Land Use Change and Natural Araucaria Forest Degradation Northeastern Misiones - Argentina

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I would return to Misiones,
only to see their trees

E. L. Holmberg
Naturalist (1852-1937)

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ABBREVIATIONS

A	Annual Soil Loss Amount Calculated in Accordance with the USLE
AVHRR	Advanced Very High Resolution Radiometer
C	Crop Management Factor USLE
CARTA	Companía Argentina de Registros Topográficos y Fotografías Aéreas (Argentinean Company of Topographical Reports and Air Photography)
CITES	Convention on International Trade in Endangered Species
CNUMAD	United Nations Conference on Environment and Development
DBH	Diameter Burst Height
DEM	Digital Elevation Model
DN	Digital Number
ETM+	Enhanced Thematic Mapper Plus
FAO	Food and Agriculture Organisation of the United Nations
FUCEMA	Fundación para la Conservación de las Especies y el Medio Ambiente (Species and Environment Conservation Organization)
GCP	Ground Control Point
GIS	Geographic Information Systems
GML	Gaussian Maximun Likelihood
GMS	Geosynchronous Meteorological Satellite
GPS	Global Position Systems
IGM	Instituto Geográfico Militar (Military Geographic Institute)
INDEC	Instituto Nacional de Estadísticas y Censos
INTA	Instituto Nacional de Tecnología Agropecuaria (National Institute of Agricultural Technology)
IR	Infrared
K	Soil Erodibility Factor USLE
L	Slope Length Factor USLE
ME y RNR	Ministerio de Ecología y Recursos Naturales Renovables (Ministry of Ecology and Renewable Natural Resources)
MSS	Landsat Multispectral Scanner
NDVI	Normalized Vegetation Index
NIR	Near infrared
NOAA	National Oceanic and Atmospheric Administration
P	Protection Measures Factor USLE

PAN	Panchromatic
PCA	Principal Component Analysis
PNUMA	Programa de las Naciones Unidas para el Medio Ambiente
R	Rainfall Erosivity Factor USLE
RMS	Root Mean Square
RUSLE	Revised Universal Soil Loss Equation
S	Slope gradient factor USLE
SWIR	Short Wave Infrared
TM	Thematic Mapper
UICN	World Conservation Union
UNESCO	United Nations Educational, Scientific and Cultural Organization
USDA	United State Department of Agriculture
USLE	Universal Soil Loss Equation

1. INTRODUCTION

1.1 Preface

Different types of forests originally covered the world approximately to 50%. Today, about 40% is denominates “forests and other forest lands" (PERSSON, 1997). In 1995 the total area of forests in the world was estimated to be 3.454 million hectares (FAO, 1997), representing the humid tropical forests – that, according to FAO (1993) include the humid forests, low humid forests, evergreen forests, semi-deciduous forests, wood lands and savannahs with trees- almost 25% of this area.

Every year, millions of hectares of these natural forests are lost irreversibly. It has been estimated that in the 1990's the deforestation in the tropics would have had a magnitude of 13 millions of hectares/year (0.6%). It has been widely recognized that increasing levels of poverty and population in the tropical and subtropical developing countries is one of the main causes of a greater pressure on the forest resources.

Forest degradation and its negative impacts on the environmental quality has lately become one of the major concerns at a worldwide scale, not only because deforestation is one of the several factors that influence the Global Change, but also because appropriate forestry measures can enormously contribute to favour environmental stability. Such measures will only be effective, if local development objectives are fulfilled, including higher production of industrial timber, lower rates of biodiversity degradation, and maintenance of biodiversity at current levels.

The United Nations Conference on Environment and Development (CNUMAD), celebrated in Rio de Janeiro in June of 1992 recognized that the forests are fundamental to assure the well-being of the local populations in the long term, and to maintain to the national economies and the terrestrial biosphere at the whole. When adopting the Declaration of Forest Principles, annexed to Chapter 11 of Agenda 21, the importance of the sustainable management of all types of forests was clearly indicated for all kinds of benefits, in order to take care of the necessities of the present and future generations.

Tropical and subtropical rainforest resources are at risk. The worldwide tendencies in these regions include ever-greater rates of deforestation and degradation of soils.

During the last century the Province of Misiones and in particular its forests, were affected by an incessant change. Increasing population around the 1930's and afterwards, due in great extent to the influx of immigrants of European origin had manifold impacts. With the new settler the necessity for more space, as well as of the generation of labour and people's livelihood arose, which consequently not only resulted in a change of cultures, but also in deforestation of ample areas of natural forests. Today, such forests are still subject of intense harvesting.

Particularly endangered in Misiones is *Araucaria angustifolia* (Bert.) O. Ktze. a species highly appreciated because of the quality of its wood. The original Araucaria forest covered approximately 200.000 km^2 between Brazil and Argentina. Given the intense exploitation that affected it over the last 50 years, at present and according to the last inventory of the forest made in 1980 (with data until 1977), in the South of Brazil only 3% of the original surface is left (MACHADO and SIQUEIRA 1980; FUPEF 1989, ACHTEN 1995) whereas in Argentina today the trees loss does not reach to 4% of his original area.

The deforestation process of huge areas of Araucaria forests and semi-deciduous rainforest whose management did not take into account a sustainable use of its natural resources, led to a substantial modification of the ecosystem, with dangerous ecological, economic and social consequences, which have contributed to natural resources degradation.

The purpose of this study is the analysis of land cover/land use changes, landscape modifications, and the reduction of the Araucaria forests of the Province Misiones, and to assist decision-makers in future planning, sustainable resource management and related processes. That may have a particular impact on the local level, but even on regional and national development.

1.2 Araucaria Forest in South America

1.2.1 Concepts Definition

Natural forest

The term 'natural forest' designates all wooded ecosystems that have not been influenced by the man, for which is usually used the concept of primary forest. In contrast to this, the concept of natural forest includes stages of development of the forest that are originated from natural catastrophes like fires, storms or inundations (BRÜNIG and MAYER, 1980 in STEINBRENNER 2000) Therefore, the term of natural forest will always be used in this work when talking about natural and not disturbed forests.

Sustainable development

The Worldwide Commission emits one of the more accepted definitions of the sustainable development for the Atmosphere and the Development (Brundtland Report) in 1987:

> " It is the development that satisfies the actual necessities without compromising the future generations possibility to satisfy their own necessities".

Thus, the sustainable management Forest consists of planning and implementing economically viable development, socially beneficial strategies of development with minimum or positive environmental impacts. It must also balance the present and future necessities

1.2.1 Araucaria angustifolia (Bert.) O Ktze.

1.2.2.1 General Considerations

Araucaria is one of the few native South American conifers, and belongs to the Order Pinales, *Araucariacea* family. This family dominated both hemispheres during most of the Mesozoic and the beginning of the Cainozoic until the appearance of Angiosperms, which eventually prevailed. Out of the 570 species that during that period inhabited both hemispheres, only 19 spp. are left, distributed all in the Southern Hemisphere and only two spp. of which live in South America (*A. araucana* and *A. angustifolia*). The other 17 are limited to Australia, New Guinea and to some other islands of the South Pacific (Fig. 1-1). Thus, today, the Araucariacea can be considered as a relict genus (LI 1953 in GOLTE 1993).

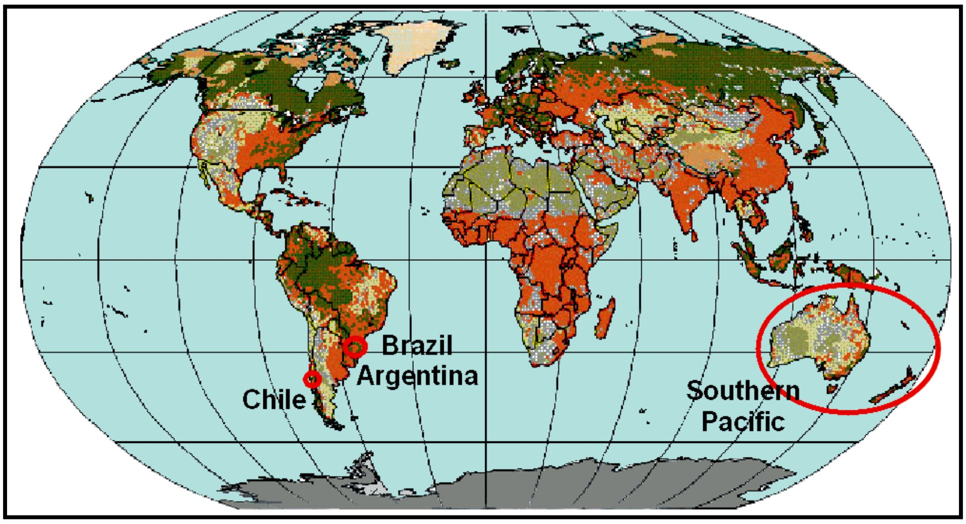


Fig. 1-1: Worldwide distribution of *Araucaria* genus. Today, remain only 19 species, which are enclosed to southern hemisphere.

According to the literature, there would exist eleven (RAMBO, 1956; REITZ and KLEIN, 1966), six (HOSOKAWA, 1976) or five (MATOS, 1972) different varieties, most of which could be differentiated only in mature stages of their seeds (ACHTEN, 1995). Other authors differentiate *A. angustifolia* in different geographic races or ecotypes (GURGEL J. and GURGEL O, 1971; GURGEL, O. and GURGEL J., 1978; FAHLER and DI LUCCA, 1980).

Varieties of *A. angustifolia* according Hosokawa, 1976:

Araucaria angustifolia dependens
Araucaria angustifolia angustifolia
Araucaria angustifolia alba
Araucaria angustifolia striata
Araucaria angustifolia caiova
Araucaria angustifolia indehisens

A number of local names are given, from which the most known ones are: in Brazil, Pinho Brasileiro, Pinho or Pinheiro do Paraná, Pinho do Brasil. In Argentina, Pino de Misiones, or Pino Paraná. In Guaraní (indigenous language) Kuri'y or Cury.

1.2.2.2 Phyto-geographical Distribution and Ecology

1.2.2.2.1 Area of Occurrence

Diverse authors early described and established the araucaria natural distribution area, such as CAVALCANTI (1908), RUHLE (1928), JAMES (1942), who were quoted by MOURA (1975), but from HUECK (1952) there is the most complete and precise description of the natural occurrence area of *A. angustifolia*, locating it between 18° and 30° South, and between 41° and 54°30' West. *A. angustifolia* is distributed forming dense groups, mainly in the eastern and central Southern Brazilian planalto (Rio Grande do Sul and Santa Catarina States), whose forest marginally extends within the boundaries of the Province Misiones (Argentina), and Paraná State (Brazil), and sparsely disseminating over the southern and northeastern São Paulo State, Minas Gerais State, and Rio de Janeiro State (Fig.1-2).

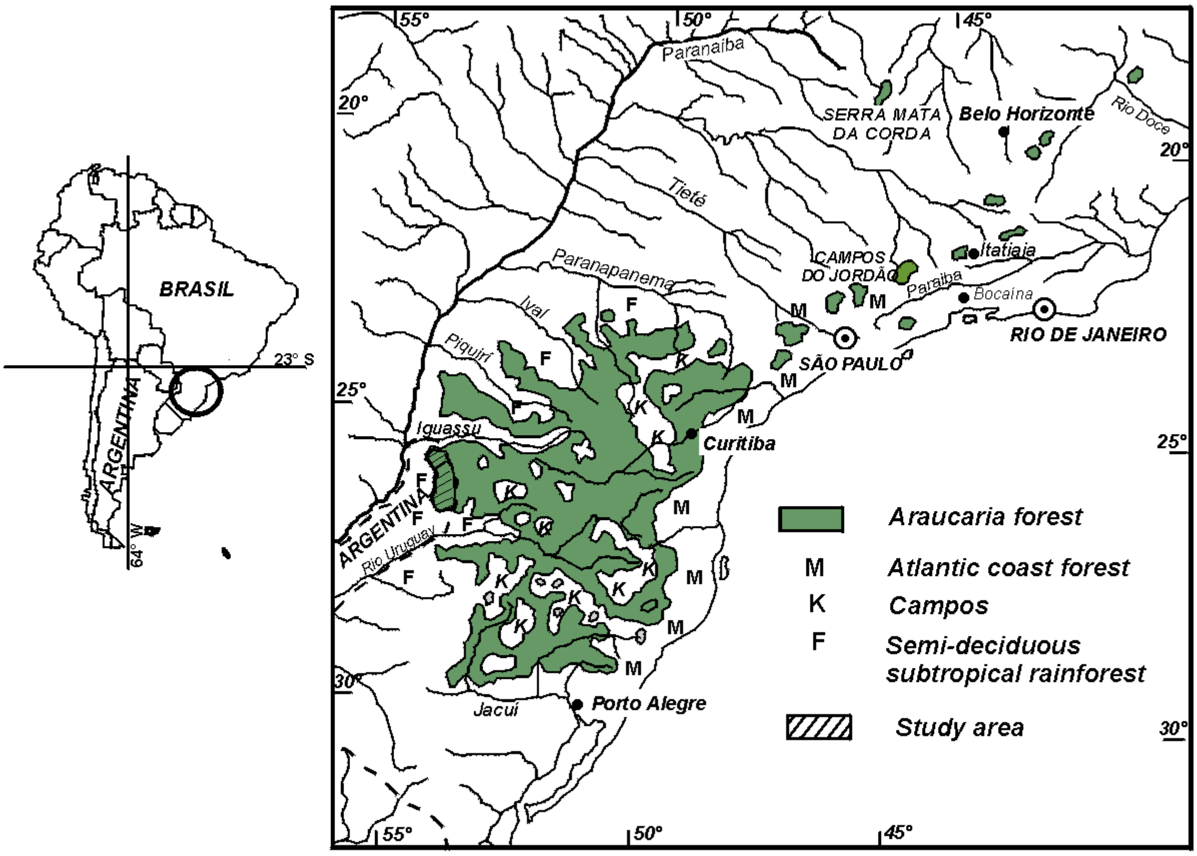


Fig. 1-2: Area of natural distribution of *Araucaria angustifolia* (Bert.) O. Ktze. in South Brazil and North Argentina (according to Hueck 1966, modified). The Araucaria forest covered approx. 200.000 km^2 between Brazil and Argentina; locating it between 18° and 30° South, and between 41° and 54° 30' West.

Araucaria forests, which falls under the Paranaense biogeographic Province, within the Amazonian Dominion (CABRERA and WILLINK, 1980), usually find its lowest boundaries between 500 and 600 m asl, climbing up to 1200 m asl, in the Serra da Matiqueira and the Itatiaia, and even up to 1800 m asl, in the Campos de Jordão region, at the north of its geographic distribution.

1.2.2.2.2 Ecological Aspects

Climate, Geology and Soils

Climate in the natural distribution area of araucarias is from temperate humid to subtropical humid (Cfb and Cfa according Köppen climate classification), with rainfalls distributed over the whole year (having a minimum in Winter), varying from 1200 mm up to 2400 mm. Mean annual temperature varies between 12°C and 20°C, according to location, height and topography (WACHTEL, 1990). Mean monthly temperature is always higher than 10°C. Frosts are recorded only in five to twenty-five days a year, during April and September.

Three geological regions can be defined, according to their varied lithology:

- An eastern region, where plutonitas (granites and gneiss) prevail.
- A central and northern region composed of sedimentary rocks, from which Upper Carboniferous sandstones are the most predominant.
- A western region, with Triassic, Jurassic and Cretaceous magmatic basalts.

Soil types and fertility vary, according to their parent material. Western soils are frequently more fertile than those from the eastern and northern areas.

As inferred from above, araucaria grows in temperate and humid climates, where the coldest month temperature may be very low, but always higher than -10°C, and mean annual rainfall over 1000 mm. Nevertheless, araucaria needs, at their youngest stages, protection against frost and direct sunlight. According to NTIMA (1971 in HOSOKAWA 1976), frosts may be a decisive factor in the development and survival of the plants of araucarias. ROGERS (1953) considers that sunlight and frosts, as well as rainfall amount play a key role in Araucaria's growth.

Several authors have referred to araucaria's soil requirements: ROGERS (1953 in HOSOKAWA, 1976) says that araucaria grows and develops in different soils derived from granites, basalts, diorites, gneisses, and sandstones, and that the amount of soil nutrients and its capability of sustaining araucaria's growth are more important than soil depth and soil physical properties. On the contrary, FRITH (1969) and MOLINO (1969) wrote that the development of *A. angustifolia* is strongly dependant of soil thickness. Results of the research from VAN GOOR (1965) and BLUM (1980 a and b) have proved that soil physical properties, such as thickness, porosity, water retention capacity and fertility are important factors for the growth and development of the araucaria.

Reproductive Biology and Fenology

A. angustifolia is a dioic and anemophily conifer. In natural forests, male individuals prevail over female ones. According SCHOLZ (1988) this relation goes from 57,1% to 42,9%, and BANDEL (1960) suggests 52,4% against 47,6%. Flowers develop in second order branches. Male cone dense, cylindrical, shortly extending beyond the axil of the leaves, 10-18 cm long by 1.2-2.5 cm wide at its pollinic maturity, scales imbricate (HUECK, 1978; REITZ and KLEIN, 1966). Female cone is globular, growing at the youngest ends of lateral branches, 18-25 cm long by 13 cm wide, chestnut-brown. Flowering occurs between April and June, fecundation between September and October, while seed production, from April to July, depending on climate and varieties (REITZ and KLEIN, 1966; GARTLAND, 1972; HUECK, 1978). Cone maturity completes after 20-22 months, reaching the cone a diameter of 15-30 cm. Each cone produces between 20-120 seeds, whose length varies from 3 to 7 cm, according to the variety. Its diameter ranges from 1.5 to 2.6 cm, and its weight, from 5 to 9 g (REITZ and KLEIN, 1966; HUECK, 1978; SEITZ, 1983). Given the nutritious properties of seeds (73% of its dry weight is starch), they are appreciated, either on the tree or on the ground, by diverse birds and mammals (SEITZ, 1983). Germination takes place from 60 to 120 days. According to RITTERSHOFER and INOUE (1979), seeds lose their viability (or germination capacity) within a year. This characteristic turns them into a recalcitrant seed, which does not allow storing (drying or freezing) a for long time (TOMPSET, 1984). Due to the time elapsed during maturation of the seeds, almost mature cones (large) and small, immature cones can be found simultaneously in female trees. According to FASSOLA *et* al. (1999), araucaria would show a four year-cycle of seed production, with a higher production during the first two years, then decreasing during the third, to eventually become almost negligible in the fourth year.

1.2.3 Structural Characteristic of Araucaria forests

The Araucaria forests are in the nature like mixed forests, in which three arboreal layers can be usually distinguished (Fig.1-3).

- The superior layer is dominated by the araucaria, which frequently can reach superior heights to 30 m and an average diameter of 1 m. Under its crown abundant vegetations are developed, which conform the lower layers.
- The middle layer is characterized by the predominant presence of Lauraceas (*Ocotea* and *Nectandra* genus), frequently accompanied by Aquifoliaceas, Leguminosas, Rosaceas, Meliaceas, Sapindaceas, Tiliaceas and Podocarpaceas (the latter absent from araucaria forests in Argentina).
- The low layer is mainly composed by Mirtaceas. Characteristic for this layer it is also the presence of arborescent ferns like *Dicksonia sellowiana* and *Alsophila procera*.

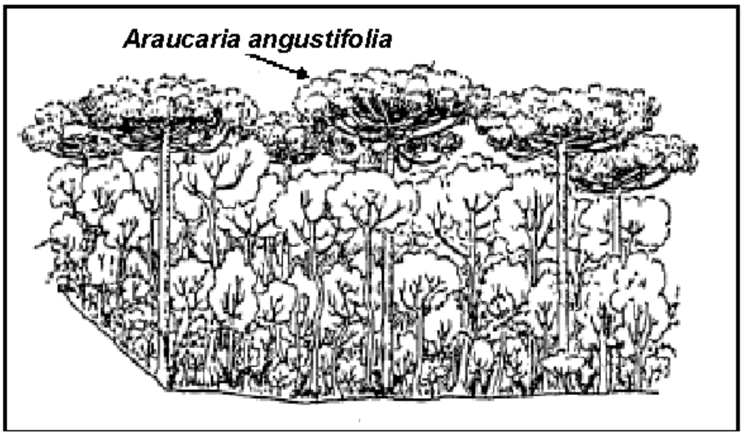


Fig. 1-3: Representation of the Araucaria forest in South Brazil (according to Klein 1980, modified).

In the middle and lower layers of Araucaria forests, around 200 species between trees and shrubs are recognized. According to the altitude and geographical proximity to the bordering forests, about 30 to 60 species per hectare can be found in average.

1.3 Current Research State of Araucaria Forests

1.3.1 Classification and Distribution

The first description of Araucaria forests, according ecological factors in its distribution area and structure comes from HUECK (1952,1966,1978). REITZ and KLEIN (1966) proposed a differential characterization of Araucaria forest association, while RAGONOSE and CASTIGLIONE (1946) worked out the first and best description of the distribution of *A. angustifolia* groups in Argentina, together with a phyto-sociologic inventory of its forests. COZZO (1960) extended, and improved the definition of the distribution area proposed by RAGONOSE and CASTIGLIONE. This author presented a new location map of araucaria stands in the Province of Misiones. MARTÍNEZ-CROVETTO (1963) introduced a phyto-geographic scheme of this Province, where the most conspicuous plant communities are clustered according to a syncorologic criterion proposed by Braun-Blanquet. CABRERA and WILLNIK (1980), in their biogeographic analysis of Latin-American flora, include these forests within the Paranaense Phytogeographic Province, Amazon Domain, and in the Neotropical Region.

1.3.2 Structure, Dynamics and Regeneration of Araucaria Forests

Structure

RAGONESE and CASTIGLIONE (1946), after an analysis and a phyto-sociologic inventory undertaken in a dense, non-exploited araucaria stand at San Antonio, gave an idea of the Araucaria forest structure in the Province of Misiones. They described four layers for this forest. In the upper one, *A. angustifolia* has been the prevailing species, with a density of 48 trees h^{-1} and individuals usually higher than 30 m averaging 1m diameters. The second layer mainly composed by semi-deciduous trees, where Lauraceas, Rutaceas, Meliaceas and Aquifoleaceas prevail; then a bushy layer with small-size trees and arborescent ferns, such as *Alsophila procera* ("chachí bravo"); and finally a grassy layer.

WACHTEL (1990) elaborated a quantitative analysis of the structure of Araucaria forests in Brazil, over a continuous area of 10 hectares, clearly dominated by araucaria both in basal coverage (30 m^2 ha^{-1}) and in abundance (100 trees per hectare). Prevailing araucarias were higher than 30 m and had diameters larger than 1 m. According to the author, a second layer occurs composed by 60 species where broadleaf trees and brushwood prevails. The broadleaved tree species *Ocotea pulchella* -which sporadically also occurred in the canopy - was the most important admixed tree species in the examined stand. Regarding the age structure of dominating araucarias in this locality, the author points out that by its distinct narrow range a common origin of these trees of about 240 years ago, and that the regeneration period at the time presumably took around 50 years. The dominated araucaria trees were at least 200 years old in average, possibly, however, also about of the same age as the dominant trees. The suppressed araucaria trees were all under 100 years old and showed only very poor growth.

Dynamics

Little is known about the dynamic of the Araucaria forests, although some theories do exist. HUECK (1952) proposes that the araucaria as a pioneer species advanced over grasslands or "campos" located in highlands, as a consequence of a climate change, from cold and dry -typical from steppes- into a warmer and more humid one, which corresponds to those of temperate forests. At the same time, the author proposes a gradual removal of araucarias from the lowest layers, which turned into a humid, subtropical and extraordinarily vital forest. This proposal is based on hypothesis that the youngest individuals of araucarias had not the capability to resist the strong competence of humid forests species, which -according to Hueck- are more tolerant to the shade and grow faster than araucarias.

KLEIN (1960, 1980) supports and broadens this theory, proposing the existence of a successional process, where *A. angustifolia* (a pioneer heliophyllic species) gradually takes over "campos" of the planalto, together with other plant species. Eventually, at the end of this successional process, broadleaf trees of subtropical humid forest replace Araucaria forests.

BEHLING (2000), based on palynological studies, infers a likely distribution of Araucaria forests during ice ages and their re-distribution over the Holocene. According to his results, during glaciations Araucaria forests would have only remained in humid, protected valleys in southern Brazil and in narrow strips along river coasts to the north of its actual area of occurrence, where climatic conditions were more favourable to their growth (minimum temperatures higher than -10°C, average annual rainfall above 1400 mm, and absence of long dry seasons). Araucaria forests would have started to expand to higher zones at the beginning of the Holocene, because of a climate warming, eventually replacing grasslands or "campos". But it would only be at a late Holocene when they would have reached their peak of expansion (1000 to 1500 years ago). Behling's results prove that araucarias occurred in the Brazilian planalto as of 14000 years ago, although no forests were formed during glaciations. Only small, protected areas of araucarias, presumably at the bottom of deep valleys with better climatic conditions existed.

Proposals from RAMBO (1942), COZZO (1957) and FRITH (1969) are also worth mentioning. They suggest that the "azure jay" (*Cyanocorax chysops*) played a major role in the process of araucaria dispersion. These authors propose that this bird, which was abundant in ancient Araucaria forests, would accumulate mature araucaria seeds in remote sites to feed on them later, but in the meantime, lots of them would germinate in sites where they could have not normally reached by the action of any other natural dispersion agents.

Regeneration of *A. angustifolia*

Both LONGHI (1980), MELLO FILHO *et al.* (1981) and SEITZ (1982) have conducted studies of *A. angustifolia* natural regeneration in different plots of the Experimental Forestry Station at São João do Triunfo (property of the Universidad Federal de Paraná), which had remained undisturbed from human action during a span of 10 years previous to the onset of such studies.

LONGHI (1980) undertook his study on a sample area of 10m by 10m, counting every individual with DBH < 20 cm, and extrapolated his results to a final surface of one hectare.

This counting results in a total quantity of approximately 24 000 trees/ha, half of which were trees shorter than 1.5 m. From this total, only 670 individuals per hectare corresponded to araucaria plants (3%), from which, in turn, around 380 were shorter than 1.5 m. LONGHI finally concluded that, given the diameter distribution frequency and the scarcity of youngest individuals of more conspicuous arboreal species, his study area would be infiltrated by other arboreal species.

MELLO FILHO *et al*. (1981) have studied those factors influencing natural regeneration of araucarias. In order to do that, they analysed the way fauna damages araucaria seeds and youngest individuals in the process of natural regeneration. Three sample plots (1 ha each) with different coverage degrees (dense, semi-dense and open forest) and sunlight intensity were used. A hundred signalised seeds were planted on each sample area. Results showed decrease of damage with increasing sunlight level. All seeds were eventually consumed after 65 days. Based on these data, the authors concluded that the araucaria natural regeneration is seriously threatened because of the likelihood of seed germination is extremely low, or even nil, as consequence of the high density of seed-eaters species in the remaining forests, plus the removal of natural predators of such species (carnivore reptiles and mammals).

SEITZ (1982) conducted his research on 41 plots (40 m^2 each) over a sampling area of 4 ha, counting those individuals with DBH < 5 cm. The result of this counting was 2.268 plants/ha, which were distributed by contagion. A 93% of individuals were shorter than 100 cm, and a 70% of these averaged heights between 20 and 40 cm. Only 7% of all young individuals got higher than 100 cm. SEITZ finally concluded that, with no human or large animal intervention, the species satisfactorily regenerated, and that the number of plants higher than 1 m was large enough to preserve the species.

SOARES (1980) postulated some hypotheses about natural regeneration of araucarias, based on diverse assumptions: 1) Araucaria would seem to be a serial species, since it does not show diagnostic characteristics typical from either pioneer nor climax species. 2) Being a serial species, some moderately intense disturbance was needed for the araucaria to naturally regenerate. In the past, fires probably induced such disturbances. 3) Lack of disturbances will allow succession to evolve up to its climax, which is characterized by dominance of broadleaf species. 4) Araucaria seems to be a fire-dependant species: it has high flammability, and it is resistant to fire, due to its thick bark and high tree crown 5) Being a serial, fire-dependant species, araucaria's natural regeneration could be induced by practicing controlled fires.

WACHTEL (1990 op. cit), on his work on the structure of Araucaria forests, has concluded that its regeneration (trees shorter than 1,3 m) is extremely scarce: barely 100 plants/ha. In addition, most of these individuals were younger than two years old, and the few older plants showed a strongly suppressed growth. Presumably, according to this author, due to the thick shading of the broadleaved trees and shrubs, which would result in a high rate of mortality during the early stages of araucaria.

1.4 Natural Araucaria Forests in Argentina

1.4.1 Phytogeographic Distribution

Araucaria forests in Argentina are located exclusively in the Province of Misiones, where they cluster to dense groups. As altitude changes, they split into smaller, scattered groups (COZZO, 1980). The area of distribution of the araucaria lies between 25°40' and 26°50' South and between 54°15' West and San Antonio and Pepirí Guazú rivers, in the Brazilian border (Fig. 1-4), covering around 210.000 hectares, up to an altitude of 800 m asl which represents the highest point of the Province, at the locality of Bernardo de Irigoyen.

It is worth to mention the presence of some other small araucaria stands, and even of isolated individuals outside the natural area of occurrence. COZZO (op. cit.) reported small isolated stands close to the Paraná River, at the locality of Maria Magdalena, whose origin could not be established. QUEIREL (1896) reported on an area close to San Javier, and at Campiña de Veranas. Both a couple of kilometres away from the southern limit of its natural distribution.

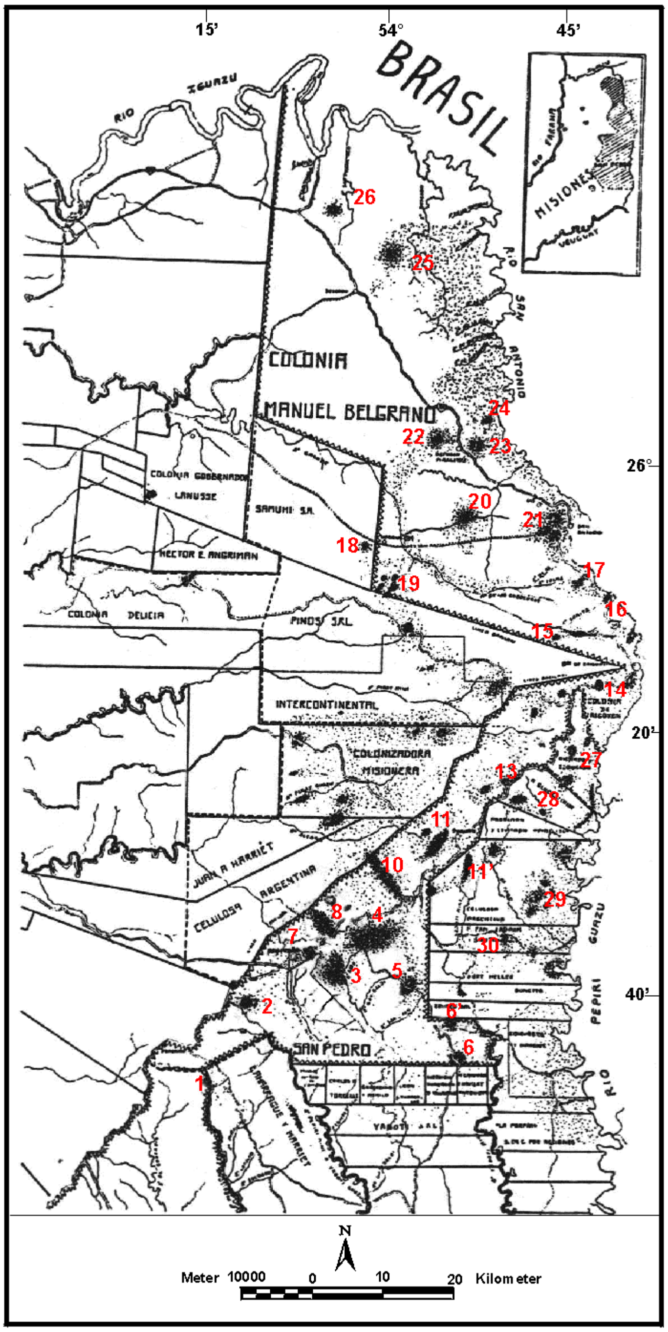


Fig. 1-4: Map of distribution of *A. angustifolia* in the Province of Misiones presented by Cozzo (1960). The black area and red numbers correspond to the stands, and the black points to isolated araucaria individuals (Source: Cozzo, 1960).

1.4.2 Conditions of the Araucaria Forests

The natural Araucaria forests in the Province of Misiones have undergone an almost complete depletion as consequence of both an intense timber exploitation and a process of immigration settlement, mainly from Southern Misiones and Brazil. Estimations showed that of approximately 210.000 ha that conformed their original global area– 185.000 ha property of the provincial state- (COZZO, 1960), by 1993, only remained approx. 2.000 ha, which is equivalent to 5% of its original existence (BURKART, 1993).

The spontaneous settlement process did not take into account that by human occupied land constituted the natural habitat of *A. angustifolia*, one of the most important forestry species of the Atlantic forest (Mata Atlantica-Selva Paranaense). The araucarias, while being one of the main forestry resources of the Province, have been strongly exploited, up to the point of getting close to the extinction of its native population, which constitute the "in situ" reserves of its germplasm. Out of the 27 araucaria stands described by COZZO (1960) in the Province of Misiones (Fig. 1-4) (including both state and private land), only 6 remains by 1977, out of which 5 along the Route N°14 have been completely clearcut, and prepared for agricultural purposes. The remaining one, according to cadastral maps, has also been cleared off, although its actual condition has not been confirmed (BURKART, 1993).

Likewise, the natural forests of Misiones are being gradually replaced by reforestations of pines (*Pinus taeda, Pinus elliottii, Pino taeda-marion*), araucarias (pino paraná), paraísos (*Lila persia* or Mora China, *Melia azedarach)* and kiris (*Paulonia fortunei*). Since 1990, different silvipasture systems have been implemented in areas where reforestation with pines had taken place. Cultivation of different grass types (pasto jesuita, pasto colonial and pasto elefante) for grazing purposes has also been applied (Instituto Nacional de Tecnología Agropecuaria-INTA).

1.4.3 Legal Framework for Forest Protection and Sustainable Uses

National legal framework

The national legal regimen on the forests is based on the Law N°13.273, known as Law of Conservation of Forestry Resources, accepted in 1948. This takes into account, among other topics, protection of water basins and soils, and recognized the value of forests as sustainers of biodiversity (BURKART et al, 1998). According to this law, the forests are divided into five legal categories:

Forest Category	Purpose	Restrictions and requirements
Protective	Stream management zones. Protection of basins, soils, lake and river coastlines; Prevention of erosion, etc.	Subject to expropriation. Need of authorization for grazing, sale or reforestation (if previous deforestation caused by the landowner)
Permanent	National, Provincial or City Protected areas Public parks or forests	
Experimental	Research	
Special	Artificial forests created to either protect or ornament agricultural plots.	
Productive	Timber production, including either natural or artificial forests.	Need of authorization to start exploitation. Presentation of forestry guides.

Regarding natural forests, obligations established by this law imply some of the following situations:

*Natural private forests: Owners must present management plans to the provincial enforcement authority in case they plan forest exploitation.
*Natural state forests: Areas larger than 2500 hectares may be exploited, if granted by public auction, prior to which a forest inventory and a dasocratic plan should be presented. The enforcing authority must approve the latter. The law establishes the need to ensure, in all cases, the persistence of the forest, and to avoid prejudicial effects on its extension and quality. State forest exploitation is subject to fee payments, whose goal is to remunerate the value of living wood (BURKART et al., 1998).

In November, 1995, Decree N° 710, which regulates without its modification the above mentioned law, and eliminates a number of bureaucratic procedures and restrictions that used to hamper private involvement in forestry activities based on artificial forests. Such a decree therefore constituted a juridical safety framework for those companies interested in investing on artificial forestry, to which it also offered a set of incentives.

Provincial legal framework

The first legal step aiming to protect Araucaria forests dates back to 1959, when the Province State created, through Decree N° 2670, the "Parque Provincial de la Araucaria" (Araucaria Provincial Reserve), whose area reached 1000 ha, so as to preserve such a species against high rates of exploitation. Unfortunately, such a Reserve was never delimitated, and therefore it remained unprotected. Thus, by 1960 almost all the araucaria stands disappeared.

The Provincial Law N° 215, approved in 1964 and was known as "Pine Law", aims to protect araucaria stocks by regulating timber exploitation in state forest. Timber production was mainly associated to the laminated timber industry. Thus, the law establishes annual extraction rates of 40 000 m^3. Such an amount did not adjust to sustainable use criteria, being 5000 m^3 those limits suggested by Cozzo, to ensure conservation of natural groups of araucaria.

Provincial Decree N° 449/75 and the Law N° 628/75, converted the remaining araucaria stands into seed reserves. The goal aimed, in one hand, to preserve the dramatically decreased araucaria population (by that time, estimations indicated that only 3000 compacted hectares survived between San Pedro and Manuel Belgrano Departments BERTOLINI, 1998), and, in the other hand, to satisfy seed demands for forestry activities. Similarly, to what happened in 1959, such reserves never have been delimitated. Therefore, when having no appropriate protection the exploitations continued.

In 1977, the Provincial State gave sanction to the Forestry Law N° 854 inspired by the National Law N° 13.273. This law in one hand regulates the use of native forests (private and provincial-owned ones), and, in the other hand controls the process of spontaneous settlings, and the definitive deforestation of little areas, converted for small scale, traditional food production. It declared Forest Reserves diverse areas of Province owner forests (several in the region of the araucarias) and designated to six araucaria stands in San Pedro's Department like seed reserves (article 21 and Annex III). The law also introduced the concept of sustainable management of timber exploitation. In addition, such a law, and its regulatory decree N°1459/78, adopted the same forest classification defined in National Law N°13.273. Thus, it defines as native forest as "All wood formation, not created originally by the man without necessary subjection to specific economic goals". The law also establishes that the use of private natural forests is subject to the established by National Law, and it adds the following scheme:

Native, private forests	Native, state forests
	- Concessions granted to individuals by public auction. - Concessions directly granted by the Provincial State.
Management Plans for properties larger than 100 hectares. (Later modified to 300 hectares, by Decree N° 1236/81)	Management Plans than for private forests, but addition of: - Investment study, road system, permanent facilities, forestry costs, cost-benefit ratio, etc.
Obligations to reforestation and enrichment: a) Either mass plantation or five-tree conifer*, or two native or exotic broadleaf trees and under-cover plantation of two native or exotic broadleaf trees by each 1 m^3 of first quality extracted wood; and mass plantation or three conifer* or one native or exotic broadleaf trees and under-cover plantation of one native or exotic broadleaf tree by each 1 m^3 of second quality extracted wood.	Commitment of enrichment of the stand either for improvements or for conversion to reforestation, when the extraction volume is overcome in stands where the existences remainders don't assure through the rotation lapse the equivalent quantitative possibility or superior to the previous one.

* Note that the condition of native or exotic species is not specified.

To prevent over-exploitation, this law also prescribes, among others measures, minimum girth limit (dbh) for harvesting of different species, management of Forest Reserves, and incentive regimes for undertaking forestry activities. It regulates conversion of native, private forests into cropland and the State leasing system for private individuals as well. Note that this law introduces the concept, though without naming it, of sustainable management of the resource native forest.

In 1979, the Cooperativa Agrícola de Eldorado publicly denounced the impossibility of harvesting araucaria's seeds in state reserves, since illegal occupation had taken over most of these areas, and an increasing number of people proceeded to conduct harvesting. It became evident that the objectives of creation of the reservations were not fulfilled. These were the protection of the last araucaria stands and the establishment of a new source of seeds to supply forest activities (BERTOLINI, 1998).

In 1982, through Decree N° 43, the logging of araucarias in state properties was banned, unless when individual trees were decrepit, over-mature and/or deformed that cutting were recommended. It also prohibited granting state rural parcels containing araucarias in such a quantity and quality, that designation as seed reserves were appropriate, according to Law N°854. Also in 1982, by means of the Law N° 2265, it created a Special Commission so as to conduct inventories and analysis of Forest and Seed Reserves included in Law N°854, whose goal was to determine their state conservation and, if regarded necessary, to designate those Reserves which do not fulfil conditions to stay as such any longer.

In May 1986, Decree N°1213 prohibited, for a period of five years and within the whole Province, extractive activities on *A. angustifolia* and *Aspidosperma polyneuron* (Palo rosa). Felling was only permitted in case of ill or dead individuals. In October of the same year, *A. angustifolia* was designated as a *Natural Monument*, through the Provincial Law N°2380, regarding it of public interest and banning its commercial trade. The law prohibited logging, burning and trading araucaria either in state or private properties. In addition, in June 1986, Decree N°1617 established new minimum girth limit (dbh) for harvesting of different species:

Species (common name)	Minimum girth limit (dbh)
Anchico, Cañafístola, Cedro, Grapia, Incienso, Lapacho, Peteribí and Timbó	0, 55 m
Azota caballo, Cacheta, Cancharana, Guatambú, Guayca, Guayubira, Laureles and Persiguero	0,45 m

In 1987, Decree N° 373 determined causes for exception to the Law N°2380, which included felling and use of araucarias, procedures for extracting and using them as well as penalties in case of breaking such a law. In 1989, through Decrees N° 240 and N° 242 respectively, the Provincial Reserve "Araucaria" and “Cruce Caballero” were created, both in the San Pedro Department.

In 1992, in relation to the serious ecological and environmental issues that native state forests were facing and the inconvenient economic situation of concession holders, the Provincial State gave sanction to Decree N° 555/92. Through of this the “Economic and Ecological Model for the Use, Management and Conservation of State Native Forests” was created. With such a model, the Government forces those concession holders of state forests wanting to use them to discuss with the *Ministerio de Ecología y Recursos Naturales R*enovables (M.E.y R.N.R.) about likely soil uses and the location of protective forests and ecological strips. The Model also incorporates the Forest Use by Selective Logging System (USLS) as exploitation modality of forestry products in state forests. In addition, Resolution N° 288/92 establishes that slash and burn permissions of state forest will not allow more than 5 ha year^{-1}, and that only one (1) USLS license can be obtained every 6 months, each with a maximum of 50 trees by permission and minimum girth limit of 30 cm dbh for harvesting. In the same year, the Provincial Government promulgated the Law N° 2932, which establishes the Natural Protected Areas System aiming to - among other things- protect samples of all natural environments and species of the Province, preserving their nature as genetic banks, buffers, and sources of raw materials in perpetuity. Its regulatory Decree N° 944/94, sets tax exemptions for those parcels retaining natural forests.

In 1993, the Yabotí Biosphere Reserve (230.000 hectares) was created through Provincial Law N° 3041, with the purpose to stop the over-exploitation and degradation of native species’ habitat. Yabotí comprises much of the San Pedro department area and part of the Guaraní department, with a state core area (Esmeralda Provincial Reserve), and a buffer belt formed by large private properties. This law, and its regulatory Decree N°2472/93, introduces for the first time the concept of Stand as a management unit, and the criteria of Multiple Use for secondary productions (span, yerba mate, etc.). Likewise, it establishes the obligation of presenting Management Plans (instead of the previous Ordinance Plans), and bans slush and burn as method for land conversion. Fishing and hunting are also prohibited.

Through Provincial law N° 3631, the Misiones Green Corridor is created in 1999. The Corridor covers one million hectares and its purpose is to bio-regionally link remnants of forest areas, to protect watersheds and higher parts of hydrological basins in the Province and to prevent gradual isolation of Natural Protected Areas.

Administrative Competence

At a National level

Two organizations are, at a national level, development authorities, and in charge of assistance regimes: the *Natural Resources and Environment Secretary* (*Secretaría de Recursos Naturales y Medio Ambiente* - SRNMA) and the *Agriculture, Cattle, Fish and Food Secretary* (*Secretaría de Agricultura, Ganadería, Pesca y Alimentación* - SAGPyA), dependant of the *Economy Ministry*.

At a Provincial level

Until 1985, when the *Ecology and Renewable Natural Resources Ministry* (M.E.y R.N.R.) was created, the *General Forest Office*, dependant of the *Agricultur Ministry* was the provincial enforcement authority. After that, the M.E. y R.N.R. took over such functions.

1.5 Research Project

1.5.1 Research Framework

This present project was performed at the Institute of Physical Geography, University of Freiburg, in cooperation agreement with the Ministry of Ecology and Natural Renewable Resources of the Province Misiones.

1.5.2 Situation prior to the research

- Most of the araucaria stands are located in the state land. The original area of araucaria forests covered around 210.000 hectares, out of which 185.000 belonged to the Provincial government (COZZO, 1960).
- In the 80's, after the Province government's impulse for settling, the agricultural border expands, to the detriment of native forests. Two extreme tenure systems are established: in one hand, a traditional small-scale system with up to 100 ha parcels, mainly used as cropland and farmland for basic survival; and in the other hand, large-scale properties owned by a few people, under an extractive system exploited by contractors.
- The *A. angustifolia* is regarded as an excellent species for industrial forestry, being the only native conifer used with such a purpose. Its market value is constantly increasing.
- The remnants of *A. angustifolia* show a high degree of over-maturity (MUÑOZ, 1993), which affects its possibilities for cultivation and expansion (FASSOLA, 1998).
- Today, 58 thousand square kilometres (less than 6%) remain from the original one million square kilometres. A very diverse fauna is associated to such forests, which many are directly related to the araucaria.

