of A plot (mmHg); SmB = soil moisture suction of B plot (mmHg).
3) Adjusted for the degrees of freedom.
4) Plot symbles were the same as in Table 1.

daily mean air temperature (Te), amount of the precipitation (Pr), amount of insolation (Ia), daily mean wind velocity (Um), soil moisture suction of A plot (SmA), and soil moisture suction of B plot (SmB).

At 6:00, daily mean air temperature, soil moisture suction and plant coverage were selected to be considered in all plots, except for the Mp_{10}. The multiple regression coefficient of the Np (0.791) was higher than the plots with the planting hole. In the plots with the plant hole, the coefficients were in the range of 0.305 to 0.669. At 15:00, daily mean air temperature, soil moisture suction and plant coverage were commonly selected for every plots. The coefficient of Nn plot was higher than the others, while the coefficients in the plots with the planting hole showed a small difference and they were in the range of 0.716 to 0.805.

From the multiple regression analysis, it was possible to conclude that the variation of the temperature difference was depended on air temperature, soil moisture suction and plant coverage.

3.1.3 Ratio of daily range of soil temperature

The period average of the ratio of daily range varying from 0% to 80% coverage was shown in Fig. 3.

At 0% coverage, the ratio was significantly higher in the Mn_{39}/Nn (1.00) than that in the Mn_{10}/Nn (0.80) and Mn_{16}/Nn (0.73). While there was no difference compared to the other plots. The ratio of the Mn/Nn, Mn_3/Nn, and Mn_{22}/Nn were 0.90, 0.92 and 0.85, respectively. The low ratio was found in the Mp_{10}/Nn and Mp_{16}/Nn because of high heat exchange. The same result was also reported[4].

At 20% coverage, the ratio in every plots was lower than 1.0 (the average of 0.78). The highest ratio, 0.90, was observed in the Mn/Nn. From Mp_3/Nn to Mn_{39}/Nn, the ratio was gradually increased with a larger planting hole diameter.

From 30% to 80% coverage, the ratio showed the same tendency as those of 20% coverage, except for the Mp_{22}/Nn. The ratio of Mp_{22}/Nn was rather small because of high soil moisture content as previously reported[1]. The average ratio in all plots at 0% coverage was 0.87. The average ratio became lower when the plant coverage was increased. Comparing the average ratio of each plant coverage, the average ratios were in the order of 80% > 60% > 30% > 20% coverage. This result was the same in that of Duangpaeng[6].

When the plant coverage was larger than 20%, the ratio was the smallest in the plot with a small hole diameter (3 cm), and increased with a bigger planting hole diameter, except in the plot with 22 cm diameter holes.

