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Impact on sediment yield due to intensification of tobacco production in a catchment in southern Brazil

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Abstract Tobacco production in southern Brazil has caused a profound impact on the environment, resulting in heavy sediment yields and diminished water quality. Public programmes have attempted to address these problems by encouraging the implementation of erosion control practices. To evaluate the impact of these programmes, a small rural catchment (1.33 km^2) in Arvorezinha, in the state of Rio Grande do Sul, has been monitored since 2001. Instruments to automatically monitor flow rate and precipitation were installed in the catchment and sediment has been measured manually using a DH-48 sampler. Despite lower rainfall in 2003, there was a significant increase in the frequency of low and average flow rates, and sediment yield increased by 25% in 2003 (91 Mg km^{-2} $year^{-1}$), compared with 2002 (73 Mg km^{-2} $year^{-1}$). These results can be explained by a 37.7% increase in the area dedicated to tobacco cultivation in 2003, due to a rise in tobacco prices.

Key words Brazil; sediment yield; small catchment monitoring; tobacco

INTRODUCTION

Most of the tobacco produced in southern Brazil is grown by peasant farmers on land with poor agricultural potential. Steep hillsides, combined with traditional cultivation practices, have caused rapid degradation of natural resources, contributing to a worsening of the cycle of poverty. Traditional cultivation practices are characterized by the use of draft animals to turn the soil prior to transplanting tobacco seedlings. Soil conservation practices are non-existent, and the excessive use of agricultural chemicals is widespread. In addition, the period of greatest rainfall erosivity coincides with the beginning of the planting cycle, when soil cover is minimal (Argenta *et al.*, 2001). This combination of factors favours runoff erosion and the transfer of sediment to rivers. This sediment, in turn, causes river siltation and a reduction in water quality due to the agricultural chemicals and nutrients transported by the sediment (Merten & Minella, 2003; Minella *et al.*, 2004). In an effort to attenuate this situation and alleviate the problem of rural poverty, the government has implemented programmes that include the introduction of soil conservation practices, with the goal of reducing erosion rates (SAA, 1999). To evaluate the effectiveness of these programmes, an environmental monitoring project was initiated in 2001 to quantify the impact of the conservation practices on soil quality, the hydrosedimentological regime, and water quality, in a small rural catchment located in the state of Rio Grande do Sul.

In 2003, a 20% increase in the price of tobacco stimulated an expansion of the cultivated area, with results measurable through the monitoring programme. This study presents the monitoring results, showing the link between sediment yield and land-use pressure, triggered by economic factors.

Description of the catchment

The catchment being monitored measures 1.33 km^2 and includes the headwaters of the Lajeado Ferreira Stream, a small tributary of the Guaporé River (Fig. 1). Altitude varies between 560 and 740 m. The geology is predominantly basalt, with rolling terrain in the upper portion (7% average slope), and steeply rolling terrain, characterized by short slopes and box canyons, in the lower two-thirds. Average channel slope is 9%, with runoff concentration time varying between 20 and 50 min. Predominant soils are Inceptisols and Entisols, with an average depth of 50 cm. According to the Köppen classification, the region's climate is Cfb subtropical super-humid mesothermic, with cool temperatures in the summer and severe frosts in the winter. Average annual precipitation is 1605 mm, evenly distributed throughout the year. The tremendous biodiversity of the original vegetation of the region, the Brazilian Atlantic Rainforest, has been seriously affected by logging and agriculture. Socio-economic indicators classify the region as possessing one of the highest indices of rural poverty in the state of Rio Grande do Sul.

