Function of Windbreaks in Hilly Areas

By RYOZO YAMAMOTO*

Faculty of Agriculture, Nagoya University
(Furo, Chikusa, Nagoya, 464 Japan)

Japan, consisting of a group of islands, stretches along the east coast of the Asian Continent, and is characterized by the continental east coast climate. In winter, the strong northwest wind from the Asian Continent blows over the country, while in summer and autumn the typhoon originating from tropical cyclone frequently hits the country every year. These strong winds cause serious damages to crop production. It is therefore desirable or even indispensable to take some countermeasures which can protect farmfields and crops from damages by winds.

The topography of Japan is largely mountainous. The wind is markedly influenced by the mountainous or hilly topography in a very complicated manner. Therefore, the effectiveness of windbreaks in mountainous or hilly areas is not similar to that in flat areas.

In the present paper, results of the agrometeorological study on the relationship between the wind and topography in mountainous areas, function of windbreaks as influenced by the mountainous topography, and sites for constructing effective windbreaks are briefly presented. The study was composed of indoor model experiments and field surveys. Observations on wind behavior in the indoor model experiments were carried out by using topographic models, hot wire anemometers and Billam anemometers. The field surveys were carried out on summits, at slopes, in valleys, and on flat lands, located in the Atsumi Peninsula, Aichi Prefecture, by using Naka-asa type anemometers, streamers, and generated smoke. This locality is characterized by complicated masses of hills.

* Present address: 9-147, Nigoriike, Inokoshi, Idaka, Meito, Nagoya, 465 Japan

Relationship between wind and topography

1) *The wind around a single isolated hill*

When there is an isolated hill in front of the wind, the wind behaves just like the water flowing around an obstacle placed in the water flow (Fig. 1 a). Changes in the wind force around an isolated hill, actually observed in the field, are given in Fig. 2, in which the wind force is expressed by the length of arrows showing wind direction. The wind force was slightly reduced at the windward side of the hill, while it increased to the maximum outside of the both flanks of the hill. As wind vortices were formed behind the hill, as shown in Fig. 1 a, the wind lost its velocity, but it recovered rapidly at some distance from the hill.

2) *The wind in a valley*

In a valley, the wind proceeds into each branch of the valley, irrespective of the main direction of the wind, as shown in Fig. 1 b, and gradually loses its velocity by the influence of the topography. However, in a valley branch which has the same direction as the main direction of the wind, the wind increases its velocity rapidly after recovering from the influences of windward topography. With a high velocity accelerated by contractive topography of valley, the wind blows toward the ridge (Fig. 3).

3) *The wind on a long and narrow hill*

On the hillside the wind blows along contour lines. The wind crossing the ridge blows

