Soils of Argentina - Nature and Use

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INTRODUCTION

The soil resources in Argentina have been the main support of economical development in the country. Long lasting periods of large harvests made the country to be called "The world barn". From other latitudes, the name of Argentina was associated with wide plains of everlasting deep, dark soils, able to produce high grain yields and meat of excellent quality.

These concepts are relatively true for the Humid Pampa that occupies somewhat less than one third of the territory, where plains are dominant, formed by modern unconsolidated sediments, with natural grasslands and temperate climate (Hall et al., 1992).

Highly contrasting are the remaining two thirds of the surface of Argentina, most of which are dominated by arid climate. Irrigation has to be applied for crop production, which is only done in the surroundings of the main rivers, or in narrow oases of small extent in the mountainous areas.

The soil studies in Argentina started as a need for producing food crops. Around 1850, cattle production was sufficient for domestic needs but it was necessary to import wheat. There were unsuccessful intents to develop farms with the natives and the government appealed to promote the immigration. For them, it was necessary to know the land quality and some scattered soil data started to be collected without the production of soil maps. In 1898 the Ministry of Agriculture was created with four Secretariats: Agriculture and Cattle, Commerce and Industries, Lands and Colonies and Immigration. Colonisation was promoted and some soil maps were produced on the basis of geological criteria. Between 1930 and 1940 at the same time that big hydroelectric dams were constructed, projects for irrigation areas were developed and the need appeared to know the soils to be irrigated (Gómez y Scoppa, 1994). During the fifties a long drought period occurred, with the concomitant intense wind erosion in the semiarid area and an important decrease in the production of grain crops, which determined a strong tendency to study the soils in order to prevent the desertification. Finally, soil cartography started as a political need for the implementation of a tax reform.

As a consequence, in the sixties, a very ambitious project started towards increasing the knowledge of the soil resource. It was named "Soil Map Project of the Pampean Region" (*Plan Mapa de Suelos de la Región Pampeana*), and was carried out by the INTA (*National Institute of Agricultural Technology*). The output of this project was very prolific in publications. Serves as an example the soil map of the Pampean Region at the scale of 1:50.000 (INTA, 1974-1997).

International aid and the compromise of young professionals from different disciplines (geology, agronomy, geography, soil science, and others) supported this undertaking. The most updated concepts and technologies of that time were utilised in soil genesis, classification and cartography works. Aerial photographs were systematically utilised, as well as the former 7th Approximation (Soil Survey Staff, 1960) as soil classification system and the Land Capability Classification (Klingebiel and Montgomery, 1966) as interpretative system. The soil and landscape studies were dedicated to the Pampean Region (Tricart, 1973; Etchevehere, 1976), but the experience constituted a true school for the specialists in soil classification and cartography. Later on they were the leaders of working groups in different provinces out of the Pampean Region and worked for national and provincial organisations, universities and research centres. In this way, the country counted on a network of specialists utilising a homogeneous methodology adapted to the peculiarities of each region.

Like a corollary, in the eighties under a United Nations Project, the Soil Atlas of Argentina (SAGyP – INTA, 1990) started to be prepared, integrating information about well studied regions because of their high productivity together with others lacking soil cartography because of their low agricultural vocation. The Atlas will be updated in the near future.

Simultaneously, many soil scientists from the universities and other research centres, particularly those working in soil genesis, carried out their postgraduate studies in well known universities from different countries, mainly the United States, Belgium and France. Presently, good postgraduate courses have been developed in Argentina.

NATURE OF THE LAND AND THE SOIL FORMING FACTORS

Different parent materials are present in the country. Various rocks outcrop in some natural regions but not all of them give rise to soil formation due to climate with low weathering potential.

The most important soils from the agricultural standpoint are developed on the aeolian quaternary sediments that cover the Chaco-Pampean Plains, indicated as eco-regions Dry and Humid Chaco, Espinal and Pampa in Fig. 1 (Secretaría de Recursos Naturales y Desarrollo Sustentable, 1999). The material is formed by debris of weathered rocks, and it also contains significant amounts of volcanic glass, product of the eruption of Andean volcanoes.

