THE EFFICIENCY OF WINDBREAKS ON THE BASIS OF WIND FIELD AND OPTICAL POROSITY MEASUREMENT

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Abstract

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Windbreaks have been used for many years to reduce wind speed as a wind-erosion control measure. To assessment of windbreak efficiency two main parameters are using: height of windbreak (H) and aerodynamic porosity. In South Moravian Region the total area of windbreaks is approximately 1200 ha. For purposes of horizontal profile measurement of wind speed and wind direction windbreaks with various spices composition, age and construction in cadastral territory Suchá Loz and Micmanice were chosen. Windbreak influence on horizontal wind profile was found out in distance of 50, 100, 150 and 200 m in front and behind windbreak in two-meter height above surface. For the optical porosity measurement the ImageTool program was used. The wind field measurement results of windbreak in Suchá Loz cadastral shows limited effect of windbreak on wind speed. The windbreak is created mainly by Canadian poplars (*Populus × canadensis*). In dependence on main species foliage stage the effect of windbreak was obvious on leeward side to distance of 100–150 m (c. 5–7 H). Average optical porosity of windbreak in Suchá Loz was 50% (April). Reduction of average wind speed was about 17% maximally in this stage. Optical porosity was 20% and wind speed reduction was about 37% during second measurement (October). The second monitored windbreak (Micmanice) had a significant influence on wind speed even to the maximal measured distance (200 m, c. 14 H). This windbreak created mainly by *Acer sp.* and *Fraxinus excelsior* reduced the wind speed about 64%. During first measurement (May) the optical porosity of 20% and maximal wind speed reduction of 64% were assessed. For optical porosity of 21% (October) the wind speed reduction was about 55%. Close relation between optical porosity and wind speed reduction was found out by statistical evaluation. Correlation coefficient regardless locality for distance of 50 m was –0.80, 100 m –0.92, 150 m –0.76 and for distance of 200 m –0.63.

windbreak, optical porosity, wind erosion, wind speed, air circulation, phenological phases

Meteorological dictionary (SOBÍŠEK *et al.*, 1993) defines windbreak as belt formed by trees and shrubs for protection of given area against harmful effects of wind. The windbreak function can perform both its particular component and whole suitable proposal system of these components whereas effect shows not only in the windbreak but mainly on its windward side and yet more on leeward. In the Anglo-American special literature categories shelterbelts fulfilling many functions in landscape and windbreaks with priority antideflationary function are relatively strictly differentiated. Shelterbelts are de-fined as wider multirow, species diverse kind of trees and shrubs and windbreak as one to two-row line tree vegetation with monotone species composition (TRNKA, 2000). In our conception the shelterbelts and the windbreaks fade into one another. Generally it deals with variously wide belt of trees and rough oriented plumb on dominant wind direction with erosion control and soil-protective function.

The ability of a windbreak to meet a specific need is determined by its structure: both external structure, width, height, shape, and orientation as well as the internal structure; the amount and arrange-

ment of the branches, leaves, and stems of the trees or shrubs in the windbreak (BRANDLE, HODGES and ZHOU, 2004).

Windbreaks have been used for many years to reduce wind speed as a wind-erosion control measure. However, there is not clear answer yet on what should be the optimal design for windbreaks. On the basis of windbreak testing (each with different stem and canopy porosity and number of rows) on their efficiency in wind-speed reduction, subsequently mentioned conclusions were found out. Evenly distributed porosity of stem and canopy resulted in the longest protected area. Dense lower parts were more efficient than more porous lower parts. Erosion was almost not observed in the case of a barrier with evenly distributed porosity. The absence of a dense lower part resulted in an excessive zone of erosion behind the barrier (CORNELIS *et al.*, 2000).

In term of permeability and efficiency windbreaks classify into wind porous, wind medium porous and non-porous (ABEL *et al.*, 1997). To assessment of windbreak efficiency two main parameters are using: height of windbreak (H) and aerodynamic porosity. Windbreak influence extends from 5 H in front of windbreak (windward) and 30–35 H behind the windbreak (leeward). The minimum wind speed is achieved in the near lee, at distances around 4 H–6 H. In a wind tunnel CORNELIS *et al.* (2000) tested the influence of single-row a two- and three-row barrier on their efficiency in wind-speed reduction and wind erosion intensity. Two- and three-row barriers were more efficient in terms of wind-speed reduction between 3 and 8 H. At higher distances, single-row barriers resulted in higher wind-speed reduction. WAN-MENG *et al.* (2005) found out a significant correlation between windbreak porosity, number of rows and row spacing.

