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Effect of cultivation techniques on the hydrodynamic and mechanical behaviour of the "Lauragais-Terreforts"

D. Boudjemline [a], E. Roose [b] and F. Lelong [c].

[a] Département d'hydraulique, Centre universitaire de Bejaia, Algérie

[b] Centre ORSTOM, BP 5045, 34032, Montpellier Cédex, France

[c] Centre des sciences de la terre, Université de Bourgogne, 6 bd. Gabriel, 21000 Dijon, France

SUMMARY

The effect of various seed bed preparations on hydrodynamic and mechanical parameters was studied experimentally by simulated rainfall on clayey-loamy soils Lauragais, which had developed on chalky molasse on a slope greater than 12 %.

The level of soaked up rain ("pluie d'imbibition", Pi) is closely connected to the inital degree of saturation of the soil ; it varies from 10 to 24 mm when the soil is humid and increases when the soil is dry (14 to 47 mm). But when the soil surface is crusted the Pi is less and seems to be no longer controlled by the degree of water in the soil. Treatments with fine structural elements show the fewest possibilities of infiltration during the soaking up stage ; thickening the seed bed does not appear to have any effect on Pi. The double packing down of the soil poses a real obstacle to infiltration.

The susceptibility to runoff is all the greater as the percentage of clods less than 0.5 cm is high. Runoff is reduced when the soil is dry and increases sharply with the intensity of the rain and superficial crusting.

The intensity of infiltration permanent regime (FN) seems better on the treatments with fairly large structural elements (from 6 to 17 mm. h^{-1}).

The thickening of the seed bed did not improve FN (from 5 to 11 mm h^{-1}). On the other hand, the double thickening of the soil is a real brake on infiltration (1 to 5 mm h^{-1}). The intensity of infiltration permanent regime drops when the intensity of the rain increases.

The average solid load is very variable, probably on account of the many "lachages" of micro-structures. It is high for the treatments with fine structural elements if the soil is dry (24 to 27 g L^{-1}) and especially if the soil is humid (19 to 41 g. L^{-1}) The average solid load is less on treatments with fairly large structures (1 to 2 g. L^{-1}). It increases sharply with the slope and appears to be independent of rainfall intensity. Treatments with fine structural elements are characterized by high solid outflows (200 to 300 g.m^2 h^{-1}). They increase sharply with rainfall intensity and the slope and drop with a low level of soil saturation.

RESUME

L'influence de diverses préparations de lit de semence sur les paramètres hydrodynamiques et mécaniques a été étudiée expérimentalement par simulation

de pluie sur les sols argilo-limoneux du Lauragais, à pente > 12 % et développés sur molasse calcaire.

La hauteur de pluie d'imbibition Pi est très liée à l'état d'humectation initial du sol ; elle varie de 10 à 24 mm lorsque le sol est humide et augmente lorsque le sol est sec (14 à 47 mm). Mais lorsque la surface du sol est encroûtée, Pi est plus faible et ne semble plus être contrôlé par l'état hydrique du sol. Les traitements à éléments structuraux fins montrent les plus faibles possibilités d'infiltration pendant la phase d'imbibition alors qu'un épaississement du lit de semence ne semble avoir aucune influence sur Pi. Le double tassement du sol représente un véritable obstacle à l'infiltration.

La susceptibilité au ruissellement semble d'autant plus prononcée que le % de mottes < 0,5 cm est élevé. Le ruissellement est réduit lorsque le sol est sec et augmente nettement avec l'intensité de la pluie et l'encroûtement superficiel.

L'intensité d'infiltration en régime permanent (FN) semble meilleure sur les traitements à éléments structuraux relativement grossiers (6 à 17 mm h^{-1}).

L'épaississement du lit de semence n'a pas amélioré FN (5 à 11 mm h^{-1}). Par contre, le double tassement du sol est un véritable frein à l'infiltration (1 à 5 mm h^{-1}).

L'intensité d'infiltration en régime permanent diminue quand l'intensité de la pluie augmente.

La charge solide moyenne est très variable à cause probablement des nombreux lachages de micro-structures ; elle est élevée sur les traitements à éléments structuraux fins (24 à 27 g. L^{-1}) si le sol est sec et surtout (19 à 41 g. L^{-1}) si le sol est humide.

La charge solide moyenne est réduite sur les traitements à éléments structuraux relativement grossiers (1 à 2 g. L^{-1}) ; elle augmente nettement avec la pente et semble indépendante de l'intensité de la pluie. Les traitements à éléments structuraux fins se caractérisent par des débits solides très élevés (200 à 300 $g.m^{-2}$ h^{-1}) ; ils augmentent nettement avec l'intensité de la pluie et la pente et diminuent avec le déficit de saturation du sol.

1. INTRODUCTION

An inquiry held next to Lauragais farmers has shown a certain number of characters relative to erosion in this region of France (1). The plots affected by erosion are often big ones (from 5 to 10 ha) having been subjected to developments such as the suppression of the slope. They are sloping (from 15 % to 30 %) and lenghthy enough (100 m) and according to the farmers, they are well prepared in spring, ie the seed-bed was relatively thin. The most sensitive months are April, May and June, ie during spring rainstorms. The cases of erosion are very evident : destroyed seedlings, packed ditchs. Following this inquiry, it has been decided to undertake a study using rainfall simulator for delimiting the parameters relative to the release of the surface runoff and its sediment load on the one hand, and to compare the effect of the different cultivation techniques on the other hand. Previous works (2 - 3 - 4) have really shown the role of the soil surface and the mechanical and structural characteristics of horizon surface on the susceptibility of the soil to runoff and erosion.

