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Soil erosion in the vineyards of Champagne

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Abstract The vineyards of Champagne are amongst the most famous in the world. The agricultural practices have been greatly modified since the 1950s and have induced extensive soil erosion on the hillsides. This erosion is associated with mud flows which directly threaten property and people. After a description of the major processes, a quantitative approach is proposed to evaluate the potential of some technical solutions for reducing the erosion problem. A sediment transport model is coupled with a rainfall/runoff model to simulate a 15-year flow and sediment transport record. The results obtained demonstrate the efficiency of the modelling approach and the modification of the agricultural practices required. A new strategy for managing the vineyard hydrology is proposed, based on modification of the agricultural practices and runoff management in all parcels prior to water concentration in channels.

INTRODUCTION

The vineyards of Champagne are amongst the most famous in the world for both the nature and the quality of their production. But today, changes in the agricultural practices are endangering this patrimony. The more the vineyard area expands, the more the steepest and highest areas on the cuesta and the sides of the Marne valley are used (Fig. 1). All the hillsides, as in other vineyards with similar morphology, are subjected to the effects of soil erosion. This process is initiated by water erosion which is locally associated with landslides. The resulting phenomena are both chronic and episodic in character.

SOIL EROSION: AN HISTORICAL PROCESS

Vineyards appeared on the hillsides of Champagne before the Romans occupied Gaul. The Roman Empire encouraged this production which was subsequently controlled by the monks. Until the seventeenth century, champagne was just a white or red "quiet" wine but it was already favoured by the European royal courts. The key development — the second fermentation — appeared only accidentally and produced "devil wines". The success story of champagne really started in the eighteenth century with the Dom Pierre Pérignon monks who developed the champagnization process and the method of blending the different wines.

The production area was originally limited to the Marne valley in order to be easily accessible to the main market of Paris. The champagne market really developed at the beginning of the eighteenth century with the rich people of Paris and London. The production area was voluntarily limited and the product stayed marginal. The end of the nineteenth century was characterized by a very strong

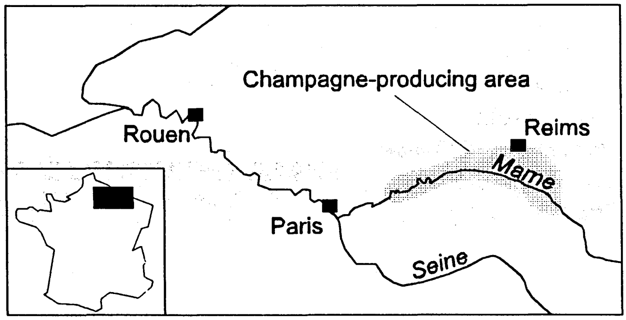

Fig. 1 Location map.

recession in the champagne producing area. The wines faced competition from the products of the south of France, which became more easily transported with the expansion of the railways. From 1890 to 1911, phylloxera devastated the French vineyards and particularly the Champagne area. The redevelopment of the vineyards, with grafting on to an American variety, has been associated with the disappearance of the "foule" structure and its replacement by the present linear pattern. The "foule" structure had a density of 30 000 plants per hectare and no specific spatial organization. Runoff and sediment transport were partially controlled when the vineyards had this structure and when the work was undertaken in the traditional manner with weeding and digging to maintain the soil. The use of tractor cultivation since the beginning of the 1950s has favoured the creation of furrows which are able to collect water and to generate channels. The intensive use of chemical weedkillers in the 1960s and the absence of cultivation under the plants have enhanced the erosion processes which threaten the long term sustainability of the soil. The major redevelopment of cultivation for the A.O.C. — "Appellation d'Origine Controlée" areas which present the production area defined in 1927 has caused a significant modification of the runoff conditions. The traditional practice of burning undertaken at the end of the winter to maintain the herbaceous vegetation disappeared 20 years ago. The hillsides have been replanted with vineyards and the waste land converted to shrub vegetation. The erosion phenomena are now associated with processes such as mud flows which directly threaten property and people.

