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The Effect of Structure on the Drag Force of a Windbreak

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The Effect of Structure on the Drag Force of a Windbreak

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The drag force exerted by a windbreak on wind flow is the primary effect of a windbreak and is related to the structure of the windbreak. Improving windbreak design and management requires a better understanding of the effect of structure on wind flow and the resulting microclimate of the sheltered zone. The drag force of various types of shelterbelts has been determined for model tree shelterbelts in a wind tunnel (Guan et al. 2003) and for both a slat fence (Jacobs, 1984) and an artificial tree barrier (Grant and Nickling, 1998) in the field. Our efforts to model the aerodynamic influence of a windbreak led us to design, build and test a system capable of directly determining the drag force of a full scale shelterbelt. Reported here are the basic design of the system and the results of two studies to determine: (1) the drag of barriers with different amounts of surface area and the same relative distribution within the barrier and (2) the drag of barriers with the same amount of surface area but different vertical and horizontal arrangements of the surface area.

Results: Comparison of two identical, full-leaf barriers indicated little difference between the two drag systems (Fig. 5A). In contrast, a comparison of the drag of a full-leaf barrier with the drag of a barrier composed of only of trunks and top sections (Fig. 5B) showed large differences.

Subsequently, the drag of a full leaf barrier was compared with the drag of barriers with three-fourths leaf, one-half leaf, and one-quarter leaf, respectively. The difference in drag between two barriers became more apparent with decreasing amounts of surface area within other barrier (See Figs. 6A, 6B, and 6C). The drag coefficients of windbreaks with the same relative distribution of surface area are summarized in Fig. 7, increasing as the amount of surface area increases. Note the increase is not linear. The drag force of barriers with the same amount of surface area but different arrangements of the surface area were also measured. The barrier with nine, one-third leaf trees had the same amount of surface area as the barrier with three, full leaf trees (Fig. 8), but with very different arrangements of the surface area. Similarly, the two barriers shown in Fig. 9 also had the same amount of surface area but different arrangements. The nine tree barrier in Fig. 8 had a higher drag force than either the three tree barrier or six tree barrier.

