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Soil Erodibility in Mediterranean Mountains of Aveyron (Southern France)

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INTRODUCTION

Soil Erosion Diagnostic of Erosion in Aveyron Region

Since 30 years, erosion has rapidly increased in the southern part of France, specially in this part of Aveyron. Today, erosion manifestations are numerous:

— sheet and tillage erosion are present on 90 per cent of arable lands;
— rill erosion is frequent on cultivated lands on more than 20 per cent slope as soon as tillage practices are obliterated and sealing crust developed;
— gully erosion is the most spectacular manifestation of the runoff energy on this hilly region;
— badlands presently cover more than 10 per cent of arable lands;
— even on good soils, decrease in forage yield has been observed because of selective erosion of organic matter and fine particles since weathered schist gravel increase each year in the topsoil;
— these last years, spectacular floods of red water have been observed in the plain and mud floods from badlands to roads and villages.

Because soil depth and biomass production are decreasing and the price of the fertilizers and pesticides are increasing, farmers are anxious for the future of their farms and their environment.

EROSION ENVIRONMENT

The studied area is located in an old Permian (250 Mg. B.P.) sedimentary basin composed of alternation of hard silicon schist and soft red argillite 300 m deep. The present topography is hilly with "cuestas".

Very little of the landscape is smooth. The valley bottom represents less than 10 per cent. In this hilly region, the hill slopes have frequently between 20 and 40 per cent gradient. As schist and argillite are very friable, frequent deep ploughing mixes up weathered schist fragments, red mineral soil and brown topsoil. With frequent tillage practices, sheet, rill and tillage erosion, the soil profile is very thin and impoverished at the top of the hill (15–30 cm) and a slightly thicker (60–90 cm) at the bottom of the valley where the rivers cut deeply in the last terraces.

The climate (Fig. 1) is oceanic with storms in the spring and automn when seedbeds are bare and pulverized. During the winter, the succession of freezing periods accelerates disintegration of schist. During the summer, violent storms alternate with dry (Mediterranean) periods. At Saint Affrique, the nearest meteorological station (324 m altitude), the average rainfall was 824 mm for 1964–91 period. Rainfall intensities are moderate: 60 mm h^{-1} during 30 minutes for the decennial frequency rainfall that was used for rainfall simulations.

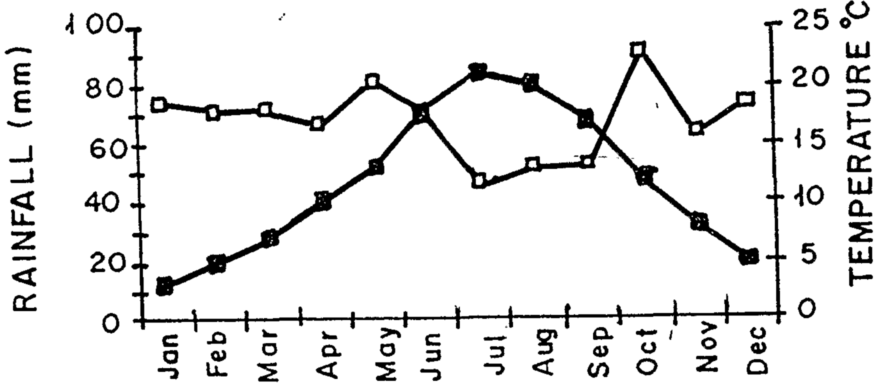


Fig. 1. Rainfall and temperature of St Affrique Station (1971–1992).

On the other hand, human activities have contributed to accelerated soil erosion, in relation to Requefort cheese production. Farmers destroyed hedges, cleared the forest to increase the cultivated surface for mechanised forage production, introduced cereals which poorly covered the soil surface against freezing, accelerated rotations and cultural practices which push the soil down the hillslope or cultipacker roller which pulverized the clods of the sealing topsoil.

EXPERIMENTAL CONDITIONS OF RUNOFF AND EROSION SIMULATIONS

Experimental Condition

The problem was to answer the farmers questions: what cultural practices can reduce runoff and erosion rate on the cultivated steep slopes?