2. FIELDS AND METHODS

The Lauragais occupies the eastern part of the Haute-Garonne department, near Toulouse (Fig. 1). It is a multivarious farming region where predominate cereal cultivations : they are characterized by the rotations of winter farming (wheat, barley, colza) and summer farming (maize, sunflower...). The soils are brown-limestone, clayey-loamy and sandy. They are referred to as "TERREFORTS" (local appelation which evokes heavy clayey-limestone soils).

The average altitude is lower than 300 m and the drainage density is important (3 km/km^2). Slopes cartography shows that 45 % of slopes are upper than 18 %.

The Haut-Garonnais Lauragais climate is intermediate between the Mediterranean and the oceanic tendencies .

The field experimentation was held at the scale of 1 m^2 experimental plots using an ORSTOM (Fig. 2) type rainfall simulator which is well described by the way (5), and able to provoke rainfalls with an intensity varying between 30 and 150 mm/h. A guard ring whose the surface depends on the jet balancement angle, surrounds the testing plots.

Two series of tests have been made :

- A first series on 13 to 20 % slop, aimed to show :
  * The influence of an over-flowing water table or a soil surface state fastned to seed-bed preparation,
  * The role of the packing down of the soil by the machine wheel,
  * The influence of the seed-bed thickness,
  * The role of the clods size of the seed-beds,

- A second series of tests on 2 to 5 % slope aims to study the effect of intensity rainfall on hydrodynamic and mechanical parameters of the soil.

The experimental field situated in Narbons, has been ploughed at 30 cm depth after the sunflower harvest. The plough has been resumed in spring to obtain the following seed-beds :

N1 and N5 : normal plough + seed-bed at average clods.
N2 : plough packed down once + seed-bed at relatively big clods.
N3 : plough packed down twice + seed-bed at relatively big clods.
N4 : like N1 and N5 but with a thicker seed-bed.
N7 : normal plough + seed-bed with very fine clods + big clods addition.
N8 : normal clough + seed-bed with very fine clods (roll).
N2b : plough packed down once + seed-bed with very fine clods (rake).

The thickness of the seed-bed is about 8 cm for all the treatments except the N 4 one which has a more thick seed-bed (about 15 cm).

From study of the climate,which has shown danger of spring rainfalls, it has been decided to simulate rainfalls of 40 mm/h, of the annual frequency, for the first series of tests. For the second series, we have simulated three levels of rainfalls intensity (40,50 and 80 mm/h). The results of each test are represented by a discharge hydrograph and a turbidity hydrograph defining Pi, ti, Fn, Rx... (Fig. 3).

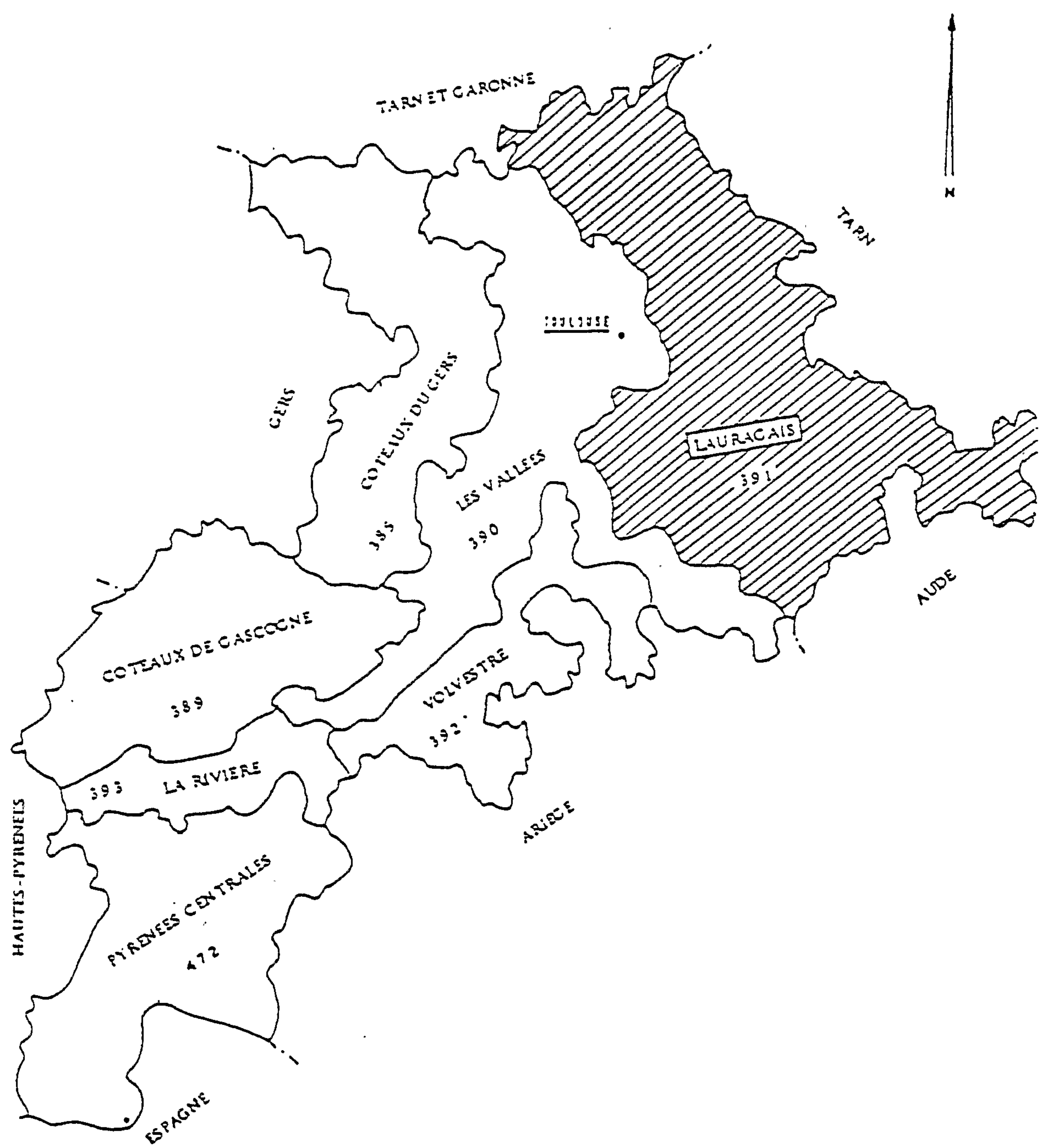

Figure 1. Situation of the Lauragais in compare with the other farming regions of Haute-Garonne.

