# Geomorphic and Hydrological Effects of Traditional Shifting Agriculture in a Mediterranean Mountain Area, Central Spanish Pyrenees

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# Geomorphic and Hydrological Effects of Traditional Shifting Agriculture in a Mediterranean Mountain Area, Central Spanish Pyrenees

*Shifting agriculture has been practiced over large areas in middle-latitude mountains in the Mediterranean basin during periods of strong demographic pressure. On average, such land 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 on plots under shifting agriculture than on plots under dense shrub cover, and almost 3 times higher than on permanent sloping fields. Erosion rates ranged between 0.1 and 1.4 t/ha/yr. The abandonment of shifting agriculture practices resulted in rapid plant recolonization and a decrease in runoff and soil erosion. Nevertheless, severe geomorphic processes were found to be still active several decades after abandonment, explaining landscape degradation and the occurrence of shallow landslides.*

**Keywords:** *Shifting agriculture; sloping fields; runoff; soil erosion; land degradation; farmland abandonment; Pyrenees; Spain.*

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## Introduction

Most Mediterranean mountains have been subjected to strong demographic pressure during various periods of their history. In the case of the Spanish Pyrenees, 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 both landscape and the dry-farming agricultural system, including enlargement of cultivated areas in marginal lands, most of which were subjected to shifting agriculture procedures or slash-and-burn practices.

Shifting agriculture is an adaptation of traditional, pre-industrial societies to population growth that can be observed worldwide. It is still practiced in Africa, South America, Southeast Asia, and Oceania, on an area of about 30% of all cultivated land in the world, while it provides food for only 8% of the total 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 northwestern 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).

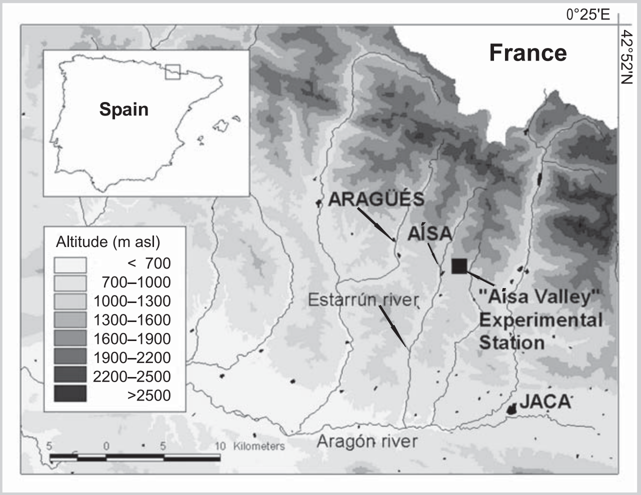
A reasonable evolution of cultivated lands in mountain areas (García-Ruiz 1988; Ives and Messerli 1989) involved the occupation of the best lands (valley bottoms, flat areas) located close to settlements during the first stages, and then steeper areas as population increased (alluvial fans, foot of hillslopes). 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 this traditional system (Lasanta 1989). Finally, continued population growth led to the appearance of a marginal population that was forced to practice shifting agriculture in peripheral areas, on very steep slopes located far from the settlements. Of course, this evolution is more complex in various local settings 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 for North African mountains at present (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 major factors in soil erosion, responsible for increased sediment yield and landscape degradation in several environments (Lasanta 1989; Ruiz-Flaño 1993; Soto et al 1995; Lianzela 1997; Barrow and Hicham 2000; Messerli 2000). However, only a few studies include quantitative, experimental information on soil loss in tropical and oceanic climate zones. In this article, we examine the geomorphic and hydrological effects of traditional 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,

**FIGURE 1** Location of the Aísa Valley Experimental Station and study area. (Source: Topographic maps 1:50,000, Instituto Geográfico Nacional; layout by Sergio Vicente)



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 in the valley bottoms, perched flats, and on the steep, south-facing hillslopes, which were cultivated even under shifting agriculture 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 and 1800 m, where deep and well-developed Haplic Kastanozem and Haplic Phaeozem 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 favorable locations) or have been reforested for land reclamation and to reduce reservoir siltation (Ortigosa et al 1990).

