Final Report

LASOTER

Pilot Area

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1 *INTRODUCTION AND BACKGROUND*

The idea of creating a global soil and terrain digital database (SOTER) was developed in 1985 in a document prepared by Sombroek (15). In 1986 an International Workshop on the structure of a Digital International Soil Resources Map annex Database was held in Wageningen, the Netherlands (1) and that same year, the SOTER Project Proposal (16) was presented. This proposal was endorsed at the 13th International Soils Congress in Hamburg, West-Germany in August 1986 and a formal ISSS Working Group on World Soils and Terrain Digital Database was formed to implement the SOTER Project. During the months following the Congress, contacts were made with possible funding agencies to solicit support for the Project. In 1987 UNEP expressed its interest in SOTER especially if the Project could contribute significantly to the assessment of man-induced soil degradation and during a workshop held at UNEP headquarters in Nairobi, Kenya in May 1987 (18) a Project document was prepared for the initial phase of the SOTER Project and in September a contract was signed between UNEP, ISRIC and ISSS to produce a general soil degradation map of the world at an average scale of 1:10 M and to develop a soils and terrain digital database at a scale of 1:1M for an area of about 250.000 km^2 including portions of Argentina, Uruguay and Brazil (LASOTER).

In this pilot area the methodology for creating a soils and terrain digital database developed by Shields and Coote (14) was tested and special attention was paid to the assessment of the status of human-induced soil degradation. Scheduled originally for completion on 31 December 1989, the LASOTER Project has made excellent progress with the following activities:

1. Preparation, printing and distribution of the first version of the SOTER Procedures Manual (14).
2. First Regional Workshop on a Global Soils and Terrain Digital Database and Global Assessment of Soil Degradation. This meeting was held in Montevideo, Uruguay, from 20 to 25 March 1988 (9). The main objectives of this workshop were:
   - a: to discuss the SOTER concept with soil scientists from the participating countries and introduce them to the use of the SOTER Procedures Manual.
   - b: to discuss the possibilities of the LASOTER pilot area and to prepare an implementation plan for its development and execution.
3. First Correlation Meeting and Field Trip into the LASOTER pilot area from 6 to 19 June 1988 (10). The objective of this activity was to test the workability of the SOTER Manual and to discuss and improve it.
4. Second Correlation Meeting and Field Trip into the LASOTER pilot area from 25 August to 1 September 1988 (11). The objective of this activity was to refine class and polygon definitions and to discuss man-induced soil degradation in the area.
5. Second Regional Workshop on a Global Soils and Terrain Digital Database and Global Assessment of Soil Degradation. This meeting was held in Porto Alegre, Brazil, from 12 to 16 December 1988 (12). During this meeting the final correlation problems were discussed and solved and the results of the activities of data acquisition and compilation were presented.
6. Final phase of compilation, correlation and coding of attribute data. The dataset of the LASOTER pilot area was completed and transferred to the ISRIC to be entered into the SOTER Database in the first half of 1989.

This report deals with the activities in the LASOTER pilot area and its content consists of a short description of the most relevant aspects of the area, a description of the methodology used to acquire, compile, correlate, translate and code the information on soils, terrain and climate that was available in the three countries participating in the Project. For more detailed information on the general aspects of the LASOTER pilot area reference is made to the source reports and maps and the final reports of the national correlation teams of Argentina, Uruguay and Brazil. Detailed information on soils, terrain, climate and landuse of the LASOTER pilot area is stored in the SOTER Database where it is freely available for use. A special chapter describes the most important aspects of human-induced soil degradation in the LASOTER pilot area.

2 GENERAL DESCRIPTION OF THE AREA

2.1 Geographical Location

The LASOTER Pilot area is located within coordinates 54°-60°W longitude and 28°-32°30'S latitude (figure 1) and covers portions of Argentina, Brazil and Uruguay. The Argentinean part of the pilot area consists of important portions of the Provinces of Entre Rios and Corrientes and small portions of Santa Fe and Misiones. This area represents 46% of the whole pilot area, that covers 286.848 km². The Uruguayan part consists of the Departments of Artigas, Salto, Paysandú, Tacuarembó, Rivera and part of Cerro Largo in the northern half of the country and totals some 67.000 km², a little less than 25% of the whole pilot area. The Brazilian part covers the eastern part of the State of Rio Grande do Sul and represents a little more than 25% of the pilot area. The pilot area's altitude above sea level ranges between 20 m.a.s.l. in the Southwest and 500 m.a.s.l. in the Northeast.