On hill slopes of 20 per cent gradient and with a sandy clay loam, superficial soil (20–40 cm) on argillite was selected to compare the runoff and detachability of 4 cultural practices subjected to 3 successive rainfalls of 60 mm h^{-1} intensity during 30 minutes and dry, wet (24 hours after the preceding rain) and very wet (1 hour after the preceding rain) situations. Five situations were tested :

- SD: zero tillage near the top of the slope;
- L + 2H b: conventional tillage with 2 harrowing at the bottom of the slope;
- L +2 H h: conventional tillage with 2 harrowings at the top of the toposequence;
- L + 2H + Cpk: conventional tillage with 2 harrowings and cultipacker.
- Ts(Vb + 2H): reduced tillage with vibrocultor and 2 harrowings at the top of the soil.

Rainfall and Runoff Simulators

The ORSTOM type of rainfall simulator (Asseline and Valentin, 1979) was used to test the impact of splash on the infiltration capacity and the runoff turbidity.

It is constitued of a pyramidal tower 4 m high with a mobile Veejet sprinkler sprinkling 10 m^2 plots. A metallic frame isolates 1 m^2 plot receiving calibrated intensities from 20 to 130 mm h^{-1} according to the selected angle of the Veejet.

The runoff simulator was used for first time at this occasion, with the objective of measuring the magnitude of superficial and subsurface runoff with the 3 cultural practices: zero tillage, conventional tillage with 2 harrowings and conventional tillage with 2 harrowings and cultipacker roller. This runoff simulator was constituted of 3 rigid PVC tubes 2 m long. Each of them was perforated by one line of holes of 1–1.5 mm diameter at intervals of 2 cm. These tubes were positioned across the slope. Contact with the soil surface was realized with a piece of cotton textile in order to obtain laminar flow with zero initial kinetic energy at the soil surface. From a tank water was injected under regulated pressure into the runoff simulator. At the end of the plot (9 m long), a fibrocement channel allowed measurement of runoff flow and turbidity. For the subsurface flow, a trench was dug down to the schist layer.

Experimental Protocols

The objective was to measure the runoff flow and its turbidity for different surface soil status (cloddy, smooth, compacted for dry and wet conditions). For the rainfall simulations, the intensity selected was 60 mm h^{-1} during 30 minutes repeated 3 times:

- a first rainfall, and dry soil conditions like during the summer storms;
- a second rainfall, 24 hours after, like in the beginning of the rainy season;
- a final rainfall, 1 hour after the preceding to simulate rainy periods of the spring.

For the runoff simulation, a similar protocol was adopted but differently distributed on the time.

The second simulation was made one hour after the dry run and the third simulation 8 days after the second.

The flow injected at the top of the plot, 2 m wide, was 0.03 Ls^{-1} Before and after each run, physical parameters of the soil surface was measured:

- Per centage of surface closed by sealing crust, sedimentation crust and gravels;
- Percentage of surface opened: clods of less than 1 and 3 cm or more, worm activities;
- Percentage of surface covered by canopy and by litter;
- rugosity observed with a chain laid on the micro-relief;
- soil moisture in the first centimetres;
- bulk density and single-ring infiltration capacity.

RAINFALL AND RUNOFF SIMULATION DATA

Rainfall Simulation Data

Four phases were observed during the rainfall simulation:

(1) rainfall amount for waterlogging (PI, initial rainfall, in mm) is the rainfall amount necessary before runoff;
(2) a transitory phase beginning with the runoff flow when the infiltration capacity is reducing by sealing crust formation and waterlogging of the porosity of the topsoil;
(3) a stabilized phase when the runoff flow is maximum and the infiltration very near the K value of permeability at soil saturation;
(4) and finally a draining phase, when the rainfall simulation has been stopped.

Runoff is expressed in intensity (mm h^{-1}) or in percentage of the rainfall amount (KR %).

The soil losses measured on 1 m^2 to represent only the detachment of particles by splash on the topsoil surface without rill and runoff energy, so that the slope effect is generally non significant at this scale.

