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"Mechanics of Soil Erosion Process"
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presented by

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Introduction

The understanding of the basic factors involved in the erosion process is a first step towards the evaluation of control measures for soil erosion caused by rainfall.

The overall process can be subdivided into two main processes: detachment of soil particles and aggregates from the soil mass, and their transport.

Detachment is mainly due to raindrop impacts (Ellison, 1947) and runoff shear stress.

Transport is mainly due to superficial runoff; subsurface flow and raindrop impact also contribute.

Splash erosion

The impact of a falling drop is characterized by the mass and velocity of the drop. When a drop hits the soil surface it releases its momentum as an impulse force. The momentum is partially reflected and partially used to detach and move soil particles, and to compact the soil surface.

Compaction.

The compaction usually determines the formation of a thin soil crust and a decrease in the soil surface porosity as soil pores are clogged by the impact force and by the fine particles that infill the pores (Young, 1972).

Detachment.

Resistence to detachment depends on the soil types: medium and coarse particles are more easily detached than clay particles (Farmer, 1973). In fact, the detaching force must overcome adhesive and chemical bonds which link particles together (Yariv, 1976). Those forces are obviuosly stronger among clay particles while their cross sections are smaller so that clay particles are more resistent.

The effectiveness of the impact force changes according to the thickness of the water film covering the soil surface. Palmer (1964) showed that rainsplash increases as the water thickness increases. When the water film is as thick as 10-20% of the drop diameter the splash is more effective, then it decreases probably because the force is dispersed in the water (Mutchler and Young, 1975).

Transport

The net downward movement of the splashed particles depends on the kinetic energy of the drops and on the slope of the soil surface (Torri and Sfalanga, 1982).

The effect of the splash as a transport agent is negligible in comparison with runoff -0.1 ÷ 0.2% of the total erosion on a 19% slope on a sandy soil in mid-Bedfordshire over 900 day period (Morgan, 1977). The relative importance of this kind of soil transport is due to the interaction with rills, as shown by Young and Wiersma (1973). The balance between particles jumping in and out of a rill is in favour of the jumping in; consequentely the amount of soil transported in rills is enreached by splash.

Drop velocity and raindrop size distribution

As we said in the previous paragraphs velocity and size of the raindrops are the characteristics which affect detachment and transport.

The fall velocity of a drop depends on the drop size. Data collected by Laws (1941) and confirmed by Gunn and Kinzer (1949) are shown in Fig.1. These velocities were measured in the laboratory (stagnant air). They are atteined after a critical fall length which is of c.20m for the biggest drops (5-6mm in diameter).

During rainfall wind usually blows, affecting raindrop velocity both in direction and intensity (Torri, 1979). These differences affect soil detachment as shown by Lyles (1977).

Natural rains are characterized by distributions of drops of different sizes, Drop size distributions change with rain intensity and type of storm. In Fig.2 data collected by Laws and Parsons (1943) show the dependence of raindrop distribution on rain intensity. Other researchers (Hudson, 1963; Carter et al., 1974; Homerin, 1980; Zanchi and Torri, 1980) working in different locations found out different relationships between raindrop size distribution and rain intensity. An example is shown in Fig.2.

Temperature too could affect raindrop size distribution as shown by Zanchi and Torri (1980).

Hillslope hydrology

The water supplied by rain can be roughly subdivided into infiltration water and overland flow.

The term 'infiltration' means the process of water entering the soil (Gerrard, 1981, p.17). A typical infiltration curve is drawn in Fig.3. Many are the equations describing infiltration. Among those only two are shown here:

a) Horton's (1945): $i(t) = i_c + (i_o - i_c)e^{-kt}$

b) Philip's (1957-8): $i(t) = a + b\,t^{-0.5}$

where: $i(t)$ = infiltration rate at t;
t = time;
i_c = final value of the infiltr. rate;
i_o = initial value of the infitr. rate;
a = constant (c; hydraulic conductivity at the surface for t=0);
b = a sorptivity value (from the rate of penetration at the wetting front);
k = constant depending on the soil.

