Micrometeorological Improvement of Paddy Fields by Using Windbreak Nets

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The danger of cool weather damage has been gradually decreasing owing to recent development of rice breeding and cultivation. However, low resistant varieties are inclined to be cropped with little attention to their vulnerability to the damage for the purpose of adopting high-yielding culture of brand and tasty rice, and transplanting of young seedlings is also prevailing. It is necessary to keep up investigation on the prevention of the cool weather damage as the recent tendency of abnormal weather has been continuing.

Observation methods

The observation of cool weather on a paddy field was carried out from June to August in Naganuma, Hokkaido.[2,3]

There were two kinds of windbreak nets: One was made of No. 110 vinylone cheese cloth net (CC) of 1.8 mm mesh and the other was 9 grade polyethylene russell net (PE) of 2.0 mm mesh. They were installed in two successive parallel lines of windbreak nets: The first line nets, CC and PE, were both 2.0 m high with the length of 50 m and 100 m, and the density of 50 and 40%, respectively. The second line net, CC, which was 2.0 m high, was extended over 125 m and was set on the leeward of the first line at a distance of 75 m.** The space between the nets and the ground surface was about 25 cm. There were grasses rather densely grown in the open space under the CC net, while rather sparsely grown grasses in the open space under the PE net.

The wind speeds were observed at the middle height of the 2.0 m height of the nets in the windward and leeward points from the nets with two sets of 3-cup photo-electric anemometers (Makino Ohyosokki Kenkyusho Inc., AF-750S). The wind velocity and its fluctuation were also measured by using a 3-component ultrasonic anemometer-thermometer of 10 cm sound paths (Kaijo Denki Co., Ltd., PAT-321-1).

The turbulent intensity indicates the value of $\sigma/\bar{u}$, where σ is the standard deviation of wind velocity and $\bar{u}$ the mean wind velocity.

The surface temperatures of water (t_w) and leaf-stem (t_l) were measured by an infrared thermometer (Barnes Engineering Co., PRT-5), which has a 0.05°C sensitivity and a 2° field of view.

Results and discussions

1) *Horizontal patterns of relative mean wind speed*

The horizontal patterns of relative mean wind speed ($\bar{u}_r$) at 1.0 m height are illustrated in Fig. 1. The wind speed was reduced significantly in the area at the distance of 1 to 5 H. The distance is expressed as multiples of the net height (H = 2 m), and negative sign denotes windward and positive one leeward, respectively.

The relative wind speeds at 2 and 5 H were 47 and 54% for CC and about 68% for PE

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** On the leeward of the second line net, there was the third line net, but it was not used in the experiment.

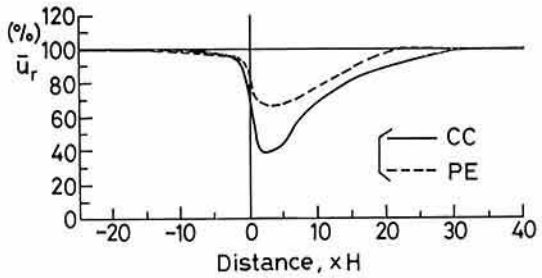

Fig. 1. Horizontal variations of the relative mean wind speed ($\bar{u}_r$) shown in percentage by taking $\bar{u}_r$, at 1 m height at −20 H as 100%
H: the height of the windbreak net (2 m). Negative and positive signs indicate the windward and leeward distances.
CC: Vinylone cheese cloth net
PE: Polyethylene russell net

with a difference about 18%. The effective extent of CC was larger than that of PE, because of the difference of density or porosity. The areas of the relatively strong wind were found at 0.5 m height at 2 H for both nets owing to less dense grasses under the net. On the whole, the protection range of CC was between −5 H and 30 H, and that of PE −5 H and 22.5 H.

