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Modelling Interrill Erosion by Means of a Laboratory Model

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I. INTRODUCTION

The erosive process plays, nowadays, an important role in the process of degradation and it is strongly influenced by the temporal and spatial variability of the parameters from which it depends [25].

The erosion rate of a soil exceeds the formation rate of the same, as result of the excessive exploitation of the ground and its productivity. This disparity between accelerated erosion and soil formation can be attributed "*in toto*" to the anthropic activity. The remarkable demographic increase in the twentieth century has drastically emphasized the risk and the extension of the degradation process of soil components [19].

A possible interpretation of this phenomenon is given by the consideration that to the economic development in a country often follows a change of the soil utilization.

In the last five decades several studies were focused on the erosion process starting from the plot scale to the global scale. A wide number of assessment models have been adopted to gather and process data, even if many doubts still remain in analyzing them [16].

The paper presents the first results of an extensive laboratory campaign in order to define the influence that the wet-dry climate regime carries out on erosion process.

The preliminary work was pointed for defining initial conditions and laboratory methodologies to achieve a reliable simulation. The first experimental results were compared with estimated values obtained by the WEPP model.

The purpose of this last analysis was to provide a first response of the capability of the WEPP model for simulating soil loss during a rainfall event.

II. INTERRIL EROSION: STATE OF THE ART

Literature data evidence that rainfall is certainly the most important factor into erosion process phenomena. Erosion due to the rain action is correlated to its characteristics time, drop diameters and rain intensities; the modality succession of the events determines two underlying fundamental parameters: kinetic energy and the momentum.

The first kind of erosion, due to the rain impact, is linked to the rainfall characteristics, slope soil, water depth and the land nature. The uncohesive soils have a different behaviour regarding the cohesive ones. In the first case the soil particles are tied only by contact forces and their breakages are due to gravitational actions [1,22]. In the case of cohesive soils there are chemical ties, known as chemical gel [1,22]; their breakage is due to the overcoming of the rain drop force. Starting from this moment the particles, scattered by the rain, are carried on by water. This action depends on the morphologic characteristics (slope, length, roughness and profile shape), from soil characteristics and hydrogeological ones (hydraulic conductivity and filtration).

These considerations show the complexity of the process and, at the same time, justify the numerous literature studies.

In the following some experimental results obtained in laboratory are summarized. Salles and Poesen [23] leaded laboratory tests on a sandy plot to estimate the incident action of rain, varying the rainfall intensity. The collected data have been used to define an erosion index of the rain that takes into account the amount of material removed with the momentum and the diameter of particles. Jayawardena and Bhuiyan [15] generated laminar flow on a plot with fixed slope and sandy soil to define a physical approach that could separate the contribute given by the action of the rain from the transport. The collected data evidence the strong contribution to the erosive process that derives from the impact of the rain on the soil.

The splash erosion depends also on the land slope. Wan and al. [26] leaded experiences varying the slope and setting the intensity of rain on a silty clay plot. It is evident that the rain erosion prevails on runoff for slopes higher than 9%, whereas under this value the behaviour seems to be inverted. This data have been confirmed from Jayawardena and Bhuiyan [15] tests.

Romkens and al. [20] highlighted the influence of the rainfall performing a experiment on a parcel of silt loam soil, scarcely erodible, and with several slope. The results shows that, as slope increases, a succession of events of decreasing intensity produces greater erosions. Moreover, the authors observe that erosion increases with roughness. Gomez and Nearing [10] attained the same conclusions studying a silty on a variable slope plot.