Both the equations are not satisfactory. Eqn(a) underestimates the first part of the infiltration curve ($t \to 0$) while Eqn (b) overestimates it. In any case, both

the eqns do not take into account the variation of the pore geometry which may occurs during the time (especially in the most superficial layer). Data collected by Roy and Ghosh (1982) during a 213 days long field trial show that infiltration rate values oscillate. They recorded 13 minima, while the lower value attained was c. 0.5 m/day and the maximum c. 6 m/day.

Two are the situations which may occur during rain:

1- $i(t) > I(t)$ ($I(t)$ = rain intensity)

2- $i(t) < I(t)$

In case 1 all rain infiltrates and the actual value of $i(t)$ is $I(t)$. In case 2 the depressions, which are present on the slope, are filled with water and overland flow eventually occurs. This kind of overland flow is called 'hortonian' after Horton (1945).

Infiltrated water, which moves through the soil layers, originates a downslope movement (throughflow) which may saturate the upper soil layer. In this case a saturated overland flow occurs.

In Fig.4 all the situations sketched in this paragraph are shown.

Overland flow, rill and gully erosion

Runoff is both a detaching and transport agent. It acts through the force that the fluid, during its movement, exerts over the particles and aggregates. Its effects can be subdivided into sheet and channelled erosion. The latter is further subdivided into rill (ephemeral feature, easily obliterable) and gully (relatively permanent water courses) erosion.

The force due to runoff depends on the velocity (v) and thickness (h) of the water film. The dependence between v and h is as follows:

$$v = \frac{h^b s^c}{n}$$

where: n = superficial roughness;
b, c = exponents;
s = slope.

Navier-Stokes equations, Manning equation, and the data collected by Savat (1977) clearly show that the exponents b and c range respectively between 2÷2/3 and 1÷0.4 as turbolence increases.

The force required to detach particles is greater than the one required to transport particles and the minimum of force needed for both transport and detachment depends on the size of the particles. (see Fig.5).

Subsurface flow transports colloids and minerals in solution (Roose, 1970). When this flow is concentrated in tunnels it could cause a tunnel collapse and the formation of a gully (Buckham and Cockfield, 1950). Moreover the subsurface flow may burst out on the surface when the soil layers are saturated - it obviously may occur near the bottom of a slope. In this case it could cause the beginning of a rill which may extend upslope (Morgan, 1977; Sfalanga and Torri, unpublished laboratory data).

Rills may be determined by other reasons such as, for example, microconcavity at the soil surface, tractor wheels tracks, and all the other factors which may determine a local accumulation of the overland flow.

Rills are usually obliterated by normal management operations.

The relative importance of rill and sheet erosion can be exemplified by the data reported by Morgan (1977): 97.8% due to rill and 2% due to sheet erosion on a sandy soil.

Gullies are often associated with accelerated erosion and slope instability. Gullies are not simply enlarged rills. Some of them develop from small depressions due to localized weakening of the vegetation cover. Water concentrates in those depressions deepening them. When some of them coalesce incipient channels are formed. Near vertical scarps develop and the headcut retreats upslope because of erosion (Olege, 1972).

Following De Ploey (1974) gullies can be subdivided into : axial gully (single headcut moving upslope by surface erosion, mainly in gravelly deposits), digitate gully (several headcuts moving following the tributary depressions, mainly in clay loams), and frontal gully (associated with tunnel collapse

or piping, mainly in loamy sands with columnar structure).

Modelling erosion considering erosion mechanics.

Modelling soil erosion is not simple because all the erosion agents usually act all together and , especially during heavy storms, they act in all the possible way.

Rill and sheet erosion are the most common forms of erosion. A model taking them both into account should be divided into two components:

$$dA/dt = S + R$$

where dA/dt = erosion per unit of time and surface;
S = sheet component;
R = rill component.

Both the component should take into account the force of transport and the force of detachment together with the reaction of the soil. The following equation might result:

$$S = k_s \left(D_s - D_{s0} \right) F_s$$

$$R = \sum_{rills} k_r \left(F_d - F_{d0} \right) F_r$$

where: K_s = sheet erodibility;
K_r = rill erodibility;
D_s = raindrop detachment force;
F_d = runoff detachment force;
D_{so} = minimum of D_s to detach;
F_{do} = minimum of F_d to detach;
F_s = sheet flow force of transport;
F_r = rill force of transport.