- A complete protective position of the forests doesn't seem opportunely, because represents an important resource for achievement of economic policies.

1.6 Research Objectives and Scope

Taking into account the situations described under 1.3.2 and 1.5.2, and the actual scarcity of publications on the present state of the Araucaria's natural forests as well as on the environmental consequences of their degradation, this study proposes the following objectives:

> To undertake a qualitative and quantitative analysis of the degradation of the Araucaria's natural forests and to evaluate their actual state, and to conduct a study on the consequent land use change during the period 1960-2000.

As it usually happens during a research project, especially if the subject of study is poorly known, lots of uncertainties arise, although restricting their scope is often a difficult task. Eventually, the following discrete questions could be posed:

- What is the present state of the Araucaria natural forest's ecosystem?
- What is the actual distribution of the Araucaria's natural forests in the Province of Misiones?
- What caused forest degradation? /What were the causes or reasons for the forest degradation?
- Are the current remnants of Araucaria forests enough and self-sustainable to implement a regional strategy for Biodiversity Conservation?
- How does native population perceive the natural forests, as part of its environment?
- Are deforestation, reforestation and other land uses causing higher rates of soil erosion?
- What possibilities and action strategies exist to achieve a future sustainable use of the region?

The following research scope therefore presents

- Identification of land-use classes and corresponding map unit.
- Estimation of potential and actual erosion rates and corresponding map unit
- Elaboration of a spatial database for a Geographic Information System (GIS), as a substantial part of a quantitative diagnosis aimed to define measures and procedures for sustainable development.

1.7 Dissertation Significance

Three elements make this research relevant. The first constitutes its contribution to the debate on human-environment interactions, specifically to subtropical deforestation together competing views on structures and agency, and making explicit their linkages with land-use/cover change. The second is its methodological perspective that sheds additional light on the analysis possibilities of processes and patterns of deforestation and land use/land cover change in the Misiones rainforest. Last but not least, are its public policy implications for policies shaping frontier expansion.

In regard to the policies shaping frontier expansion, in the Province of Misiones there is intense debate about the pathways to adopt for regional development. On one hand, a capitalist model focused on large-scale reforestation development is defended, based on arguments about the economic efficiency of large-scale production. While this model leads to greater deforestation, proponents argue that it would consolidate an intensive system of land production in the long run, which could ameliorate pressures on frontier expansion. On the other hand, the defenders of small-scale agriculture base their arguments on the belief that cultivation could be environmentally sound and highly diversified, and require minimal external inputs. Despite both positions, the provincial government has not still developed a clear agricultural and/or forestry policy. This research seeks to inform this debate by providing an empirical basis by which to assess specific social, economic, and forest conversion outcomes.

2. STUDY AREA

Considering the purposes of this work, the study area comprises the whole area of natural distribution of *A. angustifolia* within the Province of Misiones. However, due to the vast extension of study area and lack of basic road infrastructure, several field studies were concentrated in the vicinity of San Pedro city.

2.1 Geographical Location

The study area lies in the northeastern of the Province Misiones, between 25°40' y 26°50' S and between 54°15' W and the Brazilian boundary, covering an area of approximately 380.000 ha (Fig. 2-1 and 2-2). The altitude ranging between 200 and 830 m asl.

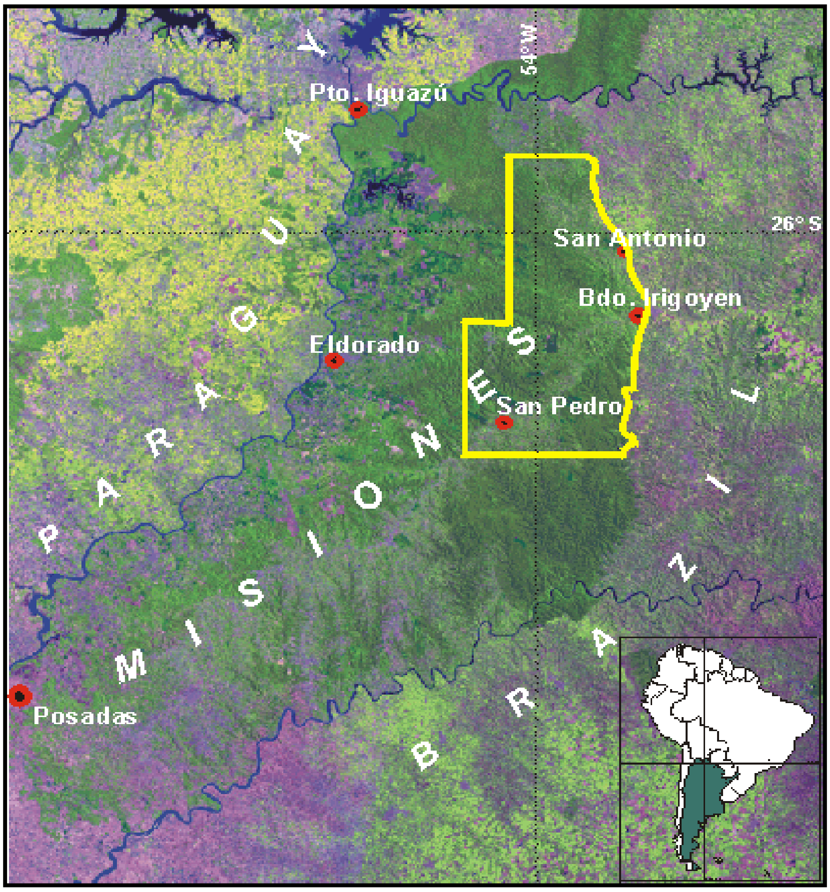


Fig. 2-1: Geographic location of the Province Misiones based on satellite image Landsat 7 ETM+ March 2002 (RGB 5,4,3).

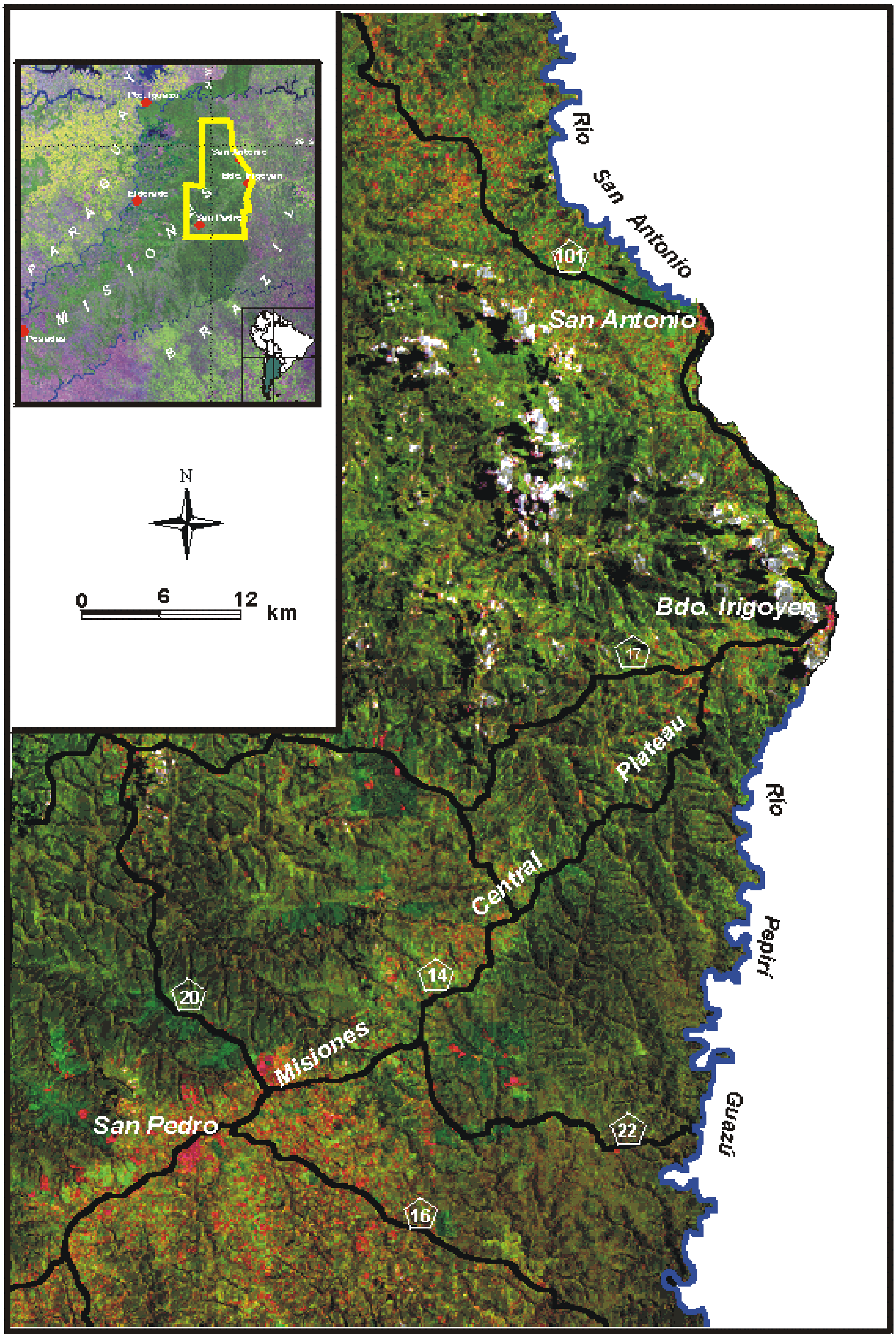


Fig. 2-2: Geographic location of the study area based on satellite image Landsat 7 ETM+ March 2001 (RGB 5,4,3).

2.2 Climate

The climate of the study area is subtropical hot and wet, without dry season, type Cfb according Köppen (1936) classification. Mean annual rainfall range from 2100 mm, in San Antonio, up to 2360 mm in San Pedro, but the actual amount in any one-year may vary from less than 1300 mm to more than 3500 mm. The rainfall pattern is bimodal with two peaks: one in October and the second from January to February. The minimum precipitations occur in July-August (Fig. 2-3/4). The dates on which these rainy seasons start and end are very variables.

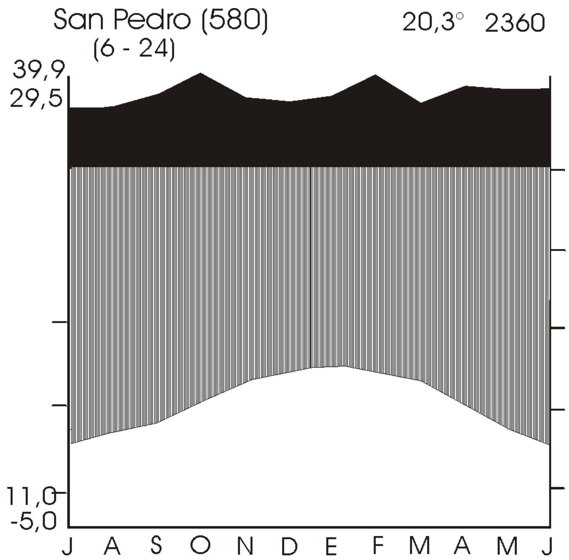


Fig. 2-3: Climate diagram of San Pedro (Data: INTA Misiones, 2002).

Thunderstorms and heavy storms occur during all the months of year although more frequently in summer and autumn, with precipitation intensities above 120 mm h^{-1}, occasionally associated with hail. In summer season, daily cloudbursts are frequent too, mainly in the warmest part of the day, with the most probable time of occurrence among 2:00 and 4:00 p.m. In average, it rains 111 days a year, being the absolute monthly maximum precipitations above 40 mm (Fig. 2-5).

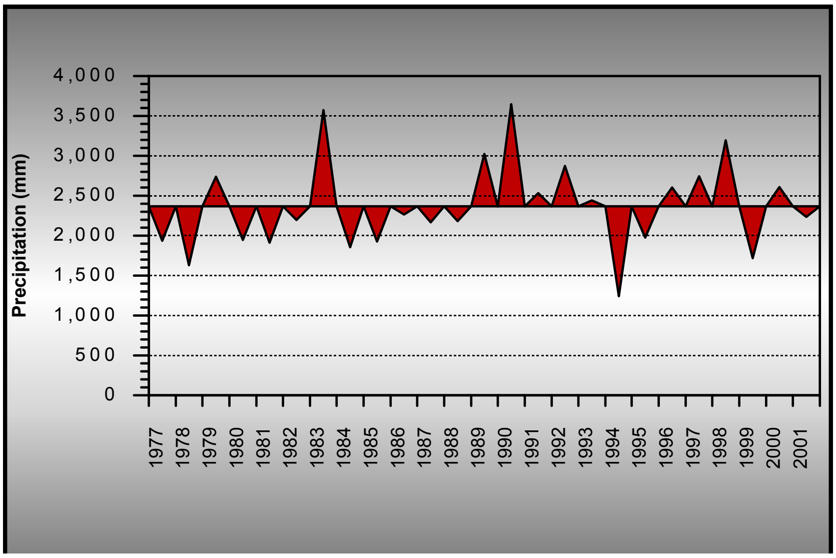


Fig. 2-4: Annual rainfall-course at the station San Pedro. The precipitation values are indicated from mean=2360 mm. The three maximum precipitation peaks coincide with years of occurrence of "El Niño" (Data: INTA Misiones, 2002).

Mean annual temperature range from 19°C, in the highest areas (Bernardo de Irigoyen) to 22°C in the lowest (Andresito). The coldest month is usually July and the warmest month is usually January or February. There are generally relatively small variations between summer and winter temperatures (Fig. 2-6). Mean minimum monthly temperatures are above 13°C, still in the highest areas. Mean maximum monthly temperatures don't overcome 26°C in the whole area. Temperatures also drop about 0.7°C for every 100 m of altitude. Between May and September, 5 to 15 days of frosts are normally recorded. Occasionally snowfall in the highest areas (Bernardo de Irigoyen). Winds prevail, during all the year, from N-NNE and SW-SSW sectors. The frequency of winds increases from E in summer (Data from INTA Montecarlo-Misiones). Squalls of up to 120 km h^{-1} associated with thunderstorms, have sometimes known to occur. During the night, the wind is usually light. Mean annual relative humidity is above 76%, although there is a very marked daily difference in relative humidity. In the early mornings, the air is frequently very close to saturation but in the afternoons, the humidity is usually about 50%. The meteorological information was received from INTA Cerro Azul, Misiones. The atmospheric pressure in the area is below the normal one (760 mm = 1012 Mb) that makes it a cyclonal center. Therefore, humid and hot winds from the Atlantic are attracted. These factors determine a high percentage of environment water vapour, which is manifested like "dew" and it contributes to maintain the soil moist degree. The annual temperatures course determines the variation of the potential evapo-transpiration (Etp). In

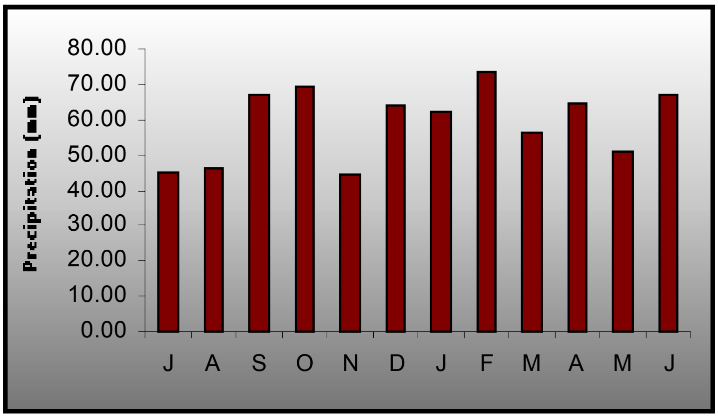


Fig. 2-5: Maximum absolute monthly rainfall at the station San Pedro (Data: INTA Misiones, 2002).

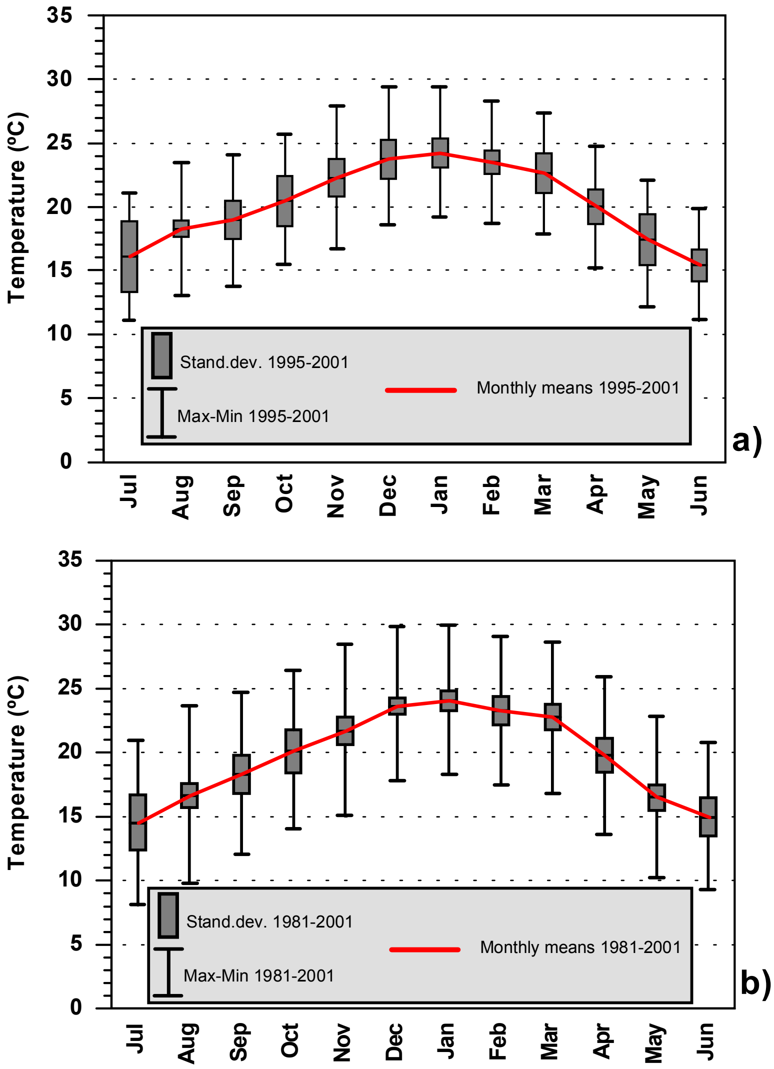


Fig. 2-6: Statistical values of monthly means temperature at the stations San Pedro and San Antonio, a) and b) respectively (Data: INTA Misiones, 2002).

summer (Dec-Feb) the monthly ET reaches numbers that oscillate between the 100 and 150 mm, in winter (May-Aug) it oscillates between 35 and 50mm, considering that these values together with the mean monthly precipitation would have a surplus (Exc) of humidity in the hydric balance of the soil. Table 2-1 lists the hydrological balance of San Pedro's area. The Etp was calculated according to Thornthwaite (1948).

Table 2-1: Hydrological balance of San Pedro area, Rmax=100 mm (maximum soil holding capacity); P: Precipitation (mm); ETP: Potential evapotranspiration (mm); R: Reserve (mm); VR: Reserve variation (mm); ETR: Real evapotranspiration (mm); Exc: Excess-surplus (mm) (Data: INTA Misiones, 2002).

	J	F	M	A	M	J	J	A	S	O	N	D
P	185	179	169	198	183	184	156	147	186	236	177	186
ETP	139	114	107	73	50	36	39	50	60	88	105	132
P-ETP	46	65	62	125	133	148	117	97	126	148	72	54
R	46	100	100	100	100	100	100	100	100	100	100	100
VR	46	54	0	0	0	0	0	0	0	0	0	0
ETRh	139	114	107	73	50	36	39	50	60	88	105	132
F	0	0	0	0	0	0	0	0	0	0	0	0
Exc	0	11	62	125	133	148	117	97	126	148	72	54

2.3 Geology

The study area lies over the Misiones plateau, part of the Serra Geral Formation, formed by Mesozoic basaltic flood lavas, which, on certain sectors, are interceded with partially metamorphosed sandstones. This plateau, extending over almost the whole Province of Misiones with orientation NE-SW, constitutes the local water dividing, from which a number of small rivers run, strongly controlled by joint systems present in basaltic flood lavas and lava flows.

These basaltic units, included in the Serra Geral Formation are tholeiitic basalts (TERUGGI, 1955 in GENTILLI and RIMOLDI, 1979), mostly with dense and microcrystalline, aphanitic textures. These basalts were formed when the region was subject to extensional stress, during the Upper Jurassic - Lower Cretaceous, which resulted in partial mantle melting and its consequent movement upwards through faults and fractures. Some of these fractures have several kilometres extension, prevailing the system with E-W direction. Eventually, flood basalts spilled over the surface. The process can therefore be defined as an anorogenic continental magmatism. The maximum thickness of this rock formation reaches 1531 m at Epitasio Pessoa (Brazil), and it is always thicker than 1100 m in the whole Province of Misiones.

2.4 Geomorphology and Soils

The topography across the area varies from undulating in north of the study area (Andresito) to hilly in the remaining one. The area is conformed by two main mountain systems: i) The Misiones Central Plateau (Sierra Central de Misiones) that crosses almost the whole province with orientation SW-NE. The altitude range between 300 m asl in deep valleys to 830 m asl in Bernardo de Irigoyen, ranging the height mean around to 529 m asl, being the height interval between 500 and 600 m asl best represented. ii) The Victoria's Plateau (Sierra de la Victoria) that crosses the extreme NE of the Province from San Antonio to Iguazú, with orientation SE-NW. The altitude ranging between 700 m asl near San Antonio to 200 m asl in Andresito. The area is characterized by a sharp relief, because of the active and intense fluvial erosion processes that form deep valleys with hillsides above to 35%, in some sites. The mean slope ranging around to 9.61%. Subtropical climate has produced a deep weathering mantle that may reach approx. 50 m. Given by particular geomorphologic characteristics of the Province of Misiones, nine geomorphologic natural regions have been defined (INTA, 1990). The study area extends over four of them (Fig. 2-7).

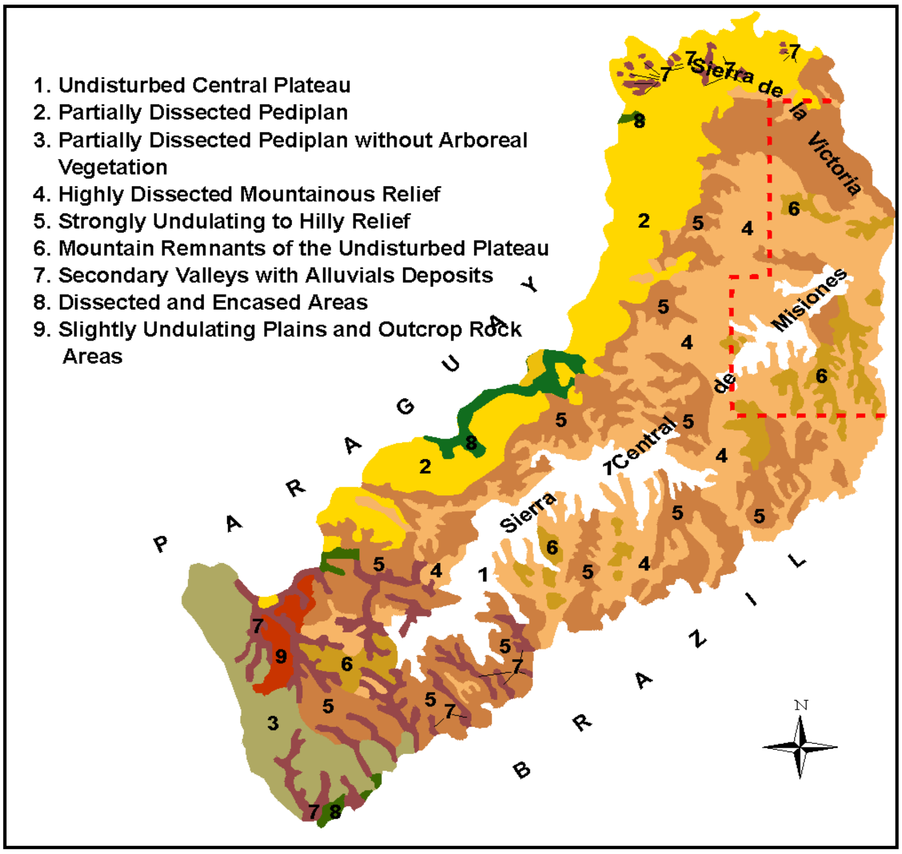


Fig. 2-7: Geomorphologic natural regions of the Province Misiones. (Source: Atlas de suelo de la Rep. Arg., INTA, 1990).

- Undisturbed Central Plateau

  It is the topographic core of the Province: a patchy flat upland interrupted by undulating hills, whose gentle slopes averages to 5 to 9%. Fault systems generate topographic steps, which tend to be higher from SW to NE. Six hundred meters are recorded in San Pedro, and up to 850 m, in Bdo. De Irigoyen. Soils are usually red, thick and formed by clay (Kaolinite prevails) derived

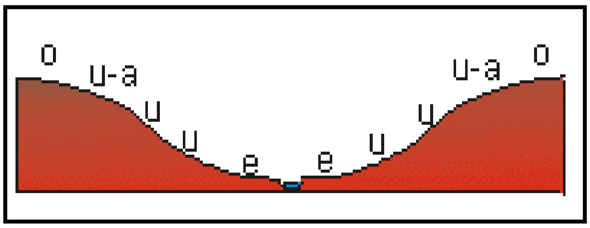


Fig. 2-8: Schema of typical soil associations in an undisturbed central plateau landscape, o=Oxisols (10-30%), u=Ultisols (60%), a=Alfisols (25-40%) and e=Entisols (10%).

from basalts. Taxonomically, they fall within the Ultisols and Oxisols orders (Soil Taxonomy, USDA 1975) (Fig. 2-8).

- Highly dissected mountainous Relief

It extends over the NW portion of the province. It is characterized by a steep sloped-relief, formed after dissection of the undisturbed Central Plateau. Typical landforms are given by isolated hills, which form the boundaries of the Pepirí-Guazú and most of the Uruguay tributary river valleys. This area has a high number of streams and creeks, carved into deep valleys without defined alluvial deposits. This implies juvenile erosive action occurring into a little-stabilized landscape. Results of active erosion processes, thin to moderately thick, pebbly to rocky soils are formed on hilly slopes. They are very poorly developed Entisols and Mollisols. Close to the slopes feet, Inceptisols, also poorly developed but with genetic horizons, can be defined (Fig. 2-9). Finally, basaltic rocky outcrops commonly form hilltops.

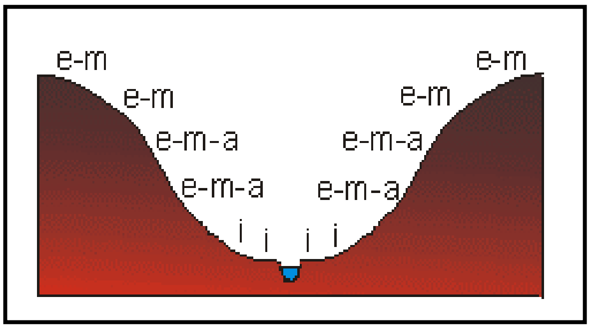


Fig. 2-9: Schema of typical soil associations in a highly dissected mountainous landscape, e=Entisols (40-50%), m=Mollisols (20%), a=Alfisols (20%) and I=Inceptisols (20%).

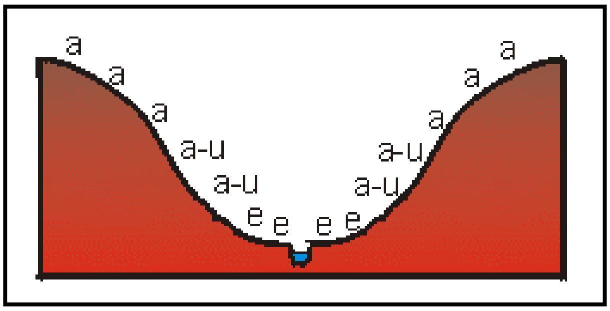


Fig. 2-10: Schema of typical soil association in a strongly undulating to hilly relief. In this region prevails the moderately deep Alfisols, which usually present partially weathered basalt. a=Alfisols (50-70%), u=Ultisols (5-30%) and e=Entisols (20%).

- Strongly undulating to hilly relief

It is characterized by hills with moderate and short slopes (up to 20%), associated to sharp sectors. Hills are normally aligned throughout the mountainous relief. This area enlarges to the north of the Province, over the Uruguay and San Antonio basins, where sub-recent colluvial deposits can be found at the foot of steep sloped hills. In the area of Uruguay River,

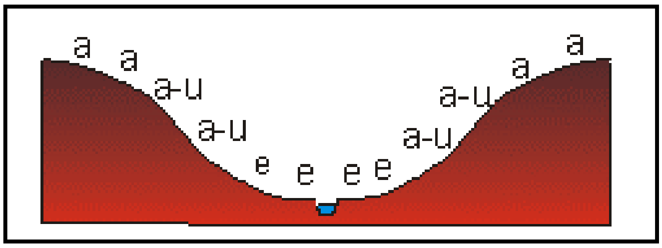


Fig. 2-11: Schema of typical soil associations in a mountain remnants of the undisturbed plateau landscape, e=Entisols (20-30%), a=Alfisols (40-50%) and u=Ultisols (30%).

prevailing soils are moderately thick, and fall within the Alfisols (good fertility associated), and Ultisols orders, the latter being affected by hydraulic erosion and its solum barely reaches 2 m. These soils are always associated to other thin, pebbly soils of hilly areas. At the mountainous area, soils are moderately developed, formed on hills and sub-recent colluvial deposits, and fall within the Alfisols order. They are moderately thick to thick soils, naturally fertile, and associated to those poorly developed Mollisols formed in hilly areas (Fig. 2-10)

- Mountain remnants of the undisturbed plateau
  It presents a moderately to strongly undulated relief, formed by hills associated to steep, highly weathered slopes. Hydraulic erosion exerts its action over this whole area. Soils fall within Alfisols (good fertility, variable solum thickness, from 100 to 200 cm), Ultisols (eroded hills, 200 cm thick from basaltic bedrock) and Inceptisols orders (pebbly slopes dipping to water channels) (Fig. 2-11).

2.5 Hydrology

Many streams and creeks cross the study area, constituting large hydrologic network. This contains three main watersheds: of the Iguazú, Paraná and Uruguay rivers. Misiones Central Plateau separates the last two watersheds from each other (Fig. 2-12). This great fluvial density is consequence of the humid climate and of the fast runoff promoted by the slopes. The climatic and soil conditions are very favourable for this runoff; therefore, the drainage coefficient is very high. The infiltration and groundwater flows

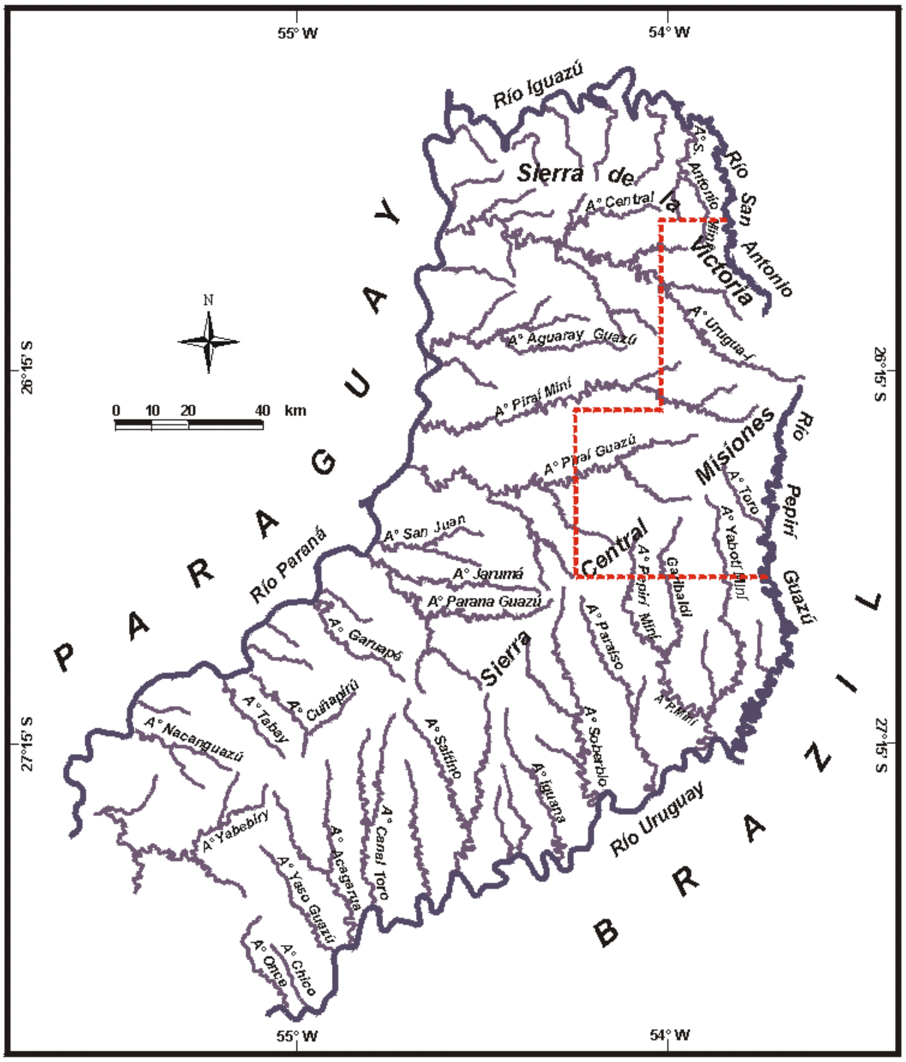


Fig. 2-12: Hydrologic network of the Province Misiones and study area.

absorb an important part of the superficial water and the restitution of the water to the atmosphere for transpiration it is of considerable magnitude, thanks to great volume of vegetation.

The fluvial erosion has played a fundamental role in the relief formation that has not still arrived to its equilibrium profile. The heavy back erosion has achieved in the Misiones streams a type of longitudinal profile that repeats in almost all the cases. Usually a stream, after the first ones 5 to 10 km, enters into a zigzagging canyon, rocky, narrow, with hillsides covered for gallery forest, and whose longitude, following the valley, is from 2 to 2.5 times the straight longitude between the ends of the tract. The area of the canyon can reach up 70-80 Km, and the mean slope of the stream channel oscillates around 1%. Stream up, begins the area of the long rapids and small and medium cascades that are developed until reaching the level of the superior plateau- tributary. Framed in this profile the rivers Piray Guazú, Urugua-i and Pepirí Miní can be mentioned.

Main tributary of the Alto Paraná, from north to south are:

- Urugua-í River: Descends from the eastern hillsides of Sierra de la Victoria. Along its course receives two important tributaries: the Uruzu stream from the right side and the Marambas or Falso Urugua-I from the left side. After a long and sinuous course empties its water north of Puerto Libertad.

- Rio Piray-Miní: extremely serpentine river, with a course mostly with orientation E-W. The Piray-Miní receives several important tributaries (Alegria, Despedido y Paquita), together with other minor ones. After developing several meanders, it falls into the Alto Paraná.

- Piray-Guazú: is one of the interior Misiones rivers of great longitude. Born in the Alegría Hill to 600 m asl, in the north of the Sierra Central de Misiones. Receives several important streams (Alegría, San Pedro and De las Antas). From this last one its course becomes very sinuous until before reaching their end, at about 3 km to the north of Puerto Piray. An evaluation of the Piray-Guazú basin was performed in order to elaborate a hydroelectric project.

Main tributary of Iguazú River:

- San Antonio River is the most important that is born in the south of the Sierra de la Victoria (Argentina) and of the Cerro Negro (Brazil) to 450 m asl, running with orientation N-S. The San Antonio forms the partial boundary between both countries, in its entire course. It is very sinuous and receives along its tract several courses of short longitude.

Main tributaries of Uruguay River:

- Pepirí-Guazú River form parts of the boundary with Brazil. It is born south of Bernardo of Irigoyen, receiving then from the Argentinean side, two important streams A° Dos Hermanas and A° Toro that are born in the Sierra Central de Misiones. After a very sinuous tract, falls into the Uruguay River.

- River Yaboty that is formed for the streams Yaboty-Miní and Pepirí Miní, which descend of the Misiones's mountain.

2.6 Vegetation

Prevailing vegetation is a tropical semi-deciduous forest and mixed semi-deciduous forest of *A. angustifolia*, according to CABRERA and WILLINK (1980), who have included this area within the "Pine district" of the Paranaense Phytogeographic Province. The forests of the Province Misiones are a continuation of the Brazilian "Mata Atlantica" or Atlantic rain-forest. They presents a high diversity, with more than two thousand know species. A vertical stratification of five layers is apparent. The first three arboreal layers have been identified as A, B, and C layers:

Fig. 2-13: Araucaria forest. In this picture it can be seen the two strata or superior layers. The A layer, represented here by araucaria and grapia trees. Immediately under this layer, the B layer, it can also be observed araucaria individuals among other arboreal species. San Pedro, Misiones. (Photo: M. F. Rau, 2002)

- A layer: the emergent. Widely spaced trees 25 to 40 m tall and with umbrella-shaped canopies extend above the general canopy of the forest (Fig. 2-13). These trees tend to have small leaves and some species are deciduous during the win-

Fig. 2-14: Arborescent ferns (*A. procera*). These ferns can reach, sometimes, up to 6 m height. In this case, the presence of brightness is due to a clearing generated by the fall of trees after a storm. San Pedro - Misiones (Photo: Frank Rau, 1999).

ter season. *A. angustifolia* dominates this layer together with, among other, *Meliaceas* (e.g. *Cedrela fissilis* or cedro and *Cabralea oblongifolia* or cancharana), *Fabaceas* (e.g. *Apuleia Leiocarpa* or grapia and *Peltophorum dubium* or ibirá-pitá) and *Apocinaceas* (e.g. *Aspidosperma polyerum* or rose stick).

- B layer: a closed canopy of 15 to 25 m trees. Light is readily available at the top of this layer, but greatly reduced below it. Some species of this layer are also deciduous during the winter season. Compound mainly for trees of the following families: *Mirtaceas* (such as *Campomanesia xanthocarpa* or guabiroba), *Rutaceas* (such as *Baufourodendron rieidelianun* or guatambú blanco), *Fabaceas* (e.g. *Holocalyx balansae* or alecrín, *Parapitptadenia rigida* or anchico rojo, *Myrocarpus frondosus* or incienso, *Lonchocarpus muehlbergianus* or rabo molle, etc), *Lauraceas* (e.g. *Nectandra saligna* o laurel negro and *N. lanceolata* or laurel amarillo, *Ocotea puberula* or guaicá), *Aquifoleaceas* (*Ilex paraguariensis* or yerba mate), *Tilaceas* (*Luehea divaricata* or azota caballo), *Bignonaceas* (e.g. *Tabebuia ipe* or lapacho negro and *T. pulcherrima* or lapacho amarillo), *Boraginaceas (Cordia trichotoma* or peteribi), *Bombacaceas* (e.g. *Chorisia speciosa* or samohú) and *Palmeras* (*Euterpe edulis* or palmito and *Sagrus romanzoffiana* or pindó), etc. Families of the A layer are also present.

- C layer: a closed canopy of 15 m trees. In this layer can be found: *Moraceas* (e.g. *Cecropia pachystachya* or ambaí), *Rutaceas* (e.g. *Helietta apiculata* or canela de venado), *Estiracaceas* (such as *Styrax leprosus* or carne de vaca), *Bignoniaceas* (such as *Jacaranda micrantha* or caroba), *Fabaceas* (e.g. *Gleditsia amorphoides* or espina de corona, *Inga urugüensis* or ingá colorado and *Bahuinia fortificata* or pata de vaca), *Solanaceas* (e.g. *Solanum verbascifolium*

Fig. 2-15: A view of the forest interior where the shortage of light can be observed in the low stratum. The eventual fall of superior strata trees allows the entrance of small light clearings. As it can be appreciated in this picture, this stratum is characterized by the presence of ferns and lianas. San Pedro – Misiones. (Photo: M. F. Rau, 2001)

or fumo bravo), *Caricaceas* (e.g. *Jacaratia spinosa* or jacaratiá), etc.

- Shrub/sapling layer: Less than 3 % of the light intercepted at the top of the forest canopy passes to this layer. It mainly constitute by arborescent ferns, bush and bambuseas, among those stand out: *Urera baccifera* (ortiga brava), *Chusquea ramosissima* (tacuarembó), *Guadua angustifolia* (tacuara), *Guadua trinii* (tacuaruzú), *Alsophira procera* (chachi bravo) (Fig. 2-14).

- Ground layer: sparse plant growth. Less than 1% of the light that strikes the top of the forest penetrates to the forest floor (Fig. 2-15). They are also covered by lianas (vines), epiphytes, ferns and few other herbs, among those can be mentioned: *Doryopteris palmata, Doryopteris submarginalis, Doryopteris concolor, Olyra latifolia, Pharus glaber, Oncidium spp*., *Pleurothallis spp*., *Maxillaria spp*., *Octomeria spp*., *Polypodium phyllitidis, P. pectinatum, P. filicula, Asplenium auritum* (güembé)*, Rhipsalis caereuscula* and *Billbergia nutans*.

3. DEGRADATION OF THE ARAUCARIA FORESTS IN NE MISIONES

Since the end of the XIX century and until the middle of the XX, the exploitation of the natural forests has been the main economic activity from the Misiones rainforest.

In 1885, AMBROSETI commented about the virtues from the araucaria when said:

> "... This wood is very good and has great conditions that make it exceptional for many uses; because of this, it is necessary to think about the possibility of its exploitation that would mean for Misiones a great element of wealth. The grain is rich and, upon everything, abundant, thus it is worthy to care about this matter...".

Years later, SPEGAZZINI (1908), returning from his trip to Misiones commented about the goodness of the araucaria wood for paper elaboration and other derived industries. But it is not until the beginning of the 1940's that began the selective harvest of *A. angustifolia* and, to a lesser extent other "valuable wood", likes the *Myrocarpus frondosus* (incienso), *Tabebuia ipe* (lapacho), *Cordia trichotoma* (peteribí) and *Cedrela fissilis* (cedro). This exploitation continued later on all those other species considerable marketable.

Today, it can be observed that the species has been drastically devastated; the natural forests have been notably reduced, as much as for the timber and fuelwood as for clearing for agriculture and forestry conversion.

Therefore, and by virtue of:

- the advanced degree of degradation of the Araucaria forests and the risk of perpetuity as ecosystem;
- the potential loss of *A. angustifolia* in Misiones as a germplasm repository;
- the scarce literature published on Araucaria forests in the Province of Misiones, Argentina;

The aim of this chapter was to carry out a research about the araucarias natural forest degradation, taking as base the work of COZZO (1960). Evaluate the actual state and distribution of the natural araucaria forest and the remnant existence of *A. angustifolia,* through the historical aerial photography analysis, field work and socio-cultural information, so much historical as current.

3.1 Data and Processing

To carry out the present work, it has been used as primary analysis source the following material:

(1) Aerial Photography of Compañía Argentina de Relevamientos Topográficos y Aerofotogramétricos (CARTA), area of San Pedro-San Antonio
- Date: acquisition date unknown
- Scenes: 6404-07; 6498-99; 6726-28; 6780-81; 6870-71; 6909-11; 6991-92; 7024-25; 7110-12; 7200-03; 7285-89; 7290-99; 7300; 7812-14; 7890-91; 7898-99 and 7901-03
- Scale approximately 1:30 000
- Size: 23 * 23 cm
- Overlap: 60%

(2) Aerial Photography of San Pedro City's and surroundings
- Date: 5/8/1997
- Scenes: 10 to 20
- Scale approximately 1:20 000
- Size: 23 * 23 cm
- Overlap: 60%

(3) Topographical Maps CARTA
- Year: 1962-63
- Maps N°: Series 2754-15: 1A/1B; A4; 2B1/B4; 2C/D; 4A/B. Series 2754-9: 2A/D; 4A/B; 4C1/C4 and 4D1/D4. Series 2754-4:2754-4: 1A, 1B1/B4, 1C, 1D/1D4, 2A3, 2C1/C4, 3A/B, 3C/D, 4A1/A4 and 4C1/C4.
- Scale 1:10 000
- Maps N°: Series 2754-16:1A/1D, 2A/C, 3A/3D, 4A and 4C. Series 2754-10: 1A/D, 2A, 2C, 3A/D, 4A and 4C. Series 2554-34: 1A/D and 3A/D.
- Scale 1: 20 000
- Datum: Campo Inchauspe (1909)

(4) Topographical Maps of Instituto Geográfico Militar (IGM)
- Year: 1997
- Maps N°: 2754-9 San Pedro; 2745-15 San Vicente; 2754-10 Tobuna; 2754-4 Bernardo de Irigoyen; 2754-16 La Gruta; 2754-3 Delicia and 2554-34 Colonia Manuel Belgrano.
- Scale 1:100 000.
- Datum: Campo Inchauspe (1969)

3.1.1 Aerial Photography and Map Analysis

In view of the size of the examined area, the application of aerial photograph offered itself because of greater surfaces can be processed freely with its help and extensive structures become clear. Therefore, the forests were recognized with help of a combined procedure from aerial photography and maps analysis.