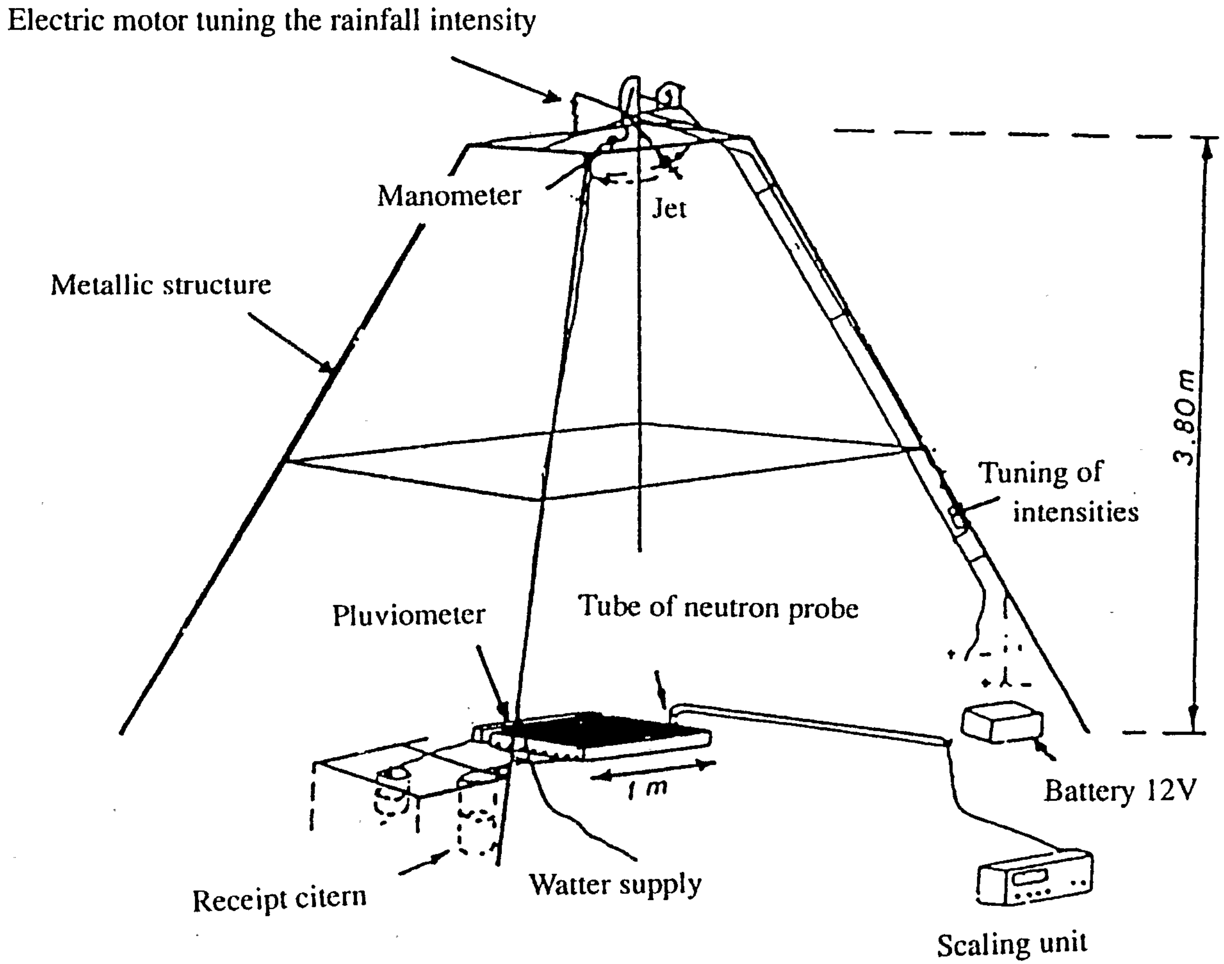

Figure 2. Schema of the rainfall simulator, ORSTOM type.

