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Relationship between shelterbelt structure and mean wind reduction

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Abstract

Optical porosity is the important structural feature of two-dimensional (2-D) artificial fences and narrow shelterbelts, but not for 3-D, or wide shelterbelts. To determine the important features of wide shelterbelts, we measured the mean wind speed around eight natural shelterbelts of various widths *W* and total area densities Ad. Our results show that the product of *W* and Ad, but not *W* or Ad alone, is useful for predicting the wind sheltering around fully 3-D shelterbelts. There was a strong negative correlation ($p < 0.01$) between $W \times$ Ad and the minimum relative wind speed. Also, the shelter distance generally increased with increasing $W \times$ Ad.

Keywords: Shelterbelt; Shelter distance; Total area density; Width; Minimum relative wind speed

1. Introduction

The primary effect of shelterbelts is the reduction in wind speed. As a result of this wind reduction, the sheltered zone has a modified microclimate, and greater crop yields generally. Many studies on the effects and aerodynamics of shelterbelts or artificial fences have been done using wind tunnel experiments (e.g. Raine and Stevenson, 1977; Perera, 1981), field observations (e.g. Sturrock, 1969, 1972; Wilson, 1987, 2004a; Nord, 1991), and numerical simulations (e.g. Wilson, 1985; Wang and Takle, 1995a,b, 1996; Wilson, 2004b). As a result, the relationship between the structures and shelter effects on two-dimensional (2-D) artificial fences and narrow shelterbelts are largely understood. The resistance coefficient, kr, is the most important parameter for the aerodynamics of artificial fences and narrow shelterbelts. But it is not easy to estimate it from the structure of shelterbelt directly. So, the optical porosity is used as a surrogate for kr. The optical porosity is closely related to the minimum leeward wind speed (Heisler and Dewalle, 1988). In addition, Naegeli (1946) argued that a dense shelterbelt has a rapid wind speed recovery, and thus, the protection distance is shorter than that from a more porous shelterbelt. However, subsequent studies (Raine and Stevenson, 1977; Wilson, 1985; Schwartz et al., 1995) showed that Naegeli's study overestimated the rate of wind speed recovery for high-density windbreaks. In any case, porosity is the important structural feature, and a useful guide to windbreak function for 2-D artificial fences and narrow shelterbelts (Heisler and Dewalle, 1988).

On the other hand, for 3-D, or wide shelterbelts, the optical porosity, as determined with a photograph, is not a useful parameter because (i) a photograph turns the real obstacle into a two-dimensional plane such that objects in the foreground look larger than those in the background, and (ii) a single photograph cannot show all the paths through which the wind can flow

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Nomenclature

Ai	Total area index (m^2/m^2)
Ad	Total area density (m^2/m^3)
$d70$	Shelter distance which the wind speed U does not exceed 70% of U_0
h	Average tree height
U_0	Average horizontal wind speed at the reference position
U_m	Minimum average horizontal wind speed
W	Width of shelterbelt
X_m	Distance of the minimum wind speed from the leeward edge of the shelterbelt

through the shelterbelt. Therefore, the optical porosity is always less than the real porosity, and the difference is especially large for a wide shelterbelt (Lindholm et al., 1988). As the optical porosity is not a good measure of a wide shelterbelt's effect on wind, researchers have considered the total area density (Ad, m^2/m^3). Ad is obtained by dividing the total area index Ai(m^2/m^2), which is defined as the projected area of leaf, branch, and stem per unit ground area, by the average crown length, because most of the total area of vegetation is in the crown mainly. Thus, Ad is a more suitable and direct index than porosity for determining the density of natural shelterbelt. But Ad is not the only guide to windbreak function for wide shelterbelts. It is known generally that shelter effects are influenced not only by the density but also by the shelterbelt width. For example, very wide barriers (Caborn, 1957; Naegeli, 1964; Grunert et al., 1984) have been reported to be less effective than narrow ones. In addition, the numerical modeling of Wang and Takle (1996) showed that the width W greatly affects the location of minimum wind speed. Thus, although these results are helpful for understanding the effect of width and density on shelter effects, a useful single parameter that determines the effect of a wide shelterbelt (i.e. the equivalent of porosity for narrow shelterbelts) has not been found. In this study, we measured the mean wind speed around natural shelterbelts of various values of W and Ad. We found a strong negative correlation between $W \times$ Ad and the minimum relative wind speed U_m/U_0. The shelter distance $d70$ increased with increasing $W \times$ Ad. These results indicate that $W \times$ Ad Ad gives an approximation to the total area of vegetation encountered along a streamline through the shelterbelt, and proportional to the effective resistance coefficient of shelterbelt. Therefore $W \times$ Ad is a useful surrogate for resistance coefficient of 3-D natural shelterbelt.

2. Experimental

2.1. Site description

We selected isolated shelterbelts that did not have other large objects nearby (e.g. buildings and high trees). But there were roads, berms, and small banks (Figs. 1–7.). These objects are much smaller than the height of shelterbelts. Therefore, we assume that the influence of these objects on wind flow around shelterbelts is not very important. The shelterbelts varied in average height from 5 to 15 m and ranged from 5 to 50 m in width. All sites were located on farmland in the Ishikari plain in the central part of Hokkaido, Japan,

Fig. 1. View from the SSW of the multiple rows of spruces at field site E1.