The aerodynamic porosity of the windbreak determines the ratio between airflow that passes through the barrier pores ("through-flow") and airflow that diverges over the barrier ("diverged-flow"). It is impractical, at least throughout the landscape, to physically measure the aerodynamic porosity of natural tree windbreaks. Porosity is therefore usually approximated by the measured optical porosity (LOEFFLER, GORDON and GILLESPIE, 1992). Besides windbreak height and porosity, the actual form of the wind speed curve depends on other important characteristics of the airflow-windbreak system. These are the characteristics, such as wind speed, wind direction, turbulence intensity, and atmospheric stability, and external windbreak properties, such as windbreak shape, width, and length (HEISLER and DeWALLE, 1988; VIGIAK, 2003).

Windbreaks only don't effect on erosion process, but also affect microclimate of near surroundings – temperature and air moisture, evapotranspiration, soil temperature etc. (LITSCHMANN and ROŽNOVSKÝ, 2005). On the basis of windbreak influence to the yield SUDMEYER *et al.* (2002) described two distinct areas in the lee of windbreaks. In distance of 3–5 times the windbreak height (H)

a zone of reduced crop yield (competition zone), in distance of 15–20 H a zone of unchanged or improved yield extending (sheltered zone). Yield between 1 and 20 H was less than unsheltered yield in years with average rainfall, similar to unsheltered yield in years, or areas, with low rainfall and higher than unsheltered yield if the unsheltered crop was subjected to sandblasting

In South Moravian Region the total area of windbreaks is approximately 1200 ha. Quickly growing trees were used for their outplanting in 50th years so liveness of windbreak is ending at present time. From this reason it is necessary to approach expeditiously to their regeneration. There is a dominant north-west and south-east air circulation with certain abnormalities in particular parts of year in South Moravia. On a local scale it happens to significant affecting of circulation directions by terrain configuration. That is why it's often difficult to use underlay from the nearest climatological station for evaluation of importance of concrete windbreak (PODHRÁZSKÁ *et al.*, 2007). On monitored windbreaks ambulatory measurement of vertical and horizontal wind profile was realized. The measurement was situated to period when arable land is the most endangered by wind erosion, it's out of main vegetative period of crop-plants. Seeing that monitored windbreaks are formed of deciduous trees, their phenological assessment with a view to erosion control function carried out.

MATERIAL AND METHODS

Characterization of selected areas

For purposes of horizontal profile measurement of wind speed and wind direction windbreaks in cadastral territory Suchá Loz and Micmanice were chosen.

Suchá Loz

Windbreak in cadastral territory Suchá Loz has W-E orientation. Its width is 4 m and height is c. 22 m. It is created by two layer whereas upper level is consists of two rows of mature Canadian poplars (*Populus × canadensis*). Its treetops are largely connected. In bottom layer younger individuals of Pedunculate oak (*Quercus robur*) and Small-leaved lime (*Tilia cordata*) with disseminated individuals of European ash (*Fraxinus excelsior*) occur. In shrub etage ididivuals of European spindle-wood (*Eonymus europaeus*), Red dogwood (*Swida canguinea*), Dog-rose (*Rosa canina*) and Single-seed hawthorn (*Crataegus monogyna*) are represented. Sporadically groups of fully connected individuals of Common black thorn (*Prunus spinosa*) occur.

Micmanice

This windbreak has SSW – NNE orientation, its width is 7 m and height is c. 14 m. It is composed of all-aged, well-connected wood species. Individuals of Ash-leaved maple (*Acer negundo*), Sycamore maple

(*Acer pseudoplatanus*), Norway maple (*Acer platanoides*) and European ash (*Fraxinus excelsior*) create main level. In shrub layer Common pea shrub (*Caragana arborescens)* is expressively represented. Sporadically European elder (*Sambucus nigra*) and Common privet (*Ligustrum vulgare*) occur.

Applied technics of measurement

Characterization of the sensors

Measurement of wind speed in various heights was taken ambulatory by the help of set with mobile anemometers type W1 and W2 made in firm Tlusťák. Sensors W1 use rotary vane cross piece for measurement of wind speed. Sensing of cross speed is done optoelectronic and to next elaboration it hand over in digital form. Sensors W2 are moreover equipped with rotary vane direction indicator for measurement of wind direction. Data are saved to datalogger HOBO.

