Simulation of Windbreaks for Wind-Erosion Control in a Wind Tunnel

W.M. Cornelis, D. Gabriels and T. Lauwaerts

Introduction

A "windbreak" is defined as any structure that reduces wind speed (Rosenberg, 1974) and is commonly associated with a natural vegetative barrier against wind. A windbreak can be a single element or a system of elements that through its presence in the airflow reduces the effect of wind speed not only at the system itself but also at a certain windward and leeward distance. The term "windscreen" refers to any artificial barrier, be it synthetic or mechanical, obstructing wind flow. The term "wind barrier" or "fence" can be used to indicate both windbreaks and windscreens.

Wind barriers can control wind erosion by reducing the travel distance of wind across a field. The wind speed can be reduced by more than 50% at a leeward distance of 20 times barrier height H (Skidmore, 1986). The efficiency of a windbreak can be evaluated in terms of the ratio between the mean wind speed of the air current as obstructed by a wind barrier and the mean wind speed of the undisturbed air at a given height and distance windward or leeward from the windbreak.

The objectives of this wind-tunnel study were the simulation and scaling of vegetative windbreaks (stem + canopy) and to evaluate their efficiency in reducing wind speed. Five single-row windbreaks, each with a different stem porosity and canopy porosity were tested. Also windbreaks consisting of different elements (2 and 3 rows) were scaled. Possible zones of deflation and deposition were determined from wind-speed measurements and compared with experimental wind-tunnel data of sand transport.

Materials and Methods

All experiments were conducted in the wind tunnel of the International Centre for Eremology, University of Ghent, Belgium (Gabriels et al., 1997) (see Figure 1) at a free stream wind speed of 6.3 $m \cdot s^{-1}$. Wind speed was measured with 16-mm vane probes, at heights of 2, 5, 10 and 15 cm above the tunnel surface, and at distances of 660, 680, 690, 695, 700, 705, 710, 720, 740, 760, 800, 850, 900, 950 and 1000 cm from the test section entrance.

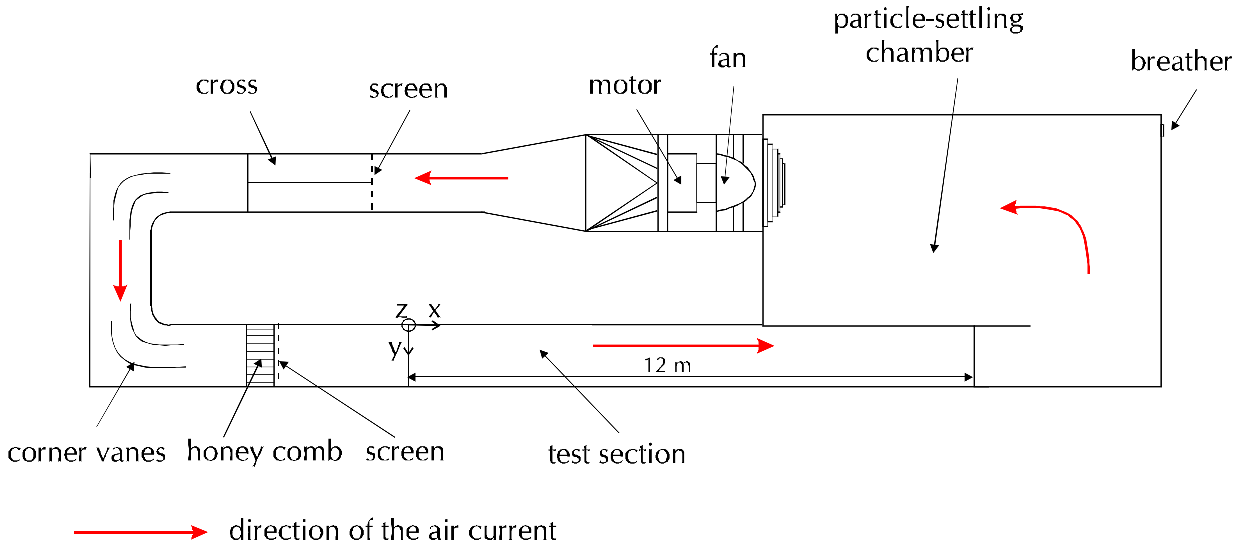


Figure 1 Schematic view of the I.C.E. wind tunnel

A uniform sand strip, 50 cm wide, 2 cm deep and 580 cm long, was placed 420 cm downwind of the test section entrance. The sand used in this experiment was dune sand (Belgian coast). The particle size distribution of this sand is shown in Table 1. Deflation and deposition of sand was determined by measuring the change in height of the sand surface.