As mentioned in Chapter 1.4.1 Cozzo (1960) presented a map of the distribution and location of the existent stands of *A. angustifolia* in Misiones. Since this is the only complete map published to date, and the presence of other stands out of the natural area of distribution was not confirmed (Ch. 1.3.1), this was taken as base to study the actual occurrence of araucaria in its natural area.

The characteristics dominance of the araucaria and the distinctive circular shape of its crown, together with a dark hue due to the reflectance of the needles, the texture caused by the disposition of their branches, shade and relative size of the image in the photographic scale, make the araucaria identifiable through the observation of a stereoscopic pair of aerial photographs (Fig. 3-1 a and b). Given this, and in support to the location of the previous stands, an analysis of the stereoscopic pairs of aerial photographs was carried out, together with their location in the current map.

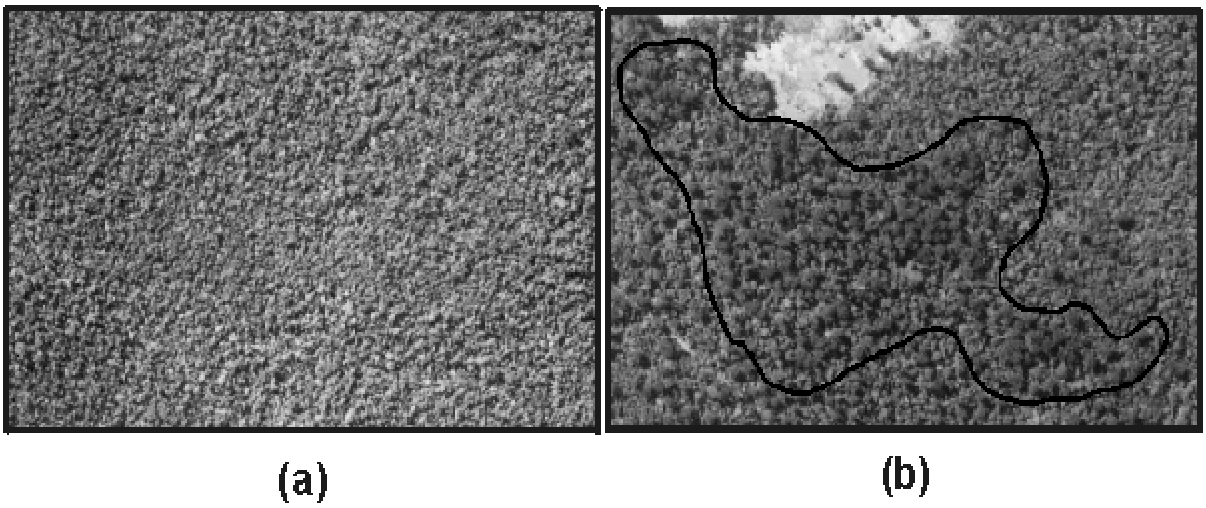


Fig. 3-1: a) Semi-deciduous rainforest. Scale 1:30.000. b) Araucaria forest. Scale 1:30.000. This forest is recognizable due the dominant crown of araucaria.

3.1.2 Terrestrial and Aerial Recognition

With the aim of verification of the actual existence and location of the *A. angustifolia* stands, during the field campaigns between years 1999-2002 terrestrial and air recognitions in the entire area of natural distribution were performed, covering approximately an area of 3500 km². To obtain a correct location of these stands, as a first steps a re-scaling of the araucaria distribution map of 1960 preceded. Then all the stands were located geographically, and finally were these points transposed to current maps. These maps were used as field guide, a journey plan was traced and proceeded to the recognition, location and count of the remnants stands and the isolated groups and individuals of araucaria. It is worth to add that in many cases the access to the stands or to the isolated individuals were most difficult.

The geoposition was established using a GPS receiver (Global Position System) Garmin, model 12. This navigator possesses the reception capacity of 12 parallel channels, differential-ready, an acquisition time of approx. 15-45 seconds and RMS: 15 m (approx.). Moreover, 120 control points were taken with this GPS to produce a subsequent georeferentiation, based on series of aerial photographs and maps mentioned above.

3.1.3 Socio-cultural Approach

Informal interviews were held with ex- forestry workers and personnel of the former General Forests Office and farmers to introduce the objectives of this study as well as to confirm general information about the exploitation of the Araucaria forests, and to acquire additional information about the agricultural system, area and location of land under agricultural activity in the area. The mentioned interviews were recorded and subsequently transcribed. Furthermore, in order to be used as ancillary information, a questionnaire of 72 questions was developed (Appendix 6) dedicated mainly to the farmers, divided in two areas: a) general farm information, b) general knowledge on environment and its protection. One hundred (100) families, between local and rural residents, were interviewed.

3.1.4 Tools

A common problem faced in conducting a research, is either the lack of available information or too large amount of data to handle. In the latter, employing Geographic Information Systems (GIS), which is capable of providing spatial analysis tools for effective data management systems, could solve the problem. A GIS is a computer-assisted system for the acquisition, storage, analysis and display of geographic data (Fig. 3-2). GIS is capable of converting georeferenced data into computerized maps, visualising the results and implementing 'what-if' analysis. The key element in conducting a research using GIS is the availability of spatial data. Application of GIS includes site suitability analysis and developing risk map. Today, a variety of software tools are available to assist this activity. However, they can differ from one another quite significantly, in part because of the way they represent and work with geographic data, but also because of the relative emphasis they place on these various operations (EASTMAN, 2001).

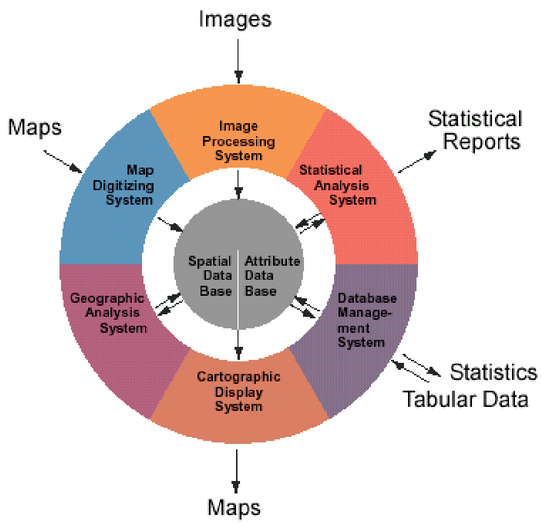


Fig. 3-2: Organization schema of the modules in a GIS.

For this project, a GIS database has been developed for the study area using three different GIS packs. Data in the GIS includes both contemporary and historical environmental and cultural ones that have been derived from a variety of sources, including historical aerial photos and maps.

Idrisi

IDRISI is a geographic information and image processing software system developed by the Graduate School of Geography at Clark University, Worcester, and U.S.A. It covers the full spectrum of GIS and remote sensing needs. The software has over 150 modules that provide facilities for the input, display and analysis of geographic data.

Erdas Imagine 8.4
ERDAS Imagine (Earth Resources Data Analysis System) is a Windows based image processing and remote sensing software that contains sophisticated tools for photogrammetric processing, 3-D mapping, and landscape visualization, in addition to a full suite of image processing modules produced by the Engineering department of ERDAS, Inc., Atlanta, U.S.A. ERDAS.

ArcView 3.2
ArcView is geographic information system software made by Environmental Systems Research Institute (ESRI). It allows visualizing, exploring, querying and analysing data spatially.

3.1.5 Mapping

Once the analysis of the aerial photographs, geoposition and counting of araucarias trees was carried out, a map with the present distribution of the remnants of *A. angustifolia* was produced. Hereby, the following processing steps were realised:

(1) Stereoscopic analysis of the aerial photographs and demarcation of the araucaria stands.
(2) Digitalisation by means of a scanner of both, the aerial photographs and maps. Import of the data into the GIS. Geometric correction of each map and mosaicking of the corresponding temporal series (1962/63 and 1997). This correction was performed using the 1st order Polynomial geometric model, Projection Transverse Mercator, Datum Campo Inchauspe, International Ellipsoid 1924 (mean RMS: 1.5 pixels).
(3) Geometric correction of aerial photographs. Hereto, a first mosaic of aerial photographs was made, those characters that remained without great modifications through the time (crossings roads, rivers, bridges, etc.) were evaluated and the present geographic placement from some of them was established by means of GPS. The points thus defined together with others obtained from present aerial photographs and maps, were used as GPCs (Ground Points Control). The geometric correction was made using the 1st Order Polynomial Transformation, Transverse Mercator Projection, Datum Campo Inchauspe, Ellipsoid International 1924. (Mean RMS: 1.84).
(4) Mosaicking of the 1962 aerial photography series and overlay to the cartographic mosaic of the series 1997.
(5) Location and demarcation on the cartographic mosaic of the araucaria stands
Those stands that were out of the area comprised within the mosaic were manually added to the cartographic mosaic.

3.1.6 Vegetation Inventory

With the aim of obtaining better knowledge of the arboreal floristic composition of the Araucaria forests and *A. angustifolia* natural regeneration in Misiones, an vegetation inventory was carried out. The inventory was conducted in an 2 ha sampling area of not very disturbed Araucaria forest - were extracted a few araucaria trees during the 1960' only - located near of San Pedro (26° 36' 34.6" S - 54° 7' 3.1" W), at 570 masl.

To carry out this inventory, the sampling area was divided into 20 rectangular parcels of 25 x 50 m each one. At the intersection point each 4 parcel a circular plot of r=14 m and 630 m^2 surface was defined (Fig. 3-3). In each plot, trees and large shrubs grater than 20 cm height were inventoried. Four tree height classes were established: <2 m, 2-4 m, 4-8 m and >8 m. Abundance and frequency were estimated for all individuals from each plot. Species richness (S), evenness (E) and community diversity for trees and shrubs larger 2 m height was calculated using Shannon-Wiener index (H') and Simpson reciprocal index (1/D).

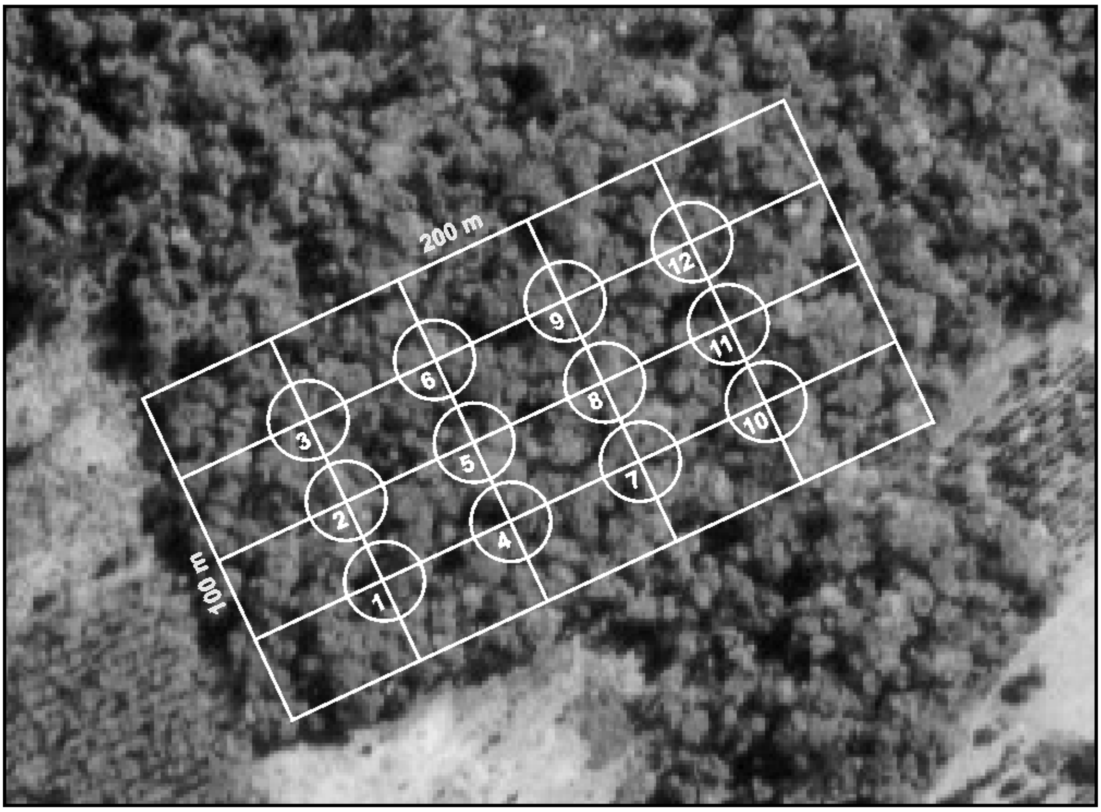


Fig. 3-3: Design of the circular parcels sampling for vegetation inventory.

The species were identified in field by their Argentinean names. Samples of each inventoried species were taken, which were determined with the help of specialists of the National University of Misiones and of the Faculty of Forest Sciences herbarium.

3.2 History of Destruction

3.2.1 Exploitation of *A. angustifolia*

In 1876, the explorers C. Bosetti and A. Luchesi, during their trip to the countryside Eré (today Brazil), give account of the existence of natural yerba mate fields in San Pedro, but the exploitation of these fields takes place in 1885 at great scale (RAMOS, 1934). In this way, and since then, San Pedro and the region of the araucarias are included in the national economy.

On his Third trip to Misiones, AMBROSETI (1885) relates the following:

> "...San Pedro de Monteagudo is situated in the middle of the region of the great pines or better said araucarias (*A. brasiliensis*). These gigantic trees are first seen there and continue for leagues and leagues occupying the backbone of the Misiones mountain range and a good part of the neighbouring Brazilian state of Paraná. The number of pines is huge, and their grouping on the heights has a special character that contrasts with the other types of vegetation."

In that same year, the Governor Balestra sent a mission with the task of studying the region and informing if San Pedro corresponded to state lands, in order to propose, if affirmative, the foundation of the town. In September of 1899, by National Decree, San Pedro city was founded, with a surface of 410 ha.

According to SPEGAZZINI (1908), the natural yerba mate fields existing within the state lands of San Pedro were almost destroyed, and most of the dwellers were migrating to Barracón (Bernardo de Irigoyen). In that place many sawmills were already installed and, being located on private land, they did not require a permission of the Argentine Forestry Office.

It is important to emphasize that Argentinean didn't count broad extensions of native coniferous, and even less conifers of long fibres. Of the three species offering certain forestry perspectives, *A. araucana, Podocarpus lambertii* and *A. angustifolia*, the latter had importance as a source of soft, light-weight and long fibre wood, given its larger area of distribution, its rich extractable content, its industrial yield and exploitation facilities.

Until the beginning of 1940's, Argentina was a forest importer country, as much as of sawed wood as of press paper. Celulosa Argentina, founded in 1929, had begun with the manufacture of paste paper from wheat straw. In 1942, and under protection of the country industrialization policy, the company Celulosa Argentina settles in Misiones for the paper paste manufacture from araucaria timber, and will be this company that will play a very important role in the exploitation of *A. angustifolia*. As of 1947, with the installation of the first big laminated timber factory in private property (Colonizadora Misionera, in Tobuna) starts the exploitation at great scale (COZZO, 1960). During the following years, until the middle 1950's, the araucaria exploitation would be limited only to private properties. In that period, many big factories for sawing and laminated timber production of araucaria, for example, Terciados Paraíso, Terciados Piñalito, Pan- Padován y Santinelli, Terciados el Liso, Fábrica Caffetti, Celulosa Argentina, etc., were installed in the region. In 1955-56 the exploitation of state land areas began in the Department of San Pedro –having these areas the greater concentration of large araucaria stands- through the denominated "Timber Operators of the Province". Through it, the province administered the exploitation, conceding part of extraction to contractors. This system lasted only 5 years, until approximately the beginnings of the 1960's. Since then, the province, through the General Office of Forestry, began with the concession of 100 hectares parcels for the araucaria exploitation. Here already the province would happen only to receive a gauging by extraction. By the end of the 1960's and beginnings of the 1970's, the existing stands in the Department of San Pedro were already exhausted, with only small isolated groups and with few trees in the smaller size classes or poor vigour left, of little value for the extraction at great scale. Consequently, the exploitation is moved towards the north of the province, to the stands located in the area of San Antonio and Deseado. In this region, given the small size of its stands, the harvesting of araucaria as profitable activity lasted only few years more.

During those years, the araucaria was subjected to intensive exploitation. According to personal comments of Mr. Duarte -old araucaria logger and later employee of the province- between 100 and 140 trucks left the area of San Pedro per day, loaded with stumps of 1.75 and 2.25 m length, mainly for the laminated timber industry (60%) and paste of cellulose (40%) (COZZO, 1960). The minimum girth limit was 0.60 m dbh and from a big tree of araucaria around 9 stumps were obtained. According to Mr. Duarte, nothing was wasted, only the branches were left in the felling place. Those individuals that were not apt for the sawing or for obtaining laminated timber were used by Celulosa Argentina to be destined to cellulose paste.

At the end of the 1970's and beginnings of 1980's, the existence of native araucarias was scanty. Although the harvesting of this species for the timber industry, the low number of individuals and its geographic isolation become of it a non-profitable business. The big laminated timber factories either reconverted towards the sawing of other hard and semi-hard wood or closed.

In 1986, with the promulgation of the Provincial Law N° 2380, every action towards the exploitation, commercialization, and use of the species *A. angustifolia* of natural origin is finished. In spite of this the few and isolated individuals that remained continued, and continue, being victims of the furtive felling. The figure 3-4 shows a chronological schema of the araucaria exploitation.

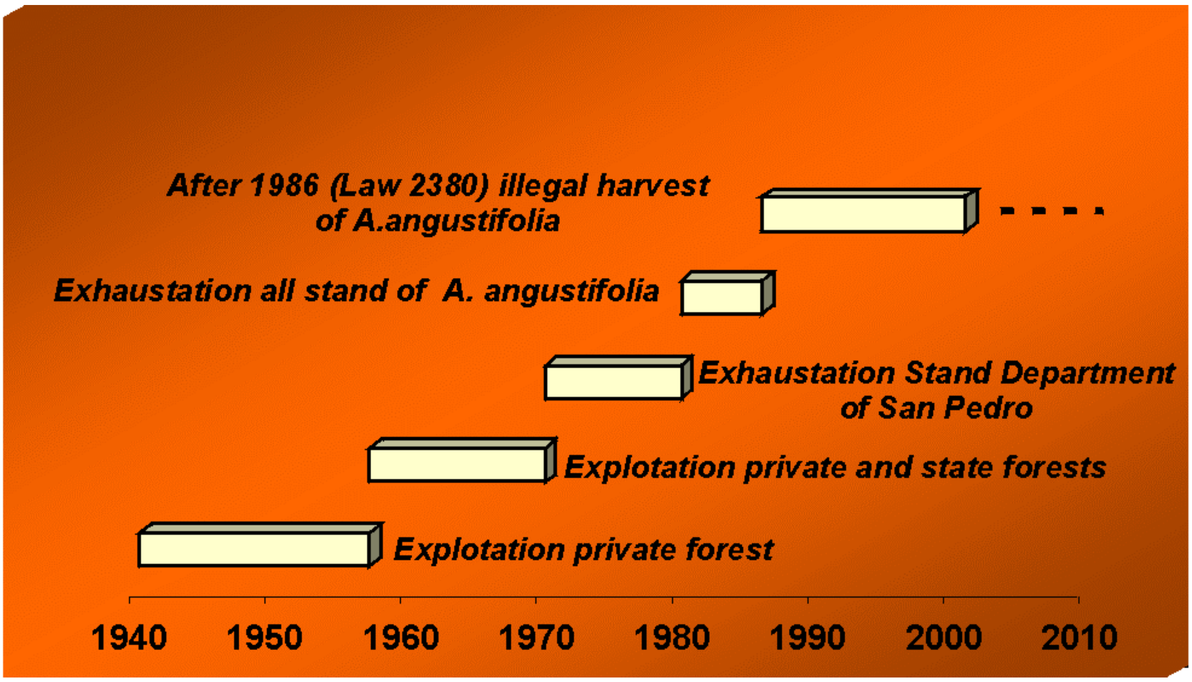


Fig. 3-4: Schematic evolution, according chronology, of *A. angustifolia* exploitation.

3.2.2 Degradation of Natural Forests

Coverage of natural forest in the Province of Misiones has been decreasing at alarming rate, from 87% of the whole area (2.610.000 ha) just before the turn of the XX century to 40% (1.230.000 ha) by the early 1980s (SCHMALTZ, 1988). Many authors have attributed forest shrinkage to population growth, economic development, and misguided government. Other factors, such as conversion of forestland to forestry and agricultural land and harvesting of trees for timber and fuelwood, are generally considered the most important in the process of forest degradation.

The major causes for the degradation of natural forests in Misiones are:

1. The harvesting activity of *A. angustifolia* and the consequent depletion of their stand, left as capital the existence of:

    - Basic road network for extraction
    - Machinery specialized to saw
    - Timber industry for the exploitation and unemployed labour force
    - Channels of commercialization established

2. The National and Provincial State forest policy and the aptitude of the forest soils conferred to Misiones the particular privilege to develop reforestations with fast growth species.

3. Increasing necessities of fuelwood and timber for construction, furniture, paper, etc., because of the population's growth, as well provincial as national (table 3-1) as well as of the demand to exports. This late because of national, provincial and worldwide economy changes and the shortage of timer products supplies produced in these markets by the destruction of other forests.

Table 3-1: Population of Argentine and of the Province Misiones, according census of 1914 to 2001 (Source: INDEC – Instituto Nacional de Estadísticas y Censos).

	1914	1947	1960	1970	1980	1991	2001 (1)
Total País	7,903,662	15,893,811	20,013,793	23,364,431	27,949,480	32,615,528	36,223,947
Misiones	53,563	246,396	361,440	443,020	588,977	788,915	963,869

4. The conversion the forest land to agricultural land because of: i) the total exploitation of the natural yerba mate's trees and the increase of the demand of this product, ii) the immigration of farmers coming from the south of the Province like consequence to the soil fertility loss and iii) the agricultural State policy.

5. The control lack and/or non-application of the forest laws that regulate the exploitation from the provincial authorities.

6. The authorities inability, so much to apply in times early concepts of sustainable management as to long-term planning of the resource use.

Until the 70's decade the *A. angustifolia* specie was harvested almost exclusively. The depletion of its stands left an established industry and unemployed labour force. This fact together with the increasing pressure for forest products, led to the conversion of the timber industry and the beginning of the harvesting of other marketable trees. Major this marketable timber trees species are *Cedrela fissilis, Tabebuia ipe, Aspidosperma polyneuron, Cordia trichotoma, Myrocarpus frondosus, Parapitadenia rigida, Peltophorum* *dubium, Apuleia leiocarpa, Enterolobium contortisiliquum, Balfourodendron riedelianum, Jacaranda serratifolia, Ocotea puberula, Nectandra saligna, Nectandra lanceolata, Ruprecchtia laxiflora* and, *Luehea divaricata*. Of all these species, five were heavily harvested (*C. fissilis, T. ipe, C. trichotoma, M. frondosus and A. polynerum)*. Today, felling *A. polyneuron* is prohibited.

Regarding the forestry, the forest clearing for reforestations is indirectly subsidies, by the National State. This promotion to the reforestation began with the decree law N° 456/74, which claimed lowering of taxes to the companies that invested in forestry. This acted as a multiplier of the afforested surface. Law N° 21.695/78 of Fiscal Incentivate for Reforestation, replaced the system of previous promotion. By this law, the government gave certificates of state credit exchangeable by money. In the province it was contemplated the deforestation costs, what means that **the state subsidized this deforestation**. This promotion system is annulled in 1991 when the proposed goals of forestry surface had not being reached. Later, the Law 25.080/98 denominated "Law of Investments for Forests Cultivated", promotes the implantation of forests either exotic species or native species. These incentives to the reforestation have played a very important role in detriment of the permanency of the natural forest. Widespread areas were completely deforested with the purpose of being replaced by mono-cultivation of forestry species.

The rural population's growth and the agricultural development are the primary social factors associated with the forest degradation. The population of Manuel Belgrano and San Pedro has been increasing continuously and often rapidly. Between 1980 and 2001, the population nearly doubled, from 28.981 in 1980 to 56.927 (Fig. 3-5). Following the revolution in 1976, when the military council took over the government, a settling farmer program took place. In 1978 Andresito town, in northeast of the province, is settled, with a clear agricultural purpose.

In the Department of San Pedro, after restoration of the democracy (1984) and with the auspices of the provincial government began the state land occupation. This settling was carried out without planning and arrangement and without taking account environmental consequences. "The spirit of settling" of Arrechea Plan, the Governor of the Province of Misiones, had a direct approach towards agriculture. An extent government political propaganda offering better land in the region was developed during this period. As consequence, there came a migratory movement toward to the interior of the province, formerly settled down in the south, owners of degraded lands for agricultural misuse migrated towards new places, too.

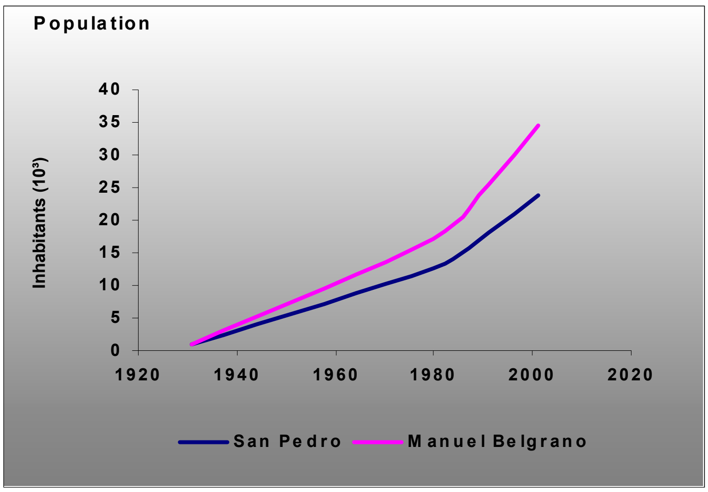


Fig. 3-5: Population growth of San Pedro and Manuel Belgrano Departments.

On the other hand, the Seed Nurseries Reserves established by Law 854 in state areas (Cap. 1.331) were given for their occupation and later subdivision for the process of spontaneous settling through temporary improvements. Clearing permission of 5 hectares per year by slash-and-burn for the yerba mate crops were given starting from 1987 as part of this settling plan (i.e., in this year 550 clearing permissions were given). In 1988-89 the use of the native forest in state areas by selective system of 50 trees per time and twice per year was established, with the purpose of diminishing the number of cleared requests and to preserve the forest. Today this system continues.

Fig. 3-6: Representative landscape of northeastern Misiones. The encroachment of farming has increased during the last years. At the bottom of the picture, degraded forest. San Pedro – Misiones. (Foto: M. F. Rau, 2002)

Although the yerba mate crop was the motor of the land occupation, later other crops such as tobacco, tea, tung, citric, corn, manioc, etc has been incorporated. This process of extension of agricultural land has resulted in the rapid and permanent loss of forest cover. Moreover, due to the rapidly growing population, average plot sizes are declining over time because of the subdivision of small plots too small to sustain larger families.

Today, undisturbed semi-deciduous rainforest can only be found in areas of steep slopes, far from towns. Most of the accessible forests have been heavily disturbed. Selective logging, encroachment of farming, grazing and agricultural use has reduced the area of forest cover and caused its degradation (Fig. 3-6). The figure 3-7 shows an schema of the sequence of the natural araucaria forest degradation.

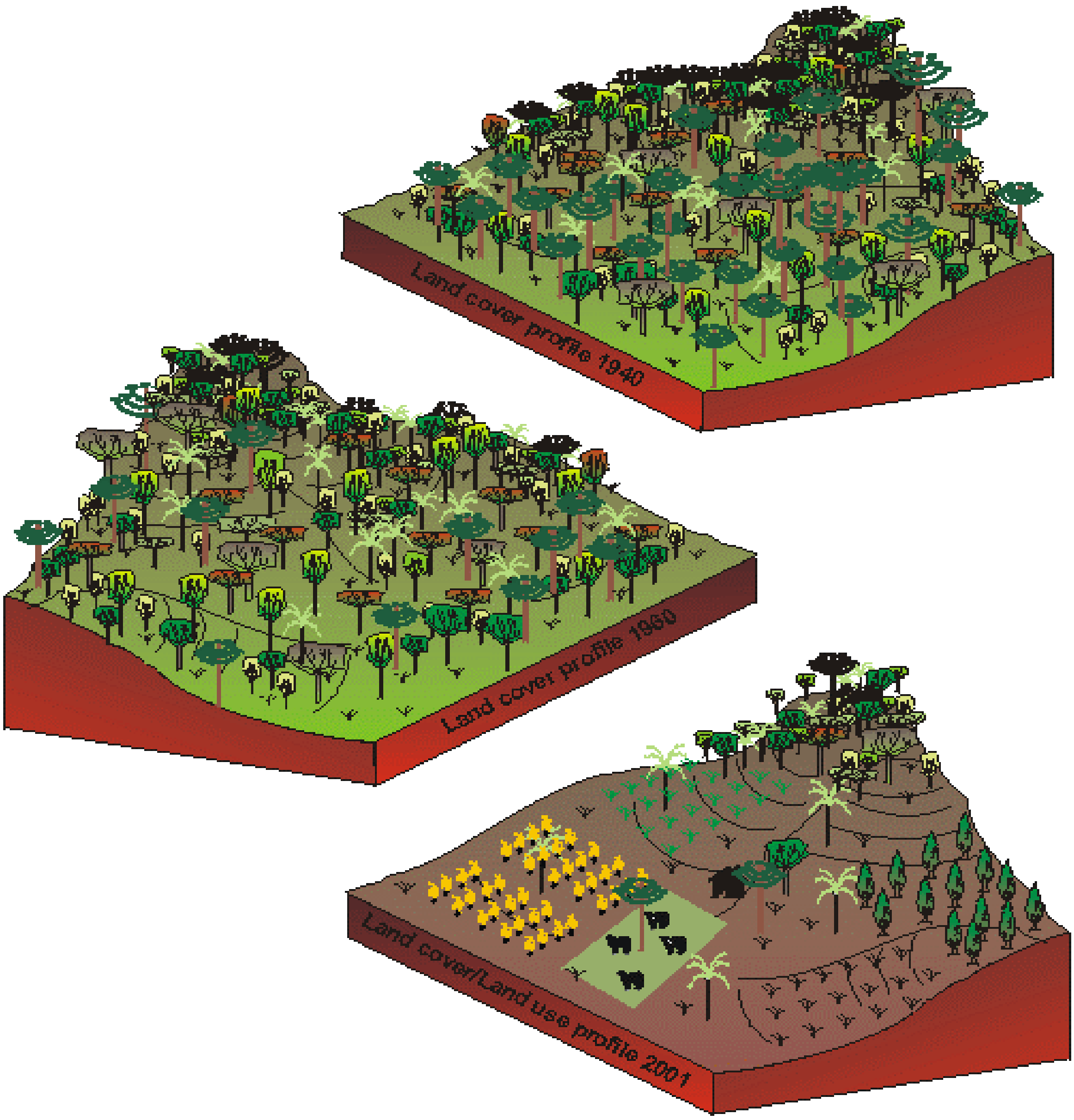


Fig. 3-7: Sequence of the natural araucaria forest degradation and land cover change between 1940 and 2001.

3.3 Results of Exploitation

3.3.1 Actual State of *A. angustifolia*

According to Cozzo (1960) the distribution of the Araucaria forests occupied in Misiones a surface about 210.000 ha (Ch. 1.3.2). If it was possible to group all the individuals in only one large stand, it would occupy a surface about 40.000 ha, and an existence of mere 2.300.000 m³. Of these, 60 percent corresponded to logging individuals and the remaining 40 percent to individuals that were below the minimum girth limit or to individuals that were total or partially decrepit, ill or unusable. Having to add to this, the author expressed, other approximately 700.000 m^3 exploited during the period going from the beginning of the araucaria exploitation, year 1940, until 1960. In agreement to the estimations made by Cozzo, the existence of *A. angustifolia* would have been of 3.000.000 m^3. In addition, the author considered that the yield average by unit logging able was of 6.25 m^3. From this, considering as much the cutable individuals as the non-cutable ones, it can be concluded that altogether there would have been approximately **480.000** trees of araucaria in all the area of distribution, with density around 12 individuals per hectare.

Although today the araucaria natural distribution area is the same one, according show the Figure 3-8 b, the number of stands, small groups and isolated individuals have diminished considerably. Of the field surveys, both terrestrial and aerial, the individual count of araucaria tree gave as result approximately **7.300** (Table 3-2). If this result is underestimated by 60 percent, due as much to the impossibility to accede to some sites by lack of access roads as to the topography, it is finally obtained an existence about **19.000** individuals of *A. angustifolia* in the whole area. Continuing with that proposed by COZZO and taking as base 12 individuals per hectare, if they were to be grouped in a single large stand, this would hardly occupy a surface of **1.580 ha**, scarcely reaching to **4%** of the original existence. A summary of the results is listed in table 3-3.

The obtained results, except for the count of the even existent individuals of araucaria, are relative and according to the review values given by COZZO, who bases part their estimates in studies carried out in the San Juan's stand. Therefore, it should be considered as mere estimate. In addition, the author does not explain if in their estimate isolated individuals were included (Fig.3-8 a). If these were not included, it would be considerably superior the number of individuals, diminishing notably in consequence, the percentage of actual existence regarding the original.

Table 3-2: Summary of previous and current existence of *A. angustifolia*.

Stand	Latitude	Longitude	Location	Previous existence	Current existence
1	26°49'10" S	54°11'30" W	Cnia.Aristóbulo del Valle	6 000 m3	100 trees
2	26°42'25" S	54°11'48" W	Ruta Nac. km 1319	6 000 m3	-
3	26°38'54" S	54°04'48" W	Barro preto	150 000 m3	330 trees
4	26°17'37" S	54°01'36" W	Ex Reserva Gendarmería Nac.	400 000 m3	450 trees
5	26°38'54" S	53°58'29" W	San Juan	25 000 m3	40 trees
6	26°43'14" S	53°55'09" W	Prop. Iguazú S.R.L.	10 000 m3	120 trees
6'	26°45'55" S	53°51'32" W	Palmera Fondo	16 000 m3	170 trees
7	26°37'32" S	54°06'50" W	Pueblo San Pedro	50 000 m3	1 500 trees
8	26°36'07" S	54°04'36" W	Ruta Nac. 14, km 1340	40 000 m3	800 trees
9	26°41'37" S	54°06'49" W	Cnia. San Pedro (Aster)	20 000 m3	700 trees
10	26°33'03" S	53°57'40" W	Ruta Nac. 14, km1352 C.Caballero)	130 000 m3	20 trees
11	26°28'11" S	53°53'35" W	Tobuna	50 000 m3	350 trees
12	26°33'52" S	54°01'22" W	West Ruta Nac.14, Km. 340 y 352	40 000 m3	170 trees
13	26°22'22" S	53°46'37" W	West Ruta Nac. 14, Km 375, 380, 398-99, 402	5 000 m3	100 trees
14	26°17'0.1" S	53°44'0.0" W	Dos Hermanas	13 000 m3	350 trees
15	26°12'40" S	53°45 30" W	Km 424, 15 Km east B.Irigoyen	1 000 m3	-
16	26°12' 28" S	53°39' 55" W	Gramado Norte	10 000 m3	20 trees
17	26°09'6.0" S	53°42'19" W	Telina	6 000 m3	15 trees
18	26°07'46" S	54°02'26" W	Mojón F Línea Barilari	40 000 m3	53 trees
19	26°10'12" S	53°57'04" W	South Parque Provincial Urugua-í	1 500 m3	70 trees
20	26°01'59" S	53°53'19" W	A° Urugua-í	10 000 m3	-
21	26°03'26" S	53°44'08" W	San Antonio	120 000 m3	
22	25°52'50" S	53°59'50" W	Cajón de Piedra	3 000 m3	-
23	25°55'10" S	53°55'30" W	Piñalito Norte	4 000 m3	-
24	25°56'59" S	53°51'46" W	North of Piñalito	3 000 m3	30 trees
25	25°45'00" S	54°00'00" W	Deseado	2 000 m3	-
26	25°40'00" S	54°07'25" W	Andresito - Cabure-í	500 m3	-
27	26°22'13" S	53°43'48" W	Ricardo Querido	65 000 m3	5 trees
28	26°24'33" S	53°44'41" W	A. Glucksmann - oeste Ruta Nac. 14		-
29	26°29'40" S 26°27'16" S 26°32'42" S 26°29'40" S	53°52' 39" W 53°49' 51" W 53°46'32" W 53°44' 50" W	Las Ratas : A° Yaboti Miní, A° Toro, A° El Persiguero, A° Dos Hermanas		250 trees
30	26°35'49" S	53"50'30" W	Pan,Padovan y Santinelli		20 trees
	26°31'15" S	53°56'59" W	Cruce Caballero (no descripto)		1 600* trees
Total				1 227 000 m3**	7 363 trees***

* 1300 entered by Muñoz (1993).
** Only included trees with girth limit >0.60m
*** Included all the individuals, without taking into account minimum girth limit.

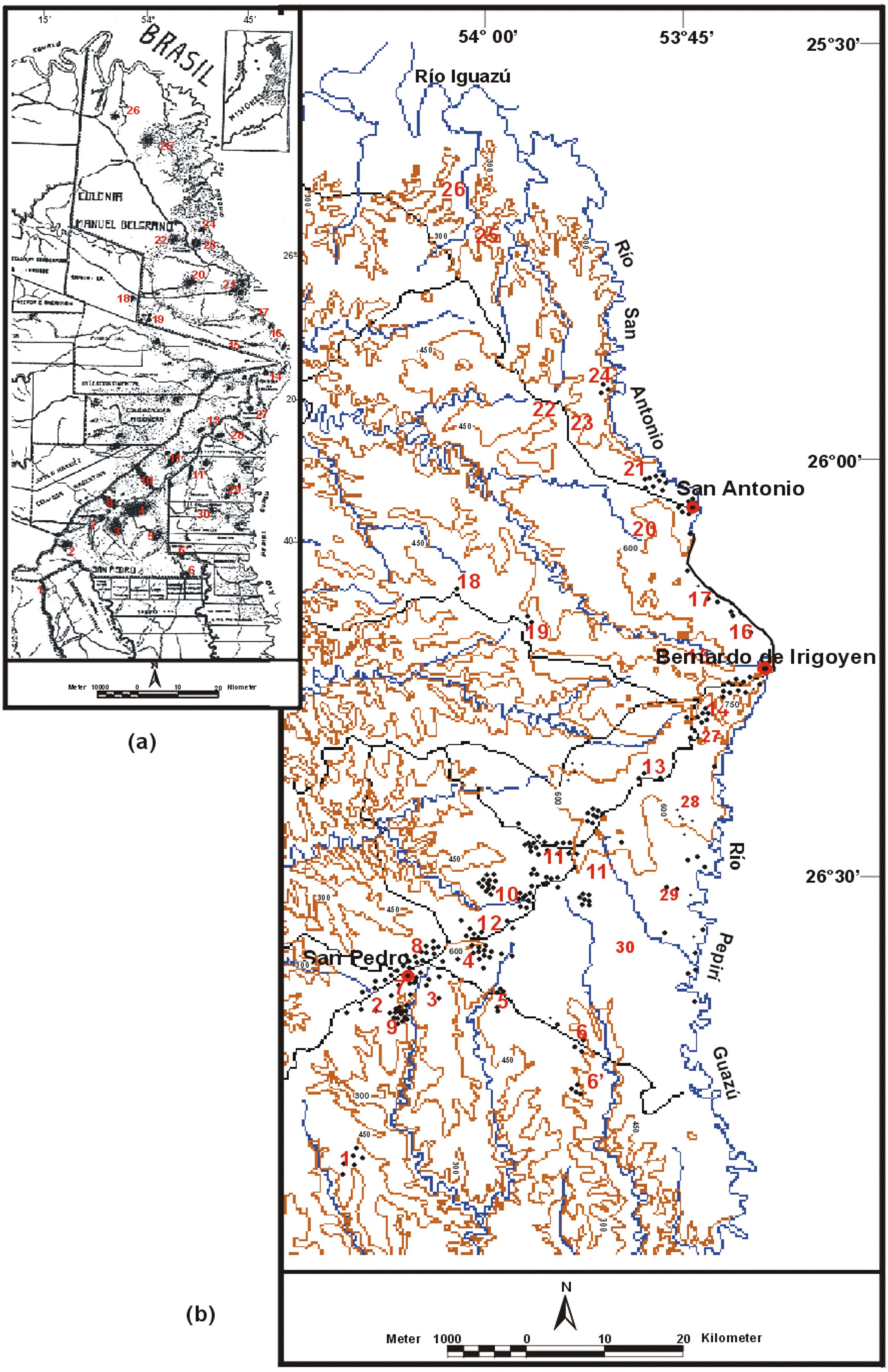


Fig. 3-8: Distribution of *A. angustifolia*. (a) Distribution year 1960, according to Cozzo. (b) Actual distribution remainders of *A. angustifolia*. The black points correspond to current areas with araucarias and the red numbers to the olds stands.

Table 3-3: Summary existence of *A. angustifolia* individuals previous and post-exploitation.

Year	Area of distribution (ha)	Group Area (ha)	Existence	Trees per ha	Percentage
1940	210000	40000	480000	12	100
1960	210000	30700	368000	12	76,67
2001	210000	1400	19000	12	3,96

3.3.2 Floristic Composition of the Araucaria Forests

The analysed flora displayed, in average, 27 species by parcel. Analyzing altogether the 10 studied parcels, 1083 individuals were inventoried distributed in 51 species and 22 families. Of these species, one belongs to the high layer, thirty at the medium and twenty to the low layer. Twenty-five are considered marketable species (Fig. 3-9). The plots 5 and 8 had to be discarded because a storm destroyed great part of the high flora, preventing correct development of inventory. In Table 3-4 there are listed the main species that compose the Araucaria forests. Figure 3-10 shows the absolute abundance distribution according height and phyto-sociological location.

In the appendix II, the complete list of the surveyed species can be seen, with its corresponding absolute abundances by height class, species, relative abundance and relative frequency.

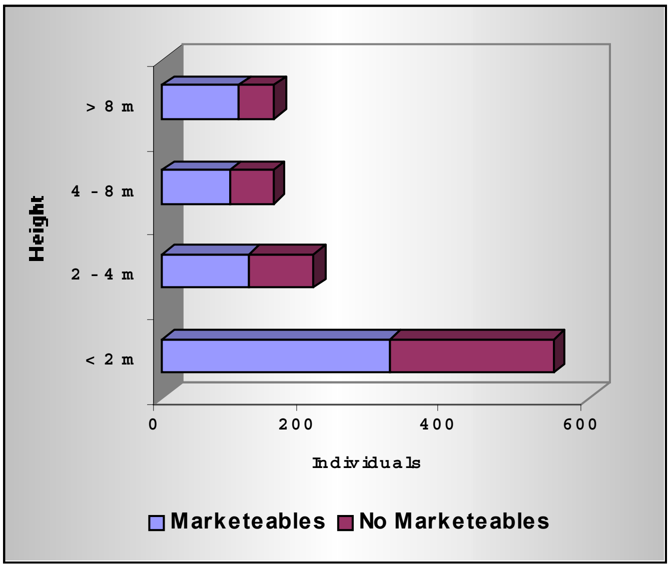


Fig. 3-9: Abundance of marketable and no marketable species.

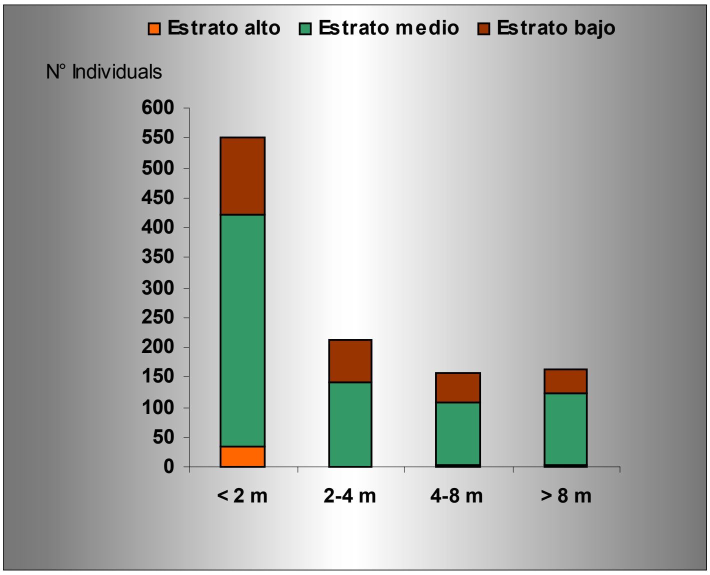


Fig. 3-10: Distribution of arboreal vegetation according height classes and phyto-sociological location.