All these factors need an equation containing other subfactors to be calculated. Only approximations can be performed at the present stage of knowledge.

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FIG. 1: terminal velocity of water drops in stagnant air (Laws, 1941)

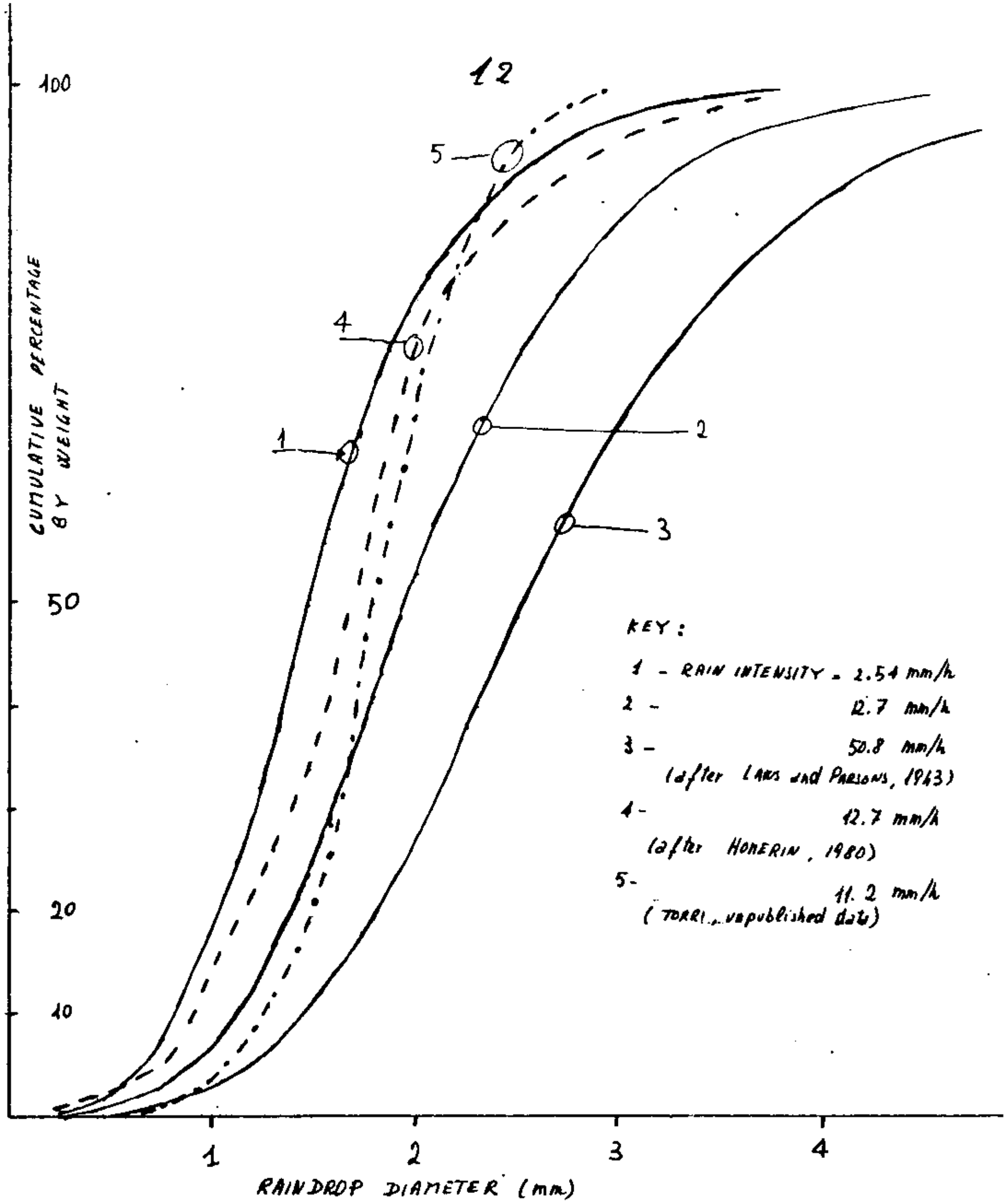

FIG. 2: Raindrop size distribution.