Table 1 Particle size distribution (%) of the test sand

fraction					
0 - 2 µm	2 - 20 µm	20 - 50 µm	50 - 100 µm	100 - 200 µm	> 200 µm
0	0	1.1	0.3	33.3	65.3

Vegetative windbreaks were scaled by combining 32%-porosity polyester strips (Cornelis, 1994) (as to represent the canopy) with 9-mm thick wooden sticks (representing the stem). Five single row windbreaks, each with a different ratio in stem and canopy area, were investigated. To determine the influence of number of rows, a single element windbreak (1 row) was compared with a 2-row and a 3-row windbreak. The rows were placed one after the other with alternating stems. In order to keep the measurements within the boundary layer of the wind tunnel, all windbreaks were 10 cm high, except otherwise mentioned. All tested windbreaks are shown schematically in Figure 2.

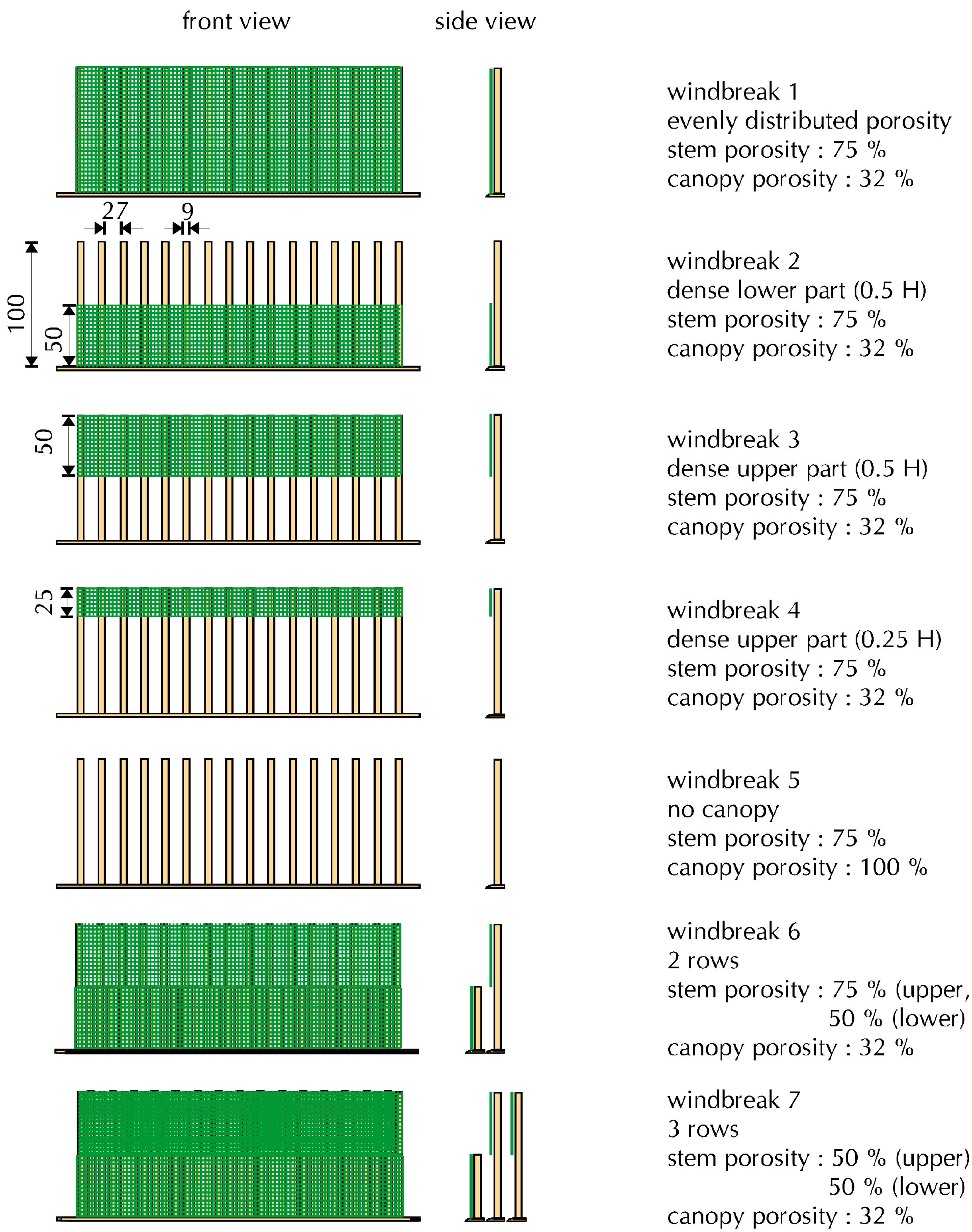


Figure 2 Schematic view of the tested simulated vegetative windbreaks (dimensions in mm)

The efficiency in reducing wind speed was expressed in terms of a Reduction Coefficient Rc_{ij} :

$$Rc_{ij} = 1 - \frac{\bar{u}_{ij}}{\bar{u}_{oij}}$$

where i = height above the windbreak (in barrier height H),

j = distance from the windbreak (in barrier height H),

$\bar{u}_{ij}$ = arimetric mean wind speed disturbed by the windbreak ($m \cdot s^{-1}$),

$\bar{u}_{oij}$ = arimetric mean wind speed in absence of windbreak ($m \cdot s^{-1}$).

