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Geomorphic and hydrological effects of traditional shifting agriculture in a Mediterranean mountain, Central Spanish Pyrenees

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Abstract: Shifting agriculture occupied large areas of middle latitude mountains during periods of strong demographic pressure. On average, this practice accounted for about 22.8% of the total cultivated area in the Central Spanish Pyrenees at the beginning of the 20th century. The use of experimental plots between 1992 and 2003 demonstrated that shifting agriculture increased overland flow, suspended sediment and solute concentration. Total soil loss was about 14 times higher under shifting agriculture than under dense shrub cover, and almost 3 times higher than permanent sloping fields. Erosion rates ranged between 0.1 and 1.4 t yr^{-1}. The abandonment of shifting practices resulted in rapid plant recolonization and a decrease in runoff and soil erosion. Nevertheless, severe geomorphic processes are still active several decades after abandonment, explaining landscape degradation and the triggering of shallow landslides.

Key words: shifting agriculture; sloping fields; runoff; soil erosion; land degradation; farmland abandonment; Central Spanish Pyrenees.

Introduction

Most Mediterranean mountains have been subjected to strong demographic pressures during periods of their history. In the case of the Spanish Pyrenees, an almost constant population growth was reported from the Middle Ages until 1840-1860 (Ayuda and Pinilla 2002), when the highest population census was recorded. These demographic changes resulted in transformation of landscape and of the dry-farming agricultural system, including the enlargement of the cultivated areas in marginal lands, most of which were subjected to shifting agricultural procedures or slash-and-burn practices.

Shifting agriculture is a worldwide traditional adaptation of pre-industrial societies to population growth. It is still used in Africa, South America, Southeast Asia and Oceania, and covers an area of about 30% of the cultivated land in the world, while it provides food for only 8% of the population (Borggaard et al 2003). Nevertheless, social and economic pressure has led to the replacement of this agricultural practice by new crop production systems (Juo and Manu 1996). Shifting agriculture was also widely used in mountain areas of the north-western Iberian Peninsula until 25 years ago (Soto et al 1995) and in the Pyrenees until the 1940s (Daumas 1976; Puigdefábregas and Fillat 1986; Lasanta 1989).

A reasonable evolution of cultivated lands in mountain areas (García-Ruiz 1988; Ives and Messerli 1989) involves the occupation of the best lands (valley bottoms, flat areas), located close to settlements during the first stages, and then steeper areas as population increased (alluvial fans, foot of hillslopes). Bench terraced fields (in most cases with stone walls) and sloping fields represented a "limit" stage during which most of the population was integrated within the system (Lasanta 1989). Finally, continued population growth led to the appearance of a marginal population, with few, if any, cultivated lands, who was forced to cultivate peripheral areas under shifting agriculture procedures, on very steep slopes located far from the settlements. In practice, this evolution is more complex and depends on the physical and cultural characteristics of the communities. However, in general, this description of land occupation is valid for most European mountains until one century ago (Rabbinge and Van Diepen 2000; Taillefumier and Piégay 2003) and currently in North African mountains (Laouina et al 1992; Coelho et al 2004).

Marginal cultivated lands may have represented a large proportion of cultivated areas in mountains in the past. This is a crucial, geoecological issue, since shifting agriculture practices are main soil erosion factors, responsible for increased sediment yield and landscape degradation in several environments (i.e., Lasanta 1989; Ruiz-Flaño 1993; Soto et al 1995; Lianzela 1997; Messerli 2000; Barrow and Hicham 2000). However, only a few studies include quantitative, experimental information on soil loss in tropical and oceanic-climate zones. Here we examine the geomorphic and hydrological consequences of shifting agriculture in a Mediterranean mountain area, and its evolution after farmland abandonment throughout the 20th century, in order to explain many of the current landscape characteristics.

The study area

The study was carried out in the Central Spanish Pyrenees, specifically in the Eocene Flysch Sector (Figure 1), where agriculture, grazing and forest logging followed by farmland abandonment introduced extensive plant cover changes. Sandstones and marls alternate in thin beds that are strongly folded and faulted. Altitude ranges from

600 to 2200 m, with smooth divides and straight, regularized hillslopes. Active headwaters of ravines, sheet-wash in most deforested areas (García-Ruiz and Puigdefábregas 1982), and shallow landslides (Lorente et al 2002) are the most active erosion processes.

The climate is sub-Mediterranean, and slightly continentalized. Average annual precipitation ranges from 700 mm in the southernmost part of the study area to about 2000 mm in the divides. The wet season runs from November to April, with a short, dry summer.

Historically, cultivated areas were located below 1600 m a.s.l. in the valley bottoms, perched flats, and on the steep, south-facing hillslopes, which were cultivated even under shifting agricultural systems. The stoniness and low field capacity of Calcaric Regosol and Rendsic Leptosol soils indicate that these slopes have been affected by water erosion. The forests have remained relatively well preserved on the north facing slopes and indeed everywhere between 1600-1800 m, where deep and well developed Haplic Kastanozems and Haplic Phaeozems soils predominate. The upper divides are covered by grasslands of the sub-alpine belt.