2) *Horizontal patterns of upward and downward winds*

Fig. 2 indicates the ratio of the mean vertical wind to the mean longitudinal wind both at the height of 1.0 m ($\bar{w}/\bar{u}$). The oncoming wind for CC was slightly upward. At the immediate windward of the net, it became upward conspicuously with ratio between the components of 7 to 8%. At the immediate leeward of the net, the wind was not downward and the ratio was similar to that of the oncoming wind since the air flew through the net at the same height. However, at 5 and 15 H, the wind became clearly downward. This is corresponding to the result that the ratio was negative around 6 to 7 H for a wooden slat fence.[1)]

The wind changed to an upward wind after about 20 H. The results for PE were similar except at −5 H, where a downward wind was observed at a level of about 70 cm above the

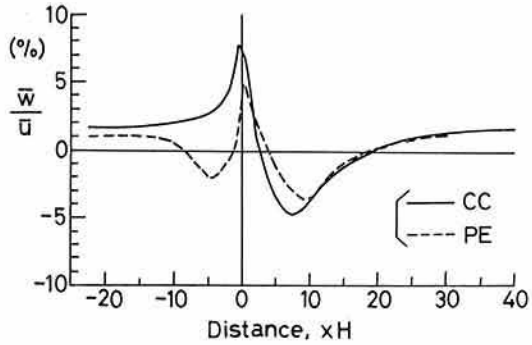

Fig. 2. Horizontal changes of the ratio of the mean vertical wind velocity to the mean longitudinal wind velocity ($\bar{w}/\bar{u}$) for CC and PE windreak nets

canopy of rice because of little grasses at the opening under the PE net.

3) *Horizontal patterns of turbulent intensity*

The horizontal patterns of turbulent intensity ($\sigma/\bar{u}$) for CC and PE nets are shown in Fig. 3. The variation of longitudinal turbu-

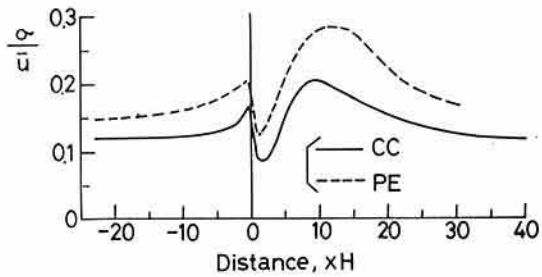

Fig. 3. Horizontal patterns of the turbulent intensity ($\sigma/\bar{u}$) of longitudinal wind velocity fluctuation for CC and PE nets
σ is the standard deviation of wind velocity fluctuation and $\bar{u}$ the mean wind speed

lent intensity for both nets was similar to those of lateral and vertical ones. All the three components increased a little at the immediate windward of the net, decreased rapidly at the immediate lee and started to rise again near 2 H. Their peaks were found around 10 H for CC and 10 to 15 H for PE. This is connected to the differences in the po-

rosity and fluff of net. The results of the present study seem in good agreement with those of other studies[1,7] on the relation between porosity and decrease of wind speed.

The effective area of windbreak was large when the turbulence was small. It could be that the low turbulent intensity at the immediate leeward is an effect of rectification by net and also that an increase at the immediate windward is effected by the depression of wind speed. The turbulent intensities for the nets were smaller than those for windbreak forest and fence at the same height.[5,7] It showed that the magnitudes of standard deviations (σ) for the nets were similar to those for the other windbreaks and that mean wind velocity ($\bar{u}$) is relatively large, i.e., it is considered to be the characteristic of nets.

The value at 30 H for CC almost returned to the windward value at −20 H and that for PE around 20 to 25 H. The manner of variation in turbulent intensity also coincided with that of surface water temperature.

4) *Horizontal patterns of temperatures*

Figs. 4-A and B show the variation of surface water temperature (t_w) and surface leaf-stem temperature (t_l) for CC and PE nets on clear-fine day and cloudy-rainy day, respectively.

(1) On clear-fine day

The region of affected t_w was located from −10 to 15 H and the range from 2 to 7.5 H was significantly affected. The maximum effect was 1.2°C at 5 H for CC and 1.1°C at 3.5 H for PE. The warming effect at 32.5 and 35 H is due to the 2nd net. The depression at 1 H just behind the net, especially for CC was clearly observed as compared with the temperatures at −2.5 and 2 H, sometimes at −20 H. This seems to be mainly attributed to the strong divergence wind blowing through the open space of 25 cm between the net and the ground, i.e., the increment of turbulent transfer by the high wind speed, and the area is shaded by the net.