The zones of deposition were determined based on earlier observations of Van den Steen (1995) in the ICE wind tunnel, who observed that deposition of the test sand started at wind speeds lower than 3 $m \cdot s^{-1}$.

Results and Discussion

The polyester screen was very effective in reducing wind speed. It had a maximum reduction coefficient *Rc* of 0.99 measured at a leeward distance of 2 H and at a height of 0.5 H. At 8 H and 20 H leeward of the screen *Rc* was still 0.90 and 0.45 respectively (Cornelis, 1994).

When comparing the five single-row windbreaks, the experiments revealed that an evenly distributed (in height) porosity of stem and canopy (windbreak 1) gives the longest sheltering zone (see also Hagen, 1976). At a distance of 10 H the *Rc* was still 0.8. Nevertheless, the *Rc* of a windbreak with a dense lower part (low porosity) (windbreak 2) was higher close to the windbreak, up to a leeward distance of 7 H (see Figure 3). This is due to the reduced shear stress in the flow at the fence top, which quickly diffuses high wind speeds back to the surface (Raine, 1974; Raine and Stevenson, 1977). A porous lower part (windbreak 3 and 4) seemed to be less effective : *Rc* dropped immediately close to the windbreak. This can be attributed to an increased pressure close to the surface. When a canopy was absent, i.e. canopy porosity 100%, the effect on wind speed reduction was very small. The drag force exerted by the windbreak was too low to reduce wind speed more then 10%.

