Soil Survey, Soil Databases and Soil Monitoring in Spain

[1]J.J. Ibáñez
[2]J. Sánchez Díaz
[3]D. De la Rosa
[1]S. de Alba

[1] Centro de Ciencias Medioambientales (Environmental Science Centre), CSIC Madrid, SPAIN
[2] Centro de Investigaciones sobre Desertificación (Desertification Research Centre), CSIC, Valencia, SPAIN
[3] Instituto de Recursos Naturales y Agrobiología (Natural Resources and Agrobiology Institute), CSIC, Seville, SPAIN

Introduction

Meetings of European Union Heads of Soil Survey Organisations were held in 1989 and 1994 respectively. Both were followed by publication of monographs describing the state-of-the-art in each of the member countries (Hodgson 1991; Le Bas & Jamagne 1996). Limited progress has been made in Spain since then, except for a proposal for an ambitious macroproject (PNCTA), the prospects for which now seem somewhat uncertain. Readers interested in historical aspects of Spanish pedology and/or soil mapping can refer to studies by Díaz Fierros (1979 and 1997) Mudarra (1989 and 1994); Sunyer (1996), Ibáñez *et al.* (1991, 1997), Boixadera and Ibáñez, (1996) and Guerra, (1997).

This paper describes progress in soil survey from 1994 to 1998 and provides additional information on monitoring and soil databases developed in Spain. Nevertheless, some Spanish soil databases arising from some initiatives in Pan-European programmes are not included in the discussion here due to their particular scope. The Spanish contribution to the ICP Forest programme, recently published on a CD-ROM that holds morphological, taxonomic and analytical information corresponding to 453 soil profiles, is a case in point (Montoya & López-Árias, 1998).

Problems of Pedology and the Soil Survey in CSIC

Through its National Pedology Institute (Instituto de Edafología y Biología Vegetal, now known as *Centro de Ciencias Medioambientales* - Environmental Sciences Centre), and its twelve regional centres (currently under an autonomous status), the CSIC (Consejo Superior de Investigaciones Científicas-Spanish National Research Council) was an active Institution (in co-operation with the Spanish Universities) in the field of pedology and soil surveying during the 1960s and 70s. Whilst the outputs from this period had certain shortcomings, such as the fact that most soil maps were drawn up at a small scale (1:200,000) (Donezar 1981; Mudarra 1989; Boixadera & Porta 1991; Boixadera & Ibáñez 1996), there is no doubt about their significant contribution to improving the knowledge of the Spanish soil resources.

However, the application of a new scientific policy in Spain during the 1980s created a situation that affected profoundly (both positively and negatively) some disciplines such as soil survey (Rey *et al.* 1998). According to Ibáñez *et al.* (1997) this led to a decline in the funding for soil surveys , a transfer of responsibility for soil survey to the Regional Autonomous Institutions, where it suffered from a lack of coordination, and an emphasis on environmental problems and the development of GIS outputs of existing information, rather than ensuring that adequate information about the soil resources of Spain was being assembled.

As from the 1980s, the CSIC lost its role as the institution responsible for the coordination of the national soil survey activity. No other institution took its place. The lack of such an institution rapidly led to a significant transformation in the development of soil sciences in the country.

This milestone marked the commencement of the decline of pedology as an integrating discipline from which the remaining soil sciences were structured, not only within the agency but also on a national level.

As in many other developed countries, the number of pedologists and soil surveyors declined sharply (Ibáñez *et al.* 1997). In 1998, the Ministry of the Environment (MIMAN) assigned to the Technological and Geomining Institute of Spain (ITGE) the responsibility for being the National Reference Centre on Soils. Nevertheless, up to now, ITGE has carried out little or no soil survey activity apart from the PNCTA programme (see below).

Main Projects Undertaken since 1994

After consulting various pedologists, experts of the Autonomous Communities and staff belonging to the Ministry of the Environment, four national and one regional programmes of research have been identified in which some progress in the collection and management of soil information has been made. Two of these initiatives are concerned with the development of soil databases, a regional one emanating from a CSIC centre (IRNAS Soil database), and a national one belonging to the *Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas* - Energy, Environment and Technology Research Centre - of the Ministry of the Environment (CIEMAT Soil Database).

Two further initiatives have been established to compile digitised soil maps. The first consists of an ambitious National Plan of Environmental Thematic Mapping (PNCTA) undertaken by the Ministry of the Environment and the other is a digitised Map Library of soil maps and soil forming factors undertaken and completed by the CSIC's *Centro de Ciencias Medioambientales* - Environmental Science Centre - (CCMA Digitised Map Library). The fifth initiative relates to the monitoring of erosion processes of representative benchmark sites, at national level, using experimental plots and catchment basins (the Ministry of the Environment's RESEL Monitoring Network).

