2000

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Brandle, James R., "Determination of Drag Properties of a Shelterbelt from Measurements and a Numerical Model" (2000). *Papers in Natural Resources*. 1127.
https://digitalcommons.unl.edu/natrespapers/1127

DETERMINATION OF DRAG PROPERTIES OF A SHELTERBELT FROM MEASUREMENTS AND A NUMERICAL MODEL

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1. INTRODUCTION

Porosity or permeability of wind barriers is easy to determine for two-dimensional obstacles that have no depth (e. g. artificial fences). It is, however, much more difficult to estimate the porosity of three-dimensional, living, aeroelastic wind barriers that are inhomogeneous in all three directions and have a wide range of rigidities. An aerodynamic model was used to simulate the mean and turbulent flow in the lee of a shelterbelt. In this numerical model the effect of the shelter is parameterized by use of a drag coefficient and an estimate of the plant surface area per unit volume (Litvina, 1987). The simulated profiles were compared with observed profiles. By varying the product of the drag coefficient C_D by the plant elements surface per unit volume S in the model, a best agreement between simulated and observed profiles is found, which suggests that the product C_D*S is quite reproducible.

2. METHODS

2.1 *Model*

The aerodynamic model used in this study is a 2-dimensional model that solves a system of non-linear equations of velocity (u,w) and turbulent kinetic energy (e). The effect of the barrier is described in the model by a drag force term in the momentum equation and by a corresponding source/sink term in the turbulent kinetic energy (TKE) equation. The horizontal component of the drag force is parameterized as:

$$F_x = C_D S u \frac{\sqrt{u^2+w^2}}{2} \qquad (1)$$

The corresponding source term in the TKE budget equation is given by the product $F_x u$. (For further details see Alkahlil (1994)).

2.2 *Observations*

The data used in this study were collected during two experiments (Sept. 1993 and May 1994) on different shelterbelts (Schmidt et al. 1995). The first one consists of two-rows of green ash, eastern red cedar, and Austrian pine uniformly distributed, with average height (H) and width of 12m and 8m, respectively. The second also is a two-row shelterbelt, but consists of only of red cedar. Its height and width were estimated at 4.5m and 5.5m, respectively.

Vertical profiles of mean windspeed and temperature were obtained in both experiments from two 10-m masts, one upwind and one downwind, along a transect perpendicular to the shelterbelts. The horizontal windspeed data were divided into sets that combined several 5-min runs. Profiles of set averages were used for this study.

2.3 *Determination of drag properties*

We examined differences between observations and simulations of the downwind profiles to find C_DS that best describes the shelter. A measure of the overall departure D of simulations from observations D is obtained by

$$D = \sqrt{\sum_i w_i \, (VS_i - VM_i)^2} \qquad (2)$$

where VS_i and VM_i are the simulated and measured windspeed at level i, respectively, and w_i is the corresponding weight. This weight is introduced for two reasons: 1) more observations were taken at lower levels and 2) departure magnitude does not have the same significance at low and high levels (e. g. at high levels the windspeed is higher than near the surface and larger absolute departure at high levels could be relatively small). Two simulations were used to obtain two wind profiles, the first with $C_D*S=0.4$ (high porosity) and the second with $C_D*S=1.8$ (low porosity). Differences from the two profiles were computed at each observation level. The weights were calculated from

$$w_i = \frac{(\Delta z)_i}{(\delta u)^2_i} \qquad (3)$$

where $(\Delta z)_i = z_i - z_{i-1}$ and $(\delta u)_i = (u_{0.4} - u_{1.8})_i$

3. RESULTS AND DISCUSSION

Data from the first experiment (Sept. 27, 1994) were used to compute the overall sum of departures using Eq. (2) for C_D*S varying from 0.4 to 1.8. The results, with the mast located at 2H downwind are plotted in Fig. 1a. Note that for the 1030-1130set, the minimum of D is at C_D*S=0.6, whereas it is at about 1 for the other sets. The 1030-1130set wind speeds are weaker than for the other sets (Alkhalil, 1994). It is expected that the windspeed influences the drag properties in this manner for conifer shelterbelts (Eimern et al., 1964), as we studied. The procedure was repeated with a shelterbelt that has different aerodynamic characteristics. Two days from the second experiment were used (May 10 and May 13, 1994). For the second experiment the downwind mast was moved for each set. The five sets were recorded at 5H, 6H, 7H, 8H, and 9H. The results are plotted in Fig. 1b and Fig. 1c. These figures indicate that the shelterbelt drag properties are reproducible because all the curves display minima, points at which there is the best agreement between simulations and observations, that are close. The second shelterbelt studied is visually less porous than the first one, and this also shows in Figs. 2 and 3. The minima are between C_D*S = 1.2 and C_D*S = 1.4. The curves also have a tendency to flatten as we move away from the shelter, which suggests that the influence of the shelter diminishes with increasing distances.

4. CONCLUSION

The results showed that for uniform windspeeds the estimates of the product of drag coefficient and plant area per unit volume were quite reproducible.

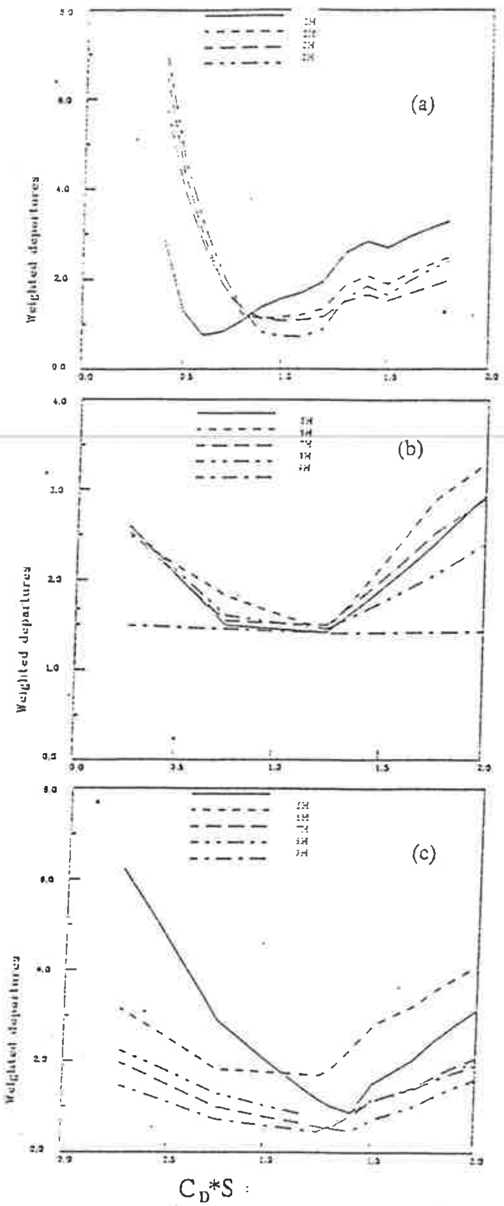

Fig. 1. Weighted departures of simulated from observed winspeeds for (a) a mixed shelter (b) eastern red cedar May 10, and (c) eastern red cedar May 13.

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