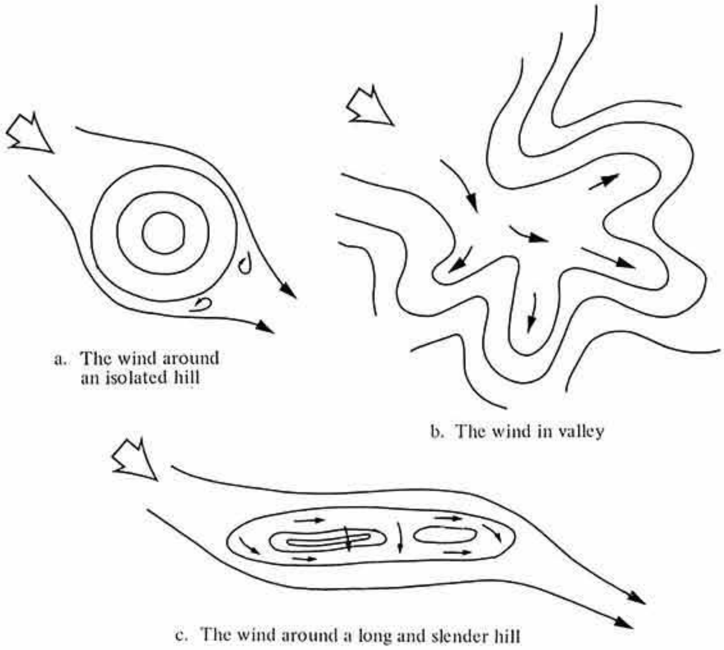


Fig. 1. Relationship between wind and topography

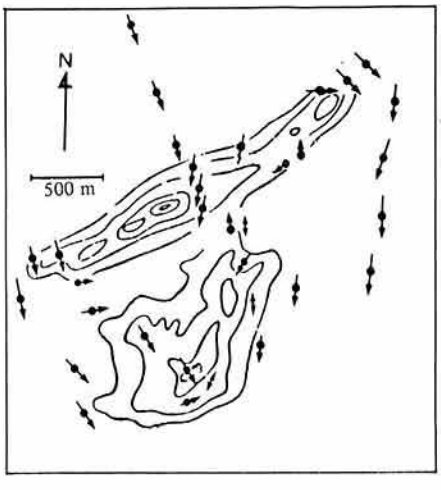


Fig. 2. Direction and force of wind blowing around a hill in flat land

Note: Wind force is expressed by the length of an arrow showing wind direction. The same symbol is used in Figs. 3 and 4.

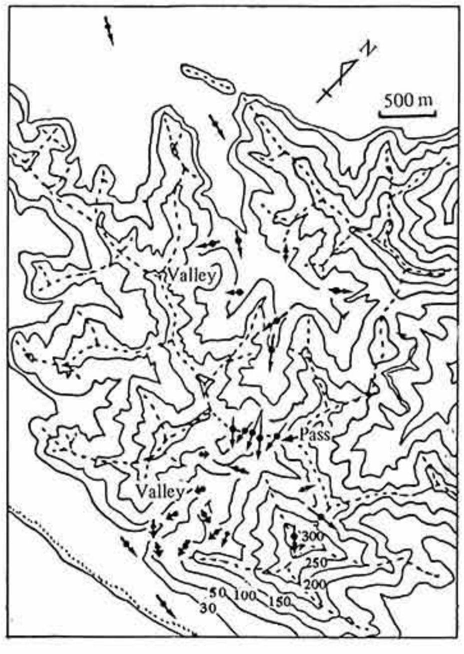


Fig. 3. The wind in a valley

at the right angle to the direction of the ridge line, and is stronger at the top of the ridge than on slopes. When there is a pass on the ridge, the wind is extremely strengthened, and its direction coincides with the direction of the pass (Fig. 1 c and Fig. 4).

Topographic effects on velocity and direction of wind

The above results give good examples of the principle regarding effects of topography on wind. However, it is natural that the direction and velocity of wind vary from time to time. To know the effect of topography on such a varying wind, a study was carried out at selected 10 sites in the western part of the Atsumi Peninsula on a day of strong wind.