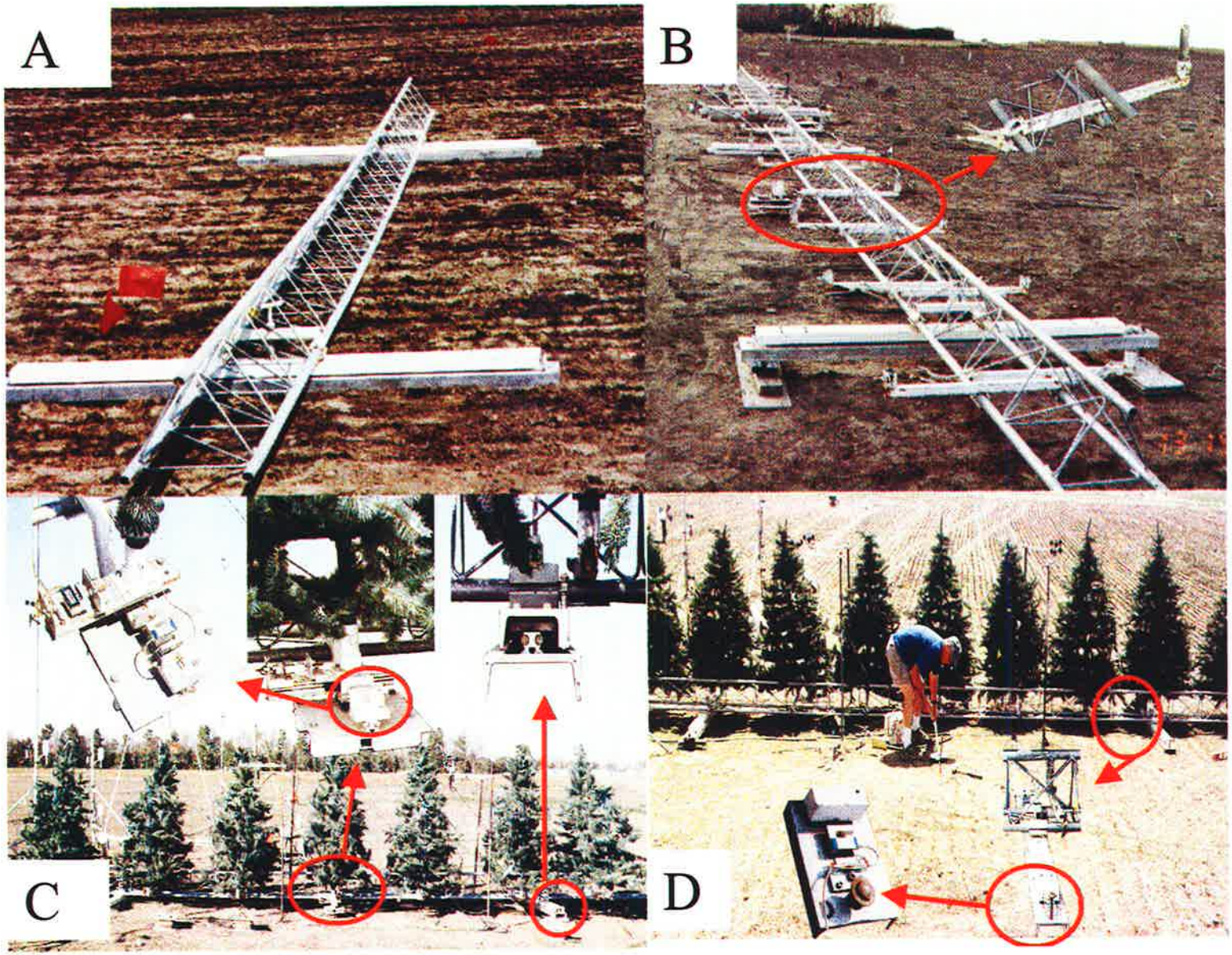
References:

Guan, D.X., Y.S. Zhang, T.Y. Zhu, 2003. A wind-tunnel study of windbreak drag. Agr. For. Meteorol, 118: 75-84.

Grant, P.F., W.G. Nickling. 1998. Direct field measurement of wind drag on vegetation for application to windbreak design and modeling. Land Degradation & Development. 9: 57-66.

Jacobs, A.G. 1985. The normal-force coefficient of a thin closed fence. Boundary-layer Meteorol. 32: 329-335.

Site and Equipment: The study was conducted at the University of Nebraska Agricultural Research and Development Center located near Mead, Nebraska. The site is nearly level with a slope of less than 1%. Wheat stubble was burned off prior to erecting the drag force system (Fig. 1A). The two drag force measurement systems were located side by side, allowing the comparison of the drag force of two windbreak structures simultaneously (same boundary-layer flow conditions). Each system consisted of a 9 m section of triangular support rack resting on two load cell platforms located 1.6 m from each end of the rack (Fig. 1B). Each platform consisted of two pieces of aluminum channel with a Techno-isel double-rail guide located between the channel pieces (Fig. 1C). A Sealed Super-Mini-AJ-100 Load Cell (Interface, Inc.) was located at the leeward end of each platform such that force applied to the barrier would be measured by the load cells (Fig. 1D).