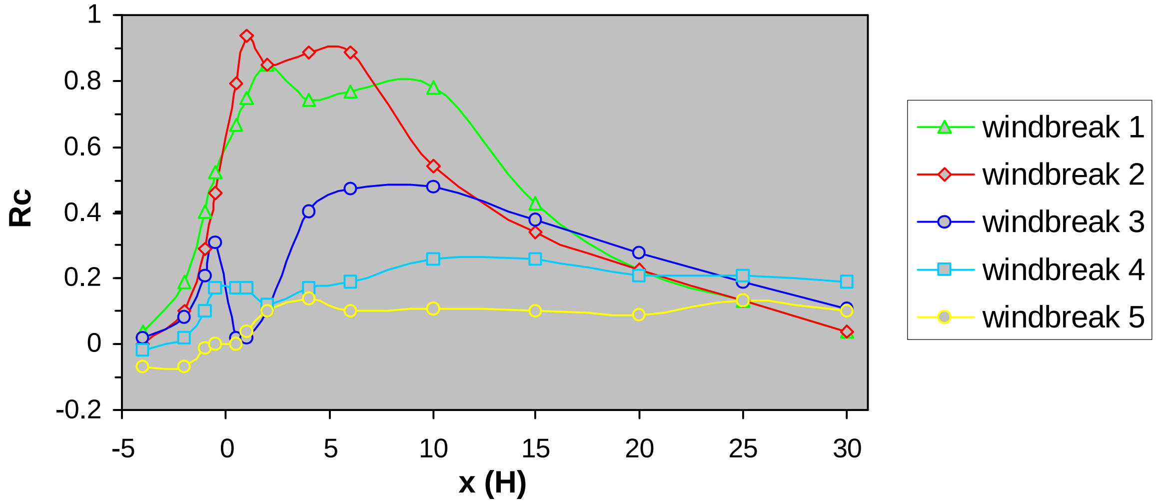


Figure 3 Trend curves of reduction coefficient of single-row windbreaks at a height of *z* = 0.2 H

When increasing the number of rows of the windbreaks, a positive effect could only be observed close to the windbreak (see Figure 4). From a distance of about 10 H on, single-row windbreaks with evenly distributed porosity were most effective in reducing wind speed. The trends observed here are analogous to what can be observed when reducing the windbreaks porosity below an optimum porosity of about 25% (Tillie, 1992; Cornelis, 1994). Although low porosity windbreaks provide a flow of very low wind speed in the near-wake zone (Perera, 1981), upstream conditions are recovered faster, i.e. leeward wind speed tends to increase more quickly than do wind speeds leeward of more porous windbreaks (Skidmore and Hagen, 1970). As the stems of the different rows were mutually alternating, porosity decreased with increasing number of rows.

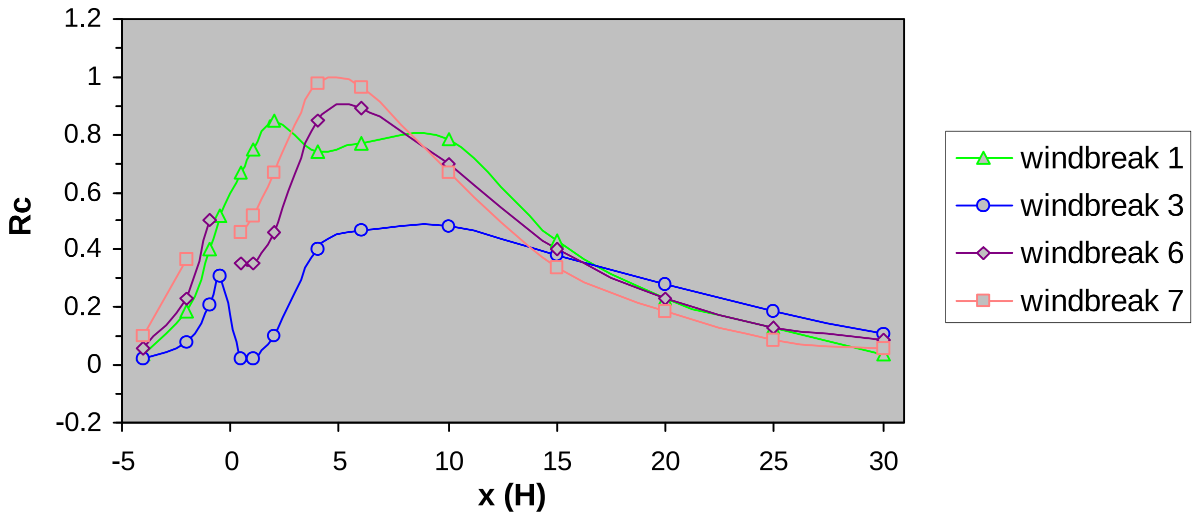


Figure 4 Trend curves of reduction coefficient of single-row and multiple-row windbreaks at a height of *z* = 0.2 H