For the *first rainfall* (30 mm in 30 minutes on dry soil), the results are summarised in Table and concern the dynamic of flow and erosion (g m^{-2}).

1st Rainfall simulation

	Initial moisture %	Pi (mm)	Kr (%)	FN (mm h^{-1})	Erosion (g m^{-2})
SD	15.3	21.8	8.2	32.3	0.9
L+2H b	14.2	>30	0	60.0	0
L+H+Cpk	12.1	25.2	2.5	49.3	4.4
L+2H h	10.8	>30	0	60.0	0
Ts(vb+H)	14.7	>30	0	60.0	0

For this first dry test, the soil moisture was very low similar from one plot to another (11–15%). The rugosity increased from 5 per cent for tillage + cultipacker to 15 per cent for conventional tillage, up to 24 per cent for the reduced tillage. During thin 30 mm rainfall on dry soil, plots with conventional or reduced tillage did not give runoff.

Runoff (%) was moderate on plots compacted by the cultipacker roller and no tillage (2.5–8%) and began after 22–25 min. But after this storm, 50 per cent of the topsoil surface tilled was closed by sealing crusts. On cultipacker plot, turbidity was very high (7g L^{-1}) but soil losses were reduced (4.4g m^{-2}) because runoff began very late. On the other hand, on the no tillage slot turbidity was very low (0.4 g L^{-1}) because it was covered by weeds killed by herbicides..

The relation between turbidity and runoff flow is not constant, the load first increasing with flow upto a maximum before the flow peak, and then decreasing because the flow protects the soil against splash effect.

The second test (Fig. 2), on humid situation was done 24 h after the first rain test. Soil moisture context was higher (19 to 22%) and more diversified : all the plots gave runoff because the soil was wet.

2nd Rainfall Simulation

	Initial moisture %	Pi (mm)	Kr(%)	FN (mm h^{-1})	Erosion (g m^{-2})
SD	19.9	8.4	43.7	19.1	4.3
L + 2H b	21.0	17.7	28.7	13.3	8.1
L + H + Cpk	21.6	3.8	45.7	14.3	92.8
L + 2H h	18.8	4.2?	19.3	35.9	20.2
Ts(vb + H)	22.6	13.0	48.3	4.8	21.1

Runoff began after 5 minutes except for conventional and reduced tillage (after 15 min).

On conventional tillage, runoff increased from 19 per cent on the summit to 29 per cent on the valley bottom proximity, the turbidity 1–3.6 g L^{-1} and erosion from 8–20 g m^{-2}. At the bottom of the toposequence, the soil moisture, the clay content and the runoff are higher than at the summit, better drained but on the other hand turbidity and erosion are lower. The turbidity and erosion remain very low for no tillage (0.3 g m^{-1} and 4 g m^{-2}), moderate for reduced tillage (1.6 g^{-1} and 21 g m^{-2}) and important for tillage

