Shows Water and Wind Erosion use on Site Relative Impact on Total Soil Erosion

MADHAVI VALISHETTY, RESEARCH SCHOLAR, SRI SATYA SAI UNIVERSITY OF TECHNOLOGY & MEDICAL SCIENCES, SEHORE

DR. DASA KARUNAKAR, ASSOCIATE PROFESSOR, GOVT. DEGREE COLLEGE, SADASIVPET, TS

ABSTRACT

Relative effects of water and wind on total erosion were investigated an Experimental-Empirical Study. Wind erosion and water erosion were measured five different Sites: (1) Mediterranean fallow, (2) Mediterranean garden, (3) wheat field, (4) vineyard and (5) Sand fertile. Mean erosion rate ranged from 1.55 to 618 g · m – 2 H-1 For air and from 0.09 to 133.90 g · m - 2H-1 Material decay due to rain at all test sites. Percentage of sediment destroyed (%) Wind and rain, respectively, were found at 2:98 on the Mediterranean Sea, 11:89 on the Mediterranean Sea Orchard in wheat field, 3:97, 98: 2 on vineyard and 99: 1 on sand substrate. For special case of clay surface layer destroyed by goat trapping, measured value emphasizes a strong potential effect herring on total soil erosion. All sites cause erosion from wind and rain, and show relationships both soil erosion can have an impact on total soil erosion depending on the characteristics of the site. The results specifically indicate a strong need to focus on both the associated wind and water erosion. Soil and fertile in vulnerable environments. Measured rates indicate a general potential decline depending on the recent development of land use and climate change and can raise awareness regarding the potential impact of the elimination forces of both scientists, farmers and decision makers. Knowledge accurate correlation is key to an accurate land use management with considerable potential reducing degradation processes related to climate change.

Keywords: Soil Erosion; Wind Erosion; Rain Erosion; Geomorphological Experiments

1. Introduction

Risk assessment and prediction of hydrological and nomological effects on soil erosion rate challenges and most urgent tasks are the same for scientists, politicians and food producers in the early 21st century [1,2]. Among the effects are ecological consequences such as low soil depth including adverse conditions for contamination of soil organisms and related surface waters sediment as well as socio-economic implications such as low soil productivity, contaminated direct health risks associated with drinking water and dust production [3,4]. The major erosive forces are water and air. In most environments, both wind and rain are active climate factors and total soil loss may be potential contributors, but most studies specifically focus on one factor.

The extent and extent of each immature force depends on several variables in varying proportions - temporal. Scales [5,6]. For both types of erosion, risk maps are available for different scales that estimate potential soil losses for a given area based on general information related to soil and surface properties combined with climate data [CLIME-10]. These are helpful for map science communication, highlighting common parameters, regional specifications and interrelationships in the soil erosion complex. However, they should not fully define research efforts and studies design, especially in the deepest light of climate change and land use demands.

The process of air and water erosion is similar to the general structure of detachment, transport and Accumulation [11]. Both types of erosion involve multiple tempo-spatial scales and a variability that is greatly complicating a comprehensive assessment. Harmful the possibility of extreme wind events is counted among the most devastating natural hazards [12,13]. Due to climate change, high intensity wind storms can pose a new threat to many people in the medium term due to either high wind power [14] or extended residence time [15]. IPCC 2014 (AR5) [16], Wind speed and spatial development of heavy storms incidence is a factor of high uncertainty, but the relative impact of high peak wind events on the total global wind erosion has not yet been evaluated. Wind erosion is not necessarily attributed to extreme events. But moderate to moderate air velocities can be reduced. Chepil and Woodruff [17] found 4.5 m · s. C 1 o'clock 0.3 m height (6 m · s) A1 at a height of 10 m) is sufficient to move dry particles and is below 0.1 mm diameter smooth condition. Wind velocity in this range can be considered very normal in many regions of the world during considerable parts of the year [18].

Still, the amount and tempo-spatial extent are highly speculative and quantitative data are rare.While traces of soil erosion by water are often evident in the field even at smaller extent, Chepil [19] estimated that soil of up to 40 t ha–1 can be eroded per year unnoticed. This is particularly problematic due to the sorting action of wind, which mainly affects the finest particles silt and clay as well as soil organic matter and soil nutrients such as phosphorus [20]. For Middle Europe, Funk et al. [12] estimated 20% of arable land is threatened by wind erosion and Buschiazzo et al. [21] state that spatial extent of wind erosion has increased in the past decades. In the recent IPCC Special Report (SRCCL), Pörtner et al. [22] define land use and land use change as a major trigger for global soil erosion and land degradation and indicates that appropriate land use is crucial to mitigate climate change effects. The extent of wind erosion and related processes is particularly mentioned as a growing threat to agricultural soils [22]. In contrast, water erosion has long been recognized as the main factor generating soil erosion globally and in most European environments [23], and focused as a main threat for ecological and socio-economic stability [24,25]. This may also be caused by the fact that water erosion-related processes generate easily recognizable forms such as rills, gullies and alluvial fans of different sizes. Besides each erosion agent’s specific effects on soil erosion rates and land degradation, Ravi et al. point out possible interactions between both processes over time and space [26] which is especially true for arid and semi-arid areas [27].