IRNAS Soil Database and Related Activities

Over the last 10 years, the IRNAS centre has placed particular emphasis on getting previously collected soil information into a 'useful format', and on developing interpretative procedures to facilitate practical use of such basic information. In order to achieve the first target, a geo-referenced soil database was developed in co-operation with FAO/AGLS and ISRIC (FAO-ISRIC-CSIC, 1995). A major part of this database consisted of morphological and analytical descriptions of soil profiles produced by IRNAS throughout more than 40 years. In all, almost 1,000 profiles, mainly from the Western Andalusian provinces of Seville, Córdoba, Cádiz and Huelva, have been compiled. Information about soil and subsoil fertility, derived from the analytical results for a total of about 20,000 samples, have also been compiled in a database.

Various semi-quantitative methodologies have been developed to facilitate interpretative or evaluation procedures for predicting soil productivity potential and the susceptibility of soils to degradation. The methods are computerised and documented so as to facilitate their automated application (De la Rosa 1996). An analysis of the relationships between pedological, climatic and agronomic variables and the production requirements of certain crops has been made using dynamic quantitative modelling procedures (Barros 1997). The final stage used a computerised application of the different evaluation models and changing scenario generation studies of climate and land use to estimate the impact of such changes on soil production capacity and conservation (De la Rosa and Crompvoets 1998).

In addition, the IRNAS soil database is currently being used to collate information on Spanish benchmark soils, within the framework of the Agreement recently signed by the Ministry of Environment and CSIC. In a pilot step, benchmark soils of Andalusia and Valencia regions are being identified and stored in the soil database. Steps to cover all the country have been also planned..

CIEMAT Soil Database

CIEMAT is drawing up a soil database to support the study of critical loads on Spanish soils. It is understood that computerised morphological and analytical data from more than 2,000 soil profiles have been compiled up to now, though the technical details and specific targets of this initiative were not available to the authors at the time of publication.

CCMA Digitised Map Library

CSIC is still the only nationwide institution currently maintaining a staff, albeit rather limited, of pedologists and soil surveyors. CSIC also holds the responsibility for providing the Spanish representative in international forums on soil survey and soil databases (e.g., European Soil Bureau, European Topic Centre on Soils).

For example, in response to the requirements of the European Soil Bureau, the Environmental Science Centre (CCMA), through one of the authors (J.J. Ibáñez) and co-workers, produced a digitised map library of pedotaxa and soil forming factors in order to respond to national and international requests for soil information. The initial aim of this map library was to act as a basis for the subsequent establishment of a nationwide Soil Information System (SIS) at small scales but this initiative has not succeeded so far because of the lack of funding.

All layers of information have been digitised in the CCMA including maps published in paper format by other administrative bodies. Many of them were corrected at various stages to improve their information from the pedological standpoint and for optimum storage and overlapping using GIS tools (Carrera 1998).

This development was recently completed and is now operational using ARC/INFO. The map library currently consists of the following layers of information digitised at a 1:1,000,000 scale for the whole Spanish territory:

1. soil map according to FAO legends of 1974 and 1988;
2. soil map according to USDA-Soil Taxonomy legend (1987);
3. map of potential plant communities;
4. land cover map;
5. two different geological maps;
6. litho-hydrological map;
7. Quaternary deposits map;
8. drainage basin map;
9. topographic map;
10. digital elevation model (DEM).

A climate database provided by the National Meteorological Institute (INM) is also available.

A numerical phytoclimatic model, also developed in the CCMA, is currently being modified so that, using the information provided in the map library, climate impact scenarios on various natural resources and/or scenarios of implications of soil erosion for vegetated landscapes can be developed. Termed "Phytoclimatic Series" (DBC), this model predicts (with approximately 90% accuracy) the natural potential vegetation of each point in the territory as a function of monthly temperature, precipitation and potential evaporation, as well as the soil waterholding capacity and run-off (González Rebollar *et al.*, 1995).

The intention was to continue in a second phase to add layers of information, to link with a soil database and additional modelling routines, and finally, to develop a SIS with capability to respond to demands for pedological information (e.g., soil erosion risk, vulnerability of soils to contamination, likely effect of climate change, etc.) at broad scales for the whole of Spain. However, to date, funds for further expansion of these activities have not been made available.