2.2 Geology

The most important events that have contributed to the geological development of the LASOTER pilot area have been the epirogenetic movements related with the formation of the Andes since the Cretaceous that ended at the boundary between Pliocene and Pleistocene. Uplifting and consequent erosive processes have formed a typical dissected landscape (peneplain) of mainly Tertiary and Cretaceous formations sometimes even older. In the western (Argentinean) part of the area a thick cover of eolian material (loess) has been deposited during the Pleistocene and the actual landscape is dominated by these sediments. Landscape formation during Pleistocene and Holocene included erosion and redeposition of these materials that suffered some transformation into secondary loess-like materials (limo calcáreo) (2). In this part of the pilot area the landscape consists mainly of flat to gently undulating very uniform peneplains (the eolian sediments) and flat colluvial-alluvial plains (colluvial loess and alluvial material). In the northeastern part of the Argentinean portion of the pilot area these eolian deposits give way to formations of Tertiary and Cretaceous age that fade into Uruguay, where almost half of the pilot area section consists of materials of the Arapuey formation of Cretaceous (7). This formation consists of basaltic lavaflows and eolian sandstones. Towards the East within Uruguay the oldest formations in the pilot area of Triassic, Jurassic, Permian and Precambrian age are found. The landscape on these materials is dissected and quite different from the almost flat sedimentary peneplain on Cretaceous sandstones in the southwestern part of the Uruguayan portion of the pilot area. The Brazilian part of the pilot area is dominated by formations of Triassic age. The most important are the Botucatú formation that consists of sandstone mainly and the Rosario do Sul of sandstone, siltstone and claystone that are alternating with lavaflows in the Northeast of the Sierra Geral formation (3). The general landscape in this area is dominated by undulating and rolling peneplains at different levels. Quaternary sediments occur in the valleys of the main rivers like Paraná and Uruguay and its tributaries.

2.3 Geomorphology

In the western part of the study area the main morphodynamic processes related to tectonic movements until the Pleistocene intensified water erosion and the formation of river valleys. During the Pleistocene sedimentation of eolian materials dominated and the extensive peneplain dissected by the Paraná and Uruguay rivers and its tributaries was formed. This extensive unit can be subdivided in the low flat poorly drained plain in the North of the Province of Corrientes and the undulating well-drained peneplain in the southern part of the Province of Corrientes and in the Province of Entre Rios. According to the SOTER attribute definitions the predominant land form in this area is: <u>Plain</u>. Also <u>Valley</u> occurs locally in the main river valleys. The most important surface forms are <u>Level</u> and <u>Undulating</u>. In general the Argentinean part of the pilot area is characterized by very extensive homogeneous units.

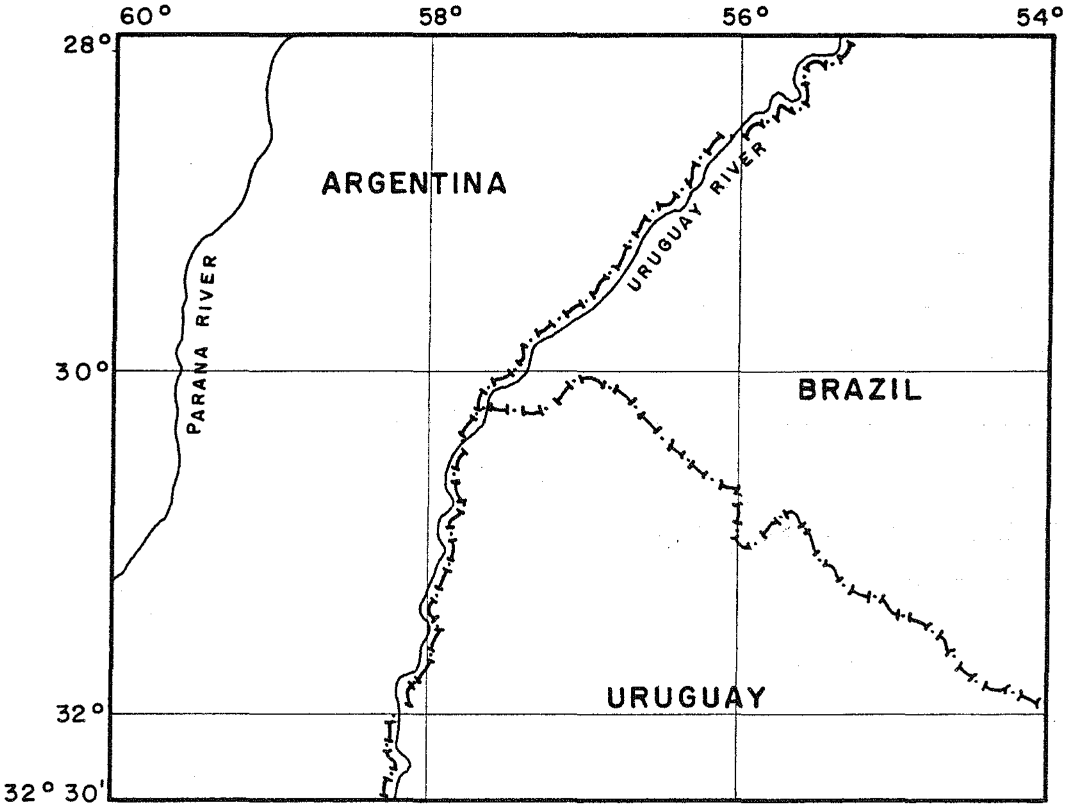

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Fig. I _ Geographical location of the LASOTER pilot area

Eolian influence has not been very important in the Uruguayan portion of the pilot area where morphodynamic processes have been determined mainly by the pre-existing geological structure. The most important geomorphological units are characterized by tectonic movements and the kind of geological formations present. In the West the dominant unit is a gently undulating area of sediments limited by the basaltic materials of the central part that present a uniform slope grading upwards to the East towards a rather irregular area of older sediments dissected by the Negro and Tacuarembó rivers. The most important land forms and surface forms according to the SOTER Procedures Manual in this part of LASOTER are: Plain, Upland, Tableland and Valley with the following surface forms: Level, Undulating, Rolling. In general the geomorphological units are more heterogeneous than in the Argentinean part.