To focus on processes and amounts on small scale and with high accuracy, on-site measurements by means of the Trier Portable Wind and Rainfall Simulator (PWRS) were conducted. The degree of impact of wind and rain on soil erosion is determined by soil surface properties related resilience to particle detachment, which is a consequence from effects and interactions between surface characteristics such as roughness, slope, aggregate stability and stone/vegetation/seal-cover [24]. The spatial variability of wind erosion is particularly strong and depends on partly slight variations of the surface [28]. Since experimental studies are mostly conducted by means of disturbed soil samples, a comprehensive assessment of soil surface response is still very difficult to obtain. A particular advantage of the experimental setup presented here is the possibility to study soils and substrates in situ. Elaborate studies highlight physical parameters of single aspects of transport processes by wind [29–31], runoff [32–35], windless raindrops [36,37] and wind-driven rain [38–40] under homogeneous, simplified substrate conditions or modelling approaches. Experimental in situ studies on soil and substrate surfaces under largely undisturbed conditions are often the only source of information about natural substrate response and are therefore of great importance to complement findings from laboratory setups and increase process understanding. The main objectives for the empirical-experimental study are to test different soils and substrates for their specific response in terms of soil erosion by wind and water to deepen the process understanding beyond traditional views, and to calculate site-specific relative impact of each erosion agent, which can be calculated to approach key parameters corresponding to soil or substrate surface, management and climate.

We hypothesize that:

1. All tested soil surfaces produce soil erosion due to action of wind and rain.

2. The relative impact of soil erosion agent differs corresponding to site characteristics.

2. Materials and Methods

2.1. Locations and Surface Characteristics

Tests were performed on five different types of surfaces representing particular environments. Table 1: (1) Mediterranean fallow, (2) Mediterranean orchard, (3) wheat field, (4) vineyard, and (5) sand substrate (Figure 1).

Table 1. Characteristics of soils and substrates of test sites. Every row presents one test.

Site	Vegetation	Crust	Substrate (Including Stones)		Slope	Texture	Roughness	C_{org}	H_2O SoiL
			[%]						
	[%]	[%]	<2 mm	>2 mm	[°]		[Cr]	[%]	[%]
Mediterranean fallow	15	20	0	65	11	SiL	5.2	0.4	4
	15	30	0	55	5	SiL	10	0.7	4
	25	25	0	50	8	SiL	5.2	0.4	3
	15	70	0	15	5	SiL	5.2	0.4	3
	20	65	0	15	5	SiL	5.2	0.4	3
	15	20	0	65	7	SL	5.2	0.4	0.5
Trampling	10	20	30	40	5	SiL	6.6	0.4	0.9
Mediterranean orchard	0	0	30	70	6	SiL	15	1.2	3
	0	0	35	65	4	SiL	15	1.2	3
	0	0	20	80	8	SiL	10.2	4.1	0.9
Wheat field	5	0	30	65	11	CL	18	2.5	47
	30	0	15	55	9	CL	24	3.5	47
	30	0	15	55	8	CL	24	3.5	47
	30	0	15	55	7	CL	24	3.5	47
Vineyard	0	0	5	95	7	SiL	17	3	0.7
	0	0	5	95	8	SiL	17	3	0.7
Sand substrate	0	0	100	0	1	FS-MS	0	2.9	1
	0	0	100	0	1	FS-MS	0	2.9	1
	0	0	100	0	1	FS-MS	0	2.9	1
	0	0	100	0	1	FS-MS	0	2.9	1

Texture: silt loam (SiL), sandy loam (SL), clay loam (CL), fine to medium sand (FS-MS); C_{org} = organic carbon; Soil H_2O = soil water content.

The environmental conditions of test plots were chosen according to recent developments in soil erosion research. All sites comprise a “hot-spot”-character concerning land use change and climate change. Agricultural sites are particularly threatened due to the combined action of management practices and climatic impact and often provide optimal conditions for both types of erosion including vast parcels and bare or sparsely vegetated surfaces during one or more stages of the cultivation cycle. Particularly vulnerable ecosystems such as semi-arid environments, which are widespread in the Mediterranean region, may respond with increased soil degradation and nutrient depletion, leading to desertification in the course of even minor land use or climatic changes [41]. The tested soils and substrates meet current research demands as stated by Poesen et al. [42] who see a research gap concerning erodibility of extreme substrates such as very fine-textured, very sandy and also stony substrates. An overview on the different landscape types and respective test surfaces is presented in Figure 1. Accordingly, the relating soil and surface characteristics of each type are aggregated in Table 1.

Figure 1. Photographs of five test environments (left) and exemplary test plots (right).

2.1.1. Mediterranean Fallow

The seven test plots of this site are located in Granada Province, Andalusia, at the easterly foothills of the Betic cordillera close to Baza at the catchment of reservoir Embalse de Negratín. The northern borders of the intramontane basin Hoya the Baza forms the border between the southernmost mountain range of the Betic Cordilleras, the Penibaetic System, and the Subbaetic System. Climatic conditions are semi-arid, including high-erosive torrential rainfalls normally occurring during spring and autumn, which account for the greatest part of annual precipitation of 200 to 350 mm and an annual mean temperature of 14.6 ◦C. [43,44]. As part of the post orogenic formation of the Guadalquivir basin, the Pliocene-Pleistocene pediment-landscape has been developing from Pliocene sediments and consists of marls with calcareous crusts [45]. The soils are severely degraded, calcaric Regosols (siltic and loamic) [46] and Leptosols [47] and have a very low Corg content (ca. 0.5%). The surface is covered by a very strong, more than 10 mm thick, physical depositional crust [48]. The potential impact of physical soil crusts is complex and varies immensely with particle structure, soil moisture and time [49,50]. They may delay actual soil detachment particularly for wind erosion [51] but show a strongly reduced infiltration capacity and are therefore very prone to runoff development, often leading to interrill- and rill-erosion [47,50,52,53]. One of the most important characteristics is the patchy distribution of semi-natural Garrigue-vegetation, which is a degradation stage of Mediterranean Maquis (Holm oak) succession. The plants are herbs, dwarf shrubs and sclerophyllous plants (e.g. Thymus vulgaris, Genista scorpius, Rosmarinus officinalis, Artemisia herba-alba, Lygeum spartum, Stipa tenacissima).

