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Soil erosion on dry farming land in two changing environments of the central Ebro Valley, Spain

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Abstract Increasing loss of productive soils is a major concern in semiarid areas of the Mediterranean region. About 40% of Spanish territory is seriously affected by erosion. One of these areas, the central Ebro valley, in northeast Spain, provides a case-study of climate and human impact on soil erosion. A rainfall gradient exists from the centre of the valley (300 mm, mean annual precipitation) towards the Pyrenean middle mountains (>800 mm). The occurrence of convective storms coupled with the high erodibility of the soils gives rise to very fragile agrosystems in which soil essentially constitutes a non-renewable resource. Socio-economic changes which have occurred in Spain over the last 50 years and more recent changes induced by the agrarian policy of the European Union have led to land abandonment and land use changes. Such changes have produced hydrological and edaphic modifications which have had an effect on soil erosion. Two areas representative of the physiographic variety of the dry farming land in the central Ebro valley have been selected to assess soil erosion caused by land abandonment and land use changes. One of the study sites is located in a semiarid environment near Zaragoza city and the other in a temperate environment of the Pyrenean middle mountains. Soil loss has been measured on experimental plots by Gerlach traps and tipping buckets connected to data loggers and by simulated rainfall in the semiarid area. Fallout caesium-137 has also been used to assess soil movement. The results obtained demonstrate significant differences between the two environments. Cultivation is the main factor causing erosion in the semiarid environment, where shrubs have a very protective effect on the soil surface. Higher crop productivity in the middle mountain area helps to protect the soil. The severity of the soil erosion along with the hydrological problems associated with farmland abandonment have produced an urgent need for appropriate soil conservation strategies.

INTRODUCTION

In some regions in Spain, such as Aragón in the middle Ebro basin, land abandonment has become an important problem affecting rainfed agriculture. The extent of this problem has generated much concern about the future of such fragile agrosystems, and the need to implement soil conservation measures. The Socio-economic changes which have occurred in Spain over the last 50 years and, more recently, the application of the agrarian policy of the European Union have encouraged land abandonment and land use change. In Aragón, land abandonment

during the 1950s mainly occurred in the middle mountains of the Pyrenees. According to Lasanta (1989), the Aisa valley was one of the most seriously affected areas and as much as 74% of its cultivated land was abandoned. In addition, recent land abandonment is strongly affecting the Zaragoza area, where the area of 21469 ha left for set-aside between 1989 and 1994 is the second highest within Aragón (Errea Abad *et al.*, in press).

These land use changes have produced hydrological and edaphic changes which have in turn had an impact on soil erosion (Ruiz-Flaño, 1993). The effect of farmland abandonment has been studied in recent years, but available results show that its consequences are very diverse, depending primarily on the environment and the potential for plant colonisation (López-Bermúdez & Torcal, 1986; Ruiz-Flaño *et al.*, 1991; Llorens, 1994). Various factors such as climate, soil type, orientation, vegetation cover and type, and land use also affect the process with implications for infiltration, runoff and erosion (Lasanta *et al.*, 1995; García-Ruiz *et al.*, 1995).

In this paper we analyse the response of two very contrasting physiographic environments, located in areas of Aragón that have suffered large-scale abandonment. One lies in a semiarid environment near Zaragoza, the other is located in the middle mountains of the central Pyrenees. Information derived from classical methods of measuring runoff and soil loss is compared with data obtained using caesium-137 as a sediment tracer. This radioisotope has been widely applied in soil erosion investigations in many different environments around the world and it has proved to be a reliable method for documenting these processes in the Ebro basin (Navas & Walling, 1992; Quine *et al.*, 1994). This study aims to analyse the effect of two types of land use; namely, cultivation and land abandonment, on soil loss in these two environments, as a means of developing guidelines for management of set-aside land in the context of landscape and soil conservation.

STUDY AREAS

The study areas located in the middle Ebro basin (Fig. 1) are characterised by different climatic, edaphic and physiographic conditions. The Zaragoza site, located in the central part of the Ebro valley, is characterized by high Tertiary plateaux dissected by a stream network draining towards the Ebro river. Miocene marls, limestones and gypsum are the most abundant lithologies, alternating with Plio-quaternary glacis and terraces. On the top of these structural plateaux it is common to find relicts of an original forest of *Pinus halepensis* which, on the flatter areas, has been cleared for cultivation. Soils developed on the horizontal limestone strata are shallow (between 20 and 30 cm) and very stony. The mean annual rainfall of around 300-350 mm is evenly distributed throughout the year and is characterised by short intense storm events. The slopes are covered by sparse shrubs and agriculture mainly found in the valley bottoms. The productivity of these dry farming systems is very low (500-1000 kg ha^{-1} $year^{-1}$), and land abandonment encouraged by the EU agrarian policy has been widespread in the area.