The variation of t_l was approximately the same as that of t_w. The effect at 2 to 5 H

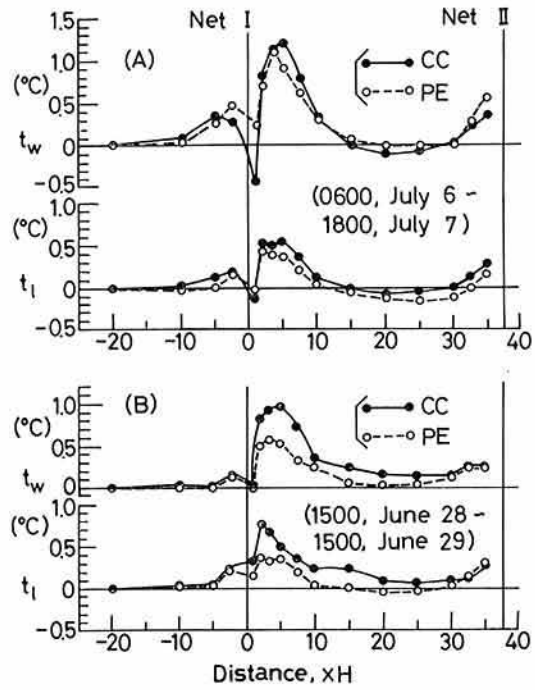

Fig. 4. Normalized horizontal variations of t_w (surface water temperature) and t_l (surface leaf-stem temperature) averaged over 0600, July 6 to 1800, July 7, on clear-fine day (A) and over 1500, June 28 to 1500, June 29, on cloudy-rainy day (B) for 2 kinds of windbreak nets (CC and PE)

was 0.5 to 0.6°C for CC and about 0.4°C for PE with the maxima 0.6°C at 5 H and 0.4°C at 2 H, respectively. The range of affected t_l was from −5 to 15 H, which was less than that of t_w. The t_l values at the area from 15 H to 25 or 30 H were lower than their respective reference (control) values. It is because the average included the data of an opposite wind direction against the prevailing wind in midday for a short period. Thus the favorable effect of windbreak net covered a greater distance on windward side, and a smaller distance on leeward side than those shown in other reports.[4,8]

Generally speaking, it can reasonably be concluded that the effect on t_l reached from −5 to 20 H. The degree of effect of CC was larger than that of PE which showed the

range from 2 to 10 H.

In a few clear and calm nights, t_i in the protected area showed a cooling in comparison with the reference temperature at −20 H for a very short period, but t_w did not. This phenomenon was recognized frequently in upland fields,[6] but rarely in paddy fields.

(2) On cloudy-rainy day

The increase of t_w at 2 to 7.5 H for CC was as large as 0.7 to 1.0°C and was about 0.2°C even at 15 to 20 H. The maxima of t_w for CC and PE were 1.0°C at 5 H and 0.6°C at 3.5 H, respectively. The effect at 2 to 5 H was 0.5 to 0.6°C and at 7.5 to 10 H about 0.3°C. Both windbreaks showed a little effect at −2.5 H, a composite effect in 30 to 35 H windward of the 2nd net and a large depression at 1 H.

The maximum effects on t_i of CC and PE were 0.7°C and 0.3°C at 2 H and the respective effects at 2 to 5 H were about 0.6 and 0.3°C. The t_i value for PE at 10 to 25 H was lower than the reference as a result of the decrease of wind speed by the 2nd net for the periods of reverse winds. The effective ranges were −5 to 20 H and −5 to 10 H respectively for CC and for PE. These ranges were smaller than those reported in other paper.[4] The warming range is generally from −5 to 20 H according to many other studies.

5) *Horizontal patterns of growth and development of rice crop*

Plant length (Pl) and stem number per square meter (Sn) of rice crop are shown in Fig. 5.

