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# Some laboratory techniques for investigating land erosion

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ABSTRACT The reaction of material to an increase or a decrease of water content and the corresponding changes in consistency are fundamental plastic properties of the stability of topsoils and subsoils. Therefore, consistency indices, such as the plasticity index Ip and the proposed index $C_{5-10}$ are useful in landslide and crustability risk assessments. Several arguments have been discussed in favour of the use of flume experiments to evaluate the erodibility of topsoils under severe rainstorm conditions. The discussion takes into account recent progress in the understanding of rill erosion.

Etudes de laboratoire concernant l'érosion des sols
RESUME La réaction des matériaux des sols à un accroissement ou à une diminution de la teneur en eau et le changement de leur consistance qui en résulte constituent une propriété plastique fondamentale concernant la stabilité des sols. Ainsi il a été constaté que l'indice de plasticité Ip et l'indice de consistance proposée $C_{5-10}$ sont utiles pour prévoir respectivement les glissements de terrain et la formation d'une croûte sur les sols par l'effet de battance des pluies. On traite de l'évaluation de l'érodibilité des sols sous des conditions spécifiques de pluviosité extrême, et on présente certains arguments en faveur de l'application de recherches en laboratoire, utilisant des canaux jaugeurs expérimentaux de dimensions réduites. Cette discussion tient compte de progrès récents dans la connaissance des modalités de l'érosion par le ruissellement concentré dans les rigoles d'érosion.

## INTRODUCTION

The Laboratory for Experimental Geomorphology in Leuven focusses research on the proper analysis of the processes of erosion and sedimentation. But in the last few years attention has also been paid to soil erodibility prediction, testing related indices which are not taken into consideration in a "white box analysis" of the processes. The question also emerged as to how far laboratory rainfall simulator experiments on flumes are useful in the prediction of soil erodibility. In this paper no definite opinion is put forward about the complex flume problem but several arguments in favour of flume experiments are discussed.

## THE PREDICTIVE VALUE OF CONSISTENCY INDICES

*Slope stability and the plasticity index Ip*

The way remoulded, cohesive, plastic soils react to an increasing or decreasing water content is manifestly correlated with their relative resistance to mass movements. Therefore the states of consistency, called the Atterberg limits, have been taken into consideration when discussing slope stability in the Brazilian Serra do Mar (De Ploey & Cruz, 1979) and in a Belgian hill region (Declercq, 1972). The coastal mountain range in southern Brazil has been frequently ravaged in recent times by massive planar slides, stripping off loamy sandy regoliths, developed on crystalline bedrocks. Microslumping and macroslumping are and were active on slopes in central Belgium underlain by Tertiary clays and sands.

Shear strengths of samples from both areas have been measured in the field and in the laboratory. Direct drained shear tests have been carried out in the laboratory for water contents, near field capacity. From these measurements resulted values of the angle of internal friction $\phi^1$, which is the main factor of shearing resistance. It was found that the $\phi^1$ values are negatively correlated with the plasticity index $Ip = w_l - w_p$ ($w_l$ is the water content of the liquid limit; $w_p$ is the water content of the plastic limit). As shown by Fig. 1 the negative relation

