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Seed losses by surface wash in degraded Mediterranean environments

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Abstract

The susceptibility of seeds of 10 species to be removed by water erosion from an abandoned field and a badland site in SE Spain was determined. Rainfall simulation experiments were conducted over 0.24 m^2 plots for a 22 minute duration, with an intensity of 55 $mm \cdot h^{-1}$. A mixture of 24 seeds of each species had been placed in these plots, and the number of seeds lost were measured. Seed losses were analyzed in relation to soil erosion rate and overland flow and to seed parameters such as seed size and form.

Seed losses were low in all cases. Total seed losses were less than 10% for all replicates, and there was no species that lost more than 25% of its seeds in any replication. There was a strong relation between total seed losses and runoff in the badland site, but not in the abandoned field. Seed losses were not significantly related to soil losses in either site. There was a wide variation of seed losses between species, but this variation could not be explained by seed weight or shape. Other seed features such as mucilage secretion and the presence of appendices, as hairs or wings, may explain the differences in seed losses at species level. © 1997 Elsevier Science B.V. All rights reserved.

Keywords: seed; erosion; runoff; badland; oldfield; Mediterranean

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1. Introduction

Soil loss by water erosion is one of the main processes of ecosystem degradation in Mediterranean areas of Spain. Antropic deforestation has been the main factor of land and soil degradation in the Mediterranean basin since the Neolithic, even though it may be difficult to separate climatic from human causes (Dupré, 1990; Le Houréou, 1981). In most cases, high soil losses can be explained by the coincidence of deforestation periods with isolated, high intensity rain storms (Wainwright, 1994). This is notably the case today, given the current rate of forest fires and abandonment of agricultural lands.

Current studies reveal that the interaction between soil erosion and vegetation establishment through space and time is poorly documented. The effects of erosion on vegetation are even less documented than those of the vegetal cover on erosion (Thornes, 1990). Erosion acts on vegetation dynamics through the removal of sediments and litter, which influences plant establishment, growth and survival. (Thornes, 1985). In Mediterranean applications of vegetation–erosion interactions, special attention has been given to the features of established plants, such as growth rate and the effects of herbivory and hidric stress (Thornes, 1988, 1990; Thornes and Brandt, 1994). However, the effect of erosion on the plant establishment phase has not received as much attention, even though it should be the most sensitive phase. Overland flow and sediment transport can carry away the seeds that arrive to the surface of the soil and those which remain in the seed bank (Chambers and MacMahon, 1994). It has been argued that this mechanism can explain the low vegetation cover in degradated areas, although it remains poorly documented (Debusche and Lepart, 1992; Francis, 1991).

On the other hand, seed characteristics may interact with the removal process contributing to explain the final plant composition of the eroded areas. If single seeds could be considered to behave like sediment particles, it would be expected that they behave in the same way regarding erosion and overland flow. For sediments, particle size is a good predictor of the susceptibility to be detached from soil and removed (Kirkby, 1980; Parsons et al., 1991; Poesen and Savat, 1980). Particle shape is also expected to have influence in the remotion process. In general, spherical particles are the most susceptible to be removed by overland flow, followed by the roller ones and then the plate-shaped ones (Winkelmolen, 1971).

Badlands and abandoned fields are two of the more sensitive ecological systems for studying the interactions between soil erosion and plant establishment in the Mediterranean. Badlands are a common geomorphological feature in southeast Spain. They develop over a variety of materials and exhibit a wide range of erosion and runoff rates (Scoging, 1982; Calvo et al., 1992). Abandoned agricultural lands are one of the major problems concerning soil resource conservation in the northern Mediterranean (Pinto, 1993). High runoff rates have been measured only in the first years after field abandonement, (Cerdà, 1996; Francis, 1986; García-Ruiz et al., 1991) but erosion rates were very variable and lower than those measured in badlands.