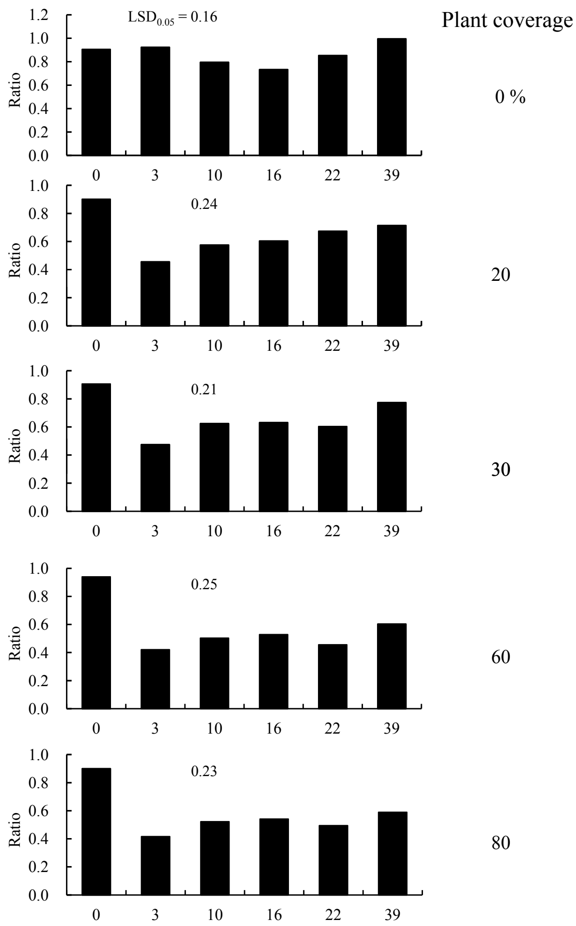

Fig. 3 Ratio of daily range of soil temperature in each plot under different plant coverage from September in 2007 to January in 2008.

3.1.4 Ratio of daily range and meteorological factors

In order to clarify the relation between the ratio of daily range of soil temperature and meteorological factors, the multiple regression analysis was used (Table 3). The criterion variable was the ratio and the explanatory variables were the same as those in the section 3.1.2.

At 0% coverage, soil moisture suction (SmA) was selected as the explanatory variable in all plots. However, in the plots with the planting hole larger than 16 cm, solar radiation and the wind velocity were selected. The regression coefficient was the highest in the Mn_3/Nn (0.693) and the lowest in the Mn_{22}/Nn (0.443).

At 20% coverage, wind velocity was selected in all plots, while in the plots with hole diameter larger than 10 cm, the daily mean air temperature, solar radiation, and wind velocity were selected. The coefficient was the lowest in the Mp_3/Nn

Table 3 Standard partial regression coefficients in the multiple regression between range ratio (range in each plot / that in Nn plot) and meteorological factors from Sep. 2 in 2007 to Jan. 26 in 2008.

Plant coverage (%)	Range ratio[1)]	Meteorological factor[2)]						Multiple[3)] regression coefficient
		Te	Pr	Ia	Um	SmA	SmB	
0	Mn/Nn	0.653			0.181	−0.186		0.618
	Mn_3/Nn	0.639				0.357	−0.538	0.693
	Mn_{10}/Nn		0.187		−0.285	−0.374		0.503
	Mn_{16}/Nn		0.241	−0.301	−0.319	−0.289		0.532
	Mn_{22}/Nn	−0.200		−0.299	−0.323	−0.323		0.443
	Mn_{39}/Nn	−0.433	0.246	0.254	−0.342	−0.386		0.509
20	Np/Nn	−0.816		0.699	−0.194		0.150	0.712
	Mp_3/Nn				−0.214		0.237	0.271
	Mp_{10}/Nn	−0.511		0.689	−0.217	0.249		0.612
	Mp_{16}Nn	−0.529		0.764	−0.211	0.224		0.668
	Mp_{22}/Nn	−0.719		0.765	−0.241			0.679
	Mp_{39}/Nn	−0.572		0.775	−0.256			0.662
30	Np/Nn	−0.686	−0.160	0.682	−0.202			0.692
	Mp_3/Nn				−0.205	0.253		0.279
	Mp_{10}/Nn	−0.267		0.763	−0.259	0.208		0.693
	Mp_{16}/Nn	−0.450		0.790	−0.237	0.162		0.678
	Mp_{22}/Nn	−0.848		0.751	−0.228			0.722
	Mp_{39}/Nn	−0.517		0.773	−0.260			0.660
60	Np/Nn	−0.595		0.593	−0.176		0.205	0.564
	Mp_3/Nn						0.186	0.143
	Mp_{10}/Nn			0.344	−0.218	0.289		0.436
	Mp_{16}/Nn	−0.317		0.649	−0.215	0.334		0.623
	$Mp_2$2/Nn	−0.381		0.343	−0.195	0.406		0.519
	Mp_{39}/Nn	−0.658		0.801	−0.244	0.135		0.693
80	Np/Nn	−0.647		0.492	−0.159		0.219	0.564
	Mp_3/Nn				−0.178		0.239	0.245
	Mp_{10}/Nn	−0.252		0.568	−0.262	0.253		0.534
	Mp_{16}/Nn	−0.324		0.677	−0.217	0.327		0.642
	Mp_{22}/Nn	−0.643		0.642	−0.181	0.293		0.655
	Mp_{39}/Nn	−0.496		0.785	−0.244	0.189		0.671