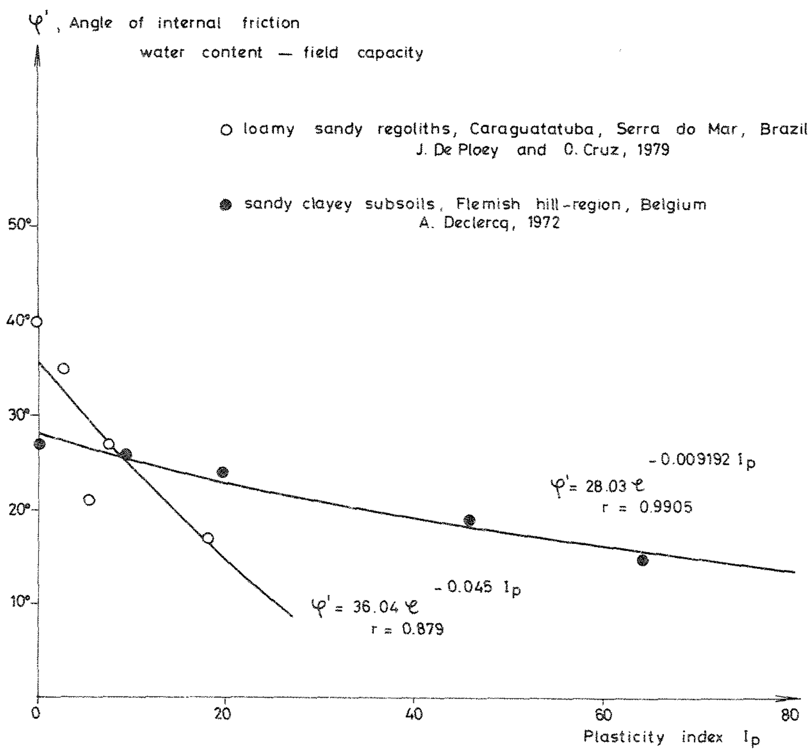


**Fig. 1** Relationship between plasticity index and angle of internal friction.

can be expressed by the general equation

$$\phi^1 = a\ e^{-b\ Ip}$$

According to Terzaghi & Peck (1967), $\phi$ for normally loaded clays, whether in a remoulded or an undisturbed state, is negatively related to the plasticity index. We found that this is also true for loamy sands and loams, with clay content varying between 5 and 50%. Of course there is a scattering from the $\phi^1$-Ip curve which Bjerrum & Simons (1960) estimated for clays to be of the order of 5°. But the scattering may be less important for sandy material than for clays, taking into account the possible mineralogical differentiations of the latter and their impact on strength and plasticity. Therefore, the plasticity index is considered, within the scope of a regional survey on slope stability, as a useful tool for landslide hazard assessment. This will be especially true for areas with marked pedological and lithological variations. It is important that the Ip tests are simple, well standardized and time-independent. The latter is not the case for shear strength measurements in the field which are always dependent upon temporary changes in hydrological conditions.

*Topsoil crusting and a consistency index $C_{5-10}$*

Crusting of loamy and sandy soils is a universal effect of rain-drop impact, promoting runoff and slope wash. Surface sealing and wash losses are widespread in different farmland areas of Belgium. Since 1975, systematic observations have been made on the evolution of winter corn fields during periods from autumn to the beginning of spring (March-April). First the relationship between the degree of crusting, estimated at the beginning of the spring, and the Atterberg limits, was tested. Fields were classified according to the increasing percentage of sealing of their total surface. It was found that neither the plastic limit $w_p$ nor the plasticity index Ip offered a distinctive parameter, but the shape of the liquid limit curves, constructed in order to define $w_l$ by interpolation, presented a discriminative criterion (De Ploey, 1977, 1979, 1980; De Ploey & Mücher, 1981). The upslope part of the liquid limit curves, in the range of low consistencies (at high water contents) is steeper for stable than for unstable soils. A distinctive parameter for all soils was found to be the so-called consistency index $C_{5-10} = w_5 - w_{10}$, in which $w_5$, $w_{10}$ are the water contents, for which the two sections of a pat of soil in the Casagrande cup touch each other over a distance of 1 cm, after respectively 5 and 10 blows. The crustability is definitely negatively related to the consistency index $C_{5-10}$, as is shown by Fig. 2 which is based on recent observations and measurements by De Smet (1979), Massy (1980) and Dewever (1980). The fact is that relatively stable soils, with a low crustability, absorb more water to lower their consistency and to become liquified than unstable topsoils. This is expressed in the liquid limit test by the difference $w_5 - w_{10}$.