A similar situation is found in Brazil where the pilot area section is dominated by the extensive undulating and rolling peneplain of Missoes, Campanha and Araucarias on Triassic formations and the central depression sculpted by erosion processes presenting a local relief of elongated hills (coxilhas) (2). Most common land and surface forms in the Brazilian section of the pilot area are: Upland, Tableland, Hill, with: Undulating, Rolling, and Steep surface forms.

2.4 Topography

The most common landforms in the pilot area are plains, uplands, tablelands, hills and some valleys with flat, undulating, rolling and sometimes steep, surface forms. A general tendency exists of increasing height above sea level form the lowest part in the poorly drained alluvial plain of the Paraná river in Argentina at about 20 m.a.s.l. to the highest part in Rio Grande do Sul in the Missoes peneplain (upland) at about 500 m.a.s.l.

Slope gradients show the same tendency ranging from 0-4% in Argentina to 16% in the eastern part of Uruguay and Brazil. Slope length ranges from 300 to 1000 m in the eolian plains of Argentina to 50 to 300 m in the eastern part of the pilot area where locally sharp ridges occur (3).

2.5 Hydrography

The most important watersheds in the LASOTER area belong to the Paraná river in the western part of the Argentinean section and the Uruguay river in the eastern part of Argentina, the western half of the Uruguayan portion and the northeastern part of the Brazilian section. Only the southeastern part of the pilot area including portions of Uruguay and Brazil drains into the Jacuí river.

2.6 Climate

The entire study area is located within the Climatic Zone C according to the Köppen Climate Classification System: rainfed temperate where the mean temperature of the coldest month ranges between 12 and 16°C and the Climatic Type Cf: moist temperate climate.

The general characterization of this climatic type is (2):

Cfw'a where:

C = warm temperate
f = without dry season
w' = maximum autumn rainfall
a = hot summers with the hottest month temperature higher than 22°C.

Only in the southern part of the Brazilian portion of LASOTER at higher altitudes the climate changes to Cfw'b with the hottest month temperature below 22 °C.
Although winters are relatively mild groundfrosts may occur mainly in the southwestern part (Argentina and part of Uruguay) from May to October with temperatures that may reach as low as -4°C.

A general tendency of the rainfall exists from the Southwest to the Northeast. In the Southwest the rainfall is about 900 mm and increases gradually to the Northeast reaching levels of 1700 mm in Brazil. In the same direction a temperature gradient exists.
The coldest month, July, varies from 12°C in Argentina to 16°C in Brazil and the hottest, January, from 25 to 27°C (mean values).
The rainfall is distributed evenly during the year although a negative water balance may occur locally from mid-spring to late summer that may cause depression in crop yields. Short but intensive rainstorms are typical and these heavy concentrated showers combined with the low permeability of the soils and the gently undulating topography in the western part of LASOTER cause a considerable run off. In the eastern part with steeper slopes these showers of very high intensity cause serious erosion problems.

2.7 Vegetation

The dominant natural vegetation type in the LASOTER area is natural grasslands of the temperate zone that cover extensive parts of Argentina (Pampaen prairie), Uruguay (Pradera or Herbazal), and the southern part of Brazil (Campanha) representing a very rich graminoid herbaceous structure of hundreds of species. Some remnants remain of mixed woodland-grasslands mainly along the rivers, but most of the original forested savannahs with galleries of trees along the rivers have disappeared as a consequence of human activity (charcoal burning). Wet grasslands occur in the poorly drained alluvial plain mainly in Argentina. In the northeastern part of the study area in Brazil some insignificant remnants remain of a subtropical forest vegetation (Floresta Estacional Decidual). In most of the pilot area under agriculture or grazing most of the original vegetation has completely disappeared and only in some isolated patches e.g. along the rivers and on plateau scarps the original vegetation can be found.

2.8 Land use

The traditional land use in the study area is grazing of natural grasslands that still occupies approximately 60% of the total extent. Grazing is often combined in a mixed land use unit, livestock production combined with agriculture based on forages and annual crops like linseed, sorghum, soybean and cereals. This type of land use is common in Argentina and the western part of Uruguay. In the eastern part of Uruguay annual crop production is covering about 25% of the total area and it is concentrated mainly on the deep soils. Main crops are corn, wheat and soybean. About 60% of the area is used for grazing. The remaining part of this area is used for extensive grazing or is kept under natural or bush vegetation for soil conservation purposes e.g. the plateau scarps. This same land use pattern extends into the Brazilian part of LASOTER.

