

PROGRESS REPORTS

THE ROLE OF SOIL PHYSICS IN FIGHTING SOIL DEGRADATION. A CASE STUDY IN THE VALENCIA REGION, SPAIN¹

FLORENCIO INGELMO-SÁNCHEZ

ABSTRACT.- Taking into consideration the peculiar characteristics of climate, topography, geology, soils and managing systems in the Valencia region, some proven general facts in soil Physics are presented, emphasizing some points needing further investigation which, as a whole, fall within the framework of actions in controlling soil degradation processes. The text is divided into two sections: the first, and longer, deals with the study of hydrological and erosion processes, involving Soil Physics in the explanation of some behaviours and mechanisms; in the second, the various mechanisms of physical degradation leading to soil compaction are shown, and the main causes and impacts are also determined.

RESUMEN.- Teniendo en cuenta las características peculiares del clima, topografía, geología, suelos y sistemas de manejo en la Región Valenciana, se exponen algunos hechos probados como suficientemente generales en la Física de suelos y algunos de los avances más significativos de dicha disciplina, enmarcando al mismo tiempo aspectos que necesitan ser investigados, como base para la aplicación de un modelo conceptual de actuación para el control de los procesos de degradación del suelo. La exposición queda dividida, por consideraciones didácticas, en dos apartados. El primero, más extenso, se dedica al estudio de los procesos hidrológicos y erosivos, implicando a la Física del Suelo en la explicación de algunos comportamientos y mecanismos. En el segundo, se exponen los diferentes mecanismos de degradación física que conducen a la compactación del suelo, identificándose las principales causas y las repercusiones.

RESUMÉ.- Compte tenu des particulières caractéristiques du climat, topographie, géologie, sols et systèmes d'aménagement des sols dans la Région de Valence, on expose ici quelques sujets bien connus, sur la Physique du Sol, et on signale certains rapports qui doivent être recherchés pour l'application d'un modèle conceptuel dans la prévision rationnelle des processus de dégradation du sol. Le travail est divisé en deux parties: dans la première on étudie les processus hydrologiques et les processus érosifs, en impliquant la Physique du Sol dans la recherche des mécanismes des condui-

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*Soil Physicist. Dept. of Ecology Valencian Institute for Agricultural Research (I.V.I.A.), 46113-Moncada, Valencia, SPAIN

tes. Dans la deuxième partie on présente les mécanismes de la dégradation physique du sol -notamment le compactage et le scellage du sol- et on identifie les causes principales menant à leur prévision, les effets de la conduite du sol, et quelques lignes de recherche applicables à la minimisation des risques de dégradation physique du sol.

Key words: *Water erosion, soil physical degradation, Soil Physics, organic matter, plant cover, green manuring, sewage sludge.*

The landscape in the Valencian Region presents widely contrasting physiographic and geological features represented by a diversity of soils and climates, as well as by the different management methods of these resources (C.O.P.U.T., 1987). An intensive land use prevails along the *coastal zone* and in the *transition zone*, below 400 meters above sea level, and a semi-abandonment under dryland conditions in the *continental zone*, beyond this level, together with forest exploitation.

The spatial organization of land uses involves the distribution of the significant degradation processes, of which, in coastal and transition zones, lixiviation, contamination, salinization, and compaction are predominant, and water erosion and compaction, in the continental zone. Each of these processes, if considered separately have been studied relatively well by different disciplines concerned with what arrangements are to be made, and the selection of influencing factors, and the effort of these research lines on independent processes have been directed towards producing valuable models for prediction and post-diction, as reported by HARTGE (1986) and de PLOEY & GABRIELS (1984).

We emphasize here the need for a methodological effort with a multidisciplinary approach which will consider soil degradation as a whole, as a result of the dependence and the cause-effect connections that occur among the various processes and sub-processes and under present day social development and landscape zonality.