Methodics of measurement

Methodics of wind speed measurement

The term of measurement was chosen with regard to air circulation direction in day of measurement so that wind blow upright on monitored windbreak. Windbreak influence on horizontal wind profile was found out in distance of 50, 100, 150 and 200 m in front and behind windbreak in two-meter height above surface. Measurement interval was 5 sec. On opposite side of windbreak one comparative sensor concurrently measures in distance of 150 m from windbreak.

Methodics of optical porosity measurement

For the optical porosity measurement the Image-Tool program was used. ImageTool is a free image processing and analysis program for Microsoft Windows. ImageTool can analyze gray scale and color images. Image analysis functions include gray scale measurements (point, line and area histogram with statistics).

In date of wind field measurement set of windbreak photos from the same place were always taken by digital camera. Methods of processing of chosen photos for assessment of optical porosity consist in their segmentation to particular squares (grids), whereas their count was given by size of windbreak on appropriate photo. In most of cases at least 14 column and 5–8 rows were evaluated. For each of these squares optical porosity was determined. It is necessary to convert each square to shades of grey (255 shades), because optical porosity is expressed as share of white points to their total count in given photo cut. It is suitable modify contrast and brightness of photo so that gaps among vegetative components of windbreak distinguish before converse to shades of grey. During the converse of photo from shade of grey to black and white points it is needed to work with its histogram and to determine border which create dividing line between black and white color, so to distinguish the points, which represent flora and which represent background.

RESULTS AND DISCUSSION

Measurement in Suchá Loz, 18th April 2007

All wood species of the windbreak in Suchá Loz were not wholly foliaged in the term of measurement yet. With regard to the windbreak construction (two-row windbreak) its influence on wind reduction was minimal too. Average wind speed was reduced only about 17% and maximum wind speed (wind blast) about 28% (Tab. I).

I: *The influence of windbreak on wind speed on the leeward, Suchá Loz, 18th April 2007*

	L 50 m	L 100 m	L 150 m	L 200 m	W 150 m
Average wind speed	3.33	3.50	3.98	4.05	4.02
%	83	87	99	101	100
Maximum wind speed	7.60	6.41	7.78	8.31	8.89
%	85	72	88	93	100

Note to table: L 50 m etc. = measurement on leeward side of windbreak in distance of 50 m from windbreak.
W 150 m = measurement on windward side of windbreak in distance of 150 m from windbreak.
Average and maximum wind speed are introduced in m.s $^{-1}$ in all tables of this contribution.

1: *Windbreak in Suchá Loz, 18th April 2007*

Measurement in Suchá Loz, 20th October 2007

The windbreak in cadastral territory Suchá Loz was partially, sporadically foliaged in term of measurement. Results of horizontal wind profile measurement are in Tab. II. Analysis of results of horizontal measurement demonstrated wind speed reduction in 50–100 m behind windbreak (34 and 37% in evaluation of average speed) with rapid increase in longer distances.

II: *Influence of windbreak on wind speed on the leeward, Suchá Loz 20th October 2007*

	L 50 m	L 100 m	L 150 m	L 200 m	W 150 m
Average wind speed	2.18	2.07	2.81	3.22	3.31
%	66	63	85	97	100
Maximum wind speed	4.63	3.74	5.94	6.29	6.76
%	68	55	88	93	100

2: *Windbreak in Suchá Loz, 20th October 2007*

Measurement in Micmanice, 4th May 2006

Part of wood species forming the windbreak in Micmanice was not foliaged yet, but with regard to species diversity and width of windbreak it happens to reduction of average wind speed on leeward side about 64% and windbreak influence was perceptible in maximum distance of 200 m (Tab. III).

III: *Influence of windbreak on wind speed on the leeward, Micmanice, 4th May 2006*

	L 50 m	L 100 m	L 150 m	L 200 m	W 150 m
Average wind speed	2.45	3.13	5.04	4.99	6.83
%	36	46	74	73	100
Maximum wind speed	5.13	6.93	11.03	8.41	11.04
%	46	63	100	76	100

3: *Windbreak in Micmanice, 4th May 2006*

Measurement in Micmanice, 12th October 2006

Wood species were already partly defoliated in Micmanice 12th October 2006. Despite it the windbreak effect considerably demonstrated even in distance of 200 m behind the windbreak. Average wind speed reduction reached up to 55% (Tab. IV).