The Aisa site is located in the central western part of the Pyrenees. The area is underlain by Eocene flysch, which is intensively folded but lithologically homogeneous. The relief is quite uniform with slopes of between 20 and 40%. The

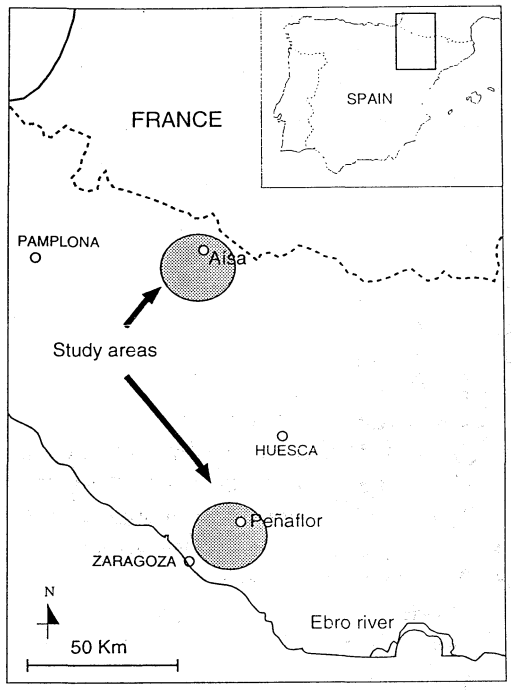

Fig. 1 The study area.

climate is of the mountain Mediterranean type with continental influences. The annual rainfall is around 800 mm, falling mainly between October and May. On the shady slopes *Pinus silvestris* forest is found, but the sunny slopes are dominated by abandoned fields with some *Quercus gr. faginea* forest and shrubs (*Buxus sempervirens, Genista scorpius*), alternating with meadows and some cereal crops that yield around 2500 kg ha^{-1} $year^{-1}$.

METHODS

Measuring runoff and sediment yield

Data on runoff and soil loss have been obtained from cultivated land (cereal crops) and abandoned land (natural vegetation cover) using experimental plots. At the Zaragoza site, the low precipitation has limited the functioning of these plots and a rainfall simulator has been used to simulate six and 13 rainfall events on the cereal and the abandoned plots respectively. The intensities applied were *ca.* 60 mm h^{-1}, lasting 30 minutes. Runoff lag time, discharge and sediment concentration were measured.

At the Aisa site, the cereal and abandoned plots were located on a field with a 32% slope abandoned 35 years ago. This field is now completely covered by dense shrubs (*Genista scorpius* and *Rosa gr. canina)*. The plots (10 × 3 m) were connected to a Gerlach trap as well as to a simple system of tipping buckets. Data loggers were

used to record rainfall and runoff for each plot continuously and information was stored every two minutes. Part of the runoff is diverted to 31 litre containers, which are emptied after each rainfall event and analysed for sediment concentration. Sediment yield and runoff from both cereal and shrub plots were recorded over four years (1992-1995).

Applying the caesium-137 technique

This technique permits the identification of areas of soil loss or gain by comparing the caesium-137 inventories over the site with the total fallout to the site. In each of the study areas, samples have been collected from both uncultivated/abandoned land (with natural vegetation cover) and land cultivated for cereals. A total of nine sites have been sampled, three in the semiarid environment and six in the middle mountain area. At each site a grid of nine sampling points was established. Whole core samples were collected using an 8 cm corer. The sample from the centre of the grid has been sectioned at 5 cm depth increments to examine the depth distribution of ^{137}Cs and to confirm the land use. To include the entire ^{137}Cs profile, the depth of sampling has been between 30 and 40 cm.

Samples were air-dried and ground through a 2 mm sieve. Caesium-137 measurements were undertaken by gamma spectrometry at the Department of Geography, University of Exeter, using a hyperpure coaxial Ge detector, coupled to a multichannel analyser. A total of 87 samples were loaded into Marinelli beakers and count times (662 keV) of 30 000-60 000 s provided an analytical precision of $\pm 6\%$. Caesium-137 activities have been expressed per unit area in mBq cm^{-2}.

Differences between the cultivated and the abandoned land found using both methods in these two environments will now be discussed.