(1) Plant length

According to Fig. 5-A and B, Pl on July 5 and August 10 was considerably high at 1 to 5 H and was fairly high at further distance until 15 H. The maxima of Pl on July 5 and August 10 were 42 and 95 cm at 2 H for CC. For PE they were 37 cm at 2 H and 90 cm at 3.5 H. Those were greater by 12 and 18 cm for CC and by 4 and 14 cm for PE than the respective values at the reference points. The effect on Pl extended through 35 H and was enhanced at 30 to 35 H by the 2nd net. A little effect also appeared at −5 and −2.5 H. The effectiveness of CC was much higher than

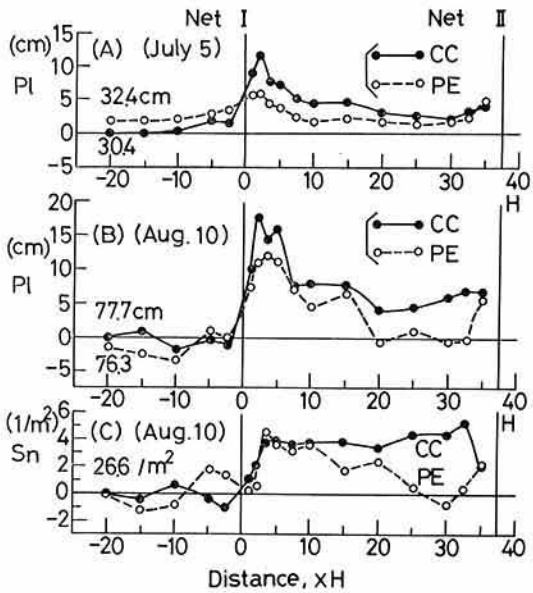

Fig. 5. Normalized horizontal patterns of plant length (Pl) on July 5 (A), Pl on August 10 (B) and stem number per hill (Sn) on August 10 as influenced by the first (I) CC and PE nets and the second (II) CC net

that of PE in the leeward side on July 5 and vice versa in the windward side. It could be caused by a difference in transplanting time.

The pattern of Pl, which does not depress at around 1 H for both of the nets, is not consistent with the depression pattern of t_w at around 1 H (Fig. 4).

This difference may be attributed to the strong divergence wind. The crop near the net was also protected even at the time of opposite wind, because the warmed water was gathered by the opposite wind and stayed around 1 H, and this effect remained during the period when weeds grew very densely under the net. Consequently the rice plants around 1 H were substantially protected during a long period of their growth.

(2) Stem number per square meter

The effect on Sn is shown in Fig. 5-C. The effectiveness of PE was large at 3.5 to 20 H and the maximum was at 3.5 H. Sn at −5 and 35 H was also fairly large. This pattern corresponds to that of Pl for PE. On the other hand, Sn for CC started to increase at

1 H and was approximately constant from 3.5 through 30 H although the windward value was small like Pl. The maximum was located at 32.5 H and showed a little decline at 35 H, as was shown at the immediate windward of the 1st net. This type of variation is different from that of Pl.

As mentioned above, the effect of a CC net was generally in the region from −5 to 30 H and over about 35 H, while that of a PE net from −5 to 20 H. The correlation coefficients between t_w or t_l and Pl or Sn excluding the data at 1 H were 0.7 to 0.9.

The rough percentage of heading on August 10 for CC was 5% at −20 H, 60% at 2 H, 50% at 5 H, 30% at 10 H, 20% at 20 H and 10% at 30 H. The growth stage of rice for CC was about 3 days more advanced than the respective reference values, and exceeded by 1 to 2 days as compared with that for PE in a good protected area.

Concluding remarks

To investigate the micrometeorological modification of cool weather damage and turbulent characteristics by the use of two kinds of 2-m high windbreak nets in a paddy field, the author carried out the micrometeorological observation during the period from June to August in Naganuma, Hokkaido. The main results obtained were as follows:

(1) Reduction of wind speed at 1 m height was found as far as 60 m and 45 m leeward for CC and PE nets, respectively.

(2) The upward and downward winds were obtained at the immediate windward and leeward of the nets and around 10 H, respectively.

(3) It could be that the violent variation of turbulent intensity at the immediate windward and leeward is an effect of rectification by net. The turbulent intensity for the nets was smaller than those for windbreak forest and fence at the same height.

(4) The warming of water and leaf temperatures increased with the increment of solar radiation. The effectiveness of nets was always recognized even under a less favoured condition of cloudy-rainy weather.

(5) The effect of nets was distinctly expressed for the plant length and stem number.

(6) The affected region of windbreak nets was generally from −5 to 20 H for decreasing wind speed, warming temperatures and the increase of growth and development. The affected range for CC net was from −5 to 30 H, and it is greater than that of the PE net because of high density of the CC net.

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