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EFFECTIVENESS AND USE OF BIOENGINEERING WORKS FOR SEDIMENT TRAPPING IN TORRENTIAL CATCHMENTS

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ABSTRACT

The objective of this study was to analyse the efficacy of bioengineering works for sediment trapping and retention in torrential catchments in the Southern Alps of France. For this, we monitored the behaviour of brush layers and brush mats on fascines, established in the floor of 8 experimental marly gullies. The two main questions of this study were: 1/ Do the cuttings regenerate? 2/ How much sediment was trapped by each bioengineering structure? The study period was characterised by very dry conditions, as well as the occurrence of a centennial rainfall event (69 mmh^{-1} during 1h). The results show that, despite of the very unfavourable climate, the *Salix* species had a very good rate of regeneration, allowing the formation of thick vegetation barriers and covers. The bioengineering works permitted an efficient trapping of movable sediments in gully floors, with an average of 0.05 m^3 per work in one year. Recommendations for the use of bioengineering works for restoring eroded catchments are proposed on the basis of the results obtained.

Keywords: Bioengineering, Sediment, Erosion, Vegetation, Salix

INTRODUCTION

Bioengineering works used in torrential catchments aim at combating erosion by favouring the installation of a vegetation cover on degraded lands (Schiechtl & Stern, 1996; 1997). However, the use of bioengineering works in France is currently very restricted, unlike civil engineering. Yet, bioengineering techniques proved their efficacy in the past and are now widely used in other European Alpine countries (EFIB, 1999). There are multiple reasons for abandoning bioengineering in France: loss of knowledge about techniques, problem for the choice of the right technique to use, lack of trust in its efficacy, etc. The use of bioengineering, in particular of cuttings, is yet often wished, by the managers of mountain lands as well as local populations. These persons need to better know the efficacy and the vulnerability of bioengineering works, submitted to hydrologic and erosive forces during floods.

Moreover, due to financial restrictions in France, managers of lands that are sensitive to erosion have to establish optimal management strategies for erosion control, i.e. they wish to guarantee sufficient protection against erosion with fewer operations (Rey and Berger, 2002).

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To do this, we think that it is not necessary to install total vegetation cover in a catchment to stop the sediment yield at its exit, due to the existence of processes of sediment trapping upslope of natural vegetation barriers (Fig. 1) (Rey, 2002). These processes occur in the catchment gullies. The plants located downslope of a gully, and in particular under-shrubby and herbaceous layers located in gully floors, constitute the most efficient barriers. An optimal dimension of vegetation barrier has been highlighted: a barrier only covering 20 % of the downslope part of a marly zone – of surface area less than 500 m² – entirely eroded can be enough to stop the sediment yield from this zone.

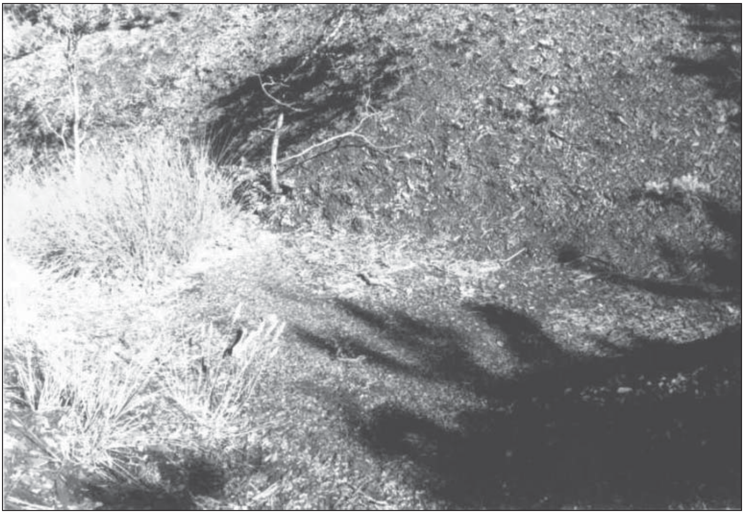


Fig. 1: Marly sediment trapping upslope of a vegetation barrier

These vegetation barriers significantly reduce the sediment yield at the exit of gullies – of a surface area between 500 m² and one hectare – and consequently at the exit of the whole catchment. The results of research have thus shown that the spatial distribution of vegetation in gullies is significant in reducing the sediment yield at their exit. Gullies with same total vegetation cover can then have very different sediment yields and it is possible to stop the sediment yield at the exit of a gully with a partial vegetation cover in the gully. Vegetation barriers in right position in the gully can allow to stop the sediment yield of gullies with only 33 % vegetation cover (Rey, 2003), percentage somewhat superior but close to the one of 20 % previously cited.