As a contribution to this task, the objective of this paper is to present some results obtained through Soil Physics that could be of interest in the application of a conceptual strategy in the fight against soil degradation such as that suggested by VARALLYAY (1987).

The following are some proven facts (with our own, or referenced results) and some significant advances reached in the development of Soil Physics, and some points needing further investigation with a multidisciplinary approach, in connection with two degradation processes: 1) Water Erosion, and 2) Physical Degradation from Compaction and Sealing.

1. Water erosion

Considering the observed features of the physical environment (geology, relief, climate, and soils) in the Valencia Region, the different types of water

erosion are represented in varying degrees of severity. Under determined conditions of geology, relief and climate, the occurrence and significance of such processes can be explained by the *intrinsic characteristics* of soils, notably by their morphological, and hydro-physical characteristics, and by *extrinsic variables*, among which the morphological and phenological characteristics of vegetation should be emphasized. The spatial distribution of vegetation -as this is a moderating system for the cycles of matter and energy- was examined as well.

1.1. *Evaluation of morphological and hydro-physical characteristics of soils*

Table 1 (INGELMO & CUADRADO, 1986) shows the qualitative standards of physical behaviour, concerning hydrological aspects, aeration, thermal characteristics, feasibility of management and water erosion (relevant to 3 types of soils well-represented in the Valencia Region, with increasing degree of evolution from Fluvents to Xerals). In this evaluation, special emphasis is placed on the spatial position of the textural class in the soil profile. On the lower part of the table there is a qualitative evaluation of the expected effects attributable to the presence of some modifying agents: organic matter, salinity, stoniness of profile, and compaction; the first one showing in general a positive effect, and a negative one in both the second and the last. The stoniness in the soil profile has an overall opposite effect because of its dependence on the degree of compaction and of moisture level. Table 2 shows, quantitatively, the effect of organic matter on soil porosity when the moisture level in the profile is at field capacity for different textural classes, and qualitatively, the positive or negative effect of other modifying agents, such as moisture level, rooting, stoniness and compaction.

1.2. *Structural stability of soils*

Because of its direct impact on studies on soil erosion, and indirect on other processes of degradation, i.e., lixiviation, contamination, surface sealing and compaction, we are presenting some advances achieved in the investigation of this parameter.

Table 3 (FARRES, 1980) shows the factors involved in the study, as the mechanisms leading to a determined condition or 'aggregation domain', and the static and dynamic variables modifying it. Within this scheme, the content and composition of organic matter of the soil has special significance as an integrator component, as it affects the assortment of involved mechanisms, acting as a static variable and modifying the other static and dynamic variables in a differentiated way.

TABLE 1
Qualitative evaluation of physical properties and their factors of variation in three common soil types in the Valencia Region, factors

SOIL TYPE (FAO)	TEXTURAL CLASS PROFILE	HYDRIC PROPERTIES				OTHER PHYSICAL PROPERTIES					
		WR	WI	WU	E	AC	AP	T	M	ER	
FLUVISOL	LOAMY SAND	LOW	HIGH	LOW	HIGH	HIGH	HIGH	HOT	EASY	HIGH	
	SANDY LOAM SAND	LOW	HIGH	LOW	HIGH	HIGH	HIGH	HOT	EASY	HIGH	
CAMBISOL	SANDY LOAM	MEDIUM-LOW	MEDIUM-HIGH	MEDIUM	MEDIUM-HIGH	MEDIUM-HIGH	MEDIUM	MILD-HOT	EASY	MEDIUM-HIGH	
	SANDY LOAM SAND	MEDIUM-LOW	MEDIUM-HIGH	MEDIUM	MEDIUM-HIGH	MEDIUM-HIGH	MEDIUM	MILD-HOT	EASY	MEDIUM-HIGH	
	CLAY	HIGH	MEDIUM	HIGH	LOW	MEDIUM	MEDIUM	TEMPERATE	DIFFICULT	LOW	
LUVISOL	SANDY LOAM	MEDIUM-HIGH	MEDIUM-HIGH	HIGH	LOW	HIGH	HIGH	HOT	EASY	HIGH	
	SANDY LOAM CLAY	MEDIUM-HIGH	MEDIUM-HIGH	HIGH	LOW	HIGH	HIGH	HOT	EASY	HIGH	
FACTORS OF VARIATION	ORGANIC MATTER	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(-)	
	SALINITY	(+)	(-)	(-)	(+)	(-)	(-)	(?)	(-)	(+)	
	STONINESS	(-)/(+)	(-)/(+)	(-)/(+)	(-)	(+)	(+)	(?)	(-)	(+)/(+)	
	COMPACTION	(-)	(-)	(+)	(-)	(-)	(-)	(+)	(-)	(-)	