METHODOLOGY

A quantitative assessment has been carried out for the development of a new vineyard in the territory of the municipality of Chartèves in the Marne valley. The hillside, with a slope of over 40%, is located just upstream of the urban area and has not been cultivated since the First World War. Runoff and sediment transport are very limited because herbaceous and shrub vegetation cover the entire hillside.

A modelling approach has been selected to evaluate the potential soil erosion and to assess the potential of different strategies for reducing erosion intensity. The method involved is more an assessment of the general controls on sediment transport rather than a deterministic analysis of the erosion phenomena. The general aim is to couple a sediment transport model with a rainfall/runoff model.

The rainfall/runoff model

The rainfall/runoff relationship has been modelled using several approaches. A very detailed model is not necessary for the present problem, because the assessment is focused on the general controls. In addition, the model is to be applied to a theoretical surface where the runoff can be easily associated with the impervious areas.

The runoff model selected forms part of the MOUSE modelling system (DHI, 1994) and is based on the time-area method (Wanielista, 1990). The runoff time lag is taken into account by using a time-area curve (here a rectangular time-area curve is used) and the specified time of concentration. Three computational assumptions are made: the rain is uniformly distributed, the runoff is generated only from the area specified as impervious and the runoff velocity is constant. The continuous runoff process is discretized in time by the computational time step. The assumption of constant velocity permits the spatial discretization of the basin surface into a number of cells in the form of concentric circles with a centre point at the point of outflow. The model calculates the area of each cell on the basis of a rectangular time-area curve which characterises the shape of the parcel. Runoff starts after the rain depth has exceeded the initial loss. At every time step after the commencement of runoff, the accumulated volume of runoff from a certain cell is transferred to the adjacent cell in a downstream direction. The actual volume in the cell is calculated as a continuity balance between the inflow from the upstream cell, the current rainfall and the outflow to the downstream cell. The outflow from the most downstream cell is the resulting surface runoff hydrograph.

The sediment transport model

The sediment transport model is the TRAP module of the MOUSE modelling system developed by the Danish Hydraulic Institute (DHI, 1994). The mobilisation of sediment particles during a rainfall event can be divided into two processes: erosion by raindrops and erosion by overland flow. Only the erosion by raindrops is taken into account in the model. Erosion by raindrops is governed by several parameters. The most important are: rainfall intensity, rainfall height, rainfall duration, drop size, basin topography, particle characteristics and vegetation. However, parameters such as drop size and rainfall height are rarely available, so a simpler approximation has been adopted in the model. This approximation assumes that raindrop erosion is a function of the rainfall intensity and a detachment rate. The equation for the detachment by rainfall can be written as:

$$V_{sr} = D_r \left(\frac{i_r}{i_d} \right)^2 LW(1-\varepsilon)A_s \qquad (1)$$

where V_{sr} is the sediment volume detached by the rainfall per unit of time ($m^3 h^{-1}$), D_r is the detachment coefficient for rainfall (m h^{-1}), i_r is the rainfall intensity (= 25 mm h^{-1}), i_d is the rain intensity constant (mm h^{-1}), L is the length of the basin (m), W is the width of the basin (m), ε is the porosity of the sediment, A_a is the fraction of surface area covered with sediment.

It is important to note that the erosion rate is independent of the diameter of the particles, hence the transport of the fine fraction is independent of the particle diameter. Transport of the coarse sediment is limited by the transport capacity of the overland flow, whilst the transport of the fine sediment is only limited by the erosion rate and the mass available at the surface. The transport capacity for the coarse fraction is calculated as the sum of the bed load and the suspended load transport capacity. The transport capacity for bed load is calculated from the Meyer-Peter bed load equation:

$$q_b = K_b(\tau - \tau_c)^{3/2} \tag{2}$$

where τ is the bed shear stress, τ_c is the critical bed shear stress, K_b is defined by:

$$K_b = \frac{1}{A_b\left(\frac{\gamma}{g}\right)^{1/3}\left(\frac{\gamma_s - \gamma}{\gamma_s}\right)^{2/3}} \tag{3}$$

where γ is the specific weight of water, γ_s is the specific weight of the sediment, A_b is a constant (0.25).