During the 20th Century, most cultivated fields were abandoned, except in the valley bottoms. Abandoned fields, accounting for about 25% of the total area (Lasanta 1988), have been affected by a natural process of plant recolonization (mainly dense shrub communities, but also woodland in the most favourable locations) or have been reforested for land reclamation and to reduce reservoir siltation (Ortigosa et al 1990).

Methods

Aerial photography from 1957 was used to calculate the area occupied by the distinct types of fields and the topographic factors that control both their spatial distribution and the process of farmland abandonment. Experimental plots in the "Aísa Valley Experimental Station" (42º 40' 24" N; 0º 36' 30" W) were used to compare runoff and sediment yield under several land uses: shifting agriculture (with barley), abandoned shifting agriculture, cereal cultivation (barley) in permanent sloping fields, and dense shrub cover. The cereal plot has been cultivated in a cycle of two years (cultivation/fallow); 1.5 kg of chemical fertilizer (equivalent to 500 kg ha^{-1}) was added to the plot, including N, P_2O_5 and K_2O_5. The experiment has been running since 1992. The data analysed here correspond to 1992-2003, except for the abandoned shifting agriculture plot, which corresponds to 1996-2003 after being cultivated between 1992 and 1995. Compared to the long term average, the study period is relatively humid (Figure 2). The average annual precipitation in the period 1992-2003 was 0.65 standard deviations higher than the average for the period 1967-2003, as measured in a nearby station in the region (Aragüés del Puerto, 8 km westward, at a similar altitude).

Each plot is 30 m2 in size (10 x 3 m), delimited by metal strips, with a Gerlach trough at the lower end of the plot, where runoff and sediment produced during each rainstorm event are collected. Runoff is continuously measured by means of a tipping bucket system connected to a data logger. A sample of water (2 l) is taken after each event to analyse the particulate and solute content. Precipitation is measured with a tipping bucket pluviometer. The evolution of plant cover has been studied yearly in the case of the plot representing abandoned shifting agriculture, making plant inventories and estimation of plant density. The Experimental Station is located in a concave, south-facing slope which was cultivated, probably for centuries, until 40 years ago. The gradient is about 22%, and the soil is a deep (about 1 m) and well structured Haplic

Kastanozem, with 5% of organic matter in the upper 20 cm. There are no significant differences between the plots in their main characteristics. This homogeneity ensures that the variability of the results is closely related to the management practices and not to environmental factors.

Finally, the nutrient content of the dry matter from *Genista scorpius*, the most common shrub in the study area, was analysed to establish whether slash-and-burn practices improve and fertilize the soil.

Shifting agriculture in the Central Spanish Pyrenees. A review

Shifting agriculture was the usual reaction of the traditional system to demographic growth. Once the best places for agriculture were cultivated, a new increase in population forced the population to occupy marginal lands, on very steep slopes located far from settlements. Barrère (1952) describes a “shifting cultivation fever” during the second half of the 19th century and the first decades of the 20th century, always coinciding with the presence of abundant manpower.

Shifting cultivation prevailed on south-facing, straight or convex slopes of communal tenure, which explains why farmers did not build structures for the diversion of overland flow and for soil conservation. Lasanta (1989) estimated that shifting agriculture occupied about 22.8% of the total cultivated area in the Central Spanish Pyrenees at the beginning of the 20th century, though in some valleys it represented a much larger area (Aísa Valley, 36.8%; Hecho Valley, 46.9%).

Shifting cultivation consisted of the following steps: (i) breaking up a part of a hillslope covered by shrubs and occasionally by trees; (ii) heaping the shrubs and covering them with herbs and soil; (iii) burning the piles slowly; and (iv) dispersing the ashes throughout the field and ploughing the soil to incorporate the ashes immediately. Several days or a few weeks later, the farmer sewed wheat, barley or rye. Field cultivation was possible only for 1 to 3 years, after which it was abandoned and recolonized by vegetation (fallow period). A new clearing occurred after 15 to 25 years, depending on the density of shrub recolonization, and the slope was cropped again. In comparison, permanent sloping fields, where land rights belonged to farmers, occupied straight and concave slopes, received organic fertilizer, was left fallow during short periods and overland flow was diverted using artificial drains.

Crop production for the shifting agriculture plot was about 700 kg ha^{-1} yr^{-1} of barley, and in the case of the sloping, fertilized field, about 2,800 kg ha^{-1} yr^{-1}. The low productivity in the former was related, on the one hand, to the poor nutrient content in soils on flysch (Lasanta 1989; Ruiz-Flaño 1993); and, on the other hand, to the low nutrient supply from ashes. *Genista scorpius* (the dominant species in the slopes cultivated under shifting agriculture) supplied extremely low amounts of nutrients (Table 1). The dry matter of the plant accounted for only 2.25% of the plant, and the P, Mg and Na content was very low.

