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Soil aggregate stability under different Mediterranean vegetation types

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Abstract

The influence of vegetation type on soil erodibility was studied by means of aggregate stability measurements using the Modified Emerson Water Dispersion Test (MEWDT), water-drop impacts (CND and TDI) and Ultrasonic Disruption (UD) methods on soils from north-facing slopes of the mountain range of *La Serra Grossa* in the eastern Iberian Peninsula. Soils with similar characteristics but covered by the main plant species at the study area were selected. *Quercus ilex* woodland showed the most resistant soil aggregates followed by *Q. coccifera* and *Pistacea lentiscus* scrubland, *Brachypodium retusum* grassland and *Pinus halepensis* woodland. Aggregates developed beneath dwarf shrubs like *Rosmarinus officinalis, Thymus vulgaris, Ulex parviflorus* and *Anthyllis cystisoides* were least resistant. The different methods and tests applied are useful to study the soil aggregate stability. The MEWDT and TDI tests showed only minor differences between samples due to the high aggregate resistance and the low energy applied by these tests. CND and UD tests are considered to be more suitable for resistant Mediterranean soil developed on limestone due to the greater energy applied. Aggregates tested from an initially moist (pF1) condition were always more stable than air dried aggregates. Rangeland management after disturbances by fire, agriculture or grazing, etc. should try to establish natural woodland (*Q. ilex*) in order to get the most stable soil. Alternative vegetation cover to the climax vegetation that give high aggregate stability are *Q. coccifera* and *P. lentiscus* scrublands. Immediately after disturbance, *B. retusum* grassland seems to be the best option for soil protection. © 1998 Elsevier Science B.V. All rights reserved.

Keywords: Aggregate stability; Vegetation; Laboratory test; Mediterranean

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1. Introduction

Soil erodibility is a measure of soil susceptibility to detachment and transport by the agents of erosion. It is the integrated effect of processes that regulate rainfall acceptance and the resistance of the soil to particle detachment and subsequent transport. These processes are influenced by soil properties, such as particle size distribution, structural stability, organic matter content, soil chemistry and clay mineralogy. Soil properties which affect soil structure, slaking, and water transmission characteristics also affect soil erodibility (Lal, 1994).

There are few good measurements of soil erodibility because most of them reflect a multitude of factors other than erodibility. Measurements of soil erodibility must be done under controlled conditions in order to avoid variations in rainfall intensity and volume, which will influence erosivity (Morgan, 1986). Soil aggregate stability affects the soil erodibility, thus, measurements of soils aggregate stability quantify indirectly the soil erodibility. Measurements of soil aggregate stability avoid the direct influence of other factors such as stoniness, litter and vegetation on soil erodibility during the measurements. Moreover, soil aggregate stability is a synthetic parameter of the soil ecosystem conditions due to its interactions with the flora, fauna, parent material and climate (Imeson, 1984).

Different aggregate stability tests were developed as indices of soil erodibility (McCalla, 1944; Low, 1954; Edwards and Bremmer, 1967; Genrich and Bremmer, 1972; Bergsma and Valenzuela, 1981). Three methods (by means of dispersion, drop impact and ultrasonic dispersion) and four tests (MEWDT, CND, TDI and UD) have been applied in this study. These tests have been widely used during the last 2 decades under Mediterranean climatic conditions (Imeson and Vis, 1984; Cerdà, 1994; Williams et al., 1995).

Vegetation cover is one of the key factors influencing soil erodibility. This is due to the positive feedback of the vegetation on soil quality due to the organic matter contribution by means of the litter. Also, vegetation increases weathering, enhances rainwater infiltration and favours a less contrasted microclimate beneath plants due to the shadow. These conditions should generate a more active fauna and flora and as a consequence, stronger aggregates (Oades, 1993; Zhang, 1994).

As other authors found, under semiarid conditions, the soil surface layer determines the infiltration process, and the mechanisms of overlandflow generation and surface wash erosion (Scoging, 1982; Römkens et al., 1990; Dunne et al., 1991), thus, soil erodibility is highly dependent on the soil surface aggregation. Microaggregates reflect the influence of parent material due to the influence of clays on aggregate formation, but macroaggregation mainly reflects the influence of plants (organic matter) on the aggregate formation (Duchafour, 1975). This is why this research has been focused on the changes of the plant cover, organic matter and the stability of macroaggregates.

The objective of this paper is to investigate the relationship between the plant cover and the soil aggregate stability. To know the plant species that favours the most stable soil will aid better planning of strategies of rangeland management for vegetation recovery after disturbances such as forest fire, the abandonment of agricultural fields or overgrazing, which are found widely on the mediterranean areas of South Europe.