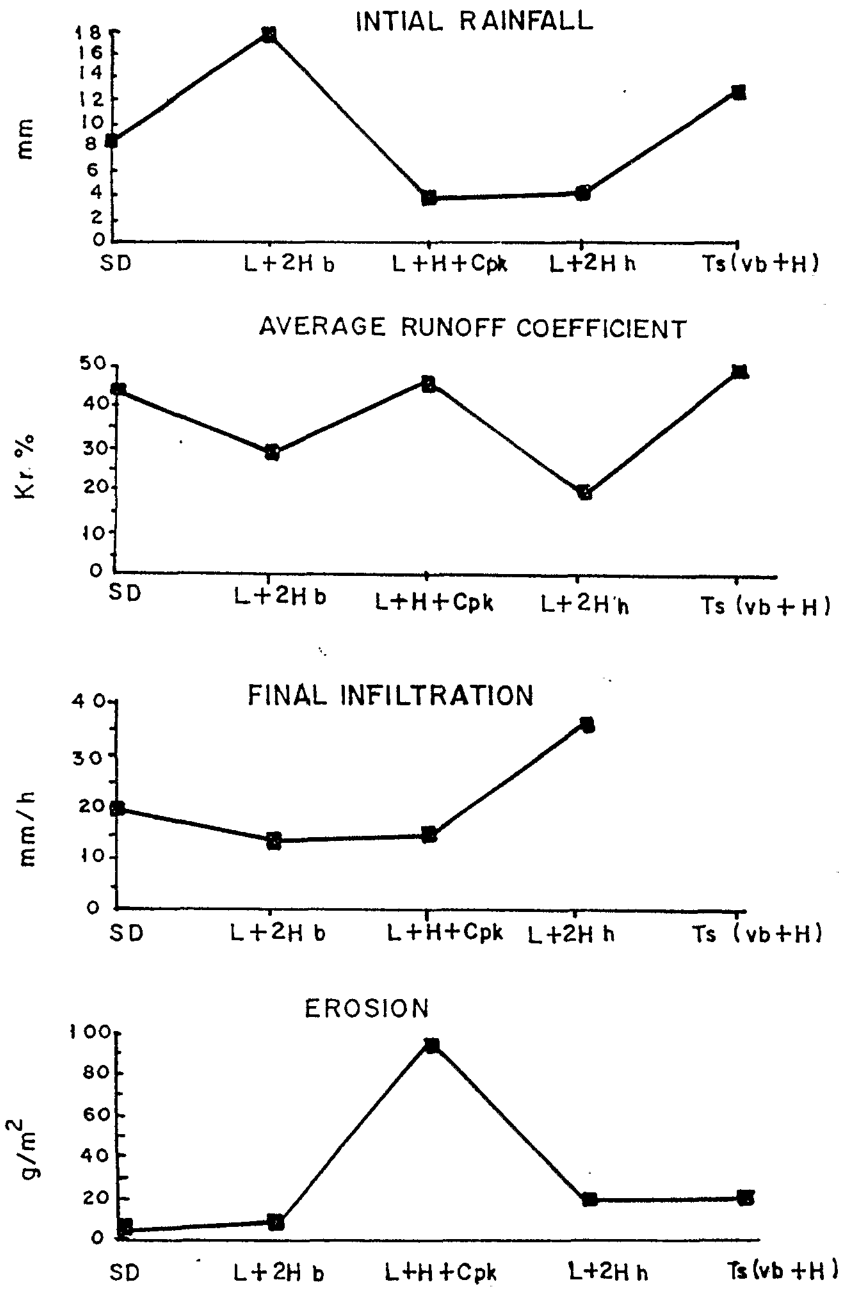


Fig. 2. 2nd Rainfall Simulation.

For the other treatments, the final infiltration capacity decreased to 10 mm h^{-1} The soil surface was still modified (<5% of open surface) and erosion was selective in clay and loam.

The third rainfall (60 mm h^{-1} during 1 hour) was simulated one hour after the preceding one.

3rd Rainfall simulation

	Initial moisture %	Pi(mm)	Kr(%)	FN (mm h^{-1})	Erosion (g m^{-2})
SD	23.1	4.2	74.7	6.2	13.6
L + 2Hb	23.0	6.5	72.2	7.9	40.3
L + H + Cpk	24.9	0.9	81.5	6.3	239.1
L + 2H h	23.1	1.5	54.4	18.7	152.1
Ts(vb + H)	25.5	5.78	1.2	1.0	37.2

The soil moisture rose to 23–25 per cent and the area covered with sealing crust was maximal. The initial rainfall before runoff was very low (1 to 6 mm). The final infiltration rate was between 8 and 1 mm h^{-1} except for the conventional tillage on the summit of the hillslope 19 mm h^{-1} because of protection by gravel

One can notice that soil moisture changed very little between the second and the third test : the significant increase of runoff was probably related to a modification of the surface condition (roughness and sealing crust). The turbidity on the other hand was more constant because the soil surface was protected by sealing crust and gravel, but erosion was higher following increase in runoff.

Runoff Simulation Data

Runoff was simulated on 20 per cent slope, 9 m-long plots with 3 treatments:

- — no-tillage on grassy compacted surface;
- — conventional tillage across the slope and rotary harrowing;
- — conventional tillage and cultipacker roller pulverizing the topsoil.