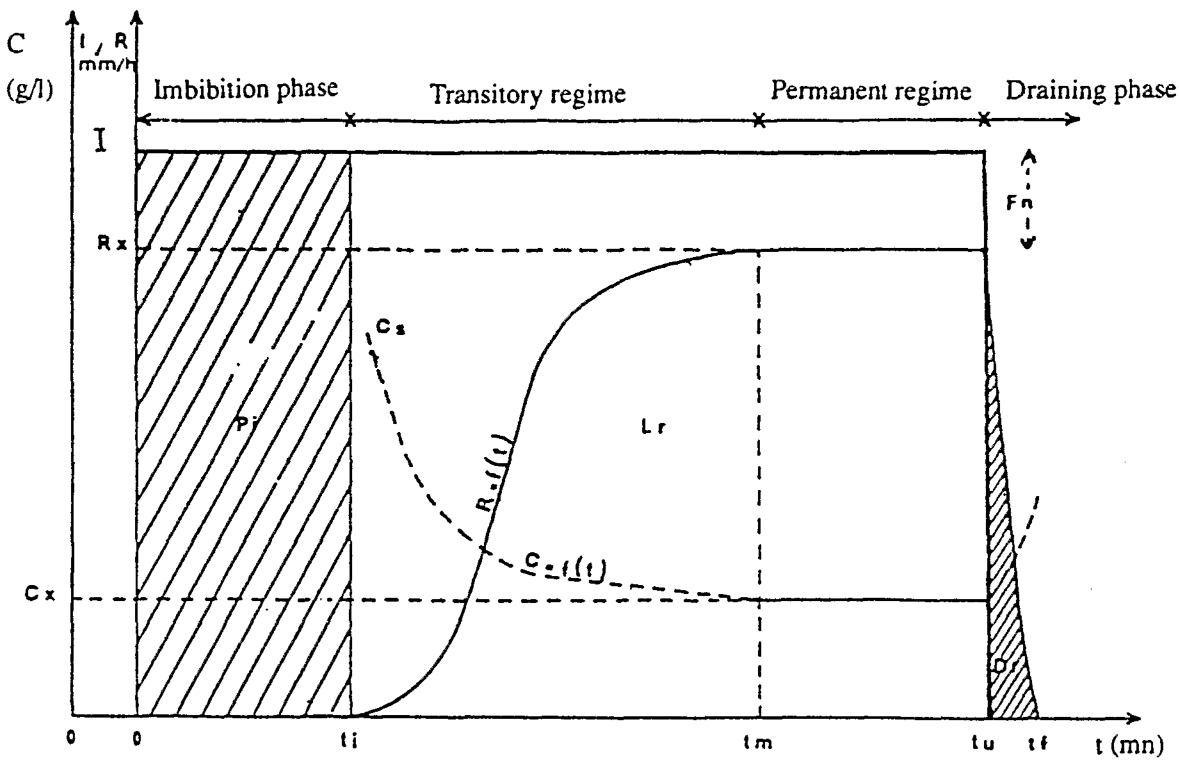

Figure 3. Theorical hydrograh of runoff and turbidigraph under constant rainfall intensity.

3. RESULTS

3.1 The level of soaked up rain,Pi.

The level of soaked up rain is closely connected to the initial degree of soil saturation when the soil surface is not degraded. The relation obtained between Pi and the descriptive factors and variables of surface states :

Pi = 45.5 - 0.3 D + 0.2 i - 1.1 S + 1.4 C.

D : rate of clods with a diameter inferior to 0.5 cm.

i : soil saturation deficit.

S : slope of field.

C : rate of culture residue.

Even if it explains only 60 % of the variations of Pi, this relation shows that in order to delay the runoff, it is desirable to avoid the seed-bed from crumbling, to ameliorate the soil water movement and to cover it with culture residue.

3.2 The runoff

The results of runoff (Tab. 1) allow to distinguish two phenomena :

a/ The packing down by the machine wheels : the "terreforts" of Lauragais are not much sensitive to the packing down ; were needed two passages tractor wheels to have a clear reaction vis-a-vis the runoff. The Proctor test confirms that the soils of Lauragais are not very compressible.

Table 1
Experimental parameters of the relation $\sum Lr = A+B (\sum Pu)$

Plots code	A	B	r	n	Depth of runoff observed for a 40 mm rainfall	Depth of runoff calculed for a 40 mm rainfall
N1-1	- 6,30	0,12	0,99	8	0,0	0,0
N1-2	- 13,90	0,38	0,97	21	1,7	1,6
N1-3	- 14,60	0,60	0,98	20	8,5	9,4
N1-4	- 8,77	0,71	0,98	18	19,7	19,6
N2-1	- 10,88	0,80	0,99	11	21,5	21,1
N2-2	- 9,05	0,64	0,99	11	17,5	16,5
N2-3	- 10,60	0,55	0,99	18	10,5	11,4
N2-4	- 17,80	0,80	0,99	11	14,5	14,2
N3-1	- 4,90	0,82	0,99	28	27,5	27,9
N3-2	- 4,40	0,85	0,99	20	30,0	29,6
N3-3	- 5,48	0,75	0,99	25	24,6	24,5
N3-4	- 10,10	0,88	0,99	15	25,3	25,0
N4-1	- 10,20	0,46	0,98	21	7,0	8,2
N4-2	- 13,90	0,68	0,99	25	12,3	13,3
N4-3	- 13,50	0,61	0,98	24	10,0	10,9
N4-4	- 20,40	0.54	0,98	38	1,8	1,5
N5-1	- 21,40	0,57	0,98	19	1,7	1,4
N5-2	- 10,30	0,67	0,99	13	16,6	16,5
N5-3	- 12,50	0,49	0,99	26	6,0	7,4
N7-1	- 10,20	0,58	0,99	28	12,1	13,0
N7-2	- 13,88	0,62	0,99	29	10,0	10,9
N7-3	- 11,40	0,58	0,99	27	10,5	11,7
N7-4	- 10,70	0,50	0,99	19	8,8	9,3
N8-1	- 10,50	0,56	0,99	26	10,8	11,9
N8-2	- 9,50	0,59	0,99	26	13,6	14,4
N8-3	- 12,20	0,62	0,99	29	12,0	12,6
N8-4	- 9,10	0,73	0,99	29	19,8	20,1
N2b-1	- 29,40	0,58	0,99	28	0,0	0,0
N2b-2	- 16,10	0,60	0,98	20	6,7	7,9
N2b-3	- 13,00	0,78	0,99	16	18,0	18,2
N2b-4	- 9,50	0,52	0,99	19	10,6	11,3