The transport capacity for the suspended load is calculated from the Einstein equation for suspended sediment transport (Einstein, 1950):

$$q_s = 11.6 u_* c_a a\left(2.303\log\left(\frac{30.2d}{k_s}\right)I_1 + I_2\right) \tag{4}$$

where u_* is the shear velocity, c_a is the concentration at a distance a from the bed given by equation (5), a is the distance from the plane bed, d is the water depth, k_s is roughness height, I_1 is the integral defined in equation (6), I_2 is the integral defined in equation (7).

c_a in the equation is the concentration at distance a from the bed, defined as:

$$c_a = \frac{q_b}{11.6 u_* a} \tag{5}$$

Equation (4) can be solved by numerical integration. The integrals in equation (4) yield:

$$I_1 = 0.216\frac{ya^{(z-1)}}{(1-ya)^z}\int_{ya}^{1}\left(\frac{1-y'}{y'}\right)^z \mathrm{d}y' \tag{6}$$

$$I_2 = 0.216\frac{y_a^{(z-1)}}{(1-y_a)^z}\int_{y_a}^{1}\left(\frac{1-y'}{y'}\right)^z \ln y' \,\mathrm{d}y' \tag{7}$$

where y' is the relative depth (y/d), y_a is the relative depth (a/d), z is w/ku_*.

The total limiting transport capacity is then given as:

$$q_t = q_b + q_s \tag{8}$$

APPLICATION

The modelling approach has been applied to a theoretical 0.5 ha parcel, underlain by typical Marne valley formations and with a slope of 30%. Different lengths of row — 125 and 70 m — have been tested to evaluate the possibility of reducing erosion.

Soil

The Marne valley is located on Tertiary strata with alternate marls, calcareous materials and silts. The incision of the Marne by over 150 m has created sloping hillsides (30 to 45%) developed on horizontal geological formations. The soils are thin — 0.15 to 0.30 m — and composed of colluvial material at the bottom of the hillsides. The modelled soil is characterized by a d_{50} equal to 0.02 mm for the fine fraction and 0.05 mm for the coarse fraction. A 35% porosity is assumed for the soil.

Rainfall data

Rainfall data have been collected at the Crézancy station managed by Meteo France. The station is located in the Marne valley and very close to Chateau-Thierry. The data are daily records and are available from 1978 to 1996. The period 1980-1995 has been used (Fig. 2). The records demonstrate that some very high intensities have

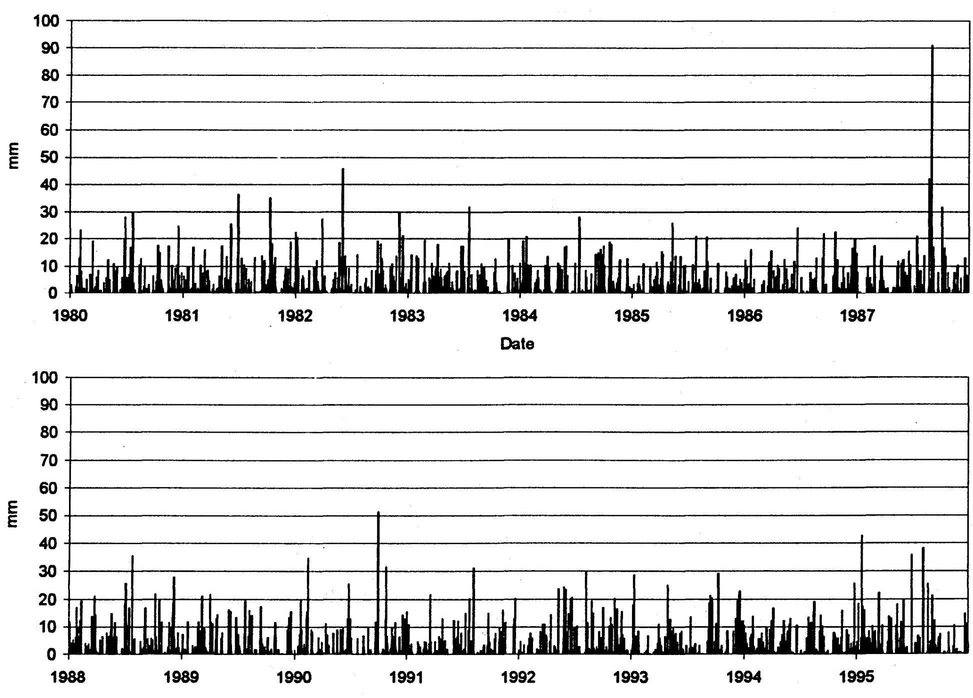

Fig. 2 Rainfall recorded at the Crézancy station during the period 1980-1995.