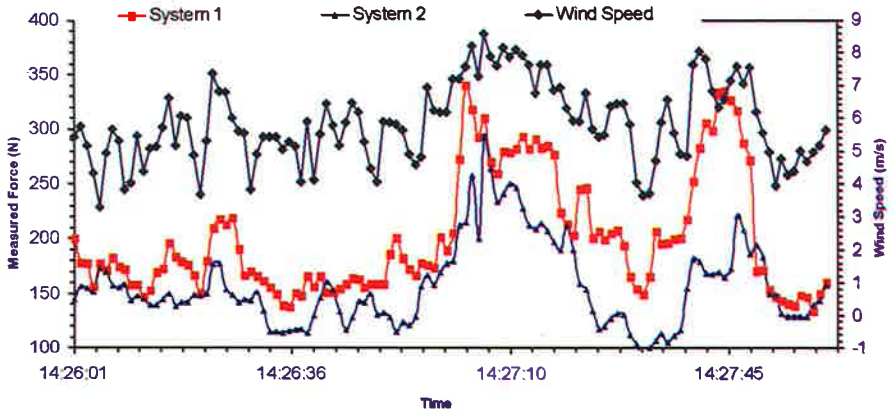


Figure 2. Response of System to wind

Calibration of Sensors: The drag systems respond to is well correlated to the applied force (Fig. 3). The rapid changes in wind speed (Fig. 2). The signal output of the system ratio of the drag force calculated using manufacturers calibration and the readings from the sensors and the amount of force applied to the support frame is approximately 1:1 (Fig. 4).

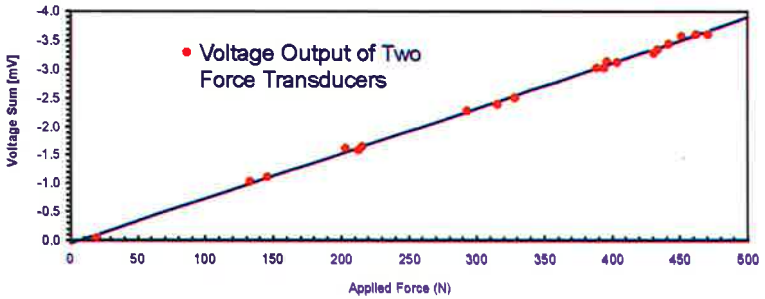


Figure 3. Voltage sums of two force transducers with applied force.

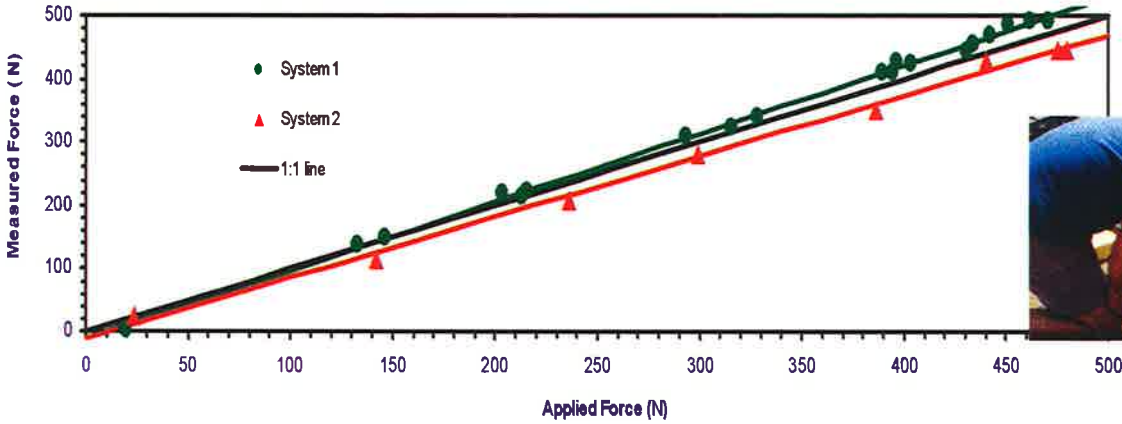


Figure 4. Comparison of measured and applied force.

Applying the force to the frame.