2.1.2. Trampling (Goats)

One test was set up to measure the impact of fresh goat trampling on the amount of eroded sediment. The test site was chosen to resemble other plots of the strongly crusted and degraded substrates, thus highlighting the impact of herding and trampling. Due to the complicated test procedure, which included the handling of animals, only one test was conducted that can give a hint to the approached question. The “Trampling (Goats)” test was not included in the group for statistical analysis but listed with only two values for comparison with other groups.

Management and Vulnerability

Experiments were conducted in a landscape of fallow land (of age 1 to >15 years) with extensive transhumance-related trampling and grazing pressure. The development of a protective vegetation coverage takes years and might be entirely prevented by grazing and trampling [52,54]. The sites are representative for large parts of the Mediterranean [48], which is considered a hot spot of climate change impact and prone to the expected effects of global change [55]. Concerning development of wind erosivity, most projections show a very likely decrease of cyclones and windstorms [56] but a higher probability to develop the hazardous category 1 strength [57].

2.1.3. Mediterranean Orchard

The three sites include two freshly ploughed olive orchards and one mango plantation in the process of construction. The orchards were also situated at the semi-arid Hoya de Baza with similar geomorphological, climatic and geological conditions (see Mediterranean fallow). The test on mango plantation was performed in the traditional wine region of Almáchar, Malaga in Southern Spain. Mean annual rainfall is 520 mm and mean annual temperature is 17.2 ◦C. Both soil substrates consisted of freshly tilled, shallow (0.3–0.4 m) calcaric Regosols with silty sand and loam as fine soil, forming a loose substrate of single grains or small aggregates, including a high stone content of fine and coarse gravel size. The recently ploughed olive orchard had a Corg content of 1.2% and the site freshly terraced for mango plantation a Corg content of ca. 4.1%. The very low Corg content of <2% (corresponding to about 3.5% organic material) can be classified as very prone to erosion [58], while the higher Corg content in the mango terrace may be due to mixing of substrate layers and available material from the surrounding.

Management and Vulnerability

Albeit extreme shallow and nutrient-poor soil substrates, traditional dry farming and also irrigated farming systems are installed not only on plains but very often on steeper slopes. For that purpose, the slopes are terraced by means of excavators and caterpillars, mixing and rearranging the soil substrate and altering chemical and physical parameters that also affect slope stability. The soil surface is generally bare throughout the year. The conversion of mainly stable hillslopes to new terraced plantations can be assumed as general practice in this area and also for larger parts of the Mediterranean. It is thus a recent land use change on a larger spatial scale that may have considerable effects with serious implications for slope stability and substrate mobilisation.

2.1.4. Wheat Field

The wheat field test sites La Tejería and Latxaga are located at the central western respectively central eastern part of Navarre in northern Spain at the south-western foothills of the Pyrenees. The climate is humid sub-Mediterranean with a mean annual precipitation of 755 to 861 mm and mean annual temperatures of 11.8 to 12.3 ◦C. The geology of this region comprises of clay marls, Pamplona grey marls, and sandstones, on which Vertic Cambisols developed with a silty clay and loamy structure. The soils are moderately shallow (0.5 to 1 m deep). The Corg content at both sites ranges between 2.5 to 3.5% and the fields were vegetated by young winter grain plants. The very high initial water content (47%) by the time of tests is common for this area at the time of year and is certainly one of the most important factors affecting measured soil erosion.

Management and Vulnerability

The agricultural fields were vegetated by young winter grain plants. They are part of a network of experimental agricultural watersheds of the Government of Navarre that comprise small watersheds (0.01 to 102 km2) with mainly agricultural land use with grains, vegetables or cattle and both contour-parallel and downhill tillage. Water erosion problems are common including high output of dissolved solids and suspended sediments [59,60]. Wind erosion can be assumed an important factor, particularly during periods of seedbed preparation. The sites can be considered representative for large parts of northern Spain [61]. The sites also resemble many other European agricultural environments; i.e., concerning management (non-irrigated, ploughed, winter grains, bare during particularly rainy periods, partly disadvantageous tillage practices) and soil character.

2.1.5. Vineyard

Four tests were performed in the traditional wine region of Almáchar, Malaga (Southern Spain). It is located at the southernmost Betic Cordillera mountain range Montes de Málaga. Mean annual rainfall is 520 mm and annual mean temperature 17.2 ◦C. The soil substrates are very shallow Eutric Leptosols developed on Palaeozoic dark metamorphic schist and quartzite with a coarse soil percentage of ca. 70% and total organic carbon of ca. 3% [62,63].

Management and Vulnerability

Management of the vineyards includes traditional steep slope viticulture practices such as manual topsoil working by means of hoes and application of organic manure (animals) and herbicides. The specific challenges of steep slope viticulture include a potentially high susceptibility to water erosion processes due to extreme slope angle and a subsequent constant threat of depletion from fine sediments including organic substance and nutrients [64]. Due to high stone content and lacking fine soil material at the surface, the substrates would not be considered prone to wind erosion.

2.1.6. Sand Substrate

The eight tests on this site were conducted on a semi-natural substrate at a roofed test field of Wageningen University in the Netherlands [65]. We chose this setting to investigate particularly sandy substrates such as found in the Netherlands, Belgium and northern Germany. They appear most often in costal zones and in inland dune areas, but are not completely restricted to these locations. The substrate could be addressed as Arenosol but is not addressed as soil here for the reason that it had been frequently disturbed and real soil development or horizons were not noticed. The substrate consisted mainly of fine (52%) and medium sand (35%), had a Corg content of 2.9% and was nearly bare of other considered aspects such as vegetation, stones or crust.

Management and Vulnerability

Agricultural use of sandy substrates is often associated with permanent pastures and forest. The substrate's grain size distribution is suitable to represent coastal areas with dunes and beaches [66] that are particularly valuable in terms of coastal protection and generally threatened due to their exposition to wind and rain. This type of sandy substrate is also found at drifting sand areas of Belgium and the Netherlands, both generally managed as conservation area due to their crucial ecological function and vulnerability.