This sediment is known as Pampean loess because of its similarities with loess materials and deposits in other parts of the world (Frenguelli, 1955; Teruggi, 1957). From the mineralogical standpoint, the loess is rich in weatherable minerals with conspicuous amounts of calcium, potassium, phosphorus and microelements and amorphous materials of volcanic origin (Scoppa, 1974). In Figure 2 (Pazos and Moscatelli, 1998) an example is shown of the average mineralogical composition of soils developed on Pampean loess, a rich source of plant nutrients. The physical characteristics of the Pampean loess favour the formation of well structured, deep, dark surface horizons, adequate for root development (Moscatelli, 1991).

The dominant climates in Argentina are arid and semiarid (Burgos and Vidal, 1951). For this reason, soils of wide areas are strongly marked by a parent material with little transformation. It is only in the NE, the Paranaense Forest in Fig. 1, that the contrast is strong between the soil and the underlying rock that has been deeply weathered *in situ* under an aggressive climate.

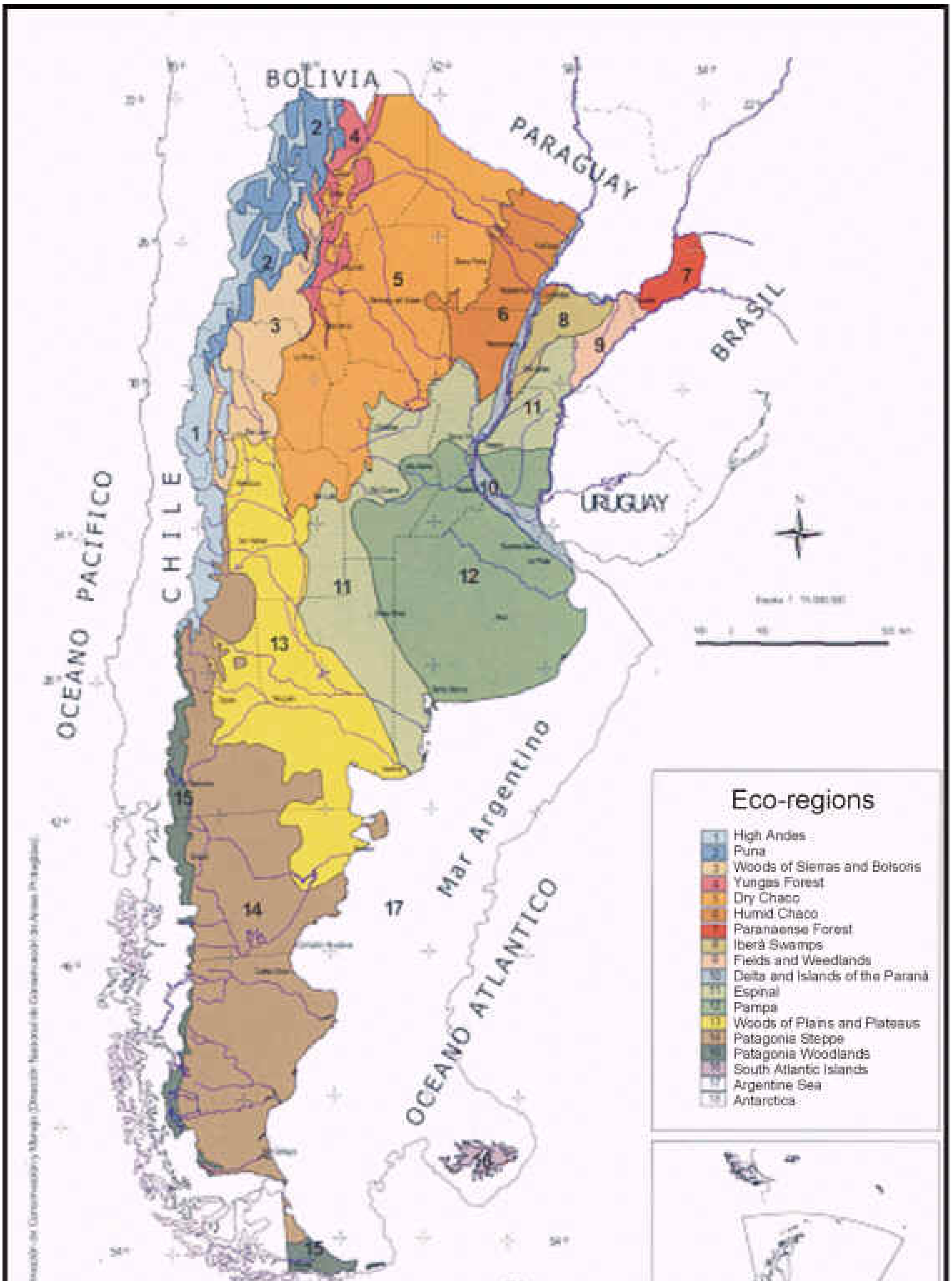

Figure 1 – Eco-Regions of Argentina (Modified from Secretaría de Recursos Naturales y Desarrollo Sustentable. 1999).

The important mountain ranges have hillsides with colluvial deposits where different types of soils are developed and the soil profile development is associated with the local climate and slope.