If seed loss is one of the mechanisms by which erosion influences plant establishment in areas with low or non-existent vegetal cover, then it can be predicted that seed loss would be positively related to erosion and/or overland flow. Furthermore, seed and soil surface characteristics will interact with runoff and erosion.

The aim of this study is to investigate experimentally the susceptibility of seeds to be removed by water erosion and the influence of seed size and shape on it.

2. Material and methods

Two sets of experiments with simulated rain were performed in a badland area at Petrer (Alicante, southeast Spain) and in an abandoned field area at Godelleta Valencia (Spain) in order to evaluate the seed losses by surface wash.

The badland area at Petrer was selected because of its extreme rate of erosion (964–1900 g m^{-2} h^{-1}) and low to medium runoff rate (2–32 mm · h^{-1}) in relation to other southeast Spain badlands (Calvo et al., 1992; Cerdà and García-Fayos, 1996). The badlands are developed on Cretaceous (Senonian) marls and there are ancient agricultural remains on the valley floor. Rilling and swelling processes produce a deeply cracked surface drained by a finelly textured network of shallow rills. The sites for the rainfall simulation experiments were slopes selected from the most representative surface-morphologies and with slope angles ranging between 20° and 55°. In Godelleta, an agricultural terraced field used for more than 30 years as vineyard culture and abandoned eighteen months prior to experiments was selected. This field has a 4% uniform slope and produces low erosion rates (25–300 g m^{-2} h^{-1}) but high runoff ones (15–35 mm · h^{-1}) (Molina and Rubio, 1996). Soils have less than 5% water stable aggregates and after rains the soil is sealed with a 2 mm depth crust. Stones ocupied on average 20% of the soil surface and plant cover did lesser than 2%.

The climate is Mediterranean semi-arid with long, dry summers (3–5 months). Average annual rainfall is 370 mm at Petrer and 500 mm at Godelleta, and average annual temperature is around 16°C. Natural vegetation in both areas has been greatly disturbed by human activities as grazing and cultivation for centuries.

Soil erosion and surface runoff were generated using a sprinkler rainfall simulator. The simulator operates over 0.24 m^2 circular plots at a constant rainfall intensity of 55 mm · h^{-1}, using destilled water (see Cerdà, 1996 for more details). This rain intensity corresponds to the smallest rain-storm intensities able to generate runoff and water circulation in watersheds in this region. Its return period is 10 years (Elías and Ruiz, 1977).

Ten rainfall simulation replicates were conducted on the badland in April, 1994, and twelve on the abandoned field in September, 1993. Vegetal cover of the badland plots was non-existent, and less than 2% in the abandoned field ones. A mixture of 24 seeds of each species was placed in the middle of each plot, along a 30 cm line from the bottom. After 22 minutes of rain simulation the runoff water and sediment and seed losses were measured. This period was considered to be long enough for attaining the steady-state runoff rate (Cerdà, 1996).

Seeds of the following species were used in the experiment: *Cheirolophus intybaceus*, *Helichrysum stoechas* and *Phagnalon saxatile* (Asteraceeae), *Cistus albidus* (Cistaceae), *Erica multiflora* (Ericaceae), *Lygeum spartum* (Poaceae), *Moricandia arvensis* (Brassicae), *Pistacia lentiscus* (Anacardiaceae), *Salsola genistoides* (Chenopodiaceae) and *Sedum sediforme* (Crassulaceae). These species were selected for their dominace in the

Table 1
Seed weight, dimensions, flatness index and average seed losses for the 10 species used in the experiments