IV: *Influence of windbreak on wind speed on the leeward, Micmanice, 12th October 2006*

	L 50 m	L 100 m	L 150 m	L 200 m	W 150 m
Average wind speed	1.92	2.39	2.53	2.90	4.29
%	45	56	59	68	100
Maximum wind speed	5.21	5.62	5.78	4.99	10.12
%	51	56	57	49	100

4: *Windbreak in Micmanice, 12th October 2006*

Evaluation of windbreak effect

The wind field measurement results of windbreak in Suchá Loz cadastral shows limited effect of windbreak on wind speed. Main species (*Populus × canadensis*) is fully foliaged in season of low risk of wind erosion (there is a vegetation cover in the field which protects the soil). Early defoliation (from the beginning of October) decreases protective windbreak effect during autumn months when there is no vegetation cover in the field any more. The windbreak influence is also limited by absence of middle and lower bush level. In dependence on main species foliage stage the effect of windbreak was obvious on leeward side to distance of 100–150 m (c. 5–7 H).

LI *et al.*, 2003 investigated the soilecological effects of a 23-year old poplar (*Populus simonii*) on wind speed, soil erosion reduction, atmospheric dust retention etc. Poplar shelterbelt loses its functions against wind at a distance of about 12-fold tree height in leeward side. Maximal effective wind-preventing range of the poplar forest is about 150 m.

The results of ZHANG *et al.* (2003) measurement showed that the daily mean wind velocity at 2 m height was reduced by 18.3 and 31.6% in the distance of 6 and 3 H in windward side, 66.1% in the center of shelterbelt, 66.0% tightly behind shelterbelt and 62.3 respectively 45.2% in distance 6 and 8 H from forest edge *Populus simonii* of the leeward side. They assessed the significant positive relationship between leaf area index of the forest and monthly declining index of mean wind speed. The daily wind erosion rates of soil surface in observation sites were reduced by as much as 85.2% to 99.9%, in comparison with the control site.

The second monitored windbreak (cadastral territory Micmanice) had a significant influence on wind speed even to the maximal measured distance (200 m, c. 14 H). This windbreak is created mainly by *Acer sp.* and *Fraxinus excelsior* reduced the wind speed about 64%. The influence on wind field was significant even during partly foliation. Main reason is the windbreak construction – multi-row windbreak, medium porous to non-porous (classification by ABEL *et al.*, 1997) with width of 7 m. High density together with relatively long vegetation period ensure the soil protection even during erosive critical periods. Using of *Acer*, concretely *Acer negundo* is recommended for instance by HERMAN, STANGE and QUAM, 1996.

### Influence of windbreak optical porosity on air circulation

CORNELIS and GABRIELS (2005) conducted a wind-tunnel study of the total wind-velocity reduc-

tion coefficient of windbreaks with a porosity ranging from 0 to 1 m².m⁻². A porosity of 0.20–0.35 m².m⁻² in terms of wind-velocity reduction was determined as optimal. With regards to the distribution of porosity with height, an evenly distributed porosity of stem and canopy resulted in the longest protected area, i.e. the area where the wind-velocity reduction is more than 50%.

