Pergamon

Phys. Chem. Earth, Vol. 20, No. 3-4, pp. 345–349, 1995.

0079-1946(95)00047-X 0079-1946/95 $9.50 + 0.00

Geomorphological Consequences of Afforestation at a Basin Scale, an Example from the Central Pyrenees

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ABSTRACT

Afforestation is a current strategy for land reclamation in the Spanish mountains. Several studies demonstrate that, at a hillside scale, the geomorphological effect of afforestation is very variable, depending on many environmental factors (especially the exposure, the shape of the hillslope and the position on the slope).When these effects are studied at a basin scale the results prove that afforestations change the hydrological behaviour of the basins, reducing the peak flows and the size of the sediments, and causing plant reestablishment in the channels and on the river banks.

KEYWORDS

Afforestation; soil erosion; land reclamation; runoff; sediment transport; Spanish Pyrenees.

INTRODUCTION

Afforestation represent severe landscape disturbances, affecting both runoff and sediment yield. Several authors emphasize the complexity of the geomorphological consequences of afforestation which depend on many environmental factors, and the techniques employed. At the hillslope scale, the results show a wide range of consequences, which make evaluation very difficult. However, in this paper a more general response at a basin scale is studied, using the fluvial beds in the valleys as indicators of what is happening in the whole basin.

THE STUDY AREA

In general the areas most affected by afforestation are those historically subject to strong demographic pressure. In the Central Pyrenees afforestation occupies predominatly sub-mediterranean environments with an average annual rainfall between 700 and 1300 mm. Relief is subdued, with smooth divides and steep gradients (20-50%), generally covered by a stony colluvium. Flysch, sandstones, clays and marls are the prevailing lithologies. The first plantations were made by a system of digging holes (hollowing); in the 1950s and 1960s oxen were used to dig furrows parallel to the contour lines. In the late 1960s, caterpillar tractors and bulldozers were introduced to construct strips or terraces.

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METHODS

Eight afforested areas, 18-25 years old, were selected, each area possessing several first and second-order basins. Adjacent to these areas, non-afforested basins (control basins) having similar characteristics of gradient, rock substratum and size.were choosen. It can be assumed that prior to afforestation all the basins showed similargeomorphological, biogeographical and land-use features. In total, 42 areas have been studied, in which the sampling method consisted of obtaining information about different characteristics of the bed and of the neighbouring taluses, at 20 randomly selected points(Fig. 1).

In the valley beds the following data were taken:

- % of plant cover
- % of bare soil
- % of each type of material in the bed, distinguishing between gravels, fine materials and rock substratum.

On the taluses, information on % of plant cover and % of different geomorphic environments were collected, using a 25 m tape laid out on the soil.