With a view to restore eroded lands, we now seek to imitate the natural processes that have been studied, by using bioengineering works able to play the same effect of barrier. We wish to test the hypothesis according to which these works can be as efficient as natural vegetation barriers, at a very short term. We thus tried to study the efficacy, in terms of quantity of sediment trapped, of different bioengineering operations. If the efficacy of the works has been proven, it will then be possible to propose different scenarios for the use of bioengineering in order to retain sediment within catchments in a sustainable way, which will lead to a reduction of sediment load in streams.

MATERIALS AND METHODS

The observations have been carried out during two years, in the Alpes-de-Haute-Provence department (French Southern Alps), in the Saignon catchment, which is a part of the large Durance River catchment (Fig. 2). They have been realised in 8 experimental marly gullies, with a surface area of less than 4000 m² and with different vegetation covers.

We have followed the behaviour of 60 bioengineering works made of cuttings, which were brush layers on fascines (Fig. 3), brush mats (Fig. 4), and brush layers combined with brush mats, on fascines (Fig. 5) or not (Fig. 6). These bioengineering works are destined to lead to the development of vegetation barriers or covers which can trap sediment. The choice of these types of works comes from the fact that they permit, due to their morphology, to play a role in trapping sediment from the first year, by constituting a reservoir at their upstream part with an effect of barrier (Fig. 7).

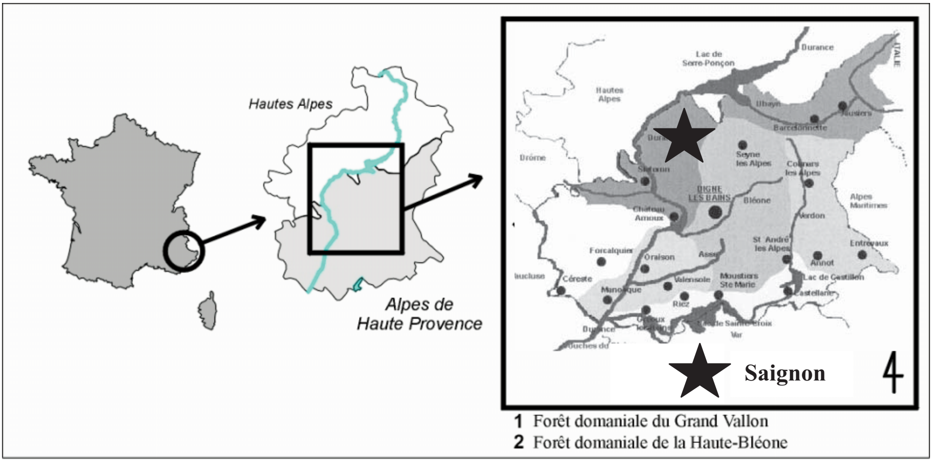


Fig. 2: Localisation of the study site

The works were installed every 1 to 3 meters in distance in gully floors. On average they were 2 metres wide. The fascines were 50 cm high and the cuttings used in brush layers and mats were sticking 10 to 20 cm out of the surface. We used different types of willows (*Salix* species): *Salix purpurea*, Sa*lix alba*, *Salix eleagnos*, and *Salix fragilis*.

Firstly, we analysed whether the cuttings regenerated, as these condition the morphology of the vegetation barriers and covers and then their efficacy. Secondly, a system, allowing to measure the quantities of sediment retained after each rainfall event by the bioengineering works, has been set up. Stakes have been installed in order to measure the variation of sediment thickness; they have been installed upstream of the brush layers (Fig. 3) and inside the brush mats (Fig. 4 and 6). The volume of sediment trapped by each work has thus been determined.