Finally, in the case of evenly distributed porosity (windbreak 1), sand deposition could be observed at distances from -5 H to 22 H (see Figure 5). The amount of deposition was highest in front of the windbreak (due to entrapment) and up to 5 H leeward of the windbreak. The absence of a dense lower part (windbreak 3) resulted in a zone of erosion leeward of the windbreak (up to 3 H). The experimental data confirmed the graphically determined zones of deposition, i.e. where wind speed becomes less than 3 $m \cdot s^{-1}$ (see Figure 6).

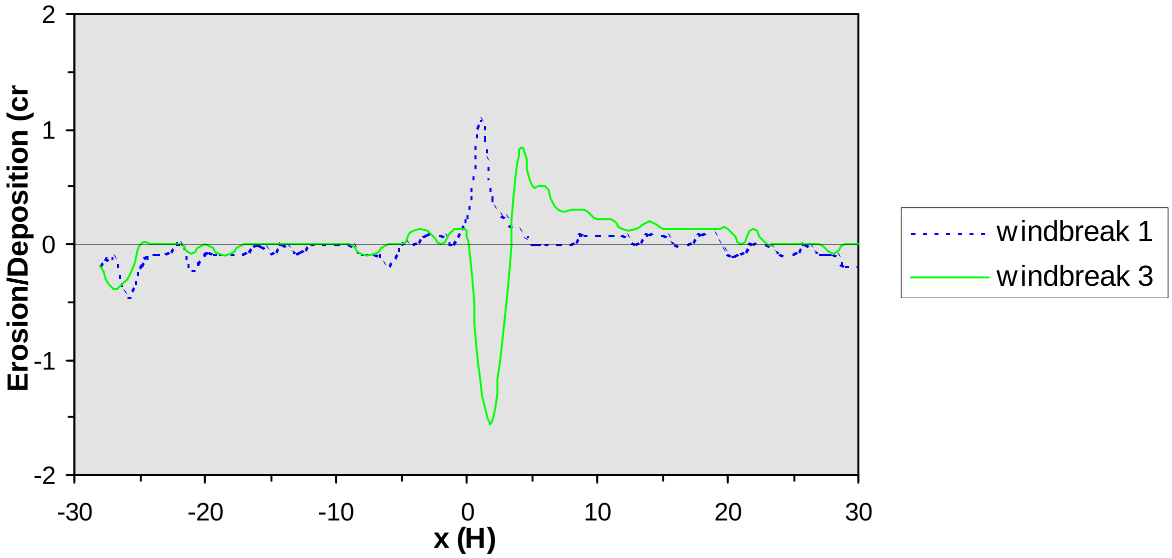
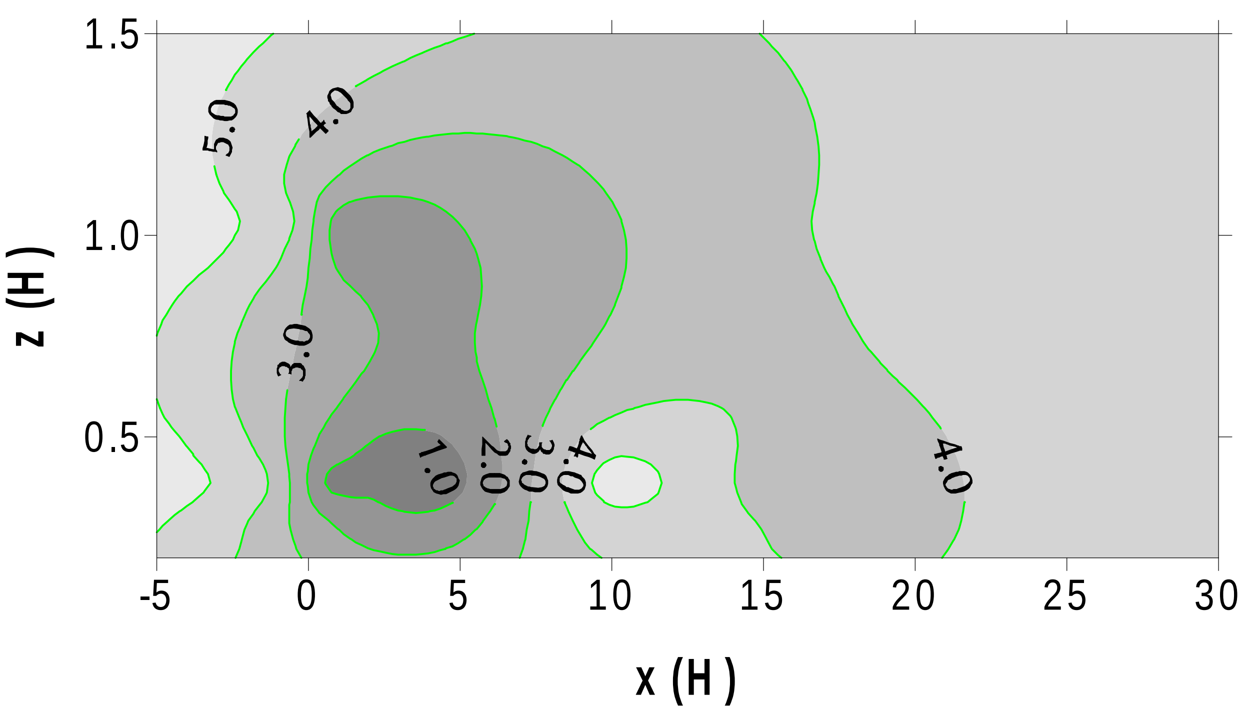