Table 3-4: Common and scientific names of main species of Araucaria forest, absolute and relative abundance and relative frequency.

Common Name	Scientific Name	Abs.Abundance by height class				Abundance		Freq. (%)
		< 2 m	2 - 4 m	4 - 8 m	> 8 m	Abs.	Rel. (%)	
Guatambu bco.	*Balfourodendron riedelianum*	86	39	14	9	148	13.67	100
Cancharana	*Cabralea canjerana*	36	14	23	11	84	7.76	100
Grapia	*Apuleia leiocarpa*	59	11	3	4	77	7.11	80
Laurel Amarillo	*Nectandra lanceolata*	21	6	8	17	52	4.80	70
Laurel pimienta		7	11	7	22	47	4.34	100
Araucaria	*Araucaria angustifolia*	34		2	4	40	3.69	100
Canela de venado	*Helietta cuspidata*	1	11	11	3	27	2.49	90
Anchico colorado	*Parapiptadenia rigida*	16	3	1	3	23	2.12	90
Cedro	*Cedrela fissilis*	11	1	3	5	20	1.85	90
Laurel ayui	*Ocotea dyospirifolia*	4	8	4		16	1.48	40
Guabiroba	*Campomanesia xanthocarpa*	10	3		2	15	1.39	80
Cacheta	*Didymopanx morototoni*	5	4	3	2	14	1.29	80
Persiguero	*Prunus subcoriacea*	4	1	2	6	13	1.20	80
Guayubira	*Patagonula americana*	4	2	4	2	12	1.11	60
Cañafistula	*Peltophorum dubium*	4	1	1	5	11	1.02	50
Incienso	*Myrocarpus frondosus*	6	1	2	2	11	1.02	60
Alecrin	*Holocalyx balansae*	8			1	9	0.83	50
Laurel Negro	*Nectandra saligna*				6	6	0.55	50
Caroba	*Jacaranda serratifolia*		2	2	1	5	0.46	40
Timbo bco.	*Enterolobium contortisiliquum*	2	1	1	1	5	0.46	40
Laurel guaica	*Ocotea puberula*		1		3	4	0.37	40
Azota	*Luehea divaricata*				2	2	0.18	20
Peteribi	*Cordia trichotoma*			1	1	2	0.18	20
Other		232	92	67	50	440	40.63	-
	Total	550	212	159	162	1083	100	-

As far as the absolute abundance, according to what comes off from Table 3-4, were inventoried 1.083 individuals in 6.300 m². Extrapolating this result to 1 ha, 1.735 trees ha^{-1} are obtained. Analysing in particular the results for *A. angustifolia* can be observed that while having been the only exploited species, it occupies the sixth place according abundance, representing 3.7% of the inventoried forest, in contrast to 13.5% that represents *B. ridelinanum*, the more abundant species. According Table 4, the abundance of *A. angustifolia* is 64 trees ha^{-1}, and 84% of these are young individuals below 2 m height (Table 3-5) of which 13 % are larger up 1 m height.

Table 3-5: Summary of abundance according to height class and relative abundance of *A.angustifolia*

		Abundance by height class				Relative Abundance (%)			
Specie	Abundance (ind/ha)	< 2	2 – 4	4 - 8	> 8	< 2	2 - 4	4 - 8	> 8
A. angustifolia	64	54		4	6	84		6,50	9,50

These results can be compared with those obtained by LONGHI (1980) and SEITZ (1982) (Ch. 1.3.2). The first one, *A. angustifolia* participates with 3% of which 56.7% were smaller young individuals up to 1.5 m height. In the second, from the total of the araucaria young individuals, only 7% were larger to 1 m height, concluding that this number is sufficient to perpetuate the species.

The results of the diversity indexes of Shannon-Wiener (H´), Evenness(E), as well as that of Reciprocal Simpson (1/D), calculated for all samplings, indicate high diversity and relative high uniformity (Table 3-6).

Table 3-6: Values of biodiversity indexes for abundance of species of the Araucaria forest arboreal vegetation (N = 1083). The used indexes are Species richness (S), Simpson Index (1/D), Biodiversity Shannon-Wiener Index (H) and the Evenness factor (E).

Index	Value
Individuals number (N)	584
Species richness (S)	49
Evenness (E)	0,846
Shannon-Wiener (H')	3,291
Reciprocal Simpson (1/D)	19,428

The observed specific diversity can be compared with results obtained by RAGONESE and CASTIGLIONE (1946), who achieved phyto-sociological inventory in a plots of 1.250 m² of an undisturbed araucaria forests in San Antonio.

Year	Superior layer	Middle layer	Low layer
1946	1	14	14 (+9)*
2001	1**	13**	10**

*9 species are shared with the mean stratum
** Average value among plots - individuals >2 m was counted

Many arborescent ferns of the genus *Alsophila,* lianas and epiphytes were observed, although they were not inventoried. Bambuseas was also observed, but in scarce quantity.

3.3.3 Has the Araucaria a Future in Misiones?

There are many of aspects to be considered regarding the continuity possibilities of araucaria, as well natural as implanted in Misiones.

Until principles of the XIX century, a use of araucaria timber was scarce, used only for construction of precarious houses for few settlers at place. The original forests provided enough material without losing its productive capacity. From half-full of the last century, due to a change in the national economic policy and increasing population after the European immigrations, the exploitation of the Araucaria forests began in order to provide as much material for the timber industry as for cellulose paste.

The shrinkage of the Araucaria forests was very fast. At the beginning of the last century, the existence of *A. angustifolia* was estimated approximately to 3.000.000 m^3 or the equivalent about to 480.000 individuals. In 1993, as estimated by BURKART, its existence had been reduced already drastically at 5% of the original existence that grouped an only stand hardly reached 2000 ha. Today, the numbers of araucaria individuals do not reach to 4%. If the exposed by BURKART is taken as correct, although the author does not express estimate method nor amount of individuals by hectare and, in spite of the great underestimation of my results, from year 1993 until today, the existence still on of *A. angustifolia* continued diminishing. This takes to the obvious conclusion that the protection of this specie, by means of Law 2380, was and is not effective.

The use of the best individuals for the timber industry leads inevitably to a negative selection. The few individuals that remain after the exploitation are mainly of very poor quality. During the exploitation, many of the young trees are also destroyed or damaged. After this exploitation, remains a mixed forest of little economic value, where the araucaria can regenerate slowly (SEITZ, 1983). Moreover, given to the demand requiring marketable products, this remaining forest is also exploited, destroying therefore the rest of young araucarias.

3.3.3.1 Natural Regeneration

Controversies exist in the literature about the actual possibility of natural regeneration of *A. angustifolia* (Ch. 1.3.2). If the results of the vegetation inventory (Ch 3.4.2), under natural conditions and with the man's scarce intervention, are compared with those obtained by SEITZ (1982), it could be affirmed that the *A. angustifolia* is regenerated satisfactorily in the forest. The number of young individuals surviving and greater than 1 m height would be enough to perpetuate the species. Despite this promissory result, it is necessary to note that the research of SEITZ was performed in a plot with an average of 100 araucaria trees per hectare against the 6 araucarias per hectare of this study parcel.

An the other hand, in contrary to many authors, I share that proposed by SOARES (1980) that the araucaria would be a series species since it does not present fundamental characteristics to be a pioneering species (size, shape and weight of the seed, fecundity, reproductive cycle, longevity, etc.) or a climax species. These aspect, added to their shade tolerance in the first years and in its natural environment, indicate that it is not a heliofilous and pioneer species, being able to settle down in the forest understorey (DUARTE *et al.*, 2004). To this can be added that expressed by COZZO (1995) that the araucaria, in its natural environment acts like an umbriferous species in the first years (until 20), but in open culture, it becomes heliofilous.

Other aspect to considerer is that it would need some type of disturbance so that the young individuals, finally, can develop naturally. According to opinion of Dr. Seitz (in personal communication) this disturbance would be the fall of trees for wind action, which would generate gaps where one or more young plants would develop. It is necessary to note that extensive gaps cause incentives in the pioneer vegetation, which will shadow the young araucaria. Being a dioic species, it needs both individuals for its reproduction, but it is still in study the number of masculine tree necessary per feminine tree to obtain a good production of seeds (CACCAVARII *et al.*, 1999).

Today, the natural areas where a relatively important number of araucaria trees are preserved, although with a density far below that of the old stands like the Cruce Caballero Reserve with a density average of 6.76 ind/ha (GARTLAND, 1984), are not only very small. This reduces the probabilities of occurrence of a natural phenomenon that may produce a gap within the area, ceding space to the young individuals to ascend towards the superior layer. To this it is necessary to add the high rate of predation that undergo the fallen seeds, as much by the high number of animals living in these reserves (that, being surrounded mainly of vast areas under agricultural use, do - some of them - almost exclusive habitat of these sites) as by the predation that the local settlers make for human food.

Besides, the predominant over-mature state of the araucaria population in this natural areas, allows to foresee a trend toward the gradual decrease in the seeds production and its mean viability; also considering that the loss of crown volume with the natural fall of its branches is a feature of the senile state of the araucaria, with the rising loss of floral yolks (BURKART, 1993).

Fig. 3-11: Isolated araucaria trees in culture fields, threatened by the fire of the burning for extension of agricultural border. In the Province of Misiones, like in many other third world regions, is usual the slash and burns practices for clearing of an area for later agricultural-forestry use. San Pedro - Mnes. (Photo: Frank Rau, 1999)

On the other hand, the young individuals in open areas, mainly small farms under agricultural use, have generally two ends: a) are simply “cut with machete" by the agriculturists given the impossibility of a later use, established by Law 2380, as to, according to their own expressions, not to be complicated in the future with the adult units of this species in their properties; b) they perish with the fires during the burning previous to the preparation of the area for later culture (Fig. 3-11).

To this impediment of the development of young individuals as to the destruction of adult trees located in populated areas, made by the settlers because of rancour created by such a law, is necessary to add clearing permissions (Fig. 3-12). An example is the Decree 195, signed by the governor Carlos Rovira and dated 03/14/2002. Because of it, the felling of 156 native araucarias, located on both sides of the route 101 between San Antonio and Bernardo de Irigoyen, for the asphalt paving of this route, was authorized. Another example would be the authorization, still in study, of the felling of other 80 native araucarias, at the edges of the national route 14 between San Pedro and Bernardo de Irigoyen, for the asphalt paving of this route. It is necessary to consider, in addition, that many of the adult units that still persist in the areas of reserve as well as in open places (state areas or private properties), are those individuals left by the exploitation, reason why many of them are overgrown, decrepit or sick, with a consequent limited production of seeds. Consequently, the natural regeneration of the species is very difficult, as well in protected an in no protected areas.

Fig. 3-12: Araucaria with exposed roots. This is not an isolated case, but rather it is usual finding exemplary with their destroyed roots, so much for the activity of the road machinery like for local residents aggressions (Photo: M.F. Rau, San Antonio - Misiones, 2000).

3.3.3.2 Forestry

The growth of the araucaria is, like in many other species of trees, a slow process. In a place with apparently inexhaustible wood reserve, nobody wants to waste time in species of slow growth where, on the other hand, the exotic species develop clearly much faster. The owners only think about the profits and not about the sustainability.

Since 1940, reforestations with araucaria were tried, first in small surfaces, and since the 1960's in larger areas. Nevertheless, in the last 20 to 30 years a decrease in the implantation of *A. angustifolia* is observed against to other exotic species like *Pinus elliottii* (slash), *P. taeda* (loblolly), *Eucaliptus spp*. etc. of a faster growth. This is a response of the increase in the demand, as much of the international market as of the national, and in spite of the differential price of the araucaria timber in these markets. This can be seen reflected in Tables 3-7, where the amount of sprouts - as well as of surface with permission of forestation with *A. angustifolia* - is visibly smaller than that with species of pine and eucalyptus. As can be appreciated, the surface to be forested with araucaria is only of 6%.

Table 3-7: Sprouts existence according forestry species in 40-forest breeding gardens of Misiones, and reforestation surface solicited, by species - year 2000. (Source: M.E.yR.N.R., Provincial Forest Service 2000).

Species	Amount of Sprouts	Solicited surface in has
P. elliottii	26.642.500	27.701, 54
P. taeda	20.929.000	22293,88
Eucalyptus dunii	24.040.000	682,38
P .caribea	12.205.000	212,64
E. grandis	11.725.000	3389,98
A. angustifolia	609	6693,82
Other natives	453	512,31
Toona ciliata	162	3429,05
Grevillea robusta	91	764,49
Melia azedarach (Paraíso)	70	10844,62

It has to be remarked that the big multinational companies installed in the province, with properties that reach almost to 30% of its surface, prioritise the implantation of species of faster growth as a response to the demand of the international market.

On the other hand, the agriculturists facing the provincial and national incentives for the forestry, and the programs of sustainability of the production performed by national institutions - such as the INTA - choose to destine small areas in their small farms for the reforestation. They do that with exotic species of fast growth, in order to be able, while waiting the cut shift, to make pasturing under cover.

Considering the exposed in 3.3.3.1, the reproductive capability of the remaining individuals of araucaria in the Province of Misiones, being these mainly overgrown or ill, is diminished. In view of this, the amount of seeds of the araucaria in Misiones, produced and destined to commercial use, is far from being enough to provide the requirements of the forest demand. This leads to that the only alternative for the foresters is to import (legally or illegally) seeds from Brazil. Nowadays, the forest plantations of *A. angustifolia* are, mostly, from seeds of varieties or ecotypes of Brazilian origin.

3.3.3.3 Conservation of the Germplasm

Gene Bank is a place where plants or plant materials are preserved to conserve the germplasm. Gene banks can be either *ex situ*, where seeds or plant parts are preserved outside their area of growth, or *in situ*, where plants, are maintained in natural preserves. The maintenance of germplasm banks is a promissory genetic conservation channel that is compatible with the conservation “ex situ” and the development, if it is carried out with complete identification with its cultural and institutional historical context. The germplasm readiness is indispensable for the genetic improvement since variability is required for those characters that limit the production.

With regard to the araucaria, given by the recalcitrant characteristic of its seeds the conservation of a germplasm is difficult “ex situ". Of here the importance of reproductive individuals' conservation, that is to say, of an “in situ” germplasm bank.

3.4 Discussion

The aim of this chapter was to carry out a research about the araucarias natural forest degradation, and evaluate the actual condition of *A. angustifolia* population, through the historical aerial photography analysis, field work and socio-cultural information. Hereto, in a first step, the map published by Cozzo (1960) was re-scaled and the air photographs of 1962 analysed. All araucaria stands were located and transposed to actual maps. Based on this maps recognitions as well air as terrestrial were carried out and both the groups and isolated trees of araucaria counted and positioned with GPS. Finally, an actual distribution map was obtained and the current existence of araucaria was estimated.

As a conclusion from the actual distribution map, of the 30 araucaria’s stands described by Cozzo in 1960, as well in state lands as in private property, today none is left as such, only some small remnant groups and isolated individuals, mostly in lands under agricultural use (Fig. 3-13).

Fig. 3-13: Air view of Araucaria Reserve (center of image) surrounded by agricultural fields. Today, this Reserve is one of the only three Provincial Reserve that conserves a greater group up 300 araucaria individuals. San Pedro - Misiones (Frank Rau, 1999).

The landscape of great giants of which once they spoke and which astonished so many men and women, and that gave shelter too much of the regional fauna is today almost disappeared. The magnitude of its fragmentation and devastation makes of its recovery something nearly impossible.

Although, for that analysed, there is not of considers at the moment to *A. angustifolia* like a species in extinction, the continuity of this and the conservation "in situ" of the germplasm in their distribution

area in the Province of Misiones is threatened, but might find a solution in the conduction of the development of young individuals through the handling of the accompanying forest. This could be carried out, not only in those places today destined to reserve and with a relatively considerable number of still reproductive adult individuals, but as well as in those where - given the conditions and aptitudes for the development of this species- can be selected, enriched and handled in order to obtain a potential new stand of seeds.
It would be of interest in a future to evaluate the potentialities of araucaria reforestation, as it contributes to the feasibility and procedures of the recovery of natural areas of the Araucaria forests.

Today, the weak policies adapted to preservation and forest resource sustainable management is noticed, suggesting the necessity to make compatible the national and provincial units of management in benefit of the forest resource.

Although there are intentions of change in the awareness of some producers and industrialists of the forest on the relevance of the totality of the primary resource, this is not sufficient. This reveals the necessity to promote changes in the methodologies of forest use, as much through a policy of forest arrangement as by the accomplishment of educative campaigns that through suitable management contribute to the sustainable development.

With regard to the Law 2380 and its modifications, tending to protect the *A. angustifolia* like specie, it becomes evident that their application and the control on the corresponding organism's side was – and is not - satisfactory. The differences in number of trees quantified since 1986 confirm it. There is a fundamental error of this law the intention to preserve only the araucaria and not the ecosystem, especially in a species so closely related to it. The lack of delimitation of more areas destined to their preservation ended at: 1) Trees that were geographically far from the control centers, were susceptible to the illegal felling for their economic value. 2) To those ones that were near all alteration of environment was allowed as much for urban constructions as for agricultural areas, clearing all accompanying flora.

The great inequalities observed in the surfaces afforested with araucarias in relation to other exotic species could be diminished through an increase in the values of the forest subsidies (national and provincial) in the reforestation *A. angustifolia* species, in those areas apt for their development. Likewise, and in view of these inequalities, it is necessary an investigation on the possibilities of a genetic improvement of the *A. angustifolia* that allows to be more competitive in relation to exotic species of faster growth.

Finally, it is also necessary to remark that the disappearance of the Araucaria forests harms and threatens to all those species associated with it, among which is possible to mention:

I. ARAUCARIA TIT-SPINETAIL (*Leptasthenura setaria*) endemic species and whose distribution is from Rio de Janeiro, Brazil, until Misiones, North Argentina, restricted to the forests of araucaria pines. This specie is currently near threatened per Handbook Birds of the World.

I. The VINACEOUS PARROT (*Amazona vinacea*), catalogued like "insufficiently known" by the UICN (1996) and "endangered" by FUCEMA et al. (1997), uses seeds of araucaria for its feeding (PRESTES and MARTINEZ, 1996). photo in captivity.

I. The RED SPECTACLED PARROT (*Amazona petrei*), is catalogued like "vulnerable/rare" by the UICN (1996), "endangered" at national level (FUCEMA, 1997) and in appendix I of CITES (CHEBEZ, 1994). According to MARTINEZ (1996), displacements from reproductive, post-reproductive and sleeping sites were verified in Brazil throughout all the year, in areas of feeding with araucaria seeds, reason why its occasional presence cannot be discarded.

I. The AZURE JAY (*Cyanocorax caeruleus*), catalogued like "almost threatened" by the UICN (CHEBEZ, 1994), and "vulnerable" by FUCEMA et al. (1997) feeds, like the common magpie (*Cyanocorax chrysops*), of seeds of araucaria, which constitute the main sustenance in the months of autumn and winter (UEJIMA and ANJOS, 1994). These authors affirm that both species are considered like dispersing of araucaria seeds.

I. The BROWN HOWLER MONKEY (*Aloutta guariba clamitans* or *Alouatta fusca clamitans*), catalogued like "vulnerable" species in Red Book of the Endangered Species of the IUCN (1996), due to the evident population declination that is suffering as due the destruction of its habitat. In the Province of Misiones has been declared Natural Provincial Monument by Law N° 3455 of the 13th of November of 1997. In Argentina is catalogued as "in danger of extinction" (FUCEMA et al., 1997), and included in the appendix II of the CITES (CHEBEZ, 1994).

On the other hand, JARDÍM and OLIVEIRA (1994), studying the ecological and ethological aspects of the brown howler monkey, established that there is a close relationship between these and the Araucaria forests. Throughout the period of study, they observed the consumption of 32 vegetal species. Most of the time was used in feeding on leaves followed of seeds of araucaria and flowers of broadleaf trees.

4. LAND USE CHANGE

4.1 Introduction

There are different degrees in alterations of the natural communities that constitute an ecosystem. These go from the simple exploitation of some of their vegetal resources and animals to the radical destruction of the communities and the soils where they are developed. The total or partial elimination of the vegetal cover, either to use the natural resources or for agriculture or grazing, is an essential practice in the colonizing action of men.

The substitution process of the natural communities by zones adapted for agriculture and grazing appears generally in the areas with greater productive potential. These are generally flat lands, of deep soils, in fertile valleys. The use of more limited potential agricultural lands, located in slope area and more susceptible the deterioration begin when the demographic pressure increases. The damage will be greater or smaller in relation to the agricultural practices.

The process previously described can also be a consequence of the social structure of the settler human group in the area, not only of its number. For example, the more powerful high class of society takes possession of the best land, forcing to move the low class towards the poorest and unproductive land. In this way, the unequal distribution of the wealth generated by the land increases this social inequality still more.

The major cause of degradation of natural forest in the Province of Misiones is the reforestation activities and encroachment into forestland to expand farmland and pasture.

4.1.1 Colonization and Agrarian Expansion in Misiones

From 1897, Misiones was practically invaded by farmers from of almost all parts of the European continent. The Slavs (Polish and Ukrainian) who settled in the South zone were the first to arrive. The Germans soon followed and occupied the high valley of Paraná River under private settling regime. Later on, the state lands of the Misiones Central Plateau range of the territory were occupied so much by Slavs and German, as for Scandinavian, Swiss, French and Englishmen.

The agrarian border has been continuously in expansion from 1897 to the present decade, when it has been considerably diminished by national socio-economic factors. Any ways, the surface under production, considered in 4% of the territory for 1895, reaches 83 % at the present time. The settling under official auspice practically non-existent from the mid of 30s, took relevance centered in the North of the province, in the area of Andresito in 1978 with certain success and continued to the end of 1984 in the East and the Northeast of the Province, mainly in the Departments of Guaraní, San Pedro and Manuel Belgrano.

The most active border is located on the East and the Northeast, throughout the valley of the Uruguay River and the dry border with Brazil. Most of the farmers settled in the last years, are legal and illegal Brazilian immigrants there. Many of them are subsistence agriculturists who practice a shifting agriculture and the slash-and-burn, and have been pushed towards Argentina by the expansion of the soybean crops in great scale in the south of Brazil. Great quantity of medium and small farmers was generated through this historical process. But their aspirations and expectations have been held up and still do by the same characteristics of the agrarian system where they belong. Such a structure includes an increased number of familiar agricultural exploitations, with a reduced capitalization capacity. This smallholder coexists with the great latifundium.

4.1.2 Land Ownership Distribution

The land ownership distribution in the study area is an important aspect for the interpretation of the natural forest degradation reasons. The condition of land holding and the size of the rural farms determine in a singular way the productive system that can be applied in each one of them (LACLAU, 1994). When analyzing the Farming National Census 1988 information (INDEC 1991) (Fig. 4-1 and 4-2), the small farm property character of the farm owner of the Province Misiones can be observed. The parcels of 50 ha or less represent 80% of the total of agricultural farms (EAP´s), these include only 24% of the total surface of the province. The 200 properties larger than 1000 ha represent the 44% of the country surface. The Department of San Pedro has 340.700 ha, which about 90.000 ha were state lands that had been transformed into small farms of mainly between 10 and 25 hectares today. The remaining land is divided between 22 large-scale properties and few properties of between 100 - 1000 ha (meso-scale). In the Department of Manuel Belgrano, with a surface of 327.500 ha, the system is based on small EAP's, and with only two large-scale properties estates (both with surfaces greater than to 30.000 ha). The conditions that define these small farms are: shortage of natural and economic resources, small parcels in function of the family nucleus, precarious land holding, low family manpower remuneration, lack of

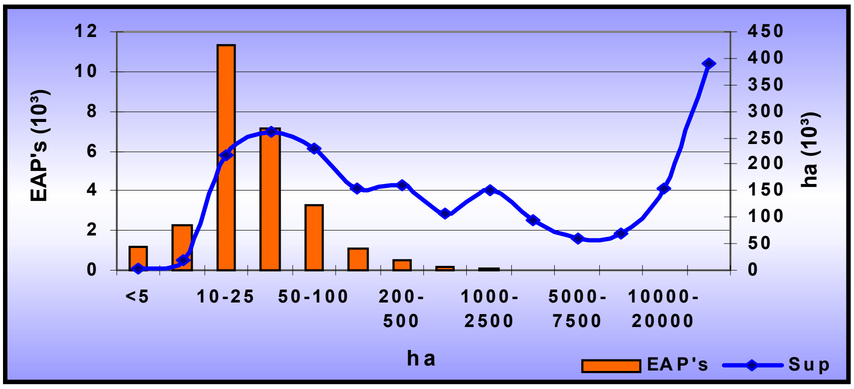


Fig. 4-1: EAP's number and surface, according defined property boundaries.

technology and appropriate technical assistance, difficulties for the access of the credit, low negotiation power in the markets and organizational weakness of the producers.

According to data of the Provincial Direction of Land, of the previously total state land, today only 20% have property title. The remaining 80% is under occupation permission or squatters. In the last years, many owners have left their great properties, heavily used, due of the tax burden and the current scarcity production of their forests. In many cases, these properties have been occupied by wandering settlers. Sometimes, parts of these properties or improvement made by the settlers have been sold in fact more than once.

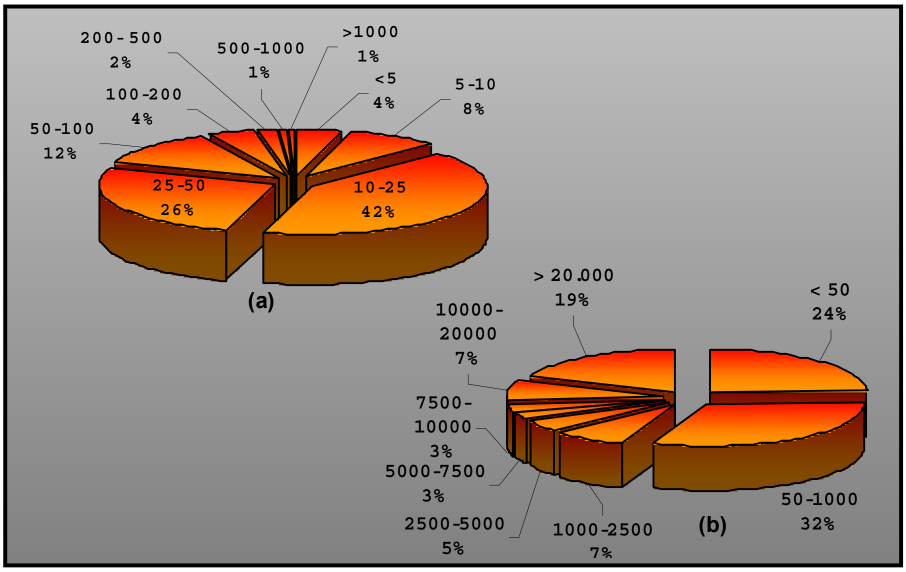


Fig. 4-2: Land ownership distribution in the Province of Misiones. a) Percentage defined boundary EAP's. b) Percentage distribution according property surface.

4.1.3 Objective

The aims of this chapter are to identify and to quantify the land use/land cover change by multi-temporal Landsat TM and ETM+ data analysis, during the last four decade. The objective is double: to detect the space variability and its more remarkable specificities like its recent temporary evolution.

The reason of adopting like one of the central objective of this work the land use classification resides in the repercussions that this land use has on the phases of the hydrological cycle and in the importance that such impacts can get to have in the hydric balance of a territory. These effects can be declared on their diverse components, as much in absolute quantitative terms, like in terms of their temporary distribution.

The knowledge of the land use comprise, therefore, information of basic character to advance in the understanding of the interrelations and feedbacks between the hydric balance and the environmental effects of the management of resources, which is necessary to be able to predict the future effects of the performances in this field.

4.1.4 Concepts Definition

Capuera

The degradation of the forest has followed two different processes, in which the final states of the vegetal succession are similar, but never identical. The first of these states is the "capuera" or " capoeira", voice derived from the guaraní "caa" that means forest, "puá " = grow and "ra" =future, that is " where the forest will grow". Technically, they are post-climax communities where the heliophyllic vegetation "heals" the wounds produced by the man in its climax state (DESCHAMPS, 1987). The origin of the capuera is always from the clearing and burning of a part of the forest, for agriculture-cattle use and then the land is abandoned after several years use. These surfaces begin to cover for a new plant-association composed by species not characteristic of the prior forest. After some years, the succession continues, some forest species are added (Fig. 4-3). This new succession state is denominated "capuerón" (MARTINEZ CROVETTO, 1963). The second process will be defined as "degraded forest" in which the continuous antropic and extractive action has impoverished the subtropical forest quality and amount. Consequently, a special type of vegetation progresses where the cane (*Guadua*, *Chusquea* and *Merostachys* species) predominates.

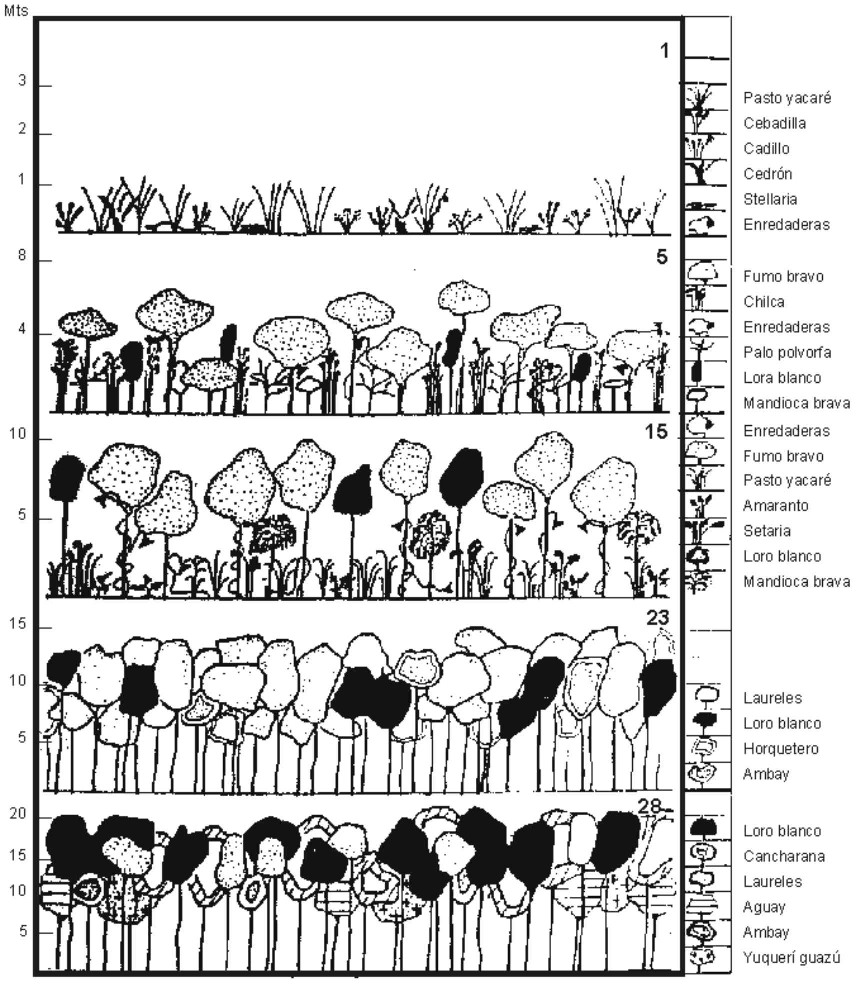


Fig. 4-3: Schema of secondary succession from "capuera" to "capuerón". The numbers to the right side indicate lapsed years and to the left side height of the community. The species are noted according their common names. (Source: DESCHAMPS, 1987).

Land Cover/ Land Use

Land cover is the observed biophysical cover on the earth's surface. Land use is characterized by the arrangements, activities and inputs people undertake in a certain land cover type to produce, change or maintain it. Definition of land use in this way establishes a direct link between land cover and the actions of people in their environment (FAO, 2000).

4.2 Methodological Processes

4.2.1 Theoretical Background

The remote sensing image data have been helpful for the recognition and location of objects in the geographic space from the beginning, with its development and improvement, the remote sensing data continues contributing an ample range of information of these objects and their surroundings that, in the case of the multi-spectral sensors, is associated with their spectral response.

In environmental studies, "change" implies an alteration in the landscape surface components. Common types of change detectable on remotely sensed imagery are associated with vegetation clearance, urban expansion, changing to water levels in surface to water bodies, vegetation regeneration after disturbance and soil disturbances resulting from mining, landslides and overgrazing (MILNE, 1988). The study of the land use patterns and the monitoring of changes are very important for economic planning and country development.

From the launching of the Landsat 1 – the first satellite of terrestrial resource- in 1972, the remote sensing brought as an important increase tool for the inventory, monitoring and management of the natural resources. The increase of the availability information generated from remote sensing images has contributed greatly to the understanding of the dynamic patterns and the systems of natural resources on all investigation scales. A particularly important application of the remote sensing data is the generation of land use and land cover maps. Compared to the traditional mapping methods such as terrestrial investigation and basic aerial photo-interpretation, the land use mapping by using remote sensing images has the advantages of lower cost, greater area of cover, repetitively and computability. Consequently, the land use information products obtained from remote sensing data such as land use maps, data and layers of information GIS, have taken an essential tool in many operational programs involving the natural resources management.

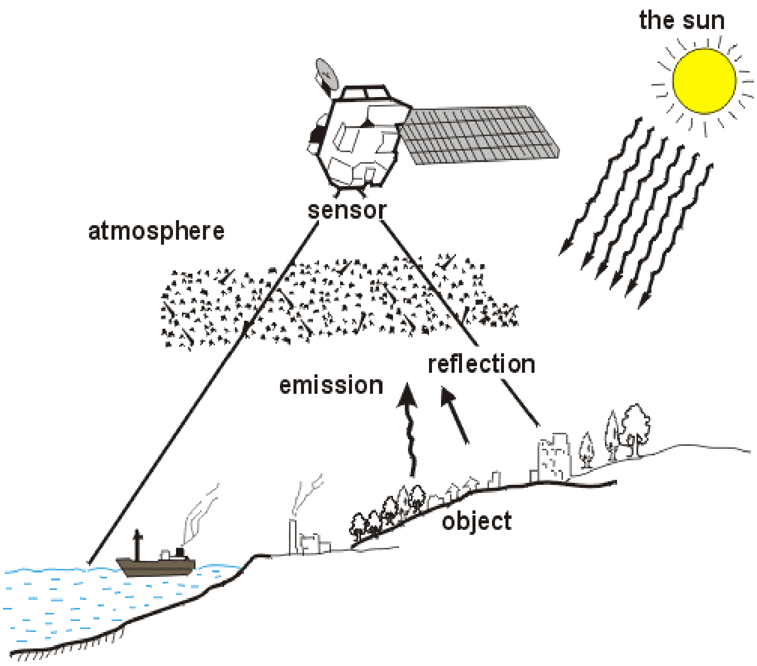


Fig. 4-4: Data collection by remote sensing.

4.2.2 Bases of the Remote Sensing Imagery

The remote sensing is defined by LILLESAND and KIEFER (1994) as".... the science and the art of receiving information of an object, an area or phenomenon, for the analysis of the obtained data, in a such way that there is not direct contact with this object, the area or the phenomenon". It is based on the registration of the emitted electromagnetic radiation, reflected or difracted for the ground, through of sensors installed in airborne platforms. These sensors classify into active and passive. The first one is based on the registry of the energy reflected from a power beam emitted by the sensor, as the radar sensor. They are supported in physical emission-scattering principles. The passive or optical sensor use natural energies as the sun or the own energy emitted by the surface to observe. They are based on the reflection or emission principles.

The characteristics of an object can be determined, using reflected or emitted electromagnetic radiation, from the object. That is, "each object has a unique and different characteristics of reflection or emission if the type of deject or the environmental condition is different". Remote sensing is a technology to identify and understand the object or the environmental condition through the uniqueness of the reflection or emission. This concept is illustrated in figure 4-4.

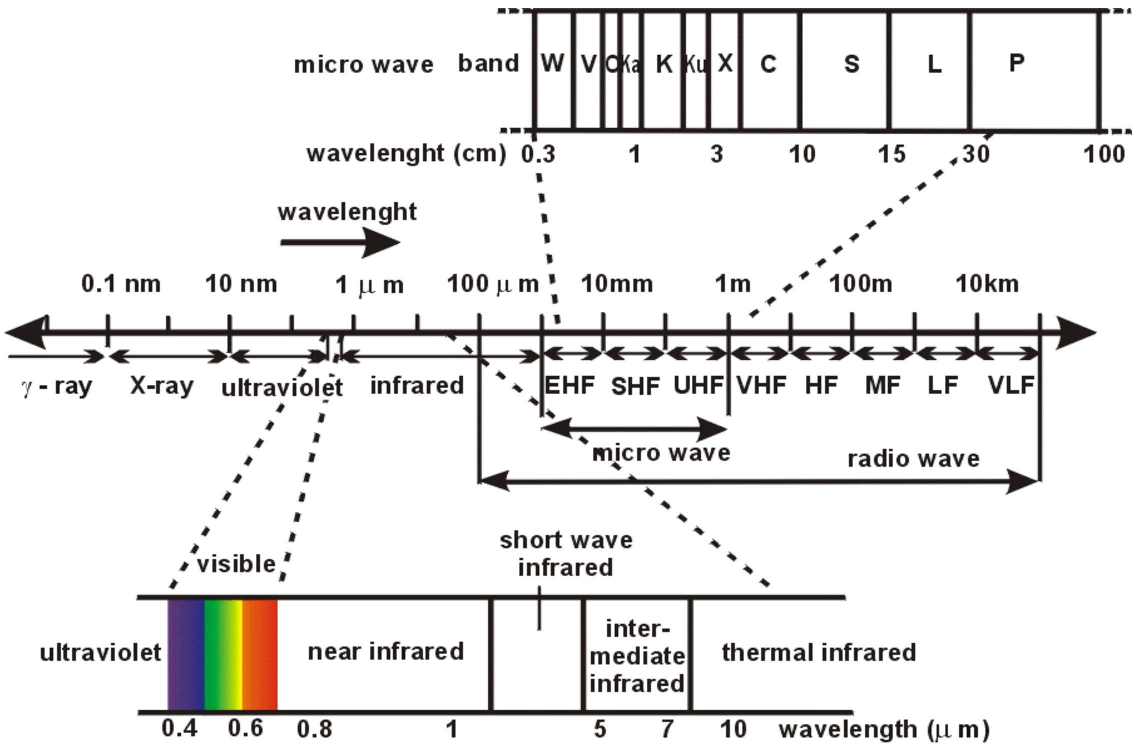


Fig. 4-5: Electromagnetic spectrum in the wavelength-range between 0.1nm and 10 km. The relevant spectral range for optical remote sensing is from 0.4 to approx. 2.5 µm.

The spectral response from the ground objects (soils, rocks, water and vegetation), are different according to the region from the electromagnetic spectrum considered, being able to present characteristics that allow to establish own spectral signatures of each material, from that is possible their identification through of the information registered by remote sensing. The major ranges utilized for sensing of terrestrial resources are between about 0.4 and 12 µm -referred to below as the visible/infrared range- and between 30 to 300 mm -referred to below as the microwave range- (Fig. 4-5). The significance of these different ranges lies in the interaction mechanism between the electromagnetic radiation and the materials being examined. In the visible/infrared, range the reflected energy measured by a sensor depends upon properties such as the pigmentation, moisture content and to cellular structure of vegetation, the mineral and moisture contents of soils and the level of sedimentation of water (RICHARDS and JIA, 1999). The figure 4-6 depicts how four earth surface materials of soil, vegetation, water and snow reflect the sun's energy in the visible/reflected infrared range of wavelengths.

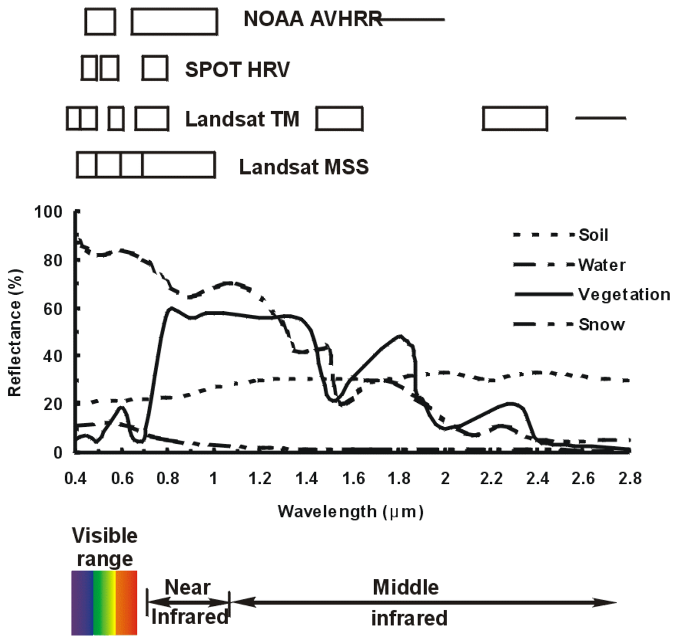


Fig. 4-6: Spectral reflectance characteristics of common earth surface materials in the visible and near-to mid infrared range. The positions of spectral bands for common remote sensing instruments are indicated (Source: RICHARDS, 1999, modified).

It is important to consider that the energy flow received by the sensor not only depends on the of the cover's reflectivity, but also of other external factors. The most important are: a) The atmospheric conditions. b) The environmental location of cover and c) the geometry of the observation.

4.2.3 Atmospheric Conditions

In the absence of an atmosphere, the signal measured by the sensor will be a function simply of the level of energy from the sun, actually incident on the pixel, and the reflectance properties of the pixel itself. However, the presence of the atmosphere can modify the situation significantly as depicted in the figure 4-7.

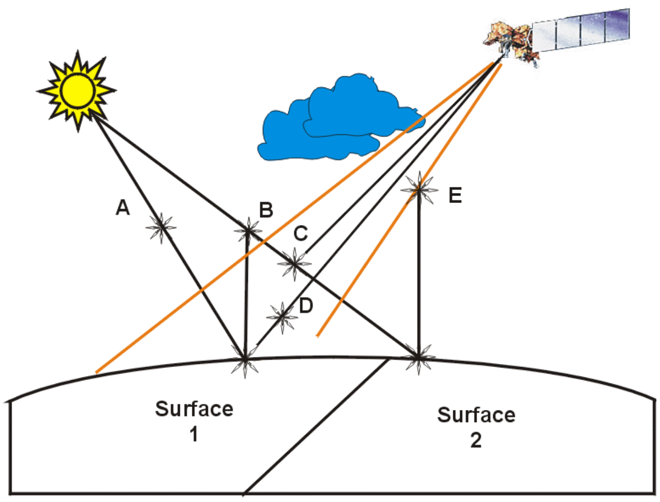


Fig. 4-7: Role of the atmosphere in remote sensing date. A: Loss of the quantity and intensity of the incident flow. B: Scattering of the incident flow to the surface direction. C: Scattering of the incident flow to the field of view direction. D: Scattering of the reflected flow to the field of view direction. E: Radiation emitted by other covers to the field of view direction (Source: Slater, 1980).

Absorption by atmospheric molecules is a selective process that converts incoming energy into heat. In particular, molecules of oxygen, carbon dioxide, ozone and water attenuate the radiation very strongly in certain wavebands. Scattering by atmospheric particles is the dominant mechanism that leads to radiometric distortion in image data (RICHARDS and JIA, 1999).

There are two broadly identified scattering mechanisms. The first is scattering by the air molecules themselves. This is called *Rayleigh* scattering and is an inverse fourth power function of the wavelength used. The other is called aerosol or *Mie* scattering and is a result of scattering of the radiation from larger particles such as those associated to ten wavelengths. Mie scattering is also wavelength dependent, although not as strongly as Rayleigh scattering. When the atmospheric particulates become much larger than a wavelength, such as those common in clouds and dust, the wavelength dependence disappears (Table 4-1). In a clear ideal atmosphere, Rayleigh scattering is the only mechanism present.

Table 4-1: Mainly scattering mechanisms (Source: LIRA, 1983).

Dispersion Process	Dependence with the wavelengths	Average diameter (d) of scattering particles	Type of Particles
Rayleigh	λ^{-4}	$d/\lambda << 1$	Air molecules
Mie	λ^{0} - λ^{-4}	d/λ 0.1 - 10	Smoke, haze
Not selective	λ^{0}	$d/\lambda > 10$	Dust, clouds

These factors are related through the following equation (CHUVIECO, 1996)

$$L_s = L_{Superficie,c}\ ,_c + L_{atm,\ c} \qquad (1)$$

where L_s is the received radiance by the sensor, $L_{Superficie,c}$ is the emitted radiance by the ground, $,_c$ is the emisivity of the soil and $L_{atm,\ c}$ it is the radiance intrinsic of the atmosphere. This expression is correct if Lambertian surfaces are assumed (LIRA, 1983). The interaction of the atmosphere in the equation (1) includes the dispersion, the absorption of the radiation for gases and particles in the atmospheric. This shows a simplification in which it can observe that the true radiance of observed surface is affected by the error caused by the atmosphere.

