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USE OF MESH WINDBREAKS FOR SOIL EROSION IN OLIVE GROVES IN SOUTHEASTERN SPAIN

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Abstract

We used windbreak nets to reduce erosion and sediment transport in a semiarid area. A 13x30thread·cm^{-2} and 39% mesh net facing the wind increased average erosion reduction up to 72% at a height of 0.4 m in recently tilled olive groves. The use of sonic anemometry techniques for identifying wind movement patterns has rarely been exploited for improving field studies, and much less for windbreaks. Sample components collected in traps placed at different heights and distances from the windbreak were analyzed. A Principal Components Analysis was carried out analyzing the combined effect of height and windbreak distance on variables associated with the first two components. Component C1 identified the height at which data were obtained, while Component C2 identified windbreak distance from the sampling point. The effectiveness of this system is shown by the reduction in weight of material caught in traps, and is a cheap and reusable tool applicable after tilling.

Key words: dust traps, soil crusting, soil fertility, sonic anemometry

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1. Introduction

Wind soil erosion, as a type of soil degradation, causes environmental, social and economic problems, impacting adversely on human health, as well as increasing pollution, crop damage and sand deposition in wells and streams (Arjmand Sajjadi and Mahmoodabadi, 2016; Novara et al., 2011; Prosdocimi et al., 2016; Sharifikia, 2013). In arid and semiarid areas, where rainfall is erratic and winds are often strong (Burtiev et al., 2013), wind erosion repositions huge amounts of soil, which may cause serious agricultural and environmental problems, such as pollution (Yildiz et al., 2017), or burying plants after emergence. Disturbed soil components, such as textural changes, can impact on soil water status (Kravchenko et al., 2016; Vaezi and Bahrami, 2014). All of this makes it necessary to improve current erosion models (Borrelli et al., 2015).

Lozano et al. (2013) and Giménez et al. (2019) analyzed the relationships between wind speed and wind erosion in semiarid regions, along with the influence of soil type and vegetation. Other authors have observed how wind erosion affects organic carbon content and nitrogen dynamics in these soils (Li et al., 2004; Asensio et al., 2015). A decrease in aggregate stability and progressive loss of nutrients from wind erosion was reported by Zobeck et al. (2013). Gomesa et al. (2003) showed that wind erodibility of soil under traditional tillage is lower than in conservation tillage because it reduces the availability of material susceptible to erosion through formation of surface crusts. Cultivation in medium-textured soils widens differences between the erodible fraction of the soil, which increases, and dry aggregate stability, which decreases (Colazo and Buschiazzo, 2010; 2015), because crops weaken the soil structure due to the loss of organic carbon and by breaking up

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aggregates. However, in fine-textured soils, formation of large resistant aggregates by tillage considerably reduces the difference between the erodible fraction of the soil and dry aggregate stability (Bogunovic and Kisic, 2017). Tilling ridges are effective in trapping aggregates transported by saltation, as demonstrated by Hagen et al. (2010), but not when aggregates are transported by suspension. Different types of soil management influence transport of the mineral fraction by wind to a greater or lesser extent (Rezaei et al., 2012), and according to Beniston et al. (2015), this causes loss of P. In a wind tunnel study, Feras et al. (2008) found that efficiency of sediment traps depended mainly on particle size and wind speed. Basaran et al. (2011) measured the vertical flow of sediments with traps placed at different heights.

Windbreaks are barriers used to reduce both leeward and windward wind speed. The intrinsic characteristics of the windbreak used, i.e. the material, height and length, determine the reduction, strongly influencing soil fertility, and thereby, crop production.

Mesh windbreaks are like a porous obstacle which slows down the wind flowing through them. They act as a roughness agent, reducing drag through net loss of wind force, thus protecting the surface and trapping soil particles (Molina-Aiz et al., 2006). Several studies have used anemometry to analyze the aerodynamics of meshes in greenhouses (Molina-Aiz et al., 2009; Valera et al., 2006), although such research is not common in the open field.

Our objectives were to use sonic anemometry to analyze the effectiveness of proposals for reducing wind erosion in crusted and recently tilled soils, and to establish the suitability of their use in olive-cropped soils, due to their climatic characteristics.