In the wide humid and subhumid plains of the Pampean Region, Pampa in Fig. 1, little differences in topography give rise to very different soils on the same parent material due to runoff and the accumulation of rainwater in the low positions of the landscape (Pazos, 1981; Pazos and Fittipaldi, 1994).

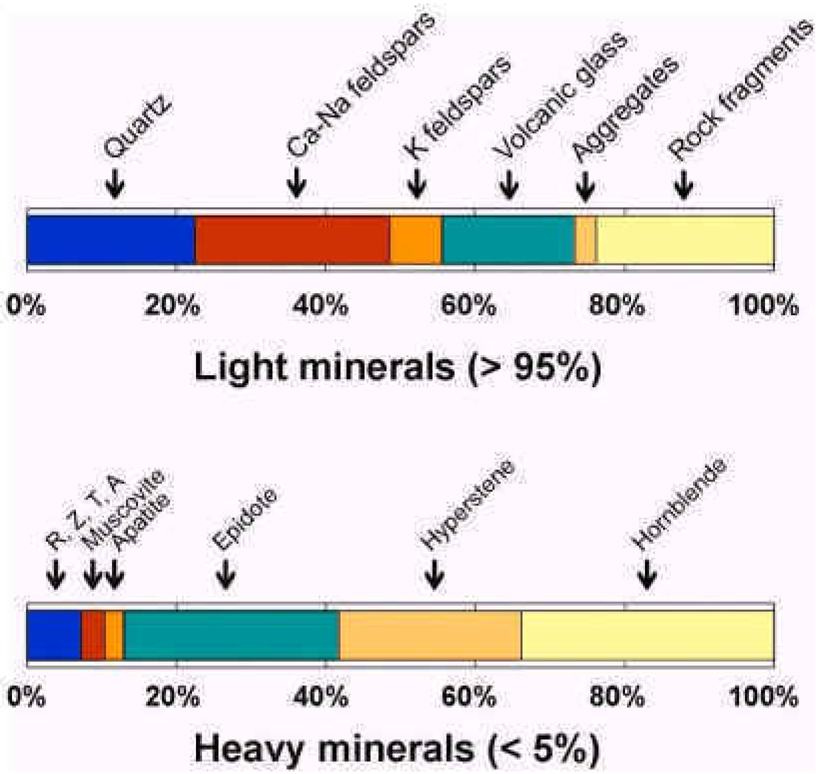

Figure 2 - Average mineralogical composition of the sand fraction of six soil profiles from Central Buenos Aires Province. R = rutile; Z = zircon; T = tourmaline; A = anatase. (From: Pazos and Moscatelli, 1998).

The natural vegetation and partially the soil fauna have been deeply modified in the areas long utilised for crop production and cattle grazing. It is only where the autochthonous flora and fauna are conserved that their influence as soil forming factor can be verified. This is still more evident when the forest is cleared to change the land use to agriculture, as in the NE of the country, and the physical and chemical soil characteristics are quickly deteriorated (SAGyP, 1995).

SOIL CLASSIFICATION

Since 1970 Argentina adopted the 7^{th} Approximation (Soil Survey Staff, 1960) as the soil classification system for the soil surveys, and later on the Soil Taxonomy (Soil Survey Staff, 1975) and all the subsequent updates until the Second Edition (Soil Survey Staff, 1999). Every soil scientist in the country is acquainted with the system that is taught in most universities both at graduate and postgraduate level.