Average optical porosity of windbreak in Suchá Loz was 50% (April 18th 2007) – only minimal foliage. Reduction of average wind speed was about 17% maximally in this stage. Optical porosity was 20% and wind speed reduction was about 37% during second measurement (October 20th 2007). Relationship between average wind speed and optical porosity for Suchá Loz locality presents Fig. 1.
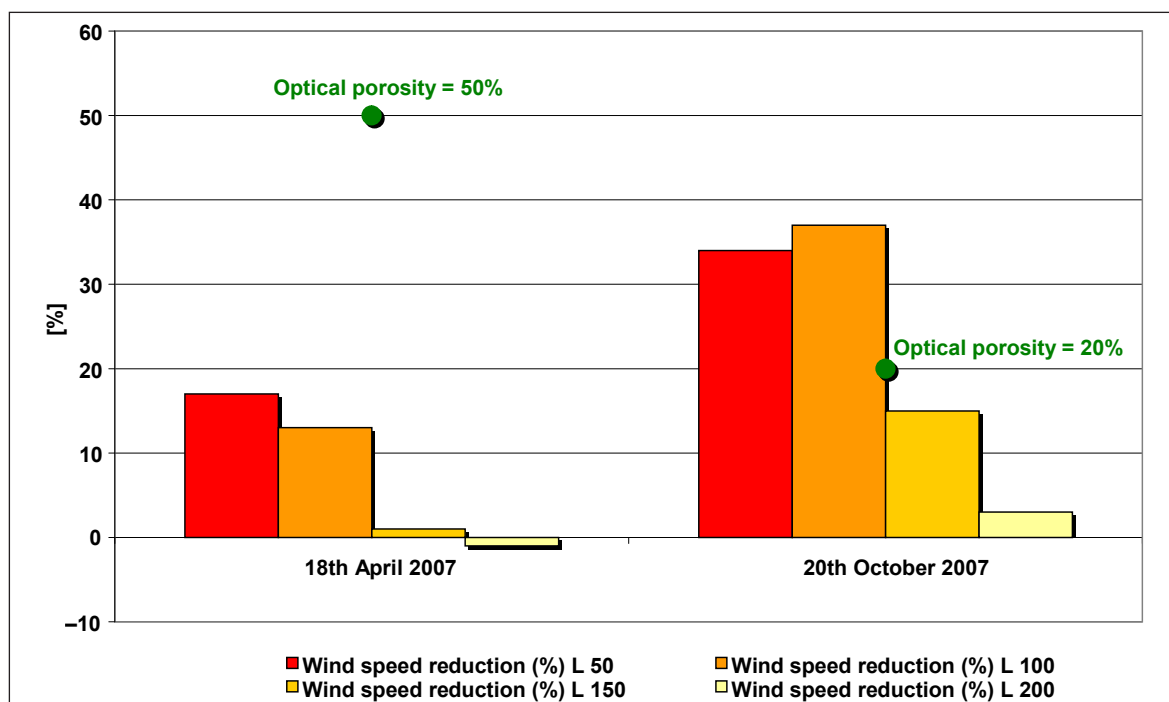
5: *Reduction of average wind speed and optical porosity on the leeward side in Suchá Loz*
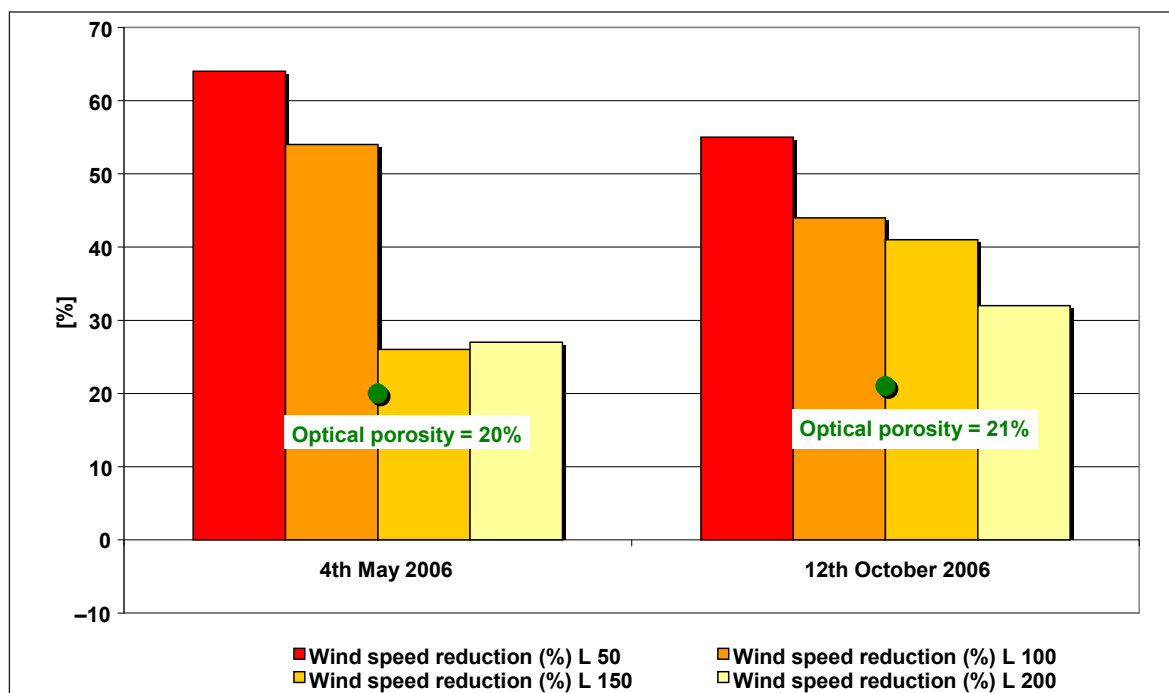
6: *Reduction of average wind speed on the leeward side in Micmanice*

Relationship between optical porosity and wind speed reduction for Micmanice windbreak presents Fig. 2. During first measurement (May 4th 2006) the optical porosity of 20% and maximal wind speed reduction of 64% were assessed. For optical porosity of 21% (October 12th 2006) the wind speed reduction was about 55%.