2.2. Experimental Procedure

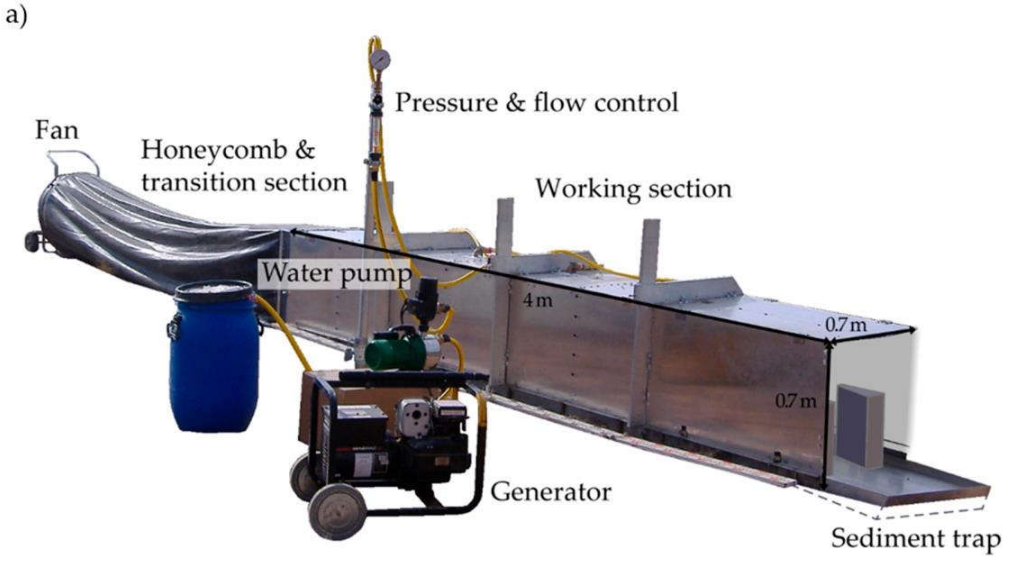
Tests were conducted on in situ soil surfaces using the Trier Portable Wind and Rainfall Simulator (PWRS) (Figure 2a). For the tests presented in this study, the PWRS was used to apply wind and rainfall, including runoff generation. Compared tests were performed in a sequence (first, wind simulation; secondly, rainfall simulation) on the same test plot in order to keep substrate response due to spatial variability as low as possible and thus to measure the impact of erosion agents as explicitly as possible. The generated processes during the "rain"-test are mostly related to raindrop splash, (raindrop impacted) sheet erosion and initial rill development. The test device is known to be reliable regarding reproducibility of air-stream and rainfall as well as properties of the simulated rainfall [67,68]. Average wind velocity was 7.5 m s^{-1} at 0.3 m height. Compared to natural conditions, the generated rainfall represents a highly erosive heavy rain event, while wind is of a comparably lower intensity with the Beaufort scale number 5 ("fresh breeze"), which is adequate for wind erosion processes to be initiated [20,69]. Figure 2b shows the parameters of the test device.

Test plots were chosen as representative surfaces for five sites (Figure 1). Since micro-conditions between plots always differ and create variability in measured rates, repetitions are used to gain representative information about processes on a larger area. We estimated vegetation, stones and crust cover in percent of area, as important surface characteristics by visual observation of the respective test plot in the field. Inclination was measured in the field. Soil Corg was measured by loss on ignition at 500 ◦C and gravimetric soil water content (%) was measured by drying at 105 ◦C in the laboratory. Roughness was approached after [70]: Cr =

(1 − L2/L1) × 100 with L1 = length of chain and L2 = length of plot. Test duration was 30 minutes for rain and 10 minutes for wind tests. Eroded material detached from the 2.2 m2 test area was collected by means of Wedgetraps (wind) and a gutter (rain/runoff),

filtered (Munktell©, production number 3.104.185, <2 µm mesh-width), dried (105 ◦C) and weighed.

Results were calculated to rates g·m−2·h−1.



b)

v_w [m s^{-1}]	I [mm h^{-1}]	d_{50} [mm]	v_r [m s^{-1}]	KE_R [J m^{-2} h^{-1}]	KE [J m^{-2} mm^{-1}]
7.5	96	1.5–2.0	2.2–2.6	270.8	5.21

Figure 2. (a) Portable Wind and Rainfall Simulator (PWRS). (b) Main wind and rainfall characteristics: mean wind velocity [vw], mean rainfall intensity [I], mean volumetric drop diameter [d50], drop fall velocities for drops of the size d50, mean kinetic energy expenditure [KER], and mean kinetic energy per unit area per unit depth of rainfall [KE] [from [65]].

The experimental setup's specification, such as the applied test sequence and physical limitations, are addressed in [40,65]. It is necessary to be aware of the general problems concerning interpretation and upscaling of experimental data so that the information can be adequately applied. The experiments fill the gap between "observation" and "model" and provide valuable data that are basis for process understanding and reliable modelling.

2.3. Statistical Analysis

Since not all data groups were normally distributed (Kolmogorov-Smirnov/Shapiro Wilk), Kruskal-Wallis (H-test) and Dunn-Bonferroni-Post-hoc-tests were performed to find central tendencies in the datasets. Correlation analysis was performed using the Spearman rank coefficient. Simple comparison may still be conducted by calculation of the mean. Statistical tests were performed with SPSS Statistics 25 [71].

3. Results

In total, 40 plot-scale experiments were conducted, of which 20 tests were wind simulations and 20 rainfall simulations on corresponding 20 test plots at the five presented sites (Table 2). Mean erosion values for each erosive agent ranged from 1.55 to 618 g·m−2·h−1 for wind and from 0.09 to133.9 g·m−2·h−1 for rain eroded material over all tested sites. The highest rain erosion rates (295.47 and 219.86 g·m−2·h−1) were measured on crusted Mediterranean fallow land, while the lowest rates (0.00 and 0.19 m−2·h−1) were measured on slate covered vineyard soils. Sand substrate was most susceptible to wind erosion (908.19 g·m−2·h−1), while minimum wind erosion was measured on water saturated winter wheat fields (0.10 g·m−2·h−1).