been observed in September and October during thunderstorms: 91.3 mm in 5 h on 1 September 1987 for example. The use of daily records is not a good approach to simulating soil erosion, because the start of particle transport is determined by the rainfall intensity. With this kind of data, erosion is underestimated. The impact is particularly important for medium magnitude events (20 to 30 mm). To correct this difficulty, the original data have been modified. The main hypothesis is that significant runoff starts with a volume over 10 mm day^{-1}. For all these events, a 10 mm h^{-1} intensity is applied to reduce the duration of the rainfall. Thus rainfall of 30 mm day^{-1} becomes a three hour rainfall. This intensity has been chosen because it is equivalent to the annual intensity determined for the Champagne area (CEMAGREF, 1972).

Validation

The rainfall/runoff model and the sediment transport model have been validated with several sets of data collected during different studies undertaken in Champagne (CEMAGREF, 1986; SOGETI, 1993). In 1991, 1992 and 1993, flows have been recorded continuously downstream in two basins in Chamery and Ecueil. The sediment transport has been estimated from the sediment mass accumulated in the detention basins over the last 10 years. These records have demonstrated that the runoff could be over 85% during periods of intense rainfall. A distinction exists for sediment transport according to slope steepness. The annual volume of transported

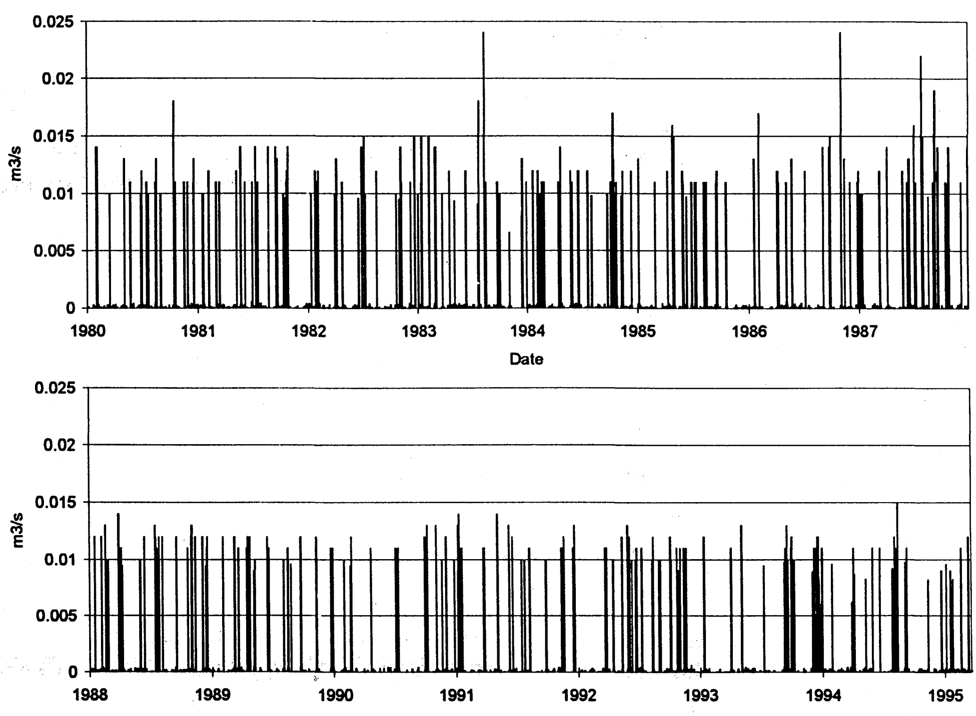

Fig. 3 Simulated runoff record for a 125 m length parcel.

sediment is about 1 $m^3ha^{-1}year^{-1}$ for areas with slopes below 10 %. When the slope is between 10 and 20%, the volume is around 5 m^3 ha^{-1} $year^{-1}$. Similar results have been also obtained from other sites by the Interprofessional Committee of the Champagne Wines which includes all the producers.