2. Methods

The study area is located in the south of the province of Valencia (east of the Iberian Peninsula), in the Betic System mountain range called Serra Grossa (Fig. 1). The parent materials are mainly Jurassic and Cretaceous limestone, although clays from the Keuper formation (Triassic) appear due to diapirism mechanisms. Vegetation composition is mainly determined by the forest fires, which have been very frequent since the 1970s due to land abandonment during the 1960s and the following vegetation recovery. The climax vegetation was dominated by a woodland of *Quercus ilex* (Costa, 1986). Wood exploitation, grazing and cultivation over a long period has resulted in the degradation of the climax vegetation, with *Q. coccifera* and *Pistacia lentiscus* being the dominant vegetation cover after a natural recovery. *Pinus halepensis* is also important, especially since the 1940s, due to the plantation programs developed by the Spanish government. After forest fire the vegetation recovery shows a very diverse floristic composition due to different stages of degradation or regeneration. Dwarf-shrubs ($<$ 1 m height) including *Rosmarinus officinalis*, *Thymus vulgaris*, *Ulex parviflorus* and *Anthyllis cystisoides* and *Brachypodium retusum* grasses are very common after forest fire or agricultural field abandonment (Fig. 2). Bare soil surfaces are abundant between the patchwork of plants. The study area was selected because it is representative of Western Mediterranean environments (Di Castri et al., 1981).

The climate of the *La Serra Grossa* region is characterised by a contrasted seasonal distribution of rainfall with a very dry and hot summer, and wet and warm spring, winter and autumn. The mean annual precipitation ranges from 500 mm on the south-facing slopes to 750 mm on the north-facing slopes. These differences are due to the dominant winds during the larger thunderstorms coming from the Mediterranean sea (NNE). Mean annual temperature is 16°C, with the mean maximum temperature in August (25°C) and the minimum in January (9°C) (Real de la Torre, 1985).

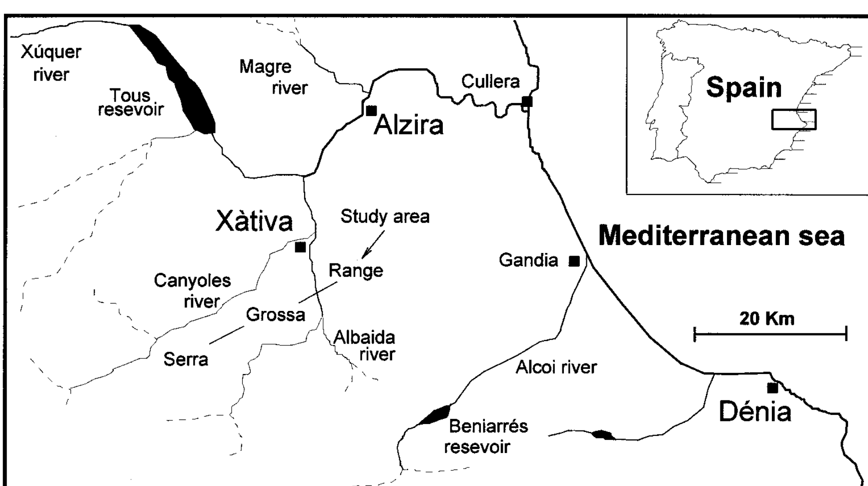

Fig. 1. Location map of the Serra Grossa study area.

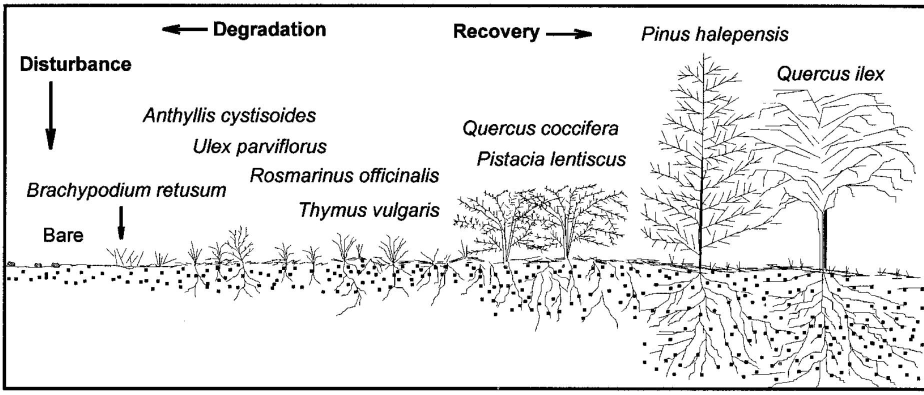

Fig. 2. Scheme of the vegetation changes following disturbance at the study area.

Soils are classified as Leptosols, although there are some differences mainly on the chemical characteristics of the soils. Soil descriptions were done following the FAO-UNESCO (1988) guidelines and sampling was carried out only on the north-facing slope because aspect has been found very important for soil erodibility at the Serra Grossa study area (Cerdà et al., 1995a). The climax vegetation, *Q. ilex* woodland, is very scarce due to wood exploitation for charcoal until the 1960s. Nevertheless, it is possible to find young trees (3–4 m height) in patches of 4–5 trees. The other vegetation types are very common in the study area. The vegetation type and cover depend on the vegetation recovery stage after the disturbance (Fig. 2).