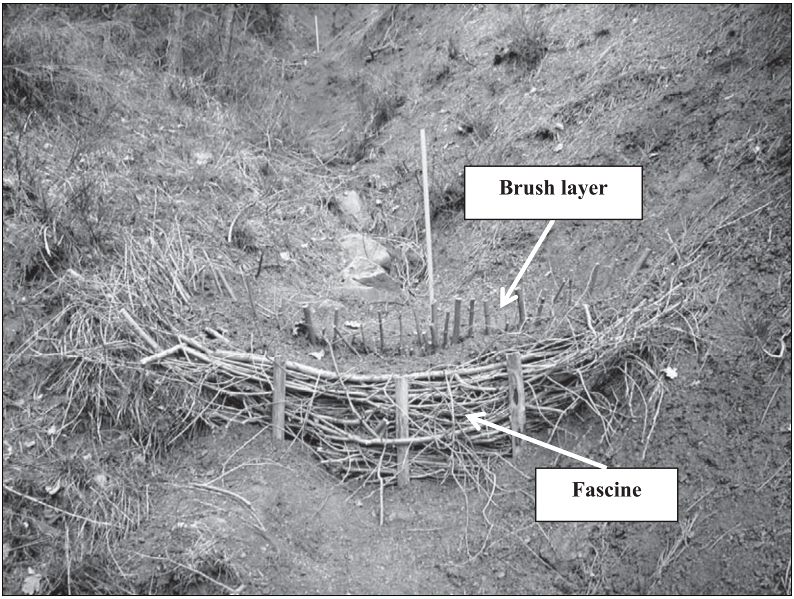


Fig. 3: Brush layer on fascine

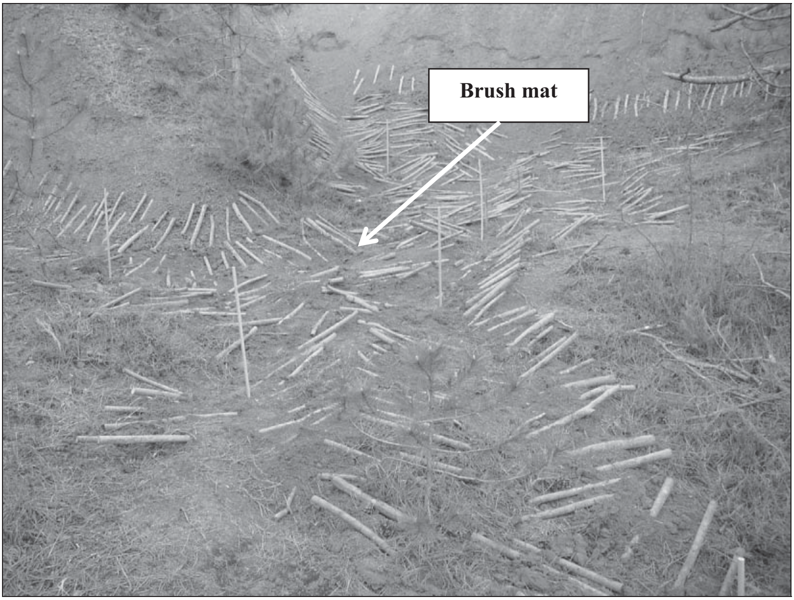


Fig. 4: Brush mat

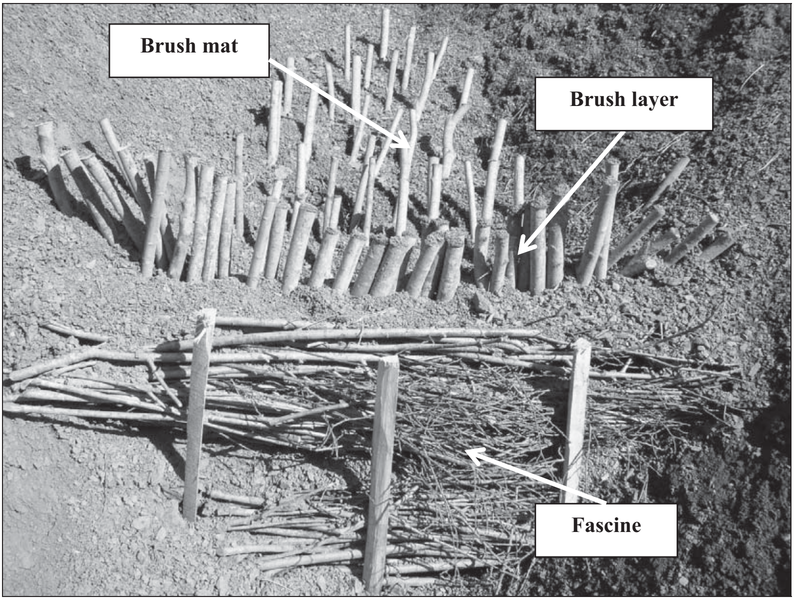


Fig. 5: Brush layer and brush mat on fascine

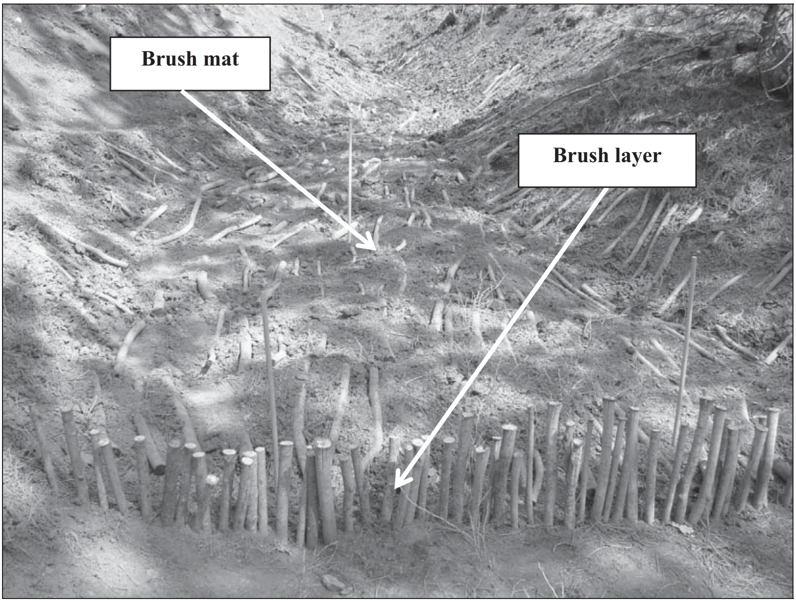


Fig. 6: Brush layer and brush mat without fascine

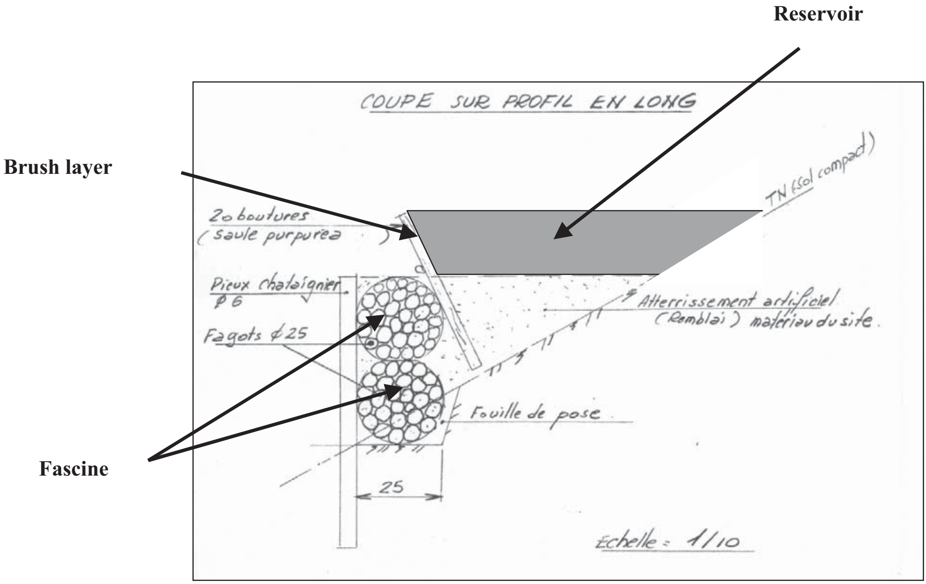


Fig. 7: Constitution of a sediment « reservoir » upstream of a brush layer

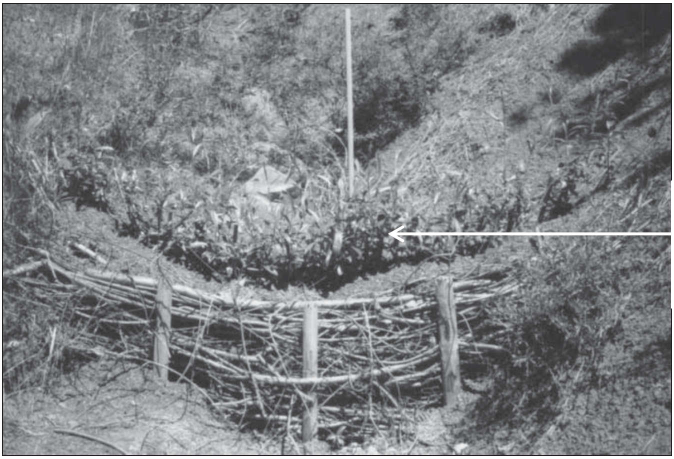
RESULTS

Rainfall events

In 2002, the total precipitation during the observation period (03/04/2002 to 12/12/2002, that is to say in 9 months) was 970 mm. This year was characterised by a very dry spring. Summer and autumn were relatively rainy, with one centennial rainfall event (69 mmh^{-1} during 1h).
Records of drought have been registered during the year 2003. The total precipitation on the study site for the first 6 months was 189 mm. These extreme conditions were particularly interesting because they allowed to test the cutting regeneration under quasi semi-arid conditions.