4.2.4 Geometry Observation

In relation to the observation conditions, the quantity of the arrived energy received by the sensor depend to the reflected incident energy angle, so much as the conformed by the incident flow and with the sensor position. This observation geometry is closely bound to the ruggedness of the surface, which is a measurement for the irregularity of a surface. Smooth surfaces act as so-called speculars reflection (i.e. mirror-like) in that the direction of scattering is predominantly away from the incident direction as shown in figure 4-8. Rough surfaces act as diffuse reflectors; they scatter the incident energy in all directions (Fig.4-8), including back towards the remote sensing platform.

Most of the covers behave, in function of their characteristics and of the wavelength, in an intermediate way between both situations (CHUVIECO, 1996).

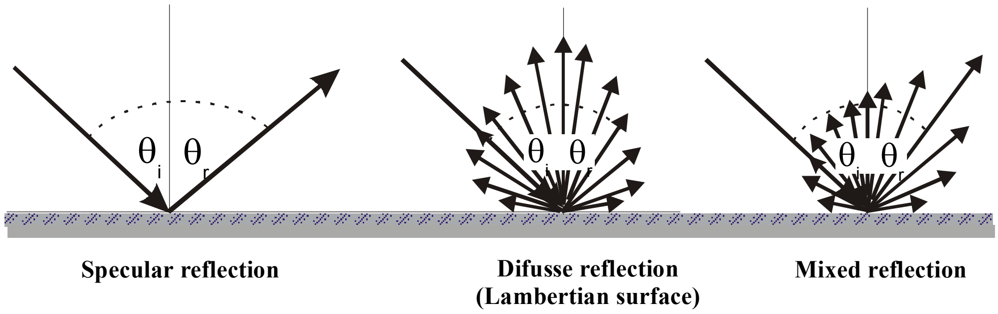


Fig. 4-8: Diverse reflection types according to roughness-surface.

On the other hand, the solar elevation angle and the observation angle also have an outstanding roll in the final response obtained by the sensor. This final response will not be influenced only by the cover features, but also for a series of external factors that modify its theoretical spectral behavior. Some of these are:

- Solar illumination angle, dependent of the day and hour pass of the satellite
- Modifications introduced by the relief in the observation angle: aspect of the hill-sides or slope.
- It influences of the atmosphere, especially the absorption of the clouds and the selective scattering in different wavelengths.
- Environmental variations in the cover: association with other surfaces, homogeneity that this presents, fenological state, etc.
- Litological substratum. It is especially influential when the observed cover doesn't present a total covering.

This peculiar way in that a certain cover reflect or emits energy of different wavelengths that has usually been denominated spectral signature (Slater, 1980), and that is the base to discriminate against that covering of others.

4.2.5 Remote Sensing Satellites

A satellite with remote sensors observing the earth is called a remote sensing satellite or earth observation satellite. Meteorological satellites are sometimes discriminated from the other remote sensing satellites.
Their altitude, orbit and sensors characterize remote sensing satellites. The main purpose of the geosynchronous meteorological satellite (GMS) with an altitude of 36,000 km is meteorological observations, while Landsat with an altitude of about 700 km, in a polar orbit, is mainly for land area observation. NOAA AVHRR with an altitude of 850 km in a polar orbit is mainly designed for meteorological observation but is also successfully used for vegetation monitoring.
The important functions of a remote sensing satellite system include the following three major systems.

- Tracking and control system: determination of satellite orbit, orbital control, processing of housekeeping data etc.
- Operation control system: planning of mission operation, evaluation of observed data, database of processed data etc.
- Data acquisition system: receiving, recording, processing, archiving and distribution of observed data.

General Characteristics of the Landsat TM and ETM+ Sensor

The *Thematic Mapper* (TM) is a mechanical scanning device as for the *Multispectral Scanner* (MSS), but has improved spectral, spatial and radiometric characteristics, and specially designed for the thematic cartography. Seven wavelength channels are used, three in the visible range (bands 1-3), three in the near and middle infrared (bands 4-5 y 7) and one thermal channel (band 6).
The sensor TM is a scanner of orthogonal scanning in this orbital track, which has a rocking mirror ant sixteen detectors for each visible and infrared band, excepting the thermal band. This has only four detectors. Their Sun-synchronous orbit has an altitude 705 Km at the Equator. Circling the Earth at 7.5 km/sec, each orbit takes nearly 99 minutes and completes just over 14 orbits per day.

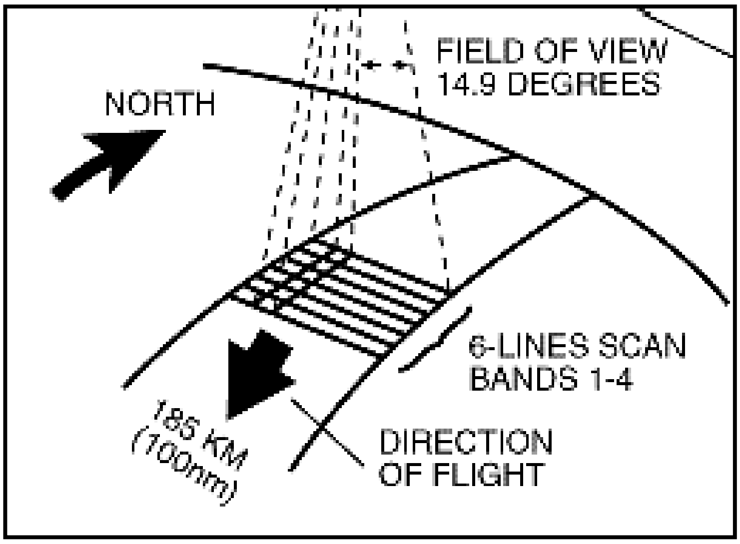


Fig. 4-9: Scanning of the Landsat TM sensor.

The Landsat 5 has a revisit frequency each 16 days. To be sun-synchronous it always crosses at the same hour a certain longitude, crossing the Equator from north to south hemisphere at 9:37 a.m. This has an angular field of view of 14.9° and a scanning width of 185 km, as it shows it the figure 4-9. The table 4-2 summarize the main characteristics of Landsat TM sensor.

Table 4-2: Summary of the main characteristics of the Landsat TM sensor.

Sensors	Multispectral
Resolution	Ground resolution of each band: 30-meter - bands 1,2,3,4,5,7 60-meter - band 6 (thermal IR) 15-meter - band 8 (panchromatic)
Imagery Spectral Response	Multispectral: #1: Blue 0.45 - 0.52 microns #2: Green 0.53 - 0.61 microns #3: Red 0.63 - 0.69 microns #4: Near IR 0.78 - 0.90 microns #5: SW IR 1.55 - 1.75 microns #6: Thermal IR 10.4 - 12.5 microns #7: SW IR 2.09 - 2.35 microns #8: Panchromatic 0.52 - 0.90 microns
Swath Widths	Nominal swath width: 185 km/115 miles at nadir
Revisit frequency	16 days / 233 orbit cycle
Viewing angle	Nadir pointing
Dynamic Range	8-bit data

The *Enhanced Thematic Mapper Plus* (ETM+), to be carried on Landsat 7, was launched in April 1999. The sensor is a derivative of the Thematic Mapper (TM) engineered for Landsat 4 and 5, but is more closely related to the Enhanced Thematic Mapper (ETM) lost during the Landsat 6 failure. The primary performance related changes of the ETM+ over the TM's are the addition of the panchromatic band and two gain ranges (added for Landsat 6), the improved spatial resolution for the thermal band, and the addition of two solar calibrators.

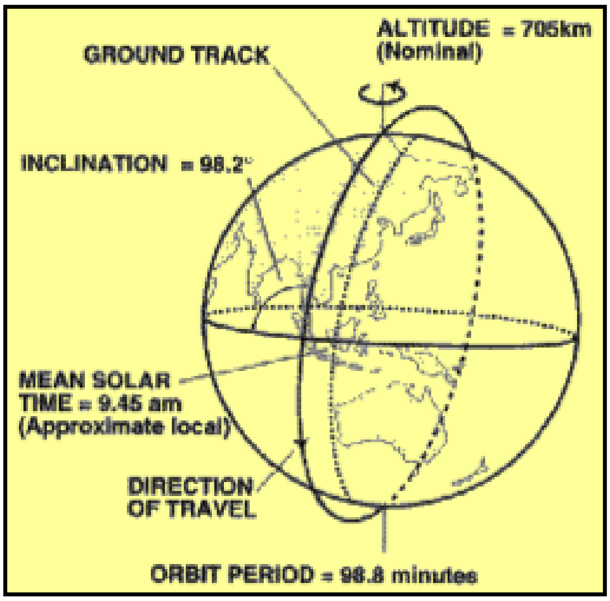


Fig. 4-10: Landsat's orbit characteristics.

The same as the Landsat TM, the orbit of Landsat 7 is repetitive, circular, Sun-synchronous, and near polar at a nominal altitude of 705 km (438 miles) at the Equator. The spacecraft crosses the Equator from north to south on a descending orbital node from between 10:00 AM and 10:15 AM on each pass. Circling the Earth at 7.5 km/sec, each orbit takes nearly 99 minutes. The spacecraft completes just over 14 orbits per day, covering the entire Earth between 81 degrees north and south latitude every 16 days. Figure 4-10 illustrates Landsat's orbit characteristics. The table 4-3 summarize the main characteristics of Landsat ETM+ sensor.

Table 4-3: Summary of the main characteristics of the Landsat ETM+ sensor.

Sensors	Multispectral
Resolution	Ground resolution of each band: 30-meter - bands 1,2,3,4,5,7 120-meter - band 6 (thermal IR)
Imagery Spectral Response	Multispectral: 1: Blue 0.45 - 0.52 microns 2: Green 0.52 - 0.60 microns 3: Red 0.63 - 0.69 microns 4: Near IR 0.76 - 0.90 microns 5: SW IR 1.55 - 1.75 microns 6: Thermal IR 10.4 - 12.4 microns 7: SW IR 2.08 - 2.35 microns
Swath Widths	Nominal swath width: 185 km / 115 miles at nadir
Revisit frequency	16 days / 233 orbit cycle
Viewing angle	Nadir pointing
Dynamic Range	8-bit data

4.2.6 Remotely Sensed Data Acquisition

Two dates of Landsat 5 TM and Landsat 7 ETM+ imagery (1986 and 2001) path 223 row 78 and 78/79 respectively, were acquired. To reduce scene-to-scene variation due to sun angle, soil moisture, atmospheric condition, and vegetation phenology differences, and since the persistent cloud cover over NE Misiones, both datasets were collected between the months of March and April. The Ministry of Ecology and Renewable Natural Resources of the Province Misiones kindly passed the images used in this work. Summary of the remote sensing images data characteristics used as source for the digital treatment are given in Table 4-4.

Table 4-4: Characteristics both remote sensing image data used for the digital treatment.

CHARACTERISTICS	IMAGE 28ABR1986	IMAGE 12MAR2001
Source	CONAE	CONAE
Satellite	LS5	LS7
Sensor	TM	ETM+
Bands	7	8
Scene Number	1	2
Path/Row	223/79	223/78 - 223/79
Quadrants	4	8
Latitude center of scene	26.4239 S	25.5936 S / 27.2555 S
Longitude center of scene	53.3556 W	53.2452 W /53.4624 W
Solar angle	35.11°	48.8°
Azimuth	47.28°	62.4°
Hour	12:55:11 (hh:mm:ss)	13:20:11 / 13:20:35
Scanning total number	918	
Clouds	>10%	>30%
Lines number	11461	5960
Columns number	7312	6920
Pixel size	28.5 x 28.5 m	30 x 30 m/15 x15 m band 8
Data type	BSQ	FAST - L7A
Calibration coefficients	SI	SI
Processing level	Level 0	Level 0

Ancillary data included topographical and thematic maps and aerial photograph (Ch. 3.2.1).

Maps			
Name	Scale	Editors	Year
Topographic Maps*	1:20.000 1:50.000	CARTA	1962
	1:100.000	IGM	1997
Thematic Maps	1:50.000	CARTA	1962

Aerial Photographs		
Type	Scale	Year of flight
Panchromatic	1:30.000	1962

*Number of maps and locality see Annex VII

The analysis of the stereoscopic pairs of aerial photographies was made with a stereoscope marks TOPCON - M900. A GPS was used for the demarcation of the GCPs. and the training sites for the land use/land cover classification.

4.2.7 Methodology

The methodology for the realization of this part of the study corresponds in general features with the habitually followed in remote sensing and change detection assessment. The figure 4-11 shows a general scheme of the methodological steps followed. Due the chosen year as beginning of the study is previous to the launching of the first space satellites, it was opted to work with historical aerial photography and thematic maps, in order mapping a historical land cover/land use map, which can be used in an multi-temporal analysis together with the images data.

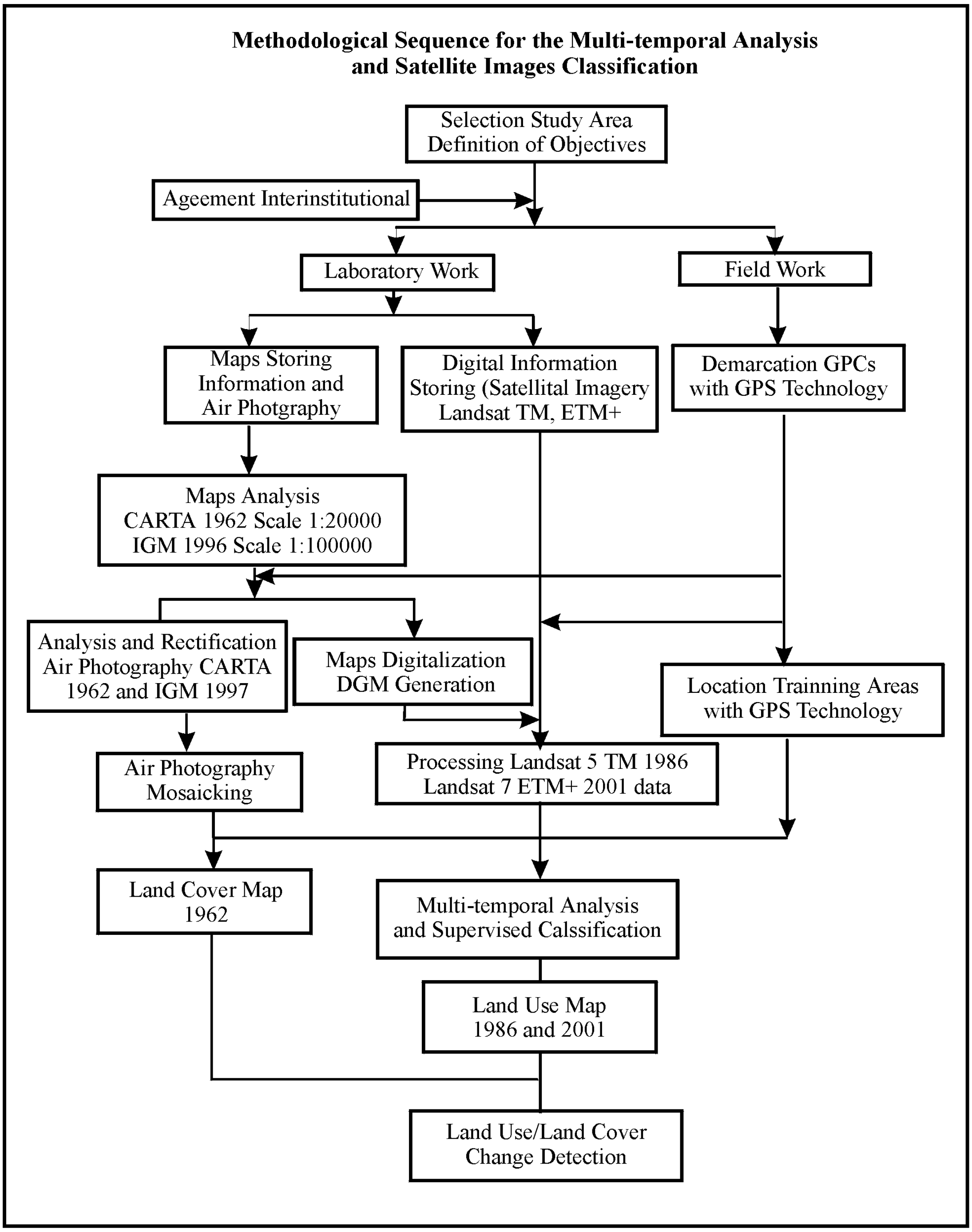


Fig. 4-11: Diagram showing major steps of this research.

Selected the dates and acquired the corresponding images, the task of digital treatment of this images began. These processes involve the rectification and restoration, enhance and classification of the images.

4.2.7.1 Field Work

It is essential to have high quality of training data to assure the accuracy in any georeferentiation process and classification of land cover. There was conducted an extensive field recognition throughout the entire area during the Winter-Summers 2000-2002. In total 247 training sites with different land cover/land use and 110 control points were demarcated. In both cases GPS technology were used. In the case of the training sites it come to make transects of 20 to 30 km length, demarcating throughout all it the continuity of the different land use/land cover. Photographs of each site were taken for documentation.

Table 4-5: Summary of the terrestrial recognition data set.

Cover Class	Measured	Omited
Eucaliptus artificial forest	6	1
Pinus artificial forest	11	0
Araucaria artificial forest	10	0
Semid-deciduous dense forest	50	0
Semid-deciduous poor forest	18	5
Semi-deciduous secondary forest	5	0
Yerba mate	41	9
Tea	20	5
Maize	23	4
Manioc	15	6
Tobacco	7	3
Capuera	19	7
Pasture	15	8
Bare soil	7	2
Total	247	50

Then to the demarcation of the training sites, an evaluation of the data was carried out in order to value the quality of the information obtained. The locations of each site were checked in the ETM+ 3,4,5 scenes. Moreover, field notes, site descriptions, and site photographs were taken to relate the site location to scene features. Through this process about 20 percent of the sites were omitted from analyses because they were not sufficiently representative of the adjacent landscape (Table 4-5). The same quantity of training sites was selected to provide an independent validation of the classification.

4.2.7.2 Land Cove/Land Use Change Detection

The goal of change detection is to discern those areas on digital images that depict change features of interest (e.g. forest clearing or land cover /land use change) between two or more image dates. An array of techniques are available to detect land cover changes from multi-temporal remote sensing data sets, for example, multi-temporal composite image change detection (EASTMAN and FULK, 1993); image algebra change detection (GREEN et al., 1994) using univariate image differencing, image regression (JENSEN, 1983), vegetation index differencing (NELSON, 1983), image rationing, post-classification comparison change detection, image differencing (JENSEN, 1996), principal components analysis (PCA), multivariate alteration detection (MAD) technique proposed by NIELSEN and CONRADSEN (in NIEMEYER and CANTY, 2002), knowledge-based system (JENNSEN and MIDDELOOP, 1992), etc. The selection of an appropriate algorithm of changes detection is very important. First, it will have a direct impact on the type of image classification to be performed (if any). Second, it will dictate whether important "from - to" information can be extracted from the imagery (JENSEN, 1996 in CHEN, 2002). Several authors have made combinations of different methods from detection of changes, or compared the effectiveness of several of them. SUNAR, 1998, for example, obtained a better result through the principal components analysis and the post-classification change detection. LYON *et al* (1998) compared seven vegetation indices to detect land cover change in a Chiapas, Mexico study site. They reported that the Normalized Difference Vegetation Index (NDVI) was least affected by topographic factors and was the only index that showed histograms with normal distributions.

Normalized Index of Vegetation (NDVI) image differencing and post-classification caparison change detection were selected to perform land cover/land use change detection in this study (Fig. 4-12). The image differencing method is simply the subtraction of the pixel digital values of an image recorded at one date from the corresponding pixel values of the second date. The histogram of the resulting image depicts a range of pixel values from negative to positive numbers, where those clustered around zero represent no change and those at either tail represent reflectance changes from one image date to the next. This last one is the most

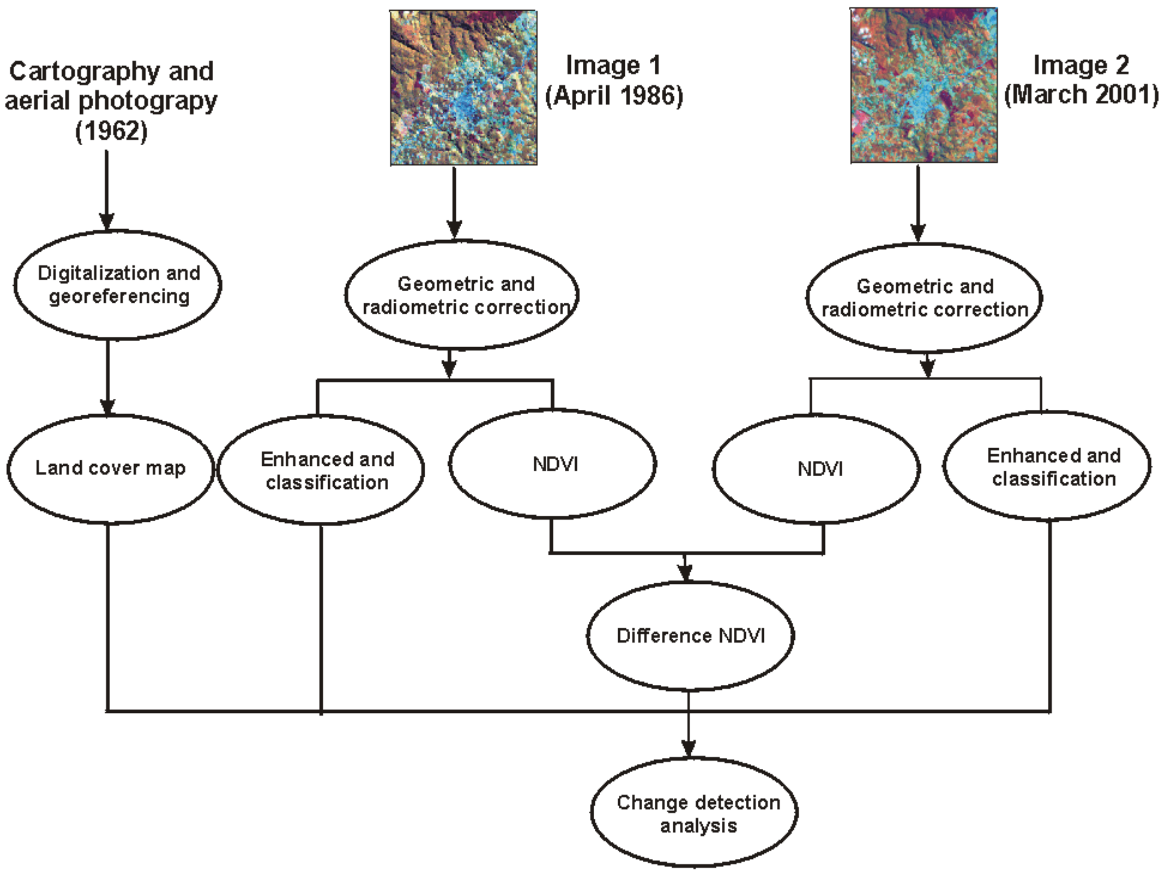


Fig. 4-12: Diagram of land use/land covers change detection based on multitemporal analysis.

commonly used quantitative method of change detection. It requires rectification and classification of each remotely sensed image. The two generated maps are then compared pixel-by-pixel basis using a change detection matrix. The advantage of this method includes the detailed from-to information that can be extracted and the fact that the classification map for the next base year is already complete (JENSEN, 1996 in CHEN, 2002). However, every error in the individual data classification map will also be presented in the final change detection map. Therefore, it is imperative that the individual classifications maps used in the post-classification change detection method be as accurate as (AUGENSTEIN et al., 1991).

4.2.7.3 Dataset and Algorithm Selection for Land Cover Classification

Through the digital classification, a new image is generated in which a class or legend to each pixels of the original image is assigned. There are two basic approaches to the classification process: supervised and unsupervised classification.
Unsupervised classification techniques share a common intent to uncover the major land cover classes that exist in the image without prior knowledge of what they might be. Generically, such procedures fall into the realm of *cluster analysis*, since they search for clusters of pixels with similar reflectance characteristics in a multi-band image. The classification's algorithms examine and recognize the pixels, and in agreement with his values, it adds them to different classes with base from his DN. The resulting classes are called spectral classes (LILLESAND and KIEFER, 1994).

With supervised classification, a very different approach is used. Here one provides a statistical description of the manner in which expected land cover classes should appear in the imagery, and then a procedure (known as a *classifier*) is used to evaluate the likelihood that each pixel belongs to one of these classes (EASTMAN, 2002)
There is a basic sequence of operations that must be followed no matter which of the supervised classifiers is used. This sequence is described here.

- Define training sites: The analyst defines areas that will be used as training site for each land cover class.
- Classify the image: Each pixel of the image is categorized belong to a land cover class.
- Accuracy assessment: Traditionally this is done by generating a random set of locations to visit on the ground for verification of the true land cover type.

The software offers a variety of methods for remote sensing data classification. Among they can be mentioned:

- Parallelepiped
- Minimun Distance
- Mahalanobis Distance
- Maximun Likelihood
- Neuronal nets
- ISODATA - Unsupervised Classification

The first five algorithms belong to the technique of supervised classification. The Maximum Likelihood method is one of the most applied and with better results currently. Due to the knowledge of the land and the number of areas of training, this algorithm for the classifications was selected.

The Maximum Likelihood classification is based on the probability density function associated with a particular training site signature. Pixels are assigned to the most likely class based on a comparison of the posterior probability that it belongs to each of the signatures being considered. MAXLIKE is also known as a Bayesian classifier since it has the ability to incorporate prior knowledge using Bayes' Theorem. Prior knowledge is expressed as a prior probability that each class exists. It can be specified as a single value applicable to all pixels, or as an image expressing different prior probabilities for each pixel.

Landsat ETM+ data taken on 12 March 2001 were used as the test dataset to select the best dataset and algorithm for land cover classification. Based on this image 150 training data or area of interest (aoi) for all classes of interest were used in order to perform the classification while the other 47 aoi were used to evaluate the accuracy of classification.

4.2.7.4 Accuracy Assessment

Accuracy assessments determine the quality of the information derived from remotely sensed data. The overall accuracy and a KAPPA analysis were used to perform a classification accuracy assessment based on error matrix analysis. By using simple descriptive statistics technique, overall accuracy is computed by dividing the total correct (sum of the major diagonal) by the total number of pixels in the error matrix. KAPPA analysis is a discrete multivariate technique used in accuracy assessments (CONGALTON and MEAD 1983, en CHEN 2002). KAPPA analysis yields a K_{hat} statistic (an estimate of KAPPA) that is a measure of agreement or accuracy. The K_{hat} statistic is computes as:

$$K_{hat} = \frac{N \sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r} (x_{i+} \, x_{+i})}{N^2 - \sum_{i=1}^{r} (x_{i+} \, x_{+i})}$$

where r is the number of rows in the matrix, x_{ii} is the number of observations in row i, x_{i+} and x_{+i} are the marginal totals for row i and column i respectively and N is the total number of observations.

In order to perform this accuracy assessment were used the 47 aoi and about 800 randomly selected points for each image.

4.3 Multitemporal Remote Sensing Data Analysis

4.3.1 Pre-processing

Accurate detection of land cover change using remotely sensed data requires that multitemporal image sets be aligned both radiometrically and geometrically. A lack of proper radiometric and/or geometric alignment will result in errors of omission and commission in change detection products. Radiometric normalization is performed by correcting and/or standardizing multiple sun, scene, sensor, and atmospheric effects, which may cause spurious differences in the magnitude of reflected light measured by remote sensing instruments between multitemporal acquisitions. Geometric registration between multitemporal image sets is commonly performed using polynomial warping algorithms and/or orthorectification procedures. However, proper radiometric and geometric calibration between high spatial resolution airborne and satellite image sets is often difficult to attain and may be time or cost prohibitive

4.3.1.1 Correction of Radiometric Distortion

4.3.1.1.1 Atmospheric Correction

Very large percentages of imagery are severely contaminated by aerosols, clouds, and cloud shadows. TM images can be potentially more useful if we can remove the effects of aerosols, thin clouds, and cloud shadows. This procedure for retrieving surface reflectance is usually called atmospheric correction.

Atmospheric correction consists of two major steps: parameter estimation and surface reflectance retrieval. As long as all atmospheric parameters are known, retrieval of surface reflectance is relatively straightforward when the surface is assumed Lambertian for TM-type data. Earlier studies attempt to develop approximate solutions to the atmospheric radiative transfer equation for quick calculations, but the typical approach that now has been widely accepted is the so-called look-up table method (FRASER and KAUFMAN, 1995).

There is a relatively long history of the quantitative atmospheric correction of TM imagery. Among some of the methods proposed for the atmospheric correction can be mentioned:
i) Apparent Reflectance Model; ii) Dark Object Subtraction proposed by GILABERT et al. (1994); iii) Histogram Minimum Method (HMM) was developed by CHAVEZ (CHUVIECO, 1996), iv) Cos(t)-Model, also developed by CHAVEZ (1996), which is a improved method that the HMM, and v) The Full Correction Model (FOSTER, 1984).

The atmospheric correction of the images data was carried out with the Method Cos(t)-Model, included in the module ATMOSC of the program Idrisi 3.2 Release 2. This model was developed as a technique for approximation that works well in these instances. It incorporates all of the elements of the Dark Object Subtraction model (for haze removal) plus a procedure for estimating the effects of absorption by atmospheric gases and Rayleigh scattering. It requires no additional parameters over the Dark Object Subtraction model and estimates these additional elements based on the cosine of the solar zenith angle (90 – solar elevation). An the other hand, the downwelling spectral irradiance is assumed to be 0.0 and path radiance due to haze is estimated by specifying the Dn of objects that should have a reflectance of zero (e.g. deep clear lakes). Spectral diffuse sky irradiance is also assumed to be 0.0 (EASTMAN, 2002). The tables 4-6 and 4-7 summarized the dataset used for atmospheric correction for both images.

Table 4-6: Data used for atmospheric correction of Landsat 5 TM image of year 1986.

Acquisition image year		1986
Acquisition month		4
Acquisition day		28
Acquisition hour		12:55 GMT
Sun elevation angle		35,11
Band	Wavelength center band	ND Haze
1	485	45
2	56	13
3	66	8
4	83	8
5	165	1
7	2215	1

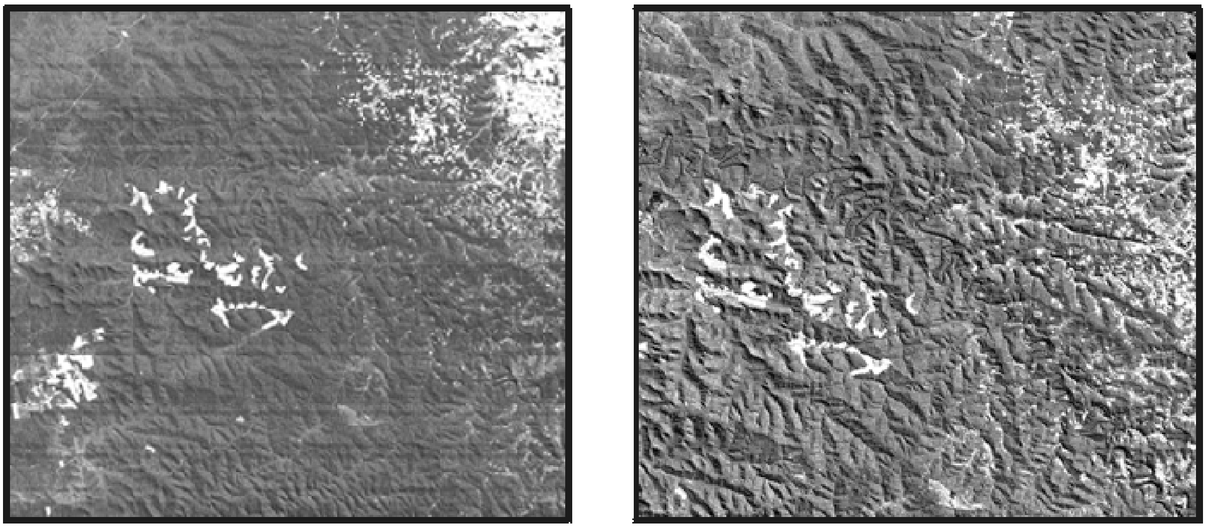
Table 4-7: Data used for atmospheric correction images Landsat 7 ETM+ images of year 2001 path/row 223/78 and 223/79.

Acquisition image year		2001
Acquisition month		3
Acquisition day		12
Acquisition hour		13:19 GMT
Sun elevation angle		47,9
Band	Wavelength center band	Dn Haze
1	485	51/50
2	57	31/31
3	66	22/21
4	84	21/13
5	165	13/11
7	222	10/7

4.3.1.1.2 Correction of Instrument Errors

Banding or striping occurs if one or more detectors go out of adjustment in a given band. The systematic horizontal banding pattern seen on images produced by electro-mechanical scanners such as Landsat MSS and TM results in a repeated patterns of lines with consistently high or low DN. In this case, a striping correction of the TM3 -

28Apr1986- using the option Destripe TM Data of the Erdas 8.4 software (Fig.4-13) was made.



(a) (b)

Fig. 4-13: Correction of striping in band 3 Landsat 5 TM image of 1986 a) Original image. (b) Image radiometrically corrected.

4.3.1.2 Geometric Correction

When a digital change detections is approached is precise that the images adjust with great level of detail, since otherwise would be being been detecting like transformations which would be only the result of a lack of adjustment between images (HORD, 1982 in CHUVIECO, 1996).

Two techniques can be used to correct the various types of geometric distortion present in digital image data. One is to model the nature and magnitude of the sources of distortion and use these models to establish correction formulae. This technique is effective when the types of distortion are well characterized, such as that caused by earth rotation. The second approach depends upon establishing mathematical relationships between the addresses of pixels in an image and the corresponding coordinates of those points on the ground. These relationships can be used to correct the image geometry irrespective of the analyst's knowledge of the source and type of distortion (RICHARDS, 1999). This technique is independent of the platform used for data acquisition and the most commonly used. The last method was selected for the geometric correction both Landsat images, and the module "Geometric Correction" of the Erdas 8.4 software was used.

The Landsat 7 ETM+ March 2001 images were geometrically corrected. A total of 30 GCP of the 100 described previously and the digital IGM georeferenced map, were used. As selection approach a homogeneous and easily identifiable distribution of the points in the map and the image, non-subject or with a minimum subjection to temporary dynamism, was assumed. The geometric correction was carried out using the 1st order polynomial transformation geometric model and resampled with Nearest Neighbor algorithm (RMS: 0.82). Afterward, the 1987 TM image was georeferenced to a previously rectified 2001 ETM+ image using the image-to-image registration (RMS:0.54). Both images were projected with Transverse Mercator, Datum Campo Inchauspe Spheroid International 1924.

4.3.1.2 Scene Mosaicing

Land cover classification of an area larger than one scene can benefit from image mosaicing. Scenes of the same date (i.e. the same Landsat path) can be mosaiced, provided they are first radiometrically calibrated. The Mosaic module of the Erdas 8.4 software was used for the overlap area between two adjacent ETM+ rows. A subscene from the mosaic of the two Landsat 7 ETM+ images was extracted. The data of 1986 also was extracted as a subscene from the original dataset.

4.3.2 Land Cover/Land Use Classification

As discussed in item 4.2.7.3 the underlying requirement of supervised classification techniques is that the analyst has available sufficient known pixels for each class of interest that representative signatures can be developed for those classes.
A total 150 training sites, which corresponding different land cover/land use, were used for the Landsat 7 ETM+ image of the year 2001.

4.3.2.1 Image Landsat 7 ETM+ Classifications

Clouds and shadows Mask

For land cover classification algorithms to operate properly cloud and cloud shadows must be masked from the image statistics used to train the classifier. It was used the first two components of a principal components analysis (PCA) developed from band 1, 2, 3 (PCA123) and 4, 5, 7 (PCA457) combinations. Cloud shadow masks were developed by differencing PCA457 and PCA123, assigning a zero value to all scene elements with positive values and a value of one to the remainder. Cloud masks were created in a similar manner, in which PCA123 values were numerically inverted and differenced with the PCA457 components. Binary image values were assigned as with the cloud shadow mask. The two masks were then combined and applied to the scene overlap areas used for band-by band image mosaicking (Fig. 4-14).

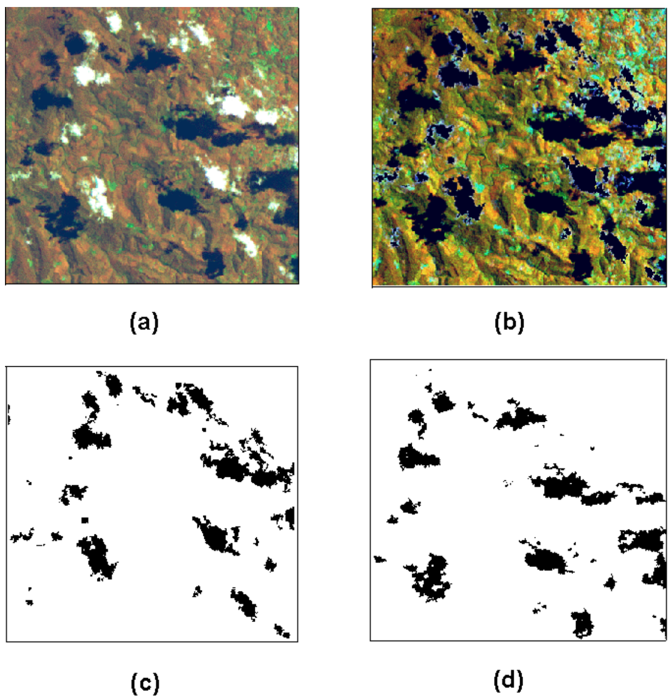


Fig. 4-14: Cloud and shadow masks derived from and applied to a portion of an ETM+ image. a) Original Band 453 (RGB) Image. b) Masked Band 453 (RGB) Image. c) Cloud Mask. d) Shadow Mask.

4.3.2.1.1 Classification System and Thematic Aggregation

Several classification schemes that can readily incorporate land use/land cover data obtained by the interpretation of remotely sensed data have been developed (e.g. U.S. Geological Survey Land Use/Land Cover Classification System, NOAA Coast Watch Land Cover Classification System, United Kingdom Land Use Classification System, Asian Land Cover Classification System). By considering the four levels of the US Geological Survey Land Use/Land Cover Classification System and the type of remotely sensed data typically used to provide the information, the following classification system, containing ten of the original fourteen classes, was created:

1. Forest land: is divided in three sub-classes: i) Semideciduous dense forest that includes the primary, secondary and/or disturbed forest. ii) Semideciduous poor forest, where the primary or secondary forests with scarce covering (<30%) are included. iii) Reforestation contains reforested areas mainly with Eucaliptus spp., Pinus spp and A. angustifolia.

2. Agriculture land: contains permanent and nonpermanent crops and pasture, it has been subdivided in five sub-classes: i) perennial cultures included by tea and yerba mate; ii) the annual cultures (maize, manioc, tobacco, etc.) as well they have been subdivided in other two classes depending on the covering degree: Soil cover 10- 30% and Soil cover 30-70%. iii) pastures.

3. Rangeland: Capuera.

4. Bareland: Bare soil

5. Water (water body)

A short description of the eleven classes used is presented on table 4-8, together with the classes ID and short level for each class.

Table 4-8: Land use/land cover classes for the study area.

Land Cover	ID	Label	Description
Water	1	HH	Water
Forest land	2	FISem	Semideciduous dense rainforest
	3	FIDg	Semideciduous poor rainforest
	4	FICu	Reforestation
Agriculture land	5	AGYMc	Yerba mate crop
	6	AGTc	Tea crop
	7	AGPT	Pasture (Past)
	8	AGC37	Soil cover 30-70%
	9	AGC13	Soil cover 10-30%
Rangeland	10	RCP	Capuera
Bareland	11	BS	Bare soil

4.3.2.1.2 Supervised Classification

Training data collection

In order to perform training data collection, it was necessary to make false colour composite images. The procedure is as follows. 1) To test composite schemes by using Landsat ETM+ data by (a) selecting three optimum bands from the seven bands; (b) using all seven bands; and (c) using all seven bands and NDVI. 2) To perform false colour composition for the Landsat TM data. Based on the test study, the best composite scheme was found to be 354 (RGB) (Fig. 4-15). Each training site was looked upon like a training site group and then in a signature editor registered. The signatures are created determining the mean, standard deviation and covariance of each satellite spectral band for each class. The table 4-9 shows the created contingence matrix for the eleven land use/land cover classes.

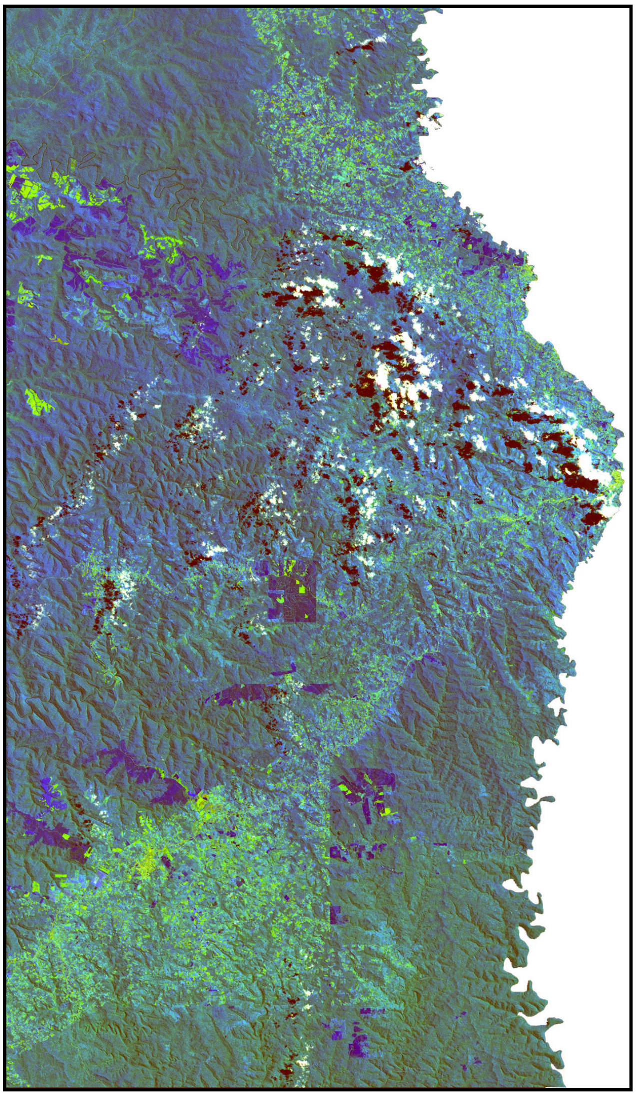


Fig. 4-15: Landsat 7 ETM+ image of the study area (RGB 3,5,4 – 15 m).

Table 4-9: Contingence matrix of eleven land use/land cover classes of Landsat 7 ETM+ band 1-5 and 7.

	1	2	3	4	5	6	7	8	9	10	11
1	100										
2		96,4	12,6								
3			87,4								
4		2,45		90,1							
5		1,15			83,3			5,8		1,43	
6						74,9	14,6				
7					6,71	13,9	85,6				
8						11,2		94,1	2,6	1,2	
9					9,95			1,2	97,2		
10										97,4	2,18
11									2,53		97,8

4.3.2.1.3 Band combination and enhancement application

In order to perform the classification it was necessary to make different band combination and spectral enhancement from the masked reference image and taking as base the spectral signature graph and the contingence matrix.
Notice: from each new obtained class a mask was created, which was subtracted from the reference image. Therefore a new reference image it was produced.
The different thematic classes were obtained in the following way:

- The water bodies were classified by combining the second component of a PCA from band 1-5 and 7 and the ETM+4, 5 bands, since it is the class with smaller digital value (table 4-10). The class HH was subtracted from the image by creating of a mask of her.

Table 4-10: Water class ND values from PCA (2) and ETM+ 4-5 images combination.

Layer	Minimum	Maximum	Mean	Std Dev.
1	-5,903	0	-4,312	0,472
2	0	5,0	1,048	0,550
3	0	4,0	0,059	0,248

- The **BS** was classified by combining the second component of a PCA (1-5 and 7bands) and the ETM+ 4,5 bands, where it also displayed a low reflectivity (Fig. 4-16). Presumably, due to the greater soil moist due to precipitations in the previous days (61 mm of water fallen in the 6 previous days and 7,5 mm one day before the taking of the image). A mask was created and subtracted to the class of the reference image.