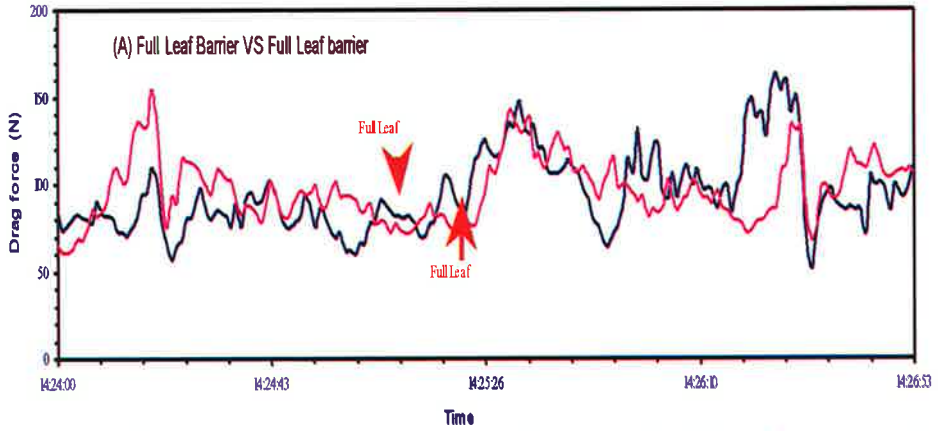
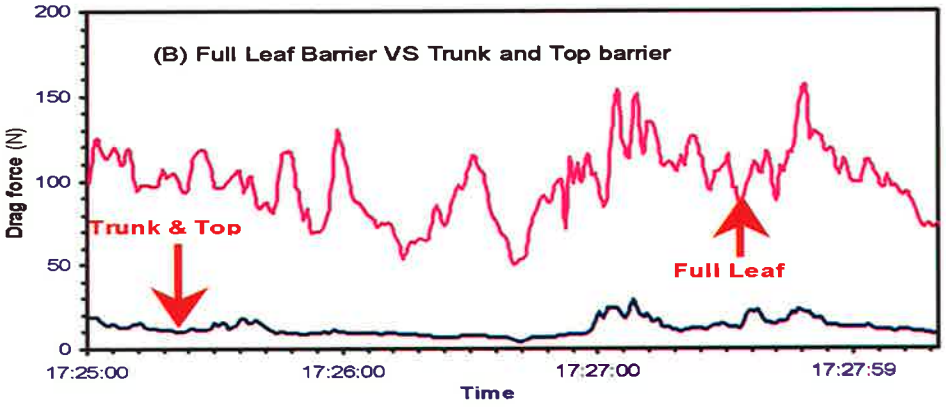


Figure 5. Comparison of drag force of two full-leaf barriers (above) and a full leaf barrier with a barrier of trunks and top sections (below).