RESEL Monitoring Network

The Experimental Erosion Monitoring and Evaluation Station Network -RESEL- in the LUCDEME Project (Combatting Desertification in the Mediterranean) started in pilot stage in 1995. The RESEL is an initiative of the Directorate General for Nature Conservation (Spanish Ministry of the Environment). The main aims of the RESEL Network are:

1. Monitoring erosion and hydrological processes in a network of stations (experimental catchment basins and plots) representative of the major erosion landscapes in Spain;
2. Standardising instrumentation and field methods used at all stations for acquiring data and procedures for processing and storing the information obtained;
3. Testing erosion, soil and water management systems, and control techniques;
4. Coordinating and integrating the Network's stations.

Within the RESEL framework, it is intended to establish a nationwide database to cover erosion processes, hydrological cycles and water quality. The aim is for field and derived data to be used to design preventative actions and use and management plans in the areas most vulnerable to desertification.

RESEL currently involves 20 associated research centres belonging to various Universities and CSIC Centres. There are a total of 41 experimental stations, distributed over 10 Autonomous Communities (*Figure* 1): Andalusia (5), Aragón (7), Canary Islands (3), Catalonia (9), Castilla-La Mancha (2), Extremadura (1), Galicia (5), Murcia (5), Navarra (1) and Valencia (3).

Figure 1: Location of the RESEL experimental stations
[Source: Rojo-Serrano and Sánchez Fuster, 1997]

The RESEL-1996 Stations Handbook gives a detailed description of the different experimental facilities in the plots and catchments (Rojo-Serrano & Sánchez-Fuster 1997). It includes an ecosystem characterisation for each station as well as an itemised description of the facilities, instruments used and the variables recorded. The stations comprise experimental areas with plot facilities for monitoring water erosion (at 27 of the 41 stations) and others where small drainage basins are monitored. The areas range between 10 and 10600 hectares (in 21 stations). A total of 19 stations are located in humid to sub-humid environments with mean annual precipitation over 600 mm, 20 stations represent semi-arid environments and the remaining 2 arid environments with mean annual precipitation of less than 200 mm.

Table 1 gives a synthesis of the ecosystems and land uses represented in the different stations. One station can support more than one kind of vegetation. Forest (20 plots), grassland (15 plots) and (brush and/or shrubs (11 stations) ecosystems stand out as the uses most studied, while in contrast there are only two stations where the responses of dryland arboreal crops and herbaceous agricultural crops are studied.

National Environmental Cartography Theme Plan (PNCTA)

General aspects

The Plan was initiated in 1995 by the Directorate General of Information and Evaluation of the Ministry of Public Works, Transport and the Environment. In 1996, this Ministry was split into two: (i) Environment and (ii) *Fomento* - Development in compliance with the Royal Decree no. 1056/95 of 23 July ("Design and Implementation of an Environmental Cartography System in cooperation with the National Geographical Institute"). The proposal for, and establishment of, the Plan was jointly agreed with the Autonomous Communities, with their active participation.

The Plan is concerned with the nationwide drafting of different thematic maps: plant communities, soil uses, lithology, geomorphology and surface processes, soil types and natural heritage (sites of special geological and biological interest).

Table 1: Summary of land uses at the RESEL stations

Land Use	RESEL Station plots	% of total
Forest	20	34
Dehesa (forested grassland)	1	2
Shrub and brush	11	18
Grasslands	15	25
Set aside fields	6	10
Herbaceous crops (drylands)	2	3
Arboreal crops (drylands)	2	3
Horticultural crops	2	3
Urban areas	1	2
Total	**60**	**100**

The working scale proposed was 1:50,000 using the national 1:25,000 digitised Topographical Map of the National Geographical Institute (IGN) as a basis. According to this scheme, the division of the National Topographical Map sheets on a 1:50,000 scale is maintained, dividing the Spanish territory into 1,114 units. It was decided that the Technological and Geo-mining Institute of Spain (ITGE) would manage the Plan. A time framework for sequentially undertaking the different work tasks was proposed in such a way that completion of the initial maps would act as a trigger for commencement of others.