- The **FICu** class was created by using the ETM+ 4,5,7 band combination from the reference image, where the conifers have less digital value than the broadleaf trees due to a greater absorption of the former ones in these wavelengths. A mask was created with this class and substracted in the reference image.

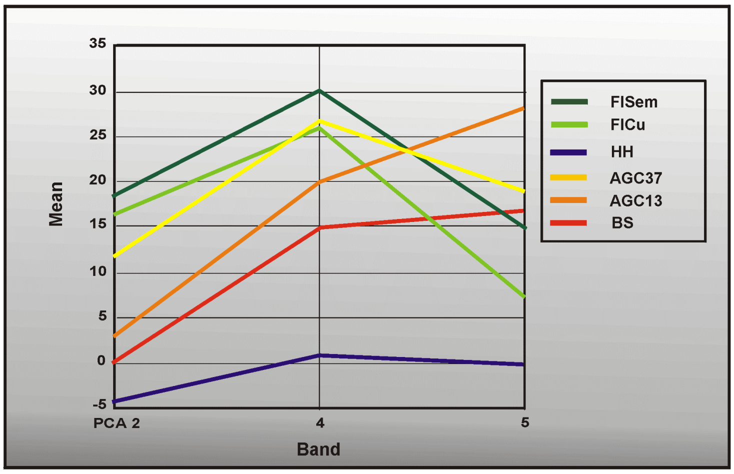


Fig. 4-16: Spectral signature of different land use/land cover from PCA (2) and ETM+ 4,5 image.

- The cover soil class was separated by using the ETM+ 4,5,7 band combination from reference image (Fig. 4-17). Cover soil mask was developed, assigning a value of one to the class elements and a zero value to the remainder. From this new image, two classes AGC13 and AGC37 were reclassificated.

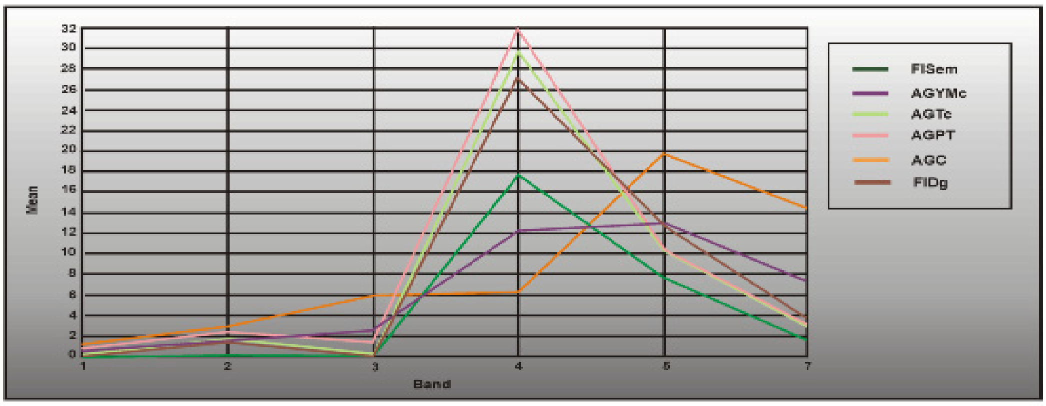


Fig. 4-17: Spectral signature masked image.

- The class pasture/capuera was classified using the ETM+ 2,3,4 band combination from the reference masked image, because of the best definition that they displayed in this combination. A mask was created following the same procedure of the previous point. Later on, with the class in positive and the remaining elements of the scene in negative, the two classes were separated: RCP and AGPT.

- The class FISem was classified by producing a texture image of the reference image from which the classes previously classified had been subtracted previously. A mask with this class was created and subtract from the reference image.

- The classes AGYMc and AGTc were classified from the combination of bands ETM+ 3,4,5 (Fig. 4-18) of the reference image. These bands were selected with regard to: i) Greater reflectivity of the yerba mate with respect to the tea in band 3 as a result of a smaller density of covering of the former and a greater contribution, therefore, of bare soil in the pixel. ii) Greater reflectivity of the tea with respect to the yerba mate in band 4 due to the youth and health of the tea leaves. iii) Smaller reflectivity of the tea in band 5 because of a greater density of healthy leaves, contrary to what happens in the case of the yerba due to the contribution of dried grasses in the pixel because of the agrarian use of the herbicide "Roundup". In both classes, masks were combined and applied to the scene.

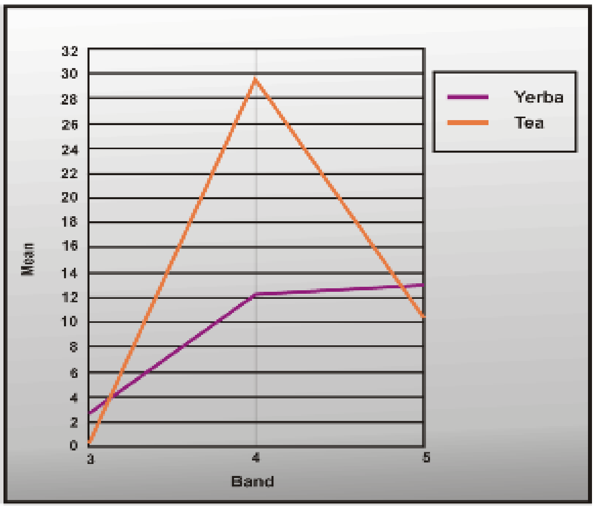


Fig. 4-18: Spectral signatures yerba mate and tea, band ETM+ 3-5 combination.

- The class FIDg was obtained as a product of the subtraction of the other classes previously obtained.

From the superposition of the obtained thematic classes, a land use/land cover map was generated (Fig. 4-18). The total surfaces corresponding to each of land use/land cover class in the classification map is given in Table 4-11.

Table 4-11: Summary of total surfaces by land use/land covers.

		Area (km^2)	Area (ha)	Area (%)
Water	HH	0,02	2	0,00
Forest	FISem	2.982,72	298.272	74,56
	FIDg	97,41	9.741	2,44
	FICu	108,7	10.868	2,72
Agriculture land	AGPT	169,83	16.983	4,25
	AGTc	2,7	270	0,07
	AGYMc	143,32	14.332	3,58
	AG37	118,03	11.803	2,95
	AG13	40,71	4.071	1,02
Rangeland	RCP	322,37	32.237	8,06
Bareland	BS	14,58	1.458	0,36
	Total	4.000,37	400.037	100

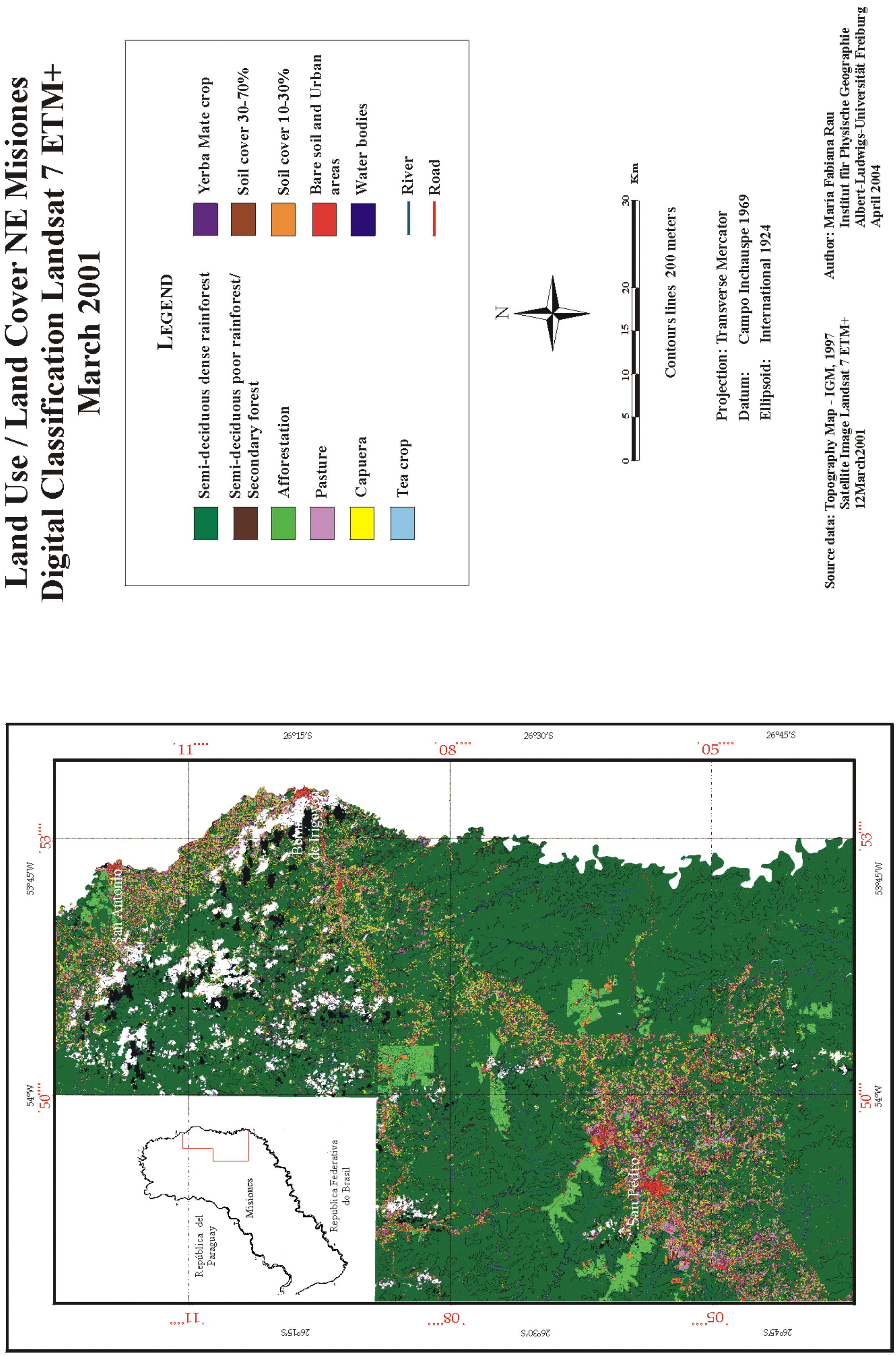


Fig. 4-19: Land use / Land covers NE Misiones digital classification Landsat 7 ETM+ of March 2001.

4.3.2.2 Classification Landsat 5 TM imagery

The methodology used for the classification of the image Landsat 5 TM of April 28 1986 was the same as for the classification of the image ETM+. These areas of interest (aoi) were delimited from the knowledge and similarity with the spectral signatures of Landsat 7 image, as well as for information provided by local settlers. In this case, eight different classes were selected. Tables 4-12 and 4-13 show the main classes of coverings and their contingency matrices, corresponding to all the bands of the Landsat 5 TM except band TM6 (thermal) of the study area scene. Figure 4-19 shows the spectral signatures of the different classes corresponding to bands TM1-5 and TM 7.

Table 4-12: Land use/land cover classes for the study area, 1986.

Land Cover	ID	Label	Description
Water	1	HH	Water
Forest land	2	FISem	Semideciduous dense rainforest (Semid)
	3	FIDg	Semideciduous poor rainforest (Clear)
	4	FICo	Conifer reforestation
	5	FIPa	Paraiso reforestation
Rangeland	6	RCP	Capuera
Agriculture land	7	AGC37	Soil cover 30-70%
	8	AGC13	Soil cover 10-30%
Barren land	9	BS	Bare soil

Table 4-13: Contingence matrix main classes of the study area scene corresponding to the Landsat 5 TM image (bands 1-5 and 7) of 28Apr1986.

	1	2	3	4	5	6	7	8	9
1	100								
2		84,6		3,38	7,44				
3		2,44	87,2			1,51	8,85		
4		3,57		96,6					
5		11,8			92,6				
6						98,6	1,24	1,8	
7			11,6			1,55	85,1	1,72	
8							6,7	99,2	1,5
9									100

Band combination and enhancement application

From the evaluation of the spectral signatures and the contingency matrix, the bands combinations that best identified the different classes, were selected. The spectral signatures corresponding to these combinations were produced for further classification. These classes were obtained according to:

- The mask of clouds was produced following the same procedure and combinations used for the ETM+ image of 2001. The mask was applied to the main image.

- The classes **AGC13** and **FlPa** were obtained from the TM 4,5,6 bands combination. The masks were created assigning a positive value to the elements of the classes and a value of zero to the rest. In the case of FlPa class, given the high level of confusion that presented with respect to the class FIsem because of the similarities of the spectral response of objects conforming them, a grouping of four nearest neighboring pixels was made. Also, a "purification of classes" (modules clump and sieve of software Erdas) was carried out, that consists of recoding the values of the pixels contaminated with a class that does not correspond to them, in order to assign them the value of the class to which really they belong.

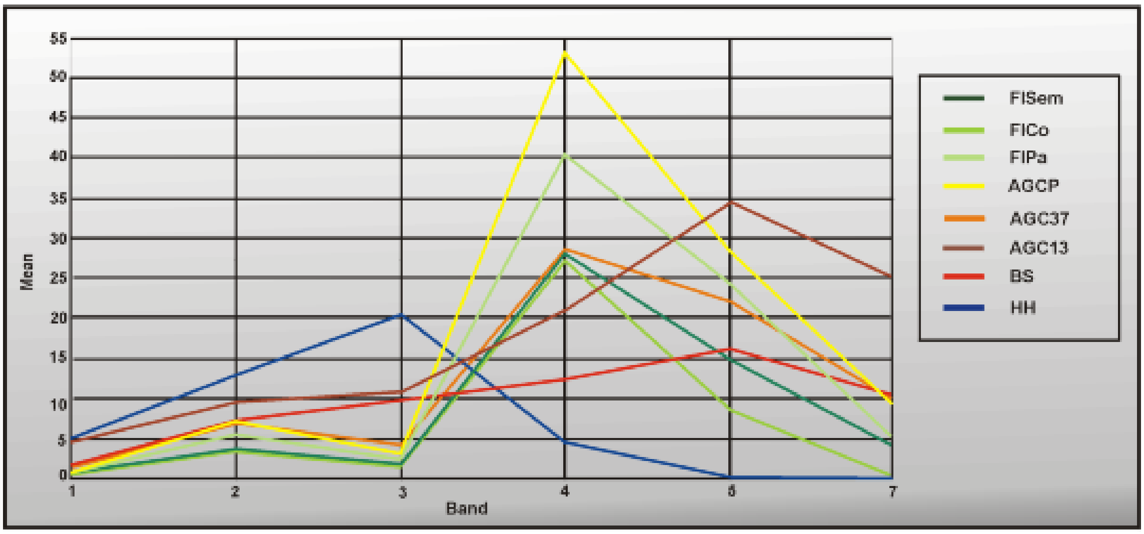


Fig. 4-20: Spectral signatures different classes from Landsat 5 TM study area sub-scene.

- The classes **RCP**, **HH**, and **BS** were classified from the combination of the second component of a PCA (1-5 and 7 bands) and TM4-5 bands of the reference image. The masks were created following the same procedure as in the previous point and applied to the scene overlap areas used for band-by band image mosaicing.

- The classes **AGC37** and **FIDg**, due to the high degree of confusion that they presented were unified in only one class in the first place obtained by reclassification of the image acquired in the previous point. The mask was got following the same procedure. Later on, and once obtained all the other classes a reclassification and differentiation were carried out.

- The class FlCo was classified from the TM 3-5 bands combination. The mask was created according to the methodology described in the previous points.

- The class FlSem resulted as a product of the subtraction of the other classes previously obtained.

As for the image of 2001 from the superposition of the obtained thematic classes, a corresponding of land use/land cover map was generated (Fig.4-21). Table 4-14 shows the total surfaces corresponding to each land use/land cover type in the classification map.

Table 4-14: Summary of total surfaces by land use/land covers class.

		Area (km^2)	Area (ha)	Area (%)
Forest land	FlSem	3.407,31	340.731	85
	FlDg	200,1	20.010	5
	FlCo+FlPa	100,62	10.062	2,5
Rangeland	RCP	122,81	12.281	3,1
Agricultural land	AGC37	131,06	13.106	33
	AGC13	30,34	3.034	0,8
Bareland	BS	17,92	1.792	0,4
	Total	4.010,16	401.015	100

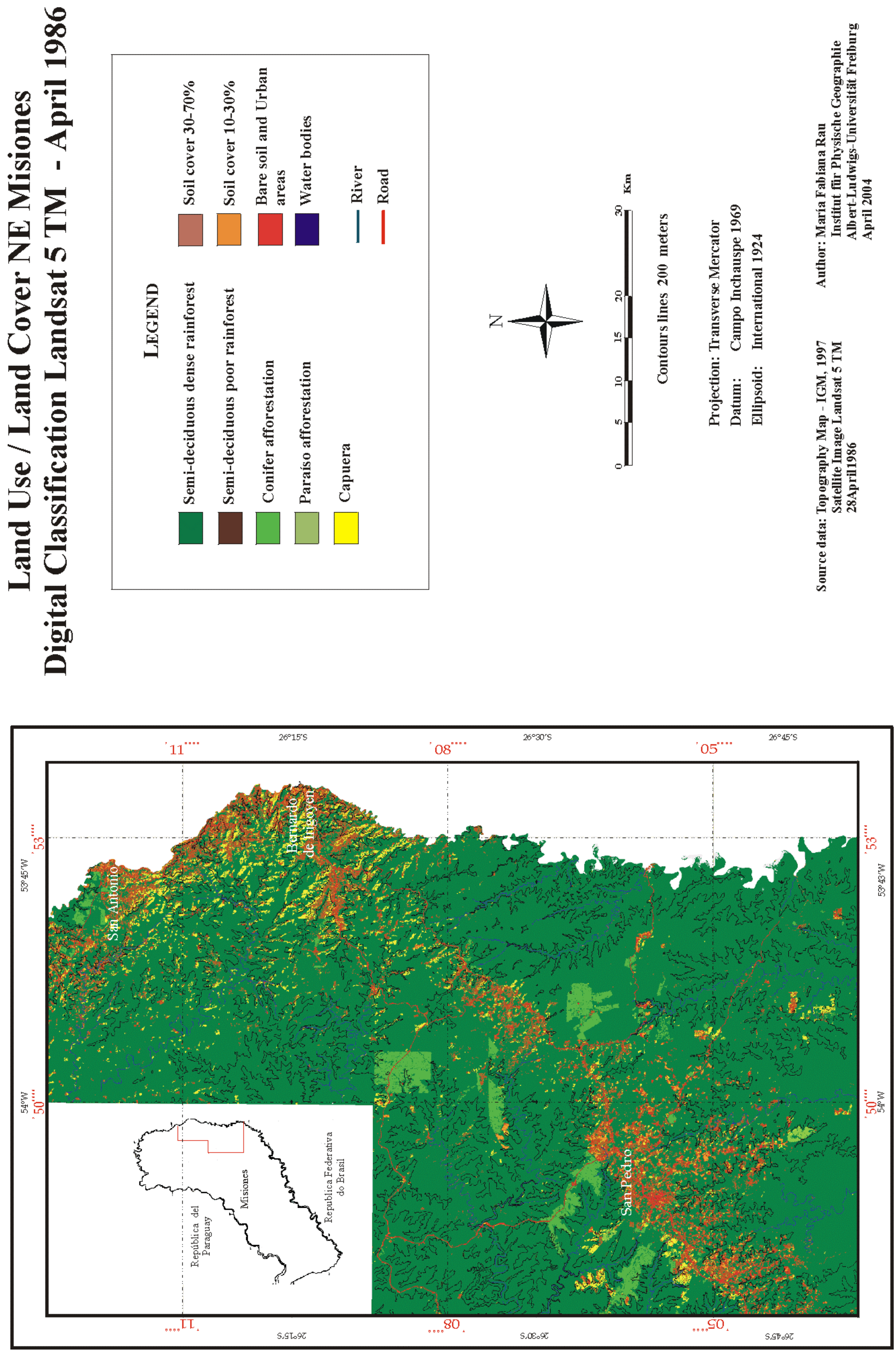


Fig. 4-21: Land use / Land covers NE Misiones digital classification Landsat5 ETM+ of April 1986.

4.3.2.3 Accuracy Assessment of Landsat ETM+ and TM imagery classification

Both Landsat images were tested in order to accuracy assessment of the classification. A direct comparison of different pixels from the two images with the corresponding classifications was made. Altogether, 849 randomly selected points for the image of 2001 and 802 points for the image of 1986 were evaluated. Tables 4-15 to 4-18 show the error matrices and compile the accuracy measurements of both images.

Table 4-15: Error matrix of accuracy assessment the Landsat ETM+ 2001 image classification.

	FISem	FIDg	FICu	RCP	AGPT	AGTc	AGYMc	AGC37	AGC13	BS
FISem	452	2	2	5	1			1		
FIDg	2	41		5			5	1		
FICu			48							
RCP				42	5	3		1		
AGPT	1				31					
AGTc						26				
AGYMc					2		42			
AGC37					1	1	11	35	4	
AGC13								1	23	2
BS										29

Table 4-16: Accuracy Assessment supervised classification of the Landsat ETM+ Apr.2001 image by Maximun Likelihood algorithm.

Class Name	Reference Totals	Classified Totals	Corrected Numbers	Accuracy Producer (%)	Accuracy User (%)
FISem	463	456	452	97,62	99,12
FIDg	54	43	41	75,93	95,35
FICu	48	50	48	100	96,00
RCP	51	52	42	82,35	80,77
AGPT	32	42	31	96,88	73,81
AGTc	26	30	26	100	86,67
AGYNc	44	58	42	95,45	72,41
AGC37	54	39	35	64,81	89,74
AGC13	26	27	23	88,46	85,19
BS	29	31	29	100	93,55
Clouds	14	14	14	100	100
Shadows	8	7	7	87,50	100
Total	849	849	790		
Overall Classification Accuracy: 93,05%			Overall Kappa Statistics: 0,8985		

Table 4-17: Error matrix of the accuracy assessment of Landsat TM5 March 1986 image.

	FISem	FIDg	FICo	FIPa	RCP	AGC37	AGC13	BS
FISem	455							
FIDg	4	54				3		
FICo			69		1			
FIPa				24				
RCP		1			70	2		
AGC37		10			2	28		
AGC13					1	1	28	1
BS								46

Table 4-18: Accuracy Assessment supervised classification Landsat TM5 March 1986 image by Maximun Likelihood algorithm.

Class Name	Reference Totals	Classified Totals	Corrected Numbers	Accuracy Producer (%)	Accuracy User (%)
FISem	455	459	455	100	99,13
FIDg	61	65	54	88,52	83,08
FICo	70	69	69	98,57	100
FIPa	24	24	24	100	100
RCP	73	76	70	95,89	92,11
AGC37	40	34	28	70,00	82,35
AGC13	31	28	28	90,32	100
BS	46	47	46	100	97,87
Total	802	802	774		
Overall Classification Accuracy: 96,51%			Overall Kappa Statistics: 0,95		

Producer's accuracy (or exclusion error): is the percentage of pixels that should have been placed into a given class but were not. It represents the proportion of a given class that is correctly identified in the image. It is calculated by dividing the correct percentage for a given row by the total for that row.
User's accuracy (or inclusion error): indicates pixels that were placed in a certain class when they actually belong to another class. It represents the probability that a given pixel will appear on the ground as it is classed (the percentage correct for a given column divided by the total for that column).

In general, the accuracy assessment of both classifications is high, with an overall accuracy and K_{hat} better than 90% and 0.9 respectively for both cases. Nevertheless, the matrix of error for the classification of the image of the 2001 shows a greater confusion. Most of the confusion cases occur among related classes, e.g. between AGYMc and AGC37, RCP, AGPT and AGTc, and among FISem, RCP and AGYMc.

A smaller accuracy for related land use classes is understandable. Nevertheless, an extensive use of auxiliary data such as the training areas it is very difficult to separate incipient capueras from pastures or reforestations in their first years from recently harvested yerba crops.

4.3.3 Land cover classification year 1962

In order to obtain the thematic land use/land cover map of year 1962, a digital database was created. For this, the thematic Vegetation maps of the study area of the time were selected. They were included in a GIS, according to the following steps:

1. Conversion to digital format through scanning of the maps and related aerial photographs.
2. Georeferencing of the thematic maps. The same procedure used in the Chapter 3.2.5 for the air photographs followed. The RMS average was of 0.153 (mean value).
3. Elaboration of a mosaic with the thematic maps. It must be stressed out that it was not possible to count on neither all the maps nor aerial photography of all the area of study because the Department of Cadastre of the Province Misiones no longer had it.
4. Digitalization and analysis of the existing vegetation cover polygons of the maps. The vegetation cover was corroborated and completed from air photographs mosaic (Cap. 3.2.5).
5. Classification of these polygons according to vegetation classes.
6. Elaboration of the land use/land cover map1962 (Fig. 4-22).

Table 4-19 shows the total surfaces corresponding to each land use/land cover class in the classification map.

Table 4-19: Summary of total surfaces by land cover/land use class.

		Area (Km^2)	Area (ha)	Area (%)
Forestland	Semideciduous dense forest	3.240,4	324.040	80,8
	Araucaria mixed forest	276,88	27.688	6,95
	Degraded forest	306,86	30.686	7,65
	Reforestation	7,93	793	0,2
Bareland	No forest	177,93	17.793	4,44
	Total	4010	40.100	100

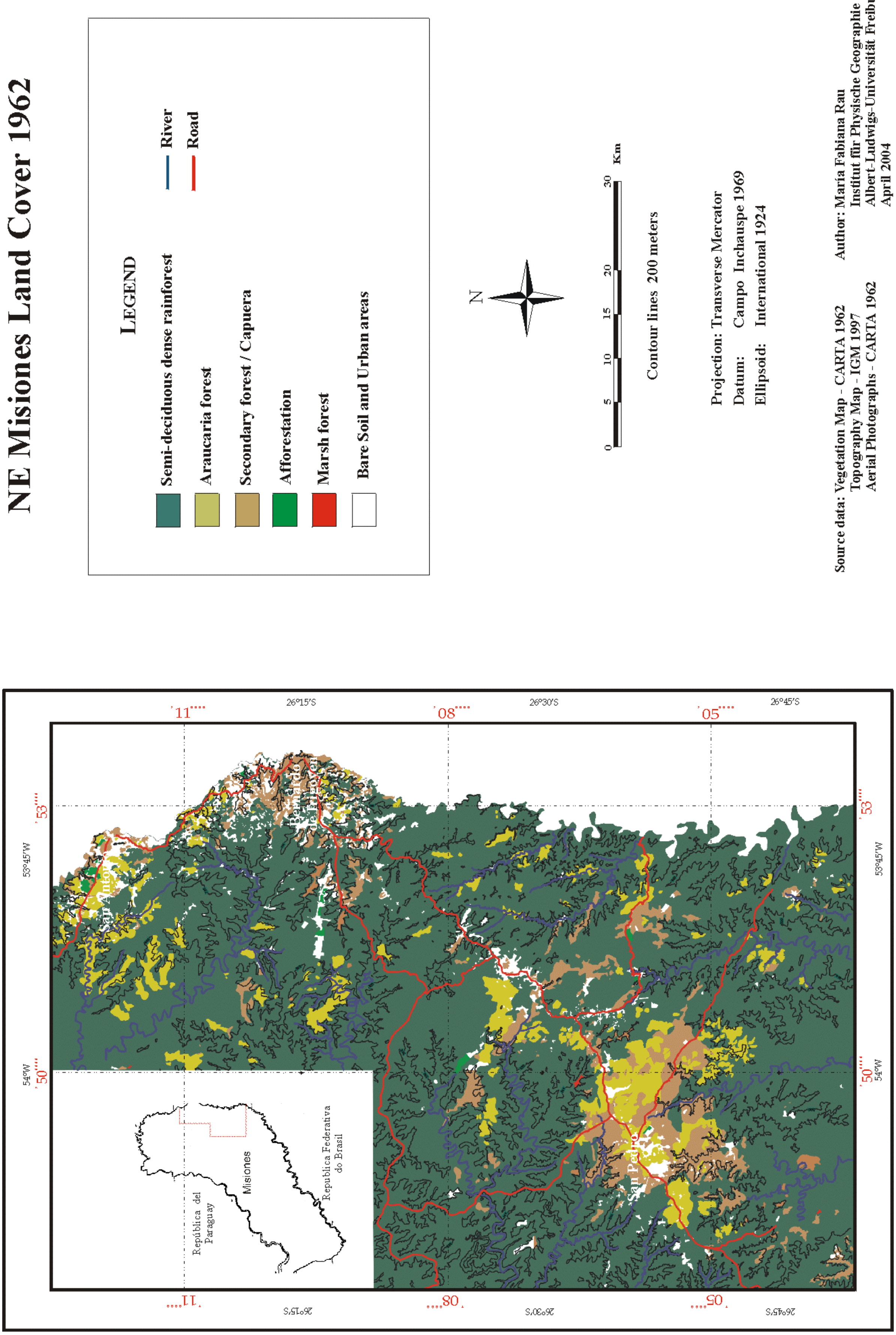


Fig. 4-22: Land cover map NE Misiones 1962.

4.3.4 Vegetation index computation and NDVI Image Differencing

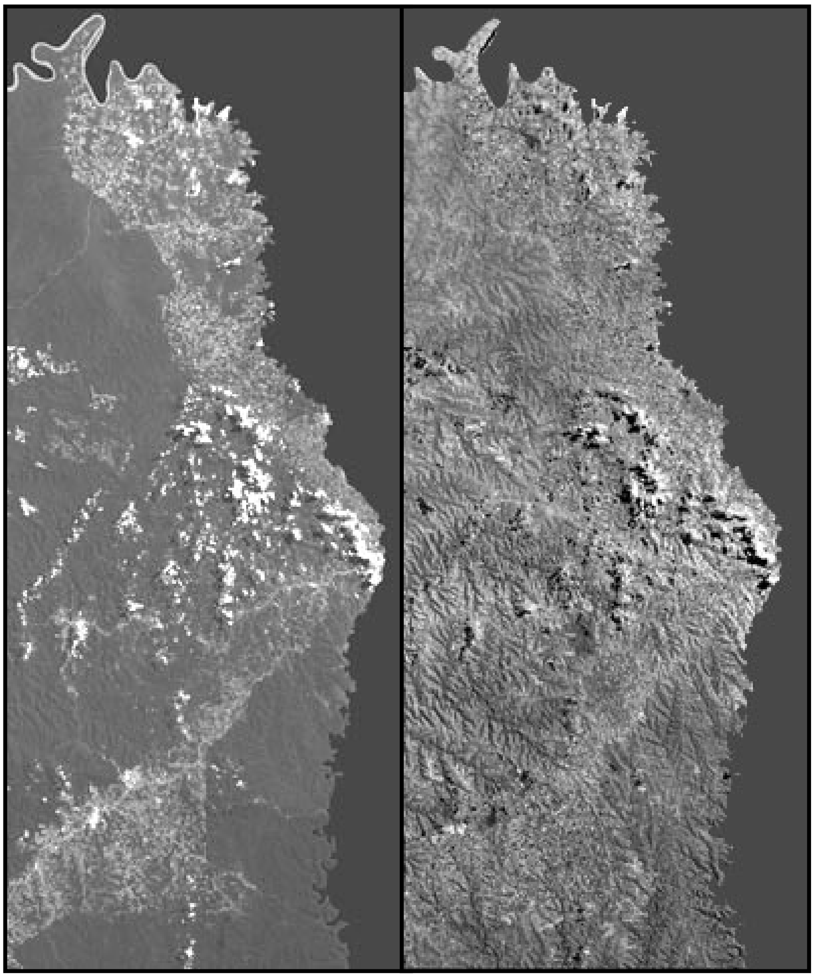


Fig. 4-23: Band 3 (left) and band4 (right) of the ETM+ images.

Vegetation Index is often used to explain the vegetation phenomena in the image data as a means to interpret differences among various vegetation types, and between vegetation and artificial objects. As every object shows different reflectance values and reflectivity patterns regarding to various wavelength, vegetation index can be computed with an algebra function compromising these characteristics. The typical spectral signatures of the healthy vegetation show a clear contrast between the visible red band (TM3) and the near infrared (NIR-TM4). While in the visible spectrum the leaf pigments absorb most of the light, in the NIR these are quite transparent. Therefore, the healthy vegetation has low reflectivity in the red band and high in the NIR. The bigger is the contrast between digital values of both bands, the greater vegetable vigor will be present the observed (Fig. 4-23). The Figure 4-24 shows the spectral signatures of three different land covers: forest, pasture and bare soil.

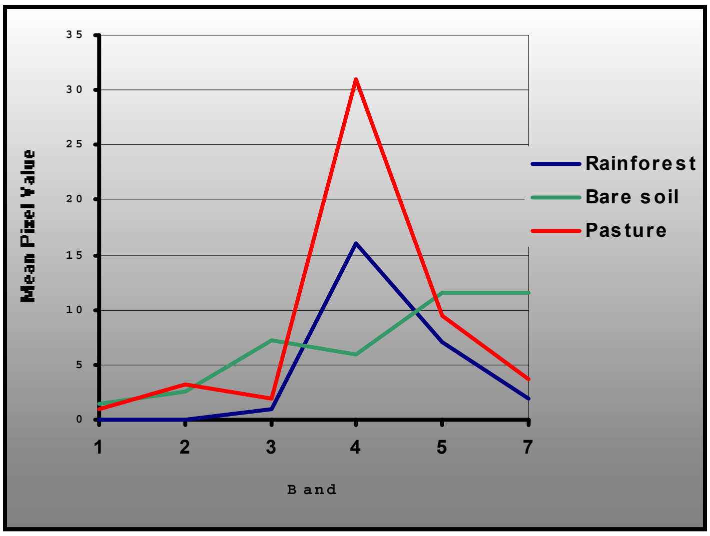


Fig. 4-24: Spectral signature of different land covers from Landsat 7 ETM+ image of March 2001.

Based on this reflectance pattern of vegetation, various models have been developed to express vegetation indexes, such us the Vegetation Index (VI), Ratio Vegetation Index (RVI), Normalized Difference Vegetation Index (NDVI). The calculation of Normalized Difference Vegetation Indices (NDVIs) can be very help-

ful in the generation of a land-use/land-cover classification. NDVIs provide useful information about the health and amount of vegetative cover across the landscape. The comparison of NDVIs can show seasonal variations within vegetative cover, helping to distinguish between deciduous and evergreen forest types. Comparisons can also be used to show variations of vegetative cover over longer temporal periods.
The following equation shows the form of calculating the value of NDVI for each pixel (CHUVIECO, 1996):

$$NDVI = \frac{D_{i,IRC} - D_{i,r}}{D_{i,IRC} + D_{i,r}} \quad (-1<=NDVI<=1) \qquad (1)$$

where $D_{i,IRC}$ and $D_{i,R}$ are the reflectance of pixel i of band NIR and band R respectively.
and for TM and ETM+ is the following:

$$NDVI = \frac{TM4-TM3}{TM4+TM3} \qquad (2)$$

where TM3 and TM4 are grey values of TM band 3 and band 4 respectively.

According Ch. 4.2.7.2, one of the most common change detection techniques is Image Differencing. In this procedure the corresponding pixel values (DNs) from one date(t_1) are simply subtracted from those of the other(t_2) as shown in the equation below.

$$DX^k_{ij} = X^k_{ij}(t_2) - X^k_{ij}(t_1)$$

where, X^k : pixel value(DNs) of band k,

ij : pixel coordinate

The result is a monochromatic (greyscale) matrix of the pixels, which have changed through time. The difference in areas of no-change will be very small approaching zero(0), on the other hand areas of change will manifest larger negative(-) or positive(+) values. Thresholds must be identified along histograms to separate changes from no change.

Difference images were created by first calculating NDVI values for each cloud / water masked Landsat data set by the equation (2). One-difference images were created by subtracting one date of NDVI values from those of the previous date, so that:

$$DIF\ (01\text{-}86) = NDVI\ (01) - NDVI\ (86)$$

4.4 Results and Discussion

4.4.1 Qualitative Assessment of the Supervised Classification

From the supervised classification of the images Landsat ETM+ and TM (figs. 4-18 and 4-20), ten and eight classes respectively of land use/land cover could be correctly identified. In addition, when more classes with cover types and vegetation were included in the classification, this became confusing. Most of the classes were mixed or confused with the others. This can be explained since the classes and subclasses defined in the field cannot be detected or classified spectrally in the image. This can be attributed to different causes, such as:

- The high dynamics of the landscape in consequence as much of the human intervention as of the economic swings that the land is put under. An example of this is the case of the yerba mate, a commercial corps that is subject of the cost-prices variations of the internal market. During the economic depression of the country in the last years, the price of this crop had a well-known fall. In many cases, the farmers had to stop the harvest, thus the "capuera" advanced into the crops. This fact made its correct classification difficult or impossible in many cases to separate it of a "capuera" in advanced succession degree.

- The yerba mate crops don't have a determined harvest season, and takes place at any time of the year. Thus, it is that in a same satellite image as in a multi-temporary analysis crops in different phenological states can be found, as it shows figure 4-25 In addition, in those crops in which the harvest was made in dates near the image taking, the bare soil contribution in the area is greater, a reason why it has led in many cases to confusion with the class AGC37.

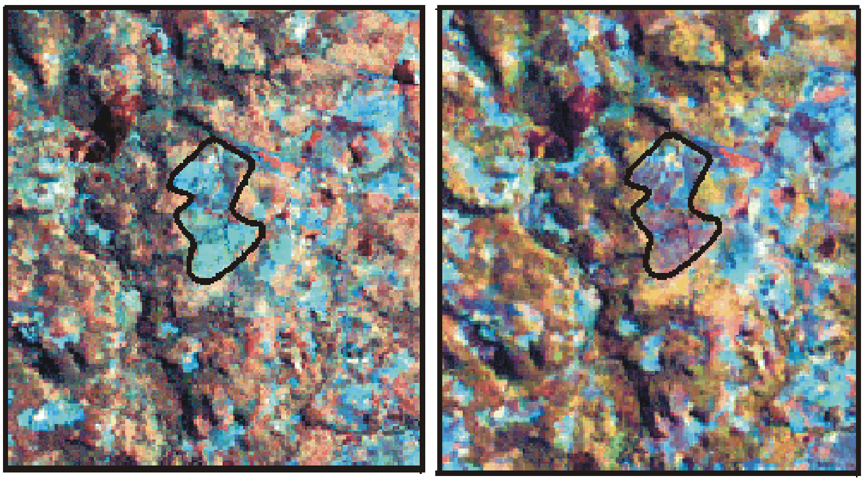


Fig. 4-25: Spectral differences according phenological variation in the yerba mate crops in a multi-temporal analysis.

- The reduced size of most of the agricultural parcels destined to certain cultures (maize, manioc, tobacco, tung), makes their separation complicated, even in the Landsat 7 ETM+ images with resolution 15 x 15 m.

- The selective extraction of the forest exploitation system practiced in Misiones makes also difficult the discernment between certain degrees of degradation from man-made alteration of the forest.

- The degree of cover soil and the structure of plantation between reforestations in the first three to four years and yerba mate crops recently harvested makes almost impossible a differentiation of these classes.

- The high contribution of bare soil in the urban areas made impossible its differentiation.

4.4.2 Change Detection using NDVI Image Differencing

Based on the NDVI values, the vegetation cover between both dates was analysed. High NDVI values represents as leaf biomass or leaf area increased. In contrary, low NDVI values indicate low vegetation cover or loss of vegetable vigour. On the colour scale NDVI image (Fig. 4-26) the vegetated area appeared in green tones, while the yellow and brown colours indicate scarce and/or any covering, respectively. Table 4-20 summarize some statistical of NDVI value over time.

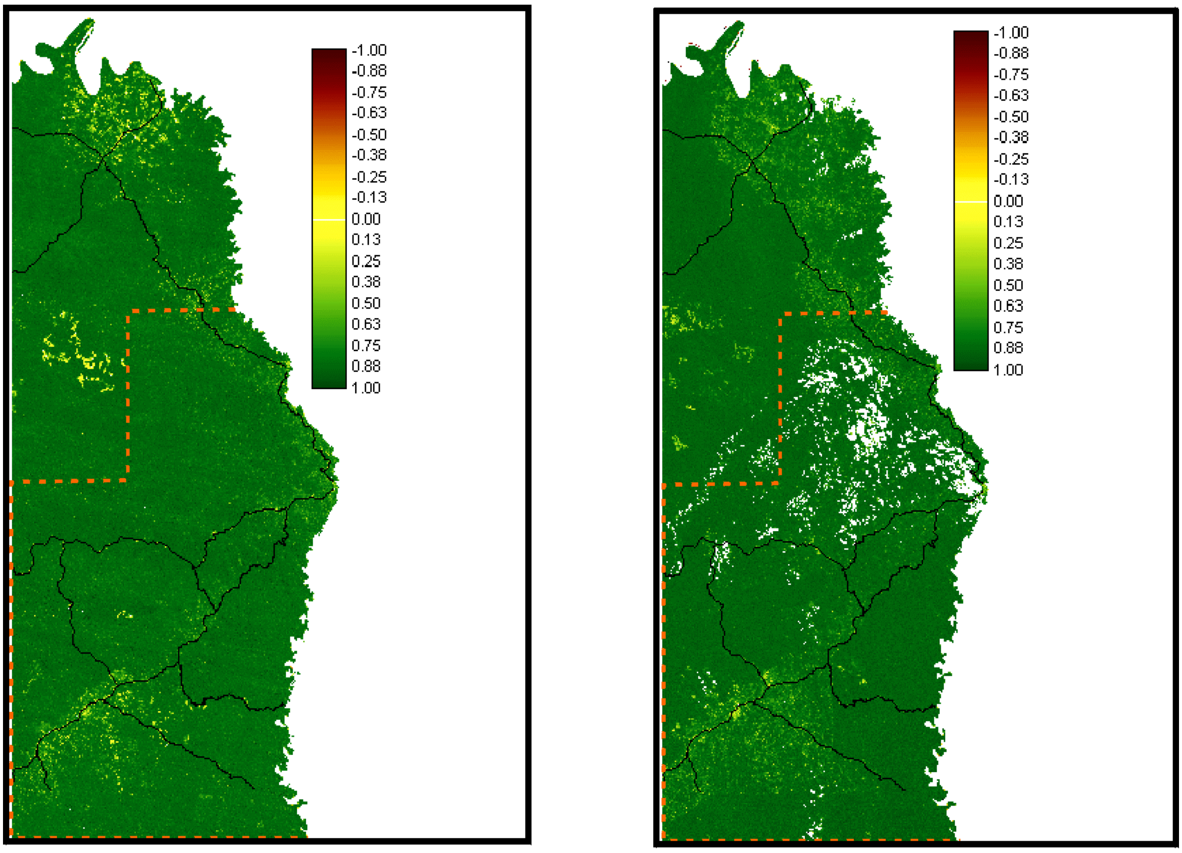


Fig. 4-26: NDVI image from 1986 Landsat 5 TM imagery (left) and 2001 Landsat 7 ETM+ (right). The NDVI values range from -1 (dark brown) to 1 (dark green). Demarcated area corresponds to study area.

Table: 4-20: Statistical value both NDVI images.

	Max	Min	Mean	Std. Dev.
NDVI 1986	0,99	-0,4667	0,562	0,397
NDVI 2001	0,99	-0,454	0,583	0,406

NDVI histograms (Fig. 4-27) showed two categories of datasets of 1986 and 2001. Green vegetation shown high values on the histogram curve. The histogram of NDVI acquired on March 1986, presented scarcely greater ranging in NDVI value between -0.470 and 0.99. Forest area appeared in the range of 0.625 to 0.99. Settlement area and built up land ranged -0.170 to 0.875. Agriculture land and rangeland ranged -0.091 to 0.867. Barren land area appeared the low NDVI value ranged -0.020 to -0.183. The histogram of NDVI on April 2001 varied from -0.450 to 0.99. Although, forest area also appeared the highest NDVI value than other cover, varied from 0.314 to 0.99. Agriculture land and Rangeland varied from -0.40 to 0.909. Barren lands and settlement areas ranged from -0.167 to 0.897.

By visually comparison of both histogram, the intermediate values corresponding to agricultural land cover a greater area in the histogram NDVI 2001. This is due to the extension of the agricultural frontier during the period 1986-2001. The increase in the superior values at 0.90, in the same histogram, presumably due to a greater surface of reforestation and the tea crops whose NDVI values range of 0.750 to 0.947 and 0.364 to 0.923 respectively. The deforestation, so much for agricultural frontier extension as for the harvesting activity, is reflected in the narrowing of the curve in the superior values at 0.82 (NDV I 2001).

