Int. J. Environ. Res., 10(2):333-340, Spring 2016
ISSN: 1735-6865

Economic Impact of Nutrient Losses From Wind Erosion of Cereal Soils in Southeast Spain

Gallardo, P.[1], Salazar, J.[2], Lozano, F.J.[1], Navarro, M.C.[2], Asensio, C.[1*]

[1]Departamento de Agronomía, CEIA3, Campus de Excelencia Internacional en Agroalimentación, Universidad de Almería, Spain

[2]Departamento de Economía y Empresa, Universidad de Almería, Spain

Received 16 Jan 2016; Revised 10 March 2016; Accepted 26 March 2016

ABSTRACT: The influence of wind erosion on soil productivity was studied applying fan-forced wind in a wind tunnel located in the Campo de Nijar area in SE Spain where the main crops are cereals. Wind erosion is highly variable depending on the type of soil (aric-haplic Calcisols, aric-calcaric Cambisols or aric-calcic Luvisols, according to IUSS Working Group WRB, 2014) and the time elapsed since the last tillage. This is because of the formation of a physical crust after tillage, which protects the soil from wind. Crusting in our area is favored by the strong effect of dew, which makes crust form in from eight to ten days.Nutrient losses from wind involve an additional cost in fertilization for a crop to be economically viable. The repeated measures ANOVA shows that very fine sand and coarse silt are the fractions most susceptible to loss due to the effect of wind. The same statistical analysis shows that the smallest differences in fertility appear in OC and K_2O, increasing in N and P_2O_5.Based on experimental data, we calculated the approximate cost of restoring organic matter, N, P_2O_5 and K_2O losses to the soil proportional to wind erosion, on the base of mineral fertilizers usually employed and average prices. This does not include the contribution to maintaining short and long-term productivity and soil fertility required for growing, or natural contributions from wind deposits and runoff.

Key words: Wind tunnel, Nutrient losses, Crusting, Restoration cost

INTRODUCTION

Although soil erosion is a natural phenomenon, human activity has accelerated it, making it an important conservation problem in arid and semiarid regions around the world which sustain about a sixth of the world's population (Skidmore, 2000). In semiarid regions, where the distribution and intensity of precipitation are irregular, wind moves enormous amounts of soil, with the consequential ecological imbalance. The Mediterranean region is severely threatened, with areas in which erosion has led to irreversible degradation and in some cases, complete disappearance of soil.

Susceptibility of soil to wind erosion varies spatially depending on soil texture, organic matter content, carbonates, aggregation and moisture. Climate and soil surface conditions influence the erosive capacity of the wind, conditioning loss of soil productivity. Wind erosion influences soil drying and its loss of nutrients, and this in turn is conditioned by soil surface compaction. Vaezi and Bahrami (2014) determined the influence of organic matter and calcic carbonate equivalent on the stability of aggregates in the relationship between soil productivity and its erosionability by water, which is also applicable to wind erosion.

The most influential factor in wind erosion is wind speed. Due to the roughness of the terrain, stoniness, vegetation and other obstacles, wind speed is slower near the soil surface and increases with height. Several authors (Liu et al., 2003; Li et al., 2004) have studied the relationships of wind erosion, wind speed, soil typology and vegetation, which affect the quality of soil by modifying the organic carbon content (Méndez et al., 2006). This is fundamental to determining soil quality, which is influenced by the combined effect of management on most of its properties, and determines agricultural productivity and sustainability (Sharma et al., 2005).

*Corresponding author E-mail: casensio@ual.es

Wind tunnels, which have both laminar and turbulent flow similar to real wind conditions, are used to control wind intensity, direction and shear, and material carried by it is collected in traps for later study. Feras et al. (2008) demonstrated that the efficiency of sediment traps in a wind tunnel study depended mainly on particle size and wind speed.

Martínez-Grana et al. (2014) stress the importance of mapping wind erosion risk to identify the protection necessary in territorial management and planning. Benlhabib et al. (2014) studied Mediterranean dryland cultivation systems, discussing and recommending sustainable technologies that show a significantly positive effect on crop productivity, yield stability and environmental sustainability. Hevia et al. (2007) found that no-till showed more large aggregates and fewer fine aggregates than traditional tillage. Tillage ridges are effective for trapping saltating aggregates but do not usually reduce erosion rates in soils where aggregates in suspension are predominant (Hagen et al., 2010).