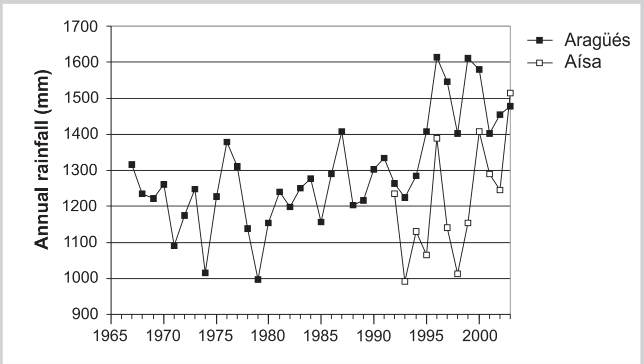
## Methods

Aerial photographs from 1957 were used to calculate the area occupied by the distinct types of fields and identify the topographic factors that control both their spatial distribution and the process of farmland abandonment. Experimental plots at the Aísa Valley Experimental Station (42°40′24″ N; 0°36′30″ W) were used to compare runoff and sediment yield under several land uses: shifting agriculture (barley), abandoned shifting agriculture, cereal cultivation (barley) in permanent sloping fields, and dense shrub cover. The cereal plot was cultivated in a cycle of 2 years (cultivation/fallow); 1.5 kg of chemical fertilizer (equivalent to 500 kg/ha) was added to the plot, including N, $P_2O_5$, and $K_2O_5$. The experiment has been running since 1992. The data analyzed here correspond to the period 1992–2003, except for the abandoned shifting agriculture plot, which was cultivated between 1992 and 1995, so that the data correspond to 1996–2003.

Compared to the long-term average, the study period was relatively humid (Figure 2). Average annual precipitation in the period 1992–2003 was 0.65 standard deviation higher than the average for 1967–2003, as measured in a nearby station in the region (Aragüés del Puerto, 8 km westward, at a similar altitude). Maximum rainfall intensity in 24 hours during the study period was 95 mm (December 1996), which roughly corresponds to a return period of 15 years. In most years, maximum rainfall intensity in 24 hours was around 60–70 mm, corresponding to a return period of less than 5 years. Thus, according to estimations of White et al (1997), almost no differences exist in rainfall erosivity between the study period and long-term precipitation records. In general, rainfall erosivity in the Central Spanish Pyrenees is considered to be relatively low (at least compared to that of the Mediterranean coast) due to the distance both from the Atlantic and the Mediterranean (White and García-Ruiz 1998).

Each plot is 30 m$^2$ 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

**FIGURE 2** Comparison between annual precipitation at the Aísa Valley Experimental Station (white squares) and the long-term precipitation measured in the neighboring Aragüés del Puerto Station (black squares).



taken after each event to analyze particulate and solute content. Precipitation is measured with a tipping bucket pluviometer. Evolution of plant cover on the abandoned shifting agriculture plot is studied every year, making plant inventories and estimating 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 top 20 cm. There are no significant differences between the main characteristics of the plots. This homogeneity ensures that the variability of results is closely related to 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 analyzed to establish whether slash-and-burn practices improve and fertilize the soil.

## A review of shifting agriculture in the Central Spanish Pyrenees

Shifting agriculture was the usual reaction of traditional societies to demographic growth. Once the best places 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 labor force.

Shifting agriculture prevailed on south-facing, straight or convex slopes of communal tenure, which explains why farmers did not build structures for diversion of overland flow and for soil conservation. Lasanta (1989) has estimated that shifting agriculture was practiced on 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 claimed a much larger area (Aísa Valley: 36.8%; Hecho Valley: 46.9%).

Shifting agriculture consisted of the following steps: (i) breaking up part of a hillslope covered by shrubs and occasionally by trees; (ii) piling up the shrubs and covering them with herbs and soil; (iii) burning the piles slowly; and (iv) dispersing the ashes throughout the field and plowing the soil to incorporate the ashes immediately. Several days or a few weeks later, the farmer sowed 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). Clearing was repeated 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, were on straight and concave slopes, received organic fertilizer and were left fallow during short periods, with overland flow being diverted using artificial drains.

Barley production on the shifting agriculture plot was about 700 kg/ha/yr, and on the sloping, fertilized field about 2800 kg/ha/yr. The low productivity of the former was related, on the one hand, to poor nutrient content in soils on flysch (Lasanta 1989; Ruiz-Flaño 1993); and, on the other hand, to low nutrient supply from ashes. *Genista scorpius*, the dominant species in the slopes under shifting agriculture, supplied extremely low amounts of nutrients (Table 1). Dry matter accounted for only 2.25% of the plant, and the P, Mg, and Na content was very low.