We saw that the consistency index $C_{5-10}$ was most closely related to the sum of the percentages of clay + 5 times the organic matter content (Fig. 3). This supports the observation

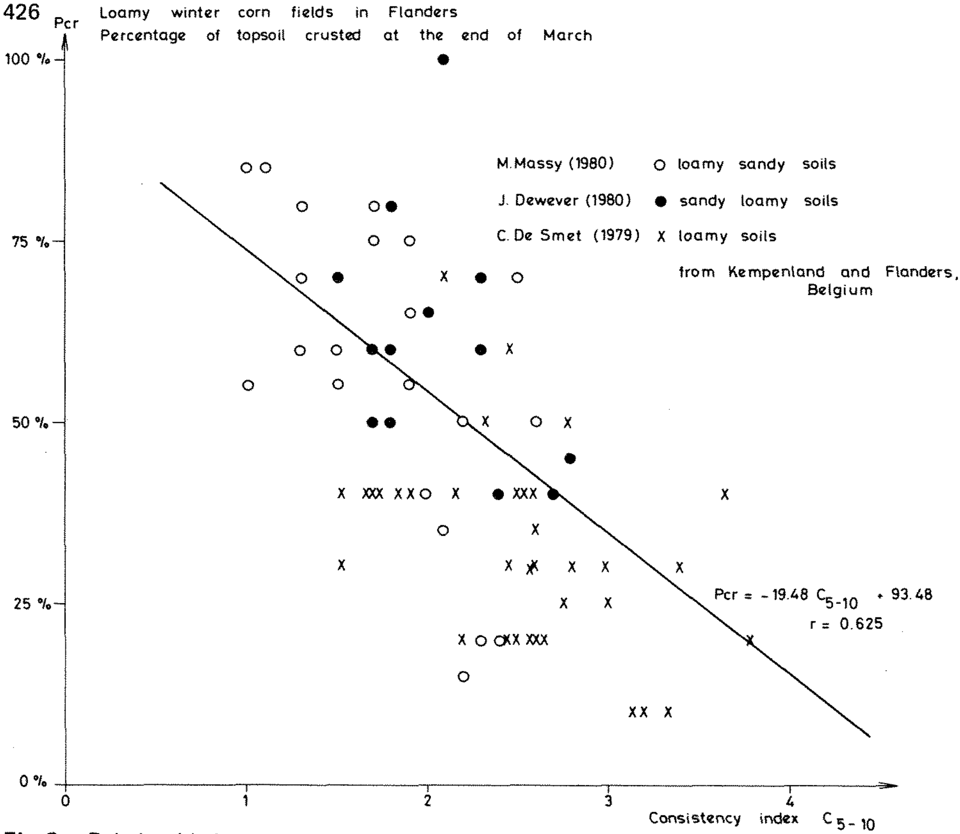


**Fig. 2** Relationship between consistency index and crustability index.

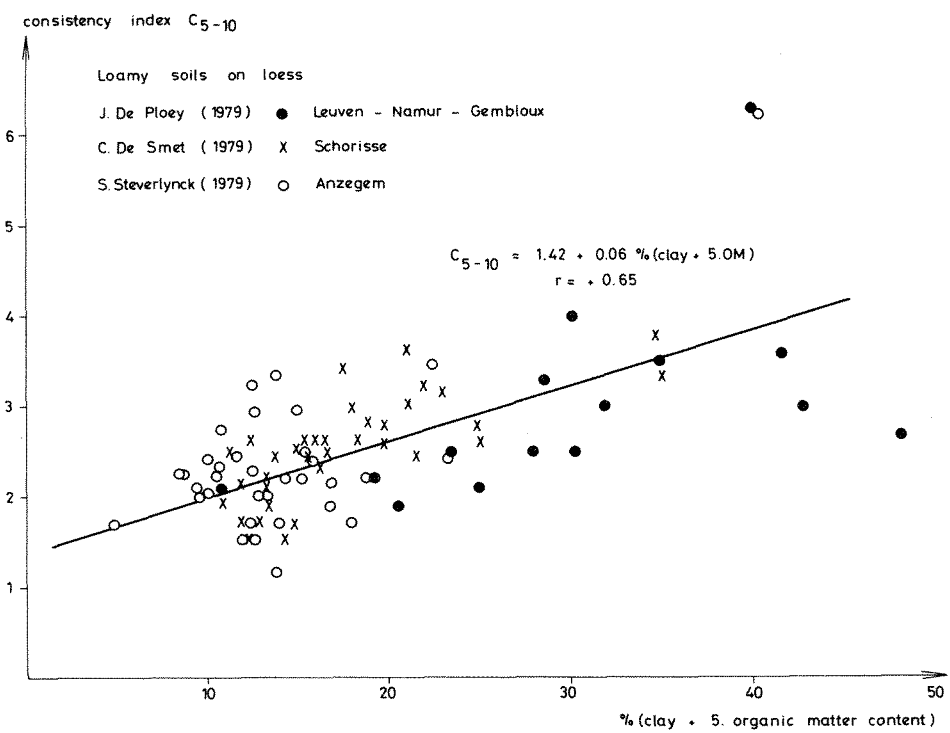


**Fig. 3** Relationship between percentage of clay + 5 times the organic matter content and consistency index.

that organic matter plays a dominant role in aggregate and topsoil stability, especially when the clay content is relatively low (Baver *et al.*, 1972; Remy & Marin-Laflèche, 1974; Hartmann & De Boodt, 1974).

Crusting is often the origin of runoff generation and soil loss. Therefore the $C_{5-10}$ index must be considered a rough parameter for erosion risk assessment, although it should be kept in mind that crustability and erodibility are not necessarily parallel properties of topsoils. From observations on farmland in the loamy areas of central Belgium it was generally found that global crusting and subsequent wash and colluviation characterize topsoils with a value of $C_{5-10} < 2$. Less than 50% of the total surface of winter corn fields, having soils with $C_{5-10} > 3$, were sealed at the end of March. Basal colluviation, the result of sheet and rill wash, was almost absent in these fields.

The plasticity index Ip and the consistency index $C_{5-10}$ are similar in that they are the expressions, in standardized tests, of the impact of the changing water content on the consistency of remoulded soil material. Landslides and crusting of topsoils are also similar phenomena in so far as they occur at a stage of lowered consistency, when the internal resistance of the material is overcome by forces (gravity, raindrop impact) that tend to deform or rupture the soil structure. This explains why the consistency indices are useful tools in landslide and crusting hazard assessment.