RESULTS

In order to examine the influence of vineyard length on erosion, the model has also been run for cases where the length of the vineyard has been limited to 70 m to reduce the runoff energy on the soil surface. The normal length is between 100 and 150 m in order to optimize the vine density and the mechanical work. A number of points must be emphasized regarding the modelling approach. The model formulation only includes erosion by raindrops. The implicit hypothesis is that any channel is created on the soil surface during runoff. In fact, some channels occur in furrows and favour sediment transport. The detachment rate of 0.005 m h^{-1} used in the wash off equation has been selected to take account of channel formation. Particle mobilization, particularly for the fine sediment fraction, is not constant in time and depends on the moisture content of the soil. Maximum particle mobilisation occurs after a period of dry weather. The drying of the soil promotes the availability of fine particles which constitute a volume which can be easily removed by runoff. For the present application, the dry period has been limited to three consecutive days.

The simulated runoff for a 125 m row parcel is presented in Fig. 3. The runoff is characterized by significant number of events which are associated with a flow of

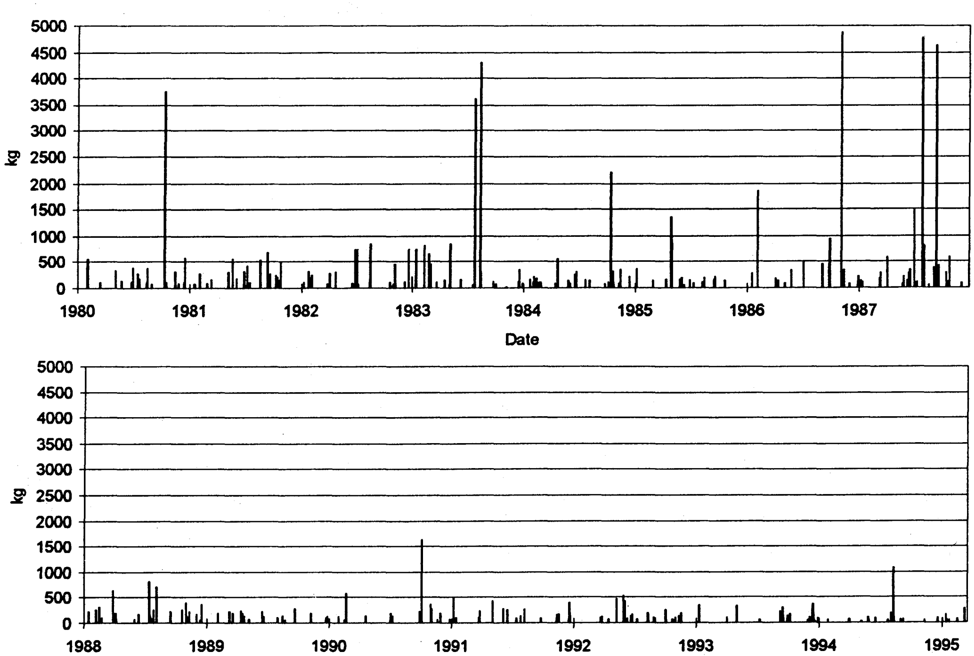

Fig. 4 Simulated sediment transport (suspended + bed load) for a 125 m length parcel.