Soil Mapping

In the design (pilot) stage of the PNCTA, the task was to map the soils at 1:50,000 scale, using a common methodology for the whole Spanish territory. It was planned that the product format would be standardised, and digitised by implementing a user-friendly GIS environment, capable of being accessed from any part of the country. Both the soil maps and GIS outputs are expected to contain information to be used for land and environmental planning, and be a source of basic documentation for environmental impact studies. The soil mapping units were defined on the basis of:

1. *Types of cartographic units.* Consociations, complexes and associations.
2. *Soil Classification.* The classification reference systems are: (a) the Soil Taxonomy (Soil Survey Staff, 1994; translated into Spanish in 1995), at a Subgroup level and (b)the third level of the FAO units (FAO-Unesco, 1988).
3. *Capacity Indicator.* This is defined as the set of soil and environmental parameters and attributes reflecting the intrinsic capability of the natural environment, supporting or limiting agricultural use. The parameters comprising the capacity indicator are: water availability to plants, thermal conditions, slope, waterlogging risk, effective soil depth, rock outcrops, surface and root area stoniness, hydromorphy, granulometry, physical properties, chemical properties, alkalinity, salinity and degree of water erosion. Five degrees of Capacity are differentiated on the basis of the values established for each of the factors (very high, high, moderate, low and very low) derived from the evaluation and linking of all the parameters chosen, the absence or presence of limiting features and, where appropriate, the type, number, degree and intensity of unfavourable properties.
4. *Vulnerability Indicator.* This is defined as the set of limitations restricting the possibilities of using the soil in a particular place. The parameters that shape the indicator reflecting soil vulnerability to degradation are: (i) potential water erosion risk, (ii) risk of salinisation and/or alkalisation, and (iii) contamination risk. Three grades of Vulnerability can be differentiated as a function of the values established for each of the parameters (low, moderate and high).

Seven thematic maps for the eleven pilot areas representative of the different climatic regions of the country were compiled in the Design stage. The pilot areas were distributed in the following Autonomous Communities: Galicia, Asturias, Cantabria, Castile-León, Aragón, Castile-La Mancha, Madrid, Valencia, Balearic Isles, Murcia, Andalusia and Canary Islands. For six of the pilot areas the maps were made at a scale of 1:50,000 and for four at a scale of 1:25,000.

The pilot area situated on the boundary between Galicia and Asturias was mapped at a scale of 1:50,000/1:25,000. A Technical Standard was drafted for drawing up the soil maps (Sánchez, Colomer and Nieves, 1996, unpublished).

An *ad hoc* Committee of the Spanish Society of Soil Science subsequently discussed this Draft. The final document included a description of the overall methods, drafting phases, soil database design used from FAO-ISRIC-CSIC (1995), and format and legend of the map. The maps for the aforesaid pilot areas were drawn up and presented during 1997 (e.g. ITGE, 1997) and the general Plan was to have been implemented as from 1998.

Obviously, this is the most ambitious plan with these characteristics ever proposed in Spain. However, the PNCTA has been provisionally suspended. The authors do not, therefore, know the future of the PNCTA.

Pedology and Soil Survey as Information Sources

After many decades during which the importance of soils in agricultural production was accepted and the need for research into soils for this purpose met, the public and the policy makers, in industrialised countries, are now more concerned with environmental problems than with an increase in agricultural production (Ibáñez *et al.* 1993; Yaalon 1997). The new EU Common Agricultural Policy (CAP) directives, for example, give priority to reducing agricultural production, with a view to reducing surpluses and preventing environmental pollution from agrochemical products.

With respect to the environment, soil degradation problems (e.g. contamination and erosion) are of high priority, as recognised recently by the European Environmental Agency (EEA, 1998), which reported that this major environmental problem was among the ones showing little or no improvement as a result of national policies. There is also concern about the sustainability of some land use practices, as highlighted by the initiative promoting a global "Soil Convention on the Sustainable Use of Soils" at an international level (Catizzone, 1998)

Therefore, it is difficult to reconcile the failure of governments and national and international institutions to promote research into soil resources and to create an inventory of them. Recent years have seen a marked decline in national funding for soil mapping and other pedological activities, both in Spain and other countries of the European Union. This trend is paradoxical inasmuch as society currently demands greater, more diversified information about its natural resources (Zinck 1990; Ibáñez *et al.* 1993). Yet over the last few years both the RTD Framework Programmes of the European Union (including that approved in 1999) and those of many of its member countries (e.g. Spain) do not address directly the need for ongoing basic research into the nature, properties and distribution of soils. Likewise, important international programmes (e.g., IGBP) either ignore basic research concerned with the structure and dynamics of the pedosphere, or treat them as an accessory (Ibañez *et al.* 1994, 1997, Catizzone 1998).