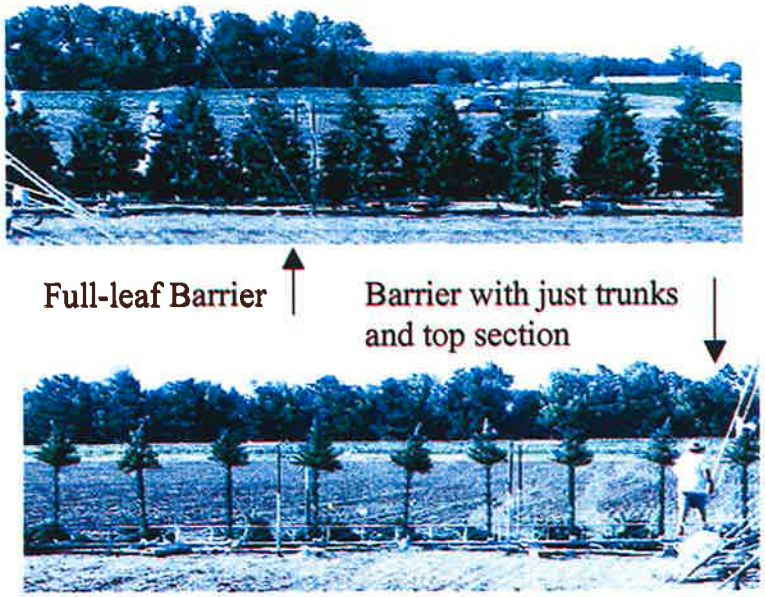
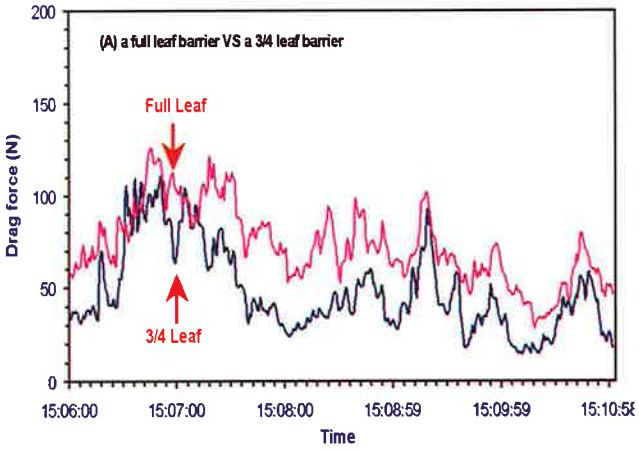
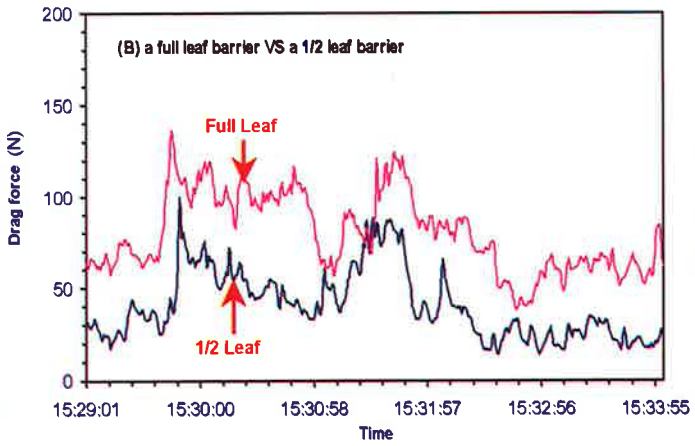
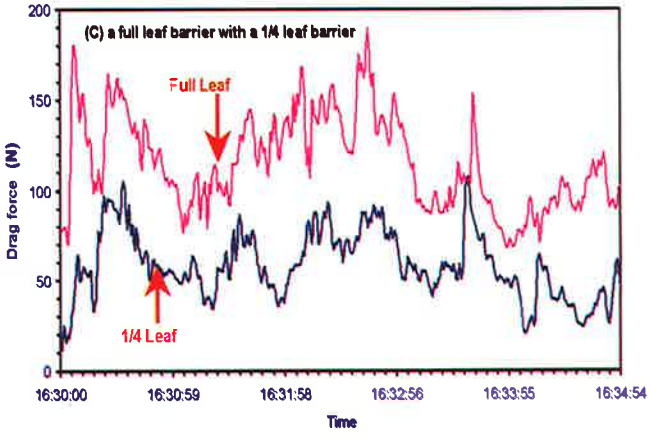


Figure 6. (Below) Drag comparison of a full-leaf barrier with a three-quarter-leaf barrier (A), a one-half leaf barrier (B) and a one-quarter leaf barrier (C)