2. Material and methods

The study area (Fig. 1) is located in Almería Province, Spain, bordering the Tabernas Desert (37°07´N, 2°18´W). The climate is semiarid Mediterranean with a mean annual temperature and rainfall of 17.8°C and 283 mm, respectively. The dominant geological material is a Miocene sedimentary series containing marls in contact with evaporites. Natural plant communities consisted of isolated native shrubs, but at present, there is an ecological olive grove mainly composed of four-year-old picual olive trees. According to the IUSS Working Group WRB (2014), soil is a hapli-chromic Luvisol (LVx). It has a loamy texture, with an average of 37% gravel fragments and a medium blocky structure.

After tillage, soils are highly erodible by wind, but in a short time, tend to be stabilized by surface crusting. According to Asensio et al. (2016, 2018 and 2019), these soils tend to recover the physical surface crust within 10 to 12 days. Removable windbreak nets installed after tillage reduce erosion until surface crusts form, and also retain sediments transported by wind. The windbreak nets used in this study had 13×30 threads·cm^{-2} and 39% porosity. Windbreaks 7.5 m wide and 0.7 m high were arranged perpendicular to the main natural wind direction, in alternating bands spaced 40 m apart. Our experiments started on October 10, 2016. Weather conditions (mean ± standard deviation) were: wind speed (u_o), 3.40 ± 0.78m·s^{-1}; wind direction (θ), 270 ± 18˚; air temperature (T_o), 21.0 ± 0.9˚C and relative air humidity (HR_o), 54 ± 3%. Samples were identified by height-windbreak distance to mesh. Leeward samples were marked with an "R".

To characterize the influence of the mesh windbreak in preventing soil erosion, we distributed devices as shown in Figs. 2 and 3, and following other authors, recorded the effect up to a distance of eight to nine times the windbreak height (Brandle et al., 2006).

For the wind speed study, we used two 3D sonic anemometers (mod. CSAT3, Campbell Scientific Spain S.L.) placed windward and leeward normal to the windbreak centrum. Measurements were recorded at 2, 4 and 6 m from the windbreak and 0.4, 0.7 and 1 m high. We also placed ten 2D sonic anemometers (mod. Windsonic, Gill Instrument LTD) around the windbreak (Fig. 2). A portable meteorological station monitored weather conditions. Wind speed vector and turbulence intensity data were recorded (López et al., 2011 and 2017; Valera et al., 2006).

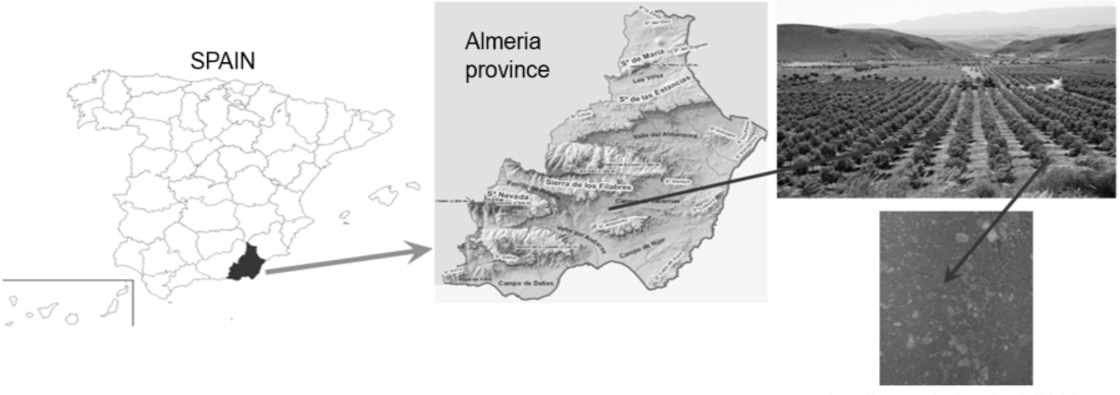

Fig. 1. Study area location

Fig. 2. Devices around windbreak

Sediment traps (Fig. 2) were installed to measure the effect of the windbreak on reducing wind erosion during three days of testing. The traps were Fryrear BSNE samplers used without mast, because they were for a fixed wind direction, that is, the main natural one (Asensio et al., 2015). Traps were located at 0.4, 0.7 and 1 m from the ground, and 2, 4 and 6 m windward and leeward from the windbreak.