Runoff and soil erosion under shifting agriculture

Figures 3 and 4 show runoff coefficients and total soil loss from active and abandoned shifting agriculture plots and also the permanent sloping field and the dense shrub cover plot (control). The period of analysis corresponds to a relatively humid period, and the results may not be a good estimation of the long term values.

The average runoff coefficient (Figure 3) was clearly higher in the active plot (19%), which was twofold that of the abandoned shifting agriculture plot (10.7%). The sloping field plot remained in an intermediate position, with a runoff coefficient of 11.4%. Runoff from the control plot recorded the lowest values (4.5%).

Active shifting agriculture clearly represented the highest soil losses (1369 kg ha^{-1} yr^{-1}) (Figure 4), much greater than the sloping field (530 kg ha^{-1} yr^{-1}), followed by the abandoned shifting agriculture plot (436 kg ha^{-1} yr^{-1}). The control plot showed low soil loss (109 kg ha^{-1} yr^{-1}), almost 14 times lower than shifting cultivation. It is interesting to note that a sloping field cultivated for 4 years at the Experimental Station and then abandoned yielded only 200 kg ha^{-1} yr^{-1}, which is less than a half the production of the abandoned shifting agriculture.

These results do not correspond to true erosion rates because of the experimental conditions in which the information was obtained (relatively small closed plots), although they serve for comparative purposes and to emphasize the main hydromorphological consequences of shifting agriculture. The low values of soil loss obtained from all of the plots is due to the characteristics of the Experimental Station, with a deep and well structured soil in a concave profile with moderate gradient, far from the conditions in which shifting agriculture fields were cultivated. It is well known that each type of fields of the traditional system (flat fields, sloping fields, bench terraced fields, shifting agriculture fields) occupied different topographic locations (Lasanta 1989), but the plots of the Experimental Station have been located under the same conditions to optimize the comparative purpose of the experiment. The relatively low intensity of rainfalls during the study period has also contributed to the low values of soil loss recorded. In any case, other experimental studies recorded also low erosion rates from runoff plots in Mediterranean landscapes, due to calcic aggregates and the presence of gravels on the soil surface (Roose et al. 1993; Roose and Sabir 2002;

Moufaddal 2002).

Regarding suspended sediment concentration (Figure 5), the active shifting agriculture plot again showed the highest values (431 mg l^{-1}), slightly greater than those from the sloping field (332 mg l^{-1}). The abandoned shifting agriculture plot recorded much lower values (180 mg l^{-1}). Again, the control plot was the lowest (50.5 mg l^{-1}). Solute concentration showed a very different behaviour: active and abandoned shifting agriculture plots recorded similar values (188 and 179 mg l^{-1} respectively), whereas the sloping field underwent the highest solute losses (213 mg l^{-1}) because of the use of organic and chemical fertilizers. Solute loss in the control plot reached 132 mg l^{-1}. The main losses were recorded in HCO^{3-} and Ca^{2+} because of the carbonatic character of the rock substratum. Relatively high losses of K^{+}, SO^{4-}, Cl^{-} and NO^{3-} were recorded, especially in the sloping field, followed by the abandoned shifting agriculture and the active shifting agriculture plots (Table 2). This result indicates that farmland abandonment has more capacity to reduce suspended sediment transport than solute outputs.

The evolution of shifting agriculture fields after farmland abandonment

One of the shifting agriculture plots was abandoned in 1996, after four years of cultivation. Since then, plant colonization progressed quickly, particularly in the case of grasses (from 20% in 1995 to 95% in 2004). At the same time, shrub cover progressed from 0% in 1995 and 2% in 1997, up to 10% in 2004. Since 2003, the grasses have shown an incipient trend to be substituted by shrubs. Therefore, after 10 years of abandonment, plant cover in the field representing abandoned shifting agriculture is about 100%, and the presence of shrubs is clearly increasing. Consequently, a marked decrease in soil loss has been detected (Figure 6), regardless of annual rainfall fluctuations.