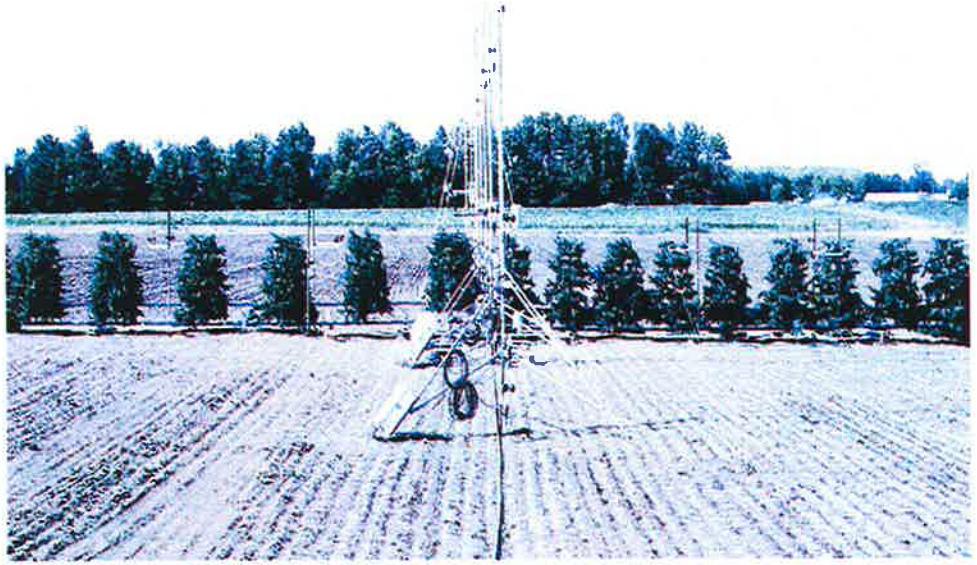


Figure 8. A nine tree, one-third leaf barrier verses a three tree, full-leaf barrier.

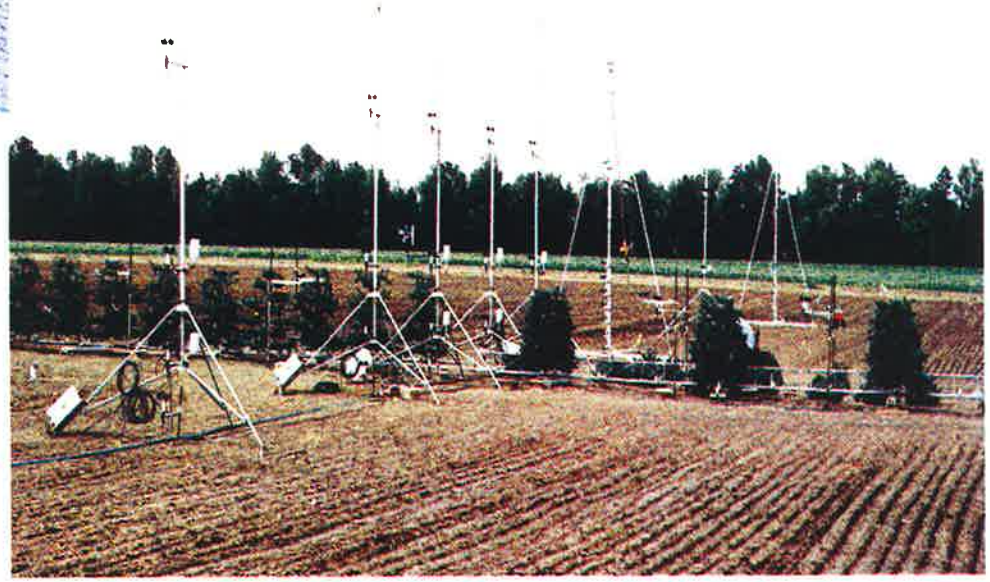


Figure 9. A nine tree, two-thirds leaf barrier verses a six tree, full-leaf barrier.

Summary: The results indicate that the drag force systems are sensitive enough to detect differences in windbreak drag due to changes in windbreak structure and will enable us to test the impact of various designs on windbreak effectiveness. These results also demonstrate that the surface area drag coefficient varies with different surface area densities and different arrangements of that surface area. Finally, the system will provide insights into the development of methods of determining the drag coefficient of natural windbreaks