2.9 Soils

The soils of the LASOTER pilot area can be subdivided into three units:

1. Soils developed in the eolian material in the western part
2. Residual soils on the Tertiary and Secondary formations of the central and eastern parts
3. Alluvial soils in the river plains.

The soils on the gently undulating eolian plains in Argentina belong to the Vertisol and Mollisol orders (Soil Taxonomy) or Vertisols and Phaeozems (FAO). The Vertisols are dominant in the undulating parts of these plains. They present all the typical characteristics like intersecting slickensides, cracks, and gilgai. The topsoil is normally very dark, and presents mollic characteristics. They occur in the landscape associated with Mollisols that show vertic characteristics normally. On the higher slopes Mollisols are found and on the more eroded backslopes where the loess material has been removed and finer textured material is exposed the Vertisols have developed. On concave slopes and in small river valleys some hydromorphic Mollisols occur.

In the central part (Uruguay) the soils pattern is more complicated and heterogeneous because of differences in lithology between the geological formations present. Most of the soils present dark colours down to B or C horizons in those cases where the parent material is sandy. A high organic matter content is common and Mollisols and Vertisols (Brunosols and Vertisol according to the Uruguayan classification system) occur on fine textured calcareous parent materials . Most soils have illuvial clay horizons and these soils that do not have mollic and/or vertic characteristics are classified as Ultisols and Alfisols (Soil Taxonomy) or Luvisols (FAO). A small area of Oxisols (Ferralsols) is found near the Brazilian border. The most developed soils of the study area are located in Brazil on the effusive materials of the Sierra Geral Formation and the sandstones of the Botucatú formation where very deep uniform Oxisols are found (Ferralsols according to FAO and Latossolo roxo y vermelho escuro according to the Brazilian system) and moreover Ultisols and Alfisols (Acrisols and Luvisols according to FAO and Podsolico vermelho escuro and Terra roxa estruturada according to the Brazilian system). In the poorly drained areas, hydromorphic soils are located. In the important river plains (Parana and Uruguay rivers) alluvial soils are found partly recent and poorly drained and partly river terrace soils that are more developed with argillic horizons. On the eroded plateau scarps eroded shallow soils Litosols (Solos Litólicos) are common.

3 *METHODOLOGY*

3.1 *Introduction*

The general methodology used in the LASOTER pilot area is outlined in chapter 3 of the original version of the SOTER Procedures Manual (14). During the Montevideo Workshop an inventory was made of the existing information on soils and terrain of the three countries involved in LASOTER and this appeared to be more than adequate (9). Nevertheless much time was spent afterwards and much work was done on organizing, selecting and normalizing the existing information and adapt it to the criteria of the SOTER Procedures Manual. The source maps, reports and information in general had been produced by three different schools of soil classification and cartography and the general approach of soil survey is different in each of the the three countries. Correlation procedures were of vital importance to unify criteria on map units (polygons), terrain components, soil components, its attributes and classes, and on the general methodology.

In spite of the differences and difficulties it became evident after a very short time that SOTER generates a uniform approach of creating a 1:1M database plus polygon maps.

3.2 *Resources and materials*

The institutional infrastructure was formed by the three national organizations responsible for soil survey in their respective countries: INTA (Instituto Nacional de Tecnología Agropecuaria) in Argentina, EMBRAPA (Empresa Brasileira de Pesquisas Agropecuarias) in Brazil and MGAP (Ministerio de Ganadería, Agricultura y Pesca) in Uruguay. Each of these institutes has sufficient backup to execute this kind of project, like highly qualified professional people, meteorological stations, facilities of interpretation of remotely sensed materials and cartography, laboratories for soil analysis, computer equipment, vehicles etc. The human resources that have been active in the LASOTER area are 11 soil scientists during 10 months supported by 16 regional surveyors, 11 climatologists, 4 cartographers, 8 secretaries and 4 specialists in data handling and processing. Three national working groups or correlation teams, one for each of the three countries involved, were integrated by them. The total of man hours dedicated to LASOTER was 21520 and the total duration of the project including presenting the polygon map and the coded information on soils, terrain, climate and soil degradation was 10 months, from April 1988 to February 1989. Of the total of man hours about 25% was used for field work, the rest for office and laboratory activities (4).

Each of the three countries used existing information on soils, terrain, climate and human-induced soil degradation to produce the polygon maps and the data necessary for the SOTER Database. This information consisted of:

1. Maps and reports of soil surveys at different scales:
   - Argentina: Soil survey maps and reports at 1:500.000 of the whole Argentinean sector of the LASOTER area and at 1:100.000 and 1:50.000 of some parts.
   - Uruguay: Soil survey maps and report at 1:1.000.000 of the whole Uruguayan sector of LASOTER.
   - Brazil: Soil survey maps and reports at 1:1.000.000 (national level) and 1:750.000 (statal level) of the whole area.
2. Thematic maps on geology, geomorphology, water erosion state and hazard, hydrology, vegetation, land use and land use capability.
3. Aerial photographs (1:10.000 to 1:40.000), photomosaics (1:50.000 to 1:100.000), and photo indexes (1:250.000).
4. LANDSAT and SLAR imagery in some areas (1:250.000).