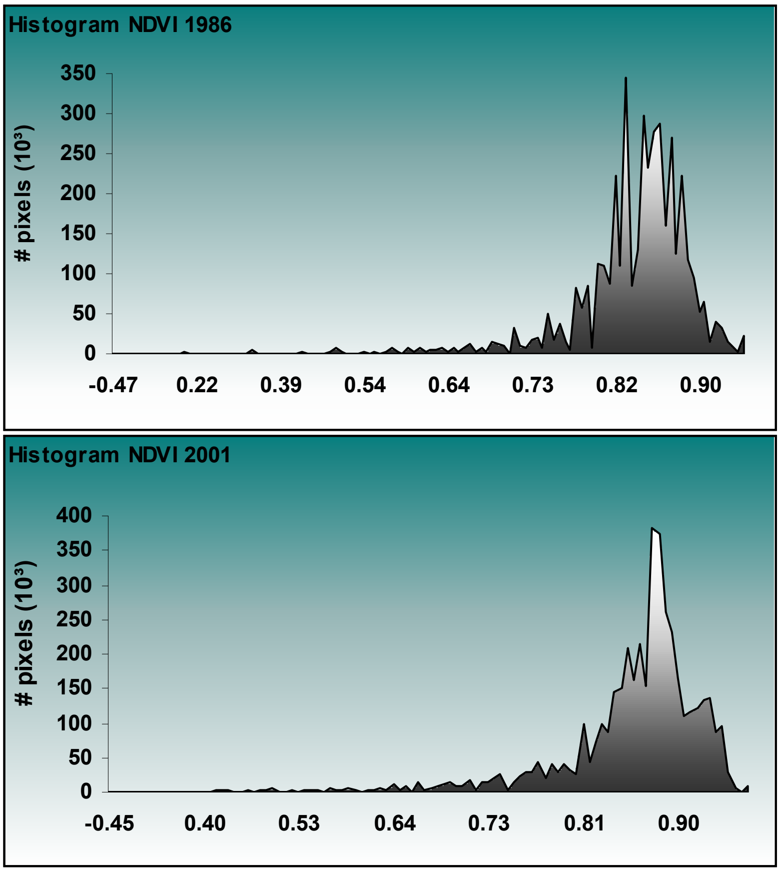


Fig. 4-27: NDVI histogram calculated from 1986 and 2001 imagery.

The figure 4-28 shows the change from April 1986 to March 2001 based on the calculated NDVI image difference from both NDVI values. An increase indicates the addition of vegetation or gain of vegetal vigour while decrease indicates removal of vegetation or loss of vegetal vigour. So, the green areas indicate increase, the yellow indicate no-change and red areas, decrease of vegetation. To determine the values change and no-change threshold by statistical values, standard deviation

(Table 4-21), was used. This image change shows clearly the forest cover decrease on both sides of main roads as well as in the areas surrounding the towns. This is mainly due to the forest substitution by crop fields, mostly yerba mate and annual crops. The isolated red areas correspond to clearings generated by the forest exploitation activity.

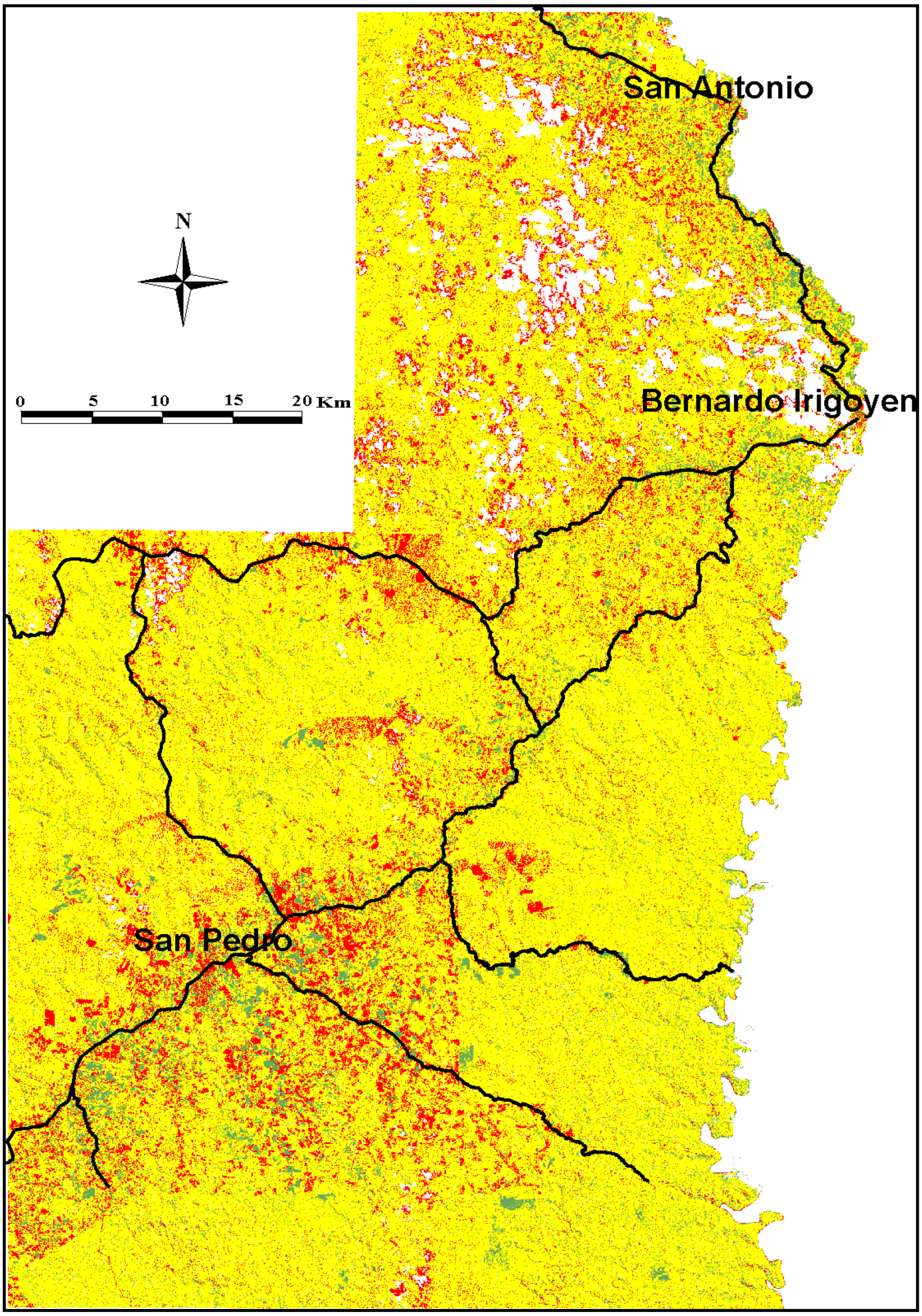


Fig. 4-28: NDVI image difference for the study area. It clearly can see the entrance of agricultural areas along the roads that cross the Province horizontally and connect Paraná River with Brazil. It is not difficult to foresee a future fragmentation and formation of forest islands generated by these agricultural intrusion lines.

Table 4-21: Statistical values of NDVI difference image.

	Min	Max	Mean	Median	Mode	Std.Dev
NDVI difference image	-1.75	0.933	0.024	0.021	0.011	0.075

In this image one can clearly see the trend of the agricultural expansion. This has taken place along the main roads that connect San Pedro - Bernardo Irigoyen - San Antonio, and it extends toward the frontier with Brazil and inside the territory along the provincial roads.

Table 4-22 summarize the change values in the study area. As it comes off this table, the relation between the loss of vigor or vegetal mass versus the increase almost it has been duplicated. Although it is not, at first glimpse, of a great magnitude, is advisable to remember that this index is an indicator of the amount of green biomass present in the zone independently of the vegetal species that compose it (BLACKBURN & MILTON, 1995 en DÍAZ DELGADO & PONS, 1999).

Table 4-22: Summary of NDVI image difference values in the study area.

	# Pixels	Hectares	Percentage
Decrease	764.323	68.789	17
No-change	3.368.580	303.172	76
Increase	311.949	28.075	7
Total	4.444.852	400.036	100

4.4.3 Post-classification Changes Detection

After the classification of the two Landsat images of 1986 and 2001, an analysis of the land cover change was performed, as well as a prediction of the trend development. The land cover of 1962 has been interpreted using the land cover map generated by digitalization.

An evident general trend took place in the last 40 years, with a great growth of the agricultural land to expenses of a noticeable decrease of the natural forest cover. In general terms, if the forest cover of 1962 is taken as a reference, the area has lost between 1962 and 2001 about 74.401 ha of natural forests, this is equivalent to 19.50% of the existing surface of these forests before the start of their exploitation. The deforestation rate (by clearing) varies through time. In the period that goes from 1962 to 1986, an average per year of 903,71 ha of forests (0.23%) was destroyed. During the period of 1986 to 2001, the deforestation rate has increased considerably, being of 3.515,2 ha of forest cleared per year (0.88%). The average rate of forest loss for all the period is of 1.907,72 ha year^{-1} (Table 4-23).

Table 4-23: Annual deforestation rate (by clearing) during 1962-2001.

Deforestation rate (ha. year^{-1})		
1962-1986	**1986-2001**	**Average**
903,04	3515,20	1907,72

The analysis of the land cover change is shown in detail in table 4-24. According to these results, the period 1986-2001 is the one of greater impact on the native forest. In this period, the deforestation by clear-cutting for expansion of the agricultural border was of 50.944 ha (including the areas without vegetation or urban areas), against 12.419 ha of period 1962-1986.

Table 4-24: Summary of land use/land cover change in the period 1962 – 2001.

	Land use/land cover (ha)					
	1962	1986	2001	Gain	Loss	Stable
Semideciduous forest	382.414	360.741	308.013	0	74.401	308.013
Reforestation	793	10.062	10.868	10.075	0	0
Agricultural and barrenland	17.793	30.212	81.156	63.363	0	0
Total	401.000	401.015	400.037	73.438	74.401	308.013

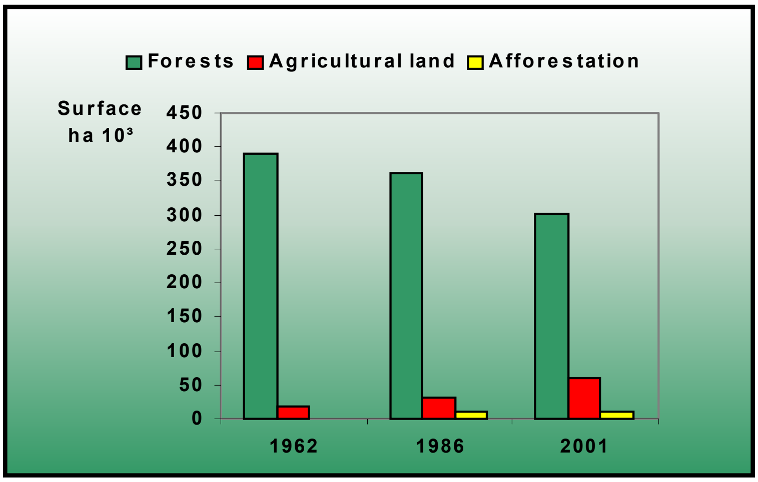


Fig. 4-29: Land cover change between 1962 and 2001, according forestland, agricultural land and reforestation surfaces.

On the contrary, the areas destined to reforestation had a greater increase between years 1962-1986 with 9.269 ha, against the 750 ha during the period 1986 and 2001. It has to be considered that approximately 21.034 ha in the image of the 2001 are under clouds and shades, great part of this surface to corresponding the agricultural areas nearby Bernardo de Irigoyen. Figures 4-29 and 4-30 show the loss of forest cover, increase of reforestation areas and expansion of the agricultural areas.

4.4.4 Discussion

The population of Manuel Belgrano and San Pedro has been increasing continuously and rapidly. In the period from 1980 to 2001, the population nearly doubled, from 28.981 in 1980 to 56.927. Although precise data are not available, the population of the region, in the 1960-decade was inferior to 20.000 inhabitants. In the period from 1961 to 2001, the amount of cultivable land nearly quadruplicated, from 17.793 ha in 1962 to 81.156 (Fig.4-31).

This process of extension of agricultural land has resulted in the rapid and permanent loss of forest cover (about 20%). Moreover, due to the rapidly growing population, average plot sizes are declining over time because of the subdivision of small plots too small to sustain larger families.

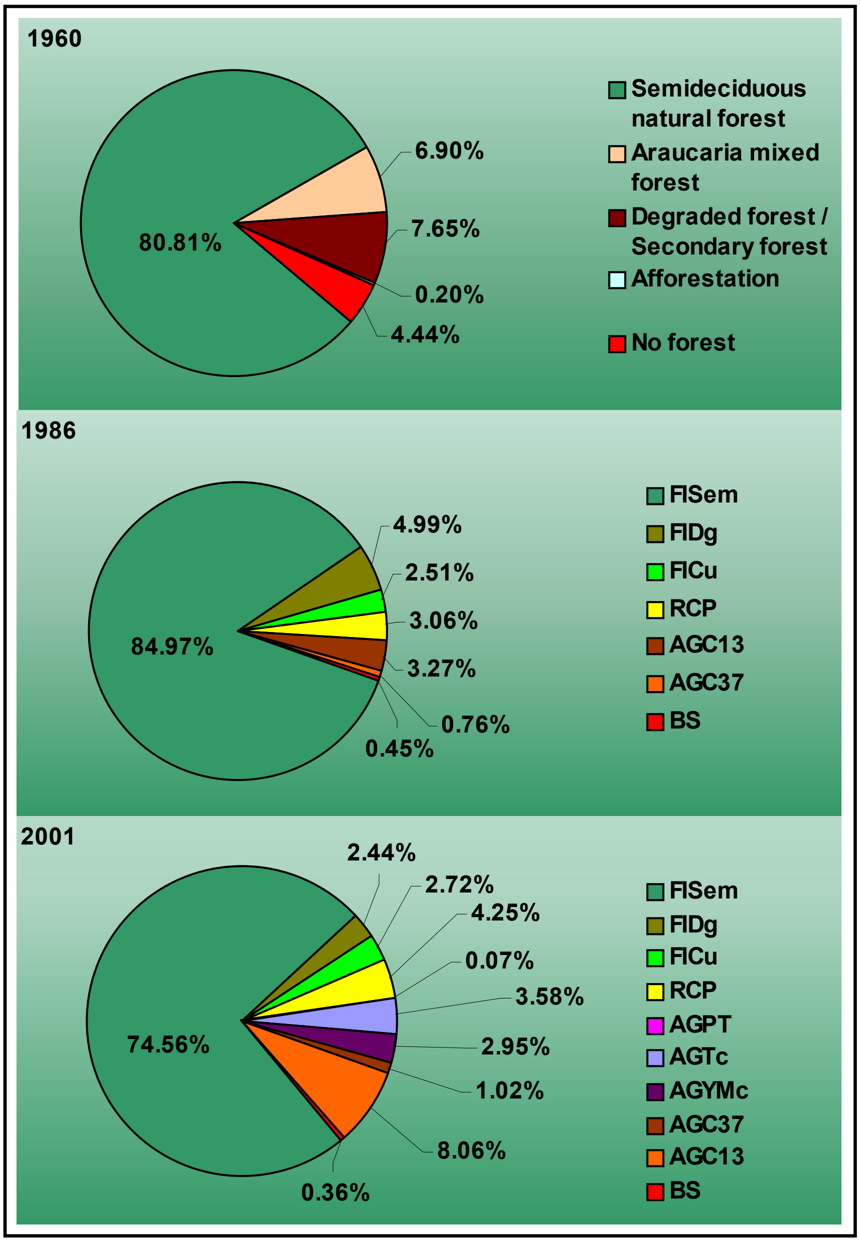


Fig. 4-30: Relative percentages of different land use/land cover from the multitemporal analysis.

On the hand, due to increasing population pressure, the surplus labor force in the agricultural sector has increased tremendously. For rural people who own no or very little agricultural land, employment in agricultural activities is the most important source of income. The scarcity of work in the rural farming society has forced the extra labour to migrate to the forest areas without the assistance of the government.

A common practice of these squatters is slash und burn large forest areas to make crop fields and plant mainly maize, tobacco and manioc, without any concern for long-term sustainability (Fig. 4-32). The rural poor themselves who are the primary agents of destruction as they clear forests for agricultural land, fuelwood and other necessities. Lacking other means to meet their daily survival needs, rural people are forced to erode the capacity of the natural environment to support themselves.

It is wholly recognized that properly managed shifting cultivation is sustainable (HARDWOOD, 1996 in SALAM & NOGUCHI, 1998). Mostly, the traditional shifting cultivators have ignored sustainable cultivation. They sometimes sell cleared land to migrating settlers after practicing cultivation for a few years.
Most of the rural populations of Misiones are still largely dependent on fuelwood for household. Given the increasing population, the demand for fuelwood as well as timber has increased. Moreover, population growth increases fuelwood collection, which removes

nutrients from the forest. Due of the intense loss of nutrient, regeneration has slowed and the forest has eventually degraded.

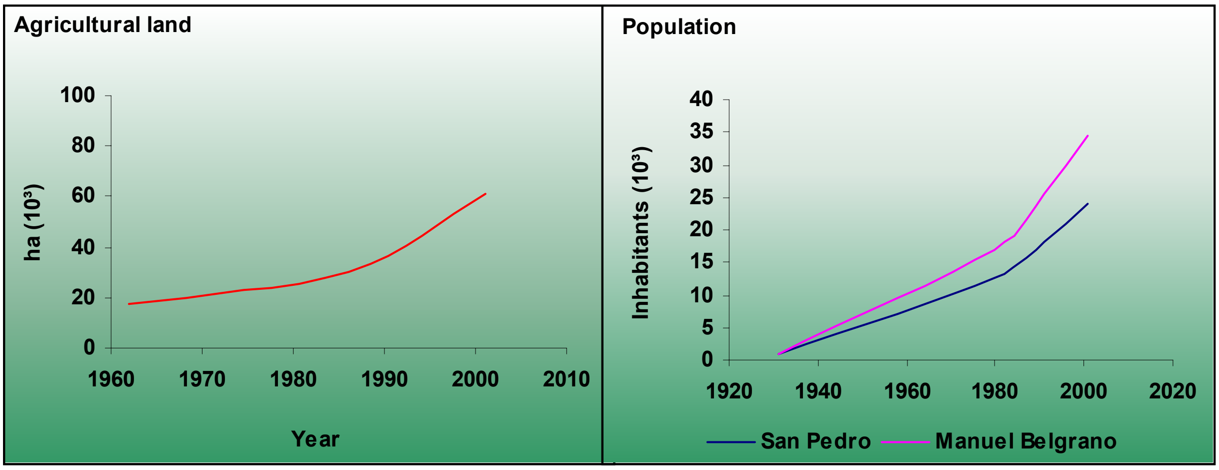


Fig. 4-31: Population and total agricultural lands (perennial and annual crops and pasture) for San Pedro and Manuel Belgrano departments.

At the present, the threats to these forests are more or less out of control. Misguided government policies that encouraged destructive practices are also responsible for the loss of forest cover. With the contemporary situation, if the Misiones policy continues to neglect the ecological consequences of further loss of forest cover, it will be difficult to control forest loss and consequently the environment will be degraded considerably.

Fig. 4-32: Slash and burn is a usual practice for forest clearing. Although this practice is carried out during the whole year, there is a marked increment during the July and August, before the period of maximum rainfall. This picture was taken after the burn a cut forest area nearby San Pedro. (Photo: M. F. Rau, 2001).

5. SOIL DEGRADATION

Soil degradation is widespread, particularly in the tropics and subtropics, representing a major economic and ecological constraint. It leads to poor yields, low life standards, and contributes to hunger and malnutrition. The ecological consequences of soil degradation include pollution of wind and water by sediment and dust, and eutrophication and contamination of natural waters by sediment-borne pollutants. Processes of soil degradation most prevalent in those regions include soil erosion and desertification, compaction and hard-setting, salt and water imbalance in the root zone, biological degradation including reduction in soil organic matter content, fertility depletion, and chemical degradation including leaching and acidification.

In the environment world vast earth areas have suffered irreversible degradation processes, caused by a wide range of processes, such as quick erosion, desertification, compactation, soil crusting, acidification, decrease in the content of organic matter, diversity and fall of the soil fertility (LAL, 1994). According to the Global Assessment of Human Induced Soil Degradation (GLASOD) in the 1990's, 15% of the total surface of the earth has suffered damage (13% light and moderate and 2% severe and very severe), mostly resulting of erosion, nutrients decrease and physical compactation. Deforestation, removal of natural vegetation, misuse of the land and overgrazing are reported to be the main reasons for loss of topsoil and terrain deformation. In Argentina, today, more that 60 millions hectares are under erosive processes and annually 650 thousand hectares with different erosion degree are added.

The increment of deforestation and the agricultural activities, in the last decades, drove to the removal of the native forest cover of extensive areas in the northeast of the Misiones Province (Ch. 4.5.3). These areas become vulnerable to erosion because of the decreased protection by vegetation cover, in reduction of effective rainfall intensity at the ground surface and the reduction of infiltration rate due to compactation from heavy machinery as a misuse of the land.

Soil erosion leads to decrease of the agricultural productivity, due to the nutrients loss, physical soil deterioration, loss of depth and in extreme cases, to the total soil loss. It is therefore necessary to ascertain the soil erosion potential to apply preventive measures that avoid the loss of this basic resource.

In this chapter the soil erosion risk and possible causes of soil erosion are assessed and determined for the study area, using satellite imagery, geographic information systems and erosion models.

Satellite imagery is generally integrated with ancillary information from various spatial databases in geographic information system environment to improve information extraction from imagery (LILLESAND and KIEFER, 1994). GIS analysed provide valuable information that can enhance management programmes for the conservation and sustainable utilization of soil resources. Erosion models can be used as predictive tools for assessing soil loss for conservation planning, project planning, soil erosion inventories, and for regulation, so as tools for understanding erosion processes and their interactions and for setting research priorities.

5.1 Soil Erosion

Soil erosion is an interactive process influenced by both natural and cultural factors. Such as: precipitation, relief, geological and soil properties, vegetation covers and land use. Soil erosion is a natural process, which is frequently exacerbated by human interventions to the environment. In extreme cases, the topsoil can suffer severe degradation. Limitations to the ecological function of soils include: human behaviour leading to soil erosion, the degradation or destruction of surface and ground waters, a decline in the water retention of soil, a decline in the regulatory role of soil in the hydrosphere generally, and a decline in soil biomass productivity. The main consequences of soil erosion by water on agricultural production and the environment can be divided into three groups: loss of soil, transport and sedimentation of soil particles, and transport and loss of chemical nutrients. Soil loss is defined in the erosion literature as the amount of soil lost in a specified period over an area of land that has experienced net soil loss.

5.1.1 Processes and Erosion Mechanisms

Erosion of topsoil begins when water detaches individual soil particles from clods and other soil aggregates. Raindrops are the major cause of soil particle detachment. The impact of raindrops on the soil surface can break down soil aggregates and disperse the aggregate material. Lighter aggregate materials such as very fine sand, silt, clay and organic matter can be easily removed by the raindrop splash and runoff water; greater raindrop energy or runoff amounts might be required to move the larger sand and gravel particles.

During rainstorms, a two-fold problem often occurs. The rate of rainfall may exceed the rate at which water can enter the soil (infiltration rate). The excess water either collects above or runs off the soil surface. Secondly, raindrop impact forces can result in a partially sealed soil surface, thus reducing in this way the infiltration of water into the soil that causes more runoff. If all the water could always enter the soil,

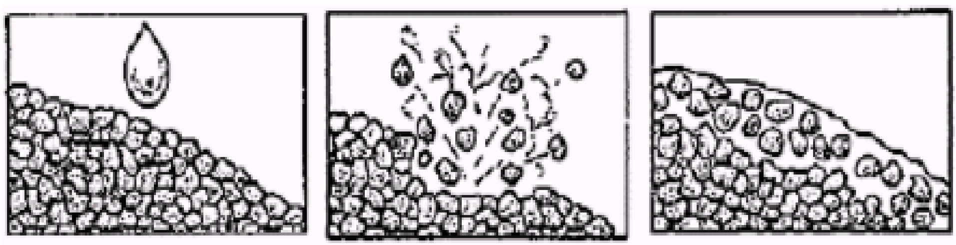


Fig. 5-1: Soil particles and aggregates that have been detached by raindrops are transported down the slope by runoff (TORRI and BORSELLI, 2000 in CHMELOVÁ and SARAPATKA, 2002.

both the detachment and splashing of soil particles would be of minor concern and the soil loss would be minimal. However, when the rainfall rate exceeds the soil's infiltration rate and the soil surface storage is filled, runoff begins. The runoff travels downhill, carrying soil particles with it (Fig. 5-1).

The amount of runoff can be increased if infiltration is reduced due to soil compaction or crusting. Runoff from the agricultural land may be greatest during spring months when the soils are usually saturated and vegetative cover is minimal.

Types of soil erosion are:

- Sheet erosion is the uniform removal of soil in thin layers by the forces of raindrops and overland flow. It can be a very effective erosive process because it can cover large areas of sloping land and go unnoticed for quite some time. Sheet erosion can be recognized by either soil deposition at the bottom of a slope, or by the presence of light – colored subsoil appearing on the surface. If left unattended, sheet erosion will gradually remove the nutrients and organic matter, which are important to agriculture and eventually lead to unproductive soil.

Fig. 5-2: Rill erosion an deposition at the foot of the slope after road construction. San Pedro, Misiones (Photo: M.F.Rau, 2001.

- Rill erosion is the removal of soil by concentrated water running through little streamlets or head cuts. Detachment in a rill occurs if the sediment in the flow is below the amount the load can transport and if the flow exceeds the soil's resistance to detachment. As detachment continues or flow increases, rills become wider and deeper. Rilling is one of the most common forms of erosion. Rill channels can temporarily be obliterated by tillage. Tillage loosens the soil making it more susceptible to rill erosion (Fig. 5-2).

- Interrill erosion. Raindrops striking exposed soil detach topsoil particles and splash them into the air and into shallow overland flows. Raindrops striking these shallow flows enhance the flow's turbulence and help to transport more of the detached sediment to a nearby rill or flow concentration. The cover provided by residues and plant canopy affects interrill detachment.

Delivery of interrill sediment to the rill channels is a function of slope, cover, and surface roughness.

- Classical gullies are an advanced stage of channel erosion. They are formed when channel development has progressed to the point where the gully is too wide and too deep to be tilled across. These channels carry large amounts of water after rains and deposit eroded material at the foot of the gully. They disfigure landscape and make land unfit for growing crops (Fig. 5-3).

Fig. 5-3: Gully erosion in a wood storing area (above 20 years). San Pedro, Misiones.

5.1.2 Erosion Factors

5.1.2.1 Soil Erodibility

Soil erodibility is an estimate of the ability of soils to resist erosion based on the physical characteristics of each soil (LAL, 1988). Generally, soils with faster infiltration rates, higher levels of organic matter and improved soil structure have a greater resistance to erosion.

Soil particle size distribution, organic matter content, and the slope of the land all influence how susceptible different fields are to the forces of erosion. Large-grained particles and aggregates are easily detached by raindrops or flowing water, but are not easily transported. Soils such as clays and fine silts that bond together tightly are not easily detached, but once free they are easily transported. For this reason, fine materials can be carried out to considerable distances, whereas larger particles may be deposited within a short distance along the flow path.

Erodibility varies with basic soil characteristics such as content of clay, organic matter and geometric mean diameter (D_G) (TORRI et al., 1997). In coarse textured soils, particles are too heavy to entrain and transport and infiltration is relatively large; all of which decrease erodibility. On the other hand, cohesive forces increase with clay content which reduces erodibility while increasing organic matter content makes aggregates more resistant to sealing and consequently decreases runoff and erosion (MORGAN, 1986). The two main forces, which resist detachment of soil particles by raindrops or running water are cohesion and adhesion (clay), and friction (sand) (JANNSON, 1982 cit. by REINING, 1992). The effect of grain size on soil erodibility is where organic matter content has been replaced by the logarithm of geometric mean diameter (D_G) of the grain size distribution: D_G = ½ S_i F_i Ln (d_i d_{i-1}) where d_i is the upper and d_{i-1} the lower limit of each size class (lower size for clay being d_o=0.005 μm, by definition) and F_i is the frequency (by weight).

Relationships within the soil indicate that soils with good granular structure are less erodible. Several authors have described the positive effect of aggregate stability in reducing erodibility. Sand, sandy loam and loam- textured soils tend to be less erodible than silt, very fine sand, and certain clay textured soils (WISCHMEIER *et al.*, 1971)

Organic matter is important for the stability of aggregates and therefore for the existence and maintenance of large pores (GREENLAND, 1977; ROOSE, 1996). Tillage and cropping practices which lower soil organic matter levels, cause poor soil structure, and result of compacted contribute to increases in soil erodibility. Decreased infiltration and increased runoff can be a result of compacted subsurface soil layers. A decrease in infiltration can also be caused by a formation of a soil crust, which tends to "seal" the surface. On some sites, a soil crust might decrease the amount of soil loss from sheet or rain splash erosion; however, a corresponding increase in the amount of runoff water can contribute to greater rill erosion problems.

Past erosion has an effect on soils erodibility for many reasons. Many exposed subsurface soils on eroded sites tend to be more erodible than the original soils were because of their poorer structure and lower organic matter. The lower nutrient levels often associated with subsoils contribute to lower crop yields and generally poorer crop cover, which in turn provides less crop protection for the soil. The orientation factor K for soil erodibility for soils typical of the Province Misiones are presented in Table 5-1.

Table 5-1: The orientation soil erodibility factor K for typical soils of the Province Misiones (LIGIER *et al.*, 1989).

	K		K
Oxisols	0.04	Inceptisols	0.16
Ultisols	0.10	Entisols	0.10
Alfisols	0.10	Mollisols	0.13
Alfisols moderately deep	0.17		

5.1.2.2 Slope Gradient and Length

Naturally, the steeper the slope of a field the greater is the amount of soil loss from water erosion. With increasing quantity of runoff, the water tends to concentrate. Therefore, the steeper the slope the more dominant is rill erosion. Depending on the slope gradient and the thickness of the water layer not only the amount but also the velocity of runoff increases. Soil erosion by water also increases as the slope length increases due to the greater accumulation of runoff, but this influence is less pronounced compared with the gradient (SCHACHTSCHABEL, 1982). Consolidation of small fields into larger ones often results in longer slope lengths with increased erosion potential, due to increased velocity of water which permits a greater degree of scouring (carrying capacity for sediment). The slope length can be influenced by measures of erosion control, such as contour strips and ridges or terracing. The effectiveness of these measures of soil conservation can be regarded as a function of the slope gradient (WISCHMEIER *et al.*, 1958 cit by REINING, 1992).

5.1.2.3 Soil Cover and Soil Tillage

Soil erosion potential is increased if the soil has no or very little vegetative cover of plants and/or crop residues. Plant and residue cover protects the soil from raindrop impact and splash, tends to slow down the movement of surface runoff and allows excess surface water to infiltrate.

The erosion-reducing effectiveness of plant and/or residue covers depends on the type, extent, density and height of the plants (WISCHMEIER and SMITH, 1978). Vegetation and residue combinations that completely cover the soil, and which intercept all falling raindrops at and close to the surface are the most efficient soil control (e.g. forests, permanent grasses, mulch). Partially incorporated residues and residual roots are also important as these provide channels that allow surface water to move into the soil and influence soil properties such as the distribution of aggregate sizes, the stability of aggregates, and also the bulk density and density of aggregates.
How strong the influence of a layer of mulch can be is shown by experiments made in Nigeria (Table 5-2). In this trial, the soil loss decreased exponentially with an increasing amount of mulch (0, 2, 4 and 6 tons of straw per ha) (LAL, 1976 cit by REINING, 1992).

Table 5-2: Effect of mulch on runoff on a 10% slope.

Mean annual values	Clean tilled fallow	Mulch rate (6 t ha^{-1})
Soil loss (t ha^{-1})	232.6	0,2
Runoff (mm)	504.1	29.3
Runoff rate (%)	42.1	2.4

The effectiveness of any crop, management system or protective cover also depends on how much protection is available at various periods during the year, relative to the amount of erosive rainfall that falls during these periods. In this respect, crops which provide a food, protective cover for a major portion of the year (for example, alfalfa or winter cover crops) can reduce erosion much more than can crops which leave the soil bare for a longer period of time (e.g. row crops) and particularly during periods of high erosive rainfall (spring and summer). However, most of the erosion on annual row cropland can be reduced by leaving a residue cover greater than 30% after harvest and over the winter months, or by inter-seeding a forage crop (e.g. red clover).

Soil erosion potential is affected by tillage operations, depending on the depth, direction and timing of plowing, type of tillage equipment and number of passes. Generally, the less the disturbance of vegetation or residue cover at or near the surface, the more effective the tillage practice in reducing erosion.

5.1.2.4 Infiltration

Infiltration is the process by which water enters the soil. It separates water into two major hydrologic components - surface runoff and subsurface recharge. Accurate determination of infiltration rates is essential for reliable prediction of surface runoff. For planning purposes, it is essential to know the stability of infiltration data and whether the infiltration capacity of individual soils is adequate to cope with the anticipated hydrologic loads.

Infiltration rate usually shows a sharp decline with time from the start of the application of water. The constant rate approached after a sufficiently large time is referred to as the steady-infiltration rate. The process is described by the equations of Kostiakov (1932) and Horton (1940), which show a decreasing infiltration rate as a function of time. As these equations and the related experiments were empirical, the coefficients of the equations have no physical meaning. Green-Ampt (1911) and Phillip (1957) developed mathematical solutions to physically based theories of infiltration. The Green-Ampt theory considers water to move downwards as piston flow. The system is assumed to consist of a uniformly wetted near-saturated transmission zone above a sharply defined wetting front of constant pressure head. The mathematical and physical analysis of the infiltration process developed by Phillip (1957) separates the process into two components - that caused by a sorptivity factor and that influenced by gravity. Sorptivity is the rate at which water will be drawn into a soil in the absence of gravity; it comprises the combined effects of adsorption at surfaces of soil particles and capillarity in soil pores. The gravity factor is due to the impact of pores on the flow of water through soil under the influence of gravity. The sorptivity is influenced by the initial and final moisture contents. As the moisture content approaches saturation, sorptivity tends to zero and the infiltration rate becomes equal to the field saturated hydraulic conductivity. This implies that the steady infiltration rate reached after a long time should be largely independent of the antecedent moisture content (PHILLIP, 1977 in SCHIFFLER, 1992).

Often, the hydraulic conductivity is greater in the topsoil than in the subsoil that is due to the presence of an argillic horizon in the subsoil (Ultisols, Alfisols), that which lead to lateral water flow (REINING, 1992). Investigations on an Alfisols in Nigeria showed a decrease in water holding capacity, clay and silt contents of the topsoil and a reduction of the infiltration rate from 3.5 to 0.2 cm h^{-1} on a clean tilled fallow plot over a period of only two years as a consequence of erosion (LAL, 1976). A comparison between the traditional system of slash and burn, and land clearing with heavy machinery in a tropical rainforest on an Oxisols in Brazil showed a strong decrease of large pores and of the infiltration rate, and at the same time an increase of the bulk density as a consequence of mechanical clearing (DIAS and NORTCLIFF, 1985 cit. by REINING, 1992).

5.1.3 Effects of the Erosion

On-Site Effects: The implications of soil erosion extend beyond the removal of valuable topsoil. Crop emergence, growth and yield are directly affected through the loss of natural nutrients and applied fertilizers with the soil. Seeds and plants can be disturbed or completely removed from the eroded site. Organic matter from the soil, residues and any applied manure, is relatively lightweight and can be readily transported off the field, particularly during spring thaw conditions. Pesticides may also be carried off the site with the eroded soil.

Soil quality, structure, stability and texture can be affected by the loss of soil. The breakdown of aggregates and the removal of smaller particles or entire layers of soil or organic matter can weaken the structure and even change the texture. Textural changes can in turn affect the water-holding capacity of the soil, making it more susceptible to extreme condition such a drought.

Off-Site Effects: Off-site impacts of soil erosion are not always as apparent as the on-site effects. Eroded soil, deposited down slope can inhibit or delay the emergence of seeds, bury small seedling and necessitate replanting in the affected areas. Sediment can be deposited on down slope properties and can contribute to road damage.
Sediment, which reaches streams or watercourses, can accelerate ban erosion, clog drainage ditches and stream channels, silt in reservoirs, cover fish spawning grounds and reduce downstream water quality. Pesticides and fertilizers, frequently transported along with the eroding soil can contaminate or pollute downstream water sources and recreational areas.

5.2 Erosion Modelling

Several empirical and physical models are available to assess soil erosion. The empirical models are based especially on observation and are usually statistical in nature. On the contrary, the physical ones are reduced scale laboratory models, which need to assume dynamic similarities between the pattern and the real world (MORGAN, 1986). Some models, applicable to a particular area, may not be directly applicable to other areas as they were designed for specific applications. Among the empirical models are: USLE, the Universal Soil Loss Equation (WISCHMEIER and SMITH, 1978), allows assessing soil loss from agricultural fields in specific conditions. It has been adapted to other conditions through modified versions such as RUSLE (RENARD et al., 1991) for sediment yield estimation. SLEMSA, the Soil Loss Estimation Equation for Southern Africa (STOCKING, 1981) was developed in Zimbabwe on the basis of the USLE model. Among the physical models are: The WEPP, Water Erosion Prediction Project (NEARING et al., 1989) is a process based erosion model, designed to replace the Universal Soil Loss Equation CREAMS, Chemicals, Runoff and Erosion from Agricultural Management Systems (KNISEL, 1980), is a field scale model, developed in the USA to assessment the diffuse contamination and the environmental consequence from different agricultural management systems. EUROSEM, European Soil Erosion Model, a single event process-based model for predicting soil erosion by water from fields and small basins. The model is based on a physical description of the erosion processes and operates for short time periods, over a period of 1 minute. EUROSEM (MORGAN et al., 1994) is a polygon-, event-based runoff and erosion model developed for the assessment of soil erosion risk and the evaluation of soil protection measures.

5.3 Research Methodology

The used methodology combines both the field and laboratory work and data analysis. The fieldwork has been centered in: a) dug of profiles and obtaining of soil samples data. Likewise, measurement of slope degree, aspect, altitude, presence of fragments degree, type vegetation cover and degree; b) measurement of slope length and slope degree for the obtaining of the USLE factor LS; c) infiltration rate measurement in different soil and under different soil uses d) bulk density measurement in the same infiltration points.

The laboratory work consisted on the physical-chemical analysis of the samples obtained at field and the soil type determination (according to *US-Soil Taxonomy*). In all the cases, the texture, structures and organic matter content was determined, together with the pH, total nitrogen, assimilable phosphor, iron and aluminium, cations and exchange aluminium and the capacity of exchange effective cation (CEC).
Once the fieldwork and the pertinent laboratory analyses were performed, the information was ordered, coded and introduced in a Geographical Information System (GIS), together with information from satellite imagery. Furthermore, a digital elevations model (DEM) of the study area was elaborated from digitised topographical maps scale 1:10.000 and 1:20.000.

5.4 Soils of the Study Area

The predominant soils of the study area are: Ultisols, Alfisols, Oxisols and Entisols (in slope areas), following by Inceptisols and Mollisols (according to *U. S Soil Taxonomy*). The first three order, which occupy more than 50% of the study area, are characterized by low fertility, high acidity, and deficient in phosphorus, potassium, calcium and magnesium. The organic matter content and soil CEC are generally low, and the aluminium and manganese contents are often so high that they are toxic to plants. The main physical constraints are the low available water holding capacity, and the susceptibility of these soils to erosion. Such soils should be considered marginal for growing food crops (non permanent crops) under traditional agricultural systems, but are still suitable for tree crops (forest plantations, fruit, etc.) perennial crops and silvipasture (tree corps-pasture systems).

5.4.1 Soils Data Collection and Profile Description

Eleven soil profiles in order to collect information for most representative soils were dug (Fig. 5-4). A soil profile description form reduced version of *Field Book for Describing and Sampling Soils-USDA* was used to annotate profile and site relevant data gathered by simple field estimation and observation: Colour, structure, texture, boundary, porosity and root density; WGS 84 location, elevation, slope and aspect, geomorphic landscape/landform, vegetation and land use for site description were taken into ac-

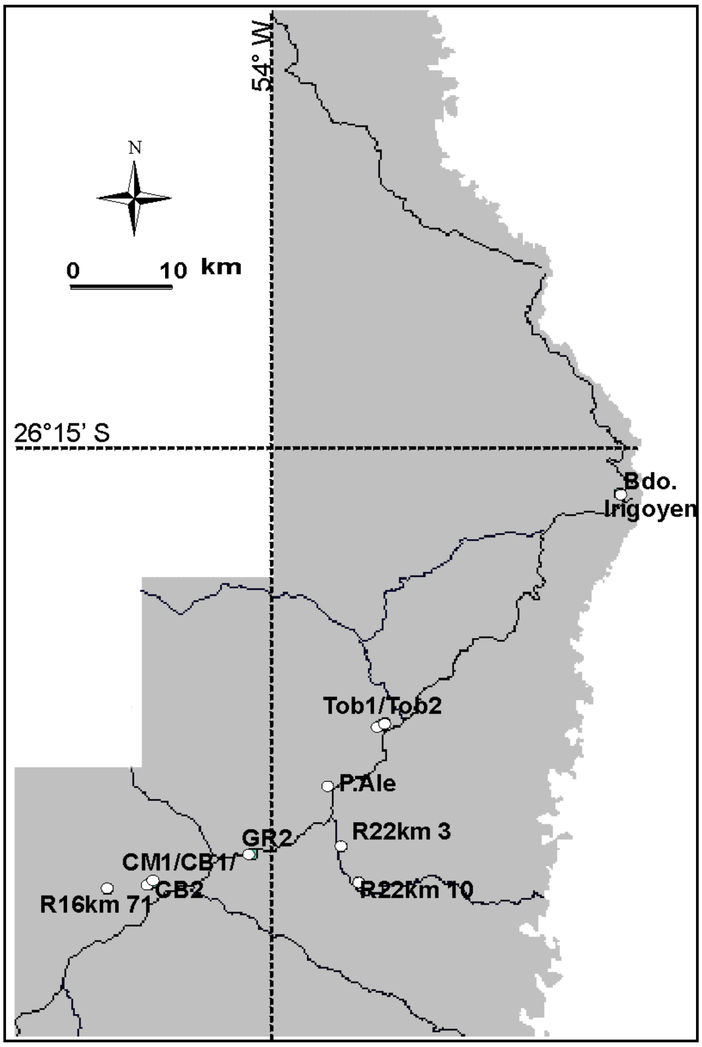


Fig. 5-4: Location of the dug soil profiles.

count. Profiles were recorded photographically.

A total of 41 soil composite samples of all horizons profiles after their description and recording were taken. The samples were prepared for shipping to the Centro de Pesquisa Agropecuaria e Extensao Rural Lab Soil of Santa Catarina, Brazil. Table 2 summarize the laboratory results of each one samples of the eleven soil profiles. Results were combined to classify soils after the "Key to Soils Taxonomy" (USDA, 1998). Pictures, legend of soil profile and soil profiles description are shown in figure 5-5 to 5-16.

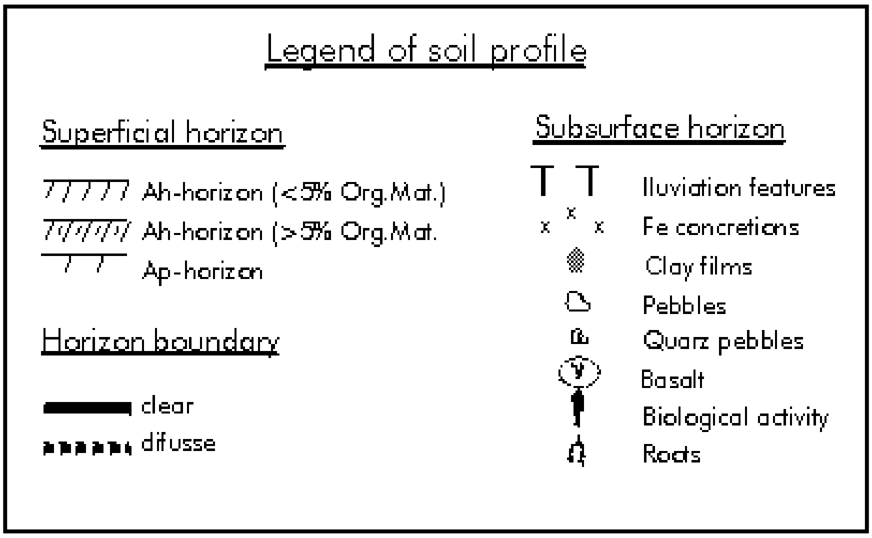


Fig. 5-5: Legend of soil profile.