(+) = Increase; (-) = decrease; (?) = unknown.
 WR = water retention; WI = Water infiltration; WU = available water uptake; E = Evaporation;
 AC = Air capacity; AP = Air permeability; T = Temperature; M = tilth; ER = erodibility.

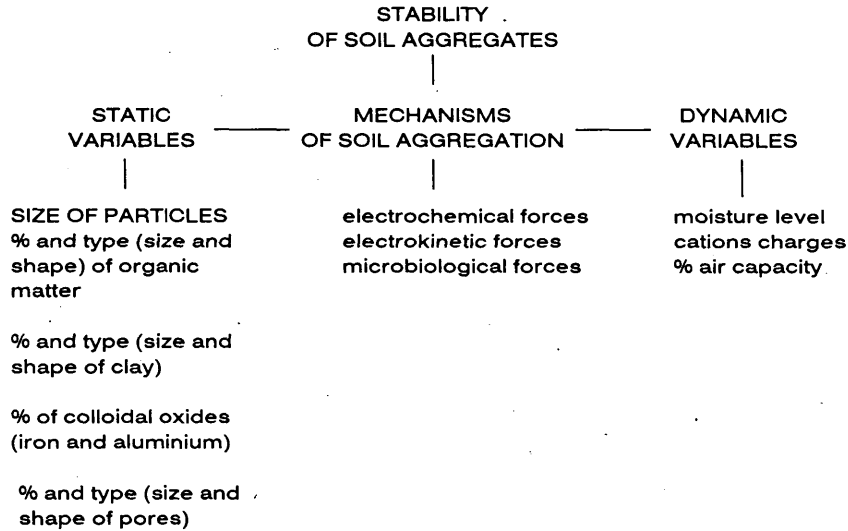
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TABLE 2
Mean values of soil density and differential porosity for 10 soil textural classes and two organic matter contents, and qualitative evaluation of variation factors