Somewhat paradoxically, part of this decline in funding for research into the nature, properties and distribution of soils is related to this increasing awareness about environmental degradation and the unsustainability of some current practices. The attention of governments and funding organisations is drawn to treating these problems rather than to ensuring that there is a solid future base of information about the national soil resource for adequately addressing current and future problems.

Many more resources are available for researching soil erosion and contamination, for instance, than for understanding the nature and distribution of soils (Ibáñez *et al.* 1997). The public interest in environmental problems has led to this paradox. Yet it is difficult to advance in the struggle against the degradation of a resource if there is a lack of basic knowledge of its structure and dynamics. In these circumstances, many works of applied research can be expected to fall short of achieving their objectives. The current situation is one of 'firefighting' rather than one of well reasoned approach to what is required for the future sustainability of the pedosphere.

Over the last few years, several papers and notes have been published, which recognise and analyse the neglect that has occurred in recent years in developing an adequate soil research policy (Dudal 1987; Nachtergaele 1990; Jacob & Nordt 1991; Hudson 1992; Miller 1992, 1993; Sposito & Reginato 1992; Warkentin 1992; Zinck 1993; Notohadiprawiro 1993; Gardner 1991, 1993; Greenwood 1993; Ibáñez *et al.* 1993, 1994, 1997; Bouma 1994; British Society of Soil Science, 1994; Bullock 1994; Bridges & Catizzone 1996; Yaalon 1996, 1997; Basher 1997).

A New Paradigm for Pedology and Soil Survey

In the light of the foregoing, it is essential that pedology and soil survey develop and evaluate new conceptual, methodological and technological tools. Since a detailed description of these topics is beyond the scope of this paper, readers interested in them are referred to the reviews made by Zinck (1990, 1993), Ibáñez *et al.* (1993, 1994) and

Basher (1997), as well as the monographs published by Mausbach & Wilding (1991) and Bryant & Arnold (1994). However, a provisional but non-exhaustive list of new requirements, and tools and technologies for satisfying them are given below.

New Requirements

1. Better understanding of the spatial variability of soil properties and pedodiversity of soil taxa.
2. Better understanding of temporal changes in soil properties (research on soil monitoring methods).
3. Improvements in cartographic representation of the pedosphere including types of boundaries between map units, less overemphasis on non-spatial taxonomic entities (i.e. towards a classification of spatial and functional soil bodies rather than current pedotaxa, etc.).
4. Improvements in the presentation of soil information, e.g. in an accessible, purpose-orientated, user-friendly language and format.
5. Rationalisation of the current excessive jargon used to name and classify soils in soil map legends and reports, and the range of schemes used for classifying soils.
6. Mapping of soilscape functional units rather than conventional soil associations: characterisation of soilscapes into areas where soils, hydrology, and landform attributes are products of common processes of formation and function in an integral manner.
7. Better techniques for designing sampling schemes for soil mapping and spatial analysis of the pedosphere.
8. Better characterisation of regoliths to depths below those traditionally considered in the soil survey and classification to address issues such as interactions between soil management and groundwater contamination, suitability for waste disposal, erosion vulnerability, etc.
9. Mapping of soil properties in addition to pedotaxa for simulation modelling and land evaluation procedures.
10. Improved knowledge of the effect of land management on soil properties in order to plan sustainable use of soil resources and environmental protection. Development of indicators of soil vulnerability.
11. Improvements in the identification of soil health indicators (or soil quality), particularly those that can be used in the field by land users.
12. Identification of keystone soil properties (pedo-indicators) that determine soil functioning and influence soil use.
13. Improvements in mathematical tools for scaling soil data from site-specific to regional and global territories.
14. Developing the knowledge of the structure and dynamics of the pedosphere at global level (global soil change).
15. Better interpretation of the paleo-environmental record contained in soils and regoliths (indicators of past climatic changes, and long-term landscape instability, using soils as relative dating tools, stratigraphic markers, etc.).
16. Improvement of our understanding of the role of pedosphere in the global climatic system; interactions with other sub-systems.
17. Study of the soil-plant-atmosphere continuum for climatic and agroclimatic modelling.
18. Conservation of unaltered benchmark soils in networks of natural reserves for research activities and preservation of soil biodiversity and pedodiversity.

Technologies

1. GIS and nested soil databases for building Soil Information Systems (SIS).
2. Quantitative numerical modelling of soil processes. Implementation of SIS, including expert systems based on cellular automata and neural networks, etc.
3. Research on non-invasive inventory techniques, such as: DEMs, GPR, GPS, electromagnetic induction, and airborne and satellite remote sensing tools (e.g., gamma-ray spectrometry).