## FLUME EXPERIMENTS ON THE ERODIBILITY OF SOILS

The universal soil loss equation (USLE) of Wischmeier & Smith (1962) has been developed to predict long term average annual soil loss from a given field slope under specified land use and management conditions. Discussing the design and limitations of the formula, Wischmeier (1976) warned against misuses of the parametric model, i.e. using it to predict specific soil loss events. So the equation is not designed to predict soil losses during specific rainstorms or rainy seasons when extreme, temporal fluctuations affect the factors in the equation.

The evaluation of infrequent extreme conditions can be tested by erosion plot measurements in the field. But this becomes quite a time-consuming operation before conclusions can be drawn from a representative number of plot-years. Hence it is also relatively expensive. Moreover, for a regional survey, the number of plot-years will considerably increase when the effects of different slope angles and soil types have to be assessed. Thus the question arises, whether or not, the laboratory offers a relevant alternative for erodibility tests by applying rainfall simulation to flumes of limited size. The advantages of laboratory tests are that the impact of different rainfall sequences, soil types and slope angles can be tested in a relatively short period of time; and there is no major problem in obtaining good replications of the structural characteristics of tilled topsoils. The main objections to laboratory experiments are the limited depth and length of the flumes.

In the Leuven laboratory the depth of flumes varies between 5 and 10 cm and the base of the flumes is drained. This means that pore water is nearly at neutral pressure when this base level is highly water saturated. The field equivalent of this set-up is a thoroughly wetted topsoil, with nearly total water saturation at a limited depth, due to very intensive rainstorms on a subsoil or a soil horizon with reduced drainage (clayey B-horizon, plough pan etc.). Therefore, flume experiments are well suited for the simulation of heavy rainy periods on topsoils with limited internal drainage. Sandy soils can also be tested because their infiltration capacity is often much reduced by topsoil liquefaction (De Ploey, 1971).

In our laboratory the maximum length of flumes is 4 m. Is this an irrevocable objection to representative erodibility experiments? Several arguments point to a considered answer to this important question.