Species	Losses in badland (%)	Losses in abandoned field (%)	Weight (mg)	Longest dimension	Intermediate dimension	Shortest dimension	Flatness Index	Appendix or mucilage
Ch. intybac.	3.33 ± 1.04	2.08 ± 0.96	4.10 ± 0.39	4.95 ± 0.08	1.57 ± 0.03	1.57 ± 0.03	2.08	none
C. albidus	2.92 ± 1.08	0.00 ± 0.00	1.00 ± 0.01	1.55 ± 0.04	1.24 ± 0.03	1.24 ± 0.03	1.12	none
E. multiflora	6.67 ± 2.42	8.68 ± 2.32	0.05 ± 0.42	1.18 ± 0.07	0.44 ± 0.03	0.09 ± 0.01	9.00	none
H. stoechas	0.42 ± 0.42	0.00 ± 0.00	0.06 ± 0.01	0.71 ± 0.01	0.38 ± 0.00	0.38 ± 0.00	1.43	mucilage
L. spartum	0.00 ± 0.00	0.00 ± 0.00	109.96 ± 4.36	12.56 ± 0.27	3.19 ± 0.14	3.19 ± 0.14	2.47	hairs
M. arvensis	0.42 ± 0.42	0.00 ± 0.00	0.31 ± 0.01	1.08 ± 0.06	0.77 ± 0.04	0.53 ± 0.04	1.74	mucilage
Ph. saxatile	5.00 ± 1.21	0.00 ± 0.00	0.07 ± 0.00	0.98 ± 0.37	0.29 ± 0.02	0.29 ± 0.02	2.19	pappus + hairs
P. lentiscus	3.33 ± 1.21	0.00 ± 0.00	15.72 ± 0.44	3.31 ± 0.18	3.53 ± 0.19	2.08 ± 0.17	1.64	none
S. genistoides	1.25 ± 0.89	0.00 ± 0.00	4.74 ± 0.20	8.29 ± 0.17	8.29 ± 0.17	1.85 ± 0.04	4.48	wings
S. sediforme	12.5 ± 2.15	4.51 ± 1.08	0.04 ± 0.00	1.02 ± 0.02	0.34 ± 0.01	0.34 ± 0.01	2.00	none

adjacent areas. Seeds were collected from populations living in the study areas, air-dried in the laboratory and then dyed with blue aniline. Seeds may have specialized dispersal structures, which may or may not be lost during dispersion. Thus, seeds were always used in the form they keep after the dispersion event. Seed size and shape were described using seed weight and Poesen's flatness index (Poesen, 1987, 1990), as follows:

$$\mathrm{FI} = (L + I)/2S$$

where FI is the flatness index, L is the longest, I the intermediate and S the shortest dimension of the seed. This index has a minimum value of 1.0 for spherical seeds, and it increases as longer and/or flatter seeds are considered.

There was a wide amplitude in seed weight, ranging from 0.043 mg for *S. sediforme* to 110 mg for *L. spartum* (Table 1). Seed shape varies from the sphaerical-prone seeds of *C. albidus* (FI = 1.12) to the roller seeds of *Ch. intybaceus* (FI = 2.08) and *L. spartum* (FI = 2.47) and to the very flat seeds of *E. multiflora* (FI = 9.00).

Average runoff rate ($\mathrm{mm \cdot h^{-1}}$) was used as an indicator of overland flow. Sediment content was used to calculate erosion rate ($\mathrm{g \cdot m^{-2} \cdot h^{-1}}$), and seed losses (%) were calculated from the number of seeds lost and the total number of seeds used. Differences in the values of these parameters between badland and abandoned field experiments were tested using one-way ANOVA analysis. The effects of runoff and soil erosion (plot level) and of seed size and shape (species level) on seed losses were analyzed separately using regression procedures. Erosion rate and seed weight were logaritmically transformed to achieve a linear relation instead of a curvilinear one. All the statistical analysis were performed using the BMDP package (Dixon, 1993).

3. Results

Erosion and seed loss rates were higher in the badland experiment than in the abandoned field one, whereas runoff rate was higher in abandoned field experiment (Table 2).