## Runoff and soil erosion on land under shifting agriculture

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

The average runoff coefficient (Figure 3) was twice as high in the active shifting agriculture plot (19%) compared to the abandoned shifting agriculture plot (10.7%). The sloping field plot occupied an intermediate position with a runoff coefficient of 11.4%. Runoff from the control plot recorded the lowest value (4.5%).

Active shifting agriculture clearly entailed the highest soil loss (1369 kg/ha/yr) (Figure 4), much more than that incurred by the sloping field (530 kg/ha/yr) or by the abandoned shifting agriculture plot (436 kg/ha/yr). The control plot showed low soil loss (109 kg/ha/yr), almost 14 times less than the active shifting agriculture plot. It is interesting to note that a

**TABLE 1** Nutrient content of *Genista scorpius* (results from dry matter).

| Nutrient content | % |
|---|---|
| Ashes | 2.25 |
| Nitrogen | 1.24 |
| Phosphorous | 0.05 |
| Potassium | 0.29 |
| Calcium | 0.53 |
| Magnesium | 0.08 |

**FIGURE 3** Average annual runoff coefficients (%) from different land uses (runoff plots) at the Aísa Valley Experimental Station (median value, 1st and 3rd quartiles, 1st and 9th deciles, and average).

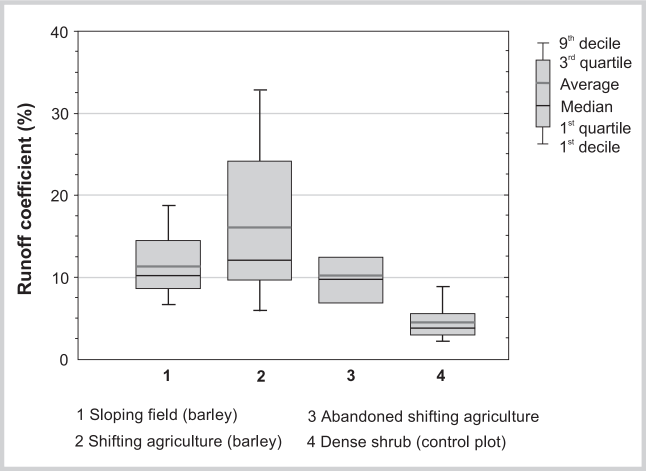
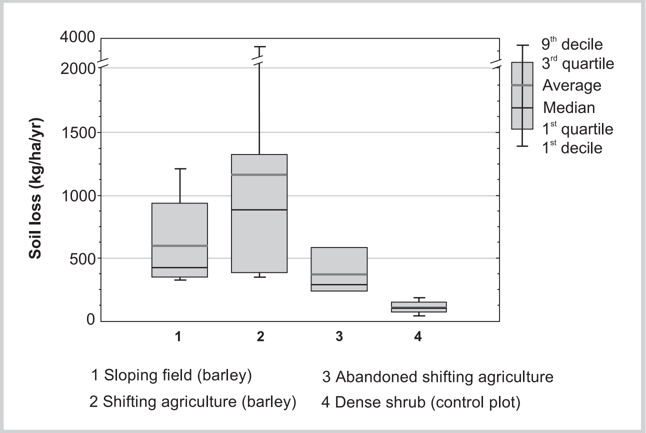


**FIGURE 4** Average annual soil losses (kg/ha/yr) from different land uses (runoff plots) at the Aísa Valley Experimental Station (median value, 1st and 3rd quartiles, 1st and 9th deciles, and average).



sloping field cultivated for 4 years at the Experimental Station and then abandoned incurred soil loss of only 200 kg/ha/yr, which is less than half the loss recorded by the abandoned shifting agriculture plot.

These results do not correspond to true erosion rates because of the experimental conditions in which the information was obtained (relatively small closed plots); but they serve comparative purposes and emphasize the main hydromorphological consequences of shifting agriculture. The low values of soil loss obtained from all plots, compared with values measured on similar plots, are due to the characteristics of the Experimental Station, with deep and well structured soil in a concave profile with moderate gradient, far from the typical conditions of shifting agriculture fields.