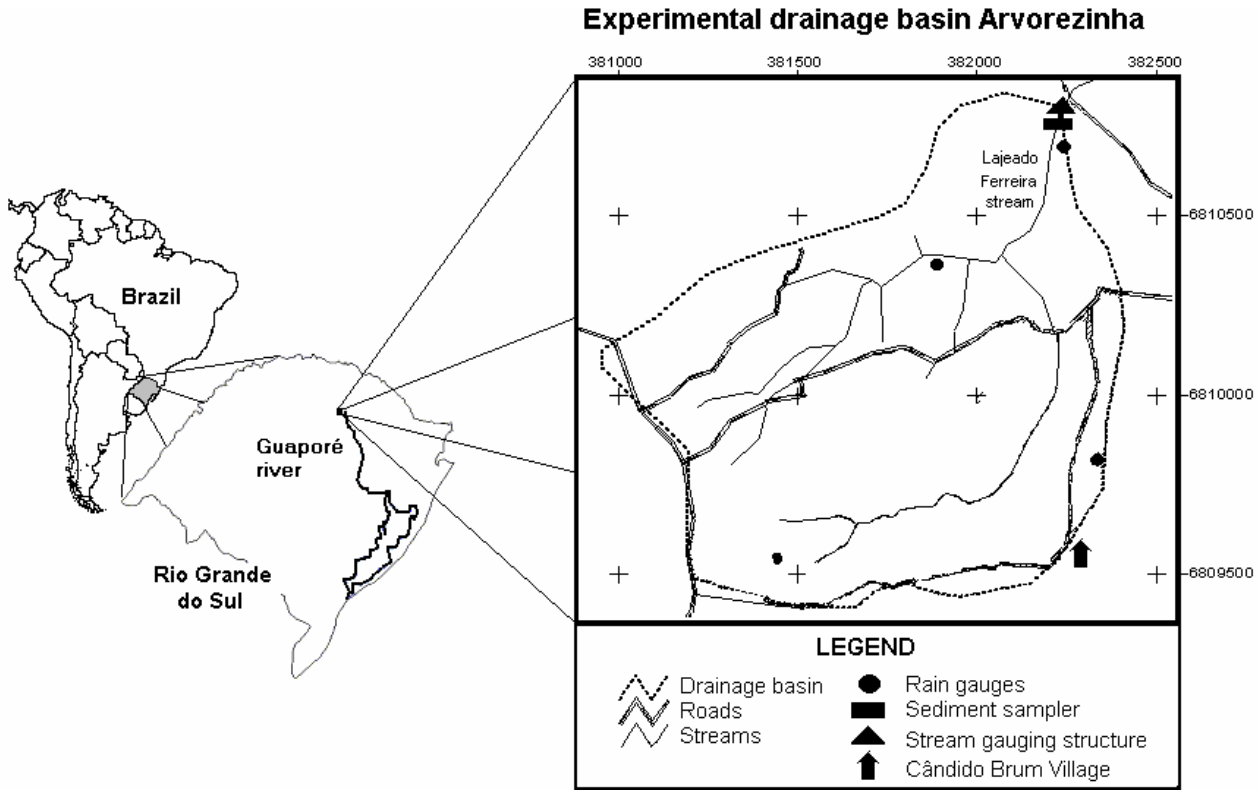

Fig. 1 Location of the catchment in the upper Lajeado Ferreira Stream.

Catchment monitoring

In order to evaluate the hydrological and sedimentological variables of the catchment, an automatic meteorological station, four raingauges, and a Parshall flume with an automatic water level sensor were installed. The rate of suspended sediment discharge was determined indirectly using US DH-48 and Single Stage (FISP, 1961) samplers. Transport of suspended sediment only occurs during rainstorms, so the frequency of sediment sampling corresponds with the majority of these events. Sediment yield was calculated based on the sampled events, using hydrographs and sedimentographs. Changes in soil use were determined by field surveys, assisted by a GPS with Spring/INPE® software.

RESULTS

Land-use survey

Principal soil uses in the catchment consist of cultivated tobacco fields, pasture, fallow and forest. Fields showing signs of reduced productivity typically are left fallow for at least two years. The category "forest" includes areas of native forest, trees planted to supply firewood for drying tobacco, and riparian zones.

Significant changes in soil use were measured in the catchment during 2003. A 37.7% increase in cultivated area (Table 1) occurred at the expense of other soil uses, especially forested areas, which were reduced by 19.9%. Of special note, riparian vegetation was diminished by 10%, principally near the headwaters of the Lajeado Ferreira Stream. This is reflected by increases in sediment transfer from the hillslopes to the channel, as riparian vegetation plays a key role in retaining sediment. A second aspect was a drastic change in wetland area. Many wetlands adjacent to the Lajeado Ferreira Stream were drained during the first half of 2003 and put into cultivation, thus contributing to an increase in surface runoff and the creation of new sediment sources.