3.3 Implementation and Time Frame

The main objectives of the First Regional Workshop on a Global Soils and Terrain Digital Database held in Montevideo from 20 to 25 March 1988 were (9):

1. Discuss the SOTER Procedures Manual
2. Form national working groups from Argentina, Uruguay and Brazil and a regional correlation team
3. Make an inventory of qualified personnel and the facilities for data processing in the three countries
4. Make an inventory of the existing information on soils, terrain, climate and human-induced soil degradation
5. Prepare an implementation plan for LASOTER including methodology time frame and financial aspects.

The following time frame was prepared (9):
1 April - 6 June 1988. First phase. Gathering and organization of existing information.
6 June - 19 June 1988. First correlation meeting plus field trip.
19 June - 14 Nov. 1988. Continued organization of information.
14 Nov. - 21 Nov. 1988. Second Correlation meeting
21 Nov. - 31 Dec. 1988. Preparation of final output.

The methodology followed during the execution of the implementation of this time frame was the following:

1. During a short meeting immediately after the Montevideo Workshop small areas were selected within each of the three national LASOTER portions. Each of the three national working groups did the organizing, translating and coding of the available information of these small areas according to the SOTER Procedures Manual independently in the period between 1 April and 6 June. The purpose of this exercise was to see if the descriptions and definitions of methodology attributes and its classes in the Manual were sufficiently clear to guarantee a uniform approach at regional level.
2. From 6 to 19 June 1988 the First Correlation Field Trip and Meeting (10) took place with representatives of each of the three working groups the regional SOTER correlator and the author of the first draft of the Manual. This field trip covered those parts of the LASOTER that had been preselected for the exercise mentioned before. The most important conclusions of this meeting and field trip were:
    1. The SOTER Procedures Manual is both workable and applicable;
    2. Correlation trips and meetings are absolutely necessary to unify concepts, definitions, and methodology;
    3. The existing information is sufficient;
    4. The Manual does generate a unifying action because although the three national working groups are of different background using information obtained by different methods the results were similar.

Nevertheless during this same meeting some very important constraints become evident:

1. Laboratory analysis. The methods used for soil chemical, physical and mineralogical analysis in the three countries are different, sometimes the attributes are not the same and the interpretation is variable.
2. Assessment of human-induced soil degradation. Obtaining information is difficult and the consulting of local experts ("expert system") was essential to get adequate data.

After this correlation meeting and after having discussed and solved some problems each group continued the organization, translating and coding of the information until 25 August when the Second Correlation field trip and meeting took place (11).

During this second meeting and field trip the results were compared and some minor problems were solved. Special attention was paid to the assessment of human-induced soil degradation and the main conclusions were:

1. The degradation assessment according to the SOTER Procedures Manual is possible but much field work must be done and the "expert system" is essential;
2. Correlation is of vital importance to maintain a uniform approach especially if the description of classes is qualitative.

The remaining part of the translating and coding was carried out between 1 September and 12 December. The results were presented during the Second Regional Workshop held in Porto Alegre form 12 to 15 December 1988 (12). It became evident that the national working groups had established an excellent regional cooperation and that the activities as planned in the original implementation plan had been accomplished on schedule. All data on soils, terrain, climate and human-induced soil degradation had been collected, organized, translated according to the SOTER criteria and coded. Polygon maps had been prepared. The final results were handed over to be stored into the SOTER Database before the end of March 1989.

3.4 Methods

The general methodology used for delineation of the polygons is described in chapter 3 of the original version of the SOTER Procedures Manual (14). The first step of the series of activities by each of the three working groups are a national level has been the inventory of existing information on soils and terrain that could be of interest for the SOTER approach. This information consisted mainly of soil survey maps and reports at 1:500.000 and 1:1.000.000. After completing the inventory in a small preselected area in each country (see chapter 3.3) this information was adapted to the SOTER methodology in the following aspects:

1. creation of map units for the SOTER map at 1:1M
2. selection of information on soils and terrain and translation of it into the SOTER terminology
3. coding of this information to store it into the SOTER Database.

Source maps were used directly or were reduced photomechanically to the adequate scale and delineations were drawn on a transparent overlay taking into account broad physiographical units, existing mapping units and the basic mapping unit for SOTER of 1 cm^2. In those cases where physiographic legends were used, the coincidence of existing mapping units and SOTER units was almost perfect, in other cases where the source map legend did not include physiographical aspects, remotely sensed materials were used to create the SOTER map unit distribution pattern. In practice in the LASOTER area, the correlation between map units of the source maps and SOTER unit was very good in Argentina, a little bit less in Uruguay and Brazil where physiographic aspects are not or to a lesser extent taken into account for legends of soil maps. Other source maps and remotely sensed materials were used to delineate the SOTER units and field work was quite elaborate in those cases.