Table 2. Results of all tests. Each row represents one (wind or rain) test on a respective test plot.

Site	Eroded Material $[g\ m^{-2}\ h^{-1}]$		Mean $[g\ m^{-2}\ h^{-1}]$		Ratio		Ratio Mean
	Wind	**Rain**	**Wind**	**Rain**	**Wind**	**Rain**	**Wind/Rain**
Mediterranean fallow	0.95	295.47	2.66	133.9	0.3	99.7	2:98
	1.27	14.89			7.8	92.2	
	3.84	60.34			6.0	94.0	
	3.7	155.31			2.4	97.7	
	2.39	57.54			4.0	96.0	
	3.81	219.86			1.7	98.3	
Trampling (goats)	4.41	151.36	-	-	2.8	97.2	-
Mediterranean orchard	4.5	61.48	4.73	44.00	6.8	93.2	10.5:89.5
	3.45	59.08			5.5	94.5	
	6.23	11.43			35.3	64.7	
Wheat field	0.1	29.05	1.55	50.29	0.4	99.6	3.0:97.0
	1.27	56.95			2.2	97.8	
	3.84	30.24			11.3	88.7	
	0.98	84.92			1.1	98.9	
Vineyard	1.86	0	6.26	0.09	100.0	0.0	98.5:1.5
	10.65	0.19			98.3	1.7	
Sand substrate	185.67	0	618.62	6.05	100.0	0.0	99.0:1.0
	554.88	9.18			98.4	1.6	
	908.19	9.73			98.9	1.1	
	825.75	5.27			99.4	0.6	

We measured highest mean water erosion rate (133.90 g·m−2·h−1) on Mediterranean fallow with 14.92 g·m−2·h−1as the lowest and 295.47 g·m−2·h−1 as the highest value. For wind erosion, we found a low mean rate compared with all other tested environments (2.66 g·m−2·h−1). While some plots produce low wind and rain erosion, others produce high wind erosion but low rain rates and vice versa. With 151.36 g·m−2·h−1, rain erosion on the trampling (goats) plot exceeds average erosion on Mediterranean plots (133.90 g·m−2·h−1). Wind erosion rate 4.41 g·m−2·h−1 is also one of the highest measured on all Mediterranean plots and twice the value of mean erosion on all Mediterranean plots (2.66 g·m−2·h−1). In comparison to mean rain erosion rate on crusted sites (133.90 g·m−2·h−1), the rate on Mediterranean orchard soils are much lower (44 g·m−2·h−1), but mean wind erosion rate is significantly higher (4.73 and 2.66 g·m−2·h−1, respectively). On down-hill directed clod-furrow pattern, a much greater transport rates for rain (61.48 and 59.08 g·m−2·h−1) were measured than on the plantation under construction without such features (11.43 g·m−2·h−1). Wind erosion is lower on orchard soils (4.5 and 3.45 g·m−2·h−1) than on plantation under construction (6.23 g·m−2·h−1), which is also the second highest value from all tests apart from the sand sediment. On wheat field, the lowest wind erosion rates (mean 1.55 g·m−2·h−1) and second highest water erosion rates (mean 50.29 g·m−2·h−1) of all sites were measured. The mean erosion rates on the vineyard substrate are comparably low in the case of water erosion (0.08 g·m−2·h−1) and second highest for wind erosion (6.26 g·m−2·h−1), but with a very high variability. Water erosion on the sand substrate was comparably low (6.05 g·m−2·h−1), but it produced the highest wind erosion rates with a mean rate of 618.62 g·m−2·h−1 and highest rate of 908.19 g·m−2·h−1. Figure 3 shows the data arranged as boxplots.

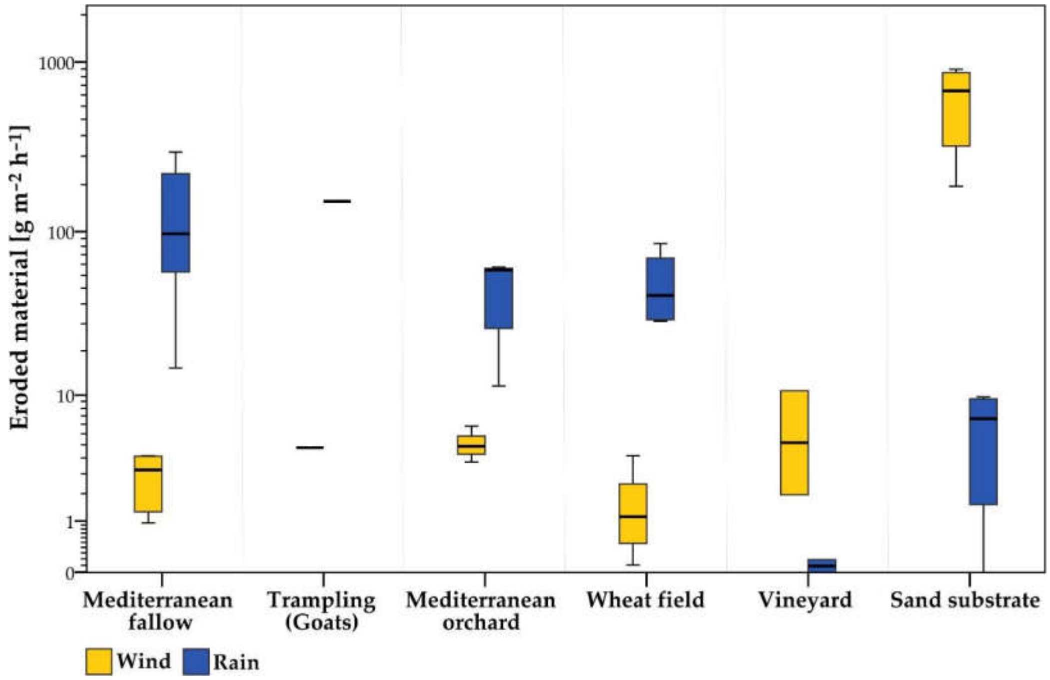


Figure 3. Erosion by wind and rain on the different sites: boxplots, logarithmic scale.