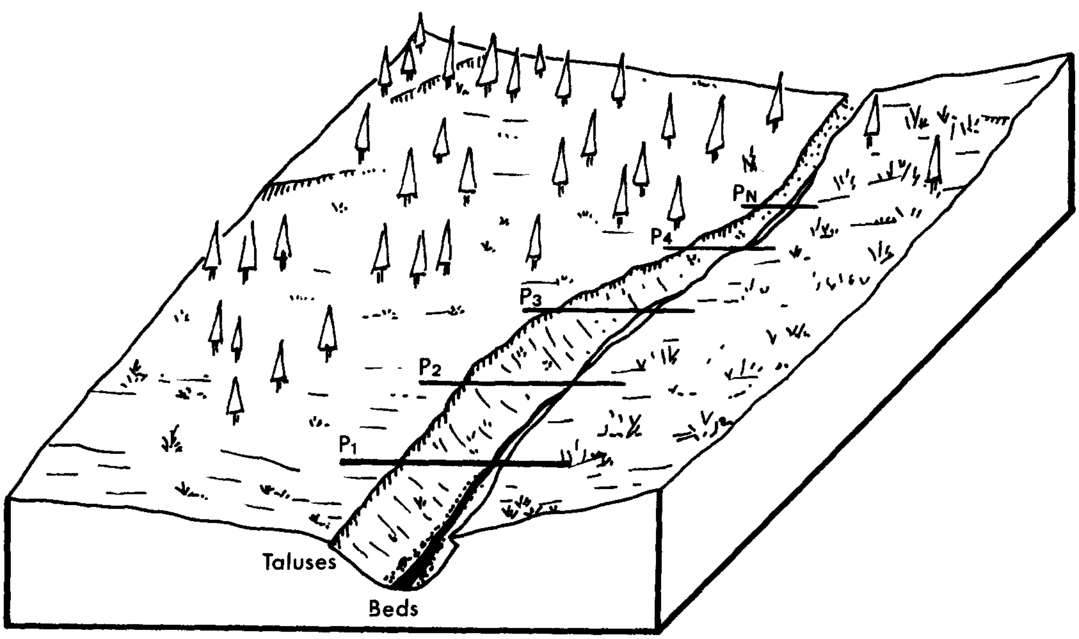

Fig. 1. The sample method

RESULTS

At a hillslope scale, the topograhical factors are the most important in explaining the geomorphological evolution of afforestations. García-Ruiz & Ortigosa (1992) demonstrated that the worst results appear on convex hillsides which are clearly water and sediment exporters, while losses are much lower on concave slopes which receive water, nutrients and sediments. Straight slopes behave in an intermediate way, but closer to the convex ones. The location of the sampled plot on the hillslope is highly significant: from the divide to the lower part a progressive decrease in soil loss can be observed, showing that afforestation does not hinder the natural, previous hydromorphological functioning of the hillslopes. This behaviour coincides with the distribution of afforested pine growth according to topographic factors, as one may verify from Fig. 2 and 3. Growth indices included in these figures have been obtained from the residuals of a correlation between the height and the age of the trees. Concave areas undergo higher than average

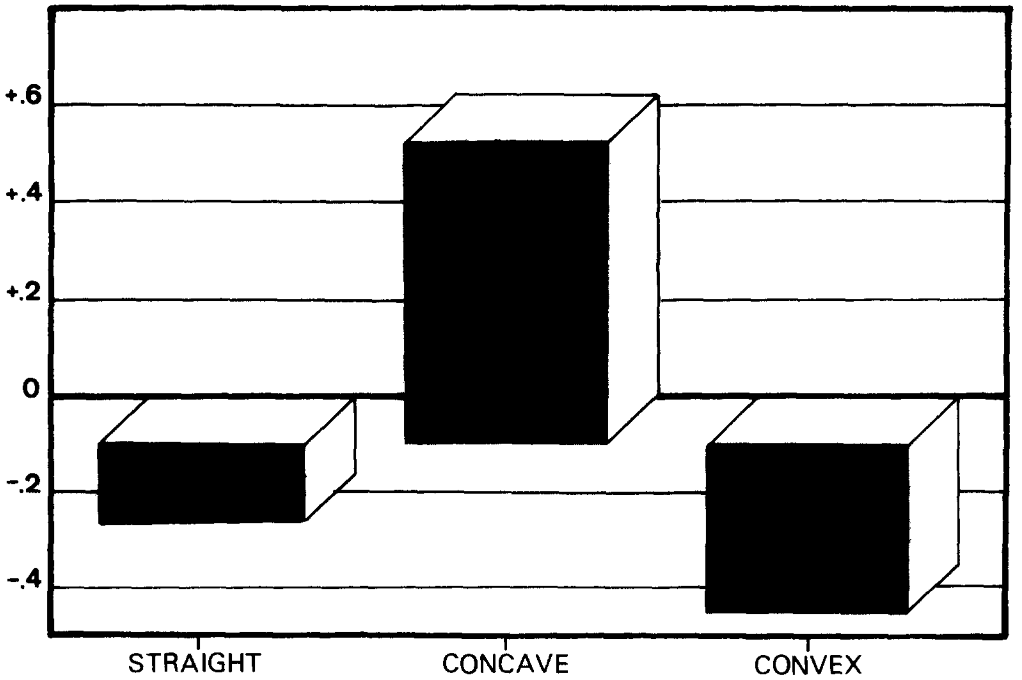

Fig. 2. Growth indexes in afforestations according to the shape of the hillslope.