Vegetation can reduce soil loss from wind, because it slows down the wind speed, lowers soil erosionability, and increases retention of eroded material (Abdourhamane Touré et al., 2011; Leenders et al., 2011; Lozano el al., 2013; Asensio et al., 2015). Udo and Takewaka (2007) in their wind tunnel experiments came to the conclusion that, in addition to vegetation density, height and flexibility are essential in determining its effectiveness in reducing soil mass transport by wind.

Our objective here is to provide a quantitative measure of soil loss from wind and study how it affects nutrient losses in different cereal soil types, including its economics.

MATERIALS & METHODS

The study area chosen is located in Campo de Nijar between coordinates 36º50' and 36º43' N and 2º01' and 2º31' E, in the SE of the Province of Almeria, where cereals were grown traditionally, but at present is mostly covered by greenhouses.

The geological material shows well-differentiated paleogeographic origins. To the north are sedimentary materials deposited from the Triassic to the Oligocene, to the south is the Mesomediterranean Microplate which collided with the Iberian Plate during the Lower Miocene, to the west, the Gibraltar Flysch Complex, made up of deep sediments from the Cretaceous Age to the Lower Miocene, appears, and to the east, volcanic outcrops are observed in Cape Gata (Marín, 2005).

The climate is characterized by scarce, irregular precipitation and high insolation. Due to its proximity to the sea, temperatures in the study area are rather gentle and there are no wide differences during the year. Data acquired from the Nijar Agroclimatic Station for 2001-2014 shows a mean annual temperature of 17.9ºC. Mean annual precipitation is about 190 mm, which makes it one of the zones with the least precipitation in Europe. There is an average of 35 rainy days per year, mainly in autumn-winter. Predominant winds in the study area vary depending on the season. In winter, N-NW winds predominate, while in summer winds are predominantly S-SW. The annual average of windy days is 70%, with a maximum mean daily wind speed of 6.8 $m \cdot s^{-1}$, which is used as the standard in the tunnel for our study. The reference for weather records was the Níjar Meteorological Station (located about 15 km far from the study area), one of the network of automatic stations belonging to the Institute of Agrarian and Fishing Research and Education of Andalusia, IFAPA (http://www.juntadeandalucia.es/agriculturaypesca/ifapa/ria/ servlet/FrontController), which is a dependency of the Andalusian Regional Government.

Although the study area presents a semiarid coastal Thermo-Mediterranean Murcia-Almeria jujube vegetation series (Alcaraz et al., 1989), in agricultural areas, cereal crops dominate.

The types of soil dominant in the study area are aric-haplic Calcisols, aric-calcareous Cambisols and aric-calcic Luvisols (according to IUSS Working Group WRB, 2014). The wind tunnel used (Asensio et al., 2013) has Fryrear BSNE particle traps (adapted for a fixed wind direction, Asensio *et al.*, 2015), located at different heights at the far end where dust is retained for later analysis and quantification of material loss (Fig. 1).

