Pergamon

Phys. Chem. Earth, Vol. 20, No. 3-4, pp. 301–307, 1995.

0079-1946(95)00041-0 0079-1946/95 $9.50 + 0.00

Changes in Runoff and Erosion as a Consequence of Land-Use Changes in the Central Spanish Pyrenees

J. M. García-Ruiz[1], T. Lasanta[1], C. Martí[1], C. Gonzáles[1], S. White[1], L. Ortigosa[2] and P. Ruiz Flaño[3]

[1] Instituto Pirenaico de Ecología, Campus de Aula Dei, Apartado 202, 50080-Zaragoza, Spain
[2] Departamento de Geografía, Universidad de La Rioja, Logroño, Spain
[3] Departamento de Geografía, Universidad de Las Palmas, Canary Islands, Spain

ABSTRACT

Both in small experimental plots and in the "Aísa Valley Experimental Station" (Central Spanish Pyrenees), the role of different land-uses in explaining runoff and sediment yield is being studied in closed, experimental plots. In these plots, continuous information on overland flow and suspended and solute sediment concentration is obtained . Results suggest that cereal cultivation in steep slopes encourages soil erosion, especially under non-conservative systems. The passage of cereals into meadows represents an improvement of the hydrological functioning, which reaches its most positive values with colonization by a dense shrub cover.

KEYWORDS

Land-use changes; soil erosion; runoff; farmland abandonment; plant colonization; Pyrenees.

INTRODUCTION

In the Pyrenees the agricultural land has been used for the production of food for the human population, even in very difficult topographical conditions. However, changes in the social organization and in the relationships between mountain and plains explain the generalized expansion of meadows in all of the valleys, while cereals are only a marginal crop (García-Ruiz & Lasanta, 1990). Most of the original cultivated area has been abandoned and many hillslopes have been reforested with conifers (Ortigosa *et al.*, 1990).

The problem is to know what are the hydrological and geomorphological consequences of such changes. It is well known that, in general, a change in land-use also means a change in plant cover density or type and that this has direct implications on the capacity of infiltration of soils, on overland flow, on interception and on erosion and sediment yield.

In this paper a comparison between runoff and sediment yield under different land-uses is made in the Central Spanish Pyrenees. The purpose is to understand the hydromorphological trends in some mountain areas subject to generalized land-use changes and to define the degree of sustainability of the new spatial organization in comparison with the old one.

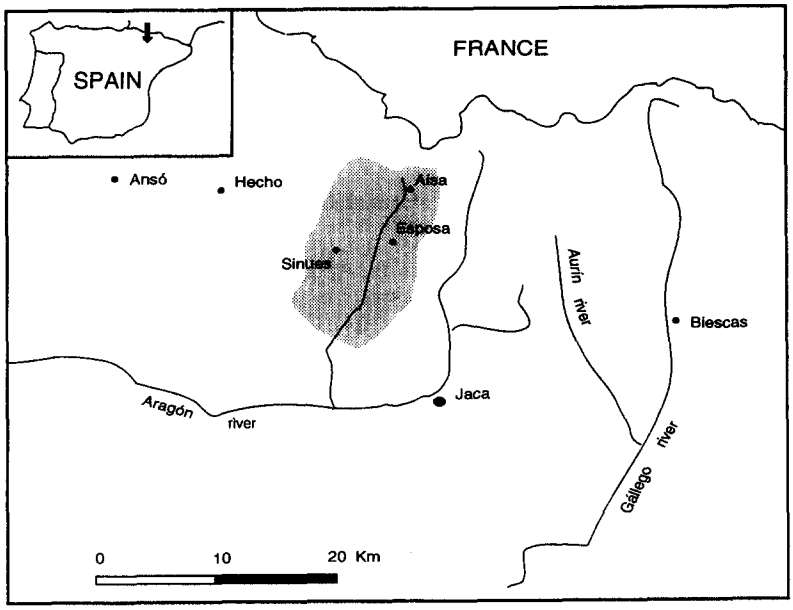

Fig. 1. The study area

THE STUDY AREA

The study is being carried out in the Aisa Valley, in the central-western part of the Spanish Pyrenees (Fig. 1). Most of the valley belongs to the flysch area, dominated by smooth divides decreasing progressively in height towards the south and by slopes with gradients between 20 and 40 percent. This area is characterized by a mountain mediterranean climate. Yearly precipitation varies between 800 mm in the lowest sectors and 2,000 mm in the divides, mainly falling in the cold season (October-May). *Pinus silvestris* woods prevail on the shady slopes, the rest of the territory being dominated by abandoned fields, small *Quercus gr. faginea* woods and submediterranean shrubs.