At present, the abandoned shifting agriculture plot is colonized by seedlings of *Genista scorpius, Rosa sp., Thymus vulgaris* and *Crataegus monogyna,* that is to say, the same species as the control plot. *Carex flacca* and *Brachypodium pinnatum* are the most abundant herbs, accompanied by *Galium lucidum, Sanguisorba minor, Blackstonia perfoliata, Dactylis glomerata, Daucus carota, Convolvulus arvensis* and *Medicago lupulina.*

Nevertheless, geomorphic processes are still very active in the abandoned plots of shifting agriculture. Thus, the propensity to shallow landsliding has been studied in the Ijuez Valley, densely populated until the 1950s, when it was totally depopulated. Until then, most of the south facing slopes were cultivated, including a large proportion of shifting agriculture fields. Afterwards, the abandoned fields underwent reforestation and colonization with shrubs. A set of aerial images dating back to 1957 was analysed to determine the effect of past shifting agriculture on the occurrence of landslides. It was found that 49.5% of the valley was cultivated on sloping fields and using shifting agriculture, accounting for 68.6% of the shallow landslides (hillslope debris flows) present in the 1957 image. By 2002, most of the shallow landslides (69.4%) still occurred in areas formerly occupied by sloping fields and areas of shifting agriculture, especially those colonized by shrubs. The areas with enhanced revegetation (natural forests and reforestations) were less prone to landslides.

Discussion and conclusions

The results obtained from experimental plots in the Pyrenees show that shifting agriculture recorded the highest runoff and sediment concentration values, and therefore, the highest soil loss rates. Although experimental plots do not supply true, natural values of overland flow and sediment outputs, they demonstrate that shifting agriculture practices contribute more greatly to soil erosion than the hillslopes covered by dense shrubs (almost 14 times more) and than permanent sloping fields (more than twofold). Therefore, the traditional substitution of shrubs by slash-and-burn fields represented a sudden increase in runoff generation and sediment yield. The difference with sloping fields, also cultivated mainly with cereals, is evident and is due to (i) the very low crop productivity of slopes cultivated under shifting agricultural systems, resulting in poor soil protection by plants, as it has been also reported in shifting agriculture of NW Spain (Soto et al 1995); and (ii) the absence of conservation structures to retain more water in the slope or to divert overland flow out of the field. This problem is obviously related to the communal character of land tenure, such that farmers showed little concern for the future sustainability of the territory; but is also related to the high ratio between investment in manpower and the low expectations of production in extreme topographic conditions. Besides, the expected increase in fertility due to the incorporation of ashes is no longer apparent some months later, due to the poor nutrient content of *Genista scorpius* and to erosion, which is considered the main cause of nutrient stock declining in shifting agriculture (Soto et al 1995).

The present landscape reflects the consequences of shifting agriculture. Steep, south-facing slopes in convex areas have thin and stony soils, with a relatively poor plant cover; they are affected by severe sheet-wash processes, accompanied by rilling (Ruiz-Flaño et al 1992; Ruiz-Flaño 1993). García-Ruiz and Valero-Garcés (1998) attributed the torrentiality of Pyrenean rivers during the periods of greater population pressure to cultivation on steep slopes and, particularly, to shifting agriculture: debris flows, rills, gullies and sheet-wash erosion supplied large volumes of sediment to the rivers, which adopted braided patterns in a context of frequent floods.

The abandonment of shifting agriculture fields resulted in a progressive decrease in runoff and soil loss, as a result of plant recolonization. Our experiment shows that the slope was covered by grasses and an incipient cohort of shrubs after abandonment. Nevertheless, soil erosion rates were at least two-fold those recorded in sloping fields after abandonment. This difference is, most probably, due to soil degradation during the years of cultivation. This observation implies that, after abandonment, the slope is still affected for many years by the effects of slash-and-burn practices, including shallow landslides, which are closely related to past agricultural activities on steep slopes (Lorente et al 2002). Experimental simulation of slash-and-burn practices in NW Spain showed extremely high soil erosion rates (about 40 times more than the control, shrub-covered plot) and increases in nutrient loss of about 20- to 50-fold that of the control plot (Soto et al 1995). In tropical environments, shifting cultivation is also a main sediment source. Thus, in the Chittagong Hill Tracts of Bangladesh a comparison was made between two catchments traditionally subjected to slash-and-burn practices, one recently burnt and cultivated, and the other in a long fallow period, with dense vegetation. The former recorded soil and nutrient losses four times higher than the latter (Borggaard et al 2003).

In conclusion, shifting agriculture was a major cause of land degradation in the Pyrenees, even when the fallow period was fairly long (15 to 25 years). Historical, relatively recent periods of increasing population density obligated to cultivate marginal lands in very steep slopes, causing not only serious land degradation, but also an increase in the torrentiality of most of the rivers. These practices had a deep impact on the landscape, which is still subjected to a number of inherited geomorphic processes, even more than 50 years after farmland abandonment. Shifting agriculture is now unthinkable in the Pyrenees, as in mountains of developed countries, where only the valley bottoms are cultivated (García-Ruiz and Lasanta 1993) in a context of general depopulation since the end of the 19th century.