Soil samples were collected from the upper 3 cm for comparison of the effects on crusted and recently tilled soils, and three replicates of each were assayed. Textural data were obtained by the Robinson pipette method. Organic carbon content was analyzed by the Walkley-Black wet digestion method. Total nitrogen content was determined from NH_3 volumetry after Kjeldahl digestion. Soil available phosphorous was calculated by photo colorimetry. Soil available potassium was found by flame photometry. Gas volumetry was used to determine carbonate content. Finally, the percentage of weight reduction in both crusted and tilled soil traps was determined by the difference from the first trap location (6 m upwind).

An Analysis of Variance determined the effect of height and trap location and a Principal Components Analysis was performed to estimate any relationships of height and windbreak distance regarding to texture, organic carbon, total nitrogen, available phosphorous and potasium or equivalent carbonate content differences in traps. Statistical analyses were done using SPSS v23 (IBM Corp.).

3. Results and discussion

Mean wind speed reductions and turbulence intensity increases in sonic anemometers located 2, 4 and 6 m windward and leeward from the mesh (Fig. 3) are shown in Table 1. Measurements taken at a height of 1 m showed that there was no significant effect at 4 and 6 m from the windbreak. Sonic anemometers surrounding the windbreak showed a 72% average reduction in the component perpendicular (ux) to the mesh (Table 1) at a height of 0.4 m. The uy component at a height of 1 m was reduced by an average of 41%, due to edge effects close to the windbreak. Turbulence intensity (i) increased leeward, as the average wind speed dropped as it passed through the mesh.

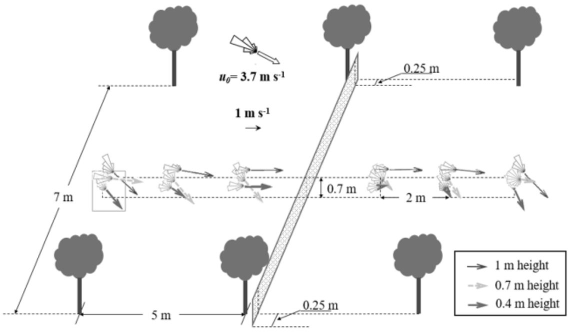

Fig. 3. Wind characterization by height and distance from windbreak

Nevertheless, the focus here is on the effects on the characteristics of sediments caught in Fryrear BSNE sampler. Tables 2 and 3 show soil and sediment values for different components and differences expressed as loss in sediment weight, in both crusted and tilled soil.

Table 1. Windward-leeward differences in wind speed (*u*) and intensity of turbulence (*i*) by comparison of x and y components for sampling locations

WINDWARD /LEEWARD	***% reduction***		***% increase***	
	u_x	u_y	i_x	i_y
0.4-6/0.4-6R	-	-	-	-
0.7-6/0.7-6R	-	-	-	-
1-6/1-6R	-	-	-	-
0.4-4/0.4-4R	31	-	4	14
0.7-4/0.7-4R	29	3	22	31
1-4/1-4R	-	-	1	2
0.4-2/0.4-2R	72	26	40	47
0.7-2/0.7-2R	41	16	31	26
1-2/1-2R	14	41	11	13

Sample names indicate sampling height-distance to windbreak (windward and, if include R, means leeward)

Table 2. Textural components in the 3-upper cm of soil (LV_x) and in sediment traps