TEXTURAL CLASS	LOAMY SAND	SANDY-LOAM	LOAM	SANDY-CLAY	CLAY-LOAM	SILT-LOAM	SILT	SILTY-LOAM	SILTY-CLAY	CLAY		
PROPERTY	MO (%)											
PARTICLE DENSITY	5	2.55	2.58	2.47	2.44	2.50	2.55	2.59	2.51	2.47	2.40	
g/cc	1	2.65	2.66	2.61	2.60	2.62	2.66	2.69	2.62	2.58	2.52	
BULK DENSITY	5	1.40	1.28	1.15	1.05	1.10	1.20	1.08	1.00	0.95	0.85	
g/cc	1	1.60	1.50	1.42	1.37	1.39	1.42	1.36	1.28	1.24	1.21	
QUALITATIVE VARIATION	LOAMY SAND		SANDY-LOAM		LOAM		SANDY-CLAY		CLAY-LOAM		SILT-LOAM	
	COMPACTON (+) STONINESS (+) WETNESS (+)		ROOTS (-)		ROOTS (-)		COMPACTON (+) STONINESS (+)		WETNESS (-) ROOTS (-)		WETNESS (-) ROOTS (-)	
POROSITY (% vol.)	5	45.10	50.39	53.44	56.97	56.00	52.94	58.30	60.16	61.54	64.58	
	1	39.62	43.61	45.59	47.31	46.95	46.62	49.44	51.15	51.94	51.98	
QUALITATIVE VARIATION	COMPACTON (-)		ROOTS (+)		ROOTS (+)		STONINESS (+) ROOTS (+)		STONINESS (+) ROOTS (+)		STONINESS (+) ROOTS (+)	
MICROPOROS (% vol.)	5	7.80	20.00	23.25	28.60	30.00	27.35	36.10	36.25	36.05	36.00	
	1	6.50	17.85	23.00	28.75	29.50	23.00	33.55	38.00	39.50	40.10	
QUALITATIVE VARIATION	COMPACTON (-)		ROOTS (+)		ROOTS (+)		STONINESS (+) ROOTS (+)		STONINESS (+) ROOTS (+)		STONINESS (+) ROOTS (+)	
MACROPOROS (% vol.)	5	37.30	30.39	30.19	28.37	26.00	25.59	22.20	23.91	25.49	28.58	
	1	33.12	25.76	22.59	18.56	17.45	23.62	15.89	13.15	12.44	11.88	
QUALITATIVE VARIATION	COMPACTON (-)		ROOTS (+)		ROOTS (+)		STONINESS (+) ROOTS (+)		STONINESS (+) ROOTS (+)		WETNESS (-) ROOTS (-)	

(+) = increase
(-) = decrease

TABLE 3
 Factors involved in the study of structural stability of soil aggregates (from FARRES, 1980)



Because of its stability, the organic matter contained in, or added to a certain substratum, as it is subject to a dynamic process of mineralization, shall affect selectively their chemical and biological characteristics and those of union affinity to the substrata, and other aspects related to the *internal cohesion* of the aggregates (with the *processes of moisturizing* and with the *degree of sponginess* and increase of *complexity of internal organization*) all of which are implied in the three main mechanisms of disaggregation: a) bursting; b) impact or shearing, and c) microfissuration.

Tables 4 and 5 involve behaviours reported by METZGER *et al* (1987), and show that a given level of organic matter, from the same origin (sewage sludges) affects the evolution of stability of water aggregates in different ways, depending on the texture of the substrata. Similarly, this evolution runs parallel to that of water soluble polysacharids. This positive behaviour of sewage sludge opens up a research line that could be applicable to *soil regeneration* and to the *establishment of substitute vegetation in degraded landscapes*, since it is an important and inexpensive source of organic matter. Further investigation into optimum criteria in its application to prevent soil pollution from heavy metals and other organic and inorganic contaminants which are commonly associated with these materials, would seen necessary.

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TABLE 4
Dynamics of the aggregation status (expressed as the relative content of water-stable aggregates; WSA > 200 μm) in three types of soil after addition of 5% sludge (temperature of incubation: 25° C) (from METZGER & YARON, 1987)

SOIL TEXTURE	WSA (%) at the time of incubation (days)						
	3	5	10	20	40	60	100
SILT LOAM	250	320	375	305	415	425	430
LOAM	160	180	215	140	165	185	190
SANDY LOAM	100	125	150	110	135	140	140

TABLE 5
Changes over 60 days of incubation at 25°C of the WSA and the water-soluble polysaccharides (WSP) contents in two types of soil after addition of 5% sludge (From METZGER & YARON, 1987)

Time of incubation (days)	SILT-LOAM SLUDGE (5%) MIXTURE		LOAMY SOIL-SLUDGE (5%) MIXTURE	
	WSA (%)	WSP ($\frac{\text{mg. glucose}}{100 \text{ g dry soil}}$)	WSA (%)	WSP ($\frac{\text{mg. glucose}}{100 \text{ g. dry soil}}$)
0	7	45	7	70
4	18	80	12	80
8	23	90	15	90
10	27	89	14	88
15	22	88	10	74
28	25	108	10	72
60	31	100	11	54