Hydrological changes

In 2002, the frequency of low flows (<2.9 l s^{-1}) was 1.6%, while in 2003 it increased to 36%. At the same time, floods of much greater intensity were observed in 2003. Figure 2 uses a flood frequency curve to analyse these differences in runoff between the two years. A flood frequency curve is defined by the frequency in which the

Table 1 Evaluation of land use in the catchment.

Land use	2002 (ha)	2003 (ha)	%
Fields	41.1	56.6	37.7 (+)
Fallow	22.1	18.8	14.9 (–)
Forest	42.3	33.9	19.9 (–)
Pasture	22.7	18.9	16.7 (–)

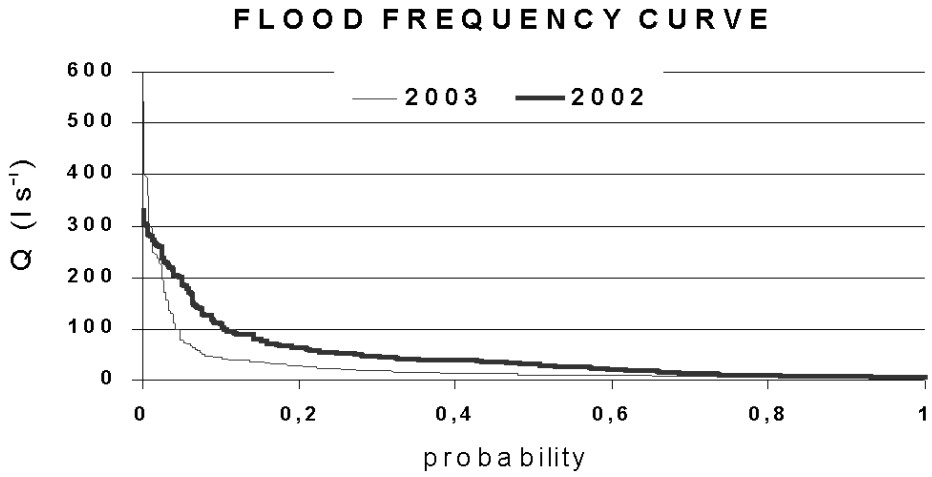

Fig. 2 Flood frequency curves for the Arvorezinha catchment during the two monitoring periods.

average daily flows measured above a certain value, Q_i. The extremes of the curve reflect the peak discharge and low flow, which vary according to the runoff characteristics of the catchment.

In 2002, the curve displays greater uniformity, characterizing a greater flow regularization capacity. In 2003, with the increase in cultivated area, associated with the removal of natural vegetation and wetlands, there was an increase in the frequency of peak flows as well as low flows, producing a curve with more accentuated extremes.

Sediment yield

The expansion of the area under tobacco cultivation that occurred in 2003 significantly altered the sediment budget for the catchment. This was registered by increases in the frequency of higher suspended sediment concentrations and in increasing sediment yield. A comparison between 2002 and 2003 clearly indicates that in 2003 there was a greater frequency of concentrations greater than 600 mg l^{-1}, whereas in 2002, concentrations of less than 450 mg l^{-1} predominated (Fig. 3).

The average flow rate and precipitation in 2003 were slightly lower than in 2002; however, there were flow spikes of up to 6000 l s^{-1} during 2003, whereas in 2002, the highest flow rate did not exceed 1200 l s^{-1} (Table 2). This fact is certainly associated with wetland drainage and with the larger area of soil exposed during field preparation.

Values for precipitation, erosivity, flow rate, and sediment yield were grouped according to the different activities involved in tobacco production (Table 2). Accordingly, soil preparation and tobacco planting take place from July to October. In November and December the fields are hoed to control weeds. From January to March the leaves are harvested, followed by a period of fallow or green manure production (April to June). If green manures are used, the soil is once again ploughed. Sediment yield in 2003 (91 Mg km^{-2} $year^{-1}$) was 25% higher than in 2002 (73 Mg km^{-2} $year^{-1}$) (Table 2). During the period from July to October alone, sediment yield for 2003

approximated the total yearly yield for 2002. It is interesting to note that 80% of the sediment yield for 2003 occurred during three rainfall events registered in July. This was due to the presence of countless newly worked areas, especially in the headwaters of the Lajeado Ferreira Stream, in which riparian vegetation had been removed, as well as to the presence of large quantities of sediment deposited next to the stream channel as a result of wetland drainage. It is also worth noting that the sediment yield values for the catchment are much higher than those found during a 1998 survey of principal Brazilian rivers, in which the sediment yield for the middle section of the Guaporé River was estimated at around 23 Mg km^{-2} year^{-1} (ELETROBRÁS, 1998).