1) Criterion variables.
2) Explanatory variables.
Notation: Te = daily mean air temperature (℃); Pr = amount of precipitation (mm); Ia = amount of insolation ($MJm^{-2}day^{-1}$);
Um = daily mean wind velocity (ms^{-1}); SmA = soil moisture suction in A plot (mmHg);
SmB = soil moisture suction in B plot (mmHg).
3) Adjusted for the degrees of freedom.

(0.271), while the coefficients in the other plots were not much in different. They were distributed in the range of 0.612 to 0.712.

When the plant coverage was larger than 20% (30%, 60%, 80% coverage), the numbers of explanatory variable in each plot were almost the same as in the plot of 20% coverage. Furthermore, the coefficient was found to be the lowest in the Mp_3/Nn, whereas the coefficients among the others showed small differences.

As described above, from the Mp_{10}/Nn to Mp_{39}/Nn with the plant coverage larger than 20%, the daily mean air temperature, solar radiation, and wind velocity were selected. From 20% to 80% coverage, the coefficient was the smallest in the Mp_3/Nn.

3.2 Frequency distributions of soil temperature difference

3.2.1 Frequency distributions

The frequency distributions of soil temperature difference were shown in Fig. 4. The distributions of Fig. 4 were at 60% coverage.

At 6:00, in the Mp_3-Nn, the frequencies were mainly distributed on the positive side because of the presence of mulch and plant canopy. Plant canopy could prevent the outgoing

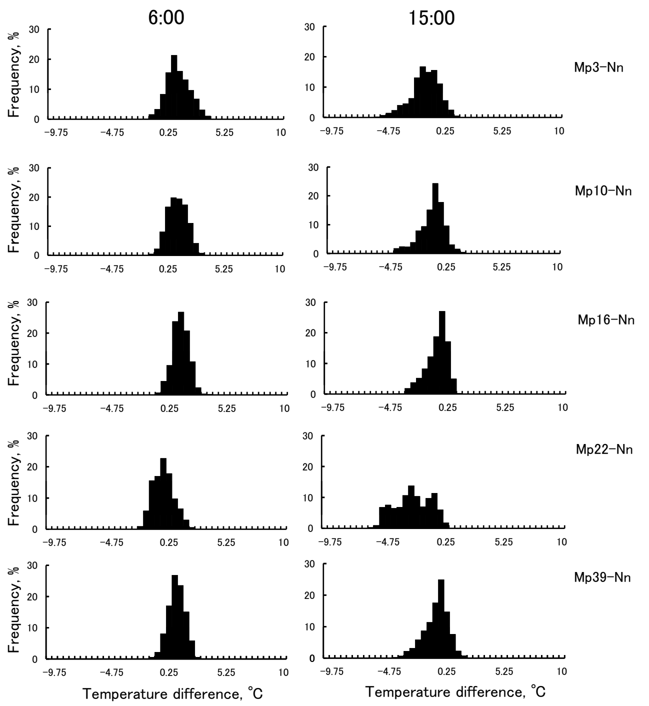

Fig. 4 Frequency distribution of the soil temperature differences at 10 cm depth between two plots at 6:00 from April to June in 2006. Plant coverage in Fig. 4 was 60%.

longwave radiation from the row surface[10]. This tendency was found in every planting hole diameters. However, from the Mp_{10} to Mp_{39}, the range (the distance between the left and the right of the X-axis) of temperature difference in each plot tended to increase with the increasing of the planting hole size.