Due to the N-S dimensions of the country and its climatic diversity, all the twelve orders are represented in Argentina. In Figure 3 the dominant soil orders in Argentina (Moscatelli and Puentes, 1998) are shown, according to the Soil Taxonomy (Soil Survey Staff, 1999). Following is a brief description of nature and distribution of each of the orders.

ALFISOLS: Geographically the Alfisols are closely associated with Mollisols. They are widely represented in the Chaco-Pampean plains and belong to the Alfisols mostly due to a surface horizon that is too thin or too low in organic matter or too light coloured for a mollic epipedon. They usually occupy flat or concave areas between higher parts of the landscape. Very frequently they have natric horizon and/or aquic soil moisture regime (Moscatelli, 1991). The Alfisols are utilised for cattle grazing, as natural grasslands or for water and sodium tolerant pastures. There are also Alfisols with lower base saturation than the Mollisols, which are restricted to the NE of the country where they occur in association with Oxisols and Ultisols.

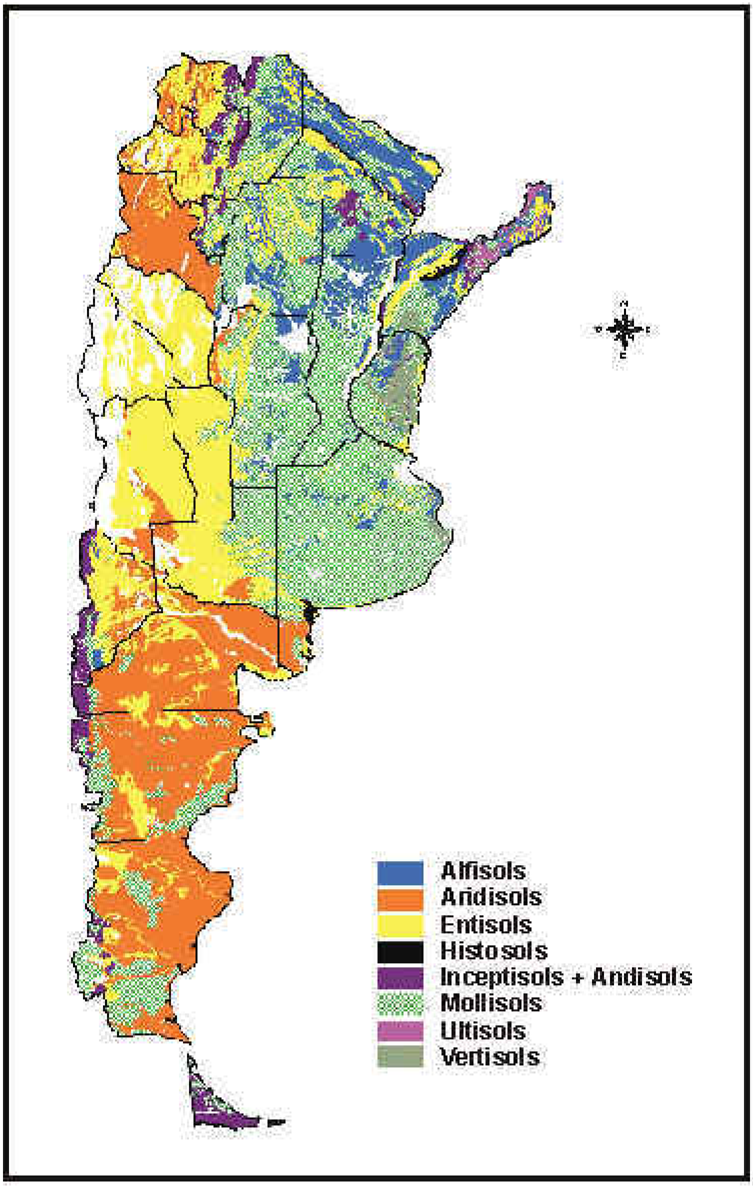

Figure 3 – Dominant soil orders in Argentina according to the Soil Taxonomy (Moscatelli and Puentes, 1998).