Percentages (%) of eroded sediment for wind and rain, respectively, were found to be 2:98 (Mediterranean fallow), 11:89 (Mediterranean orchard), 3:97 (wheat field), 98:2 (vineyard) and 99:1 (sand substrate) (Figure 4).

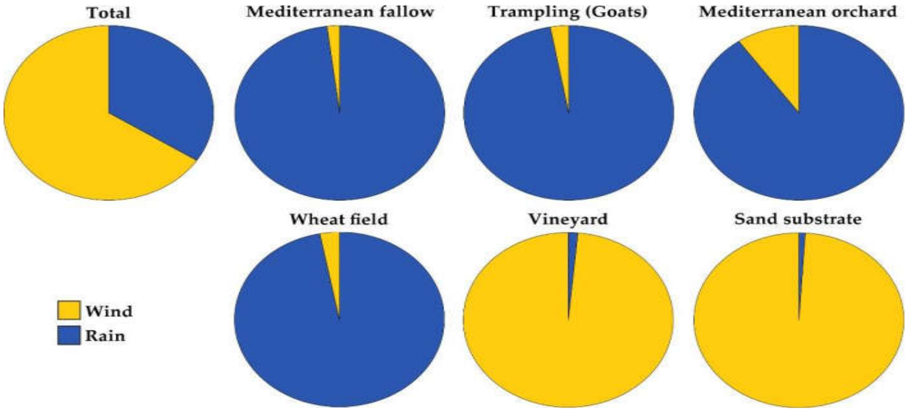


Figure 4. Percentage of erosion for wind and rain on the different sites.

From the H-test results (Table 3), we can derive that there are differing tendencies between groups 1–6 (sites). The Dunn-Bonferroni- Post-hoc-tests showed for wind erosion that only group 4 and 6 show significant differences (adjusted significance 0.017), while no significant differences were found for rain erosion. This means that the statistical analysis found all sites to produce similar erosion output for both wind erosion and rain erosion. The only exception is the case of a comparison between wind erosion output from sites wheat field and sandy substrate, where a significant difference was found. These results can be expected from the initial explanation concerning number and range of values.

Table 3. Kuskal-Wallis test (H-test) for six sites.

6 Groups	Wind	Rain
ChiSquare	13.051	13.716
Asymptotic significance	0.023	0.018

Correlation analysis (Table 4) finds wind erosion positively relating to the available fine material on the surface and negatively with soil H_2O, slope, vegetation and roughness.

Table 4. Correlation coefficients (CC) for erosion agents and test plot characteristics.

Spearman's Rho		Veg	Fine Soil	Coarse Soil and Stones	Crust	Slope	H_2O %	Roughness	C_{org}
Wind	CC	0.587**	0.503*	0.441	0.236	0.617**	0.655**	0.561*	0.166
	Sig.	0.006	0.024	0.052	0.317	0.004	0.002	0.010	0.485
Rain	CC	0.599**	0.581**	0.002	0.638**	0.266	0.025	0.105	0.597**
	Sig.	0.005	0.007	0.995	0.002	0.258	0.916	0.660	0.005

Correlation is significant at the 0.05 level (two-tailed). ** Correlation is significant at the 0.01 level (two-tailed).

Rain erosion correlates strongly with crust and vegetation and negatively with fine soil and Corg, indicating that crust is the most important factor considering high water erosion rates in our tested environments.

4. Discussion

Wind erosion and rain erosion were both found to occur in every tested environment, with often one type prevailing under specific conditions (Figure 3). Measured total erosion and impact on total soil erosion for each erosive agent differed according to site.

The high variability of results reflects the inherent complexity of the soil surface interacting with respective erosion agent. Rainfall simulations are generally known for their highly variable output [46,72–74]. However, the values presented here appear consistent in terms of range of values and plausible concerning expected substrate response.

4.1. Mediterranean Fallow

Semi-arid regions are known to be prone to erosion by both wind and water [27,75]. Our results show a complex situation concerning total measured values as well as the relationship between wind and rain tests of the same test plot. The substrates comprise a large share of the most easily erodible fractions silt and fine sand, but they do not always produce high erosion rates. The key explanation is that susceptibility to runoff generation and erosion by water and wind is to a great extent determined by specific surface characteristics such as crusts, stone cover, roughness, and vegetation - particularly in arid and semi-arid environments [76].

The strong physical crust acts as a protection against initial soil erosion processes such as raindrop splash, bombardment and creep. Crusts increase the threshold shear stress necessary for the initiation of erosion, decrease water infiltration and increase runoff [77,78]. The prevailing type of runoff is thus Hortonian overland flow. The transported and captured material during the first stage of the detachment process is loosely on the surface sitting material, which has already been loosened before the test/erosion event. Only when the crust is destroyed, e.g., by longer lasting wetting, scouring, initial rill development or hoof impact, fresh erosion can occur. This is particularly true for wind erosion, which can only lead to fresh scouring if travel and fetch-distance of saltating particles is long enough. Following the concept of fetch effect including avalanching, aerodynamic feedback and soil resistance mechanism, we can expect an increasing sediment flux with increasing field length [79]. However, the experimental plot length is limited to 4 m, which is not enough to develop this effect, and the steady air stream lacks the erosive energy of instant velocity changes and gusts. Thus, measured rates must be interpreted as the least possible amount of erodible material provided by the respective soil or substrate surface. It can be assumed that variations in erosion rates are associated with 1. a higher amount of easily available sediment on the surface and 2. micro-fissures in the crust leading to decreased cohesive forces and increased erodibility. The overall high variability of results points to complex interactions between not yet addressed soil parameters and supports scientists calling for a multidisciplinary research approach particularly in semi-arid and arid regions [80].