In field surveys carried out after the events, many gullies were observed in the steeper areas where runoff erosion was more severe, as well as a striking change in the morphology of the stream channel due to sediment deposition. It is likely that these deposits will constitute an important sediment source during the next few years, contributing significantly to the catchment's sediment yield.

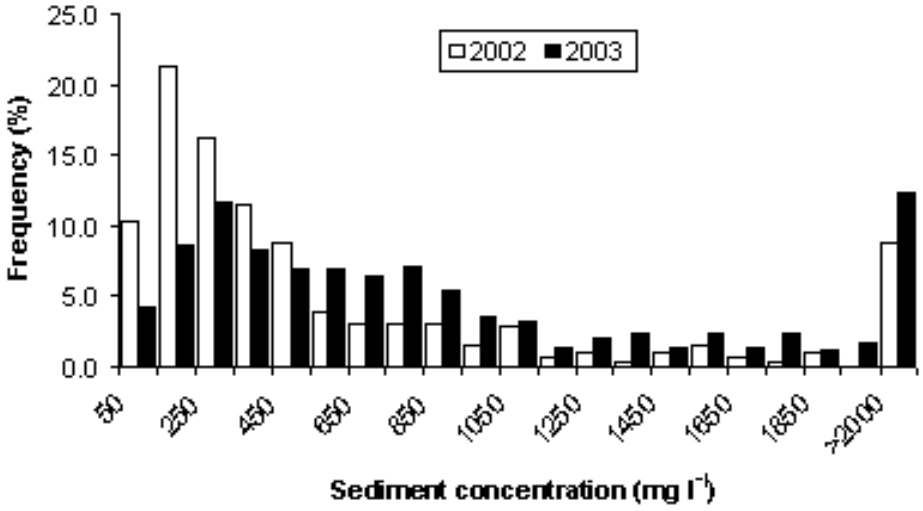

Fig. 3 Frequency histogram of suspended sediment concentration for the Arvorezinha catchment during the two monitoring periods.

Table 2 Precipitation, erosivity, average flow rate, number of measured events and sediment yield for the Lajeado Ferreira Stream catchment.

Variables	Jan.–Mar.		Apr.–Jun.		Jul.–Oct.		Nov.–Dec.		Year	
	2002	2003	2002	2003	2002	2003	2002	2003	2002	2003
P	210.5	410.1	680.8	429.0	867.7	585.5	460.6	410.7	2219.6	1835.3
E	443.5	1280.7	3016.9	1449.7	3798.9	2404.3	2046.3	1868.4	9305.6	7002.8
Q	9.0	17.3	44.2	33.5	65.3	33.7	55.9	25.7	43.6	27.6
Ne	0	3.0	5.0	2.0	11.0	4.0	0	2.0	16.0	11.0
SY	0	7.25	20.79	8.53	52.15	70.53	0	4.83	72.94	91.14

P: precipitation (mm); *E*: erosivity (MJ mm ha^{-1} h^{-1} month^{-1}); *Q*: average flow rate (l s^{-1});
Ne: number of measured events; *SY*: sediment yield (Mg km^{-2}).

CONCLUSIONS

Based on the monitoring results of the hydrological and sedimentological characteristics of the Lajeado Ferreira Stream, it was possible to conclude that the shift to more intensive tobacco production in ecologically-fragile areas, such as wetlands, riparian zones, and steep slopes, resulted in severe impacts on the hydrological system and sediment yield. Given that tobacco is grown by very poor farmers on marginal lands, the economic stimulus represented by a price increase can greatly accelerate the process of environmental degradation, unless accompanied by an equal or greater stimulus to implement adequate environmental protection measures, especially improved soil management practices.

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