Sample	*Very coarse sand (2000-1000 μm)*	*Coarse sand (1000-500 μm)*	*Medium sand (500-250 μm)*	*Fine sand (250-100 μm)*	*Very fine sand (100-50 μm)*	*Coarse silt (50-20 μm)*	*Fine silt (20-2 μm)*	*Clay (< 2 μm)*
LV_x	0.3	5.3	6.1	8.9	25.9	26.8	6.3	20.4
0.4-6	0.1±0.0	0.1±0.0	0.3±0.1	0.5±0.2	23.0±2.6	40.2±3.1	9.4±0.5	26.6±2.8
0.7-6	0.0±0.0	0.0±0.0	0.2±0.0	0.3±0.1	15.3±1.1	42.3±3.9	14.9±1.4	27.0±1.3
1-6	0.0±0.0	0.0±0.0	0.0±0.1	0.2±0.1	11.4±1.3	42.6±0.8	15.5±0.3	30.3±1.6
0.4-4	0.0±0.0	0.0±0.0	0.2±0.1	0.4±0.2	23.4±2.0	41.1±3.4	10.1±0.7	24.8±2.2
0.7-4	0.0±0.0	0.0±0.0	0.2±0.1	0.2±0.1	15.5±1.1	43.5±3.9	15.2±1.5	25.3±1.2
1-4	0.0±0.0	0.0±0.0	0.0±0.0	0.2±0.1	11.8±1.7	42.2±0.5	15.3±0.3	30.5±1.4
0.4-2	0.0±0.0	0.0±0.0	0.2±0.1	0.3±0.2	23.7±2.1	42.4±3.9	9.9±0.6	23.6±3.9
0.7-2	0.0±0.0	0.0±0.0	0.1±0.1	0.2±0.1	15.6±1.1	43.5±4.4	15.4±1.5	25.1±1.9
1-2	0.0±0.0	0.0±0.0	0.0±0.0	0.2±0.1	11.5±1.3	42.9±0.8	15.7±0.4	29.8±1.6
0.4-2R	0.0±0.0	0.0±0.0	0.1±0.1	0.2±0.1	24.9±2.2	43.6±2.8	10.7±0.5	20.5±3.2
0.7-2R	0.0±0.0	0.0±0.0	0.1±0.0	0.2±0.1	16.0±1.2	44.1±3.7	16.1±1.5	23.5±1.0
1-2R	0.0±0.0	0.0±0.0	0.0±0.0	0.1±0.0	11.5±1.3	41.4±1.7	15.9±0.3	31.1±1.4
0.4-4R	0.0±0.0	0.0±0.0	0.2±0.1	0.2±0.1	24.2±2.1	43.2±3.2	10.3±0.4	21.8±3.5
0.7-4R	0.0±0.0	0.0±0.0	0.1±0.1	0.2±0.0	16.0±1.1	44.9±3.6	15.7±1.7	23.1±1.3
1-4R	0.0±0.0	0.0±0.0	0.0±0.0	0.2±0.1	11.6±1.3	42.8±0.6	15.9±0.2	29.5±1.3
0.4-6R	0.1±0.0	0.1±0.1	0.2±0.0	0.3±0.1	23.7±2.0	40.6±3.1	9.7±0.5	25.4±2.8
0.7-6R	0.0±0.0	0.0±0.0	0.2±0.1	0.2±0.1	15.9±1.1	42.7±4.0	15.2±1.4	25.7±1.3
1-6R	0.0±0.0	0.0±0.0	0.0±0.0	0.2±0.1	11.8±1.2	42.7±0.8	16.0±0.3	29.3±1.4

Data are showed as % and represent means ± standard deviation (n=3)

Table 3. Organic carbon (OC), total nitrogen (N), available phosphorous and potassium (P_2O_5 and K_2O), equivalent carbonate ($CO_3^=$) content in the 3-upper cm of soil (LV_x) and in traps, and can be observed the weight reduction in traps for crusted and tilled soil