4.2. Trampling or Tillage Impact

Test results show an immense possible impact of animal trampling on soil erosion, particularly due to rise in sediment availability. Prior to trampling, erosion is supply limited, but it shifts to transport limited when the crusted surface is destroyed. By that, erodible material and thus much higher erosion rates are generated. The results are in accordance with [54] who found animal trampling a considerable trigger for the generation of easily erodible sediment.

Field observations also indicate the highly effective mechanism of entrainment of sediment due to animal trampling—even on sites without measurable wind erosion (Figure 5). Moving animals of different sizes (including hooves and paws) can be a crucial impulse for erosion in two ways: first, the sediment and/or biological crust is destroyed, thus threshold shear velocity is strongly reduced and easily available sediment generated [81].

Figure 5. Sheep trampling on crusted substrate as a trigger for wind erosion.

Second, entrainment of soil particles by active lifting into the air stream even if lifting and dragging force of the airflow is not strong enough for entrainment.

The effect of animals or tillage during a wind event may act as a trigger for the initiation of wind erosion processes, and thus on surfaces were no wind erosion is measured by experimental procedures. Mechanisms and effect of this animal or tillage impact therefore differ from those during “tillage erosion” [82,83] but may be a paramount, yet not quantified, factor to assess soil loss budget for certain regions.

Conclusions

The results may raise awareness of scientist, farmers and decision makers about the potential impact of both erosive forces on agricultural sites. Knowledge about the exact relationship is a necessary step towards implementation of highly efficient soil protection strategies adapted to specific soil surface conditions-related erosion susceptibility. Relations between rain erosion and wind erosion amounts show that impact on total soil erosion depends on soil and substrate surface characteristics related to sites and applied management. The highest erosion rates were measured on sand substrate, followed by Mediterranean fallow/goat trampled crust, wheat field and Mediterranean orchard, and lowest on slate covered vineyard. Even locations with extreme surface conditions such as an almost complete coverage by slate stones are susceptible to soil erosion. Water erosion is the most important erosion agent on Mediterranean fallow as well as on wheat field sites. On sandy substrate, wind erosion exceeds water erosion by far.

The findings are important in terms of climate change and (climate change-driven) anthropogenic land use and land cover change under which extreme substrates are increasingly reactivated for food production. Erosion rates potentially rise due to higher pressure generated by land use change. A clever adaption to soil substrate and climatic factors can be considered a valuable option to adapt and mitigate the impact of climate change and to face socio-economic demands of a growing population.

References

1. Mann, C.; Garcia-Martin, M.; Raymond, C.M.; Shaw, B.J.; Plieninger, T. The potential for integrated landscape management to fulfil Europe’s commitments to the Sustainable Development Goals. Landsc. Urban. Plan. 2018, 177, 75–82. [CrossRef]

2. Montanarella, L.; Pennock, D.J.; McKenzie, N.; Badraoui, M.; Chude, V.; Baptista, I.; Mamo, T.; Yemefack, M.; Singh Aulakh, M.; Yagi, K.; et al. World’s soils are under threat. Soil 2016, 2, 79–82. [CrossRef]

3. Goudie, A.S. Desert dust and human health disorders. Environ. Int. 2014, 63, 101–113. [CrossRef] [PubMed]

4. Duniway, M.C.; Pfennigwerth, A.; Fick, S.; Nauman, T.; Belnap, J.; Barger, N. Wind erosion and dust from US drylands: A review of causes,

consequences, and solutions in a changing world. Ecosphere 2019, 10, e02650. [CrossRef]

5. Baumgart, P.; Eltner, A.; Domula, A.R.; Barkleit, A.; Faust, D. Scale dependent soil erosion dynamics in a fragile loess landscape. Z. Für Geomorphol. 2017, 61, 191–206. [CrossRef]

6. Nadal-Romero, E.; Martínez-Murillo, J.F.; Vanmaercke, M.; Poesen, J. Scale-dependency of sediment yield from badland areas in Mediterranean environments. Prog. Phys. Geogr. Earth Environ. 2011, 35, 297–332. [CrossRef]

7. Borrelli, P.; Robinson, D.A.; Fleischer, L.R.; Lugato, E.; Ballabio, C.; Alewell, C.; Meusburger, K.; Modugno, S.; Schütt, B.; Ferro, V.; et al. An assessment of the global impact of 21st century land use change on soil erosion. Nat. Commun. 2017, 8, 1–13. [CrossRef]

8. Borrelli, P.; Lugato, E.; Montanarella, L.; Panagos, P. A New Assessment of Soil Loss Due to Wind Erosion in European Agricultural Soils Using a Quantitative Spatially Distributed Modelling Approach. Land Degrad. Dev. 2017, 28, 335–344. [CrossRef]

9. Oost, K.V.; Quine, T.A.; Govers, G.; Gryze, S.D.; Six, J.; Harden, J.W.; Ritchie, J.C.; McCarty, G.W.; Heckrath, G.; Kosmas, C.; et al. The Impact of Agricultural Soil Erosion on the Global Carbon Cycle. Science 2007, 318, 626–629. [CrossRef]

10. Panagos, P.; Borrelli, P.; Poesen, J.; Ballabio, C.; Lugato, E.; Meusburger, K.; Montanarella, L.; Alewell, C. The new assessment of soil loss by water erosion in Europe. Environ. Sci. Policy 2015, 54, 438–447. [CrossRef]

11. Visser, S.M.; Sterk, G.; Ribolzi, O. Techniques for simultaneous quantification of wind and water erosion in semi-arid regions. J. Arid Environ. 2004, 59, 699–717. [CrossRef]

12. Funk, R.; Frielinghaus, M. Winderosion. In Handbuch der Bodenkunde; Blume, H.P., Ed.; Wiley: Berlin, Germany, 1998; pp. 1–22.