Figure 5 Trend curves of erosion/deposition after 30 min at u_{ref} = 6.3 $m \cdot s^{-1}$

(a)



(b)

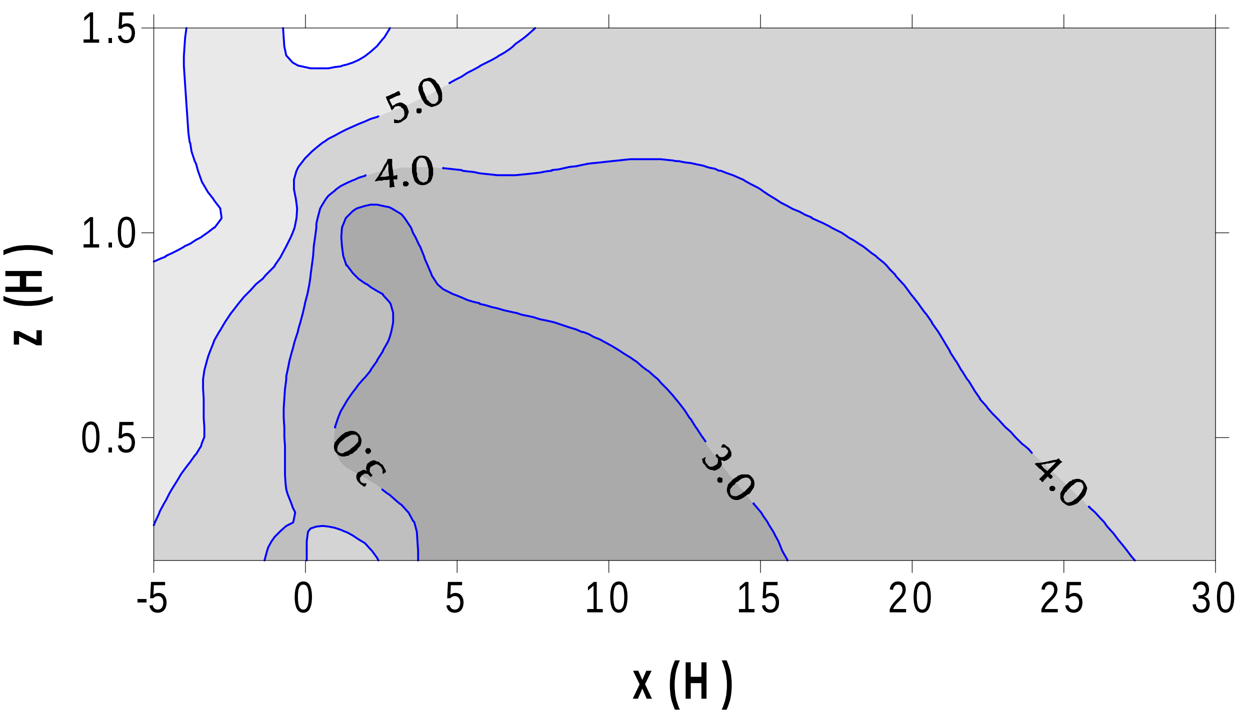


Figure 6 Wind-speed isotachs (m·s^{-1}) for (a) windbreak 1 and (b) windbreak 3

Conclusions

It can be concluded that an evenly distributed porosity of stem and canopy gave the longest sheltering zone, although the absence of a canopy (dense upper part) resulted in a higher *Rc* close to the windbreak. Increasing the number of rows seemed only efficient in terms of reducing wind speed close to windbreak. At longer distances leeward of the windbreak single-row windbreaks were most effective. From the point of view of a soil conservationist or forester, the experiments underlined the importance of a first horizontal layer with shrubs, grasses or hedges. To increase the extension of the protected area a second layer preferably composed of high trees with a long and narrow canopy should be planted. An alternative could be to split the second layer in a layer with small and relatively low trees and a layer with high trees with a wide canopy.

These different horizontal layers could be established within one single row. The type of trees - deciduous or conifer trees - planted has a considerable bearing on the year-round effectiveness and the choice of tree species depends strongly on climatic and soil conditions. Anyhow, indigenous species should always be the first considered for planting.

Finally, it was concluded that deposition zones can be determined graphically from wind speed measurements windward and leeward of the windbreak, when threshold wind speed for deposition of the test sand is known.