The system has undergone a rain set with increasing intensity and it has been observed that the roughness influences significantly the beginning of the phenomenon. According to Fox and Bryan [8], also sandy loam lands present the same behaviour. The roughness influence increases for higher slopes becoming constant for flat slope. Moreover, by means of tracers, they have observed that the erosion and the average speed change with the slope square root. Chaplot and Le Bissonnais [7] have obtained the same results thank to a parcel of silty loam with different slope. They evidence that the interril measures are connected to the size of a plot. These aspects are in agreement with the Hairsine and Rose [12] and Rose [21] cinematic analytical model. Gabriels [9] performed experiments on two plots of sandy and sandy loam soils, deducing that the influence of plot length is not very important for flat slopes; instead on a steep slope a sandy soil presents an erosion process for unit of length different from the sandy loam plot. The reduction of the interril erosion for loamy sand is confirmed from the Stomph e al. [24] experiences. Using a modular plot with fixed slope they found, in presence of hortonian flows, a scale effect due to the length of the profile. In fact, modules of 1.5 m, subjected to a short rainfalls, are characterised from a length unit runoff greater than that of multiple modules. This behaviour seems attenuated for rains of equal intensity and short time. Recently, Hancock and al. [11] have correlated the slope to the shape of land profile. They considered a particle of fixed sizes and have reproduced three profiles using mixture of flying ashes with a low cohesion and poor infiltration capacity. They found that an half of a rain intensity produces an half of erosion on a single profile, beside an increase of the slope, for a fixed intensity, produces an increase of eroded material of one order of magnitude higher. These aspects highlight the presence of a threshold in the slope value, which, once exceeded, leads to a remarkable increase of shear stress. These results was similar to Romkens and al. [20], Jayawardena and Bhuiyan [15] and Wan and al. [27].

The experiences leaded from Huang and al. [13], using a dual-box system with silty loam soil, have lead to the same results concerning the role of the slope and the rain intensity.

A dual-box model simulates vertical flow movement in a soil from the top to the bottom and vice versa or it assures a constant hydraulic level to a given depth in a soil. Data collected during these experiences show that the last plot, object of the analysis, in condition for free drainage and with a 5% slope, presents the formation of little concavities on surface as the rainfall intensity increases. This phenomenon already starts with a low intensity and with 10% slope profile and it evolves gradually through reciprocal connections, up to generating rills of higher intensity. In the same conditions, but adding filtration flow from the bottom, we can observe a precocious appearance of rills and a sediment production in the order of three or six times higher than the previous. This situation tends to attenuate itself following the formation of rill canalized erosion.

This aspect was confirmed by Owoputi and Stolte [18] experiences on sandy loam and sandy clay soils. The results show that vertical ascending flow does not influence the erosion. However, with the simultaneous presence of the rain, it was observed greater erosion in comparison to the case of rain only. Moreover, the experiment highlights that the soil erodibility is connected to the filtration from the bottom and manages indirectly the formation and the evolution of the canalized erosion.

Runoff cannot be used for the study of erosion when the contribution of the filtration is not very important. Although the behaviours of two lands are similar, a great profile erosion of the with sandy loam, uncohesive lands, implies a great influence of the regimes of flow from the bottom. The soil erodibility is connected both to soil characteristics and regime of established underground motion.

III. LABORATORY SET-UP AND MEASUREMENTS PROCEDURES

At the literary review, above mentioned highlights the opportunity to better analyze the role of the wet-dry climatic regime and the concomitant action driven by the infiltration process in the interrill erosion phenomenon.

The soil behavior, related to the intensity of the rainfall, depends on the length of the previous dry period. From the increase of this length a loss of the water content ratio takes place, until a water deficit threshold is achieved. The latter situation brings a mechanical modification in the soil characteristics, which is manifested by cracks and fractures. The formation of these erosion structures enhances the soil bent to erosion and transportation.

This is a typical condition of the southern Italian soils, where frequent and intense rainfalls and long and dry period alternate. It appears interesting to focus the attention on such aspect.

This paper summarizes and highlights some recent researches, above mentioned, which examines the role of the main parameters that affect soil erosion. The goal is to provide more details thanks to carefully controlled laboratory experiences.

Experimental tests were conducted with a slope-adjustable plot equipped with a rainfall simulator, a tensiometric system, a solar irradiation system, a profile meter, an outlet flume to collect runoff and sediment load and, finally, a graduate tank to measure infiltration volume (figure 1). A brief description of the equipment and soil preparation are reported below.

Figure 1. The experimental set-up.

A. *Experimental set-up*

The laboratory experimental setup was built in the Large Model Laboratory of the Department of Water Engineering and Chemistry, Technical University of Bari. The main purpose of the 2.0 x 1.0 x 0.5 m (l x b x h) plot was to simulate as closely as possible the sediment transport, deposition and detachment that occur on the soil during or after a rainfall event. In order to accomplish this, the following design variables and restraints was taken into account:

- the slope of the plot should be variable from 0 to 14%
- free infiltration on the bed and the bottom of the plot

- the end of the plot should have an endplate which can be adjustable to different heights to allow natural erosion on the bottom

B. Soil preparation

The sediment chosen for all the experimental runs was a sandy loam (13.5 clay, 16.5% silt, 70 % sand) and was taken from a slope of Rendina dam, in Basilicata region (Southern Italy).