r : Correlation coefficient
n : Size
A and B : Experimental parameters

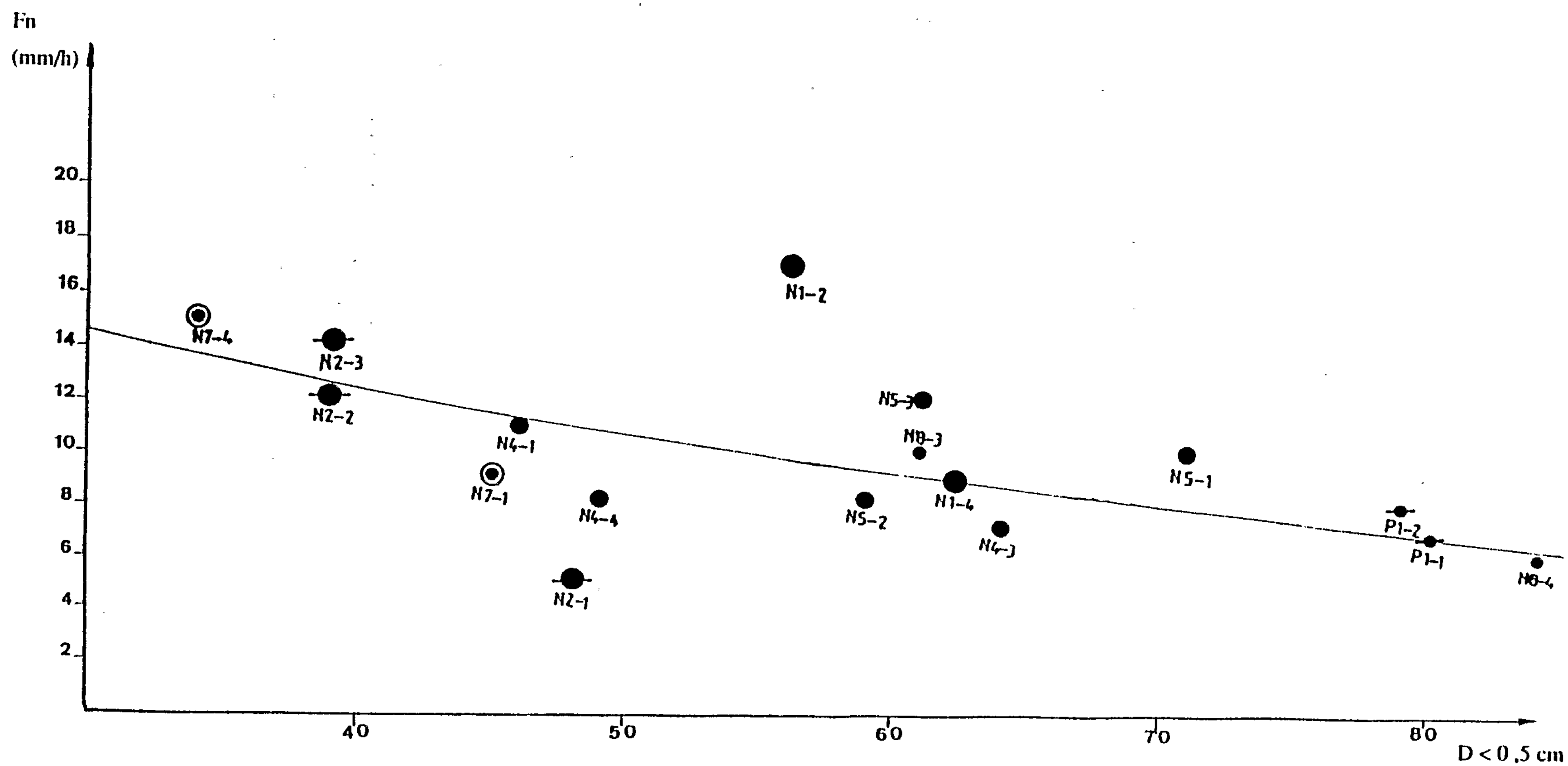

Figure 4. Evolution of Fn with the rate of clods inferior to 0,5 cm.

b/ The susceptibility of the soil to runoff (represented by the experimental parameter B of the relation Lr = f (Lr Pu), with : Lr = cumulated depth of runoff and Lr Pu = cumulated depth of rainfall,increases with the rate of clods with a diameter inferior to 0.5 cm ; it decreases slighthy when the index of roughness increases.

c/ In the various slopes studied (from 13 to 20 %), the slope does not have a clear and a significant effect on the susceptibility to runoff of the different treatments. The slope is probably not the 221explanatory factor to runoff, at least at the scale of 1 m plots.

3.3 The infiltration

We will be interested particulary in the intensity of a minimal infiltration with a permanent regime, Fn. Fn seems to be influenced by the percentage of clods less than 0.5 cm (Fig. 4) as well as by the index of roughness IR (Fig. 5), at least for plots without an intense packing down (treatment N3).

3.4 Influence of rainfall intensity on hydrodynamical parameters

The influence of the rainfall intensity on hydrodynamical parameters (Pi,Rx and Fn) has been studied on weak slope plots (from 2 to 5 %) with identical surface state (Tab. 2), with ta = time separating two successive storms. Table 2 shows that despite the disparity of the results, Pi and Fn tend to decrease when the rainfall intensity increases.

Table 2
Variation of hydrodynamics parameters function of rain intensity

Plots	I mm/h	Slope %	ta h	Pi mm	Kr 40 %	Fn mm/h
P1 to P3			1	12-16	25	
P4	40	2-5	24	24	2	4-24
P6			114	38	0	
P7 to P8			1	10-14	20-37	
	50	2-3				9-13P9
P9			144	25	5	
P12 to P13			1	9	22-53	
P10	80	4-5	16	13	19	4-6
P11			120	16	28	

3.5 The exportation of sediments

At the scale of 1 m plots, we measure only the sheet erosion which results from the detachability of particles by the "splash effect" of rainfalls ones which, in their turn, are driven by the runoff. We consider two variables :

* The average concentration,Cm (g/l) of solid particles in the runoff volume.
* The sediment discharge (g/m /h), exported from the plot.