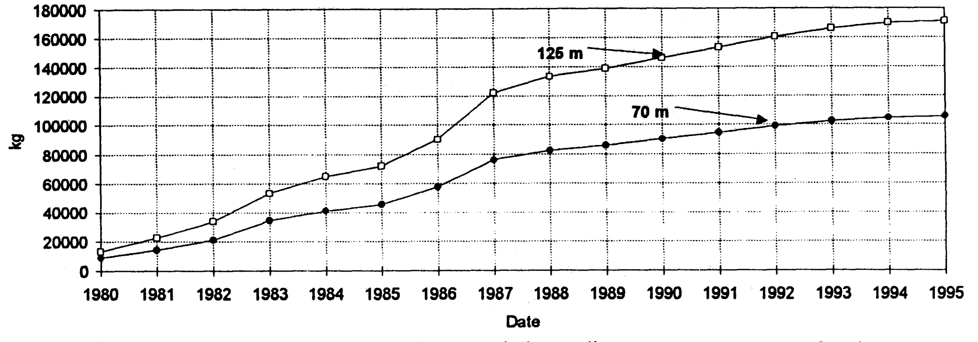

Fig. 5 Comparison between the cumulative sediment transport curves for the 125 m and 70 m length parcels.

0.01 $m^3 s^{-1}$. These events are associated with rainfall during summer and autumn.

The total sediment transport for the 125 m rows is presented in Fig. 4. The results emphasize two aspects of the soil erosion: namely its chronic and episodic character. During the 15 years, only a few events (6) have exceeded a volume of 3500 kg. For these exceptional events, the sediment volume transported in one day could equal the mean annual volume. Sediment transport management during intense rainfall constitutes a major difficulty. For a small basin (e.g. 5 to 10 ha) the daily volume can vary from 17 m^3 to 34 m^3.

A comparison of sediment transport between a parcel associated with 125 m rows and 70 m rows is presented in Fig. 5 and in Table 1. The reduced length limits sediment transport and particularly the bed load transport because the flow energy decreases. The volume reduction is around 40%. However, the erosion hazard remains important.

Table 1 Annual sediment transport for the 125 m and 70 m parcels.

Date	Suspended load transport		Bed load transport		Suspended+bed load	
	125 m (kg)	70 m (kg)	125 m (kg)	70 m (kg)	125 m (kg)	70 m (kg)
1980	8 804	8 804	4 694	7	13 498	8 811
1981	5 382	5 382	3 682	9	9 065	5 391
1982	6 760	6 760	4 625	24	11 385	6 784
1983	13 274	13 274	6 209	45	19 484	13 319
1984	6 776	6 776	4 354	36	11 130	6 812
1985	4 531	4 531	3 100	7	7 631	4 538
1986	11 888	11 888	6 056	0	17 944	11 888
1987	18 384	18 384	13 691	2	32 076	18 386
1988	6 744	6 744	4 613	59	11 357	6 803
1989	3 169	3 169	2 169	31	5 338	3 200
1990	4 388	4 388	3 001	44	7 391	4 432
1991	4 234	4 234	2 897	15	7 131	4 249
1992	4 244	4 244	2 904	7	7 149	4 251
1993	3 355	3 355	2 296	38	5 652	3 393
1994	2 301	2 301	1 574	110	3 876	2 411
1995	681	681	466	175	1 147	856
Total	104 923	104 923	66 338	615	171 261	105 538

CONCLUSION

Erosion processes are very active in the Champagne area. The morphological conditions associated with the geological characteristics provide favourable conditions for soil erosion. The rainfall intensity coupled with the current cultural practices are also conductive to an increase in erosion. The creation of new vineyards should be associated with new strategies to manage the runoff. The modelling approach has demonstrated that the classical structure — 125 m rows without vegetation under and between the vines — could be associated with an annual sediment loss of 8.6 $m^3 ha^{-1} year^{-1}$. The reduction in row length causes this loss to be reduced to 5.3 $m^3 ha^{-1} year^{-1}$. Despite this reduction, the sediment transport remains potentially very high and constitutes a potential threat. A new strategy for the hydrologic management of vineyards should be developed. The central concept is founded on the idea that the runoff must be managed on the hillside before the water is concentrated in channels with a high transport capacity. Each parcel must be associated with an efficient structure to collect the runoff and the transported sediment. To complement the structures, cultivation between and under plants should be promoted to limit the runoff. Some experiments have demonstrated the possibility of reducing the runoff by more than 75% compared to situations with grass under the plants. This new strategy will be applied in Chartèves. The modelling approach was necessary to convince the wine growers to modify their practices.

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