All samples were collected in the mid-slope section, upslope of the colluvium, in order to eliminate the influence of the geomorphological position, and on limestone due to the influence of parent material on soil erodibility (Sanroque et al., 1990; Ternan et al., 1994; Cerdà, 1996a). Old agricultural terraces were avoided and sampling took place during summer on natural soils. Samples were selected from the top surface layer (0–2 cm) which is affected by natural rainfall and is the key layer for the erosion processes. Samples were taken avoiding the top crust formation on the bare soil and the litter layer on the vegetated soils.

Aggregates of 4–4.8 mm diameter were selected by dry sieving, and four different tests applied to each sample: Modified Emerson Water Dispersion Test (MEWDT) (Emerson, 1967), Drop-test (CND and TDI) (Imeson and Vis, 1984) and Ultrasonic Disruption test (UD) (Cerdà, 1994). The 4–4.8 mm size aggregates were selected due to the importance of this range on the aggregate size distribution at the study site. Other authors selected similar soil aggregate sizes on Mediterranean soils (Imeson and Verstraten, 1985; Lavee et al., 1991; Boix et al., 1995; Cerdà, 1996a; Lavee et al., 1996) mainly due to the size of the drops used on the drop-test.

Modified Emerson Water Dispersion Test (MEWDT) was applied to each sample for 10 aggregates. The procedure was to immerse the aggregates in 40 ml of distilled water and at time intervals of 5, 120 (2 h) and 1440 min (1 day) determine the degree (on a scale of 0 to 4) of aggregate dispersion:

0, No dispersion. Aggregate completely entire.

1, Dispersion of some particles. Milkiness close to the aggregate.

2, Aggregate partly dispersed or divided into different smaller aggregates.

3, Considerable dispersion. Most of the aggregate have been dispersed and the milkiness is very large.

4, Total dispersion. The aggregate does not exist.

Water-drop test, a burette nozzle with silicon tubing was used, together with a supply system with a constant head. The drops produced with distilled water had a weight of 0.1 g. The water-drops were allowed to fall through a polythene pipe (15 cm diameter) from 1 m height onto aggregates placed on a 2.8 mm gauge metal sieve. The time interval between drops was 1 s, and it was controlled in order to avoid differences between samples due to the influence of time of wetting on aggregate breakdown. The water-drop test is an established technique and there are many possible procedures. The Imeson and Vis (1984) procedure was followed here.

–CND: Counting the Number of Drop impacts required to disrupt the aggregate sufficiently for it to pass through the 2.8 mm sieve.

–TDI: Ten Drop Impacts. This consisted of measuring the weight of aggregates > 2.8 mm after applying ten drop impacts.

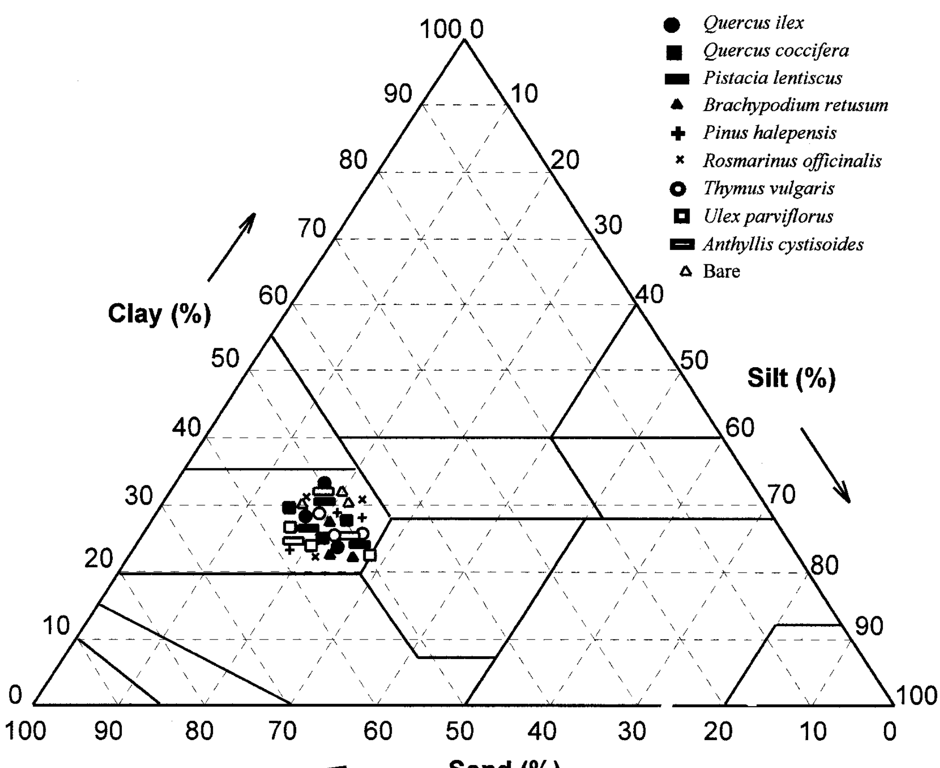

Fig. 3. Soil grain size at each of the three samples collected on the 10 studied vegetation types.