Runoff flow, velocity of the flow on the topsoil and turbidity of flow after 9 m were measured during three tests.

The results of *the first runoff simulation* test are in the following table

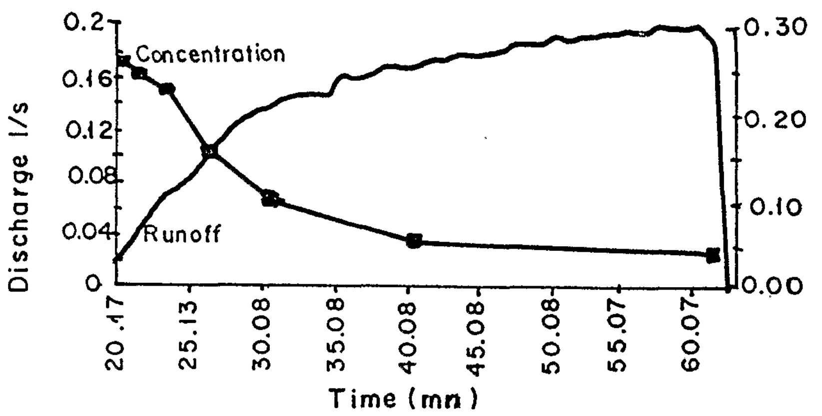
1st Runoff simulation

	Slope %	Kr(%)	Erosion (g)	Vm (m s^{-1})	Kr max %
SD	21.5	47.3	44.8	0.05	74.1
L + 2H b	20.0	Subsurface flow		(40.0)	
L + 2H + Cpk	20.0	31.9	1637.9	0.18	47.7

A flow of 0.3 L s^{-1} was given at the top of the slope, on a soil surface at field capacity (soil moisture content approximately 20%).

On the grassy "no-tillage" plot, runoff was slow (0.05 m s^{-1}) and reached the bottom after 20 min, but it took only 10 min for the conventional tillage and cultipacker pulverized plots (Fig. 3) where the velocity was 0.18 m s^{-1} just enough to initiate rills. The runoff coefficient was very high for the no-tillage plot (74%), important for the cultipacker plot (48%) and zero for the conventional tillage across the slope, but subsurface flow was observed in this case.

RUNOFF SIMULATION (SD)



RUNOFF SIMULATION (L+2H+Cpk)

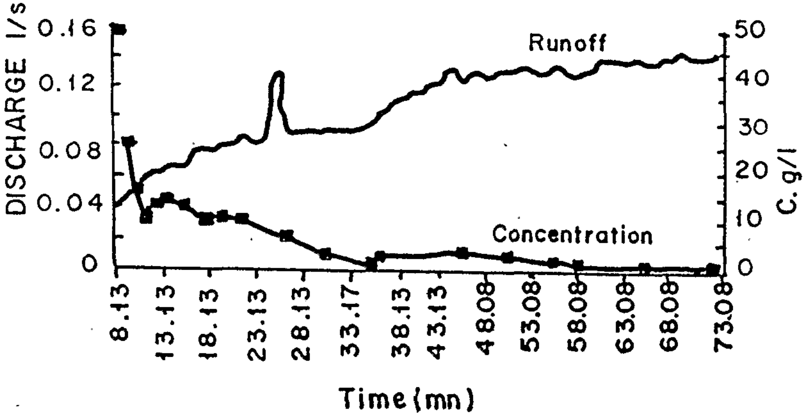


Fig. 3. 1st Runoff simultion

The sediment concentration in the runoff was almost zero for the grassy compacted surface (0.1 g L^{-1}) but large on the surface pulverized cultipacker (39 g L^{-1}): the high flow velocity concentrated on some lines (tractor traces) was able to transport aggregates and even small gravels. In this case, the erosion was 1.6 kg during a 73-minute test.