Very important seems to be the wetting process to seed losses. During the first seconds of the rain seeds were frequently moved due to splash effect. After several seconds, when the soil surface was wet, most of the seeds remain fixed onto the soil surface and only few were carried out by the surface wash. As a result, seed removal rate was always low. In the badland site, between 0.4 and 7.9% of the seeds placed in

Table 2
Comparative values of erosion, runoff and seed losses for the badland and the abandoned field experiments

	Badland	Abandoned field		
Erosion ($\mathrm{g \cdot m^{-2} \cdot h^{-1}}$)	2867 ± 264	314 ± 39	$F = 215.78$	$p < 0.0001$
Runoff ($\mathrm{mm \cdot h^{-1}}$)	32.4 ± 2.0	44.0 ± 1.4	$F = 23.87$	$p < 0.0001$
Seed losses (%)	3.58 ± 0.60	1.53 ± 0.35	$F = 8.88$	$p < 0.01$

Table 3
Erosion and runoff rates and seed lossed by species and by plot for the badland experiments

Experiment	Slope angle (°)	Erosion ($g \cdot m^2 \cdot h^{-1}$)	Runoff ($mm \cdot h^{-1}$)	Seed losses (%)										
				Chi	*Ca*	*Em*	*Hs*	*Ls*	*Ma*	*Phs*	*Pl*	*Sg*	*Ss*	All seeds
BD-01	42	2256	24.9	4.17	4.17	0.00	0.00	0.00	0.00	4.17	4.17	0.00	12.5	2.92
BD-02	35	1748	19.7	0.00	0.00	4.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.42
BD-03	35	2876	42.3	8.33	8.33	25.0	4.17	0.00	4.17	4.17	0.00	0.00	25.0	7.92
BD-04	25	1980	33.6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	16.7	1.67
BD-05	25	2974	36.1	4.17	0.00	8.33	0.00	0.00	0.00	4.17	0.00	0.00	8.33	2.50
BD-06	22	2624	31.9	0.00	0.00	4.17	0.00	0.00	0.00	4.17	0.00	0.00	16.7	2.50
BD-07	40	2762	37.6	8.33	4.16	0.00	0.00	0.00	0.00	8.33	8.33	8.33	8.33	4.58
BD-08	30	2752	27.6	4.17	8.33	4.17	0.00	0.00	0.00	4.17	8.33	0.00	12.5	4.17
BD-09	50	4514	38.2	4.17	0.00	8.33	0.00	0.00	0.00	12.5	4.17	0.00	0.00	4.58
BD-10	55	4183	32.3	0.00	4.17	12.5	0.00	0.00	0.00	8.33	8.33	4.17	4.17	4.58

Chi: *Cheirolophus intybaceus*, *Ca*: *Cistus albidus*, *Em*: *Erica multiflora*, *Hs*: *Helichysum stoechas*, *Ls*: *Lygeum spartum*, *Ma*: *Moricandia arvensis*, *Phs*: *Phagnalon saxatile*, *Pl*: *Pistacia lentiscus*, *Sg*: *Salsola genistoides*, *Ss*: *Sedum sediforme*.

Table 4
Erosion and runoff rates and seed losses by special and by plot for the abandoned field experiments

Experiment	Slope angle (°)	Erosion ($g \cdot m^2 \cdot h^{-1}$)	Runoff ($mm \cdot h^{-1}$)	Seed losses (%)										
				Chi	*Ca*	*Em*	*Hs*	*Ls*	*Ma*	*Phs*	*Pl*	*Sg*	*Ss*	All seeds
AF-01	2	245	37.4	8.33	0.00	12.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.08
AF-02	2	223	41.0	0.00	0.00	16.7	0.00	0.00	0.00	0.00	0.00	0.00	4.17	2.08
AF-03	2	228	45.0	0.00	0.00	4.17	0.00	0.00	0.00	0.00	0.00	0.00	4.17	0.83
AF-04	2	512	45.6	8.33	0.00	16.7	0.00	0.00	0.00	0.00	0.00	0.00	8.33	3.33
AF-05	2	353	43.2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AF-06	2	374	44.9	0.00	0.00	25.0	0.00	0.00	0.00	0.00	0.00	0.00	8.33	3.33
AF-07	2	252	37.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.17	0.42
AF-08	2	422	46.0	0.00	0.00	4.17	0.00	0.00	0.00	0.00	0.00	0.00	4.17	0.83
AF-09	2	525	45.9	4.17	0.00	8.33	0.00	0.00	0.00	0.00	0.00	0.00	4.17	1.67
AF-10	2	245	50.7	0.00	0.00	4.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.42
AF-11	2	132	41.5	4.17	0.00	12.5	0.00	0.00	0.00	0.00	0.00	0.00	4.17	2.08
AF-12	4	259	50.2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	12.5	1.25