THE SEMIARID ENVIRONMENT

The results of the rainfall simulation measurements undertaken at the Zaragoza site have shown that in general, runoff increases slightly through time due to the saturation of the soil and the sealing of the soil surface, while sediment yield decreases because the loose particles are removed by the initial runoff. As can be seen in Table 1, the runoff coefficient is much higher and the runoff lag time is shorter for the abandoned plot than for the cereal plot. The wetting front is deeper in the cereal plot. The mean discharge and the peak flow for the abandoned plot are almost double the values for the cereal plot. Both, the sediment concentration and soil loss are, however, much higher for the cereal plot.

Table 1 Sediment yield and hydrological response to simulated rainfall of the cereal and abandoned plots in the semiarid experimental area near Zaragoza.

Plot	Runoff coefficient (%)	Time lag (s)	Wetting front (cm)	Discharge (ml s^{-1})	Sediment concentration (g l^{-1})	Soil loss (g m^{-2})
Cereal	45	585	12	1.09	9.26	109
Abandoned	75	175	5	2.19	1.18	40

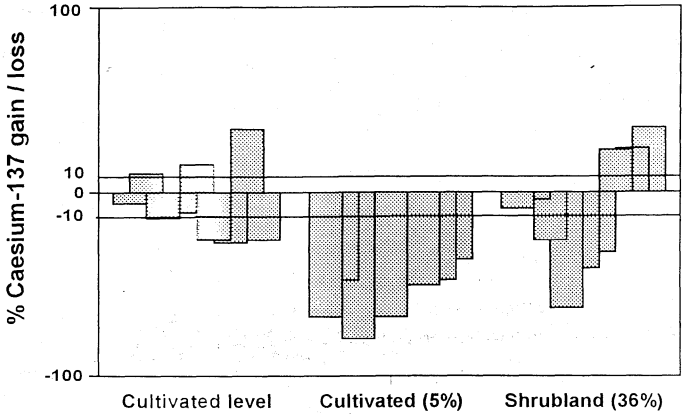

Fig. 2 Percentage deviation of caesium-137 inventories from the input fallout (gain or loss) for the cultivated level soil, the cultivated soil (5% slope) and the shrubland (36% slope) in the semiarid area of Zaragoza.

The average ^{137}Cs input for the Zaragoza area is around 170 ($\pm$20) mBq cm^{-2}. This has been established from 27 samples collected from stable level sites, generally forested and located on the upper part of the Tertiary plateaux. The sampled area covers a zone 100 km in diameter surrounding the city of Zaragoza and it is representative of the physiography and climate of the central part of the middle Ebro valley. The entire ^{137}Cs profile has been sampled and it exhibits the typical pattern of accumulation in the upper 10 cm and a sharp exponential decrease with depth below this level.

To investigate further the effect of land use on soil loss, caesium-137 inventories have been measured at three sites representing: (a) cultivated soil (level), (b) cultivated soil (<5% slope) and (c) shrubland (36% slope). At each of the three sites a total of nine samples was collected.

Data presented in Fig. 2 show that the cultivated level soil has a caesium-137 content similar to the reference inventory. Its average is 160 mBq cm^{-2} and the radioisotope is evenly distributed down the soil profile. In the cultivated soil with 5% slope, the ^{137}Cs inventories are strongly depleted. The average activity is 85 mBq cm^{-2}, which represents a loss of around 55%. Finally, the sloping shrubland soil, with 50% of its surface vegetated, has an average inventory of 152 mBq cm^{-2}. This site exhibits some aggradation (three of the nine points have gained between 10 and 20% of the ^{137}Cs inventory), but the other two points can be considered stable, and depletion and thus erosion is clearly registered at four sampling points, where the inventory is depleted by about 40%. The ANOVA test presented in Table 2

Table 2 Least square means of the caesium-137 activity and standard deviation for the three sites in the Zaragoza semiarid environment.

Site	*n*	Caesium-137 (mBq cm^{-2})		Standard deviation
Cultivated level soil	9	160.5	a	36
Cultivated soil (5% slope)	9	85.6	b	42
Uncultivated shrubland (36% slope)	9	152.1	a	56

Different letters are significantly different ($p < 0.005$)

indicates that the cultivated soil with a gentle slope differed markedly from both the cultivated level soil and the shrubland, which in turn are not significantly different, although the slope is much greater for the latter. In agreement with these results, Quine *et al.* (1994) recorded erosion rates on cultivated land five times greater than on the uncultivated land when applying the ^{137}Cs technique along a slope transect in a similar environment nearby.

These results demonstrate the influence of land use on soil loss and confirm the different hydrological and erosion patterns found under natural vegetated conditions and on cultivated land. Therefore, in this semiarid environment, cereal cultivation is an important cause of soil erosion that should be taken into account in any conservation programme.