ANDISOLS: The Andisols are distributed in narrow belts along the Andes in the S of the country, mostly under temperate to cold climate. Thick deposits of volcanic ash overlie glacial deposits or outcropping igneous rocks. They constitute a soil cover on which native tree species have thrived. The natives called the ash deposits as "manna from the sky" meaning that God distributed productive soils covering the inert rock. Important contributions to the knowledge of Andisols and its mineralogy have been obtained through the research of both ORSTOM and Argentinian universities from the S of the country.

ARIDISOLS: The Aridisols are widely distributed in Argentina covering 60% of the country, mostly in Patagonia, Cuyo (Centre E) and NW. They amount to 160 million hectares with different percentages in 17 out of the total 23 provinces. The severe conditions that determine the occurrence of Aridisols bring about socio-economical problems and difficulties to settle sustainable towns or villages in many areas of the country with very low population density in very wide regions. These circumstances determine population exodus with negative rates of population growth, subsistence economies with low or no insertion in the markets resulting in very low investment and technology incorporation (José Ferrer, personal communication, 2000). Moreover, the poor environmental offer is worsened by the subsistence difficulties of the population who frequently perform unsuitable tillage or irrigation, or overgrazing, searching for short term results. These procedures undoubtedly cause the quick deterioration of these labile lands. An important action to prevent desertification is and has been carried out from different government institutions. Most of the land involved in these projects and studies consist of Aridisols and there exists a healthy consciousness with respect to the need of knowing these soils in detail.

ENTISOLS: They are widely distributed in the arid and semiarid areas, occupying large parts of Patagonia and the NW of the country. This order is particularly important because most of the soils under irrigation along the main rivers are Entisols. They are also common along the extensive coasts, utilised in this case for tree plantations and horticultural crops.

GELISOLS: (Not shown in the map) The Gelisols have been described in Antarctica where there are Argentinian military bases, particularly in the studies carried out at the Marambio Island after the introduction of the order in 1998. The classification at the suborder level is not yet completed but it is already clear that the introduction of this order was very helpful and contributed to solve previous uncertainties in the classification of soils of Antarctica.

HISTOSOLS: The Histosols are poorly represented in Argentina. They are mostly localised at high elevation and/or latitude as in Tierra del Fuego, Malvinas islands, Antarctica and some areas in the Andes. In the N they occur in low areas with permanent wetness close to lagoons and salt accumulations. In the southern part of the country they constitute peat deposits. Histosols are utilised for cattle grazing but the southern peat deposits are utilised only during very favourable periods.

INCEPTISOLS: The Inceptisols occur in a wide range of environments in Argentina, from the southernmost provinces as Tierra del Fuego and Malvinas Islands to the north in Jujuy and Formosa. In consequence, very different soil profiles classify as Inceptisols. They have been described in half of the provinces. Due to their diversity a common land use cannot be established for the order. In general they do not constitute good agricultural soils.

MOLLISOLS: They occupy important areas in the Chaco-Pampean plains and constitute the dominant soils among those with the best aptitude for agriculture. Mollisols have been mapped in every province from the subtropical area in the NE to the island of Tierra del Fuego in the S. Mollisols have been mentioned as occurring in Antarctica, being still under discussion if such soils actually belong to the Mollisols.

The Pampean Region, both humid and semiarid, is characterized respectively by Udolls and Ustolls with minor occurrence of Aquolls in flat areas utilized for cattle production. The Mollisols have been the object of many studies and postgraduate theses mostly referred to its genesis. This wide research subject is based on the undoubtedly polygenetic character of the soils. There are layers of materials with similar lithology and origin that have been deposited during alternating episodes of dry and moist climate. The intent to show such discontinuities in the soil name has introduced some confusion in the local classification of Mollisols, an issue that still has not been solved with a general agreement among the soil scientists. Another feature of the Pampean soils is the presence of a $CaCO_3$ enriched horizon that sometimes qualifies as petrocalcic horizon, and occupies wide areas under humid climate. To solve this peculiarity some local modifications were introduced to the

Soil Taxonomy, which are not yet fully satisfactory. Neither are adequate the recent changes in the second edition of the Soil Taxonomy.