Laboratory measurements were made to provide correct information about soil properties, in particular the soil has a dry unit weight of 1.46 g/cm^3, a void ratio of 0.45 and a volumetric water content 1.95%.

The Rendina reservoir is a pilot river basin on which, during the last few years, various investigations were conducted [3,4,5,], nevertheless, for its same history, it represents a singular and, at the same time, representative case for the analysis of the interrill erosion process.

The soil was air-dried and coarsely grinded and finally blended, before to be settled into the plot over the perforated bed and covered by geotextile material above which five subsequent layers of 10 cm each one were spread out. The layers were gently tamped with a steel straight roller and by hands.

C. Tensiometric system

Four water pressure devices were placed along the plot respectively at 70 cm and 180 cm apart the upstream edge of the plot on two different height, 15 cm and 35 cm from the bottom respectively.

The purpose of these sensors, mod. 2100F produced by Soilmosture Equipment Corp, was to test the possibility of measuring water height when no infiltration is present in the soil and to identify infiltration trends when infiltration occurs. They are able to acquire suction values in a range from 0 to 85 KPa and to transfer data in continuous to a data acquisition board for their management and treatment.

D. Rainfall simulator

The plot was provided with a rainfall simulator consisting of several spray sprinkler, series PS Hunter, performing different rainfall intensities with a fall height of 5.40 m. They were supplied by a pressurized pipeline. The head pressure was controlled by throttle valve and checked by a Bourdon pressure gauge.

The properties of generated storms are very similar to the natural storms of corresponding intensities. In particular, drops, supplied by sprinklers, have as a average diameter of 4 mm, is in agreement with Hudson [14] and Ferro [2].

In this experience a fixed rainfall volume was supplied at four different intensity levels but each one having the same amount of rain. The rain unit volume applied in every test was 60 mm and the relative intensities were approximately 120, 60, 30 and 15 mm h^{-1}

Rainfall was measured during each experiment to check if there was spatial homogeneous distribution over the plot.

E. Solar irradiation simulation

Two high pressure sodium vapours lamps, produced from Leuci series NA-T, of 400W, generating a light flux of about 48000 lumen each, was used in order to reproduce the effect of the solar radiation.

In this earlier stage of the test the goal was to simulate in very short time the effects of irradiation on the southern Italy soils at the end of summer season. In this period of the year the soils are characterized from a cracking process (fig.2), that in the following winter season often determines a trigger of erosive process. For this purpose the lamps were settled in such way to achieve the maximum possible radiation, checked by a ground temperature measurement.

In particular, the lamps lit up 11 hours per day catching up on the land a temperature of approximately 55 °C. Once caught up a typical representative condition of the end of summer, made evident by the suction pressures measured by tensiometric system, the plot underwent a wash away effect due to high intensity rain event.

In a second future phase, after estimated the total entity of the phenomena, the experiences will continue through the reproduction of the solar irradiation in more adherent way to the reality, taking into account the daily excursion.

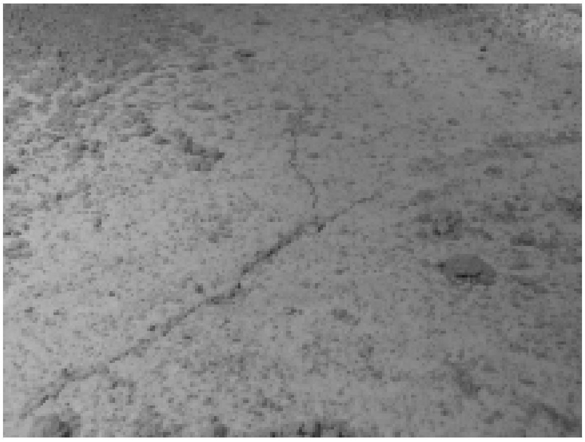

Figure 2. A typical cracking due to solar irradiation effect.

F. Soil loss measuremnts

Variation in sediment yield during plot evolution was measured by collecting sediment samples from the outlet flume at regular intervals depending on the length of the run. The volume of water and sediments derived during each sample interval was determined by means of a graduated scale on the bottle and, after the water was driven off by placing the collected sample in a oven at 105°C, the mass of dry sediments was measured.

Moreover the infiltrated water, was collected by hopper, stored in a transparent glass tank and measured by means a graduated scale.