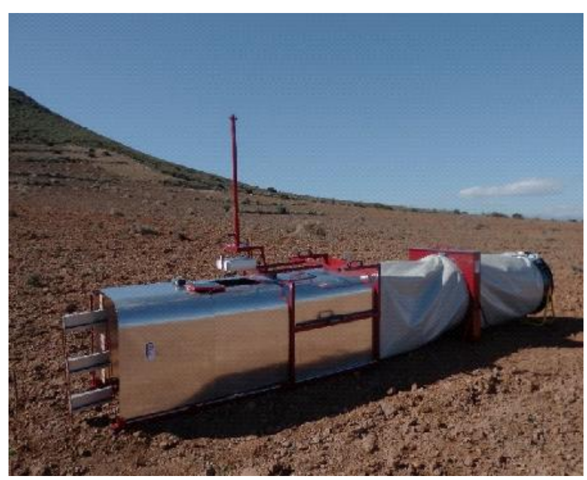

Fig. 1. Cambisol wind tunnel

Simulation blow is for a 10-minute exposure time, following criteria of Fister and Ries (2009). This device has a laser scanner which is run before and after each simulation, thereby producing two point clouds in each experiment (before and after wind simulation), and generating two digital terrain models (DTM) from them. The volume of eroded soil is estimated by the difference in volume between DTMs and erosion is mapped. From the volume of eroded soil found, we estimated the quantity of soil lost by means of the bulk density of each soil. The organic matter (OM) and nutrient (N, P_2O_5 and K_2O) losses resulting from the application of an artificial wind stream were analyzed as done by Lozano et al. (2013) who worked with adapted blowers and samples from BSNE particle traps. Sampling with traps placed at the end of the tunnel at 0, 15, 40 and 70 cm allows the particles carried by the wind by rolling (0 cm), saltation (15 and 40 cm) and suspension (40 and 70 cm) to be differentiated.

Soil samples were taken from the upper 3 cm. Ground samples were dried, crushed, and passed through a 2 mm sieve to eliminate large fragments. Ground and trap sample particle size distribution was assessed by dry sieving and the Robinson pipette method after eliminating organic matter with H_2O_2 (30%) and dispersion by agitation with sodium hexametaphosphate (10%). The sand fraction was separated by wet sieving, dried in an oven and later fractionated by dry sieving. The total organic carbon content (OC) was determined using the Walkley-Black wet digestion method (Nelson and Sommers, 1982). Total N (N) was calculated from NH_3 volumetry after Kjeldahl digestion. Available soil phosphate (P_2O_5) was calculated by colorimetry. Available soil potassium (K_2O) was calculated by flame photometry. Equivalent carbonate was determined by gas volumetry. To determine bulk density (BD), 100-cm^3 cylinders were used to refer to sample dry weight by cylinder volume. Variables under study were tested for normality by normal probability plot, Kolmogorov-Smirnov and Shapiro-Wilks tests, and their homoscedasticity by the Levene's test. Then a repeated measures ANOVA, in which the within-subjects factor was the tunnel and between-subjects effect was soil type, was done to compare the means and analyze any differences. The Friedman nonparametric test was also done as an alternative to the ANOVA. The level of significance was 0.05 in all tests. All the statistical techniques employed in the study were carried out with *SPSS 15.0*.

RESULTS & DISCUSSION

To analyze the volume of soil lost by wind erosion and its effect on nutrient loss, we did wind tunnel tests on crusted soil and immediately after tilling. Crusted soils were shown to be strongly protected from wind erosion, while immediately after tilling they were highly susceptible. After tilling, physical crust on the soil surface tended to reform within a period of eight to ten days, thus providing soil with additional wind protection. We therefore concentrated on recently tilled soils for which three samples were assessed with three repetitions of each. Mean soil characteristics before applying artificial wind recorded for three replicates of Calcisols, Cambisols and Luvisols (CLh_0, CMc_0 and LVk_0) are shown in Table 1. Later we analyzed texture, OC, N, available P_2O_5, available K_2O and $CO_3^=$ from a mixture of three samples of each soil type and three replicates of each after blowing, in order to obtain a large enough sample mass (Table 2).

The surface of these soils is very stony, and gravel averages 36% in CL, 42% in CM and 38% in LV.
The results of the scans in the wind tunnel only take a loss model into account. If deposits had also been considered, the erosion balance would have been more moderate. Nevertheless, in this study, we concentrated on losses and deposits in micro-plot, the laser scanner detection limit. As an example, images of Luvisol surfaces and their digital models are shown along with the result of scanning (erosion map) before (Figs 2 and 3) and after (Figs 4 and 5) tilling.

The average results for soil loss in crusted and tilled samples for the three typologies artificially blown in the tunnel with the same wind intensity are shown in Table 2. After tilling, these soils are rather susceptible to wind erosion, but in a short time, usually no longer than 10 days, they tend to stabilize due to formation of a physical crust on the surface. Dew, intense in the area, has an important role in stabilizing the soil surface and drastically reducing its erodibility. We therefore concentrated on working with recently tilled soils.