At 15:00, in the Mp_3-Nn,the frequencies were mainly distributed on the negative side. Soil temperature in the Mp_3 was lower than that in the Nn plot because of decreasing of solar radiation due to the canopy[11]. Similar tendencies were also found in the plots with larger hole diameter (Mp_{10} to Mp_{39}). However, in the Mp_{22}, two peaks of frequency distribution was observed whereas only one peak was noticed in the others.

3.2.2 Mean and range of temperature difference

Frequency distributions of soil temperature difference between two plots were shown in Fig. 5. Mean and range of temperature difference were used for the analysis of distribution patterns.

Mean of soil temperature difference: At 6:00, when the plant coverage was 0%, the mean temperature difference between any two plots (Nn plot and the others) showed positive values (Fig. 5 (a)). The mean was the highest in the Mp_3, while the mean became lower as the planting hole size increased, except in the Mp_{39}. When the plant coverage was larger than 30%, the mean temperature was the lowest in the Mp_{22} plot. This may be a cause of high soil moisture content under the Mp_{22} plot which could reduce soil temperature difference. Teasdale and Abdul-Baki[9] found that soil temperature difference between black polyethylene mulch and hairy vetch mulch decreased due to high soil moisture content. Besides, the mean of temperature difference (average value of all plots) in each the plant coverage was almost the same.

At 15:00, when the coverage was 0%, the mean difference in all plots (Fig. 5 (b) also showed the similar tendency as noted in the 6:00. However, from 20% of the coverage and above, the mean differences in all plots became lower and the order of the mean temperature difference was the highest in the Mp_{39}. The temperature difference was decreased with a decreasing of hole diameter, except in the Mp_{22} plot. The lowest temperature difference was observed in the Mp_{22} plot because of high soil moisture content[12]. Comparing the average temperature among the plant coverage, from 0% to 60%, the mean temperature differences were decreased with the increasing of plant coverage, while no difference was observed in the plots with the coverage between 60% and 80%. Hence, increasing of the plant coverage would decrease the mean temperature difference between the two plots. Suzuki *et al.*[13] reported that soil temperature differences between two plots decreased with the decreasing amount of solar radiation.

Range of soil temperature difference: At 6:00, the ranges of temperature difference of all plots showed the positive values (Fig. 5 (c)). At 0% of the coverage, the lowest range was observed in the Mp_3. This could be a result of high soil moisture content which could increase a heat capacity in the Mp_3. Thus, the temperature of this plot was lower than the others, while in the Nn plot, the heat was easily radiated to the atmosphere[14]. From 0% to 30% coverage, the average of range in all plots was increased with the increasing of the coverage. On the other hand, the range had become lower when the coverage was still increased.

At 15:00, from 0% to 30% coverage, the range of temperature difference of all planting hole diameter was increased with a higher percentage of the plant coverage (Fig. 5 (d)). When the coverage was larger than 30%, the range in all plots remained higher than those in the coverage of 0%. This might be a result of decrease solar radiation owing to the plant canopy[10] while the Nn plot was exposed to the solar radiation.