Ultrasonic Disruption (UD). The estimation of aggregate stability by ultrasound was undertaken using a Sanfier 1312 cell destructor (Branson Sonic Power, Danbury, CT). The procedure used involved immersing 10 aggregates (4–4.8 mm) moist at pF1 in 40 ml of distilled water in a cylindrical container (4 cm depth), and then subjecting these to the probe output for 5 or 10 s with the probe tip placed 10 mm under the water surface. The power applied varies between 30 and 115 W. After the treatment, the surviving aggregates (> 2.8 mm) and the aggregate fragments (< 2.8 mm) (Imeson and Vis, 1984) were weighed.

Measurements of soil organic matter content were done for each vegetation type (average of three samples) by means of the method of Walkley and Black (1934). Samples were taken in summer under more than one plant (three sampling points per plant) for each vegetation type. Sampling was done at surface (0–5 cm) and other physical soil characteristics such as grain size were found to be very similar (Fig. 3).

At each of the sample (three per vegetation type) 20 aggregates were selected randomly in order to apply the four tests. Average values of the three samples are shown. Summing up, 20 aggregates per sample, three samples per vegetation type, 10 vegetation types and four tests (two of them under dry and wet conditions, CND and TDI, one under wet conditions but at 5 and 10 s duration and at 18 different intensities from 30 to 115 W, UD, and one under dry conditions, MEWDT) results in 5040 aggregates measured.

3. Results

3.1. Modified Emerson water-dispersion test

The whole set of samples collected show a very large aggregate stability, which resulted in negligible water milkiness after 5 min of treatment (Table 1). The water

Table 1
MEWDT test

Time (min)	5	120	1440
Vegetation types			
Q. ilex	0.0	0.0	0.0
Q. coccifera	0.0	0.0	0.0
P. lentiscus	0.0	0.0	0.2
B. retusum	0.0	0.1	0.4
Pin. halepensis	0.1	0.2	0.5
R. officinalis	0.3	0.4	0.8
T. vulgaris	0.3	0.5	0.9
U. parviflorus	0.3	0.5	1.1
A. cystisoides	0.4	0.8	1.3
Bare	0.5	1.1	1.7

Mean values of the index of the Modified Emerson Water Dispersion Test (MEWDT) (three samples of 20 aggregates). 0, No dispersion. 1, Dispersion of some particles. 2, Aggregate partly dispersed. Index of 3 and 4, very large dispersion and total dispersion were not measured.

milkiness and the amount of dispersed aggregates increased with time. The index of dispersion increased from 0.19 after 5 min to 0.36 and 0.67 after 120 and 1440 min, respectively for average values of the whole set of samples. The most stable soil was found under *Quercus* (*Q. ilex* woodland and *Q. coccifera* scrubland), with aggregates that survived the immersion for 24 h without any dispersion. *P. lentiscus* shrubland, *B. retusum* grassland and *Pin. halepensis* woodland have also very stable soils, although for large immersion times these aggregates were less stable than beneath *Quercus*. The soil beneath dwarf-shrubs (< 1 m height) of *R. officinalis*, *T. vulgaris*, *U. parviflorus* and *A. cystisoides* have less stable soil aggregates. Bare soils were much more erodible specially for longer immersion times (Table 1).

3.2. Water-drop impact tests

Aggregate stability measurements under water-drop impacts were done for initially wet ($pF = 1$) and air-dry conditions. The test TDI shows very stable aggregates. In average values and under dry conditions, 81% of the sample survived after 10 drop impacts. Under wet conditions, the percentage of sample surviving was larger: 83.5%. The larger differences were found between different types of vegetation. Soils beneath *Q. ilex* were always the most stable. *Q. coccifera*, *P. lentiscus*, *Pin. halepensis* and *B. retusum* cover soils with slightly less stable aggregates. Soils beneath dwarf shrubs show greater aggregate stability than bare soils (Table 2).

CND drop-test shows a similar behaviour. Moist samples were more stable than under dry conditions. In average values, the mean number of drop impacts for reaching the breakdown of an aggregate was 137 for air-dried and 162 for wet conditions. Also, the larger differences were found between vegetation types. *Q. ilex* was again the most stable and after 200 drop impacts, the aggregates were not broken. Table 3 shows how other vegetation types respond to the drop impacts. *Q. coccifera* and *P. lentiscus* are more stable than *B. retusum* and *Pin. halepensis*, but this vegetation type forms a homogeneous group with the highest aggregate stability after *Q. ilex*. However, *R.*

Table 2
TDI test

Vegetation types	Air-dry (%)	pF1 (%)
Q. ilex	95.36	98.36
Q. coccifera	93.25	94.56
P. lentiscus	92.54	94.02
B. retusum	90.25	92.54
Pin. halepensis	92.56	92.86
R. officinalis	76.58	78.36
T. vulgaris	78.36	82.14
U. parviflorus	70.21	75.45
A. cystisoides	68.25	71.24
Bare	52.36	55.24

Percentage of sample surviving as aggregates after 10 drop impacts distinguishing between initially moist and dry conditions (three samples of 20 aggregates).