The second runoff test was made one hour after the preceding in wet topsoil situation where rills were already organized:

2nd Runoff simulation

	Slope %	Kr (%)	Erosion (g)	Vm (m s^{-1})	Kr max %
SD	21.5	63.5	0	0.05	82.0
L + 2H b	20.0	>37	Subsurface flow	51.0	
L + 2H + Cpk	20.0	51.4	518.1	0.16	60.7

The runoff velocity was about the same (0.05 and 0.16 m s^{-1}) but maximum runoff coefficient was higher (82 and 61 %). There was no runoff for conventional tillage plot but subsurface flow. Turbidity was nearly zero on grassy no-tillage plot and 2.4 g L^{-1} on the cultipacker plot for an erosion of 518 g during 25 minutes test.

The *third runoff simulation* was done after one windy and dry week.

3rd Runoff simulation

	Slope %	Kr (%)	Erosion (g)	Vm (ms^{-1})	Kr max %
SD	21.5	12.5	0	0.05	39.5
L + 2H b	20.0	>33	Subsurface flow		65.0
L + 2H +Cpk	20.0	12.0	33.1	0.17	29.9

Runoff was lower than during the second wet test (12%). The grassy no-tillage plot gave the best protection against erosion but let 40 per cent of the flow run outside the plot; this leads to risk of gullying on the adjacent plot if it is ploughed.

On the tillage and cultipacker plot, 30 per cent of the flow ran off but the aggregate stock free on the soil was eroded without splash effect and the turbidity (0.5 g^{-1}) and erosion (33 g during 37 minutes test) decreased: rills seem to be stable.

On the tillage plots, not compacted by roller, no superficial runoff was observed during 3 successive tests, though a large volume of water had been injected in the runoff simulation:

— 800 L h^{-1} during 116 minutes on 2 m wide ramp;
— 2000 L h^{-1} during 40 minutes (1 hour later);
— 1300 L h^{-1} during 89 minutes (8 days later).

The flow penetrates into the soil between clods and circulates between 20 and 40 cm just above the schist layer (or a plough pan). Progressive (10 cm for 1 min) the soil profile became wet and the subsurface flow progressed many decimetres per minute. After the end of the injection, the subsurface flow continued for a long time (86 minutes for the third test), so that the maximum subsurface runoff was up to 40–65 per cent of the flow. These values are minor because we measure the flow in a trench of 4 meters long but the total wet soil is 8 metres long. A 50 per cent average runoff coefficient is quite reasonable.

Such strong subsurface flow is in good reaction with the observation of little damp spots. This type of subsurface flow on steep slopes can be the origin of landslides and river pollution by fertilizers and pesticides.

CONCLUSION

Farmers known quite well the functioning of their landscapes, but experimental rainfall and runoff simulations have revealed the importance of surface and subsurface flow as soon as the soil are ploughed, disc-harrowed and rolled for the seedlbed.

The cultural practices indeed modify the processes (runoff or subsurface flow), significantly decrease the velocity of the flow (0.05–0.20 cm s^{-1}) and the peak flow. But it is difficult. on these thin soil covers to avoid the movement of water, nutrients and pesticides.

No tillage protects the soil surface well against erosion but the runoff flowing on the next plot may dig a gully if nothing is made to guide the excess water safely. It cannot be a safe practice as long as herbicide and pesticides are not better adapted to fight against snails.

Conventional tillage limits the losses by superficial runoff during 30–60 min. but when the soil is badly covered the topsoil surface is degraded by splash and wash so that the rugosity and a part of the water infiltration capacity are lost. As soon as soils are bare, they are affected by splash and sealing crust development, so that the positive effect on infiltration is limited except if roots, crop residues and gravel are protecting the topsoil. (case of the reduced tillage).

But worst cultural practice consist in rolling the seedbed with cultipacker: it pulverizes the clods and compacts the topsoil accelerating runoff development and soil losses.

Finally, all these cultural practices must come with supplemental measures like manuring, living hedges and grassed ditch to manage excess water.

REFERENCE

Asseline, J. and C. Valentin, 1979, Construction et mise au point d'un infiltromètre à aspersion. *Cah. ORSTOM, Sér. Hydrol. Vol.* XV, n°4, Paris.

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Volume 1

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