Chi: *Cheirolophus intybaceus*, *Ca*: *Cistus albidus*, *Em*: *Erica multiflora*, *Hs*: *Helichysum stoechas*, *Ls*: *Lygeum spartum*, *Ma*: *Moricandia arvensis*, *Phs*: *Phagnalon saxatile*, *Pl*: *Pistacia lentiscus*, *Sg*: *Salsola genistoides*, *Ss*: *Sedum sediforme*.

each plot were removed (Table 3), while in the abandoned field seed losses ranged between 0.0 and 3.3% (Table 4).

Correlation analysis showed that seed losses increased significantly as runoff increased in the badland experiment ($r = 0.72$, $p = 0.019$), but this increase was not significant in the abandoned field one. There was also an increase in seed losses when soil erosion rates increase, but it was not statistically significant in either the badland or the abandoned field experiments.

Seed removal susceptibility varied between species (Table 1). Seed losses were relatively low for all species, and not a single species presented losses in all replications. The species that showed the greatest seed losses potential were *S. sediforme* and *E. multiflora*, which had their seeds removed in at least 50% of the replications on both the badland and the abandoned field. On the other hand, not a single seed of *L. spartum* was removed, and *H. stoechas* and *M. arvensis* had seeds removed only once out of 22 replications. The maximum seed loss rate was reached by *S. sediforme* and *E. multiflora* in experiments BD-3 and AF-6 with 25% losses (Tables 3 and 4).

There was not any significant relationship between seed losses and seed weight nor flatness index in either the badland and the abandoned field experiments.

4. Discussion

The relatively low values of seed losses obtained in the present study are in agreement with those obtained empirically in badland ecosystems (García-Fayos et al., 1995) and in burned areas (Cancio et al., 1993).

It is possible that the lack of statistical relations in the abandoned field experiment between seed losses and erosion and overland flow is the consequence of the short range obtained in the parameters used (see Table 2). However, despite the longer range of these parameter in the badland experiment, there was still only a significant relationship between seed losses and runoff. Erosion and runoff are very variable spatial processes (Kirkby, 1980) and soil surface properties such as rugosity, and presence of stones, crusts and cracks at the scale of the experimental plots, may affect these results. Therefore, many replications are needed to obtain a higher statistical significance.

At the species level the results show that there is no relationship between seed losses and size or shape of seeds. However, the susceptibility of a seed to be removed clearly varies between species, suggesting that the existence of seed features other than size and shape may have a significant impact. Consequently, seed coat characteristics such as presence of awns, hairs, pappus and other structures may be important (Van der Pijl, 1972). Only three species have seed coat structures (see Table 1). The seeds of *S. genistoides* have wings, the seeds of *L. spartum* have long hairs, and the seeds of *Ph. saxatile* have a long pappus and hairs in the achene. In order to elucidate if the presence of these species masked the relationships between losses and seed size and shape, the statistical analysis was carried out again excluding these species. However, no significant relationships were found.