The SOTER map units were defined mainly on:

1. landform and surface form
2. slope gradient
3. parent material
4. textural class of parent material

Soils information was not used as a differentiating criterion as is described in the original version of the SOTER Manual (14). After delineating the map units in the small preselected areas, the attributes classes of each map unit were determined and coded for the polygon file, terrain component file, and soil layer file.

During the first correlation meeting and field trip the results from the three countries were compared and correlated and a series of problems of interpretation were solved. Moreover, a number of modifications of the SOTER Procedures Manual was proposed (10) in order to facilitate the systematic and uniform approach of the whole LASOTER area. Definitions of a number of attributes and attribute classes were improved to avoid duality and misunderstanding.

After having unified criteria the whole LASOTER area was executed. During the second correlation field trip and meeting the last problems were discussed and solved and special attention was paid to soil degradation. The assessment of soil degradation induced by human activity proved to be rather complicated because very little organized information does exist. In many cases the consulting of local experts was necessary and field checks had to be done. The main problem in the assessment of human-induced soil degradation is its relation with terrain components and land use rather than with SOTER map units. For assessment and coding of soil degradation the GLASOD guidelines were used (8). In this same period binational correlation meetings were organized between the three national working groups to guarantee correlation in the border areas, mainly in those areas with 'dry' borders. After finishing this systematical approach of the whole LASOTER area the SOTER map was transferred to stable based ONC sheets to be digitized afterwards. The information on attributes was delivered on coding sheets to be introduced into the SOTER Database. The final results of LASOTER activities were presented during the Second Regional Workshop (12).

During the execution of the LASOTER pilot are the vital importance of a well functioning correlation became evident, because although the definitions of attributes and attribute classes are as precise as possible, in those cases where these definitions and descriptions are qualitative different interpretations are possible (13).

A special study on the application of remotely sensed materials in the delineation of map units according to the SOTER methodology and in the assessment of human-induced soil degradation in the LASOTER area was carried out by a MSc student of the ITC in Enschede, the Netherlands (2).

3.5 Constraints

Although the general methodology as proposed in the SOTER Procedures Manual proved to be both workable and applicable some constraints became evident.

1. Each of the three countries involved in LASOTER is using a set of laboratory analysis methods that is different. Between Argentina and Uruguay some differences exist in laboratory methods, but in general the chemical and physical attributes determined in soil chemical and physical analysis are comparable. Brazil has its own soil classification system and uses a unique set of parameters to characterize chemical, physical and mineralogical properties of soils. For the moment this information has been stored into the data base including complete information on the laboratory where the analysis has been carried out, the laboratory methods used and the interpretation of the results.
2. Many attributes required for the SOTER Database, mainly those related with physical soil properties are not available and in this case estimated values must be used, that will be stored and labeled as such to be deleted afterwards as soon as real data become available.
3. The concept of soil layer versus soil horizon (genetic) did cause some problems. In some cases soil horizons were equal to soil layers, in other cases there was confusion about similarity or dissimilarity between the two concepts.
4. The assessment of human-induced soil degradation was a rather time consuming aspect of the LASOTER activities. The main problems were: lack of information and the apparent relation between land use, terrain component and human-induced degradation, that makes correlation at map unit level difficult because per map unit several terrain components and several different kinds of land use may occur.

4 HUMAN-INDUCED SOIL DEGRADATION

4.1 Introduction

Human-induced soil degradation is the process describing the phenomena caused by man which lower the current and/or future capacity of the soil to support human life.

The main factor to be considered when evaluating soil degradation induced by man is land use. Other degradation factors are: climate, terrain (geology, geomorphology, topography) and soils. Within the LASOTER area the main soil degradation types are water erosion and physical soil degradation. Other degradation types occur locally (wind erosion, chemical degradation) but are of less importance.

The degradation status of the soils of the LASOTER area has been assessed using the GLASOD guidelines (8) that were used for the 1:10M soil degradation map of the world. First the degradation types were determined and afterwards its degree, extent, causative factor(s) and its recent past rate.

The three countries involved in the LASOTER project present different natural conditions of climate, terrain and soils and different land use patterns. Nevertheless some general tendencies do exist in degree, extent, rate and causative factors that will be discussed. Before entering into detail a clear differentiation must be made between natural degradation and human-induced degradation of soils. For instance water erosion may be defined as the result of the natural combination of external geodynamic factors that after acting upon the earth surface during a relatively long time transform it into a stable landscape. This natural landscape equilibrium can be disturbed by accelerated erosion caused by human interference giving origin to human-induced degradation of soils.

4.2 General aspects of the area

In chapter 2, the important general aspects for soil degradation are described and only a short description of the most relevant aspects will be given here. The principal natural factors intervening in soil degradation are the following:

1. Climate (rainfall intensity, duration and total)
2. Terrain (relief and slopes)
3. Soils (erodability or erosion susceptibility, and infiltration).

1. Climate

The determining climatic element in degradation and specifically water erosion is rainfall and its most important aspects are intensity and duration which determine run off and rainfall erosivity. The yearly rainfall in the LASOTER area shows a clear tendency of increasing from the Southwest to the Northeast from 900 mm in Argentina up to 1700 mm in Brazil. The yearly run off follows this same pattern from 200 mm Argentina to 600 mm in Brazil. The showers are of a high intensity particularly in spring and autumn. According to information available in Argentina and Uruguay rain erosivity shows the same tendency of increasing from the Southwest to the Northeast.