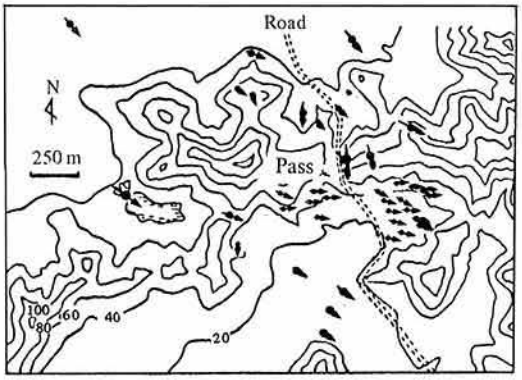


Fig. 4. The wind blowing through a pass

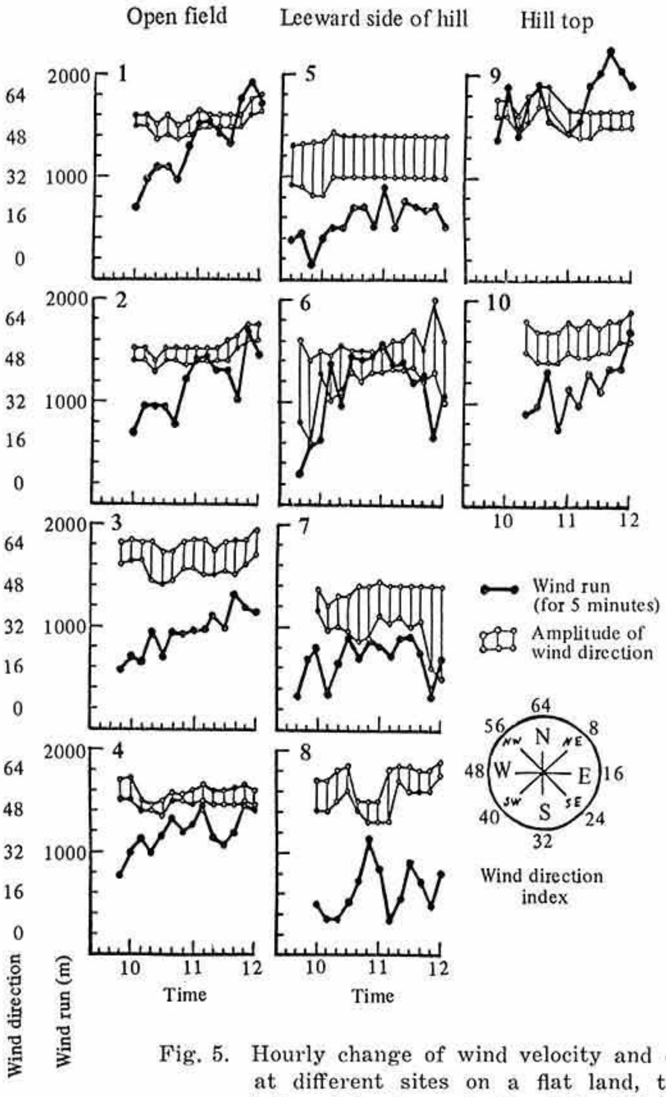


Fig. 5. Hourly change of wind velocity and direction at different sites on a flat land, top of a hill and the leeward side of the hill in a hilly area

In Fig. 5, 4 sites distributed on an open field are arranged according to the distance from the coastal line (site 1 : closest to the coast). Another 4 sites are selected from the leeward side of a hill, and 2 sites at the top of the hill.

The wind at the site 1 represents the wind blowing from the sea. On the open field, the wind was gradually weakened by the friction to the ground surface with many growing plants and various structures. The friction causes irregular motions of the wind, but the direction of wind at the 4 sites was found to be almost unchanged.

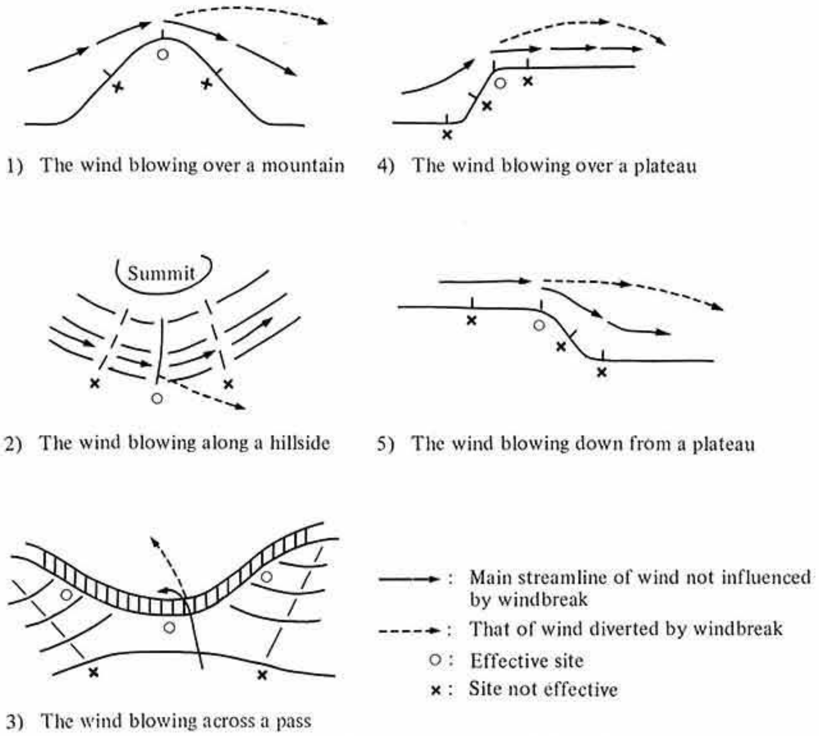
On the contrary, at the leeward side of the hill, the wind velocity was apparently lower than that on the open field and the wind direction was also different from the latter, with a great fluctuation, which shows occurrence of air turbulence (vortices).