13. Hoffman, O.; Yizhaq, H.; Boeken, B.R. Small-scale effects of annual and woody vegetation on sediment displacement under field conditions. Catena 2013, 109, 157–163. [CrossRef]

14. Beniston, M.; Stephenson, D.B.; Christensen, O.B.; Ferro, C.A.T.; Frei, C.; Goyette, S.; Halsnaes, K.; Holt, T.; Jylhä, K.; Koffi, B.; et al. Future extreme events in European climate: An exploration of regional climate model projections. Clim. Chang. 2007, 81, 71–95. [CrossRef]

15. Guglielmi, G. Hurricanes slow their roll around the world. Nature 2018, 558, 15–16. [CrossRef]

16. Intergovernmental Panel on Climate Change (IPCC). AR5 Synthesis Report: Climate Change 2014; IPCC: Geneva, Switzerland, 2014.

17. Chepil, W.; Woodruff, N. The physics of wind erosion and its control. Adv. Agron. 1963, 15, 211.

18. Ravi, S.; D'Odorico, P.; Breshears, D.; Field, J.; Goudie, A.; Huxman, T.; Li, J.; Okin, G.; Swap, R.; Thomas, A.; et al. Aeolian processes and the biosphere. Rev. Geophys. 2011, 49, Rg3001. [CrossRef]

19. Chepil, W.S. Conversion of Relative Field Erodibility to Annual Soil Loss by Wind. Soil Sci. Soc. Am. J. 1960, 24, 143–145. [CrossRef]

20. Katra, I.; Gross, A.; Swet, N.; Tanner, S.; Krasnov, H.; Angert, A. Substantial dust loss of bioavailable phosphorus from agricultural soils. Sci. Rep. 2016, 6, 24736. [CrossRef]

21. Buschiazzo, D.; Funk, R. Wind Erosion of Agricultural Soils and the Carbon Cycle. In Soil Carbon: Science, Management, and Policy for Multiple Benefits; CABI: Wallingford, UK, 2014.

22. Intergovernmental Panel on Climate Change IPCC. IPCC Special Report on Climate Change, Desertification, LandDegradation, Sustainable Land Management, Food Security, and Greenhouse Gas Fluxes in Terrestrial Ecosystems; IPCC: Geneva, Switzerland, 2019; p. 43.

23. García-Ruiz, J.M.; Beguería, S.; Nadal-Romero, E.; González-Hidalgo, J.C.; Lana-Renault, N.; Sanjuán, Y. A meta-analysis of soil erosion rates across the world. Geomorphology 2015, 239, 160–173. [CrossRef]

24. Savat, J.; De Ploey, J. Sheetwash and rill development by surface flow. In Badland Geomorphology and Piping; Bryan, R.B., Yair, A., Eds.; Geobooks: Norwich, UK, 1982; pp. 113–126.

25. Keesstra, S.; Mol, G.; De Leeuw, J.; Okx, J.; Molenaar, C.; De Cleen, M.; Visser, S. Soil-Related Sustainable Development Goals: Four Concepts to Make Land Degradation Neutrality and Restoration Work. Land 2018, 7, 133. [CrossRef]

26. Ravi, S.; Breshears, D.D.; Huxman, T.E.; D'Odorico, P. Land degradation in drylands: Interactions among hydrologic–aeolian erosion and vegetation dynamics. Geomorphology 2010, 116, 236–245. [CrossRef]

27. Bullard, J.E.; Livingstone, I. Interactions between Aeolian and Fluvial Systems in Dryland Environments. Area 2002, 34, 8–16. [CrossRef]

28. Siegmund, N.; Funk, R.; Koszinsky, S.; Buschiazzo, D.E.; Sommer, M. Effects of low-scale landscape structures on aeolian transport processes on arable land. Aeolian Res. 2018, 32, 181–191. [CrossRef]

29. Ho, T.D.; Valance, A.; Dupont, P.; Ould El Moctar, A. Aeolian sand transport: Length and height distributions of saltation trajectories. Aeolian Res. 2014, 12, 65–74. [CrossRef]

30. Iversen, J.D.; Rasmussen, K.R. The effect of wind speed and bed slope on sand transport. Sedimentology 1999, 46, 723–731. [CrossRef]

31. Shao, Y.; Lu, H. A simple expression for wind erosion threshold friction velocity. J. Geophys. Res. 2000, 105, 22437–22443. [CrossRef]

32. Kaiser, A.; Neugirg, F.; Schindewolf, M.; Haas, F.; Schmidt, J. Simulation of rainfall effects on sediment

transport on steep slopes in an Alpine catchment. In Sediment Dynamics from the Summit to the Sea; IAHS-AISH publication/IAHS Press: New Orleans, LA, USA, 2015; Volume 367, pp. 43–50.

33. Sachs, E.; Sarah, P. Effect of Raindrop Temperatures on Soil Runoff and Erosion in Dry and Wet Soils. A Laboratory Experiment. Land Degrad. Dev. 2017, 28, 1549–1556. [CrossRef]

34. De Lima, J.; Isidoro, J.; De Lima, I.; Singh, V. Longitudinal Hillslope Shape Effects on Runoff and Sediment Loss: Laboratory Flume Experiments. J. Environ. Eng. 2018, 144, 04017097. [CrossRef]

35. Iserloh, T.; Wirtz, S.; Seeger, M.; Marzolff, I.; Ries, J. Erosion processes on different relief units: The relationship of form and process. Cuad. Investig. Geogr. 2017, 43, 171–187. [CrossRef]