OXISOLS: (Not shown in the map) The Oxisols are little represented in Argentina, mostly in Misiones province, in the NE of the country, indicated as Paranaense Forest in Fig. 1. It is practically the only area of the country where soils have developed through intense weathering of the parent rock, mostly basalt. Oxisols occur on old stable surfaces. In their virgin state they are under natural forest and preserved from degradation. Oxisols are utilised for yerba mate, tea, tung tree and tobacco and wide areas are found where land has been abandoned because of the quick loss of fertility after few years of crop production. Satellite images clearly show that deforestation in the neighbouring countries, Brazil and Paraguay, is quite more intense than on the Argentinian side.

SPODOSOLS: (Not shown in the map) They occupy small areas, restricted to high latitudes, as those described in Tierra del Fuego and the Andean area of Santa Cruz province. Their occurrence in such areas is due to the lower height of the mountain range with orientation W-E that allows the influence of moist W winds from the Pacific Ocean. The natural vegetation on Spodosols is a coniferous forest.

ULTISOLS: They are well represented in the provinces of Corrientes and Misiones, in the NE of the country. They cover a wider area than the Oxisols on younger developed landscapes. The considerations about natural vegetation, crops and land use are similar to those of the Oxisols.

VERTISOLS: They are found under different moisture conditions: humid, semiarid and arid. Vertisols are characteristic of the eastern half of Entre Ríos province in the NE of the Pampean Region, the coastal area of Buenos Aires province at Samborombón and they have also been described in some river valleys in Patagonia. Its genesis is attributed to materials coming from Brazil through its very wide runoff network. Vertisols in Argentina are mostly utilised for cattle because of their restrictions for tillage. To a minor extent, they are also utilised for crops as wheat, soybean, sunflower and flax. Vertisols are particularly suitable and utilised for paddy rice. Many Vertisols occur in rolling landscapes which contribute to water erosion. Entre Ríos is the best developed province in legislation on soil conservation which has been widely accepted due to the combined characteristics of low soil permeability and strong slopes. From the classification standpoint, there have been difficulties to classify the Vertisols from Entre Ríos with the Soil Taxonomy, reason for which some local modifications are still in use.

As it has been described in the previous paragraphs, some peculiarities of the Argentinian soils, particularly those of the Pampean Region, gave rise to propose some amendments to the Soil Taxonomy. Some proposals have already been accepted and they can be found in the second edition that specifies some taxa as developed for use in Argentina (cf. Natrudolls and Calciudolls) while other proposals are still under discussion.

Besides the wide acceptance of the Soil Taxonomy in Argentina, some experiences have been made applying the Legend of the Soil Map of the World (FAO- Unesco, 1974) and presently the WRB (ISSS-ISRIC-FAO, 1998). The WRB appears as an interesting option and particularly helpful in those cases where the Soil Taxonomy is not yet fully developed.

In Figure 4 the soils of the Humid Pampa are shown, classified according to the WRB (ISSS-ISRIC-FAO, 1998).