It is well known that each type of field in the traditional system (flat fields, sloping fields, bench-terraced fields, shifting agriculture fields) occupied different locations with specific topographic characteristics (Lasanta 1989), while the plots at the Experimental Station share the same conditions to optimize comparability between these plots. The relatively low intensity of rainfall events during the study period also contributed to the low values of soil loss recorded. Other experimental studies likewise obtained 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; Moufaddal 2002; Roose and Sabir 2002), which is also the case in the study area. For our purposes, the fact that the erosion rate on the shifting agriculture plot was 14 times higher than that on the dense shrub cover plot clearly indicates soil loss problems in marginal mountain lands subjected to strong demographic pressure.

Regarding suspended sediment concentration (Figure 5), the active shifting agriculture plot again showed the highest value (431 mg/l), slightly greater than that of the sloping field (332 mg/l). The abandoned shifting agriculture plot recorded a much lower value (180 mg/l). Again, the control plot value was the lowest (50.5 mg/l). Regarding solute concentration, the plots showed a very different behavior: the active and abandoned shifting agriculture plots recorded similar values (188 and 179 mg/l, respectively), whereas the sloping field underwent the highest solute losses (213 mg/l) because of the use of organic and chemical fertilizers. Solute loss in the control plot reached 132 mg/l. The main losses concerned $HCO^{3-}$ 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 and active shifting agriculture plots

**FIGURE 5** Average annual suspended sediment and solute concentrations (mg/l) from different land uses (runoff plots) at the Aísa Valley Experimental Station (median value, 1st and 3rd quartiles, 1st and 9th deciles, and average). A: Suspended sediment concentration. B: Solute concentration. C: Total concentration.

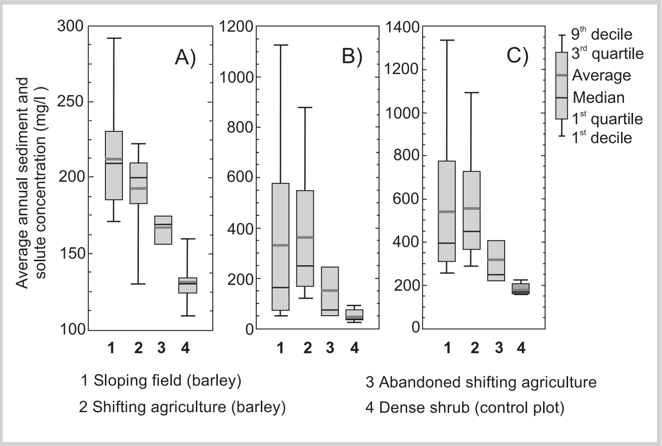


**TABLE 2** Annual solute losses (g/m$^2$) in the period 1992–2003, with average (av) and standard deviation (sd).

| Land use or land cover | Content | Ca$^{2+}$ | Mg$^{2+}$ | Na$^{+}$ | K | SO$^{4-}$ | SiO$_2$ | Cl | NO$^{3-}$ | HCO$^{3-}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| **Shifting agriculture** | av | 5.03 | 0.25 | 0.18 | 0.34 | 0.24 | 0.54 | 0.43 | 0.09 | 15.24 |
| | sd | 2.14 | 0.11 | 0.11 | 0.07 | 0.25 | 0.15 | 0.39 | 0.06 | 6.94 |
| **Abandoned shifting agriculture** | av | 7.95 | 0.33 | 0.24 | 0.68 | 0.29 | 0.87 | 0.78 | 0.20 | 22.29 |
| | sd | 6.42 | 0.25 | 0.20 | 0.78 | 0.22 | 0.62 | 0.77 | 0.23 | 16.11 |
| **Sloping field (barley)** | av | 5.50 | 0.23 | 0.21 | 0.64 | 0.63 | 0.52 | 0.98 | 0.33 | 14.99 |
| | sd | 2.38 | 0.11 | 0.12 | 0.27 | 0.39 | 0.24 | 0.63 | 0.23 | 4.98 |
| **Dense shrub cover** | av | 1.78 | 0.08 | 0.06 | 0.25 | 0.07 | 0.30 | 0.18 | 0.07 | 4.98 |
| | sd | 1.55 | 0.06 | 0.08 | 0.18 | 0.09 | 0.23 | 0.15 | 0.07 | 3.56 |