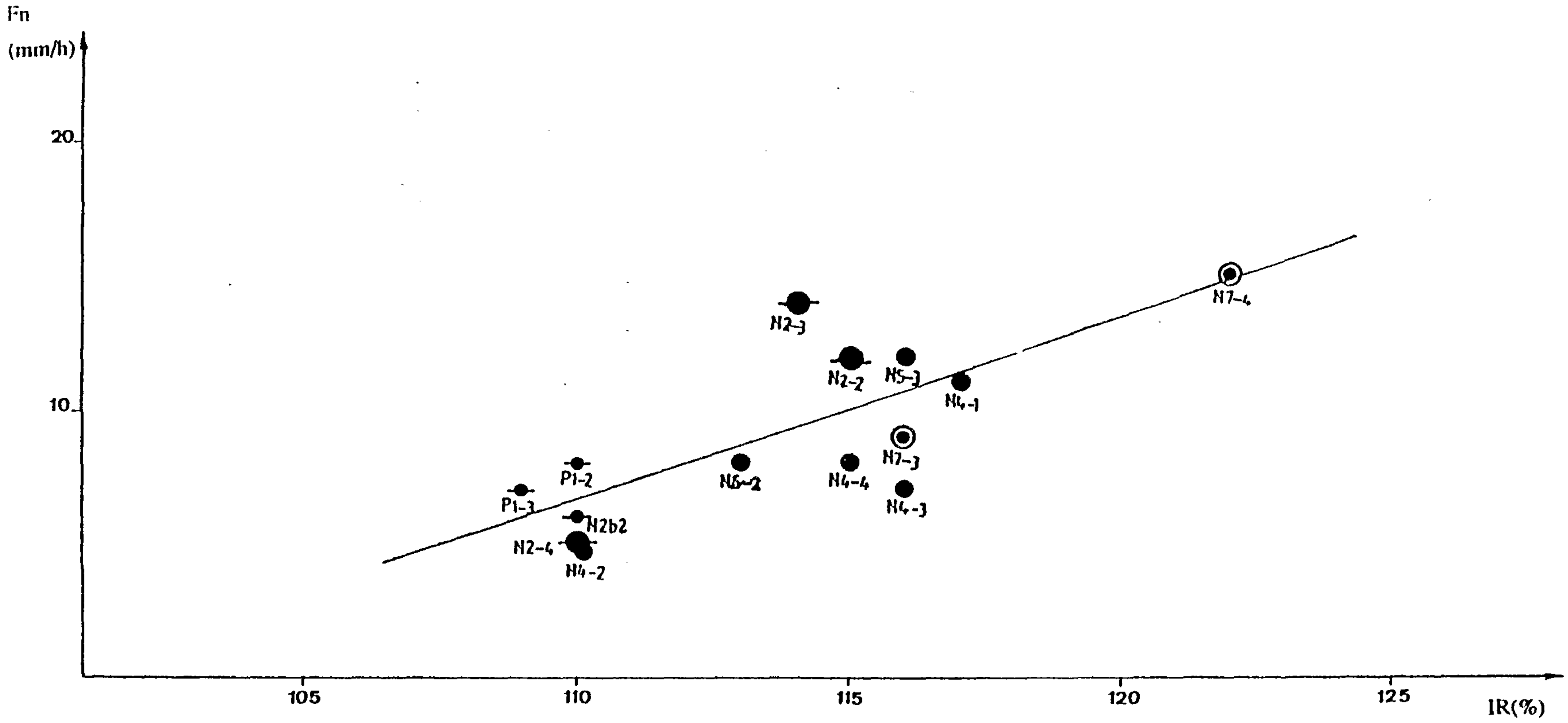

Figure 5. Evolution of Fn with the index of roughness.

3.5.1 The average concentrations,Cm,

The average concentrations increase sharply with the rate of clods less than 0.5 cm (Fig. 6) ; they also increase with the soil slope (Tab. 3) and are four to five times higher when we move from 2 % to 15 % slope soil.

Table 3
Slope influence on mean solid charge and solid debit for 40 mm rainfall during one hour

Pente %	Solid charge C_{40} g/l	Solid debit Qs_{40} g/m^2/h
2	0,0-2,9	0,0-29
15	0,0-13,6	0,0-175

3.5.2 The sediment discharges

The sediment discharges are three to five times higher when we move from 15 % to 2 % slope plots (Tab. 3). Then it tends to increase with very fine seed-beds (Tab. 4) and increase very quickly with the intensity of storms.

Table 4
Treatments influence on runoff, solid charge and solid debit for a 40 mm rainfall during one hour (15% slope)

Treatment	Kr_{40} %	C_{40} g/l	Qs_{40} g/m^2/h
Mean (N1,N4,N5)	0-30	0-8	0-75
Mean,packed down once	27-36	5-13	70-220
Mean,packed down twice	60-75	2-9	48-257
Fine + big clods addition	22-30	7-19	90-170
Fine + roll	27-50	2-20	23-280
Fine + rake	0-45	0-14	0-175