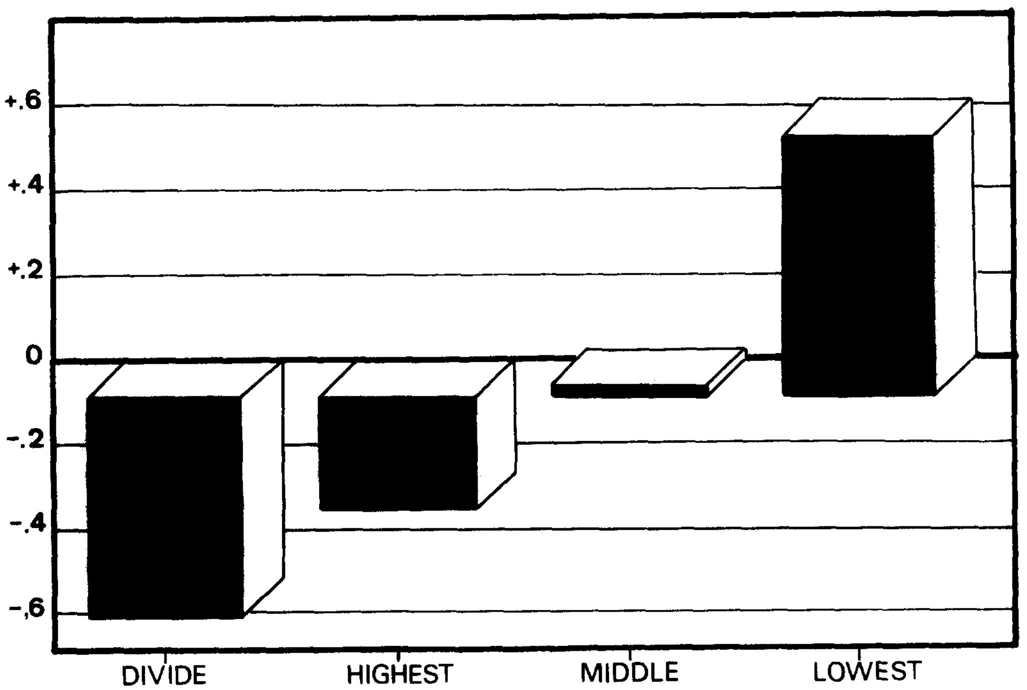

Fig. 3. Growth indexes in afforestations according to topographic location

growth unlike convex slopes, and from the divides toward the lower parts of the hillslopes growth is progressively greater as a consequence of soil quality and water availability. But the problem is different when it is studied at a basin scale. In order to assess the geomorphological effects in the whole basin, some characteristics of the channels were studied, especially those indicating changes in the capacity of sediment transport and in plant reestablishment compared with non-afforested areas (García-Ruiz & Ortigosa, 1988).

In Table 1 the results of an Analysis of Variance (ANOVA) are included. Only the most significant results have been included. It is evident that the combination between the order of the basin (first and second order) and the sector (afforested and non-afforested) explains an important part of the variability of results. Valley beds in second-order afforested basins contain a higher percentage of plant cover (79,7%), have the lowest average of bare soil (20.9%) and gravels (23.8%) on the surface, and the highest proportion of fine sediments (60.9%).

On the other hand, the beds in second-order non-afforested basins (control basins) have the lowest plant cover, the greatest proportion of bare soil and gravels, and the lowest of fine sediments.

The Analysis of Variance applied to the taluses shows that taluses of second-order basins in afforested areas have the greatest plant cover and are less affected by both concentrated and diffuse overland flow; this is why they have the greatest proportion of non-erosion areas.