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Table 1. Nutrient content from *Genista scorpius*

(Results from dry matter)

	%
Ashes	2,25
Nitrogen	1,24
Phosphorous	0,05
Potassium	0,29
Calcium	0,53
Magnesium	0,08

Table 2. Annual solute losses (g m^{-2}) in the period 1992-2003 (average and standard deviation)

		Ca^{2+}	Mg^{2+}	Na^{+}	K	SO_4^{-}	SiO_2	Cl	NO_3^{-}	HCO_3^{-}
Shifting agriculture	aver.	5.03	0.25	0.18	0.34	0.24	0.54	0.43	0.09	15.24
	st. dev.	2.14	0.11	0.11	0.07	0.25	0.15	0.39	0.06	6.94
Abandoned shift. agriculture	aver.	7.95	0.33	0.24	0.68	0.29	0.87	0.78	0.20	22.29
	st. dev.	6.42	0.25	0.20	0.78	0.22	0.62	0.77	0.23	16.11
Sloping fields (barley)	aver.	5.50	0.23	0.21	0.64	0.63	0.52	0.98	0.33	14.99
	st. dev.	2.38	0.11	0.12	0.27	0.39	0.24	0.63	0.23	4.98
Dense shrub	aver.	1.78	0.08	0.06	0.25	0.07	0.30	0.18	0.07	4.98
	st. dev.	1.55	0.06	0.08	0.18	0.09	0.23	0.15	0.07	3.56

Figure captions

Figure 1. Study area. Location of the “Aísa Valley Experimental Station”.

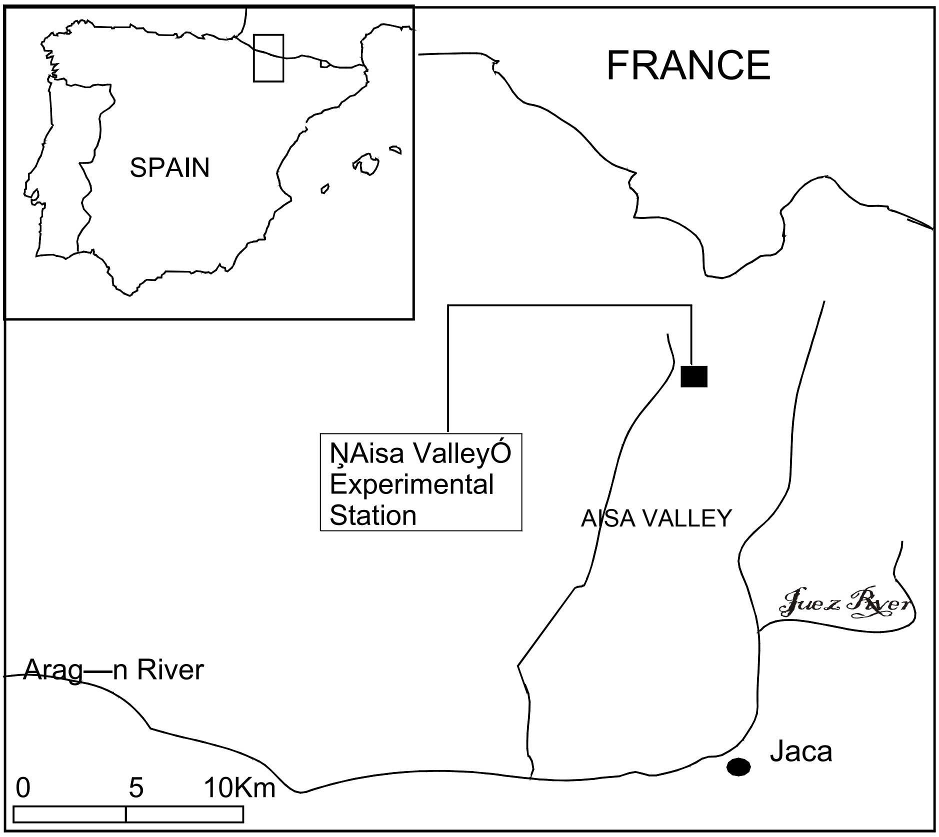
Figure 2. Comparison between annual precipitation in the Aísa Experimental Station (white squares) and the long term precipitation measured at the neighbouring Aragüés del Puerto Station (black squares).