THE MIDDLE MOUNTAIN ENVIRONMENT

For the Aisa valley, the response of the cereal and the shrub plots to rainfall is shown in Fig. 3. The relationships between precipitation and runoff are exponential in both cases, but higher correlation coefficients are obtained for the cereal plot. This plot always yields runoff, while the shrub plot shows a greater inertia and a more moderate hydrological behaviour, and hence, higher intensity rains are needed to trigger runoff. Records collected over 4 years showed similar sediment yields from both plots. Average sediment concentrations were 243 mg l^{-1} for the cereal plot and 207 mg l^{-1} for the shrub plot. Cereal cultivation could therefore be considered a conservative land use in this temperate environment.

To provide a comparison with these experimental results, the caesium-137 technique has been applied on three fields abandoned 35 years ago and with similar vegetation cover and slope and on another three fields still under cultivation. For the Aisa valley area, the local fallout input which is around 350 (±25) mBq cm^{-2} has been calculated from 16 samples collected at vegetated stable sites.

Within these sloping fields, the geomorphological elements of crest, talus and bottom slope have been distinguished. For each geomorphologic element, two or

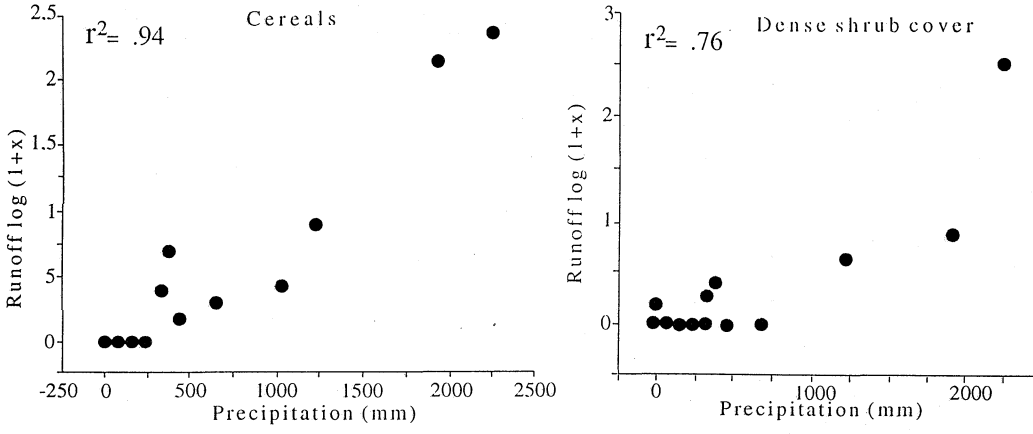

Fig. 3 Relationships between precipitation and runoff for the cereal and abandoned plots at the Aisa experimental station.

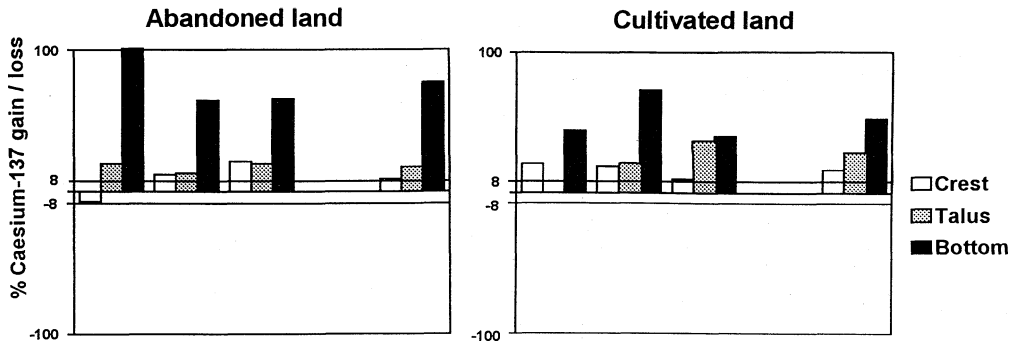

Fig. 4 Percentage deviation of caesium-137 inventories from the input fallout (gain or loss) for the crest, talus and bottom slope in the abandoned and cultivated fields in the middle mountain at Aisa.

three samples have been taken to make up a composite sample. The total number of samples collected was 42, of which 17 composite samples have been analysed for caesium-137 content. As can be seen in Fig. 4, in the abandoned fields, the caesium-137 content is around the input level at the crest. On the talus, deposition predominates, although the percentage deviation from the input fallout does not exceed 10%. On the bottom slope there is deposition, but deviations from the inventory are much higher (77)%. On the cultivated fields, the crest has an average caesium-137 gain of around 10%, 20% on the talus and 45% on the bottom slope.