Conceptual and Mathematical Tools

1. Chaos theory (synergetics, non-equilibrium thermodynamics, percolation theory, theory of non-linear systems, self-organised criticality, etc.).
2. Fuzzy logic methods for analysing continuous soil variation and fuzzy soil classification schemes (pedosphere as a continuum entity).
3. Theory of hierarchical systems.
4. Fractals and other relevant techniques for the analysis of scale invariant structures, patterns and processes.
5. Spatial analysis (e.g., geostatistical tools and auto-correlation analysis).
6. Temporal analysis (time series analysis) and temporal GIS

New Focus

1. Transition of the current paradigm (soil use as a medium for agriculture) to another based on

the consideration of soils as a basic natural soil resource, as well as a component of ecosystems, a repository of waste disposal, an ameliorator of water quality, a medium for bioremediation and engineering uses, a source of environmental, paleo-environmental (paleopedology) and cultural (soil geo-archeology) information.

2. A more holistic approach to soil system structure and function, as well as to soil management.

In addition funds for conducting research into soil-landscape models, soil geomorphology and soil stratigraphy (current basis of soil survey activities) need to be made available.

Conclusions

Spain has experienced a serious decline in resources for soil survey in the past few years. The absence of a National Soil Survey Organisation and the temporal discontinuity of survey programmes (frequently caused by short-term contracts) aggravates this decline.

Decentralisation policies in matters of agriculture and the environment have given rise to very disparate situations within and without regions and led to products (e.g. soil maps, soil databases) drawn up from with different approaches from territory to territory. Consequently, as Boixadera & Ibáñez (1996) pointed out, many of the old problems remain, such as lack of coordination, different standards and methods between regions, uneven correlation, different scales of mapping, difficulty with the availability of information, variable long term programmes, etc.

The PNCTA programme described above could solve some of the severe problems affecting soil information compilation. However, suspension of this Programme after the pilot stage had been completed raises serious doubts about its future.

Currently, on a national and even a regional level, the only soil monitoring initiatives of which the authors are aware are those on soil erosion, coordinated and funded by the Ministry of the Environment through the RESEL Network.

References

Ayala, F.J. (1995). La Ciencia española en la última década. Política Científica, 43, 5-12.

Barros, J.M.C. de, (1997). Quantitative analysis of selected land use systems with sunflowers. Doctoral thesis. Wageningen Agricultural University, Wageningen, The Netherlands (viii)+169 pp, 65 tbs, 67 figs, 4 annexes (on diskette), 62 refs, English and Dutch summaries. ISBN 90-5485-665-3.

Basher, L.R. (1997). Is pedology dead and buried?. Australian Journal of Soil Research, 35, 979-994.

Boixadera, J. & Porta, J (dir). (1991). Información de Suelos y Evaluación Catastral: Método del Valor Índice. C.G.C.T. Monografías 3. Ministerio de Economía y Hacienda. Madrid, Spain, 151pp.

Boixadera, J. & Ibáñez, J.J. (1996). Soil survey and soil databases in Spain. In *Soil Databases to Support Sustainable Development.* C. Le Bas & M. Jamagne (eds). European Soil Bureau Research Report No. 2. EUR 16371 EN, p.99-105.

Bouma, J. (1994). Sustainable land use as a future focus for pedology? (a guest editorial). Soil Sci. Soc. Am. J., 58, 645-646.

Bridges, E.M. and Catizzone, M. (1996). Soil science in a holistic framework: discussion of an improved integrated approach. Geoderma, 71, 275-287.

British Society of Soil Science. (1994). The decline in soil science? BSSS Newsletter, 24, 6-7

Bryant, R.B. & Arnold, R.W. (eds.). (1994). Quantitative Modeling of Soil Forming Processes. SSSA Special Publication n° 39, Madison, Wisconsin, 185pp.

Bullock, P. (1994). The need for a paradigm change in soil science in the next century. Trans. 15th World Cong. Soil Sci., Acapulco, Mexico, 9, 427-436.

Carrera, C. (1998). Implantación de un Sistema de Información Geográfica en el Centro de Ciencias Medioambientales (CSIC). Proyecto Fin De Carrera, ETSI Geodésica, Cartográfica y Topográfica, UPV, Valencia, 171pp.

Catizzone, M. (1998). For an agreement on the soil. 16° World Congress of Soil Science, Volume with the Introductory Conferences and Debate (pp.118), Montpellier (20-26 August), France

De la Rosa, D. (coord) (1996). MicroLEIS 4.1: Microcomputer-based Land Evaluation Information System. Integrated system for land data transfer and agro-ecological land evaluation. Software + Documentation. CSIC-IRNAS Pub., Seville. http://irnase.csic.es/microlei.htm.