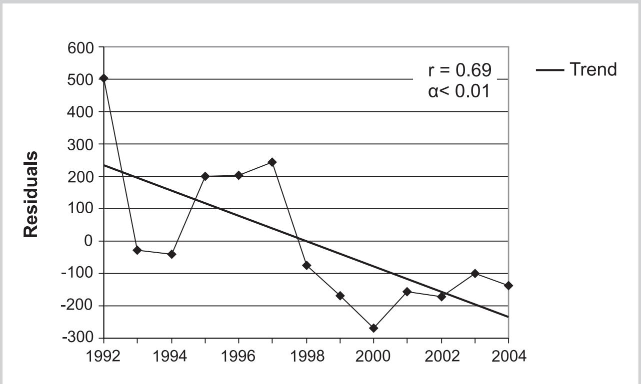
(Table 2). This indicates that farmland abandonment has a greater effect on suspended sediment transport than on solute outputs.

## Evolution of shifting agriculture fields after farmland abandonment

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

At present, the abandoned shifting agriculture plot is colonized by seedlings of *Genista scorpius*, *Rosa* spp., *Thymus vulgaris*, and *Crataegus monogyna*, the same species as on 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*.

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



Nevertheless, geomorphic processes are still very active in the abandoned shifting agriculture plots. 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 had been 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 were analyzed to determine the effect of past shifting agriculture on the occurrence of landslides. It was found that 49.5% of the valley had consisted of sloping fields and lands under shifting agriculture, accounting for 68.6% of the shallow landslides (hillslope debris flows) present in the 1957 images. By 2002, most of the shallow landslides (69.4%) still occurred on former sloping fields and on lands formerly under shifting agriculture, especially those colonized by shrubs. The areas with enhanced revegetation (natural forests and reforestations) were less prone to landslides.

## Discussion and conclusions

At the Experimental Station in the Pyrenees the shifting agriculture plot 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, it was demonstrated that land under shifting agriculture undergoes greater soil erosion than hillslopes covered by dense shrubs (by a factor of almost

14) and than permanent sloping fields (by a factor of over 2). Therefore, traditional substitution of shrubs by slash-and-burn fields brought a sudden increase in runoff generation and sediment yield.

The difference with respect to sloping fields, also cultivated mainly with cereals, is evident and is due to (i) the very low crop productivity of slopes under shifting agriculture, resulting in poor soil protection by plants, as it has also been reported in shifting agriculture areas of northwestern Spain (Soto et al 1995); and (ii) the absence of conservation structures to retain surplus water in the slope or to divert overland flow out of the field. The problem of lacking conservation structures is obviously related, on the one hand, to the communal character of land tenure, which induced farmers to show little concern for the future sustainability of the territory. On the other, it also related to the unfavorable ratio between high investment in labor force and low production under extreme topographic conditions. Besides, the increase in fertility due to incorporation of ashes wears off within a few months, due to the poor nutrient content of *Genista scorpius* as well as to erosion, which is considered the main cause of nutrient stock declining in land under shifting agriculture (Soto et al 1995).

The present landscape reflects the consequences of shifting agriculture. Steep, south-facing, convex slopes 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 periods of greater population pressure to cultivation of 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.

Abandonment of shifting agriculture fields resulted in a progressive decrease in runoff and soil loss, as a result of plant recolonization. In our experiment, the abandoned shifting agriculture plot was covered by grasses and an incipient cohort of shrubs. Nevertheless, soil erosion rates were at least twice as high as those recorded in the sloping field. This difference is most probably due to soil degradation during the years of cultivation. This implies that, after abandonment, fields formerly under shifting agriculture are 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 northwestern Spain showed extremely high soil erosion rates (about 40 times higher than those of the shrub-covered control plot) and nutrient losses (about 20 to 50 times higher than those of the control plot) (Soto et al 1995). In tropical environments, shifting cultivation is also a main source of sediments. Thus, in the Chittagong Hill Tracts of Bangladesh a comparison was made between 2 catchments traditionally subjected to slash-and-burn practices, one recently burned and cultivated, and the other in the middle of a long fallow period, with dense vegetation. The former recorded soil and nutrient losses 4 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 (15–25 years). Historical, relatively recent periods of increasing population density forced the local population 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 shifting agriculture 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 only the valley bottoms are cultivated (García-Ruiz and Lasanta 1993) in the context of general depopulation since the end of the 19th century.

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