Table 3
CND test

Vegetation types	Air-dry	pF1
Q. ilex	199.75	200.00
Q. coccifera	189.60	197.90
P. lentiscus	183.20	196.80
B. retusum	175.15	188.75
Pin. halepensis	171.50	176.65
R. officinalis	120.35	150.15
T. vulgaris	108.85	161.05
U. parviflorus	92.90	128.30
A. cystisoides	81.45	120.20
Bare	51.10	97.95

Mean number of drop impacts necessary to break down an aggregate for soils beneath different plant types distinguishing between previous wet and dry conditions (three samples of 20 aggregates).

officinalis, T. vulgaris, U. parviflorus and *A. cystisoides* develop more erodible soils. *R. officinalis* and *T. vulgaris* aggregates are more stable than at *A. cystisoides* and *U. parviflorus*, although they form a quite homogeneous group with greater erodibility. Bare soils have the least stable aggregates.

The existence of soil groups with different aggregate erodibility is due to the influence of the plant cover which also affect soil conditions such as organic matter. Fig. 3 shows aggregates surviving curves for 10 vegetation types under wet and dry conditions. The differences between groups are much clearer under dry conditions, when aggregate stability is lower. The group of highest aggregate stability is formed by the grassland (*B. retusum*), the woodlands (*Q. ilex* and *Pin. halepensis*) and the more dense scrublands (*Q. coccifera* and *P. lentiscus*) (group 1). *Q. ilex* develops the more stable soils. The group of lowest aggregate stability is *R. officinalis, T. vulgaris, U. parviflorus, A. cystisoides* and the bare soils (group 2). The last one is clearly more erodible than dwarf-shrub covered soils.

The differences between groups and individual samples are less clear under initially wet conditions (Fig. 4). This is due to the increase in soil stability under wet conditions, which reduces the differences between vegetation types. Also, it was found that differences between wet and dry conditions were lower for the more stable soils (Fig. 5). This figure also shows the differences between group 1 and 2 mentioned above. The group 2 have always greater differences between the dry and wet conditions than group 1. The differences between the mean number of drop impacts for the dry and wet conditions are greater than 30 drop impacts for group 2 and lower than 14 drop impacts for group 1. The linear regression shows the trend mentioned above.

3.3. Ultrasonic disruption test

The UD test was applied for 5 and 10 s in order to simulate two energy intensities. Obviously, a greater number of aggregates was disrupted after 10 min. The vegetation influences result in important differences among samples. For 5 s duration and average

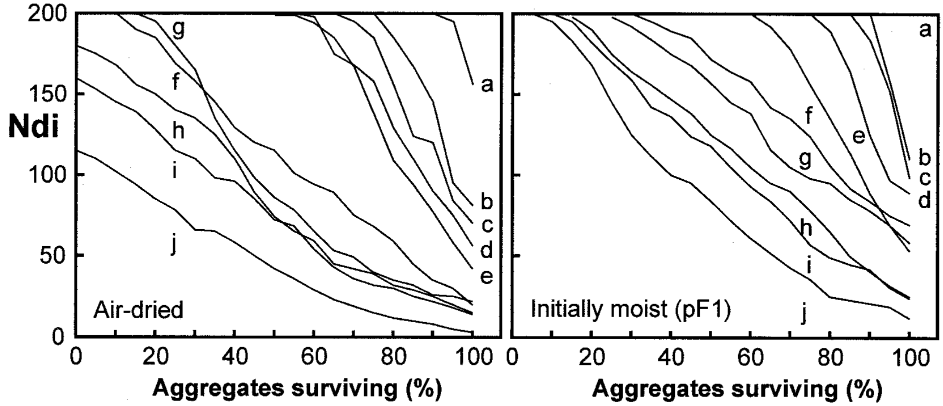

Fig. 4. CND test. Percentage of aggregate surviving at different number of drop impacts (Ndi) distinguishing between the air-dried and the initially moist (pF1) runs. (a) *Q. ilex*; (b) *Q. coccifera*; (c) *P. lentiscus*; (d) *B. retusum*; (e) *Pin. halepensis*; (f) *R. officinalis*; (g) *T. vulgaris*; (h) *U. parviflorus*; (i) *A. cystisoides* and (j) Bare. Three samples of 20 aggregates.

values for different intensities of power (from 30 to 115 W), the test showed that more than 60% of the aggregates in group 2 (*R. officinalis, T. vulgaris, U. parviflorus, A. cystisoides* and the bare soils) always survived. For 10 s duration, more than 49% of the aggregates survived. Group 1 (*Q. ilex, Q. coccifera, P. lentiscus, B. retusum* and *Pin. halepensis*) had much lower aggregate stability. The percentage of aggregates surviving was less than 57% for 5 s and less than 40% for 10 s duration. Bare soils reached the lower aggregate stability: 33 and 30% of the aggregates survived after 5 and 10 s,