De la Rosa, D. and J. Crompvoets. (1998). Evaluating the Mediterranean soil contamination risk in selected hydrological change scenarios. Agriculture, Ecosystems & Environment 67: 239-250.

Díaz-Fierros,F. (1979). Análisis estadístico y Sociométrico de la Ciencia del Suelo. Anal. Edaf. Agrobiol. 38, 331-347

Diaz-Fierros, F. (1997). Apuntes históricos sobre la edafología española. El periodo anterior a la Guerra Civil. 50 Aniversario de la Sociedad Española de la Ciencia del Suelo, 1947-1997. (volúmen de ponencias), (24-26 de Septiembre, 1997). p.17-24.

Donezar, M. (1981). Caracterización y Aprovechamiento Integral de los Suelos del TM de Viana (Navarra). Tesis Doctoral. ETSIA-UPM, Madrid, Spain, 314pp.

Dudal, R. (1987). The role of pedology in meeting the increasing demands on soils. Soil Survey and Land Evaluation, 7:101-110.

European Environmental Agency (EEA). (1998). Europe's Environment: The Second Assessment. Luxembourg, 293pp.

FAO-UNESCO, (1971-1981). Soil Map of the World, 1:5,000,000. Vols 1-10. Paris, UNESCO.

FAO (1988). FAO-UNESCO Soil Map of the World: Revised Legend. FAO World Soil Resources Reports nº 60, Rome. 119pp.

FAO-ISRIC-CSIC. (1995). SDBm: Multilingual soil database. World Soil Resources Report No. 81. FAO, Rome.

Gardner, W.R. (1991). Soil science as a basic science. Soil Sci., 151, 2-6.

Gardner, W.R. (1993). A call for action (a guest editorial). Soil Sci. Soc. Am. J., 57, 1403-1405.

Gonzalez-Rebollar, J.L. García-Alvarez, A & Ibañez, J.J. (1995). A mathematical model to predict climate change in Mediterranean Bioclimate Landscapes. In: S. Zwerver, R.S.A.R. van Rompaey. M.T.J. Kok & M.M. Berj (eds.) Climate Change Research: Evaluation and Policy Implications (p.757-762). Studies in Environmental Sciences No. 56B, Elsevier, Amsterdam.

Greenwood, D.J. (1993). The changing scene of British soil science. J. Soil Sci., 44, 191-207.

Guerra, A. 1997. Historia de la Sociedad Española de la Ciencia del Suelo. 50 Aniversario de la Sociedad Española de la Ciencia del Suelo, 1947-1997. (volúmen de ponencias), (3-16 de Septiembre, 1997). p.25-66.

Hodgson, J.M. (ed.). (1991). *Soil Survey -A Basis for European Soil Protection.* Soil and Groundwater Research Report, (p. 81-90), EC, Brussels-Luxenbourg. 214pp.

Hudson, H.D. (1992). The soil survey as paradigm-based science. Soil Sci. Soc. Am. J., 56, 836-841.

Ibáñez, J.J., Rubio, J.L., López-Lafuente, A. & Monturiol, F. 1991. State of soil mapping in Spain. In: Hodgson,J.M. (Ed.). Soil Survey -A Basis for European Soil Protection. Soil and Groundwater Research Report, 1. EC, Brussels-Luxenbourg. p.81-90.

Ibáñez, J.J., Zinck, J.A. and Jiménez-Ballesta, R. (1993). Soil survey: old and new challenges. ITC Journal, 1993-1, 7-14. (Holland).

Ibáñez, J.J., García-Alvarez, A. & Boixadera, J. (1994). Current Paradoxes in Soil Survey. 1st Meeting of the Soil Information Focal Point's EU-Working Group on Soil Information System Development, Hannover.

Ibáñez, J.J., Méndez, I., Martín-Sempere, Mª.J., Plaza, L. & Rey, J. (1997). La edafología en el CSIC: evolución o involución. Productividad y política científica en los antiguos centros relacionados con la edafología y agrobiología durante el periodo 1980-1995. 50 Aniversario de la Sociedad Española de la Ciencia del Suelo, 1947-1997. (volúmen de ponencias) 24-26, de Septiembre, 1997). p.25-66.

ITGE (1997), Pedological cartography of Page 1034 (Lebrija). National Environmental Theme Cartography Plan. Technological and Geomining Institute of Spain (Unpublished). Madrid.