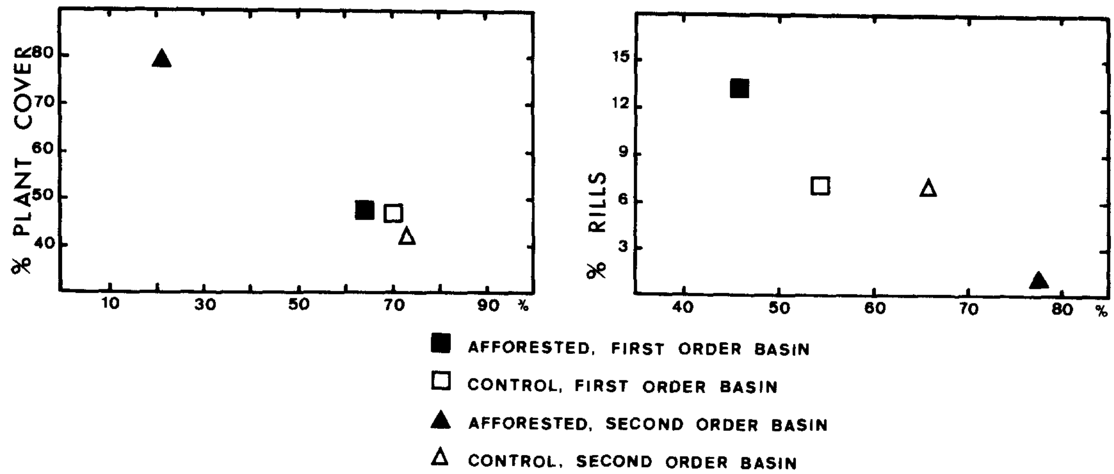

Fig. 4. A) Distribution of plant cover and bare soil averages in different types of torrential channels.
B) Distribution of moderate erosion and rill averages in different types of taluses.

CONCLUSIONS

Characteristics of beds and taluses are a good approach for defining the most important geomorphological changes produced in a basin by the disturbance of its plant cover. Nevertheless, this approach is only significant if the order of the basin is taken into account. Results obtained demonstrate that second-order beds in afforested basins have a more regulated functioning, as their plant cover and the low percentages of bare soil and gravels show. This indicates that they are beds supporting less intense floods, which allows the relatively dense development of vegetation; on the other hand, the lower transport energy can be deduced from the greater proportion of fine sediments and the relatively low content of gravels. All the results confirm that the hydrologic behaviour of control, non-afforested basins is more extreme.

In the case of taluses, the reduction of peak flows encourages plant recovery on the valley banks. Moreover, the reduction of mass movement by undermining in the taluses is directly related to the lower frequency and intensity of floods.

The study of channels and taluses allows us to confirm in an indirect way some of the hydrological and geomorphological effects caused by afforestation. An improvement of the hydrological behaviour of the basins can be deduced, above all as a consequence of interception, soil protection and development of shrub cover under the canopy. In the same study area, Martínez-Castroviejo *et al.* (1991) showed that in torrential, braided rivers incision has been the dominant process over the last few decades, coinciding with the colonization of old abandoned fields by shrub cover and with the afforestation of extensive areas, both factors decreasing sediment yield and overland flow and obligating the channels to take up sediments sediment concentration increased considerably but it quickly decreased to reach the original levels several months later (Binns, 1979; Painter *et al* ., 1974).

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Table 1. Analysis of Variance (ANOVA) of valley beds and taluses in afforested basins and control basins, considering different features as factors

A) In valley beds

	% Plant cover	% gravels	%fine sedim.
First order, afforested basins	48.6	49.9	37.8
First order, control basins	47.6	41.6	43.9
Second order, afforested basins	79.7	23.9	60.9
Second order, control basins	42.0	56.3	32.1
Signification level	0.198	0.077	0.052

B) In the taluses

	% Plant cover	% incised rills	% no-erosion
First order, afforested basins	62.4	13.6	45.7
First order, control basins	63.2	7.1	54.1
Second order, afforested basins	93.7	1.2	77.5
Second order, control basins	74.6	7.1	65.0
Signification level	0.171	0.081	0.163