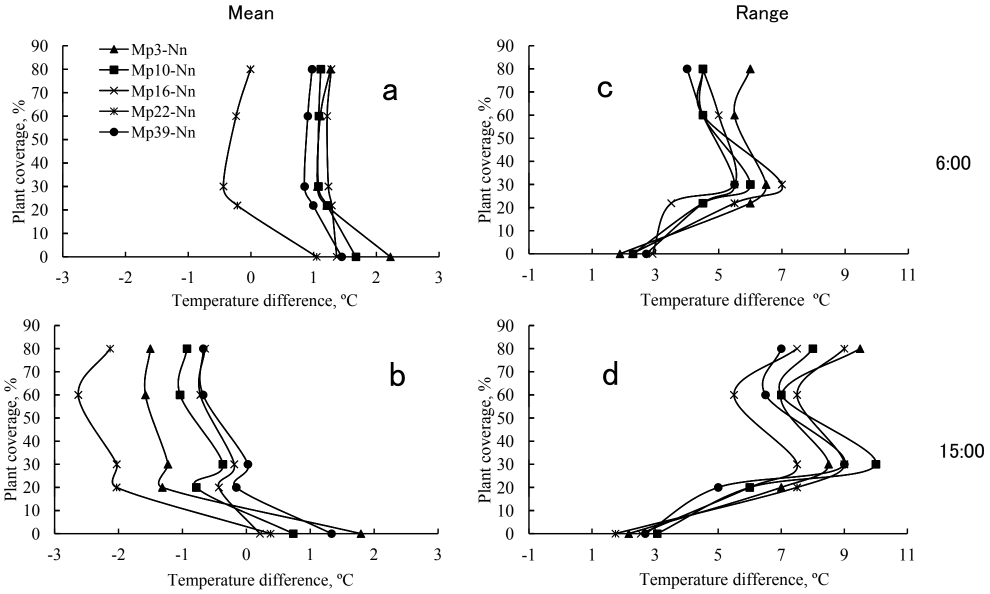

Fig. 5 Relations between plant coverage (%) and soil temperature difference at 10 cm depth from September 8 in 2007 to January 5 in 2008. Mean: Mean of soil temperature difference, Range: Range of soil temperature difference.

3.2.3 Frequency distribution and meteorological factors

Mean and range of temperature difference were used for the analysis of distribution patterns. In order of clarifying the effect of the planting hole and plant canopy on the frequency distribution (criterion variable), a multiple regression analysis was conducted (Table 4). The explanatory variables were the same as those in the sections (3.1.2, 3.1.4).

Mean of temperature diffrence: At 6:00, soil moisture content and the plant coverage were selected in the Mp_{10}-Nn and Mp_{39}-Nn, however, soil moisture suction was not selected in the Np-Nn relationship and the plant coverage was not selected in the Mp_{16}-Nn. The multiple regression coefficient (average = 0.460) of the relationships that had the planting hole was lower than that of the Np-Nn (0.733). This might be because the plant coverage suppressed the amount of solar radiation[13]. Thus, the coefficient of the plots with the plant canopy showed the lower values.

At 15:00, the numbers of the selected explanatory variables were more than that of at 6:00. The plant coverage and soil moisture suction were selected in all plots, except in the Mp_{22} that soil moisture suction was not selected. The coefficients (average = 0.688) in the plots with the planting hole were lower than that in the Np-Nn (0.778).

Range of temperature: At 6:00, the daily mean air temperature and solar radiation was selected in all plots. The average of multiple regression coefficients in every plots with the planting hole was about 23.8% lower than the case of Np-Nn relation.

At 15:00, solar radiation, wind velocity and plant coverage were selected in all mulch plots. However, the plant coverage was the main factor affecting the average of the temperature difference. The presence of plant on the surface can reduce a diurnal range of surface temperatures[13]. Some of incoming solar radiation could be intercepted by the plant surface causing a reduction of the amount of solar radiation reaching the surface. Therefore, the surface temperatures during the day time are uniformly lower under the plant than over a bare soil surface. At night, the outgoing longwave radiation is also partly intercepted by the plant, and it would radiate the energy back to the surface[15].

The mean of soil temperature difference was decreased by the increasing of the planting hole diameter. This tendency was found in both of 6:00 and 15:00 observations. The range of temperature difference was changed by the planting hole, however, a definite correlation was not observed between the range and the planting hole. The plant coverage influenced the mean and range of the temperature difference. The mean temperature difference tended to decrease by the increasing of the plant coverage whereas the range tended to increase.

Table 4 Standard partial regression coefficients in the multiple regression between frequency distribution factor and meteorological factors from September 2 in 2007 to January 26 in 2008.