Focusing on tilled soils, Table 3 presents the analytical results of the samples collected in the traps at the end of the tunnel after mixing the soil mass collected in nine trials (three zones and three repetitions of each type of soil) at the different sampling heights. From a statistical point of view, the granulometric analysis of the trap samples shows that there is no reason for rejecting normality of the data. The repeated measures ANOVA shows significant differences in the fractions of very fine sand and coarse silt according to the Geiiser method, with p-values of 0.021 and 0.011, respectively, and the non-parametric Friedman test as an alternative to the ANOVA, provides p-values of 0.061 and 0.012 for the same parameters, confirming that very fine sand and coarse silt are the fractions most susceptible to loss due to the effect of wind. The same statistical analysis shows that the smallest differences in fertility appear in OC and K_2O, as shown by Zhao et

Table 1. Initial soil characteristics for the three soil types tested Data are means ± standard deviation in the three replicates before blowing

SOIL TYPE	% Very coarse sand	% Coarse sand	% Medium sand	% Fine sand	% Very fine sand	% Coarse silt	% Fine silt	% Clay
CLh0	0.2±0.0	4.7±0.2	5.8±0.3	1.5±0.1	11.9±0.8	32.6±1.2	19.5±0.8	23.8±1.8
CMc0	0.1±0.0	7.7±0.4	8.0±0.2	8.2±0.4	20.7±0.7	25.3±0.9	8.1±0.5	21.9±0.7
LVk0	0.0±0.1	4.9±0.1	6.8±0.4	8.4±0.6	23.2±1.1	24.6±1.6	6.5±0.2	25.5±1.0

SOIL TYPE	% OC	% N	Available P_2O_5 ($mg \cdot 100\ g^{-1}$)	Available K_2O ($cmol \cdot kg^{-1}$)	% $CO_3^{=}$
CLh0	1.01±0.07	0.033±0.005	5±1	0.52±0.04	37±4
CMc0	2.57±0.14	0.198±0.027	6±0	0.31±0.03	22±3
LVk0	1.78±0.32	0.265±0.015	3±1	1.37±0.11	3±1

SOIL TYPE	pH		E.C. ($dS \cdot m^{-1}$)	pF		A.W.C. (mm)	Bulk density ($g \cdot cm^{-3}$)
	H_2O	KCl		% H 33 kPa	% H 1500 kPa		
CLh0	7.84±0.12	7.41±0.09	5.72±0.41	28.147±0.527	12.436±0.345	33.4±0.9	1.26±0.01
CMc0	8.21±0.09	7.70±0.13	1.56±0.08	15.985±0.318	8.324±0.128	16.1±0.5	1.34±0.02
LVk0	7.78±0.07	7.42±0.11	3.27±0.24	12.751±0.114	7.274±0.084	10.8±0.2	1.37±0.02

Table 2. Average soil loss

SOIL TYPE		Laser-scanloss (mm)	Bulk density ($t \cdot m^{-3}$)	Wind erosion ($t \cdot ha^{-1}$)
CLh	Crusted	0.41	1.26	5.2
	Tilled	1.02		12.9
CMc	Crusted	0.18	1.34	2.4
	Tilled	0.84		11.3
LVk	Crusted	0.07	1.37	1.0
	Tilled	1.08		14.8

