Research Article

Turbulent Velocity Fluctuations as Affected by Biotic and Abiotic Windbreaks under Field Conditions

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ABSTRACT

Windbreaks have been used for centuries to shelter crops from wind damage and to protect soils from wind erosion. This study was performed in 5 steps to evaluate the effects of biotic and abiotic windbreaks on mean horizontal flow and turbulent velocity fluctuations under field conditions. These steps included granolometery analyzing, determination of field threshold velocity of soil erosion, estimation of acceptable wind speed, optimizing windbreak distance and wind speed recording. Two kinds of windbreaks were used in this study, biotic windbreak (Tamarix aphylla) with 45% density and abiotic windbreak (Mud wall) with 100% density. Results of field experiment showed that optimized distances for abiotic and biotic windbreak are respectively observed at 7.87h and 4.5h after windbreak. Finally mud wall is applicable for high decreasing wind speed at the back of windbreak but its high wind speed fluctuation and high turbulence were limited to these windbreaks in agro ecosystem. Tamarix aphylla with 45% density is applicable for medium decreasing of wind speed and creating low turbulence after windbreak.

Keywords: Mud wall, Tamarix aphylla, threshold velocity, windbreak, Wind

INTRODUCTION

Wind erosion is the prevailing factor in desertification in most arid and semi –arid countries of the world. Wind flow carries the fertile part of the soil which is the nutrient source for plants. Windbreaks have been used for centuries to shelter crops from wind damage and to protect soils from wind erosion. They reduce wind speed and alter the characteristics of airflow around them, inducing changes in the surrounding atmospheric, plant, and soil environments (Cleugh, 1998). The interaction between the windbreak and the airflow is complicated by the turbulent characteristics of the wind and by the complex behavior caused by natural obstacles. Although much effort has gone into the measurement and characterization of wind flow in the lee of wind barriers and isolated obstacles at a range of scales, relatively little attention has been given to the direct interaction of the air with the individual plants that can be characterized by a drag coefficient. Our understanding of wind interaction with three-dimensional, porous obstacles, however, such as tree windbreaks and isolated trees and shrubs, is much less complete (Heisler and DeWalle, 1988). The consequence of this lack of knowledge results in the use of surrogate data in models. For example, Raupach (1992) and Raupach, et al. (1993), by necessity, used drag coefficients of solid roughness elements reported by Taylor (1988) to represent natural, porous vegetation. Furthermore, the very causes of wind-speed reduction, pressure perturbation related to width and structure, permeability and drag force, are largely unknown for three-dimensional, porous obstacles (Wang and Takle, 1996).

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 approach flow 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). The effects of these factors are important but often contradictory and they are seldom defined analytically (Cleugh, 1998; McNaughton, 1988; Heisler and Dewalle, 1988).

The evaluation of properties of different windbreaks and its effects on turbulent velocity fluctuations is very important and necessary for designing suitable windbreaks for agro-ecosystems in any climatic conditions.

The objectives of this study were to determine:
(1) The effects of biotic and abiotic windbreaks on mean horizontal flow and turbulent velocity fluctuations under field conditions
(2) Estimation of optimal distance between parallel windbreak to reduce soil erosion in the space between.

METHODS AND MATERIALS

Field study:
The case study was Jiroft catchment which located between 28° 33' N and 28° 45'N latitudes and between 57°43'E and 57° 45'E longitudes in East south of Iran. The climate of this region is sub humid with warm summer and moderate winter (UNESCO, 1979). In the Jiroft station average temperature is 25˚C, and annual rainfall is 150mm which 85% is concentrated in the winter and autumn seasons and 15% in the spring. Average of maximum velocity of dominant wind has been 54 km per hour. The forestry and rangelands covered 320000 and 1467517 hectares respectively.

Step1: Granolometery analyzing

This step was performed in order to estimate the threshold velocity of wind erosion. Threshold velocity is defined as the minimum velocity which causes soil particles to move. For evaluation this parameter, the soil samples were collected from 0-20cm depth. Soil samples were powdered and categorized according to ASTM (American Society for Testing and Materials International. GR (Graph software) was used to determine the granolometery index and soil texture.