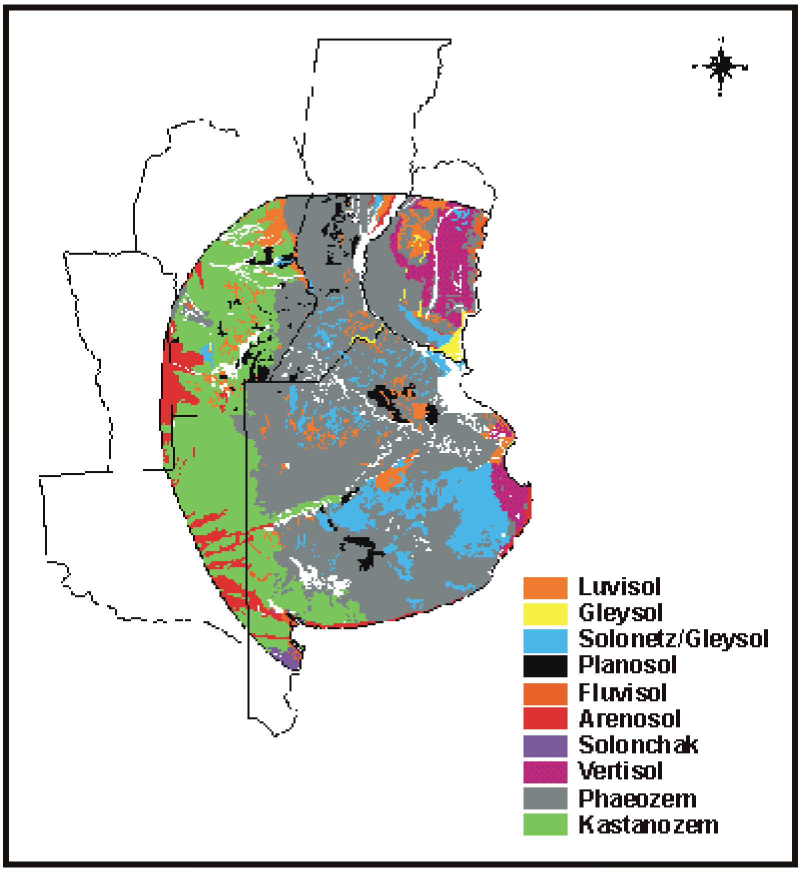

Figure 4 – Soils of the Pampean Region according to the WRB (Modified from Moscatelli and Puentes, 2000).

SOIL DEGRADATION

In the middle of the seventies due to increasing food demands and better agricultural prices, stronger pressure started to be applied on agricultural lands and even on the marginal ones. The latter were utilized carelessly of the sustainability principles, which in fact were developed afterwards, thus generating "conflict areas" with regard to their actual capability and traditional land use.

An increase in production was achieved through the application of technology with inputs as fertilizers, biocides and heavy machinery, for example.

The message from agronomists and scientists was always to harmonize a profitable production with the preservation of the resources but the short-term interest was difficult to overcome with a slow but relentless soil deterioration as a consequence. In some way, the seemingly everlasting richness of the natural resources in the Humid Pampa together with the utilization of new genetic varieties, fertilization and irrigation masked for a rather long period the decrease of soil productive capacity.

Soil deterioration in numbers:

Data reported by FECIC (1988) on 219 million surveyed hectares, corresponding to 17 provinces out of 23 (78% of the country surface) indicate that about 21.400.000 ha are affected by water erosion to a moderate and severe degree. An estimation made by INTA (Musto, 1979) reports an increase of 4.400.000 ha eroded to a severe degree.

At present it is accepted that a total of 60.000.000 ha are affected by wind or water erosion at different degrees. Wind erosion is mainly expressed in arid and semiarid regions as Patagonia and the Semiarid Pampean Region, while water erosion affects particularly the humid areas as the Humid Pampean Region and Mesopotamia (NE of the country).

INTA made an evaluation of land degradation for the period 1985 up to present and considering 5.000.000 ha at the core area for grain production (Michelena, et al., 1989) with the conclusions shown in Figure 5.

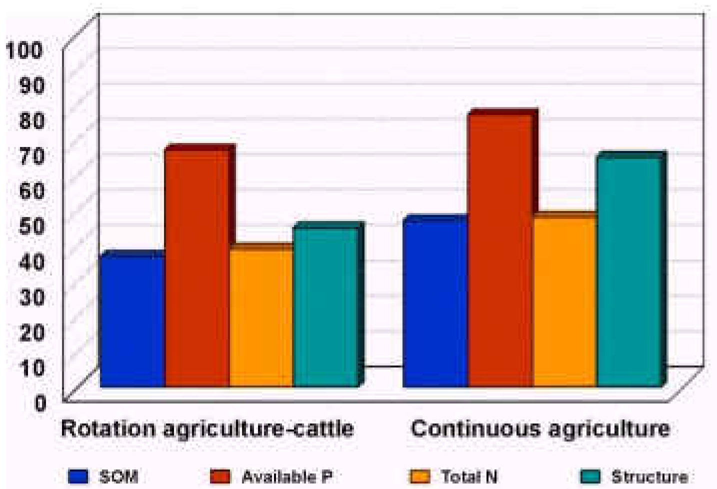

Figure 5 – Loss of SOM, P, N and structure in percentage under rotation agriculture-cattle and continuous agriculture. The level in non-cultivated soils should be considered 0%.

Other marks of soil degradation include 1.280.000 ha with partial to total loss of the surface horizon and an increase in soil acidity that depends on the intensity of soil use. The pH decreases in 0.4 in areas under agriculture-cattle rotation and 0.9 under continuous agriculture with respect to the non-cultivated lands.