The cultivated area reached its maximum extent between 1,000 and 1,400 m. a.s.l. During the 19th century, coinciding with the maximum demographic pressure, the farmed area, cultivated with cereals, also occupied the slopes. During the 20th century most of the fields on the hillslopes were abandoned (Lasanta, 1988). Meanwhile meadows replaced cereals and on many hillslopes afforestation with conifers was the main land reclamation policy.

o

METHODS

Two types of experimental plots have been used in order to obtain information on runoff and sediment yield:

1. Between 1990 and 1992, 19 closed plots were installed in different, degraded environments on slopes cultivated several years ago and now abandoned. All the plots are small in size (from 2.5 to 3.5 m^2). At the lower end of the plots a Gerlach trap was located, connected to a 62 l. container to collect the water and sediment generated by each rainfall event. There were 3 plots with a 100% shrub cover, 3 plots with

85% shrub cover, 3 plots with 65% shrub cover, 4 plots with 40% shrub cover, 3 plots with 15% shrub cover (the soil being covered by a stone pavement), and 3 plots with 85% meadow cover.

2. The Experimental Station is located 1 km east the village of Aísa, on a field abandoned 35 years ago. Eight closed, 10 x 3 m plots were installed, including in the lower part a Gerlach trap and a simple system of tipping buckets connected to data loggers in order to record the runoff of each plot continuously. Likewise, a pluviometer is connected to a data logger. In order to monitor the sediment concentration, a part of the runoff is diverted to 31 l. containers, which are emptied after each rainfall event.

The plots, installed in 1991, reproduce different land-uses: shifting agriculture with cereals (barley fertilized with ashes), fallow land, cereals (adding chemical fertilizer), burnt plot, dense shrub cover (with the unaltered, original vegetation) and meadows. In 1993 the plot in fallow passed into cereal, whilst the cereal plot was left as stubble, initiating a process of abandonment. Moreover in 1993 two new plots were incorporated: one with cereals (barley) and the other a new burnt plot. In this paper preliminary results are presented, including information on sediment yield and runoff during two springs (1992 and 1993).

RESULTS

Fig. 2 gives information on runoff and sediment concentration from each plot, according to the density of shrub cover. It is important to take into account that the information obtained is acceptable only for comparative purposes, that is, to have orders of magnitude of overland flow and erosion in different environments. They cannot be treated as absolute coefficients or rates. Obviously, the characteristics of the plots -due to their size, the exhaustion of sediment, the modifications of the soil caused by their installation and the interruption of natural overland flow by the border of the plots- reduces the absolute validity of the data, but the results give a good indication of the differences between the environments.

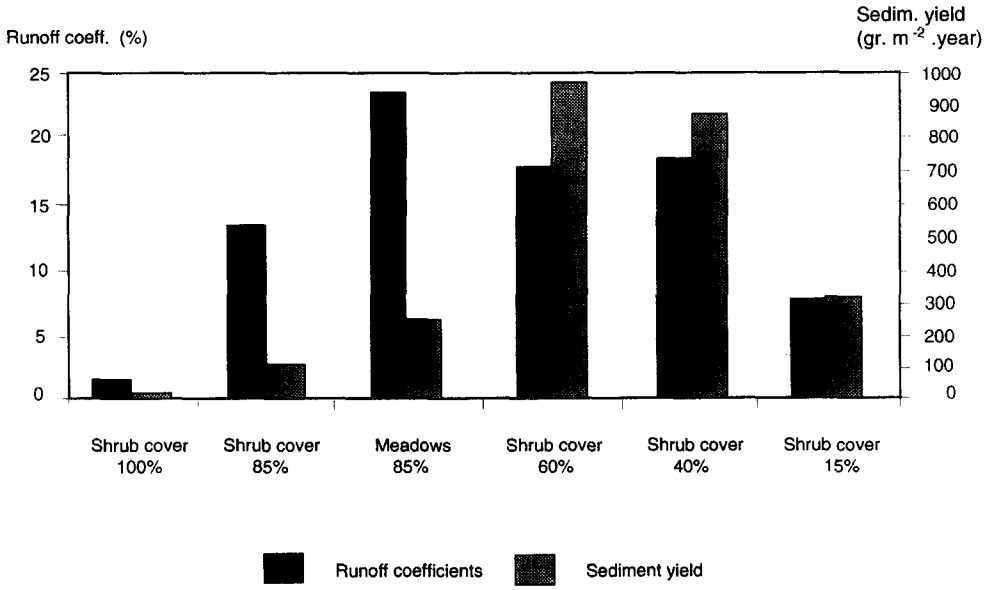

Fig. 2. Runoff and sediment yield from different environments

Plots with dense shrub cover show the lowest runoff coefficients. But as the density of the plant cover decreases, the quantity of runoff increases by several orders of magnitude, suggesting that once the opening of the shrub cover begins, overland flow increases more than might be expected. The greatest runoff is produced from plots where the shrub cover is around 40-60 per cent. Finally, plots with a very poor shrub cover (15 per cent) yield a moderate quantity of runoff, but in this case the reason is probably