Step2: Determination of field threshold velocity of soil erosion

Threshold velocity was determined base on Ekhtesasi method (1993) using wind erosion meter (wind tunnel-Field Model W.E Meter), which was made in Iran (Ekhtesasi, 1993). As this method described, 7 kilogram of powdered soil, was put into the wind tunnel (fig1) then the minimum speed which able to raise soil particles was recorded as threshold velocity (Ekhtesasi, 1993). Von Karman method (1921) which described the following was used in converting tunnel threshold velocity of soil erosion to field threshold velocity of soil erosion.

$$V_{2(\frac{m}{s})} = V_{1(\frac{m}{s})} \times (H2/H1)^{0.16} \qquad \text{(equation1)}$$

V_1= tunnel wind speed; V_2= field wind speed which estimated above 10 meters of ground surface; (H2= standard for field wind speed estimation that is 10 m (Ekhtesasi, 1993); H1= for wind erosion meter was 0.2 meter (Ekhtesasi, 1993).

Step3: Estimation of acceptable ratio of wind speed

In this step, acceptable wind speed ratio was estimated using equation (2). Acceptable ratio of wind speed is defined

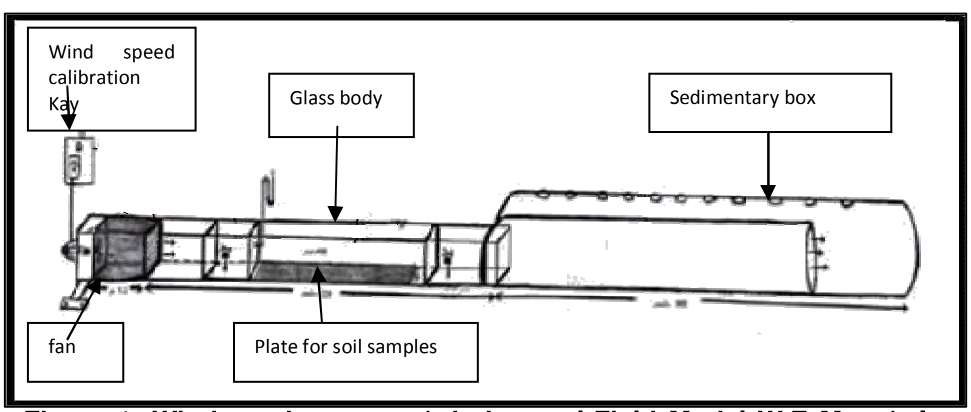

Figure 1: Wind erosion meter (wind tunnel-Field Model W.E Meter), Iran (Ekhtesasi, 1993)

as ratio of threshold velocity (which estimated in step2) to maximum velocity (which estimated from long term wind data of Jiroft climatology station). Acceptable ratio shows how much of wind speed should be deceased which will not cause soil erosion (Amiri, 2007). This ratio was applied for each windbreak to determine acceptable ratio of wind speed. Base of equation (2) optimized parallel windbreak distance was estimated.
This means the amount of wind speed which is acceptable is

Acceptable ratio $= (V_e / V_m) \times 100$ *(equation2)*
V_e: field threshold velocity of wind erosion soil
V_m: maximum of wind speed

Step4: Optimizing windbreak distance

This step determines the location of the next rows of the windbreak based on soil texture, threshold velocity of wind erosion soil and acceptable wind speed. The next rows were located in distance from previous windbreak where the wind speed increases above acceptable wind speed.

Step5: Wind breaks wind recording

Two kinds of windbreaks were used in this study, biotic windbreak (*Tamarix aphylla*) and abiotic windbreak (Mud wall) (table1). Wind velocity was recorded in front of windbreaks at -20, -1, 1, 2,3,4,6,8,10,11,12,16 and 18 times distances of its height and 1 meter above ground level. Wind speed was recorded in 3 replications using Digital Anemometer (General DAF. 2005.MDL).

Table 1 : characteristics of studied windbreaks

windbreak	height of windbreak	Density
abiotic wind break (Mud wall)	2 meter	0% porosity
biotic wind break (*Tamarix aphylla*)	4 meter	55% porosity

Fig2: View of Mud wall wind break which was used in this study as an abiotic windbreak

Figure3: View of Tamarix aphylla wind break which was used in this study as a biotic windbreak

RESULTS

Results of step1 -4 are presented in table2. Based on the Ekhtesasi method (1993), the threshold wind velocity in the wind tunnel was recorded as 4m/s. This velocity was converted to field velocity using Von Karman method (1921).