The seeds of several species *Ph. saxatile*, *H. stoechas* and *M. arvensis* modify their coat characteristic when wetted. On *Ph. saxatile*, the angle between the achene hairs and

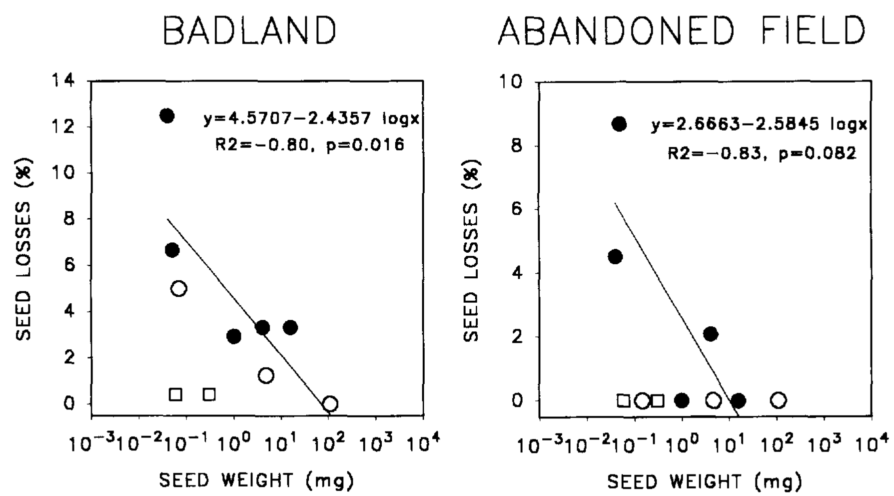

Fig. 1. Seed losses plotted against seed weight for the 10 species studied. Curve of best fit for the badland experiment corresponds to the set of species with normal seeds and seeds with appendices ($n = 8$). Curve of best fit for the abandoned field experiment corresponds to the set of species with normal seeds ($n = 5$). (○) Normal seeds; (●) seeds with appendices; (□) seeds with mucilage secretion.

the seed surface increases, while on *H. stoechas* and *M. arvensis*, the seeds segregate mucilage. The achene hairs of *Ph. saxatile* return to their original position when air dried, and moved every time they are wetted and dried. Harper (1977) described also higroscopic movements of pappus hairs in seeds of other Asteraceae.

The seeds of *H. stoechas* and *M. arvensis* also kept their capability to segregate mucilage after they were air dried and wetted again at least 10 times. When the mucilage was secreted, the seeds remained "glued" to the surface, even when air dried. They could not be removed from the glass to which they adhered even when washed with abundant water. Mucilage secretion has been described from some other genera and species of the families Cruciferae, Plantaginaceae, Compositae Acanthaceae, Cistaceae (see Mayer and Poljakoff-Mayber, 1989; Van der Pijl, 1972 and references therein). This phenomenon has been associated to water uptake improvement (Harper, 1977; Mayer and Poljakoff-Mayber, 1989), and also to seed anchorage (Gutterman et al., 1967; Van der Pijl, 1972).

Statistical analyses were repeated removing from the data set the species which their seeds segregate mucilage. Then seed weight was significant and negatively related to seed losses in both the badland experiments ($r = -0.80$, $p = 0.016$) and the abandoned field ones ($r = -0.63$, $p = 0.096$), despite the loss of degrees of freedom of the residuals (from 8 to 6) (Fig. 1). When all species with special features in the seed coat were removed from the data, the seed weight was significantly related to seed losses only in the abandoned field experiment ($r = -0.83$, $p = 0.082$), but did not in the badland one. Seed shape was not significantly related to seed losses in either experiment. These results confirm the expected negative relation between seed size and removal, as for mineral particles.

It may be concluded that despite the relatively low rate of seed losses per event with a moderate rain intensity (55 mm · h^{-1}), seed losses may play a role in the vegetation–erosion competition, at least in ecosystems with low or zero vegetal cover. Likewise, this study shows that seeds have specific mechanisms to avoid remobilization by water, which may obscure the relationships between seed removal and seed features such as size. Further research on their ecological consequences is needed.

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