(a) Heavy rainstorms generally provoke sheet and rill wash on fields. The concept of "a belt of no erosion" is still quite a common idea, according to which rill generation only starts at a certain critical distance from the water divide or from the upper limit of the fields. This misconception is based on the premise that the onset of rill erosion depends primarily on a critical discharge of the flow, a function of the length of the slope. However, field observations show that rill generation starts within a very short distance from the divide (Yair, 1972; Schmidt, 1979). This is confirmed by experiments on 1 m flumes (De Ploey, 1980). From his experiments and hydraulic considerations, Savat (1975, 1977, 1979) gave an explanation for this fact: the onset of rill erosion is not primarily determined by a growing unit discharge, q, of the flow, but by the slope factor, S. Rill generation is related to a critical value of the Froude number

$$Fr = \bar{u}/\sqrt{g\ R}$$

in which $\bar{u}$ = mean velocity, g = gravity constant, and R = hydraulic radius or depth of flow. Critical Froude numbers for starting rill erosion on loamy soils vary between 2.0 and 3.0. These critical values occur on slopes that are equal to or steeper than 2° to 3°, on most loamy to loamy-sandy soils. This explains why the literature reports rill erosion starting mainly at these critical slope angles (Savat & De Ploey, 1981). Since the unit discharge does not influence the Froude number, it is not surprising that rills appear in flumes of limited length when they are tilted at the critical slope angles.

(b) The soil erodibility factor K of the USLE is calculated independently from the topographic factor LS, which is the product of slope length and steepness. Wischmeier (1975, 1977) has published a nomograph with LS values, calculated for slope lengths, down to 10 feet or 3.3 m. This means that the USLE is applicable for short as well as for extended slopes and for runoff which passes from a laminar to a turbulent regime. Thus, the eroded slope is marked by continuity, from the first metre down to the basal area of predominant colluviation. The foregoing explanation of rill generation corroborates this concept. From this point of view the flume with limited length is not "out of slope reality".

(c) The LS-L nomograph of Wischmeier shows that the increase of LS-values depends more on the growing steepness of the slope S than on the increase of the slope length L. Thus, as in the case of rill generation, it indicates that the slope factor S is the predominant topographic parameter. This statement favours the flume experiments.

(d) Bryan (1969, 1974) investigated the erodibility of a large series of soils from Derbyshire (England) and from Alberta (Canada), using small sample pans of 30 x 30 cm. The thus obtained classification was meaningful in accordance with general field observations. It was demonstrated for most aggregated soils that erodibility is significantly negatively correlated to the quantity of water-stable aggregates. The influence of textural properties is more apparent for poorly aggregated sandy soils.

Bryan mentioned that the recorded "wash" losses consisted mainly of material which was entrained by splash though evacuated by thin runoff. This means that a very small 30 x 30 cm flume is certainly representative of the erosive systems on inter-rill areas. On larger flumes, 1 m or more long, rill generation is currently observed, as already discussed. The question here arises, with reference to field conditions, whether or not ablation by rill incision is more important that ablation by inter-rill wash. In some areas it looks as if the rills are merely conveyors for the transport of material, supplied by inter-rill wash. Elucidation of this problem requires intensive field and laboratory study in the near future.

## CONCLUSIONS

Consistency indices, derived from the Atterberg tests, are manifestly useful and simple tools for the prediction of phenomena related to land erosion. A so-called $C_{5-10}$ consistency index has recently been proposed for the prediction of the crustability of topsoils.

Regarding the question of the use of flume experiments for the evaluation of the erodibility of soils, several arguments have been put forward which favour this approach, which may be an economic way to predict specific soil loss events, especially the impact of very rainy periods. Such events pose the problem of short term, time-dependent erodibility variations which are not considered by the universal soil loss equation and its erodibility factor K.

At the moment the Leuven laboratory, jointly with the Soil Erosion Laboratory of Toronto, is engaged in a project on flume experiments. This project intends to specify the comparability of results obtained from differently equipped laboratories. The final aim is to evaluate the efficiency of flume tests in specific erodibility research.

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