The cutting regeneration

The cuttings used for the brush layers and the brush mats (*Salix purpurea*, *S. alba* and *S. eleagnos*) had a very good regeneration and allow to constitute very dense vegetation barriers and covers (Fig. 8). Cuttings were maximum 1.30 metre high. If the cutting leaves developed well, root systems in the buried part of cuttings were also largely present, letting us think that the cuttings would be alive the next years. The cutting regeneration was effective for all the bioengineering works (60 in total), although the cuttings of the works located more upstream were less developed.
The cuttings of *Salix fragilis*, that were used only in fascines, had a very bad regeneration (Fig. 8). One explanation is that this species was not adapted to dry conditions. This questions the sustainability of this “dead” work. However, the cuttings of the fascines, for which *Salix alba* was used, had a good regeneration.



Vegetation barrier developed from a brush layer

Fig. 8: Brush layer on fascine after the cutting regeneration

At the beginning of the summer, the willow leaves turned yellow at the bottom of the cuttings and dead leaves fell down. Some of the cuttings were even completely dry. This concerns mainly the cuttings with the smallest diameter, as well as cuttings located at the border of the works. At those places, less water is available because of the minimum soil depth. However, all the vegetation around also turned yellow, due to the very dry and warm climate, with high temperatures close to the soil surface. Cuttings in the shadow turned less yellow than the ones in direct sunlight. The removal of leaves at the bottom of the cuttings led to a decrease of the barrier opacity, thus reducing the sediment trapping efficacy.

Quantity of sediment trapped by the bioengineering works

Sediment trapping was significant in all the works (Fig. 9). Brush layers appeared to be very efficient structures for sediment trapping. The screen constituted by the cuttings that have been installed (before the cutting regeneration) acts immediately as an efficient barrier. The height of the cuttings is important, as the height of sediment mass that is trapped is almost equal to the height of the cuttings. In the coming years, the growing of the cuttings will allow the barrier to expand and then it will trap the sediment that will arrive during the following heavy rainfall events.

Despite the occurrence of a centennial rainfall event, cuttings resisted hydrologic and erosive forces and allow an efficient trapping of sediment in gully floors. Two brush layers were yet not efficient enough because the distances between the cuttings were too large, allowing floods to pass through the barrier. This shows the significance of the density of the screen constituted by the cuttings. The diameter of cuttings is also important for the barrier opacity.

The results have shown a trapping efficacy of 0.05 m^3 sediment per work in one year. This result shows that it is possible to retain sediment with bioengineering works from the first year onwards.

Fig. 9: Sediment trapping upstream of a brush layer

From the second year onwards, the vegetation dynamics should lead to a colonisation of trapped sediment by new plants. This allows on one hand to retain the sediment in a sustainable way by the root systems of colonising plants and on the other hand it facilitates the growing of the barrier, which permits additional sediment trapping.

CONCLUSION

Recommendations for the use of bioengineering works

These first observations allowed to identify the willow species that should be used to build bioengineering works in a Mediterranean climate. *Salix alba*, *S. purpurea* and *S. eleagnos* can efficiently be used, both for the fascines as well as for the brush layers and mats. *Salix fragilis* should not be used. It is important to use cuttings with big diameters (more than 2 cm) for a good regeneration and resistance to drought. For brush layers, cuttings must be installed very close one to the other, in order to form a dense barrier, even without leaves.

The results can be used as a reference to calculate the dimension of bioengineering works for restoring eroded gullies. By considering the average capacity of sediment trapping of one work, it is possible to determine the number of works required in a gully to stop the sediment yield in one year. Then the vegetation dynamics allow the vegetation barriers to grow, which permits them to stop additional sediment.

Effect at a global scale

At a more global scale, the use of vegetation for protection operations and to retain sediment in catchments in a sustainable way, could reduce the sediment load in rivers and hydroelectric dams as well (case of the Durance River in the French Southern Alps) (Brochot, 1993). The ecological solution proposed to retain sediment in catchments as an alternative to the removal of sediment in reservoirs is an effective action at a very short term (from the first year), with economic and ecological interests. At a long term, it would be possible to determine the efficacy of a bioengineering works to retain 1 m^3 of sediment in the catchments and to compare the costs for building and maintaining these works, with the costs for removing 1 m^3 of sediment in a dam impoundment.

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