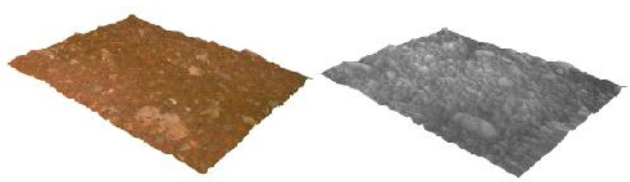

Fig. 2. Image of crusted LVk surface and DTM

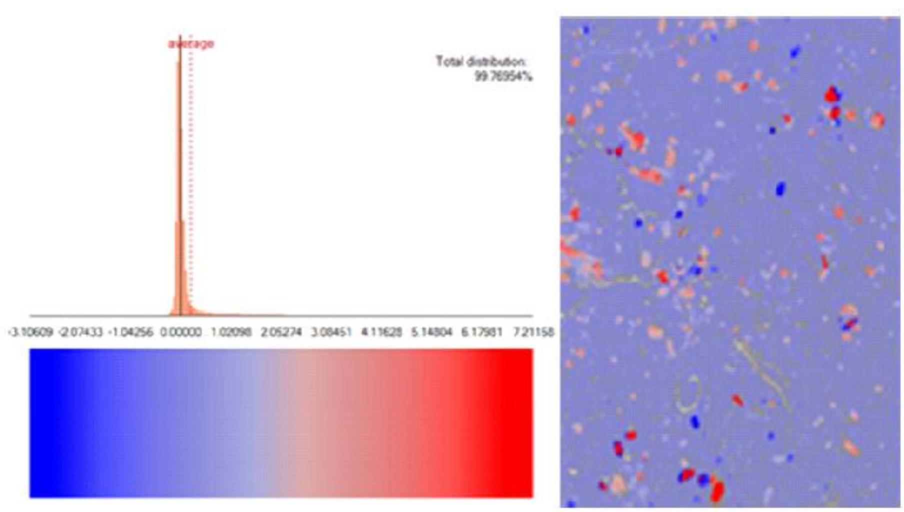

Fig. 3. Erosion map of crusted LVk

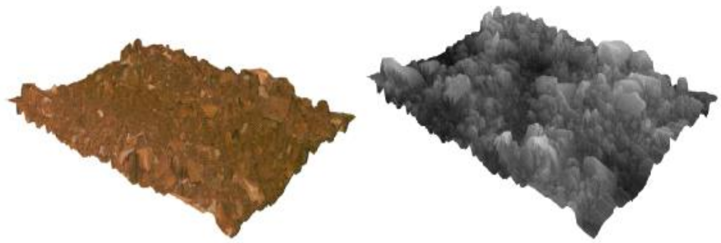

Fig. 4. Imagen of LVk surface and DTM after tilling

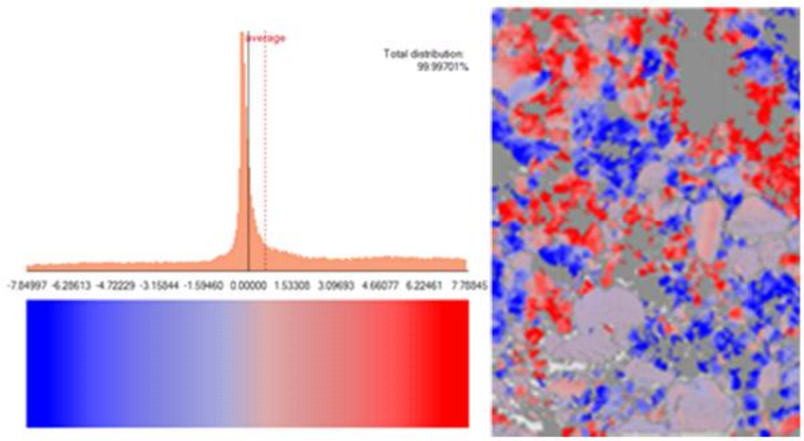

Fig. 5. Erosion map of LVk after tilling

Table 3. Characteristics of the three soil types tested at different trap sampling heights

SAMPLE	% Verycoarse sand	% Coarsesand	% Medium sand	% Fine sand	% Very fine sand	% Coarsesilt	% Fine silt	% Clay
CLh 0	0.0	1.2	1.8	2.3	12.2	29.3	25.2	28.0
CLh 15	0.0	0.1	0.3	1.8	16.4	39.6	16.3	25.6
CLh 40	0.0	0.1	0.3	0.3	12.2	41.6	17.7	27.8
CLh 70	0.0	0.0	0.2	0.2	6.6	45.1	20.4	27.5
CMc 0	0.1	5.5	6.5	8.0	21.1	23.9	12.3	22.6
CMc 15	0.0	0.2	0.5	6.8	28.0	32.3	9.1	23.2
CMc 40	0.0	0.0	0.2	0.3	18.0	42.5	13.7	25.3
CMc 70	0.0	0.1	0.3	0.2	18.3	43.3	7.1	30.8
LVk 0	0.0	5.2	10.4	10.5	19.7	25.2	6.5	22.5
LVk 15	0.0	0.0	0.2	9.7	32.3	30.5	5.2	22.1
LVk 40	0.0	0.1	0.2	0.2	25.0	39.9	8.4	26.1
LVk 70	0.0	0.0	0.2	0.3	12.9	46.7	13.2	26.6