At the top of the hill, the wind blow was stronger than on the open field, while the wind direction was similar to that of the wind coming from the sea.

At the site 6 and 7, an interesting phenomenon was observed. Although the wind became stronger with time in the morning, the wind velocity at these sites suddenly decreased at about noon, in response to the change of wind direction from northwest to north. It shows that the topographic effect on local wind is variable, in some cases, depending on changes in main wind, and that it must be examined on the spot.

Effective sites for setting windbreak

Based on the model experiments and actual measurements conducted on the hilly land of the Atsumi Peninsula, effective sites for setting windbreaks (wind shield) are determined. In Fig. 6, the arrows show the main streamline of wind. Arrows of solid line indicate natural steramline (without windbreak), and those of broken line show the main streamline



1) The wind blowing over a mountain
4) The wind blowing over a plateau
2) The wind blowing along a hillside
5) The wind blowing down from a plateau
3) The wind blowing across a pass

Fig. 6. Effective sites for installing windbreaks

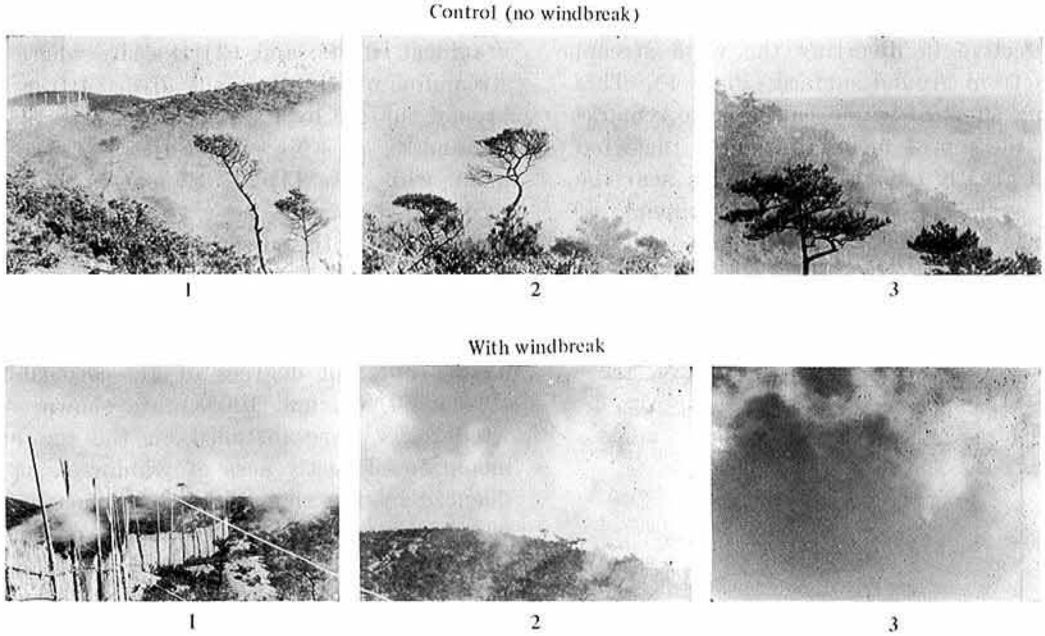


Plate 1. Wind diverted upward by a windbreak installed on the top of a mountain. Wind movement is shown by the movement of smoke and can be traced by following the pictures from 1 to 3.