the high quantity of stones on the surface (stoniness equal to 100 per cent), encouraging infiltration as several authors have shown (see, for example, Poesen, *et al.*, 1990). A very interesting point is that meadows yield much surface water, with very similar figures to those of the highest values from open shrubland, showing that a herbaceous cover acts like a semi-impervious layer, hindering immediate infiltration.

The soil loss data show that plots with a dense shrub cover behave moderately, with very small sediment outputs. When plant cover density reduces from 100 to 85 per cent, sediment yield multiplies by ten demonstrating the importance of a very dense plant cover. As the density of plant cover decreases, soil loss increases rapidly, reaching the highest values around 40-60 per cent of shrub cover. It is interesting to point out that meadows have a moderate soil loss, though erosion is higher than in the areas of dense shrub cover. From a hydromorphological point of view this means that meadows yield much water but it is relatively clean (Ruiz-Flaño *et al.*, 1991).

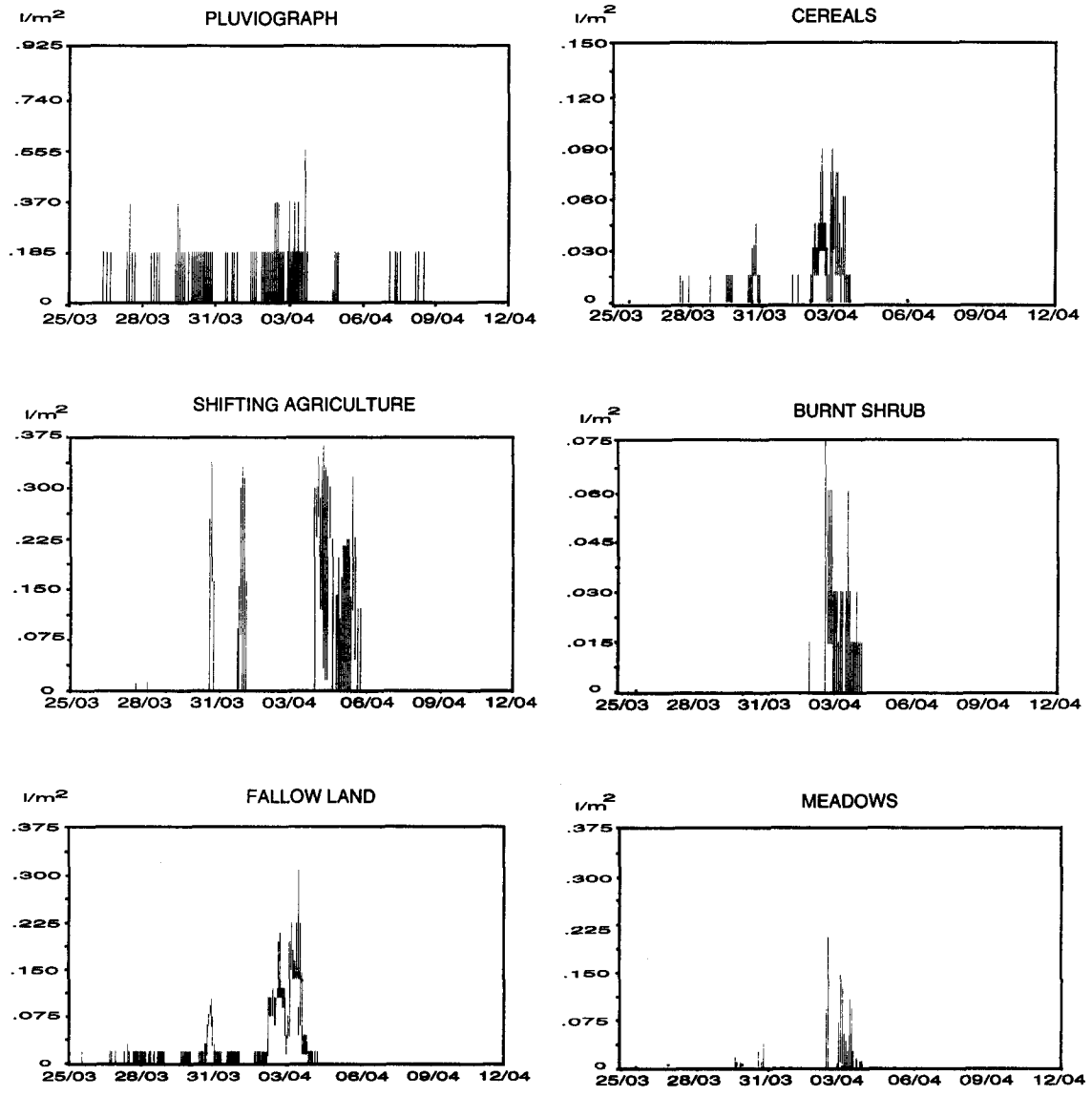

Fig. 3. Precipitation and runoff for different land-uses during a short period of rainstorms

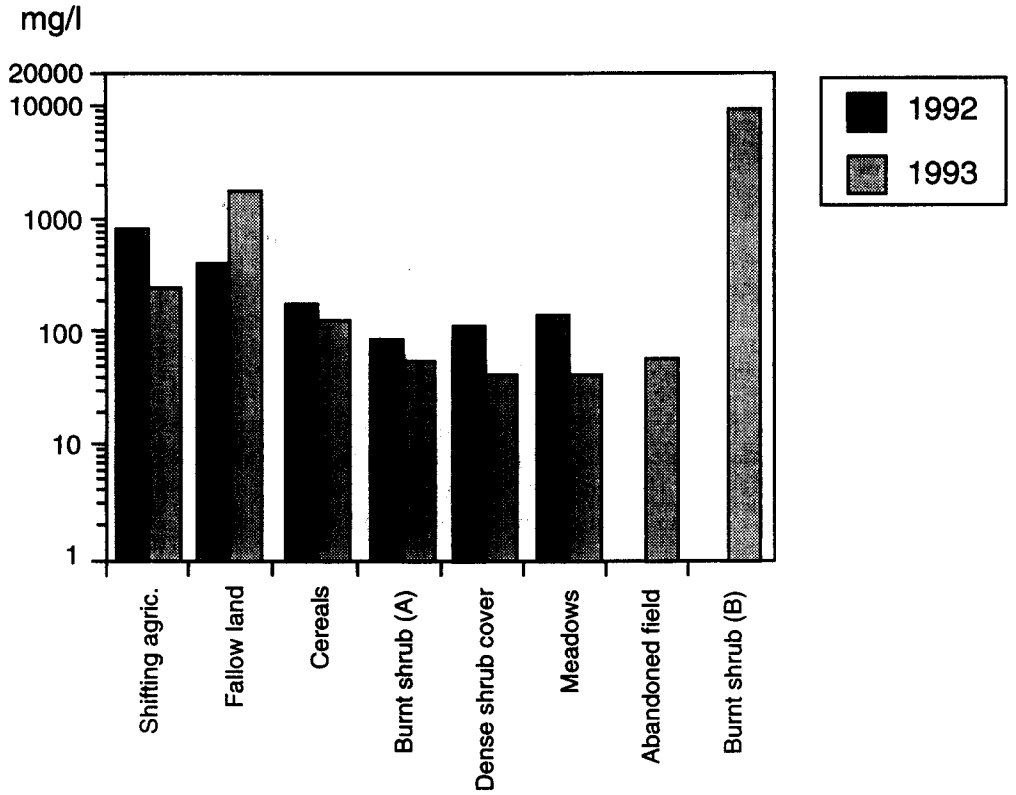

Fig. 4. Suspended sediment concentration from different land-uses during the springs of 1992 and 1993

In the "Aísa Valley Experimental Station" the information obtained is more complex. Fig. 3 shows the hyetogram and the hydrographs from the days March, 25th, 1992 to April, 12th, 1992. Unfortunately, the plot with burnt shrub cover had connection failures and this is why it did not yield information in this period. Note that the ordenate axes of the graph are represented with different scales in order to facilitate the visual display of the hydrographs.

Fallow land and shifting agriculture have the quickest and strongest response, reacting to almost any precipitation. Cereal with chemical fertilizer always yields runoff, but the peak-flows are much less extreme, especially during the first precipitation of the period. The meadow plot also yields much water, while the dense shrub cover has a low (see the scale) and belated response. The proof of this moderate behaviour is that the shrub cover does not record runoff up to 2nd April, having completely absorbed all the rainfall during the rainstorms before. The results confirm the good hydrological functioning of a dense shrub cover and the better behaviour of the cereals with chemical fertilizer than the fallow land. Shifting agriculture -cereals fertilized with ashes- yields very high quantities of water.