1.3. Rate of water infiltration in the soil

Water infiltration features are also involved in processes of soil degradation. Soil Physics has provided significant advances in experimental knowledge and in the task of modelling, and also in the arrangement of influence factors. As for the variables explaining their temporal reduction, it appears that the most significant are the following:

- 1) Rainfall kinetic energy on soil.
- 2) Roughness of soil surface.
- 3) Saturated hydraulic conductivity of soil.
- 4) Structural stability of soil.
- 5) Unsaturated hydraulic conductivity of soil.
- 6) Available water retention in the soil.
- 7) Initial moisture in surface horizon and in soil profile.
- 8) Characteristic moisture curves in horizons of soil profile.
- 9) Compaction level in superficial horizon.

- 10) Surface sealing and/or cracking.
- 11) Cracking level in soil profile.
- 12) Stoniness on soil surface and in soil profile.

This list of variables is not in order of priority order. The rooting level of vegetation has not been considered, nor the presence of vegetation, which is strictly related to variables whose modifying role shall be approached in the following section.

Concerning modelling, THORNES (1984) reviews two models: that of HORTON which is valid for heavy rainfall levels, and the model of RUBIN, suitable for moderate to low levels of rainfall. In the first one excess of water on the surface is achieved by saturating only a few centimeters of the soil profile. In this case the significant variables above, are 1 to 4, and 7 to 12, and for a determined value of 1, 3 is the most important. In the second model, it takes longer to reach a stagnant degree, and the soil profile gets gradually saturated with water. The variables 1 and 2, and 4 to 12 are the most significant, and those with more bearing on a certain value of 1, are the 2, 4, 5, 6, 7 and 8.

We should emphasize that, given the rainfall characteristics in the Valencia Region concentrated rainfalls, of medium intensity- RUBIN's model may serve as a prediction tool; but taking into account that, although less frequently, there are also short, heavy rainfalls, the task of modelling should be directed towards a joint model, making it necessary to know the more weighty explanatory variables involved in both models in detail, to maintain the optimum rates of infiltration.

Spatial variability is another important consideration related to the rate of water infiltration in soil, which is directly involved in a precise determination of the soil surface contributing to runoff production. Interesting to note is that the morphological survey relevant to the compaction and stoniness conditions of the site, and to moisture and organic matter of the superficial horizon are crucial in explaining the spatial variations of this parameter within a given plot.

TABLE 6

Variation of the relative runoff coefficient (ratio of runoff value to total rainfall volume) with cover for two rock fragment positions in the top soil: A (on the soil surface) and B (embedded in the soil surface) (from POESEN, et al, 1990)

Cover (%)	Relative runoff coefficient	
	A	B
0	1,00	1,00
20	0,91	1,00
34	0,92	1,41
49	0,80	2,09
65	0,08	2,00
83	0,30	2,03

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Concerning the role played by stoniness in the control of hydrological and erosion processes on hillslopes, we have conducted investigations (POESEN *et al*, 1990) under controlled conditions with simulated rainfall from which hydrological behaviours of opposite directions can be drawn (Table 6). Such behaviours depend on the fact that a certain amount of rock fragments be on the surface of the soil, or that they be embedded in it, thus simulating rocky outcrops. The difference in behaviours might partially explain the variability of results that can be found in the literature with regard to the stoniness effect on the erosion processes.

1.4. *Plant cover effect on the hydrological and erosion processes*

Based on the revision done by SMITH *et al* (1987) we have made the scheme shown in Table 7. In the upper part there appear the three major mechanisms in reducing erosion and runoff by the action of plant cover, all of them inter-related and whose efficacy shall depend upon the phenological and morphological features:

TABLE 7
Erosion and runoff reduction mechanisms using plant cover (according to SMITH et al, 1987)

-
- 1. Soil structure improvement.
 - Positive effects on stability and aggregation.
 - Positive direct effects on water infiltration and water retention.
 - Indirect effects on water infiltration.
 - Indirect, negative effects on runoff and soil loss.
 - 2. Management of water cycle in the soil.
 - Greater evapotranspiration.
 - Greater dessication of soil profile.
 - Better soil preparation to absorb short-time, intense rainfall (capillary absorption).
 - 3. Moderation of the kinetic energy of water.
 - Interception and dissipation of energy.
 - Greater superficial roughness.
 - Decrease of energy of runoff.