After each rainstorm event a profile meter with a graduate rod was used to assess the variation level of plot surface, defining the erosion process evolution. In this way the surface topography was analysed to define erosion and drainage network patterns.

IV. RESULTS AND DISCUSSION

This paper presents the results of the first laboratory experiments. Long time was spent to define initial conditions measuring some parameters as bulk density, water content etc. So, a set of four different rain intensity was tested on a slope steepness of 7%. Every simulation presents the same condition in terms of rainfall volume and crusting effect on the plot surface, obtained using the solar irradiation simulation system.

In particular, it was interesting comparing measure data with the numerical results estimated by using the WEPP model, *a physical based model considered to possess state-of-the-art knowledge of erosion science* [6], aiming to evaluate reliability of the model.

A. Hydraulic Conductivity

To prepare the plot for the tests, a preliminary rain with a 15 mm/h intensity was applied. Sprinklers used for the preliminary phase had the aim to reach a proper soil humidity. In order to obtain it, the sprinklers adopted were designed to minimize the effect of rainsplash reducing the drop size.

The first operation was to define the value of hydraulic conductivity parameter. In order to compare the measure data obtained by laboratory experiences and simulated data by WEPP, the value of hydraulic conductivity parameter was evaluated in both cases.

Infiltration in WEPP model is calculated using a solution of the Green–Ampt-Mein-Larson equation by means of the effective hydraulic conductivity parameter (K_e) definition, in order to obtain reliable evaluation of infiltration and runoff. The Green-Ampt equation is a widely used equation for modelling one dimensional vertical flow of water into soil. It was developed from an integration of Darcy's law by assuming infiltration from a ponded surface into a deep homogenous soil of uniform antecedent water content. The value of K_e estimated for the plot using the above mentioned modified Green-Ampt equation was equal to 8.11 E-06 m/s.

Using measured data in the initial unsaturated stage and by visual observation of wetting front velocity, during the first preparatory rainfall simulation of 15 mm/h, the effective hydraulic conductivity parameter (K_e) was calculated using the classical expression of the same Green-Ampt equation, without any adjustment. The value was assessed equal to 3.28E-07 m/s which corresponds to the equilibrium value as shown in the fig. 4.

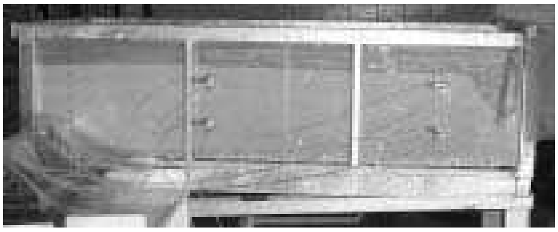

Figure 3. Photograph of the plot with the position of the wetting front after 1h of experiment.

The value estimated with the WEPP model is higher than the measured data. The difference between these values can be ascribed to the several calibrations and adjustment of the equation in the WEPP model and the great dependence of the same from soil granulometry and management.

Another simplification of WEPP model is that the value of K_e, entered in soil input file of the model, was used as an effective conductivity for each of the storms within the entire simulation and settled as a constant. This assumption doesn't match reality because of the fact that the hydraulic conductivity is a variable quantity, as a non-linear function of the volumetric water content (θ). Starting from this consideration and using the infiltration volumes, collected during that first experience at regular time range, the hydraulic conductivity at saturation (K_s) was estimated by means of a simplified procedure such as the infiltration velocity. The value defined by the above-mentioned procedure was equal to 3.20E-06 m/s.

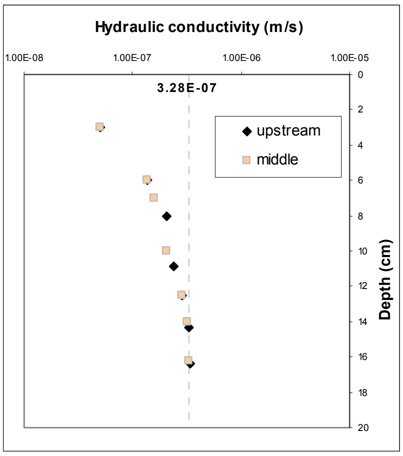

Figure 4. Evolution of hydraulic conductivity.

B. Discussion

During each rainfall simulation, overland flow samples were taken at the flume outlet at several time defined as a function of the run length and its rain intensity, in order to reproduce a fixed rainfall volume on the plot.