2. Terrain

The most important terrain element in water erosion is slope in its two aspects, degree and length. Within the LASOTER area in a very general way the landforms and surface forms show a tendency of increasing slope degree from the Southwest to the Northeast from the level to undulating plains of the Entre Rios Province in Argentina through the undulating and rolling plains and uplands of northern Uruguay into the undulating rolling and even steep uplands and hills of Brazil. Slope length is variable being longest the slopes of the eolian deposits in Argentina and shortest those in the sedentary materials in Uruguay and Brazil.

3. Soils
The soils of the level and undulating plains in the western part of the LASOTER area are generally fine textured because of its predominantly eolian origin. They present vertic characteristics and belong to the orders Vertisol and Mollisol according to Soil Taxonomy, and Vertisol and Phaezoms according to the FAO system. These soils are characterized by a very low infiltration rate that favours run off. Within the alluvial plains of the Paraná and Uruguay rivers young alluvial soils occur partly poorly drained mainly in the northwestern part of the area.
In the eastern half of the LASOTER area soils are more heterogeneous because of differences in lithology and a more pronounced topography. Most of the residual soils are characterized by argillic B or latosollic B horizons. The former is predominant in the Uruguayan part where Alfisols and Ultisols according to Soil Taxonomy, and Planosols, Argisols, Luvisols or Acrisols according to FAO are common. This topography is even more pronounced in Brazil where Oxisols are found in the northern part (Latosols according to FAO) mixed with sandy Ultisols (Acrisols according to FAO) and shallow soils with a lithic contact. Most of these soils of the eastern part of the pilot area have a well developed somewhat compacted B horizon under natural vegetation.

4.3 Land use and degradation

The determining causative factor of human-induced soil degradation is land use. Land use has its effect on soil qualities that might lower the capacity of the soil to produce food and fibre and to support human life.

The traditional land use in the LASOTER area since the sixteenth century has been extensive grazing that did not have too much negative effect upon soil qualities. During the second half of the nineteenth century a great number of immigrants from European origin wandered into the area, mainly from Germany and Italy. Inevitably land use became more intensive and crop production systems European style were introduced. This occurred mainly in the eastern part of the LASOTER area, specially in Rio Grande do Sul. In a very short time the first human-induced soil degradation phenomena became evident. These were caused by soil loss, water erosion and exhaustion (loss of topsoil) (6). The occupational history of the whole study area is responsible for the acceleration of the previously natural erosion processes that had reached an equilibrium situation. An intensive plan of deforestation took place, for instance in Rio Grande do Sul, Brazil, only 3% of the original forest vegetation is left and in the Province of Entre Rios, Argentina, only some forest is left along creeks and waterways.

Intensive agricultural farming systems were introduced and because of this pressure on land use grazing became more intensive, resulting in overgrazing in many cases. The European immigrants imported agricultural management systems that were not suitable for the natural conditions of soils and climate specially in the eastern (subtropical) part of the pilot area, where precipitation is very intensive, and leaving the soil bare for long times is dangerous.

The introduction of chemical fertilizer made the poor soils in the eastern part of the pilot area highly productive and in the first half of this century intensive cropping systems were introduced with "cash" crops like wheat, corn and soy-bean. In the western part occurred the same on the fine textured soils of eolian origin where crops like wheat, linseed, and soy-bean appeared. These management systems included an excessive use of machinery that induced severe soil degradation problems. In the fine textured soils in the Argentinean part of the LASOTER area compaction of the topsoil occurred immediately lowering the infiltration rate of the soils and favouring run off. Because of very slight slope degrees and very long slopes under these circumstances sheet erosion is a common feature in soils with slopes of more than 1% and almost the whole area is affected by this problem. This degradation type is little visible in the field at first sight but it can be detected with auger and spade when making small transects to determine the thickness of the topsoil. On aerial photographs the change in colour tone makes it easy to identify this phenomenon. This degradation type (loss of topsoil, Wt) is not as spectacular as rill and gully erosion but it is a main contributor to soil degradation by water erosion. If sheet erosion intensifies by increasing run off, microchannels are formed and in the case of the Vertisols and

Mollisols of the western part with a very high erodibility without adequate cover in spring and autumn under agricultural cropping system in a very short time rills can be formed. These rills are easily identifiable in the field. They may be permanent or they may disappear after tillage. If the run off increases gullies are formed, that are commonly irreversible and cannot be eliminated by common tillage (terrain deformation, Wd). These permanent degradation phenomena dissect the agricultural land reducing the possibility of easy access.

The coarser textured soils of the central and eastern part of LASOTER suffered similar degradation processes. Overgrazing and intensive use with chemical fertilizer and heavy machinery caused compaction of the topsoil in the Oxisol (Ferralsol) area. With increasing run off the topsoil was removed and in many cases the latosollic B horizon is within the plow layer and with subsequent tillage suffers compaction, that increases run off even more resulting in gully formation.