Distribution factor[1]	Time	Plot[2]	Meteorological factor[3]							Multiple regression coefficient[4]
			Te	Pr	Ia	Um	SmA	SmB	Pc	
Mean	6:00	Np-Nn	−0.410		0.153				0.657	0.733
		Mp_3-Nn		−0.179			−0.250		−0.365	0.502
		Mp_{10}-Nn			0.146			−0.299	−0.350	0.495
		Mp_{16}-Nn		−0.131				−0.314		0.312
		Mp_{22}-Nn	−0.169						−0.519	0.535
		Mp_{39}-Nn	0.252					−0.189	−0.310	0.455
	15:00	Np-Nn	−0.192		−0.218		0.978	−0.992	−0.373	0.778
		Mp_3-Nn				0.118	−0.227		−0.650	0.709
		Mp_{10}-Nn			−0.142			−0.356	−0.575	0.679
		Mp_{16}-Nn		−0.156	−0.404		−0.217	−0.230	−0.453	0.625
		Mp_{22}-Nn	−0.106		−0.220				−0.658	0.713
		Mp_{39}-Nn						−0.272	−0.662	0.715
Range	6:00	Np-Nn	−0.197		0.152				0.749	0.759
		Mp_3-Nn	−0.518		0.489	−0.118			0.267	0.514
		Mp_{10}-Nn	−0.587		0.590	−0.141		0.131		0.535
		Mp_{16}-Nn	−0.598		0.564	−0.113	0.242		−0.351	0.711
		Mp_{22}-Nn	−0.623		0.608	−0.115	0.191			0.583
		Mp_{39}-Nn	−0.475		0.424			0.121	−0.356	0.548
	15:00	Np-Nn			0.194		−1.123	1.042	0.353	0.735
		Mp_3-Nn		0.099	0.668	−0.193		−0.104	0.127	0.718
		Mp_{10}-Nn	0.149		0.669	−0.204		−0.084	−0.169	0.838
		Mp_{16}-Nn			0.677	−0.151			−0.235	0.736
		Mp_{22}-Nn			0.522	−0.206	−0.105		0.194	0.621
		Mp_{39}-Nn			0.649	−0.215			−0.191	0.718

[1] Criterion variables.
[2] Plot symbles were the same as in Table 1.
[3] Explanatory variables.
Notation: Te = daily mean air temperature. (°C); Pr = amount of precipitation (mm); Ia = amount of insolation ($MJm^{-2}day^{-1}$);
Um = daily mean wind velocity (ms^{-1}); SmA = soil moisture suction of A plot (mmHg);
SmB = soil moisture suction of B plot (mmHg); Pc = plant coverage (%).
[4] Adjusted for the degrees of freedom.

4. Conclusions

Soil temperature was depended on the planting hole and the percentage of the plant coverage. The planting hole could affect the ratio of daily range of soil temperature. The average of the ratio was decreased with the increasing of the percentage of the coverage. Soil temperature differences between each plot and the Nn plot at 6:00 were decreased by the increasing of soil temperature in Nn plot. This tendency was observed when the plant coverage was larger than 30%, regardless of the planting hole diameter. At 15:00, the differences showed the same tendency as that at 6:00, however the differences of each pair of plots were larger. Furthermore, the difference was decreased with the increasing of the plant coverage. From the multiple regression analysis, the variation of the temperature difference was depended on air temperature and soil moisture suction.

From the frequency distribution, the means of the temperature difference were affected by the planting hole size and the percentage of the plant coverage. At 6:00, under 0% coverage, the mean was found to be the highest in the Mp_3 plot and be the lowest in the Mp_{22} because of high soil moisture content in the Mp_{22}. From 20% to 80% coverage, the mean of each planting hole diameter showed a small difference. At 15:00, the mean tended to decrease with the increasing of the percentage plant coverage. As for the range, both of 6:00 and 15:00, there was no linear correlation between the range of temperature difference and the planting hole diameter. While, from 0% to 30% coverage, the average of range in all plots was increased with the increasing of the coverage. On the other hand, the range became lower when the plant coverage was remained to increase. However, the range at 6:00 was smaller than that at 15:00 due to the effect by solar radiation.