Jacob, J.S. and Nordt, L.C. (1991). Soil and landscape evolution: a paradigm for pedology. Soil Sci. Soc. Am. J., 55:1194.

Le Bas, C. & Jamagne, M. (eds). (1996). Soil Data Bases to Support Sustainable Development. EU-JRC & INRA France. 149pp.

Mausbach, M.J. & Wilding, L.P. (eds). (1991). Spatial Variabilities of Soils and Landforms. SSSA Special Publication nº 28, Madison, Wisconsin 270pp.

Miller, F.P. (1992). Soil science: should we change our paradigm?. Bull. ISSS 81, 26-27.

Miller, F.P. (1993). Soil science: a scope broader than its identity (A guest editorial). Soil Sci. Soc. Am. J., 57: 299 and 564.

Montoya, R. & López-Árias, M. (1998). La red Europea de Seguimiento de Daños en los Bosques (Nivel 1); España, 1987-1996 (including a soil database on CD-ROM) O.A.

Parques Nacionales, Ministerio de Medio Ambiente, Madrid. 557pp.

Mudarra, J.L. (1989). Situación actual de la cartografía de suelos. Ponencia invitada a las Jornadas sobre Cartografía de Suelos y Planificación Regional. Spanish Soil Science Society. Madrid, Spain.

Mudarra, J.L. (1994). Referencias históricas de la cartografía de suelos y perspectivas de futuro. Conferencia de Clausura del XXI Curso Internacional de Edafología. Sevilla, Spain.

Nachtergaele,F. (1990). Soil surveyors: an endangered species. Soil Survey Horizons, 31, 83-84

Nielson, D.R. (1987). Emerging frontiers in soil science. Geoderma, 40, 267-273.

Notohadiprawiro, T. (1993). Rethinking soil science paradigm. In: New Ways in Soil Science. ITC Publ. Nº. 4, 4-16. ITC, Ghent, Belgium.

Pascual, J.A. (1997). El Arca de la Biodiversidad: De genes, Especies y Ecosistemas. Celeste Ediciones, Madrid, 366pp.

Reale, L., Nori,M. and Ferrari, G (ed.). (1995). Holistic Approach to Sustainable Development: Interactions of Soil Science with Different disciplines. EU, DG XII & ASTER, Florence. 117 pp.

Rey, J., Martín,. M.J., Plaza, L., Ibañez, J.J. y Méndez, I. (1998). Changes on publishing behaviour in response to research policy guidelines: The case of the Spanish Research Council in the field of agronomy. Scientometrics, 41: 101-111.

Rojo-Serrano, L & Sánchez-Fuster, M. (Coor), (1997). *Catálogo de estaciones - 1996. Red de Estaciones Experimentales de Seguimiento y Evaluación de la Erosión y Desertificación.* Ministry of the Environment. Madrid. 121pp.

Simonson, R. (1991). Soil science-goals for the next 75 years. Soil Sci., 151, 7-18.

Soil Survey Staff (1995). Claves para la Taxonomía de Suelos, versión 1994. Traducción de: Carlos A. Ortiz Solorio, Ma. del Carmen Guitierréz Castorena y Jorge Luis García Rodríguez. Primera Edición en Español. 1995. Publicación Especial 3. Sociedad Mexicana de la Ciencia del Suelo (SMCS). Chapingo, México, 306pp.

Sposito, G. and Reginato, R.J. (1992). Opportunities in Basic Soil Science Research. Soil Sci. Soc. Am., Madison, Wisconsin. 109pp.

Sunyer, P. (1996). La Configuración de la Ciencia del Suelo en España (1750-1950). MAPA, Madrid. 612pp.

Warkentin, B.P. (1992). Soil science for environmental quality: how do we know what we know? J. Envir. Qual., 21, 163-166.

White, R.E. (1993). The role of soil scientists in shaping policies for sustainable land management. Soil News 93, 1-4.

Wild, A. (1989). Soil scientists as members of the scientific community. J. Soil Sci., 40, 209-221.

Yaalon, D.H. (1996). Soil science in transition: soil awareness and soil care research strategies. Soil Sci., 161: 3-8.

Yaalon, D.H. (1997). Soil science in transition. Soil awareness and soil care research strategies (in press).

Zinck, J.A. (1990). Epistemology of a vital discipline. ITC, Enschede, The Netherlands. 40pp.

Zinck, J.A. (1993). Introduction. ITC Journal 1993-1: 2-6.