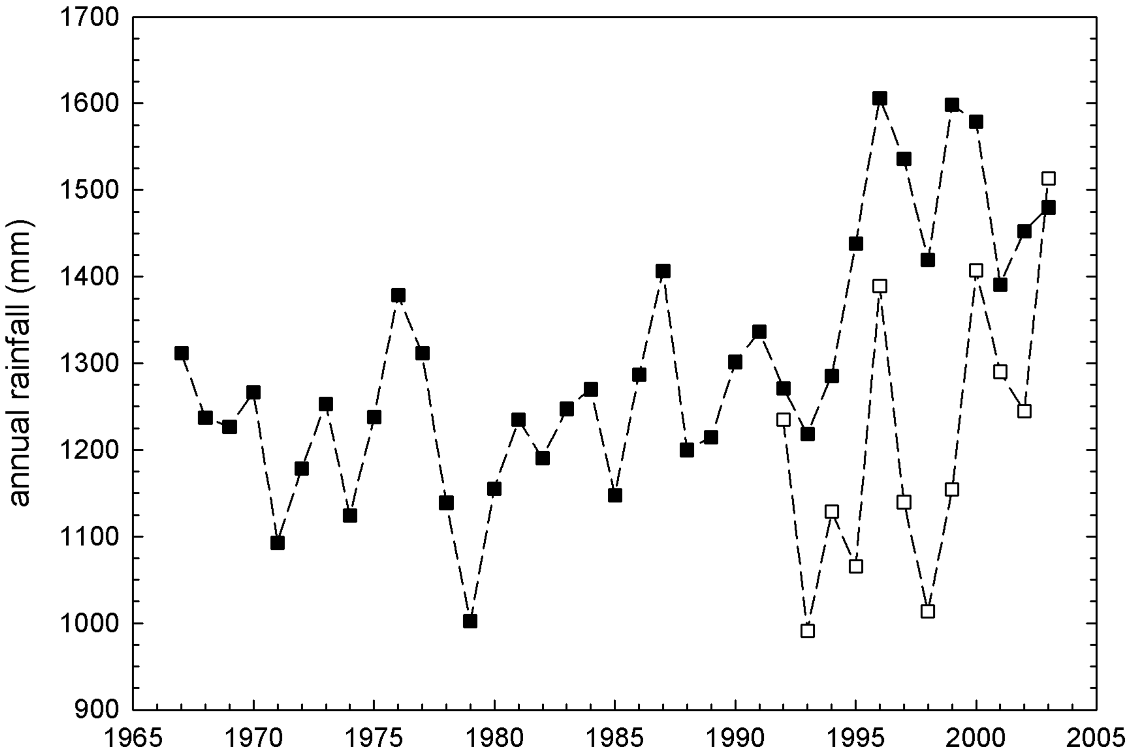
Figure 3. Average annual runoff coefficient (%) from distinct land uses (runoff plots) at the “Aísa Valley Experimental Station” (median value, 1st and 3rd quartiles, 1st 9th deciles, and average). 1: Sloping field (barley). 2: Shifting agriculture (barley). 3: Abandoned shifting agriculture. 4: Dense shrub (control plot).

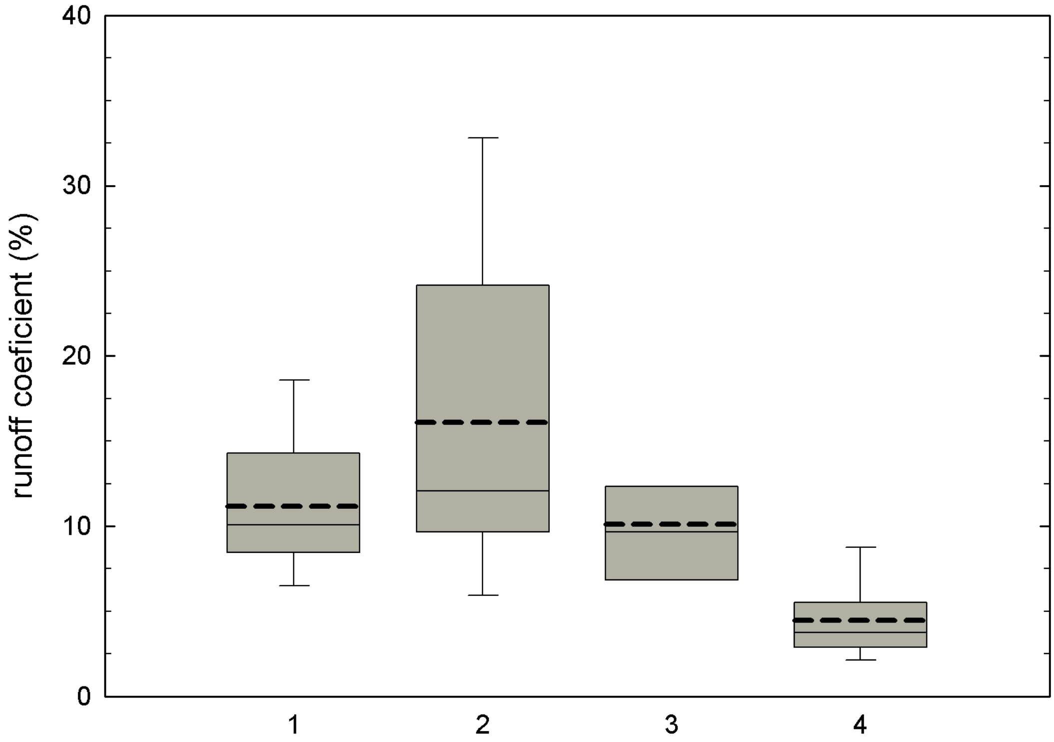
Figure 4. Average annual suspended sediment and solute concentration (mg l^{-1}) under different land uses (runoff plots) at the “Aísa Valley Experimental Station” (median value, 1st and 3rd quartiles, 1st 9th deciles, and average). A: Suspended sediment concentration. B: Solute concentration. C: Total concentration. 1: Sloping field (barley). 2: Shifting agriculture (barley). 3: Abandoned shifting agriculture. 4: Dense shrub (control plot).