SAMPLE	% OC	% N	Available P_2O_5 ($mg \cdot 100\ g^{-1}$)	Available K_2O ($cmol \cdot kg^{-1}$)	% $CO_3^{=}$
CLh 0	1.13	0.128	5	0.56	34
CLh 15	1.00	0.046	6	0.77	27
CLh 40	1.07	0.168	6	0.79	26
CLh 70	1.17	0.218	7	0.89	18
CMc 0	1.99	0.152	2	0.98	28
CMc 15	1.68	0.264	3	0.34	22
CMc 40	1.69	0.176	3	0.39	24
CMc 70	2.04	0.180	3	0.41	19
LVk 0	1.74	0.297	5	0.38	7
LVk 15	1.40	0.241	7	0.49	4
LVk 40	1.61	0.198	7	0.53	3
LVk 70	1.89	0.236	8	0.12	3

al. (2007), increasing in N and P_2O_5. Similar data were found in studies by Lozano et al. (2013) and Asensio et al. (2015) in the Tabernas Desert.

From the analytical data on the trap deposits at different heights, we observe how organic matter and nutrient transport is mainly by suspension and by rolling aggregated particles (higher values at 70 and 0 cm height). However, in $CO_3^{=}$ rolling predominates, followed by saltation and finally suspension.

The approximate cost of compensating for organic matter, N, P_2O_5 and K_2O losses calculated based on mineral fertilizers employed and average prices in 2014 (acquired from the *AsociaciónNacional de Fabricantes de Fertilizantes*, ANFFE, www.anffe.com) was as shown below for each soil typology in $€\cdot ha^{-1}$. Data are for the fertilizers most commonly used in the study area. Thus organic matter was replaced using cattle manure which has an average price of $10€\cdot m^{-3}$. When the cost of replacement is adjusted to product richness, we could talk about $0.04€\cdot kg^{-1}$ of OM to be compensated. Nitrogen is replaced using urea, which has an average price of $45€\cdot 100\ kg^{-1}$, and its replacement cost adjusted to richness is $0.45€\cdot kg^{-1}$ of N. Available phosphate is compensated with diammonium phosphate, which has an average price of $380€\cdot t^{-1}$. Replacement cost by richness is $0.33€\cdot kg^{-1}$ of P_2O_5. Finally, available potassium lost from the effect of wind is compensated for with KCl, which has an average price of $285€\cdot t^{-1}$, or $0.29€\cdot kg^{-1}$ of K_2O replaced. These costs, given the low crop productivity, make it necessary to also recommend that farming focus on savings in cultivation in general and in nutrient contributions in particular.

Data on organic matter and macronutrients lost in the different types of soil were adjusted to the area in the tunnel studied (second compartment, since the first is inoperative because it is protected by metal sheeting and the third by latex to keep the natural roughness of the soil and prevent undesired losses) which is 80 x 80 cm, and compared (Table 4). Loss of components for simulation was calculated based on the means of material analyzed in the traps and the data found previously on wind erosion (laser) for each soil typology.

In the study area, the mean maximum wind speed is 6.8 $m\cdot s^{1}$ (standard blower speed used with the tunnel), while the mean wind speed is 1.9 $m\cdot s^{1}$. If these soils are plowed twice a year, and the soil is crusted ten days after that, we can make an idealization of a loss model (not considering deposits) in which there are gusts of 6.8 $m\cdot s^{1}$ on 20 days, and the rest of the year, the crusted soil appears to be protected from the wind. Thus the costs of regenerating organic matter and macronutrients lost from the effect of the wind during the year would depend on the number of gusts during those 20 days, possibly depleting soil or surface moisture when several gusts overlap. Those costs could be as high as 52.8, 43.95 and 37.96 $€\cdot ha^{-1}\cdot yr^{1}$ at 2014 prices for Calcisol, Cambisol and Luvisol soils respectively, observing that the costs of regenerating Luvisol are around a third lower than in Calcisol, even though the highest absolute wind erosion values were

Table 4. Data adjusted for area, estimated loss and restoration cost for different soil types