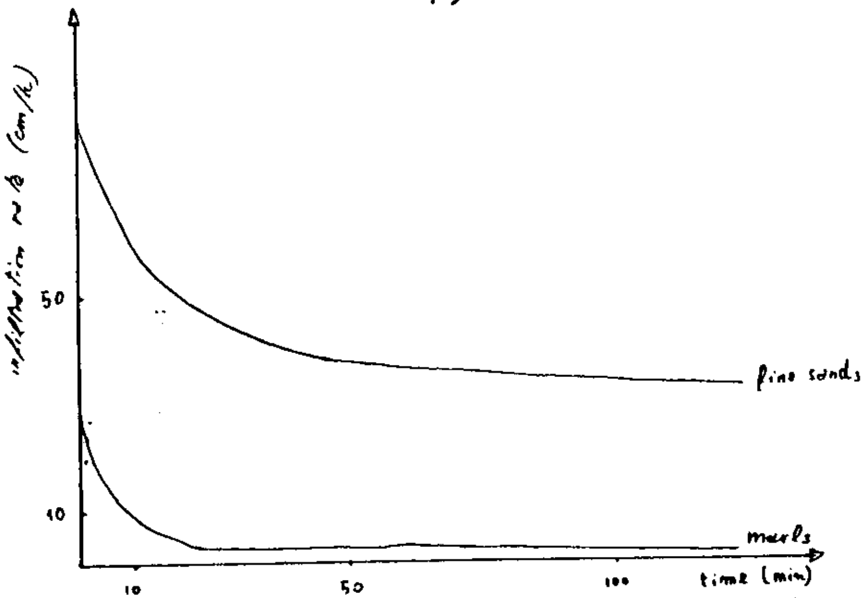

FIG. 3 : Typical infiltration curves (ponded infiltration).

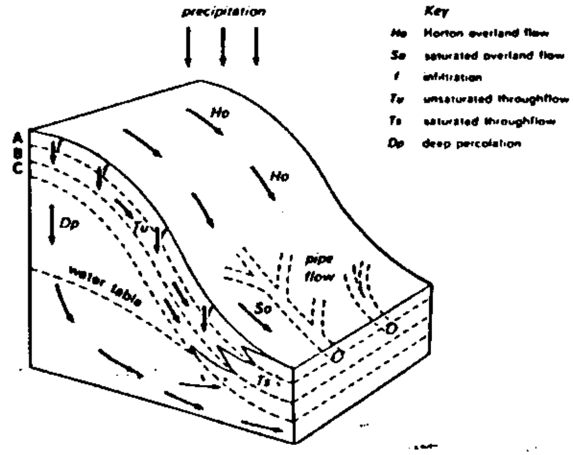

FIG. 4 : water movement on slopes (after GERRARD, 1981).

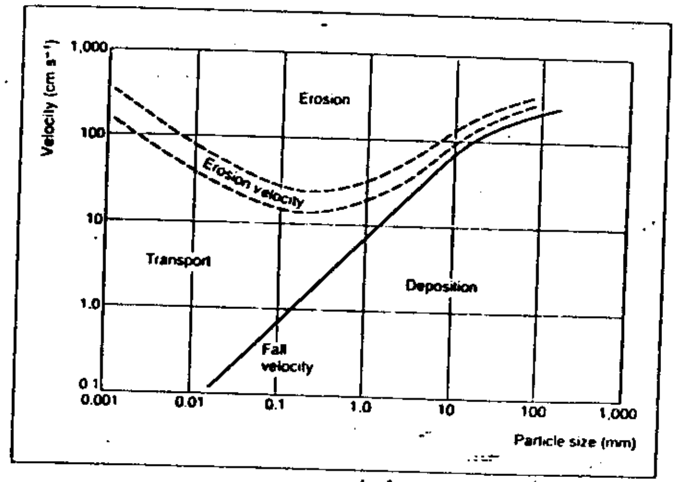

FIG. 5: water velocity and particle size, as they are related to erosion, transport and deposition (Hjulström, 1935).