The misbalance of organic matter is a cause for physical and chemical land degradation, particularly under traditional continuous agriculture and wheat-soybean double cropping. In these cases, the incorporation of organic matter through straw is reduced to a minimum due to both burning and cattle grazing. Surface sealing and crusting and the development of plow pans are frequent phenomena associated with these practices.

The relationship between degree of water erosion and yields of the main crops, (wheat, maize and soybean) was evaluated. A moderate degree reduces grain yields in 12% for wheat, 17% for soybean and 30% for maize, while a severe degree changes the effect to 24, 34 and 61% respectively. When transforming these rates into economical loss, 230 to 300 million dollars are lost due to decrease in yields of the three main crops because of water erosion (irurtia, 1995).

The economical loss due to water erosion in the entire Pampean Region amounts to 700-800 million dollars. At national level it can reach 1000-1200 million dollars due to water erosion and 3000-4000 million dollars taking into account all land degradation processes as well as the damages to infrastructure.

The main causes for land degradation in the Pampean Region are the "agriculturization" process or intensification of agriculture, the introduction of the double annual cropping wheat-soybean; the change from the rotation cattle-agriculture to continuous agriculture, and an inadequate land use with excessive and/or untimely tilling sometimes along the slopes.

To prevent and control the degradation processes, many alternative practices of land reclamation and land and water conservation are applied. An effective system to prevent erosion and maintain soil structure that has been widely incorporated in the Pampean Region is the no-tillage or direct planting, which presently covers 5.000.000 ha in the country. In relative terms, places Argentina as the country with the higher extension of this practice. It is worth to mention the permanent work of AAPRESID, the Argentinian Association of Farmers utilizing No-tillage, which is a private undertaking that has contributed to the diffusion of the system. AAPRESID has joint research projects with research and technological centers, universities, and extension and experimentation organisms in order to evaluate the advantages and drawbacks of the system in the different ecological regions.

CHALLENGES FOR THE XXI CENTURY

The dynamic reality faces Argentina to new challenges that the soil studies must also accept. Priority has to be given necessarily to those research issues with economical importance or consequences, to satisfy people needs and to strengthen the country competitive capacity in the market to place agricultural products. In this sense, the environmental certification of processes and products appears as an obliged condition in order to facilitate placing the products. In fact, the international norms ISO 14001 constitute a way of environmental protection (Viglizzo, 1999).

The already mentioned processes of intensification of agriculture, widening the frontiers and the industrialization of the agricultural products brought soil, water and air contamination to the rural area. Foreign experience and knowledge about the high impact of such processes on human health and biodiversity shows that Argentina must adequately prevent this danger, but the matter has been underestimated for those making the political decisions.

A system should be implemented for monitoring and recording the land transformations as a consequence of changes in land use as well as the climatic variations of the last thirty years. It is also essential to obtain sound data of the impact and consequences of supplementary irrigation, a practice that has invaded the Pampean Region during the last five years and may introduce both soil erosion and salinization and depletion of the groundwater reserves.

The urban soil studies deserve particular attention. Urban soil studies about different types of degradation are incipient in Argentina. Moreover, it is necessary to make the inhabitants of large cities to accept their dependence on what is happening in the rural area. Normally they see the countryside as far away, with its own problems without realizing that in the countries with strong agricultural base their interdependence is particularly close.

The creation of the Mercosur has unified an area of almost 13 million square kilometers, area in which people and goods can freely transit. Since the opening of the frontiers a change is occurring in demand and pressure on land use facing the need to improve competitiveness. Agrochemical utilization is increasing together with the use of heavy machinery and irrigation will be performed regardless of water quality, always in the search of the short-term profit. The increase in industrial development will produce more waste and contaminants. The incorporation of present forestlands to crop and cattle production is unavoidable (Moscatelli, 1995) with the already known deterioration of soil physical and chemical properties. The processes are more evident and quickly occurring at the borderline. The transport and communication network is changed and increased, the cities are under an expansion process and public works are developed. All of them grow at the expense of the surface formerly occupied by soils, introducing surface sealing as asphalt and concrete.

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