After each of the rainfall simulation or after solar irradiation, a survey of the plot surface was made, verifying the expected shape erosions by counting the number of appeared rills; pictures were taken to compare the situation before and after each experience (fig. 5).

Figure 5. Example of the final surfaces after a rainfall simulation of 120 mm/h.

At the end of each experience lamps for solar irradiation simulation were lit for several days to reproduce crusting effect on the plot surface and a new rainfall simulation was carried on later.

Table I resumes the amount of eroded materials and runoff in each rainfall simulation. For the first two simulation: rainfall events of 15 and 30 mm/h, there was no reply of the plot in terms of runoff and sediment load. Figure 6 illustrates, the runoff only for rain intensity of 60 and 120 mm/h each. At shown in fig. 6 high rainfall intensity caused a reduction in infiltration and, after the first minute, was produced runoff, that was higher than the previous one.

The high rainfall intensity substantially produced about 2.7 kg sediments, this quantity is about one order of magnitude higher than that produced by the low rainfall intensity.

TABLE I.
TOTAL RUNOFF AND SOIL LOSS FOR EACH RAINFALL EVENT

Rainfall intensity (mm/h)	Soil loss (kg)	Runoff (mm)
15	0.00	0.00
30	0.00	0.00
60	0.15	8.98
120	2.75	28.44

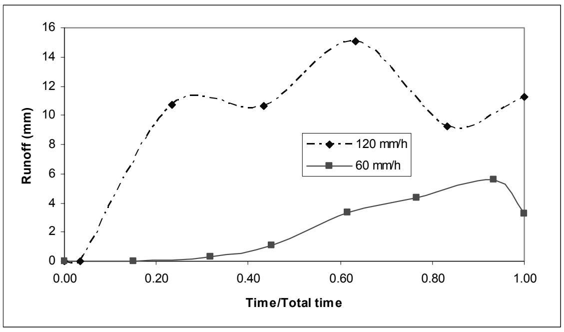

Figure 6. Runoff output data versus dimensionless time..

Figure 7 shows the sediment concentration relationship as a function of cumulative rainfall during, respectively, a simulated rainstorm of 60 mm/h and 120 mm/h. This relationship shows the rapid rise in the sediment concentration and, at the same time, the reaching of a stable equilibrium condition. This behavior was related to different type of events, because during the early stage of a rainfall, the soil erosion is dominated by soil detachment due to drops impact. Upon ponding, runoff rate and solid load rapidly increase until the local compacted soil lead to a constant contribute of sediment concentration, due mainly to runoff effect.

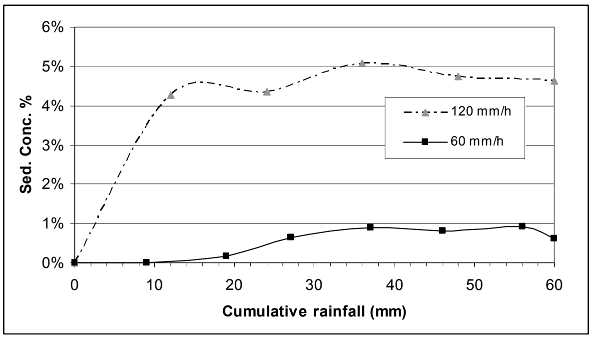

Figure 7. Sediment concentration as a function of the accumulative rainfall.

In a second phase these data were compared with simulated data, obtained from the WEPP model application. This model is able to evaluate runoff and erosion from a daily basis scale to a annual one. Erosion process can be simulated at hillslope or watershed scale. The present simulation, however, was restricted to a hillslope profile identical to experimental plot.

The main discrepancy between WEPP model simulation and measured data was the entity of soil loss and predicted runoff volume. Figure 8 and 9 illustrate this behavior, in particular the plot and the model do not provide a answer in terms of runoff or soil loss for an rain intensity of 15 and 30 mm/h, whereas in the other cases WEPP over-predicts runoff and soil loss.

This results was in agreement with those observed by Nearing [17]. In particular, he wrote that soil erosion models tend to over-predict erosion for a small measured values and under-predict erosion for large measured values. This discrepancy is due to fact that the models have a deterministic in nature and the measured data has a significant random component for which the models cannot account. That fact is a practical and, at the same time, unavoidable limitation in defining a prediction model function of numerous parameters; e.g. local variation in rainfall intensities from plot to plot, or microtopography or different erosion or sedimentation location.