Close relation between optical porosity and wind speed reduction was found out by statistical evaluation. Correlation coefficient regardless locality for distance of 50 m was –0.80, 100 m –0.92, 150 m –0.76 and for distance of 200 m –0.63.

CONCLUSION

- In all phenological phases of windbreaks reduction ability of wind speed was proved. Effect of speed decrease was perceptible especially on leeward side, on windward side it was less expressive.
- Decrease of average wind speed on leeward side in distance of 50 m behind the windbreak reached values from 17% (Suchá Loz 18th April 2007) to 64% (Micmanice 4th May 2006).
- In some cases decrease of wind speed in upper highs was found out in Suchá Loz. This effect was probably induced by vegetation heterogeneity.

- The effect of the windbreak on wind reduction is decreased by needy species composition of dominant wood species in Suchá Loz. Missing wood species would be suitable to complete with new species – especially in bottom and middle layer and later to replace senescent poplars with more suitable wood species with longer vegetative period.
- The windbreak in Micmanice reduce wind speed about 64% (measurement on 4th May 2006) and about 55% (measurement on 12th October 2006) on leeward side.
- In Micmanice expressive influence of the windbreak despite of expectations (it is windbreak with the low high) demonstrated even in distance of 200 m behind windbreak.
- Ambulatory measurements depend on weather course and also on type of vegetation in surroundings of windbreaks. This fact doesn't allow ensure higher number of measurements.
- Demandingness of ambulatory measurements requires find simpler method for evaluation of windbreak influence. Use of optical porosity is one of hopeful ways.
- Correlation coefficient between optical porosity and wind speed reduction regardless locality for distance of 50 m was –0.80, 100 m –0.92, 150 m –0.76 and for distance of 200 m –0.63.

SUMMARY

The influence of forest shelterbelts of various spices composition, age and construction on wind orientation and speed is evaluated in the paper. Parameters of windbreaks were assessed in the area of South Moravia endangered by wind erosion. Horizontal wind field close to windbreak was monitored with the help of ambulatory measurement by mobile anemometers set. Measurements were realized during the period of highest risk of wind erosion i.e. expect for main vegetation period of field crops and during varied windbreaks phenological phases. Windbreak effect to horizontal wind profile was monitored in distance 50, 100, 150 and 200 m far from windbreak in 2 m high. Average wind speed in leeward side 50 m behind windbreak in compare with control detector placed 150 m in windward side decreased from 17% (defoliaged windbreak in Suchá Loz) up to 64% (windbreak in Micmanice). Windbreak also influenced wind characteristics during the defoliation period of its main species. Unexpected strong windbreak influence in Micmanice (low windbreak) was perceptible up to 200 m. For assessment of windbreak effectivity optical porosity was determined.

SOUHRN

Účinnost větrolamů na základě měření větrného pole a optické porozity

V práci je posouzen vliv ochranných lesních pásů odlišné druhové skladby, stáří a konstrukce na rychlost a směr proudění vzduchu. Hodnoceny byly parametry dvou větrolamů v oblastech jižní Moravy ohrožených větrnou erozí. Horizontální pole větru v blízkosti větrolamu bylo monitorováno prostřednictvím ambulantních měření mobilní sestavou anemometrů. Měření byla prováděna v období, kdy jsou pozemky větrnou erozí ohroženy nejvíce, tj. mimo hlavní vegetační období polních plodin a v různých fenologických fázích větrolamu. Efekt větrolamu na horizontální pole větru byl sledován ve vzdálenostech 50, 100, 150 a 200 m od větrolamu ve výšce 2 m nad povrchem při pětisekundové frekvenci měření. Snížení průměrné rychlosti větru na závětrné straně ve vzdálenosti 50 m za větrolamem oproti kontrolnímu čidlu umístěném 150 m před větrolamem dosahovalo až 64 %. Vliv větrolamu na proudění vzduchu se projevoval i v době, kdy jeho hlavní dřeviny nebyly ještě olistěné, ovšem se sníženou účinností (především u dvouřadého větrolamu v katastru obce Suchá Loz). V Micmanicích se výrazný vliv větrolamu oproti předpokladům (jedná se o nízký větrolam) projevoval i ve vzdálenosti 200 m za větrolamem. Pro zhodnocení účinnosti větrolamu v různých fázích vegetace byla také stanovena optická porozita větrolamů.

větrolam, optická porozita, větrná eroze, rychlost větru, cirkulace vzduchu, fenologické fáze

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