If there are conditions of water stress

Competition between erosion and vegetation

Hydrology		Angle
	Slope	
Topography		Shape

a) The possibilities that the various *radicular systems* explore the soil profile coming up against the mechanical obstacles (compaction in some horizons, soil surface sealing, soil profile stoniness, etc.), and that during

their development, rooting mainly modifies the hydrophysical features of the "solum" in order to satisfy the two first mechanisms.

b) The stability of the vegetation cover and its suitability to rainfall occurrence, which is attained by favoring the *species diversity* and *complementarity* in their phenological cycles. At the same time, the third mechanism is better met with rapid growth species, such as herbaceous and bushy vegetation. The establishment of these species would lead to optimisation of the soil's rainfall intake, i.e., by minimizing stem runoff concentration and maximizing dissipation of kinetic energy of rainfall translocation.

This objective is attained by investigating the following morphological characteristics in these species: height/volume ratio; canopy complexity; spatial distribution; sclerophyllia; hydrophyllia, or hydrophobia in the stem and in the leaves, amongst others, to select the best species.

On the other hand, as shown on the lower part of the table, under conditions of *moisture stress* as reported by FRANCIS *et al* (1986) the success in the stages of vegetation establishment will only be achieved by consideration for, or imitation of the competitive model which in such conditions is established between erosion and vegetation, a competence that arises from the hydrological control depending upon the topography of the hillslopes (basically, depending on angle and shape, -concave, straight, or convex- of the hillslope).

2. Physical degradation

Physical degradation, although not less important, has not been investigated so deeply as water erosion. These are directly related, in that they involve the majority of explanatory variables, and have the same main causes. Physical degradation consists of a *degradative alteration of the soil structure mainly due to climatic and anthropic actions*, such as raindrop impact, soil management under unsuitable moisture conditions, and machinery overload; in such a way that in both cases the mechanical and physical properties of the soil are -sometimes irreversibly- modified.

The main mechanical and physical properties related to physical degradation are: rupture modulus, plasticity limits and textural and structural porosity, and the main effects are *soil surface sealing* and *sole of ploughing*, which negatively influence *water infiltrability*, *oxigen diffusion rate*, *soil aeration*, and *hydrological properties*. Consequently, the intrinsic features of soils lead them to react *selectively* before a given cause of physical degradation. Research on this area is directed towards reaching *indexes* (PLA, 1989) serving as predictors of soil behaviours under certain conditions determined by climate and management systems. Within these considerations, the most significant is soil texture and type and percentage of organic matter.

Concerning the soil texture-physical degradation ratio, most authors

agree in that soils with a high silt content and a low expanding clays content are those most susceptible to such kind of degradation. Interesting to note is that these types of soils (Entisols, i. e., Fluvents; Orthents and Psamments; and Inceptisols: i.e., Ochrepts), are widely represented in the Valencia Region. Concerning the type and percentage of organic matter ratio, it is well known that its role consists of lessening the susceptibility to sealing, as a consequence of the increase in internal cohesion and structural stability of the soil, (where it is found stabilized and united to the fine fraction of the soil), and the increase of soil resistance to compression (due to the effect of raindrop impact, or to that of machinery overload) by the relaxing effect which the presence of organic matter implies (GUERIF *et al*, 1979).