Sample	*O.C. (%)*	*N (%)*	*P_2O_5 ($mg \cdot kg^{-1}$)*	*K_2O ($mg \cdot kg^{-1}$)*	*$CO_3^=$ (%)*	*Weight reduction crusted (%)*	*Weight reduction tilled (%)*
LV_x	2.84	0.195	5	16	2	-	-
0.4-6	1.94±0.13	0.318±0.036	4±1	18±3	2±1	0	0
0.7-6	1.90±0.11	0.229±0.028	8±1	8±4	2±1	0	0
1-6	1.77±0.08	0.201±0.014	7±1	6±4	2±0	0	0
0.4-4	1.89±0.11	0.306±0.040	4±1	18±2	2±1	10±2	9±3
0.7-4	1.83±0.12	0.218±0.030	7±1	9±6	1±1	6±1	5±2
1-4	1.69±0.11	0.202±0.015	5±1	7±4	1±1	1±1	1±0
0.4-2	1.83±0.12	0.299±0.031	6±1	14±2	2±0	22±2	17±2
0.7-2	1.85±0.10	0.212±0.039	8±1	8±2	0±0	14±2	11±1
1-2	1.75±0.08	0.195±0.014	6±2	6±1	1±0	3±1	2±1
0.4-2R	1.76±0.13	0.265±0.024	3±1	12±2	1±0	59±4	45±5
0.7-2R	1.78±0.11	0.184±0.023	6±2	6±3	0±0	34±2	26±3
1-2R	1.66±0.09	0.165±0.018	5±1	4±3	0±0	9±1	7±2
0.4-4R	1.84±0.14	0.289±0.035	5±2	16±2	1±0	36±1	31±2
0.7-4R	1.82±0.10	0.211±0.027	9±1	9±2	0±0	43±1	37±2
1-4R	1.70±0.08	0.186±0.015	7±1	7±1	0±0	3±2	3±1
0.4-6R	1.88±0.10	0.311±0.037	5±1	15±3	1±0	6±0	6±1
0.7-6R	1.81±0.11	0.222±0.031	8±1	8±1	0±0	3±1	3±2
1-6R	1.69±0.06	0.193±0.015	7±2	7±2	0±0	1±0	2±1

Data are means ± standard deviation (n=3)

It should be kept in mind that wind erosion estimated by Asensio et al. (2016) for this site was 6.3 + 0.8 for crusted soil and 15.9 + 1.8 t•ha^{-1} for tilled soil (n = 5). Only sediment components from crusted soil are shown here, because significant differences were found only in very fine sand, coarse silt and organic carbon contents at the 0.4 m height. Weight differences are related to the first sampling point (6 m, windward and same height).

The ANOVA statistical analysis of the characteristics of the sediments captured in the different traps showed that the height-windbreak distance interaction effect was only significant ($p<0.05$) for the weight reduction variable. A two-factor ANOVA for the main effect height showed that there were significant differences for height in most variables, except silt. For the main effect windbreak distance, there were significant differences in most variables, except very fine sand, silt and OC.

A Principal Component Analysis (PCA), applying the arithmetic mean criterion for selecting the number of components, found four components which explain 81.3% of the total variance. According to the C1-C2 component matrix (Fig. 4), variables such as very fine sand, N or available K2O, were positively associated with Component C1. On the contrary, fine silt was negatively associated with that component, and was therefore the opposite. Weight reduction was positively associated with Component C2, and clay negatively.

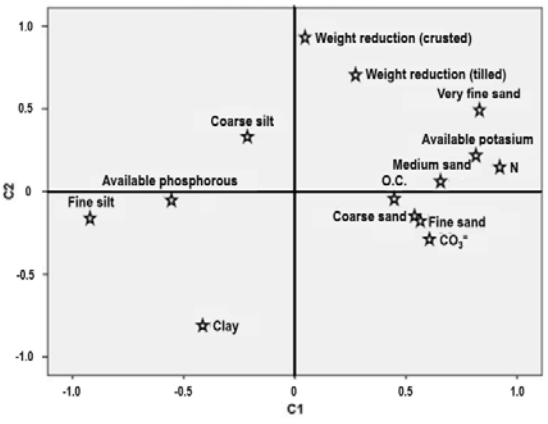

Fig. 4. Analytical characteristics of the Components C1-C2 matrix

Analysis of the combined effect of height and windbreak distance (WD) on variables associated with the first two components (Fig. 5) shows that Component C1 differentiated the height at which analytical data were acquired, and within this height, the data with the highest C1 corresponded to those acquired at 6, 4 and 6R m WD, then those acquired at 2 and 4R, and finally those at 2R. For Component C2, the lowest were acquired 0.4 m high and 6 and 4 m WD. On the contrary, data at a height of 0.4 m and 2R and 4R m WD stand out for their strong reduction in weight and low in clay. Data acquired at 0.7 m high, have null at 6, 4 and 6R m WD compared to negative for 2, 2R, and 4R, although they are moderate in variables associated with C1. In Component C2, it may be seen how data corresponding to 4R and 2R m WD are more extreme, that is, they have a strong reduction in weight and lower in clay. Nevertheless, at 6 and 4 m WD, C2 has low , while at the rest of the WDs, in C2 it is practically nil, presenting moderate in both weight reduction and clay. Data from 1 m high show similar behavior at all WDs. Thus, Component C1 may be identified as a differentiating factor for height, while Component C2 discerns distance from windbreak.