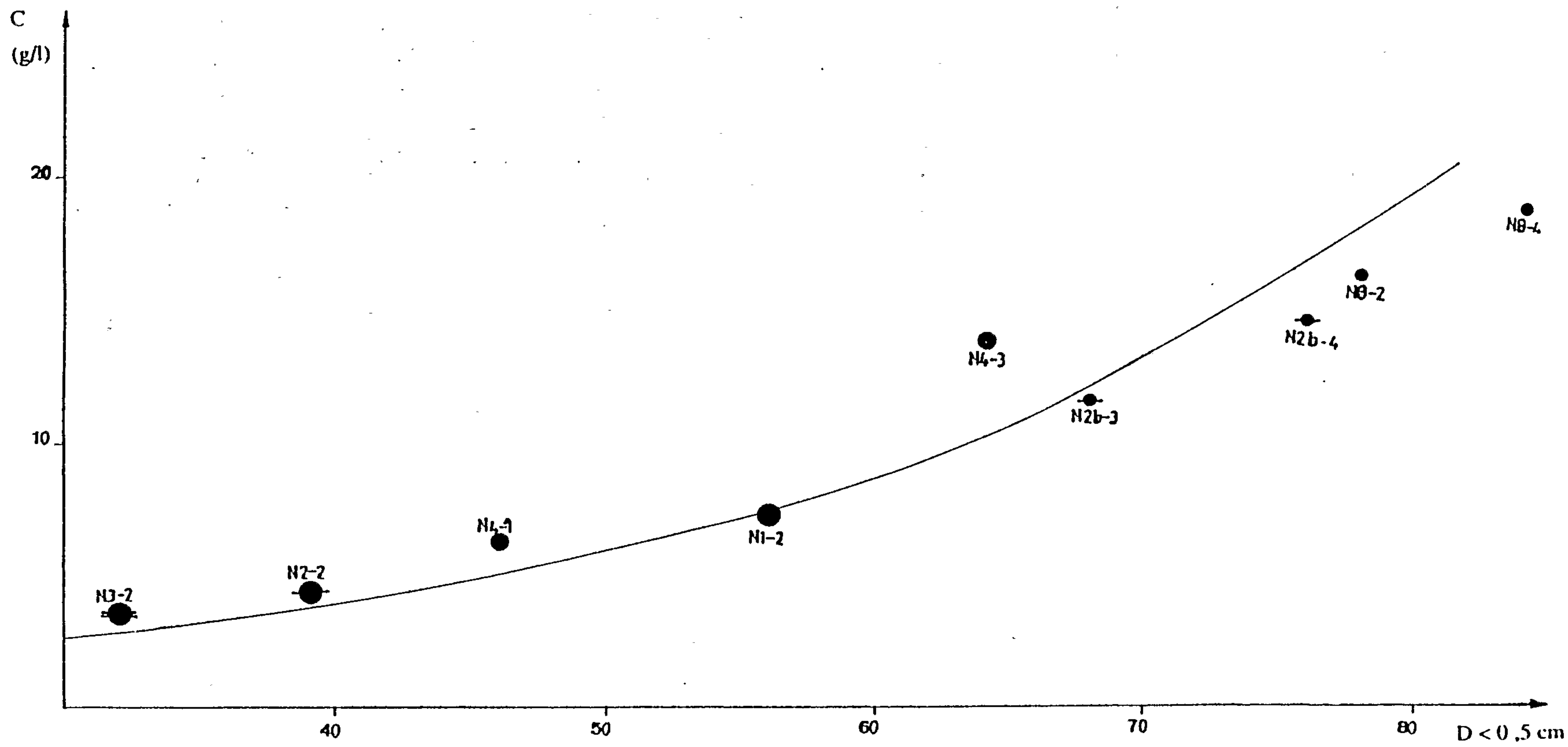

Figure 6. Evolution of the turbidity with the rate of clods at diameter inferior to 0,5 cm.

4. DISCUSSIONS

4.1 Hydrodynamical aspects

The previous results show clearly the role of surface state and size clods of seed-beds (from 5 to 15 cm), on the susceptibility to runoff. The runoff is more precocious (Pi decreases) and more intense (Rx increases) when the percentage of fine clods (diameter inferior to 0.5 cm) increases and when the index of roughness decreases. On the other hand, the slope soil does not seem to have a clear effect on the runoff intensity. Authors notice effectively various answers (positive or negative effects of the slope soil on Rx) according to the studied cases :

For Zingg (6) ; (7 - 8 - 9 - 10), the runoff increases with the slope. For the others, (11 - 12), it rather tends to decrease with the slope increase. Roose interprets this fact as the result of the partial removal of the figle packed down by the sheet erosion when the slope increases.

The intensity of storms influences both the soaked up rain duration and the intensity of runoff. The decreasing of Pi and the increasing of Rx when the rainfall intensity (I) increases, justify the big increase of the runoff coefficient of storms, with the same increasing intensity duration.

Although its dispersed, the relation Fn = f (I) is decreasing, as it has been observed elsewhere (13) on bare and deteriorated soil plots, liable subjected to a packing down and or to the formation of surface crust under the influence of rainfalls energy. The soil capping phenomenon has been analyzed by Boiffin (14). It unwinds in several phases : The desintegration of soil aggregates gives first structural crusts during the soak up rain phase by the padding of micro-depressions, then it gives a stratified sedimentation crusts in the puddles the crusts whose thickness depends on the mobilized soil mass. This phenomenon which provokes an important reduction of the structural porosity, thus of the hydraulic conductivity of soil surface, is then controlled by the desintegration of the aggregates, the detachability of particles and by the redistribution (training and redeposit) of these ones in the topographic micro-depressions. It is logical that the more rainfall intensity increases, the more kinetics energy necessary for desagregating the soil and provoking the closing of this one, increases as Moldenhauer and Long (15) observe it. In this way, we can explain the existence of the relation Fn = f (I) decreasing on soils with surface crusts, when we simulate storms with increasing intensity (13). We call back that according to Lafforgue (16), the increasing relations Fn = f (I) correspond to rough surfaces with heterogeneous permeability, and constant relations Fn = f (I), to smooth surfaces with homogeneous permeability.