Suspended sediment concentration show large differences between each land-use. Apart from the plot burnt in 1993, the highest suspended sediment outputs correspond to shifting agriculture and fallow land, with values exceeding 1g. l^{-1} in some cases. In contrast, the plot burnt in 1991 and that covered with a dense shrub record more moderate results, slightly below meadows. The stubble plot -which in 1992 was cultivated with barley- has similar losses to that of the latter plots cited; this result must be interpreted as a consequence of the quick plant recolonization after the addition of chemical fertilizer to the cereals (Fig. 4).

All the land-uses have almost the same trend in 1992 and 1993. However, the behaviour of the plot burnt in 1993 must be considered separately, above all in comparison with the plot burnt in 1991. This latter records very low values of suspended sediment concentration because of the quick plant recovery several months after the fire. On the other hand, the plot burnt in 1993 suffered the fire immediately before the hydrological records, showing the effects of soil loss as a consequence of bare soil. Suspended sediment concentration in this plot was 10 times greater than in shifting agriculture and in fallow land, and 100 times greater than in dense shrub cover, meadows or the plot burnt in 1991.

CONCLUSIONS

Land-use changes affecting many mountains in the world have large consequences on runoff and sediment yield and probably are the most important factor in controlling soil conservation and sustainability. In the Pyrenees the worst results are obtained with shifting agriculture. This traditional system of cereal cultivation was very extensive in past centuries on steep sunny hillslopes. Nowadays the hillslopes cultivated in the past by means of shifting agriculture are characterized by an open submediterreanean shrub on a very thin and stony soil, a proof of intense soil loss.

Soil erosion is not so great under cereals with chemical (or, probably, organic) fertilizer because of the increase in productivity (up to 2,500 kg. Ha^{-1}) and the resulting soil protection. But the traditional system of alternating cereals and fallow can increase soil erosion. The consequences of fertilizing the cereal fields can be observed several years later not only by the solute outputs, but also by the quick plant colonization after farmland abandonment.

The most moderate hydromorphological behaviour is recorded under a dense shrub cover, controlling runoff and sediment yield almost completely. A decrease in shrub cover density results in a quick increase in runoff and erosion. The burning of shrub cover implies very important losses of suspended sediments. Nevertheless, in a few months erosion rates equal those prevailing before the fire. This result agrees with the conclusions of many other papers and means that fire can only be a cause of serious soil erosion if it is a repeated process, i.e. when every few years the shepherds burn the shrub cover in order to improve the pastures in spring and summer.

Finally, meadows yield much water but few sediments. The abandonment of meadows and their colonization by a dense shrub cover will reduce runoff and erosion in the whole basin, that is, both in the hillslopes and in the fluvial channels, a good strategy from a conservation point of view but not so good if the loss of productivity and of water resources is considered.

The results obtained suggest that cereal crops on steep slopes encourage soil erosion, especially under low conservation systems (such as shifting agriculture). The substitution of cereals by meadows represents an improvement of the hydromorphological functioning, which reaches the most positive values with colonization by a dense shrub cover.

ACKNOWLEDGEMENTS

This work was funded by CICYT throughout the research project AMB93-0806 "Erosión de suelos tras el abandono de explotaciones agrícolas en montaña media: interacciones con las estrategias de colonización vegetal, los usos del suelo y la disponibilidad de nutrientes".

REFERENCES

García-Ruiz, J.M. & T. Lasanta (1990). Land-use changes in the Spanish Pyrenees. *Mountain Research and Development*, **10(3)**: 267-279.

Lasanta, T. (1988). The process of desertion of cultivated areas in the Central Spanish Pyrenees. *Pirineos. Revista de Ecología de Montaña*, **132**: 15-36.

Ortigosa, L., J.M. García-Ruiz and E. Gil, (1990). Land reclamation by reforestation in the Central Pyrenees. *Mountain Research and Development*, **10(3)**:281-288.

Poesen, J., F. Ingelmo-Sánchez and H. Mücher, (1990). The hydrological response of soil surfaces to rainfall as affected by cover and position of rock fragments in the top-layer. *Earth Surface Processes and Landforms*, **15**: 653-671.

Ruiz-Flaño, P., J.M. García-Ruiz, and L. Ortigosa, (1991) The diversity of sediment yield from abandoned fields of the Central Spanish Pyrenees. *IAHS Publ.*, **203**: 103-110.