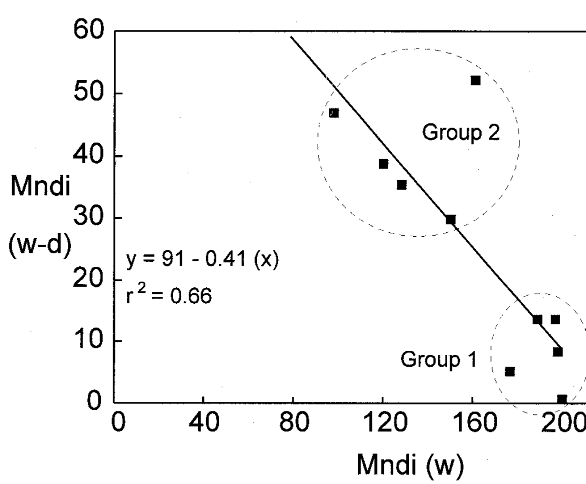

Fig. 5. Relationship between the mean number of drop impacts (Mndi, air-dried conditions) with the differences between the mean number of drop impacts under initially moist and air-dried conditions (wet–dry). Group 1: samples f, g, h, i and j, and group 2: samples a, b, c, d and e (see caption Fig. 4).

Table 4
UD test

Vegetation types	5 s	10 s
Q. ilex	7.00	6.06
Q. coccifera	6.39	5.17
P. lentiscus	6.22	5.11
B. retusum	6.00	5.00
Pin. halepensis	6.11	4.94
R. officinalis	5.61	3.89
T. vulgaris	5.67	3.94
U. parviflorus	4.67	3.44
A. cystisoides	4.17	3.39
Bare	3.28	3.00

Number of aggregates (from 10) surviving at different energy applications (from 30 to 115 W) during 5 and 10 min distinguishing between the dry and the wet (pF1) runs (three samples of 20 aggregates).

respectively of ultrasound application (Table 4). The UD test confirms the influence of plant cover in aggregate stability. *Q. ilex*, *Q. coccifera*, *P. lentiscus*, *B. retusum* and *Pin. halepensis* have the strongest aggregates and the dwarf-shrubs develop soils with aggregates less stable than the other shrublands or woodlands.

4. Discussion

The influence of vegetation on soil aggregate stability has been measured on different vegetation covers on eastern Iberian Peninsula. Always, the most unstable sample was the *Bare* soil, although lichens, mosses, and soil microfauna activity still give a high stability in comparison to soil affected by ploughing, grazing, etc. (Wood and Blackburn, 1981; Weltz et al., 1989; Cerdà et al., 1994, 1995b) or soil developed over other parent materials such as marls (Sanroque et al., 1990; Ternan et al., 1994; Cerdà, 1996a). The vegetation cover of dwarf-shrubs develops soils more stable than under bare conditions, but the aggregate stability is stronger than under other shrubland, woodland and grassland conditions. Scrubland of *Q. ilex* and *P. lentiscus* develops the most stable soils beneath shrubs due to the larger biomass and density. *B. retusum* grasses also determine the formation of very stable aggregates. The less erodible soil was found beneath *Q. ilex* woodland. *Pin. halepensis* woodland showed a similar behaviour than *P. lentiscus* and *Q. coccifera*, but always aggregates slightly more breakable than *Q. ilex*.

Under the vegetation type with greater shade more stable soils are developed. Beneath plants, fluctuations in temperature and soil moisture are less marked and this will result in more stable aggregates. The influence of climate has been found very important by other authors on Mediterranean climatic conditions (Boix et al., 1995). Another influence of vegetation is the litter and organic matter production. The greater the organic matter incorporated into the soil and the less contrast in climate beneath the plant, the more stable the aggregates. *Q. ilex* is the best plant cover due to his large biomass. *Q. coccifera* and *P. lentiscus* scrubland and *Pin. halepensis* woodland also develop a very dense cover which explain the greater aggregate stability. However, *B. retusum* grassland have a very stable soils although the biomass is smaller. The root system of the grass must improve the aggregate and this is because although the perennial dwarf shrubs are far more developed that the annual plants, the root system of the annuals is more dense. The dwarf-shrub develops soils with lower aggregate stability due to the reduced biomass of this type of shrubs in comparison to the woodlands or the scrublands such as *Q. coccifera* and *P. lentiscus*. It seems clear that changes in the floristic composition results in changes in the soil aggregate quality. The more developed is the vegetation (floristic succession) the greater is the aggregate stability. This explains the influence of vegetation type on runoff and erosion such as other researchers found in Central Spain (González del Tanago et al., 1994; Williams et al., 1995).

Soil organic matter seems to be the most important factor in order to determine the aggregate stability at the study area (Fig. 6). The other test shows similar trends, always organic matter shows a positive relationship with aggregate stability. Similar relationships were found by other authors (Ternan et al., 1996) between different types of vegetation and within the same type of plant cover. The formation of aggregates by means of the cementing agents of the organic matter (litter and plant decomposition) (Zhang, 1994) and the formation of macroaggregates around the plant roots (Oades, 1993) explain the positive effect of a more developed and dense vegetation cover on aggregate stability. There is evidence that 2% organic matter is an important threshold for soil aggregate stability (Oades, 1988). Field studies of water erosion of arable land in England suggest that the 2% organic matter threshold is the explanation of accelerated erosion (Evans, 1996). The soils studied at the Serra Grossa Range have greater organic matter content than 2%, which is the reason for the general high aggregate stability.