$4m/s \times (10/0.2)^{0.16} = 7.5m/s = 27km/h$

So according to average of maximum wind speed which recorded in meteorological data (54km/h) the acceptable ratio of wind speed was calculated as follow:

$$Ve/Vm=(27^{km/h}/54^{km/h}) \times 100=50 \text{ percentage of maximum wind speed(Vm).}$$

Table2: results of step1 to 4

Step1	Step2		Step3	Step4 for abiotic wind break	Step4 for biotic wind break
Soil texture	Threshold velocity of soil erosion	Average of max wind speed	Acceptable ratio of wind speed **(%)**	Optimizing windbreak distance	Optimizing windbreak distance
Medium sand	7.5 m/s	15m/s	50% of the initial wind speed	8h (16m)	3h (=12m)

Mud wall windbreak distance was optimized according to acceptable wind speed (50% of the initial wind speed) and the field experimental result which is presented in table2. Wind speed decrease in the distance of 6h and 8h was respectively 15.27% and 77.2% of initial wind speed. Using interpolation 50% wind speed decrease of initial wind speed will occur in 6.87h (which approximately equal to7h). According to table3, the distance of 1h back of windbreak, the wind speed was lower than estimated threshold (50% of the initial wind speed) so this was added to 7.87h (1h+6.87h) for estimating the location of next windbreak (Fig2).

Table 3: means and standard deviation of wind speed due to distance from wind break

distance from wind break	Tamarix aphylla	Mud wall
-20	100±2.64	100±2.7
-1	77.56± 2.55	48.9±2.8
1	41±3.51	13.7±4.24
2	43±3.1	8.65±4.26
4	71.6±2.02	38.9±3.88
6	79.2±3.1	15.3±3.81
8	86.21±3.2	77.2±4.03
10	88.8±4.03	50±2.41
12	94.86±4.02	59±2.40
14	100.9±5.02	75±2.85
16	103.46±3.01	86.98±4.03

So in order to control soil erosion or decreasing wind speed under estimated threshold, the next windbreak should be

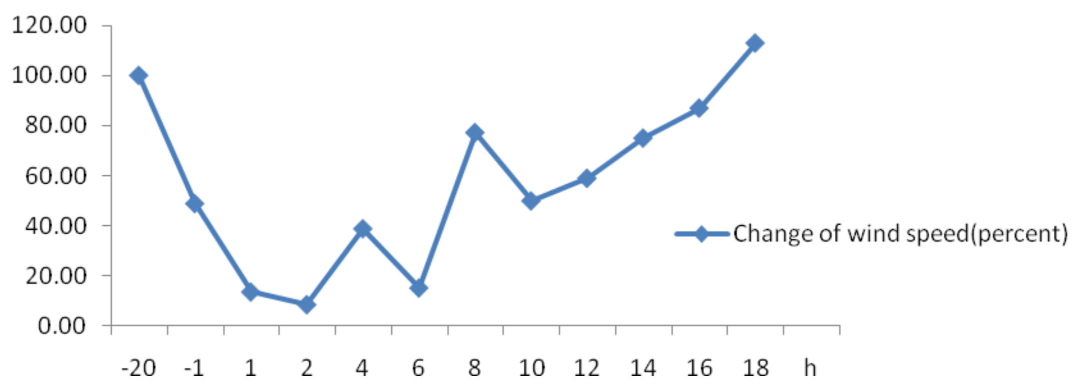

Figure 4: wind speed fluctuations around windbreak zone of Mud wall.

set at a distance of 7.87h from the previous windbreak. Turbulent velocity fluctuations of abiotic windbreak (mud wall) with density of 100% compressed was shown in figure4 (table 3).

Tamarix aphylla was studied as a biotic windbreak in this research. Windbreak distance was optimized according to the estimated acceptable wind speed (50% of the initial wind speed) and the field experimental result which is presented in table4. Wind speed decrease in the distance of 2h and 4h was respectively 43% and 71.6% of initial wind speed. Using interpolation 50% wind speed decrease of initial wind speed was estimated in 3.5h. According to table4, at the distance of 1h back of windbreak, the wind speed was lower than the estimated threshold (50% of the initial wind speed) so this was added to 4.5h (1h+3.5h) for estimating the location of the next windbreak. So in order to decrease wind speed under estimated threshold, the next windbreak should be set at a distance of 4.5h from the previous windbreak. Turbulent velocity fluctuations of biotic windbreak (Tamarix aphylla) with density of 45.5 uncompressed was shown in fig5 (table 3).