SOIL TYPE	Variable	Average intraps	Adjust average· m^{-2}	Loss ($kg\cdot ha^{-1}$)	Restore ($€\cdot ha^{-1}$)
CLh	OM	1.87 %	2.92 %	3.77	0.15
	N	0.140 %	0.219 %	0.28	0.13
	P_2O_5	6 $mg\cdot 100\ g^{-1}$	9 $mg\cdot 100\ g^{-1}$	0.01	0.00
	K_2O	0.75 $cmol\cdot kg^{-1}$	1.17 $cmol\cdot kg^{-1}$	14.19	4.12
	Simulation balance				**4.40**
CMc	OM	3.19 %	4.98 %	5.63	0.23
	N	0.193 %	0.302 %	0.34	0.15
	P_2O_5	3 $mg\cdot 100\ g^{-1}$	5 $mg\cdot 100\ g^{-1}$	0.01	0.00
	K_2O	0.53 $cmol\cdot kg^{-1}$	0.83 $cmol\cdot kg^{-1}$	8.81	2.55
	Simulation balance				**2.93**
LVk	OM	2.86 %	4.47 %	6.62	0.26
	N	0.243 %	0.380 %	0.56	0.25
	P_2O_5	7 $mg\cdot 100\ g^{1}$	11 $mg\cdot 100\ g^{-1}$	0.02	0.01
	K_2O	0.38 $cmol\cdot kg^{-1}$	0.59 $cmol\cdot kg^{-1}$	8.29	2.40
	Simulation balance				**2.92**

recorded for it. These costs would increase with restoration of micronutrients and soil water dried out by the wind. Additionally, it is recommended that straw and crop residues be plowed under and crops be rotated with legumes, such as *Vicia sativa*, which increase productivity because of the value of their nitrogenated residues when they are plowed under.

CONCLUSIONS

Soil crusting after tilling, favored by the strong effect of dew, protects it from wind erosion. The erosion balance, insofar as a total balance of soil material lost, is lower in calcareous Cambisols, increasing in haplicCalcisols and calcic Luvisols. However, we observed higher loss of organic matter and N in Cambisols than in Calcisols, probably due to soil conditions related to their aggregation.

Assuming that soil is plowed twice a year, the approximate cost, based on average prices in 2014 for organic and mineral fertilizers commonly used in the area to restore calculated organic matter, N, P_2O_5 and K_2O losses from wind are about a third lower in Luvisols than in Calcisols, even though they loses a higher absolute soil volume. The costs in some cases are hard for the owner to assume because of the low productivity of the crop, so it is recommended that other farm work focus on saving in cultivation in general and in nutrient contributions in particular.

ACKNOWLEDGMENTS

The authors are grateful to Deborah Fuldauer for the English translation of the manuscript. This work was funded by the Andalusia Regional Government (RNM 3614 grant), and European Union ERDF funds.

REFERENCES

AbdourhamaneToure, A., Rajot, J.L., Garba, Z., Marticorena, B., Petit, C. and Sebag, D. (2011). Impact of very low crop residues cover on wind erosion in the Sahel. Catena, **85(3),** 205-214.

Alcaraz, F., Díaz, T.E., Rivas Martínez, S. and Sánchez Gómez, P. (1989). Datos sobre la vegetación del sureste de España: provincia biogeográfica Murciano-Almeriense. Itinera Geobotánica, **2,** 5-133.

Asensio, C., Giménez, A., Amador, M.V., Torres, J.A. and Lozano, F.J. (2013, February). Nuevo sistema para la evaluación de la erosión eólica. (Paperpresented at the VI Simposio Nacional sobre Control de la Degradación y Restauración de Suelos, Almería, Spain).

Asensio, C., Lozano, F.J., Ortega, E. and Kikvidze, Z. (2015). Study on the effectiveness of an agricultural Technique based on aeolian deposition, in a semiarid environment. Environmental Engineering and Management Journal, **14(5),** 1143-1150.

Benlhabib, O., Yazar, A., Qadir, M., Lourenço, E. and Jacobsen, S. E. (2014). How can we improve mediterranean cropping systems? Journal of Agronomy and Crop Science, **200(5),** 325-332.