As a consequence of the above considerations, one of our research lines in this field is centered on the search for levels of organic matter; simultaneously testing a number or sources of organic matter to achieve optimum economical application criteria that must be maintained in each type of soil so that it can *stand* a determined *climatic erosivity* and a determined *managing system*. Another soil research line, independent or complementary of the previous one, is *non tillage* or *minimum tillage* (with additional legume cover and green manuring), which has been widely developed in the last decade.

3. Conclusions

The aim of this short review has been to explain the contribution of Soil Physics to the fight against soil degradation in the Valencia Region, basically concerned with evaluation and recording of physical and hydrophysical properties which have a direct influence on the dynamics of the overall processes and subprocesses, so that useful selection criteria can be obtained for the study of feasibility of their control, and to suggest technological strategies for the optimum use of soil. Present requirements for research work have been emphasized as well.

References

- C.O.P.U.T. (1987).- *El Medio Ambiente en la Comunidad Valenciana I., 1: El medio natural* (pp. 20-56). Generalitat Valenciana. Valencia.
- De PLOEY, J. & GABRIELS, D. (1984).- Medición de la pérdida del suelo y estudios experimentales. En: *Erosión de Suelos*. (Kirkby, M. & Morgan, R., eds.), Cap. 3, p. 93. Limusa, México.
- FARRES, P. (1980).- Some observations on the stability of soil aggregates to raindrop impact. *Catena*, 7 (2-3): 223-231.
- FRANCIS, C.; THORNES, J.; ROMERO-DIAZ, A.; LOPEZ-BERMUDEZ, F. & FISHER, G. (1986).- Topographic control of soil moisture, vegetation cover and land degradation in a moisture stressed Mediterranean environment. *Catena*, 13: 211-225.

- GUERIF, J. & FAURE, A. (1979).- Role de la matière organique sur le comportement des sols au compactage. *Ann. Agron.*, 30 (5): 387-399.
- HARTGE, K. (1986).- Demands on soils increasing in diversity and intensity. *Trans. XIII Congr. I.S.S.S.*, Hamburg, 13-20. August. Plenary papers, Vol I, 1-12.
- INGELMO-SANCHEZ, F. & CUADRADO-SANCHEZ, S. (1986).- *El Agua y el Medio Físico del Suelo*. Monografía n.º 18, 101 pp. Centro de Edafología y Biología Aplicada de Salamanca (C.S.I.C.). Exma. Diputación Provincial de Salamanca. Salamanca.
- METZGER, L. & YARON, B. (1987).- Influence of Sludge Organic Matter on Soil Physical Properties. In: *Adv. in Soil Sci.* (Stewart, B., ed.) Vol. 7, 141-161. Springer-Verlag, New York.
- PLA, I. (1989).- *Desarrollo de Índices y Modelos para el Diagnóstico y Prevención de la Degradación de Suelos Agrícolas en Venezuela*. Monografía. 56 pp. Premio Agropecuario Banco Consolidado, Maracay, Venezuela.
- POESEN, J.; INGELMO-SANCHEZ, F. & MÜCHER, H. (1990).- The Hydrological response of Soil Surfaces to Rainfall as affected by Cover and Position of Rock Fragments in the Toplayer. *Earth Surface Processes and Landforms*, 15: 653-671.
- SMITH, M.; FRYE, W. & VARCO, J. (1987).- Legume Winter Cover Crops. In: *Adv. in Soil Sci.* (Stewart, B., ed) Vol. 7, 95-132: Springer-Verlag, New York.
- THORNES, J. (1984).- Procesos erosivos de las corrientes de agua y sus controles espaciales y temporales. Un punto de vista teórico. En: *Erosión de Suelos* (Kirkby, M. & Morgan, R., eds), Cap 5, 171-175. Limusa, México.
- VARALLYAY, G. (1987).- Conclusions on Symposium: Soil Structure in fully mechanized cropping systems. *Trans. XIII Congr. of the I.S.S.S.*, 13-20 August, 1986. Symposia papers, Vol. V, 328-329, Hamburg.