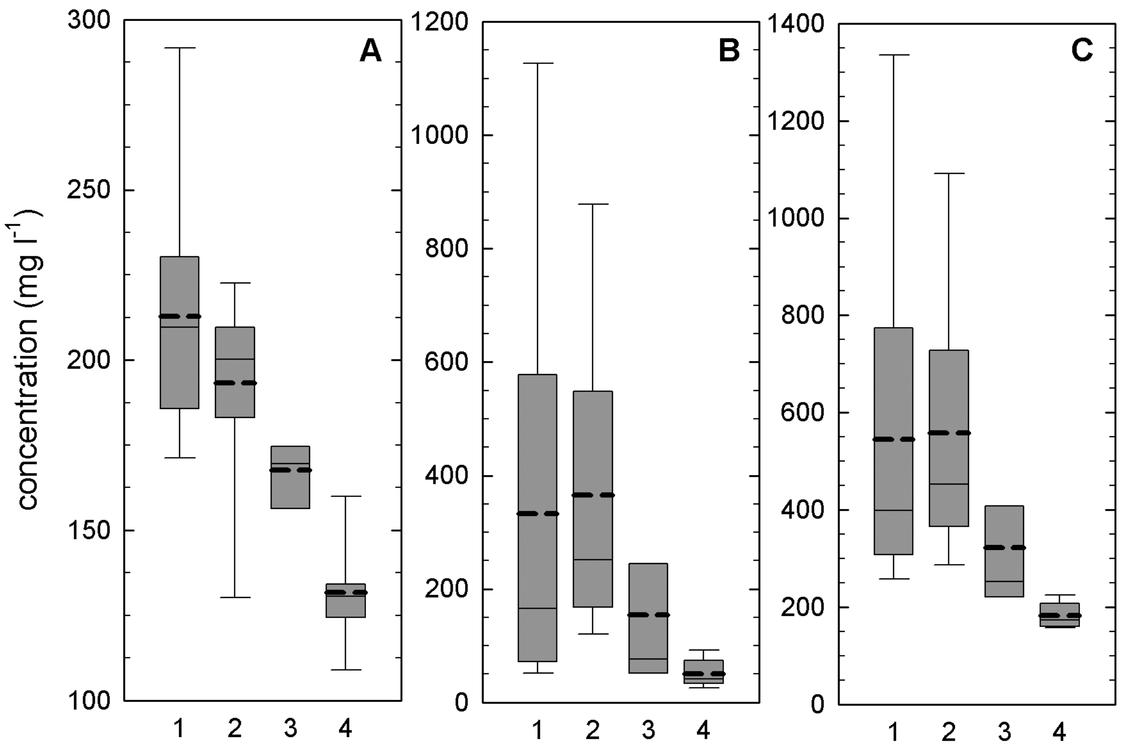
Figure 5. Average annual soil losses (kg ha^{-1} yr^{-1}) from the land uses considered (runoff plots) at the “Aísa Valley Experimental Station” (median value, 1st and 3rd quartiles, 1st 9th deciles, and average). 1: Sloping field (barley). 2: Shifting agriculture (barley). 3: Abandoned shifting agriculture. 4: Dense shrub (control plot).