In the coarse textured Ultisols (Acrisols, Luvisols) with an argillic B horizon overgrazing and intensive agricultural management practices have produced a very spectacular gully erosion pattern that, although it is not very common yet, with only up to 5 per cent of the map units affected, indicates the very high water erosion hazard of these soils under inadequate management. In some cases in this area, agricultural land has been abandoned.

The most important human-induced degradation types that were encountered were:

- Wt: water erosion, loss of topsoil (sheet and rill erosion)
- Wd: water erosion, terrain deformation (rill and gully erosion)
- Pc: physical deterioration, compaction

In some areas but only very locally:

- Et: wind erosion, loss of topsoil
- Cn: chemical deterioration, loss of nutrients.

In many cases the differentiation between natural and human-induced degradation is not easy because very often human-induced degradation is superposed on a natural degradation process. In those cases were an acceleration of natural degradation processes by human intervention was evident the all over process was considered human-induced.

4.4 Methodology

The assessment of the status of human-induced soil degradation in the LASOTER area was concentrated mainly on water erosion and to a lesser degree on soil compaction, that is closely related to it. The evaluation of type of degradation (Wt or Wd), its degree and the extent, was done in the field with the support of local experts that proved of vital importance. The recent past rate was assessed with the help of experts with sufficient local knowledge. Recently published information on the status of human-induced soil degradation did not exist.

For coding, the same criteria were used as in the GLASOD soil degradation map of the world at a 1:10M scale (8). Main problems encountered were:

1. the necessity to do an overall check of the map units to be able to assess the extent of the degradation problem. Point observations were not sufficient and in many cases were not representative;
2. human-induced soil degradation is related to terrain component rather than map unit and the assessment per polygon in many cases causes confusion;
3. much time was necessary in order to be able to consult local experts.

A special study was carried out for a MSc thesis of an Argentinean post-graduate student of the ITC in the Netherlands to check the possibility to develop a methodology to use LANDSAT and SPOT images in human-induced soil degradation status, mainly water erosion, with very good results (2). The level of detail of the information submitted by the local experts did vary from area to area. The information on human-induced soil degradation has been coded and introduced in a special degradation file of the SOTER database.

5 *FINAL REMARKS AND CONCLUSIONS*

The experience obtained during the execution of the LASOTER Project shows that the methodology proposed in the SOTER Procedures Manual to develop a soils and terrain digital database on world level is workable and sufficiently flexible to unify criteria and information on soils and terrain provided by different schools of soil survey and classification. The polygon map and the coded information produced represent the result of a combined action of organizing, translating and coding of three working groups at national level and a well functioning regional correlation. The methodology after some modifications proposed after the correlation field trips and meetings (10, 11) can be considered a useful tool in creating a global soils and terrain database.

The SOTER methodology proved to have a unifying effect upon working groups of a completely different background because the results produced by Argentina, Uruguay and Brazil were completely comparable. A well functioning correlation at internal and external level is of vital importance. This correlation activity includes the normalization of classes of attributes and the definitions, the composition of map units, the drawing of the map and a permanent control of quality. The total are covers 282840 ha and a total of 503 polygons or map delineations were created.

The expert system proved to be of vital importance, particularly in soil degradation assessment and in providing estimated values where laboratory data were not available, for instance physical soil characteristics.

The main problems that came up during the execution of LASOTER were the following:

1. Laboratory analysis. The analytical data available in the three countries were products of different laboratories and sometimes analytical methods. In some cases a set of analytical data was used that was completely different from the others, e.g. in Brazil for taxonomic classification purposes a unique set of physical and chemical data is used. For the moment the data have been coded and introduced into the database with information on the laboratory where the analysis had been carried out and on the analytical methods used. An international programme of correlation of this kind of information is of vital importance.
2. Many data that are required for the SOTER database, mainly physical and chemical characteristics were not available and the expert system had to be used. This information must be deleted as soon as real values become available.
3. Availability of hard and software was desirable in order to facilitate coding and avoid the laborious process of filling out coding forms and matrix tables.

At this moment a group of soil scientists well trained in the SOTER methodology exists and for future SOTER activities this expertise will be of great value. Nevertheless the final part of the training of the members of the three national working groups could not be realized until this moment because of lack of funding to install the necessary hardware and software in the three countries. This software includes the Geographic Information System that will be of vital importance to produce the desired output that will show the utility of the SOTER Database. This output will be essential to get funding for the follow-up activities in the area of influence of LASOTER.

The conclusion of LASOTER has generated a series of proposals for follow-up activities. At a regional level a proposal is being prepared to create a database using the SOTER methodology of the whole watershed of the La Plata River that includes five countries: Brazil, Bolivia, Argentina, Paraguay and Uruguay. At national level the creation of databases according to the SOTER is proposed in Uruguay, Argentina and Brazil.

The SOTER Procedures Manual has proved to be a unique tool for creating a soils and terrain digital database on world level and after testing it on the first pilot areas the methodology is ready for the operational phase of the SOTER Project.

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ANNEXES

1. List of participants

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