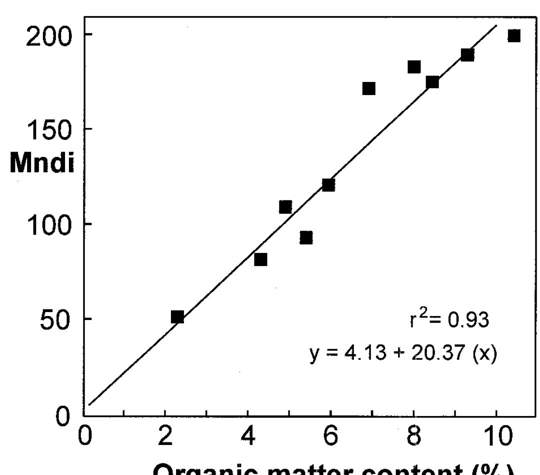

Fig. 6. Relationship between the organic matter content (%) and the mean number of drop impacts (Mndi, air-dried conditions) for the 10 studied vegetation types.

Following disturbances such as land abandonment, forest fire, and overgrazing, a program for vegetation recovery should favour a quick regeneration of grasses (sow) due to the quick improvement of the soil aggregation and the fast recovery of the grasses within the first year. The grasses should be followed by shrubland of *Q. coccifera* and *P. lentiscus* because they will improve the soil resistance to erosion much better than the dwarf-shrubs. The climax woodland of *Q. ilex* develops soil with stronger aggregates stability than the *Pin. halepensis* plantations.

The drop-tests demonstrated that aggregate stability is greater for initially moist soils. This implies that under natural rainfall events soil erodibility will be greater at the beginning of the thunderstorms, when the soil surface still is dry. Soil erodibility will decrease during the rainfall events, which explains the decrease of runoff sediment concentration measured by other authors under semiarid conditions as here (Abrahams et al., 1988; Cerdà et al., 1995a). Also, these results allow one to say that higher runoff sediment concentration should be expected after a dry period, such as the autumn storms following the summer dry season. However, the winter and spring runoff should have very low sediment concentration due to the previous wet conditions of the soils.

These results relate to the climatic situation of summer, under dry and hot weather conditions. A greater aggregate stability during the wet seasons due to the increase in soil moisture and microbial carbon biomass is expected (Cerdà et al., 1995b). The seasonal changes of aggregate stability under different vegetation covers should be studied in order to know the behaviour of the soil erodibility under different conditions, which can show more differences between plant types.

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References

Abrahams, A.D., Parsons, A.J., Luk, S.H., 1988. Hydrologic and sediment response to simulated rainfall on desert hillslopes in southern Arizona. Catena 15, 103–117.

Bergsma, E., Valenzuela, C.R., 1981. Drop testing aggregate stability of some soils near Merida, Spain. Earth Surf. Processes Landforms 6, 309–318.

Boix, C., Calvo, A., Imeson, A.C., Soriano, M.D., 1995. Climatic and altitudinal effects on soil aggregation in slopes of Mediterranean environment. Phys. Chem. Earth 20 (3–4), 287–292.

Cerdà, A., 1994. Aplicación del test de la gota y de la dispersión por ultrasonidos para la determinación de la estabilidad de los agregados en suelos sobre calizas afectados por fuego. Cuaternario y Geomorfología 8 (1–2), 69–85.

Cerdà, A., 1996a. Soil aggregate stability in three mediterranean environments. Soil Technol. 9, 133–140.

Cerdà, A., García-Álvarez, A., Cammeraat, L.H., Imeson, A.C., 1994. Agregación del suelo en una catena afectada por el abandono del cultivo en la cuenca del Guadalentín (Murcia): I. Estabilidad y distribución de los agregados del suelo. In: García Ruiz, J.M., Lasanta, T. (Eds.), Consecuencias Geomorfológicas del Abandono de Tierras. Editorial Geoforma, Logroño, Spain, pp. 9–19.

Cerdà, A., Imeson, A., Calvo, A., 1995a. Fire and aspect induced differences on the erodibility and hydrology of soils at La Costera, Valencia, Southeast Spain. Catena 24, 289–304.

Cerdà, A., García-Alvarez, A., Cammeraat, L.H., Imeson, A.C., 1995b. Agregación del suelo en una catena afectada por el abandono del cultivo en la cuenca del Guadalentín (Murcia): II. Fluctuación estacional y dinámica microbiana. Pirineos 145–146, 3–11.

Costa, M., 1986. La vegetación en el País Valenciano. Universitat de València, València, 246 pp.

Di Castri, F., Goodall, D., Specht, R., 1981. Ecosystems of the World 11. Mediterranean Type Shrublands. Elsevier, Amsterdam, 610 pp.

Duchafour, P., 1975. Manual de edafología. Barcelona, Toray-Masson, 476 pp.