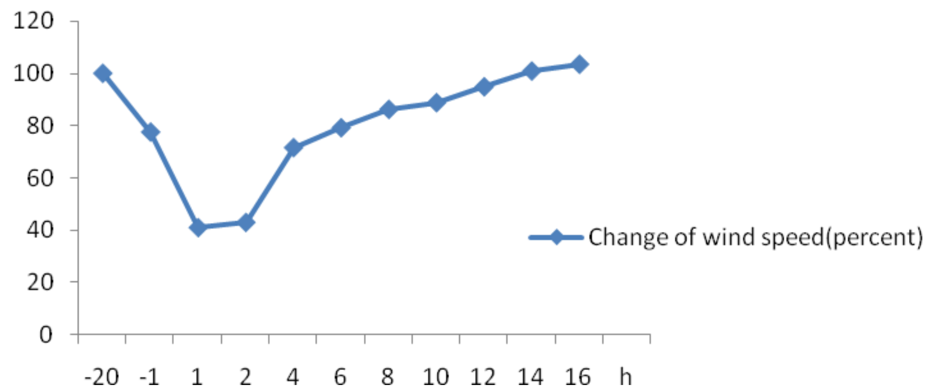

Figure 5: wind speed fluctuations around windbreak zone of Tamarix aphylla.

DISCUSSION

This study was performed to improve agro ecosystems under arid climatic conditions. Windbreak could improve crop yields, soil stabilization, and evaporation but these effects are related to the types of windbreaks and its planning over the agro-landscapes.

Windbreaks are barriers used to reduce and redirect wind. They usually consist of trees and shrubs, but may also be perennial or annual crops and grass fences, or other materials. The reduction in wind speed behind a windbreak modifies the environmental conditions or microclimate in the sheltered zone. Mud wall as an abiotic windbreak with 100% density creates high turbulence behind the windbreak. This turbulence increase soil erosion. So we don't suggest this kind of wind break for sensitive soils in arid conditions.

In this study Tamarix was used as a biotic wind break. The results showed that wind speed fluctuation of biotic windbreak was lower and fewer than abiotic windbreak. Decrease of wind speed fluctuation can increase stability of agro ecosystems (Puri et al, 2004).

Heisler and Dewalle (1988) report in studies of shelterbelts field, that medium-porous barrier are the most effective in reducing the mean, near-ground wind speeds for the longest distances. The rate of wind speed recovery is faster in the near lee (between 0h and 10h), and slower afterwards, hence low porosity windbreaks are slightly less effective than medium porosity windbreaks (Wang and Takle, 1996).

According to figure1, wind speed at 2h back of the Mud wall windbreak was decreased fewer than 9 percent of its initial speed. So the high density of the windbreak created a zone at the back of windbreak which had a very low wind speed. Other researchers reported this zone created at 2 to 10h back of windbreak (Guanming and Wenhu, 2003; Vigiak, et al., 2003; Cornelis, et al., 1997).

A maximum wind speed reduction for biotic wind break was observed at 1h back of windbreak. The wind speed increase after the minimum point has an interesting pattern. This pattern shows the gradual change in wind speed and low fluctuations in contrast to solid windbreak. These findings are in qualitative agreement with simulations using the numerical model of Wilson (1985), Banzhaf et al., (1992) and Olga (2003). Wilson (1987) reported differences in wind reduction and turbulence behind the two fences are fairly slight. Mean wind speed is reduced somewhat more effectively (an additional 10 to 15%) near ground in the near lee (x/H = 7) of the fence which is dense at the ground, with no apparent penalty in the turbulent field but with reduced effectiveness at larger distances relative to the uniform fence.

Wilson (1985) examined the results of several relatively modern windbreak fence experiments and found that in these cases, a denser windbreak yielded not only greater speed reduction, but also a greater range of shelter. This concurred with the prediction of the numerical model of windbreak flow which was the main subject of Wilson (1985).

The maximum wind speed reductions, which occur close to the slat-fence windbreaks, ranged from 70 percent for the solid windbreak to about 50 percent for the 60-percent porous windbreak. However, average wind speed reduction over the leeward area was 5 to 10 percent larger for the 40-percent porous windbreak than that for any other windbreak (Heisler et al., 1988).

Finally we conclude that the mud wall is applicable for high decrease of wind speed at the back of windbreak but its high wind speed fluctuation and high turbulence were limited in these applications in agro-ecosystems that lie in arid or semi arid regions. Tamarix aphylla with 45% density is applicable for medium decrease of wind speed over a larger zone after windbreak. So this biotic windbreak may be more useful for agro-ecosystems that lie in arid or semi arid regions.

Growing of trees or other biotic windbreaks are interesting properties for improving windbreaks, because its annual growth increases the windbreak zones (Bisal, et al., 1964). Other benefits of biotic wind breaks are their applications to fuel, fruit production, forage and wild shelter in agro landscapes (Wojtkwski, 2003).

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