References

Cornelis, W.M. (1994). A wind-tunnel study on the reduction coefficient of synthetic windscreens. M.Sc. Thesis. University of Ghent, Belgium. 96 p.

Gabriels, D., W.M. Cornelis, I. Pollet, T. Van Coillie and M. Ouessar (1997). The I.C.E. wind tunnel for wind and water erosion studies. Soil Technology, **10**, 1-8.

Hagen, L.J. (1976). Windbreak design for optimum wind erosion control. In : Shelterbelts on the Great Plains - Proceedings of the Symposium, Great Plains Agricultural Publication, No. 78, 31-36.

Perera, M.D.A.E.S. (1981). Shelter behind two-dimensional solid and porous fences. J. Wind Eng. Indust. Aero., **8**, 93-104.

Raine, J.K. (1974). Wind protection by model fences in a simulated atmospheric boundary layer. In : Fifth Austrasian Conf. On Hydraulics and Fluid Mech., Univ. of Canterbury, Christchurch, New Zealand. 200-210.

Raine, J.K. and D.C. Stevenson (1977). Wind protection by model fences in simulated atmospheric boundary layer. J. Indust. Aero., **2**, 159-180.

Rosenberg, N.J. (1974). Microclimate : the biological environment. John wiley & Sons, New York.

Skidmore, E.L. (1986). Wind erosion control. Climatic Change, **9**, 209-218.

Skidmore, E.L. and L.J. Hagen (1970). Evapotranspiration and the aerial environment as influenced by windbreaks. In : Proc. Of Great Plains Evapotr. Sem., Bushland, Texas. Great Plains Agr. Council, Pub. No. 50, 339-368.

Tillie, M. (1992). Ambiance dans les batiments d'élevage bovin. Session Institut de l'Elevage No. 222.

Van den Steen, J. (1995). Reduction of sand transport by synthetic windscreens : a wind-tunnel study. M.Sc. Thesis. University of Ghent, Belgium. 90 p.