4.2 Mechanical aspects : detachment and particles transport

The previous results show that the refinement of the seed-bed favours the detachability of the particles, thus, the release of these ones redistributed near at hand or exported. The exportation increases with the slope, as observed by Wischmeier and Smith (17) and Hudson (18), for the latter increases the speed of runoff flow and its competence of transport, even though this speed remains weak for 1m slope length (from 2 to 6 cm/s) according to Bryan (19) and Valentin (20), at the same time that it decreases the roughness efficiency (21) ; moreover it increases with rainfall intensity, for it acts on both rainfall (22) and on runoff discharge, thus on transport capacity (18). In short,the rainfall intensity acts on the detachment and the release of the particles, whereas the runoff intensity acts on their transport and exportation. The leveling up of the soil and the formation of surface crusts lead a partial or a total closing of the structural porosity, thus to a relative impermeabilization of soil surface (in addition to a certain mechanical stabilization of superficial film).

So, the evolution of the hydrodynamical properties noticed at the scale of 1m plots during the tests appears to be more of the consequence than of the cause of the variations of the mechanical properties of the soil. But at the scale of flank, where the concentration of the sheet flow releases the formation of channels and gullies, it is the clipping of the soil by runoff flow which is the principal cause of erosion where as the sediment transports related to these incisings are only the consequence.

4.3 Order of greatness of sheet erosion

The sediment discharges measured in the lower part of a stream of plots are rather tests of detachability at the scale of 1m than field erosion assessments, for the cumulative effect of slopes and the important spacial heterogeneity of soil are not taken into consideration. However, if we extrapolate at the scale of the hectare, the values obtained on plots (Tables 3, 4 and Tab. 5) vary with a factor 1 to 20 according to the soil slope, the soil treatment and the storms intensity. They are of 0.2 to 2 t/ha order on a thin slope (2 %) for a 40 mm/h storm intensity during one hour (storm with annual probability occurrence in the Lauragais). They are from 2 to 5 times more important for 15 % slope and they increase quickly for more important rainfall intensities. Knowing that the acceptable load sediment doorstep is from 1 to 2 t/ha/year, we understand that the optimization of the cultivation pratices (preparation of seed-beds, supply of culture residue and the ploughing calendar) is an essential aspect for the management of these soils.

Table 5
Influence of rainfall intensity on runoff and solid debits (40 mm rainfall with different intensities

I mm/h	Kr_{40} %	Qs_{40} $g/m^2/h$
40	0-26	0-29
50	5-37	4-35
80	19-53	15-209

5. CONCLUSION

The susceptibility to runoff and erosion of the soils of Lauragais seems to depend heavily on the soil surface state and notably on the preparation of seed-beds. The refinement of these ones favours the speed of desintegration of soil surface and the release of the particles which are redistributed under the form of a superficial film, not very permeable. The degradation of the structural properties of this film seems to control the decrease of the infiltrability, the increase of sheet runoff and transport capacity of this one.

For reducing the loss soils caused by this form of erosion, we can have to :

- reduce "splash effect" of rainfall : supply of culture residue.

avoid of refinement of the seed-bed, for it is the fine structural elements which are sensitive to the desintegration and "splash effect".

- favour the soil water movement of soils by avoiding as much as possible the packing back caused by the repeted passages of the cultivation machines.

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On-site and Off-site Damages by Erosion in Landscapes of East Germany

M. Frielinghaus and R. Schmidt

ZALF Müncheberg, 0-1278 Müncheberg, Germany.

SUMMARY

Off-site damages by soil and nutrient inputs into waters, hollows, and wetland biotopes are increasingly in addition to the long-known damages on crop areas caused by erosion. Up to 11 per cent of the calculated N input per year and 58 per cent P input per year into running waters are attributed to erosion.

First results have been achieved about on-site and off-site damages in the 169 km² catchment area of the Lake Uckersee in the East - German young moraine area.

The Lower Lake Uckersee drains via the Prenzlau weir into Ucker River discharging into the Stettiner Haff (the lagoon opening into the Bay of Pommerania) after having flown 63 km through a catchment area of 2.420 square kilometers.

The off-site damages have become evident by the fact that the water quality of the Lower Lake Uckersee decreased by one class and has been classified into class 3 now (eutrophic waters). The total load of the lake was in 1990 : 5,118 kg orthophosphate, 9,978 kg total phosphorous, 189,197 kg inorganic nitrogen.

RESUME

A côté de dégâts "in situ" il existe des risques associés qui affectent les eaux et augmentent les dangers d'entrophisation. Pour 1 tonne de sol : 3,1 à 23 kg de carbone, 0,3 à 1,3 kg d'azote, jusqu'à 0,5 kg de phosphore soluble et l'équivalent en potassium sont exportés. Dans le cas particulier des sols sur moraines la perte de particules fines < 0,0063 mm est aussi importante pour la fertilité des sols que le transport de sédiment intervenant lors des orages et des phénomènes éoliens. Il est donc nécessaire d'envisager la protection des sols dans un schéma global d'aménagement.

Concernant les dégâts "in situ" les premiers résultats ont été obtenus dans le bassin de 169 km² du Lake Uchersee dans une moraine récente de l'Allemagne orientale.

Le Lower Lake Uchersee s'écoule via Prenzlan dans Ucher River, se déchargeant dans le Stettiner Haff (lagon s'ouvrant dans la Baie de Pouréranie). Les dégâts sont devenus évidents au niveau qualité de l'eau du Lower Lake Uchersee qui a été déclassé de 1 à 3 maintenant (eaux eutrophiques). En 1990, la charge totale du Lac était : 5,118 kg d'orthophosphate, 9,978 kg de phosphore, 189,197 kg d'azote.