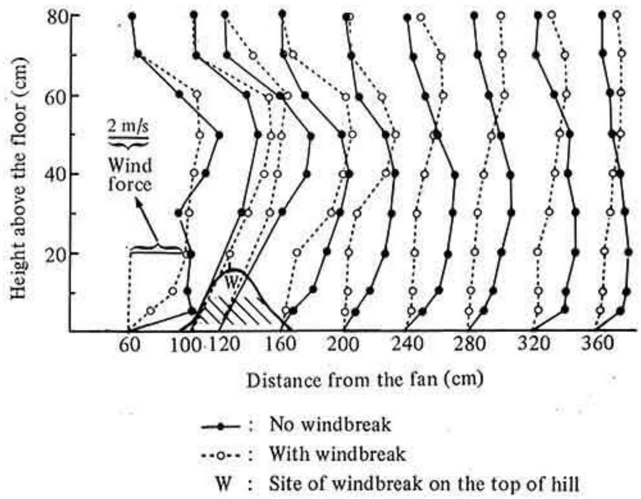


Fig. 7. Vertical profile of wind force as influenced by windbreak (model experiment)

diverted by a windbreak. For example, for the wind blowing over a mountain, a windbreak installed at the top of the mountain is very effective in diverting the wind stream upward from ground surface (Plate 1). This diverting effect of windbreak is more remarkable at the top of mountain, where the wind force is greatly enhanced at a layer near the ground surface as shown by the principle of continuity. The vertical distribution of wind force before and after the installation of a windbreak is given in Fig. 7.

The effective sites for setting windbreak must meet one or both of the following two requirements, i.e. (1) the site where the streamline of wind is constricted by topographical effects, and (2) the site where the streamline of wind is easily diverted from the ground surface by its curvature. Site 1), 2), 3), and 4) in Fig. 6 meet the first requirement, while site 1), 2), 3), and 5) meet the second requirement.

In addition, the effectiveness of windbreak to divert the wind is influenced by density and shape of windbreak. In Fig. 8 the main streamlines of wind diverted by windbreaks having different degrees of air permeability (0, 34, 50, 67, and 100%) are shown. The windbreaks were installed on the top of a mountain. Effectiveness of windbreak as influenced by the shape (cross section) of the windbreak is shown in Fig. 9. Apparently, the slender vertical line with a sharp top is most effective in diverting upward the wind.

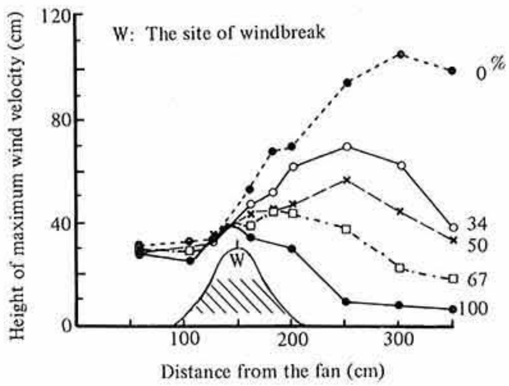


Fig. 8. Relation of air-permeability of windbreak to the effectiveness of windbreak (model experiment)

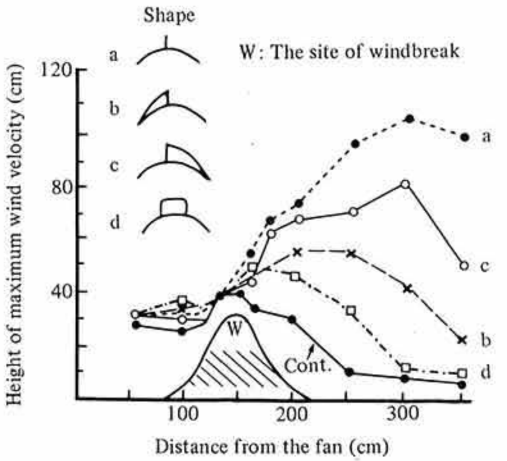


Fig. 9. Relation of shape (cross section) of windbreak to the effectiveness of the windbreak (model experiment)

Conclusion

The velocity and direction of wind blowing near the ground surface at a given location are not always same as those of the main wind blowing over the wide area, because local wind is under the topographic effect. Although the principle of topographic effect on the wind is known, as presented in this paper, actual measurements of velocity and direction of the local wind on the spot are needed in an area with complicated topography.

After the behavior of the local wind is made clear, windbreaks are installed to protect farmfields and crops from the strong wind. To obtain full effectiveness of windbreaks, selection of effective sites for windbreaks and the shape and density of the windbreaks must be taken into consideration, and the windbreaks have to be installed at the right angle to the main direction of the local wind.

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(Received for publication, October 14, 1983)