Feras, Y., Erpul, G., Bogman, P., Cornelis, W.M. and Gabriels, D. (2008). Determination of efficiency of Vasaline slide and Wilson and Cook sediment traps by wind tunnel experiments. Environmental Geology, **55,** 741-757.

Fister, W. and Ries, J.B. (2009). Wind erosion in the central Ebro Basin under changing land use management. Field experiments with a portable wind tunnel. Journal of Arid Environments, **73,** 996-1004.

Hagen, L.J., van Pelt, S. and Sharratt, B. (2010). Estimating the saltation and suspension components from field wind erosion. Aeolian Research, **1,** 147-153.

Hevia, G.G., Mendéz, M.J. and Buschiazzo, D.E. (2007). Tillage affects soil aggregation parameters linked with wind erosion. Geoderma, **140,** 90-96.

IUSS Working Group WRB. (2014). World Reference Base for Soil Resources 2014. International soil classification system for naming soils and creating legends for soil maps. World Soil Resources Reports No. 106. FAO, Rome.

Leenders, J.K., Sterk, G.and Van Boxel, J.H. (2011). Modelling wind-blown sediment transport around single vegetation elements. Earth Surface Processes and Landforms, **36(9),** 1218-1229.

Li, F.R., Zhao, L.Y. and Zhang, T.H. (2004). Wind erosion and airborne dust deposition in farmland during spring in the Horqin Sandy Land of eastern Inner Mongolia, China. Soil & Tillage Research, **75,** 121-130.

Liu, L.Y., Shi, P.J., Zou, X.Y., Gao, S.Y., Yan, P., Li, X.Y., Dong, Z.B. and Wang, J.H. (2003). Short-term dynamic of wind erosion of three newly cultivated grassland soils in Northern China. Geoderma, **115,** 55-64.

Lozano, F.J., Soriano, M., Martínez, S. and Asensio, C. (2013). The influence of blowing soil trapped by shrubs on fertility in Tabernas district (SE Spain). LandDegradation&Development, **24,** 575-581.

Marín, C. (2005). *E*structura y evolución tectónica reciente del campo de Dalías y de Níjar en el contexto del límite meridional de las cordilleras béticas orientales. Tesis Doctoral Universidad de Granada. (Granada: Editorial Universidad de Granada).

Martínez-Grana, A.M., Goy, J.L. and Zazo, C. (2014). Water and wind erosion risk in Natural Parks-A case study in "Las Batuecas-Sierra de Francia" and "Quilamas" protected Parks (Central System, Spain). International Journal of Environmental Research, **8(1),** 61-68.

Méndez, M.J., Oro, L.D., Panebianco, J.E., Colazo, J.C. and Buschiazzo, D.E. (2006). Organic carbon and nitrogen in soils of semiarid Argentina. Journal of Soil and Water Conservation, **61,** 230-235.

Nelson, D.W. and Sommers, L.E. (1982). Total carbon, organic carbon, and organic matter, In: Page, L.A., Miller, R.H., Kenney, D.R. (Eds.), Methods of Soil Analysis. Part

2. Chemical and Microbiological Methods, 2nd edition. American Society of Agronomy, Madison, Wi, pp. 539-579.

Sharma, K.L., Mandal, U.K., Srinivas, K., Vittal, K.O.R., Mandal, B., Grace, J.K. and Ramesh, V. (2005), Long term soil management effects on crop yield and soil quality in a drylandAlfisol. Soil &Tillage Research, **83(2),** 173-286.

Skidmore, E.L. (2000). Air, soil, and water quality as influenced by wind erosion and strategies for mitigation. (Paper presented at the Second International Symposium of New Technologies for Environmental Monitoring and Agro-Applications Proceedings, Tekirdag, Turkey).

Udo, K. and Takewaka, S. (2007). Experimental study of blown sand in a vegetated area. Journal of Coastal Research, **23(5),** 1175-1182.

Vaezi, A. R. and Bahrami, H. A. (2014). Relationship between Soil Productivity and Erodibility in Rainfed Wheat Lands in Northwestern Iran. Journal of Agricultural Science and Technology, **16(6),** 1455-1466.

Zhao, H.L., Zhou, R.L. and Drake, S. (2007). Effects of aeolian deposition on soil properties and crop growth in sandy soils of northern China. Geoderma, **142,** 342-348.