The results of an ANOVA test summarised in Table 3, indicate that there is no significant difference in the caesium-137 content between the abandoned and the cultivated land. In both cases, there were also significant differences between the caesium-137 content at the bottom of the slope and the levels found for both the crest and talus. These results show the similar pattern of soil movement produced under both shrub cover and cultivation. Caesium-137 contents are also very similar, but tillage distributes sediment more evenly across the cultivated field. Therefore, the caesium-137 data also demonstrate that in this environment no significant difference in erosion patterns are found between old abandoned land with dense shrub cover and cultivated land. The same result has been provided by classical methods. It appears that the higher level of productivity in the cereal crops (around 2500 kg ha^{-1}) helps to protect the soil surface.

Table 3 Least square means of the caesium-137 activity and standard deviation for the crest, talus and bottom slope of the abandoned and cultivated areas of the middle mountain at Aisa.

Site	*n*	Caesium-137 (mBq cm^{-2})		Standard deviation
Abandoned field	9	470.4	a	121
Cultivated field	8	465.3	a	71
Abandoned & cultivated fields:				
Crest	6	394.5	b	37
Talus	5	425.4	b	30
Bottom slope	6	577	a	76

Different letters are significantly different ($p < 0.001$)

CONCLUSIONS

The results from this study show the very different impact of land use in the semiarid and the middle mountain environments. In the semiarid area, cultivation is a major factor causing erosion and consequently any attempt to reduce soil loss and off-site impacts should focus on erosion control on the cultivated land. In the middle mountain area, the higher productivity of crops equalises the functioning of these two different land uses. This study also demonstrates the potential of the caesium-137 technique to provide useful data to complement the information derived using classical methods of measuring soil loss.

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REFERENCES

García-Ruiz, J. M., Lasanta, T., Ortigosa, L., Ruiz-Flaño, P., Martí, C. & González, C. (1995) Sediment yield under different land uses in the Spanish Pyrenees. *Mountain Research and Development* **15,** 229-240.

Errea Abad, M. P., Ortigosa, C. M. & Lasanta, T. (in press) Retirada de tierras de la producción en Aragón por aplicación de la política agraria comunitaria (1988-1994). *Alisios*.

Lasanta, T. (1989) *Evolución Reciente de la Agricultura de Montaña: el Pirineo Aragonés*. Geoforma ediciones, Logroño.

Lasanta, T., Pérez-Rontomé, C., García-Ruiz, J. M., Machín, J. & Navas, A. (1995) Hydrological problems resulting from farmland abandonment in semiarid environments: the central Ebro depression. *Phys. Chem. Earth* **20**, 309-314.

López-Bermúdez, F. & Torcal, L. (1986) Procesos de erosión en tunel en cuencas sedimentarias de Murcia (España). Estudio preliminar mediante difracción de rayos X y microscopio electrónico de barrido. *Papeles de Geografia Física* **11**, 7-20.

Llorens, P. (1994) Hydrological implications of afforestation in Mediterranean mountainous abandoned lands: findings and questions arisen from the simulation of a small basin water balance. In: *Assessment of Hydrological Temporal Variability and Changes* (ed. by P. Llorens & F. Gallart), 75-86. CSIC, Barcelona.

Navas, A. & Walling, D. E. (1992) Using caesium-137 to assess sediment movement on slopes in a semiarid upland environment in Spain. In: *Erosion, Debris Flows and Environment in Mountain Regions* (ed. by D. E. Walling, T. R. Davies & B. Hasholt) (Proc. Chengdu Symp. July 1992), 129-138. IAHS Publ. no. 209.

Quine, T. A., Navas, A., Walling, D. E. & Machín, J. (1994) Soil erosion and redistribution on cultivated and uncultivated land near Las Bardenas in the central Ebro river basin, Spain. *Land Degradation & Rehabilitation* **5**, 41-55.

Ruiz-Flaño, P. (1993) *Procesos de Erosión en Campos Abandonados del Pirineo*. Geoforma ediciones, Logroño.

Ruiz-Flaño, P., Lasanta, T., García-Ruiz, J. M. & Ortigosa, L. M. (1991) The diversity of sediment yield from abandoned fields of the central Spanish Pyrenees. In: *Sediment and Stream Water Quality in a Changing Environment: Trends and Explanation* (ed. by N. E. Peters & D. E. Walling) (Proc. Vienna Symp., August 1991), 103-110. IAHS Publ. no. 203.