References

(1) Suzuki, H., D. Shirasu and T. Takemasa: Effects of planting hole of film mulch on soil temperature. *Agricultural Meteorology of Chugoku and Shikoku*, 4, 1-9 (1991).

(2) Khan, A.R., D. Chandra, S. Quraishi and R.K. Sinha.: Soil aeration under different soil surface conditions. *J. Agronomy & Crop Science*, 185, 105-112 (2000).

(3) Anikwe, M.A.N., C.N. Mbah, P.I. Ezeaku, and V.N. Onyia: Tillage and plastic mulch effects on soil properties and growth and yield of cocoyam (*Colocasia esculenta*) on an ultisol in southeastern Nigeria. *Soil & Tillage Research*, 93, 264-272 (2007).

(4) Pongsa-anutin Teerasak: Studies on soil temperature beneath film mulch and plant growth in relation to planting hole. pp.1-128 (2009). [Ph.D. Thesis, Ehime University]

(5) Kwabiah, A.B.: Growth and yield of sweet corn (*Zea mays* L.) cultivars in response to planting date and plastic mulch in a short-season environment. *Sci. Hortic*. 102, 147-166 (2004).

(6) Duangpaeng, A., H. Suzuki, K. Nakanishi, N. Okuda, T. Matsui and Y. Fujime: Effects of canopy type on soil temperature beneath film mulch. *J. Agric. Meteorol*., 58, 23-32 (2002).

(7) Agele, S.O., G.O. Iremeren and S.O. Ojeniyi: Effects of plant density and mulching on the performance of late-season tomato (*Lycopersicon esculentum*) in southern Nigeria. *Journal of Agricultural Science*, 133, 397-402 (1999).

(8) Tanaka, K. and S. Hashimoto: Plant canopy effects on soil thermal and hydrological properties and soil respiration. *Ecological Modeling*, 196, 32-44 (2006).

(9) Teasdale, J.R. and A.A. Abdul-Baki: Soil temperature and tomato growth associated with black polyethylene and hairy vetch mulches. *J. Amer. Soc. Hort. Sci*., 120, 848-853 (1995).

(10) Stathers, R.J. and W.G. Bailey: Energy receipt and partitioning in a ginseng shade canopy and mulch environment. *Agric. For. Meteorol*., 37, 1-14. (1986)

(11) Oke, T.R.: Boundary Layer Climates, p.372. Halsted press. London (1978).

(12) Nachtergaele, J., J. Poesen and B. van Wesemael: Gravel mulching in vineyards of southern Switzerland. *Soil & Tillage Research*, 46, 51-59 (1998).

(13) Suzuki, H., T. Hashimoto and K. Miyamoto: Studies on the microclimate of the mulched row surface. VIII. Effects of canopy and mulching with black polyethylene film on the soil temperature in plastic greenhouse. *Tech. Bull. Fac. Agric. Kagawa Univ*., 34, 129-138 (1983).

(14) Li, F., A. Guo and H.Wei.: Effects of clear plastic film on yield of spring wheat. *Field Crops Research*, 63, 79-86 (1999).

(15) Arya, S.P.: Introduction to Micrometeorology,. p.307. Academic Press, London (1988).

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異なる植穴径のフィルムマルチによる地温と植被率との関係

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要　　　約

本実験の目的は、フィルムマルチ下地温に及ぼす影響をフィルム植穴径と植被率との関係から明らかにすることである。６時地温と15時地温ともに、対照区（裸地）地温が上昇して植被率が高くなるほど各区の地温は低下したが、植穴径による明瞭な差はみられなかった。地温日較差比について各植被率下では、植穴３cmの区（Mp_3）が最も比が小さくなった。また各植被率下の地温日較差比については、Mp_3区以外の区は日平均気温、日射量日総量、日平均風速の３要因が共通して影響を及ぼした。