Observing the comparison between measured and simulated data it can be supposed that the hypothesis of Nearing is correct and that small changes into the behavior of a plot, during a rainfall in terms of runoff and soil loss, can modify its answer on the contrary of the conclusion of study by Bowen et al. [6].

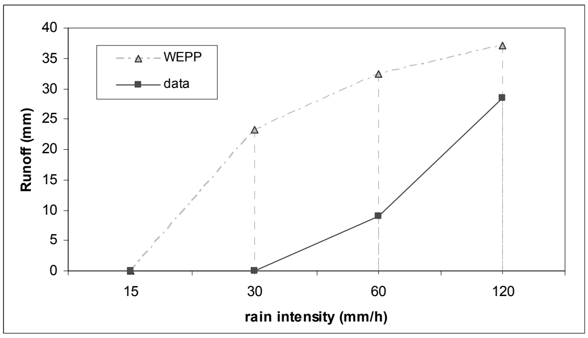

Figure 8. Runoff rate comparison between WEPP and experimental data for each rainfall simulation

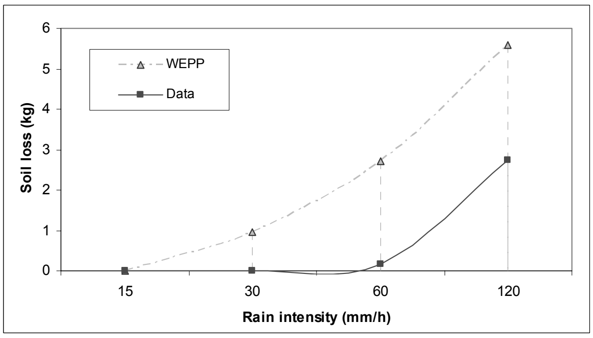

Figure 9. Total soil loss comparison between WEPP and experimental data for each rainfall simulation.

V. CONCLUSION

This paper represents only the first stage of a large laboratory campaign with the aim to evaluate the dependence of soil erosion process on wet-dry climatic regime. This aspect, which seems to have not been examined in a complete way by technical literature, is crucial for many southern Italian soils, where long dry season is followed by a intense rainfall period.

In order to prepare the physical model and the numerical one as backgrounds to this experimental study, a slope-adjustable plot was built.

A long preliminary study was conducted to define the geometrical scale, instrumental devices and soil features.

This chosen soil was a sandy loam soil for simulating a real soil texture, present in southern Italy, which behavior is well known. The first results allow to assess the effective hydraulic conductivity parameter (3.28E-07 m/s) and hydraulic conductivity at saturation (3.20E-06 m/s).

The first value does not match the value provided by the WEPP model, as expected by the empirical nature of WEPP algorithm.

Further, the rainfall-runoff and runoff-soil loss relationship were investigated. For a constant slope, the sediment concentration achieves a constant value at low rainfall intensity. Moreover the soil loss seems to be strongly related to rainfall at different intensities.

The numerical simulation, by WEPP models, shows a similar trend even if meaningfully over-predict the measure values.

In a second phase planned for next future the experiences will continue through the reproduction of the daily solar excursion in order to add further informations and experimental evidences.

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REFERENCES

[1] Annandale G.V. "*Scour Technology* ", McGraw-Hill, (2006).

[2] Bagarello V, Ferro V., Giordano G., "*Trasporto d' acqua e sedimenti a scala di versante*", Editoriale BIOS, 2001 (italian).

[3] Balacco G., Di Santo A., Fratino U., Piccinni A. F.: "*Valutazione della potenziale erodibilitá di un bacino a differenti scale di applicazione*", Giornata di studio su "La Gestione degli invasi artificiali: monitoraggio batimetrico, recupero di capacità e riutilizzo dei sedimenti", Potenza (2002) (italian).

[4] Balacco G., Santaloia F., Fratino U., Cotecchia F., Castorani A. "*I processi di erosione nel bacino della diga di Abate Alonia: analisi fenomenologica e modelli di previsione*" - 28° Convegno di Idraulica e Costruzioni Idrauliche; Potenza (2002) (italian).

[5] Balacco G., "*Modelli interpretativi del processo erosivo nei bacini idrografici*", Phd Thesis, National Libraries of Rome and Florence, (2003) (italian).