Dunne, T., Zhang, W., Aubry, B.F., 1991. Effects of rainfall, vegetation and microtopography on infiltration and runoff. Water Resour. Res. 27, 2271–2285.

Edwards, A.P., Bremmer, J.M., 1967. Microaggregates in soils. J. Soil Sci. 18, 64–73.

Emerson, W.W., 1967. A classification of soil aggregates based on their coherence in water. Aust. J. Soil. Res. 5, 47–57.

Evans, R., 1996. Some soil factors influencing accelerated water erosion of arable land. Prog. Phys. Geogr. 20 (2), 205–215.

FAO-UNESCO, 1988. Soil Map of the World. 1:5.000.000: I. Revised Legend. World Soil Resour. Rep. FAO, Rome, 138 pp.

Genrich, D.A., Bremmer, J.M., 1972. Effect of probe condition on ultrasonic dispersion of soil by probe-type ultrasonic vibrations. Soil Sci. Soc. Am. Proc. 36, 975–976.

González del Tanago, M., Cañadas, N., Blanco, R., Ternan, L., 1994. Erosión bajo diferentes cubiertas vegetales, en un suelo de rañas de Guadalajara. In: Arnáez, J., García-Ruiz, J.M., Gómez Villar, A. (Eds.), Geomorfología en España, pp. 227–237.

Imeson, A.C., 1984. An eco-geomorphological approach to the soil degradation and erosion problem. En Fantechi, R., Margaris, N.S. (Eds.), Desertification in Europe, pp. 110–125.

Imeson, A.C., Verstraten, J.M., 1985. The erodibility of highly calcareous soil material from Southern Spain. Catena 12, 291–306.

Imeson, A.C., Vis, M., 1984. Assessing soil aggregate stability by water-drop impact and ultrasonic dispersion. Geoderma 34, 185–200.

Lal, R. 1994. Soil erosion research methods. Soil and Water Conservation Society (Ankeny), 3rd edn. St. Lucie Press, Delray Beach, 340 pp.

Lavee, H., Imeson, A.C., Pariente, S., y Benyamini, Y., 1991. The response of soils to simulated rainfall along a climatological gradient in an arid and semiarid region. Catena 19, 19–37, Suppl.

Lavee, H., Sarah, P., Imeson, A.C., 1996. Aggregate stability dynamics as affected by soil temperature and moisture regimes. Geogr. Ann. 78A, 73–82.

Low, A.J., 1954. The study of soil structure in the field and the laboratory. J. Soil Sci. 5 (1), 19–54.

McCalla, T.M., 1944. Water drop method of determining stability of soil structure. Soil Sci. 58, 117–121.

Morgan, R.P.C., 1986. Soil Erosion and Conservation. Longman, New York.

Oades, J.M., 1988. The retention of organic matter in soils. Biogeochemistry 5, 35–70.

Oades, J.M., 1993. The role of biology in the formation, stabilization and degradation of soil structure. Geoderma 56, 377–400.

Real de la Torre, F., 1985. Morfología de la parte central de la Sierra Grossa y valles adyacentes. Tesis de licenciatura. Universitat de València, 229 + carthography.

Römkens, M.J.M., Prasad, S.N., Whisler, F.D., 1990. Surface sealing and infiltration. In: Anderson, M.G., Burt, T.P. (Eds.), Process Studies in Hillslope Hydrology, 127–172.

Sanroque, P., Rubio, J.L., Izquierdo, L., 1990. Relationship among erodibility, parent material and soil type in areas of the Valencia Province (Spain). Soil Technol. 3, 373–384.

Scoging, H., 1982. Spatial variations in infiltration runoff and erosion on hillslopes in semi-arid Spain. In: Bryan, R., Yair, A. (Eds.), Badland Geomorphology and Piping, 89–112.

Ternan, J.L., Williams, A.G., González del Tanago, M., 1994. Soil properties and gully erosion in the

Guadalajara province, Central Spain. In: Rickson (Ed.), Conserving Our Soils Resources, 56–67, Cambridge, CAB International.

Ternan, J.L., Williams, A.G., Elmes, A., Hartley, R., 1996. Aggregate stability of soil in Central Spain and the role of management. Earth Surf. Processes Landforms 21, 181–193.

Walkley, A., Black, I.A., 1934. An examination of the Degtjarett method for determining soil organic matter and proposed modification of the chromic acid titration method. Soil Sci. 37, 29–38.

Weltz, M., Wood, M.K., Parker, E.E., 1989. Flash grazing and trampling: effects on infiltration rates and sediment yield on a selected NM range site. J. Arid Environ. 16, 95–100.

Williams, A.G., Ternan, J.L., Elmes, A., González del Tanago, M., Blanco, R., 1995. A field study of the influence of land management and soil properties on runoff and soil loss in Central Spain. Environ. Monit. Assess. 37, 333–345.

Wood, M.K., Blackburn, W.H., 1981. Sediment production as influenced by livestock grazing in the TX Rolling Plains. J. Range Manage. 34 (3), 228–231.

Zhang, H., 1994. Organic matter incorporation affects mechanical properties of soil aggregates. Soil Tillage Res. 31, 263–275.