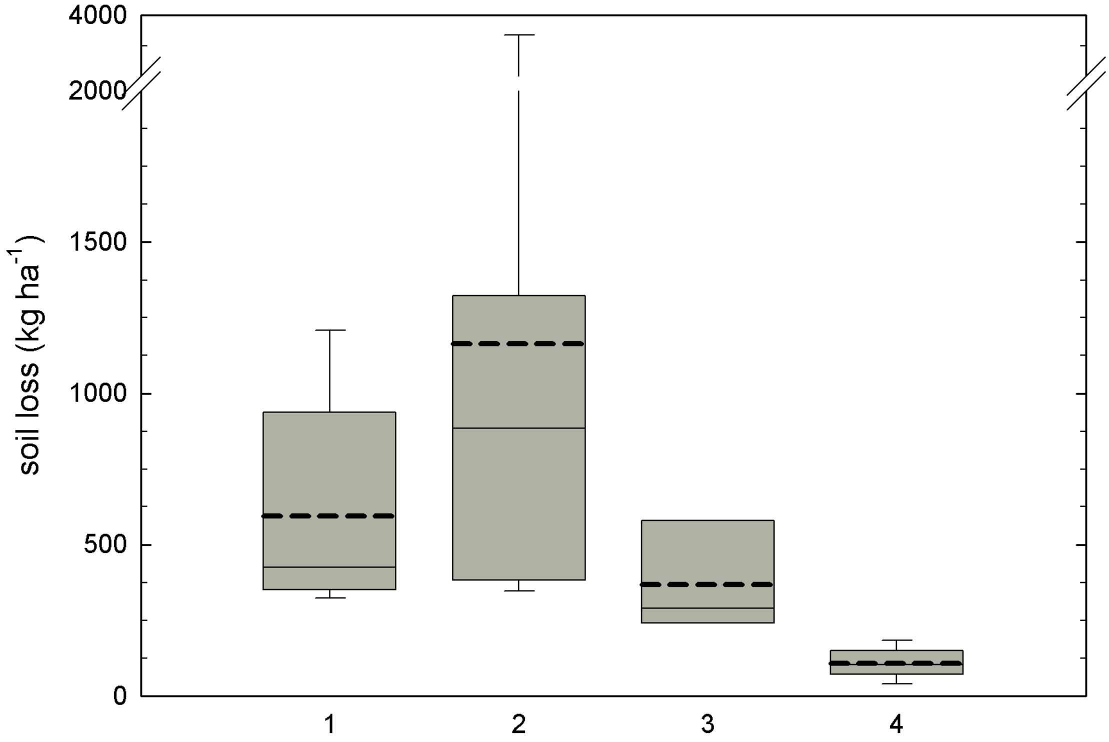
Figure 6. Trend in soil erosion after the abandonment of shifting agriculture, from the residuals of the correlation between annual precipitation and erosion.

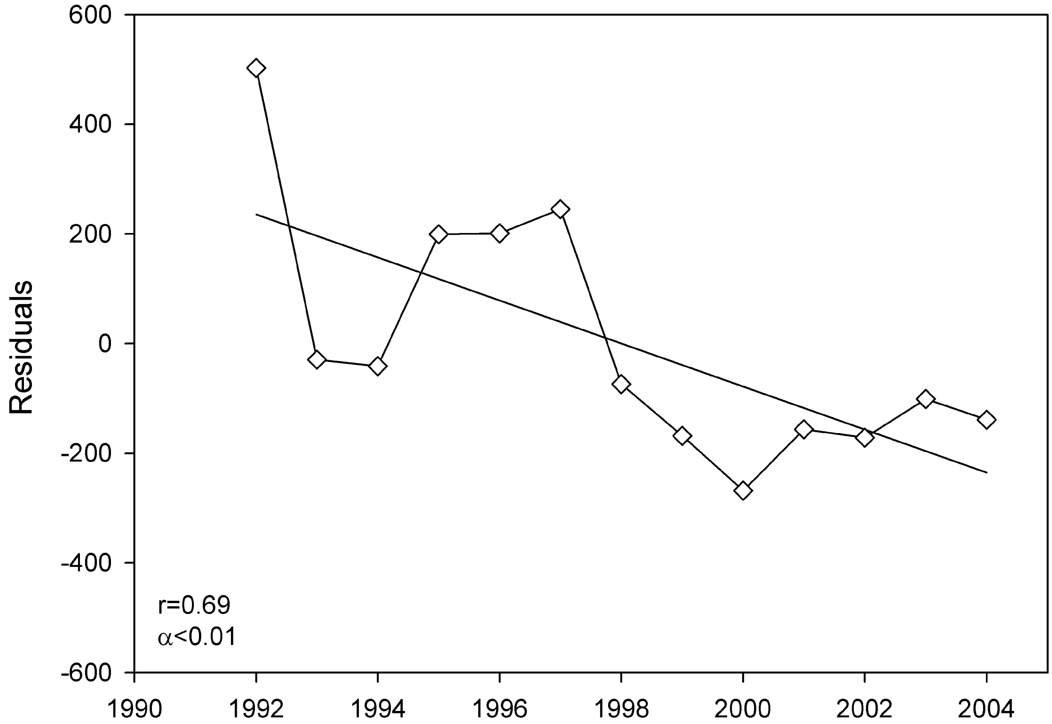

FRANCE
SPAIN
ŅAisa ValleyÓ Experimental Station
AISA VALLEY
Arag—n River
Jaca
0 5 10Km


1700
1600
1500
1400
1300
1200
1100
1000
900
annual rainfall (mm)
1965
1970
1975
1980
1985
1990
1995
2000
2005


runoff coeficient (%)
40
30
20
10
0
1
2
3
4


concentration (mg l-1)
A
B
C
300
250
200
150
100
1200
1000
800
600
400
200
0
1400
1200
1000
800
600
400
200
0
1
2
3
4


4000
2000
1500
1000
500
0
soil loss (kg ha^{-1})
1
2
3
4


Residuals
600
400
200
0
-200
-400
-600
1990
1992
1994
1996
1998
2000
2002
2004
r=0.69
α<0.01