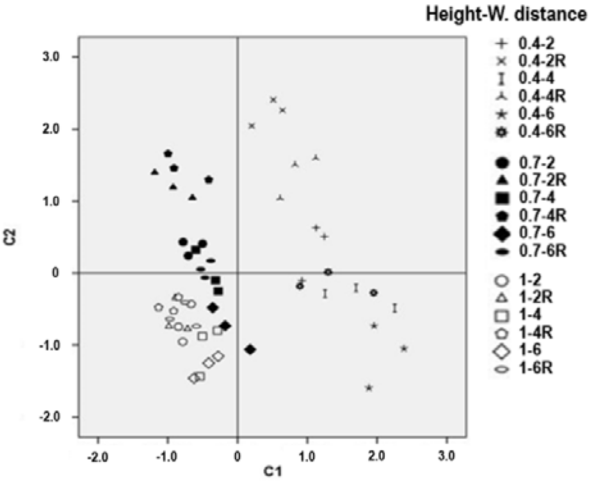

Fig. 5. Height-Windbreak distance sampling point categories (windward and leeward including R) in the Component C1-C2 matrix

During testing, wind erosion was mainly in very fine sand, silt and clay fractions (Hagen et al., 2010). Fine silt and clay were collected in larger amounts by traps placed 1 m high than at 0.4 m and 0.7 m. On the contrary, very fine sand and coarse silt were collected in larger amounts by traps placed at 0.4 m, with smaller amounts collected as trap height increased. Logically, the higher the barrier height, the more effective the windbreak is, increasing both sediment retention and effective distance. But the higher the barrier, the more it costs, and the more work is required for its installation. Thus, a height of 0.7 m could be an appropriate balance for these soils.

In general terms, the closer traps were to the windbreak, the less sediment they collected, both windward and leeward. The increase in total sediment weight collected by traps with sampling distance shows the positive effect that a windbreak could have on particle loss reduction. Comparing sediment weight collected by traps, the amount from crusted soils was lower than tilled. It should be considered that wind erosion evaluated in these soils (Asensio et al., 2016) is over 2.5 times higher in tilled soils, where in addition, the particle suspension mechanism is much more intense, exceeding sampling height. However, retained clay, very fine sand and organic carbon increased over 3, 3.5 and 6.8%, respectively, at 0.4-2R, making the effect on crusted and tilled soils comparable. This is only for one wind episode. Gains over time may be imagined.

A strong decrease in sediment transport was concentrated near the windbreak (Colazo and Buschiazzo, 2015). As shown, the windbreak had very little effect on overall sediment transport at a distance of 6 m downwind from the windbreak (8.6 times its height). Nevertheless, considering the cumulative effect of wind erosion and results for crusted and tilled soils, we recommend the use of a mesh windbreak in this olive grove, just after tilling and for the following 10 days until soil crust formation. These meshes are economical and can be stored until the next tilling. That very low economic investment will have an impact on lowering production costs.

4. Conclusions

This study confirmed that sonic anemometry techniques enable wind movement patterns around windbreaks to be identified and parameters, such as wind speed vector components or characteristics of turbulent flow, which are directly related to wind erosion, to be analyzed.

Mesh windbreaks are a useful tool for reducing wind erosion. Using the mesh tested, a 72% mean reduction in wind speed was achieved at a height of 0.4 m, 2 m from the windbreak. Wind turbulence intensity increased leeward due to the decrease in wind speed. These values became less pronounced at greater distances from windbreak or at closer distances to its upper edge.

In addition to reducing erosion and sediment transport, these meshes have been shown to be a cheap reusable tool for after tilling ecological olive groves.

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