[6] Bowen W., Baigorria G., Barrera V., Cordova J., Muck P. and Pastor R., "*A process-based Modell (WEPP) for simulating soil erosion in Andes*", p. 403-408. CIP Program Report 1997-1998. International Potato Center, Lima, Peru.

[7] Chaplot, V., Le Bissonnais, Y., "*Field measurment of interrill erosion under different slopes and plots*", Earth Surf. Process. Landforms 25, (2000), pp. 145-153.

[8] Fox, D.M., Rorke, B.B., "*The relationship of soil loss by interrill erosion to slope gradient*", Catena 38, (1999), pp. 211-222.

[9] Gabriels, D "*The effect of slope length on the amount and size distribuzion of eroded silt loam soils: short slope laboratory experiments on interrill erosion"*, Geomorfology 28 (1998), pp. 169-172.

[10] Gömez, J.A., Nearing, M.A. "*Runoff and sediment losses from rough and smooth soil surfaces in a laboratory experiment"*, Catena 59 (2005), pp. 253-266.

[11] Hancock, G.R., Nuake, J., Fityus, S.G., "*Modelling of sediment dynamics in a laboratory-scale experimental catchment*", Hydrological processes DOI:10.1002/hyp.5899 (2005).

[12] Hairsine P.B. and Rose C.W., "*Modeling water erosion due to overland flow using physical priciples,1. Sheet flow*" Water Resources Research, 28, 237-243 (1992).

[13] Huang,C., Wells, L.K., Norton, D.L., "*Sediment transport capacity and erosion processes: model concept and reality*", Earth Surf. Process. Landforms 24, (1999) pp. 503-516.

[14] Hudson N. W., *"Field measurement of soil erosion and runoff"*, Food and Agriculture Organization of the United Nations - Rome, 1993.

[15] Jayawardena, A.W., Bhuiyan, R.R., "*Evaluation of an interrill soil erosion model erosion using laboratory catchment data*", Hydrological processes 13, (1999), pp. 89-100.

[16] Lal R., "*Soil Degradation by Erosion*", Land Degradation and Development 12: 519-539 (2001).

[17] Nearing M.A., "Why soil erosion models over-predict small soil losses and under-predict large soil losses", Catena 32 (1998), pp. 15-22.

[18] Owoputi, L.O., Stolte, W.J., "*The role of seepage in erodibility*", Hydrological processes 15, (2001), pp 13-22.

[19] Richards J.F., "*Land Transformation*", in The hearth as Transformed by Human Action: Global and Regional Changes in Biosphere Over the Past 300 Years, Turner B.L., Clark W.C., Kate R.W., Richards J.F., Mathews J.T., Mayer W.B. Cambridge University Press: New York; 163-178 (1991).

[20] Römkens, M.J.M., Helmig, K., Prasad, S.N. "*Soil erosion under different rainfall intensites, surface roughness, and soil water regime*", Catena 46 (2001), pp. 103-123.

[21] Rose, C.W. 1993. "*Erosion and sedimentation*" pp. 301-343. In: M. Bonell, M.M. Hufschmidt and J.S. Gladwell (eds), "Hydrology and Water Management in the Humid Tropics - Hydrological Research Issues and Strategies for Water Management" (Cambridge University Press, Cambridge).

[22] Rucker M.L. "*Percolation Theory Approach to Quantify Geo-Material Density - Modulus Relationship*", 9Th ASCE Specialty Conference on Prabablistic Mechanics and Structural Reliability, (2004).

[23] Salles C.and Poesen J., " *Rain properties controlling soil splash detachment*", Hydrological processes 14:, (2000), pp. 271-282.

[24] Stomph, T.J., De Ridder, N. Steenhuis, T.S., Van De Giesen, N.C., "*Scale effect of hortonian overland flow and rainfall-runoff dynamics: laboratory validation of a process-based model*", Earth Surf. Process. Landforms 27, (2002) pp. 847-855.

[25] Toy T. J., Foster G.R., Renard K.G., *"Soil Erosion – Processes, Prediction, Measuremnet and Control",* J. Wiley & Sons, (2002).

[26] Wan, Y., El-Swaify, S.A., Sutherland, R.A.,"*Partitioning interrill splash and wash dynamics: a novel laboratory approach*", Soi L Technology 9, (1996), pp. 55-69.

[27] Wang X. and Wang Z.Y. *"Effect of land use change on runoff and sediment yield ",* International Journal of Sediment Research, Vol.14, No.4, (1999).

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