Table 5-3: Description data profiles

Sample	Horiz. Profile	Depht	Textura			Textural Class	pH H2O 1:1	M.O	C.O	P	Exchangeable Cations				ECEC	S	Bas.Sat.
			Sand	Silt	Clay						K	Al	Ca+Mg	H+Al			
		cm	%					%	%	meq/100 g							%
CM1	**Ap**	0-10	N/D	N/D	N/D	clay	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
CM1	**B1**	10.-35	5,50	16,50	77,90	clay	4,6	2,0	1,1	0,0594	0,0468	2,2	1,90	3,90	4,15	1,95	46,95
CM1	**B1ox**	35-110	7,40	16,40	76,20	clay	4,2	1,5	0,9	0,0542	0,0286	2,3	0,40	4,50	2,73	0,43	15,71
CM1	**B2ox**	110-+	5,60	15,30	79,10	clay	4,6	1,0	0,6	0,0594	0,0286	2,7	0,60	4,10	3,33	0,63	18,88
CB1	**A**	0-10	7,50	23,20	69,30	clay	4,3	4,2	2,4	0,0555	0,5044	2,0	1,60	3,70	4,10	2,10	51,27
CB1	**B2ox**	10.-.80	7,00	18,10	74,90	clay	4,5	2,6	1,5	0,0581	0,1404	3,3	1,20	5,40	4,64	1,34	28,89
CB1	**B3ox**	80-120	6,30	18,20	75,50	clay	5,1	0,6	0,3	0,0659	0,0338	1,3	0,90	3,50	2,23	0,93	41,80
CB1	**IA**	120-+	32,30	31,90	35,80	clay loam	5,3	0,4	0,2	0,0684	0,0286	1,4	1,10	3,20	2,53	1,13	44,63
CB2	**A**	0-25	28,40	41,70	29,90	clay loam	5,5	3,2	1,8	0,0710	0,5200	0,0	5,20	N/D	N/D	5,72	N/D
CB2	**AC**	25-50	39,30	28,70	32,00	clay loam	5,7	1,3	0,7	0,0736	0,1404	0,3	3,60	N/D	N/D	3,74	N/D
CB2	**C**	50-+	15,00	18,80	66,20	clay	5,7	0,9	0,5	0,0736	0,0650	0,6	2,40	N/D	N/D	2,47	N/D
R22 Km3	**A**	0-25	19,00	30,10	50,90	clay	4,3	2,5	1,4	0,0555	0,1794	2,9	2,50	4,90	7,58	2,68	35,35
R22 Km3	**B2t**	25-110	10,40	21,10	68,50	clay	4,9	1,5	0,9	0,0633	0,0650	2,3	2,70	3,90	6,66	2,77	41,52
R22 Km3	**B3**	110-180	22,40	26,60	51,00	clay	5,0	1,5	0,9	0,0646	0,0572	2,6	2,30	3,50	5,86	2,36	40,23
TOB1	**A1**	0-35	15,60	35,00	49,60	clay	4,8	3,2	1,8	0,0620	0,4160	0,0	6,60	3,20	10,21	7,02	68,72
TOB1	**Bw**	35-80	8,40	22,40	69,20	clay	4,9	1,8	1,0	0,0633	0,1560	1,3	3,80	2,90	6,85	3,96	57,75
TOB1	**Cr**	80-140	13,90	30,50	55,70	clay	5,1	1,2	0,7	0,0659	0,0624	2,7	3,00	3,10	6,16	3,06	49,71

Table 5-3: Description data profiles (continuation)

Sample	Horiz. Profile	Depht	Textura			Textural Class	pH H2O 1:1	M.O	C.O	P	Exchangeable Cations				ECEC	S	Bas.Sat.
			Sand	Silt	Clay						K	Al	Ca+Mg	H+Al			
		cm	%					%	%	meq/100 g							%
TOB2	**A1**	0-20	13,00	40,00	46,90	silty clay	5,0	2,3	1,3	0,0646	0,3172	0,2	4,80	2,80	7,91	5,12	64,69
TOB2	**B2t**	20-110	8,70	27,10	64,30	clay	5,1	1,5	0,9	0,0659	0,0754	1,1	4,70	3,00	7,77	4,78	61,46
TOB2	**B3**	110-+	10,10	37,00	52,80	clay	5,1	1,2	0,7	0,0659	0,0754	0,5	5,90	2,50	8,47	5,98	70,55
R14 P.Ale	**A1**	0-20	16,70	41,30	42,00	silty clay	5,0	1,9	1,1	0,0646	0,1144	0,2	5,70	2,50	8,31	5,81	69,97
R14 P.Ale	**Bt**	20-110	22,20	24,10	53,70	clay	5,2	1,4	0,8	0,0672	0,0754	2,4	9,10	4,60	13,77	9,18	66,63
R14 P.Ale	**Cr**	110-+	58,80	26,40	14,90	clay	5,0	0,8	0,5	0,0646	0,0650	5,7	10,00	8,90	18,96	10,07	53,09
R22 Km10	**A1**	0-25	30,70	34,40	34,80	clay loam	5,1	0,9	0,5	0,0659	0,2158	0,3	9,50	2,50	12,21	9,72	79,57
R22 Km10	**Bw**	25-130	16,50	35,60	47,90	clay	5,1	0,9	0,5	0,0659	0,0624	0,3	8,80	1,80	10,66	8,86	83,14
R22 Km10	**C**	130-+	18,20	32,80	49,00	clay	5,5	1,7	1,0	0,0710	0,1690	0,0	7,10	1,40	8,67	7,27	83,84
GR2	**Ap**	0-15	2,10	26,80	71,10	clay	3,9	2,9	1,7	0,0504	0,0936	3,2	2,60	7,20	9,89	2,69	27,24
GR2	**B2ox**	15-110	1,30	18,10	80,60	clay	4,6	1,8	1,0	0,0594	0,0468	2,8	2,90	4,80	7,75	2,95	38,02
GR2	**B3ox**	110-+	1,10	12,10	86,80	clay	4,7	1,6	0,9	0,0607	0,0468	2,2	2,70	4,00	6,75	2,75	40,69
BIrigoyen	**A1.1**	0-6cm	60,63	23,45	15,92	sandy loam	5,3	6,9	4,0	N/D	1,2600	N/D	8,30	16,83	26,25	9,56	36,85
BIrigoyen	**A1.2**	6-30 cm	41,95	32,98	25,07	loam	5,2	3,8	2,2	N/D	0,4200	N/D	4,25	16,33	21,39	4,67	23,66
BIrigoyen	**B**	30-60	28,38	25,37	46,25	clay	5,1	2,7	1,5	N/D	0,4100	N/D	3,50	16,83	19,98	3,91	19,98
BIrigoyen	**BC**	60-80	31,58	20,05	48,37	clay	5,0	2,7	1,5	N/D	0,3200	N/D	3,75	18,81	23,30	4,07	19,28
BIrigoyen	**C (o Cr)**	80-105	50,83	12,80	36,37	sandy loam	5,6	1,0	0,6	N/D	0,5100	N/D	3,80	19,80	24,32	4,31	18,59
R.16 Km71	**A1.1**	0-15	70,75	16,55	12,70	sandy loam	6,7	4,3	2,5	N/D	1,7100	N/D	36,00	11,55	49,90	37,71	76,86
R.16 Km71	**A1.2**	15-50	51,10	29,38	19,52	sandy clay loam	6,9	4,0	2,3	N/D	0,7000	N/D	26,25	2,31	29,73	26,95	92,24
R.16 Km71	**A/C**	50-80	54,58	22,50	22,92	sandy clay loam	6,9	1,1	0,7	N/D	0,9300	N/D	26,70	6,93	35,20	27,63	80,32
R.16 Km71	**C**	80-160	59,20	30,15	10,65	sandy loam	6,5	0,5	0,3	N/D	0,5600	N/D	20,80	9,40	31,50	21,36	70,16

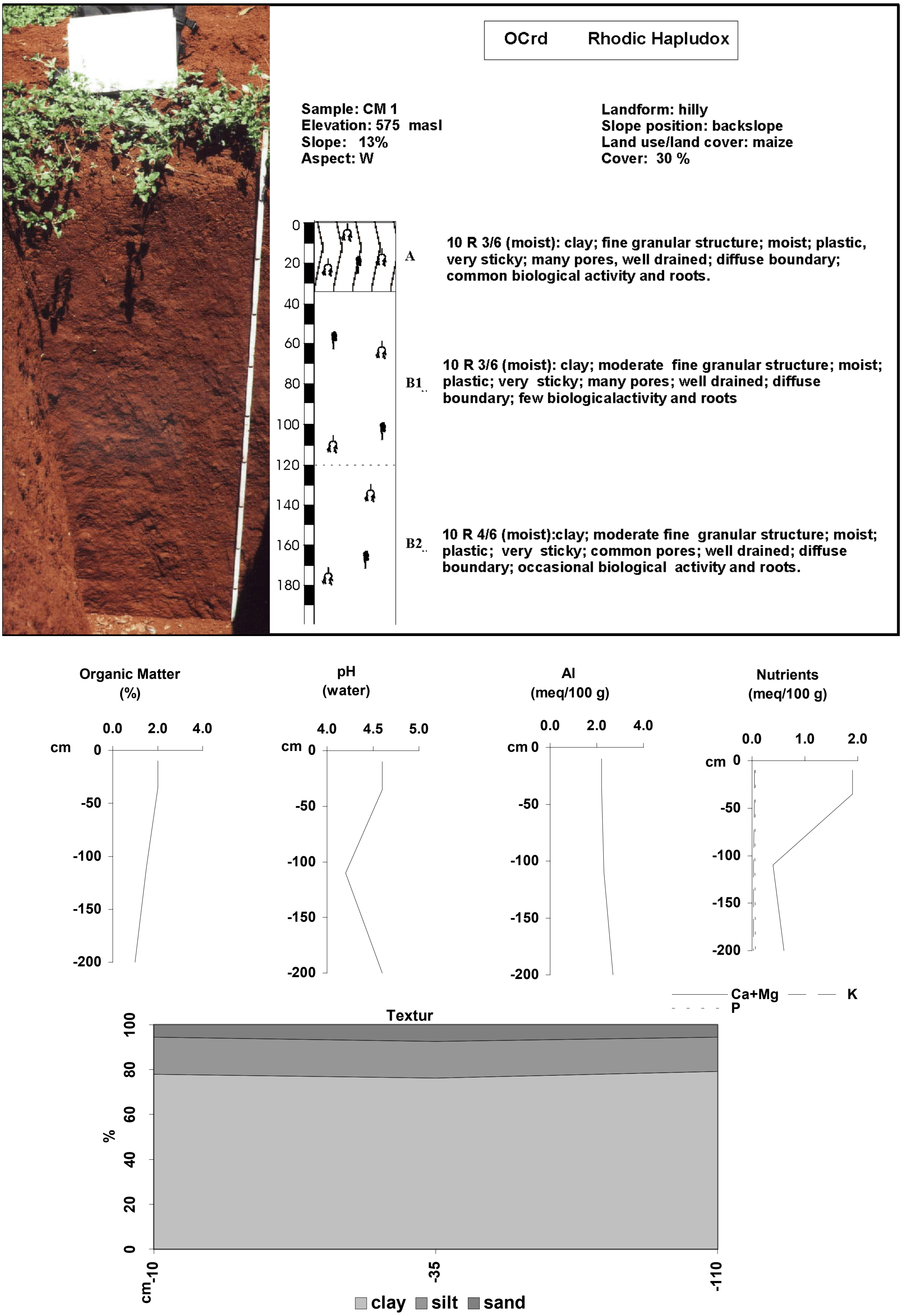
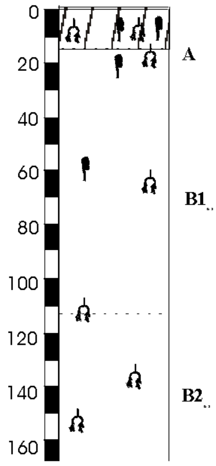


Fig. 5-6: Profile CM1 (San Pedro)

OCrd Rhodic Hapludox

Sample: GR 2
Elevation: 570 masl
Slope: 13%
Aspect: S

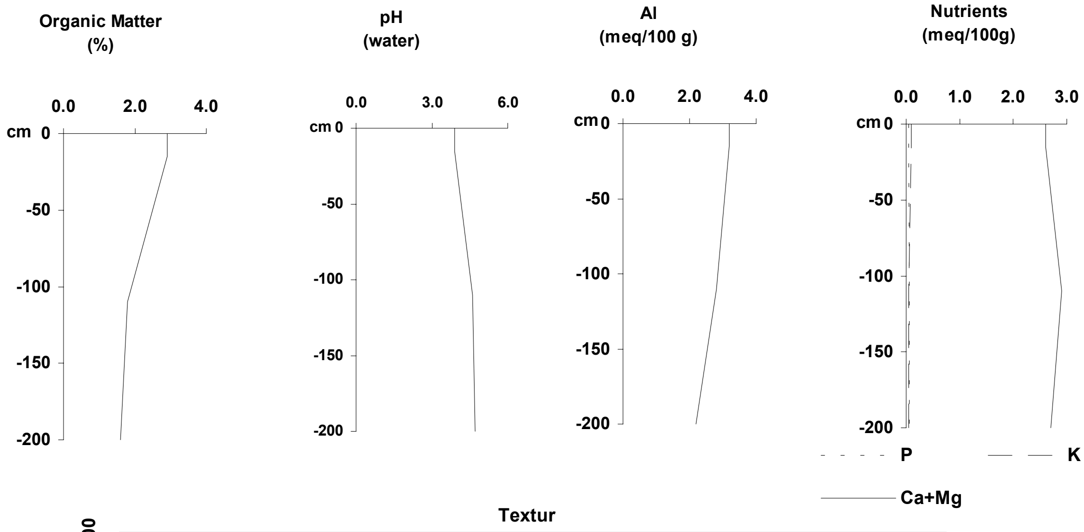
Landform: hilly
Slope position: backslope
Land use/land cover: yerba mate
Cover: 80 %



10 R 4/6 (moist): clay; fine granular structure; moist; plastic, very sticky; many pores,well drained; diffuse boundary; medium biological activity and common roots.

10 R 4/6 (moist):clay; moderate granular structure; moist; plastic, very sticky; many pores; well drained; diffuse boundary; low biological activity and few roots.

10 R 4/6 (moist): clay; moderate granular structure; moist; plastic, very sticky; common pores; well drained; diffuse oundary; few roots.



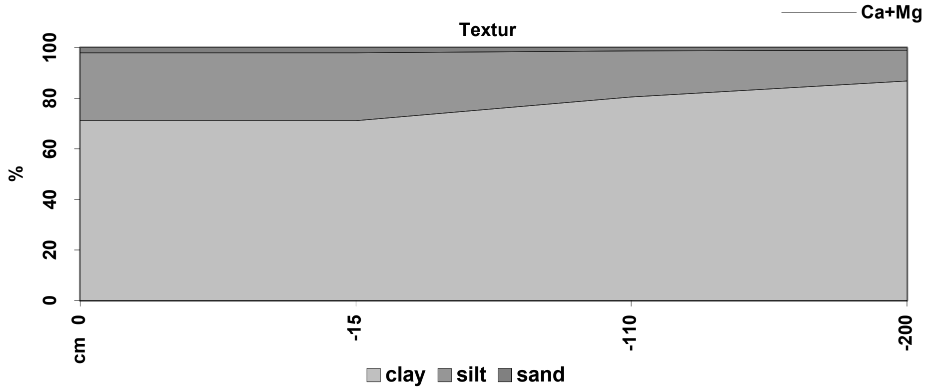
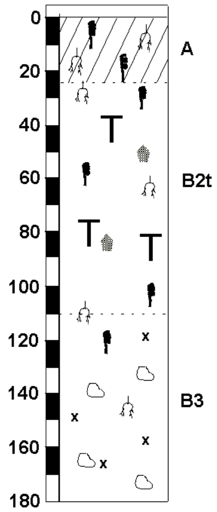


Fig. 5-7: Profile GR2 (Gramado, San Pedro)

ALrd Rhodic Kandiudalfs (moderatly deep)

Sample: R22 Km3
Elevation: 585 masl
Slope: 19%
Aspect: W

Landform: hilly
Slope position: backslope
Land use/land cover: degraded forest
Cover: 100%



O1/O2:0-2 cm.: Litter to partially descomposed litter

A: 2.5 Y/R 2.5/4 (moist): silty clay; fine granular structure; moist; plastic; sticky; many pores; well drained; diffuse boundary; high biological activity and many roots.

B2t: 2.5 YR 3.5/4 (moist):clay; moderate granular structure; few faint clay films; moist, plastic; sticky; many pores; well drained; gradual boundary; medium biological activity and common roots.

B3: 2.5 YR 3.5/4 (moist): clay, moderate granular structure; moist, plastic, sticky; common pores, well drained; scarse basalt fragments and Fe coated concretions; clear broken bondary; low biological activity and few roots.

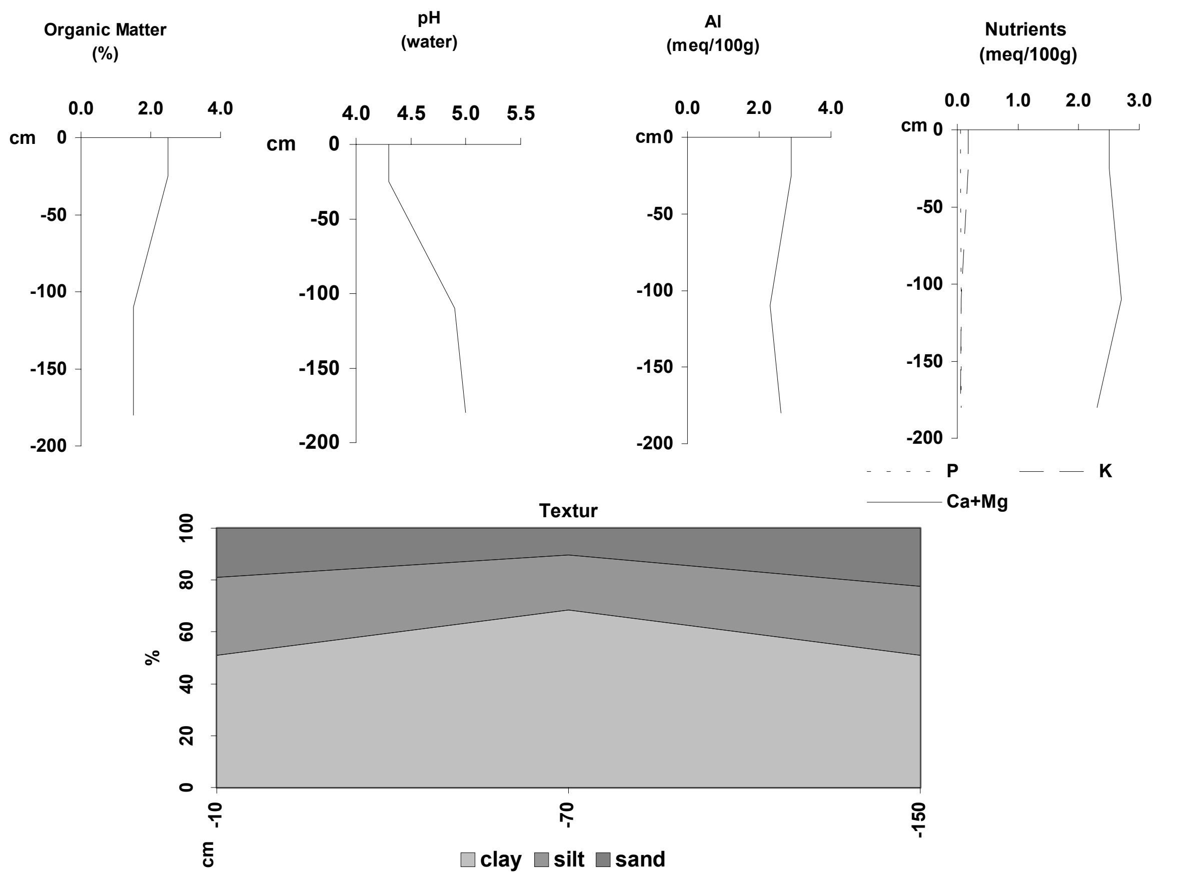


Fig. 5-8: Profile R22 Km 3 (Cruce Caballero, San Pedro)

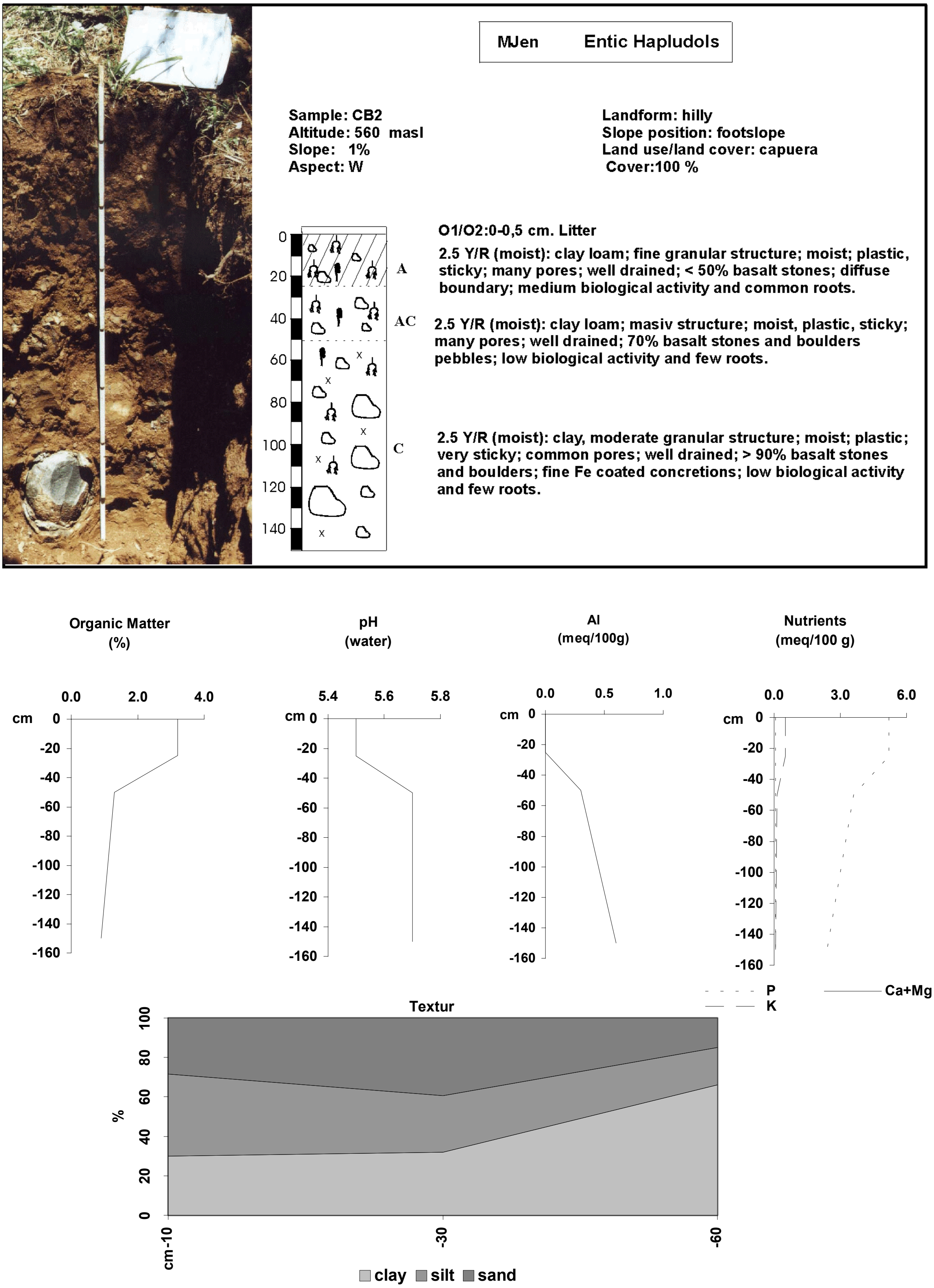


Fig. 5-9: Profile CB2 (San Pedro)

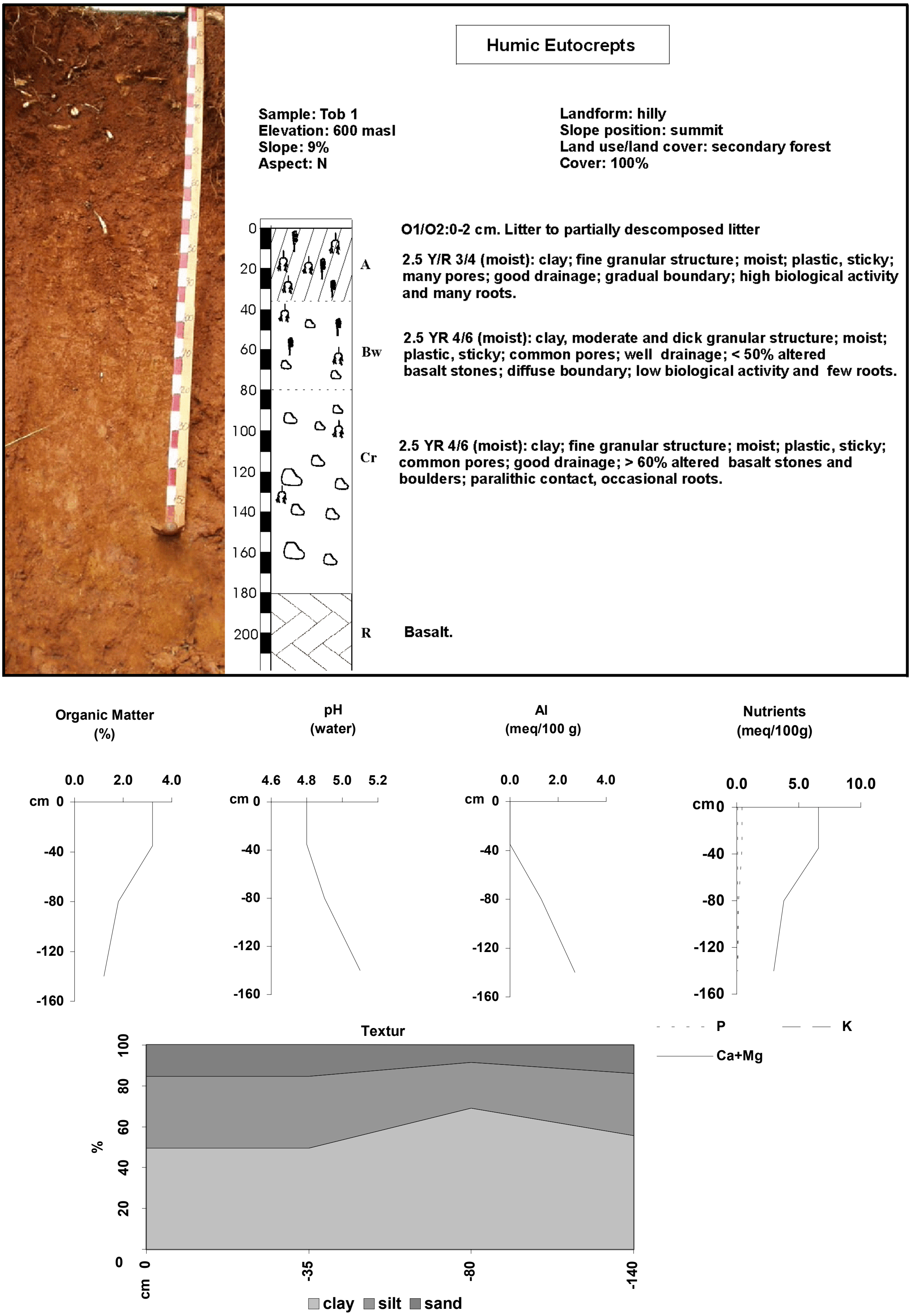


Fig. 5-11: Profile Tob.1 (Tobuna, San Pedro)

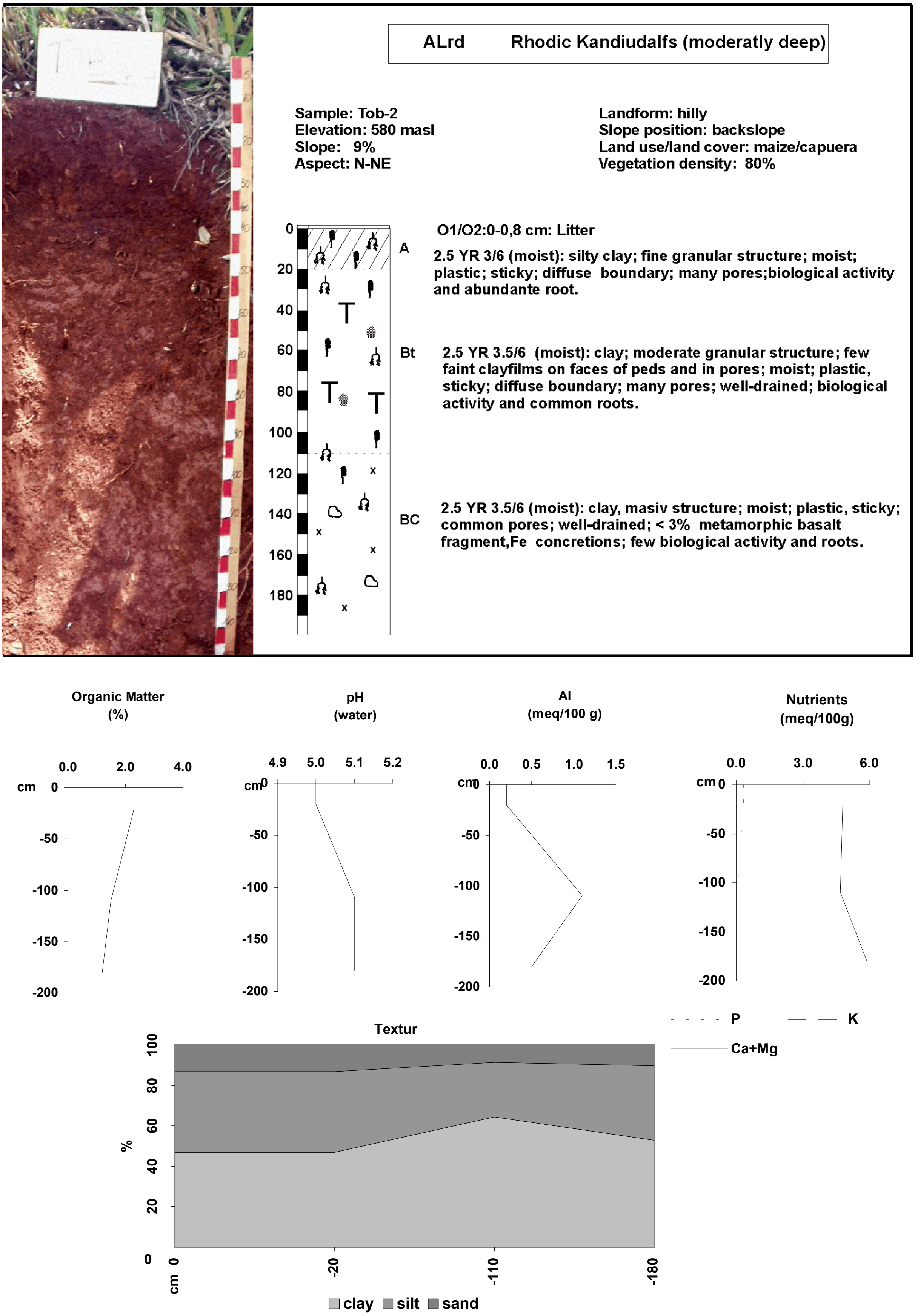
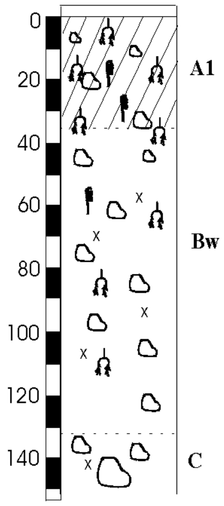


Fig. 5-11: Profile Tob. 2 (Tobuna, San Pedro)

AQ5 Typic Eutrudepts

Sample: R22 Km 10
Altitude: 505 masl
Slope: 25%
Aspect: N

Landform: hilly
Slope position: backslope
Land use/land: forest
Cover:100 %

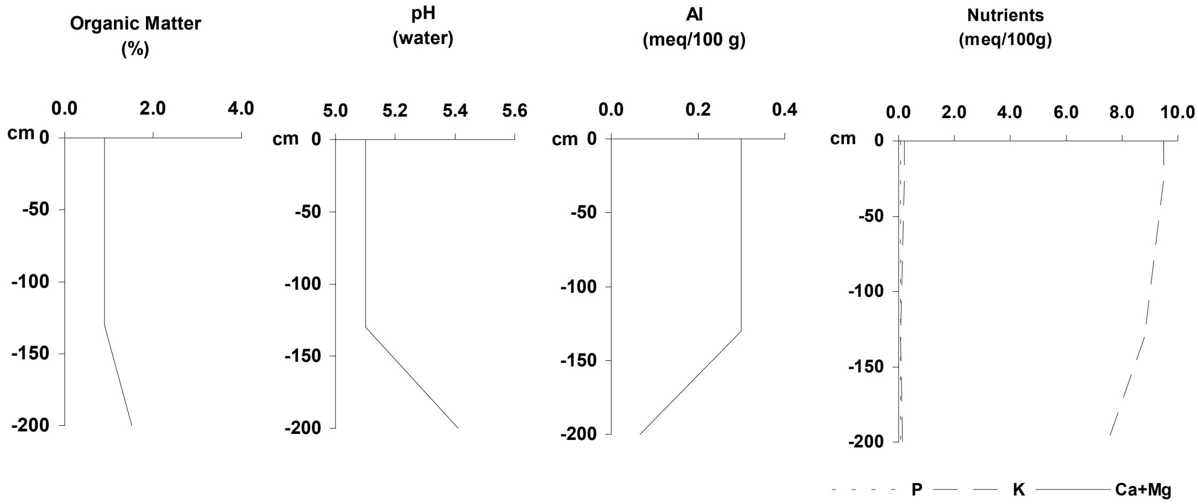


O1/O2:0-2.0 cm. Litter

2.5 Y/R 3/6 (moist): clay loam; fine granular structure; moist; plastic, sticky; many pores; well drained; < 10% basalt stones; diffuse boundary; high biological activity and many roots.

2.5 Y/R 3.5/6 (moist): clay,medium granular structure; moist, plastic, very sticky; many pores; well drained; 30-50% basalt stones and boulders; low biological activity and few roots.

2.5 Y/R 3.5/6 (moist): clay, moderate granular structure; moist; plastic; very sticky; common pores; well drained; 60% basalt stones and boulders; fine Fe coated concretions..



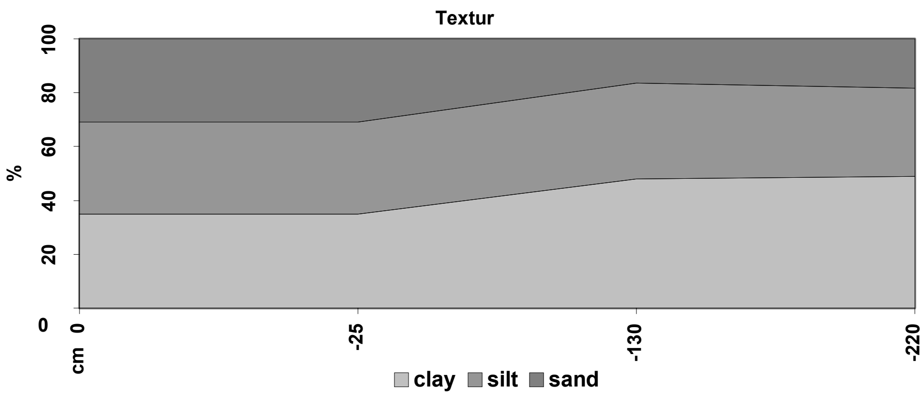


Fig. 5-12: Profile R22 Km 10 (Cruce Caballero, San Pedro)

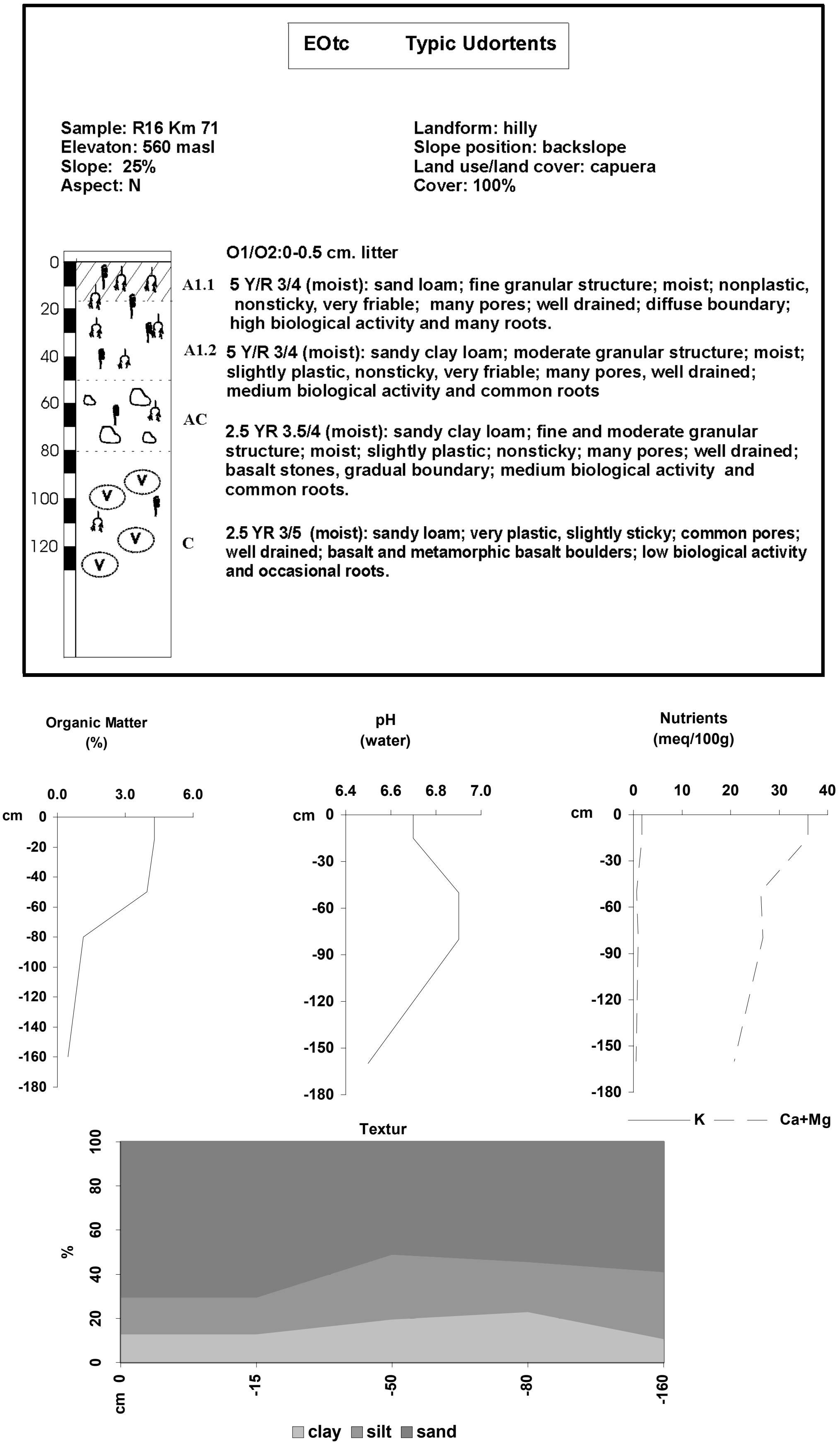
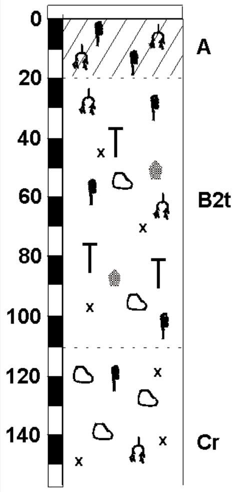


Fig. 5-13: Profile R17 Km 71 (San Pedro)

ALrd Rhodic Kandiudalfs (moderatly deep)

Sample: R14 P.Ale
Elevation: 690 masl
slope: 18%
Aspect: N

Landform: hilly
Slope position: backslope
Land use/land cover: capuera
Cover: 100%

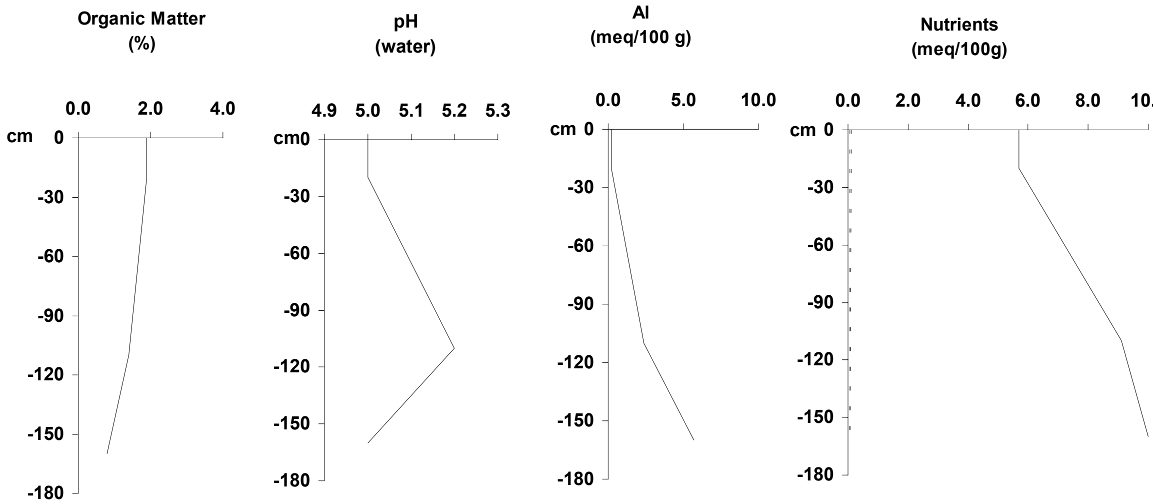


O1/O2:0-0.2 cm. Litter

A 2.5 Y/R 3/6 (moist): silty clay; fine granular structure; moist; plstic; sticky; many pores, well drained; diffuse boundary; medium biological activity and many roots.

B2t 2.5 YR 4/6 (moist): clay; moderate granular structure; moist, plastic, sticky; common pores, well drained; scarse faint clay films; scarse Fe concretions and basalt cobles; low biological activity and common roots.

Cr 2.5 YR 4/6 (moist):sandy loam; fine granular structure; moist; slightly plastic, nonsticky; common pores, common drainage; scarse basalt stones and Fe coated concretions; gradual boundary, low biological activity and few roots.



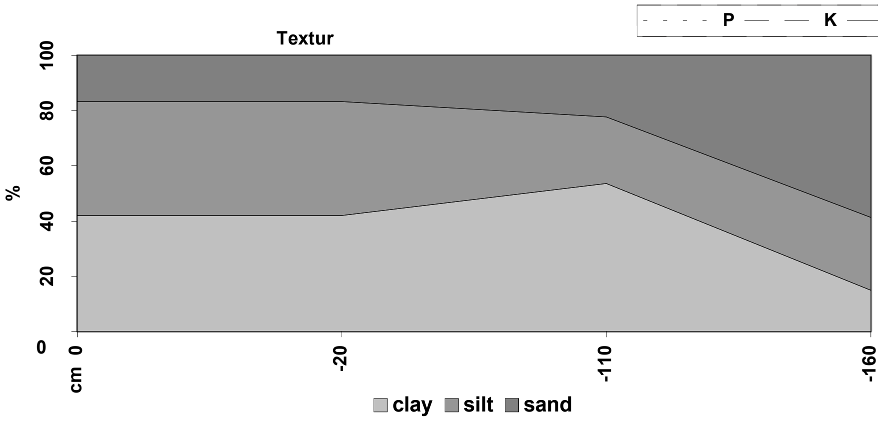
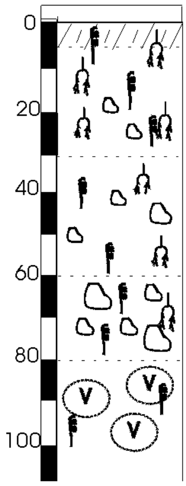


Fig. 5-14: Profile R14 P. Ale (Paraje Alegria, San Pedro)

IQdi Distric Eutocrepts

Sample: Bdo. de Irigoyen
Elevation: 760 masl
Slope: 5%
Aspect: SW

Landform: hilly
Slope position: footslope
Land use/land cover: degraded forest
Cover: 100%



O1/O2:0-0.7 cm. litter

A1.1 5 Y/R 4/3 (moist):loam; fine granular structure; moist; slightly plastic, nonsticky, very friable; smooth boundary; common pores, well drained; high biological activity and many roots

A1.2 5 Y/R 4/3 (moist): loam, moderate granular structure; moist; slightly plastic, nonsticky; gradual boundary; <5% altered basalt stones; common pores, many fine roots;

B 5 YR 4/6 (moist): clay, moderate to dick granular structure; moist; slightly plastic, nonsticky; gradual boundary; < 5% alered basalt stones; common pores; common fine roots.

BC 5 YR 4/6 (moist):clay, moderate and dick granular structure; moist; very plastic, sticky; 60% altered basalt stones; few pores; few roots.

C 90% altered basalt boulders, paralithic contact. scarse pores, slow drainage; few roots.

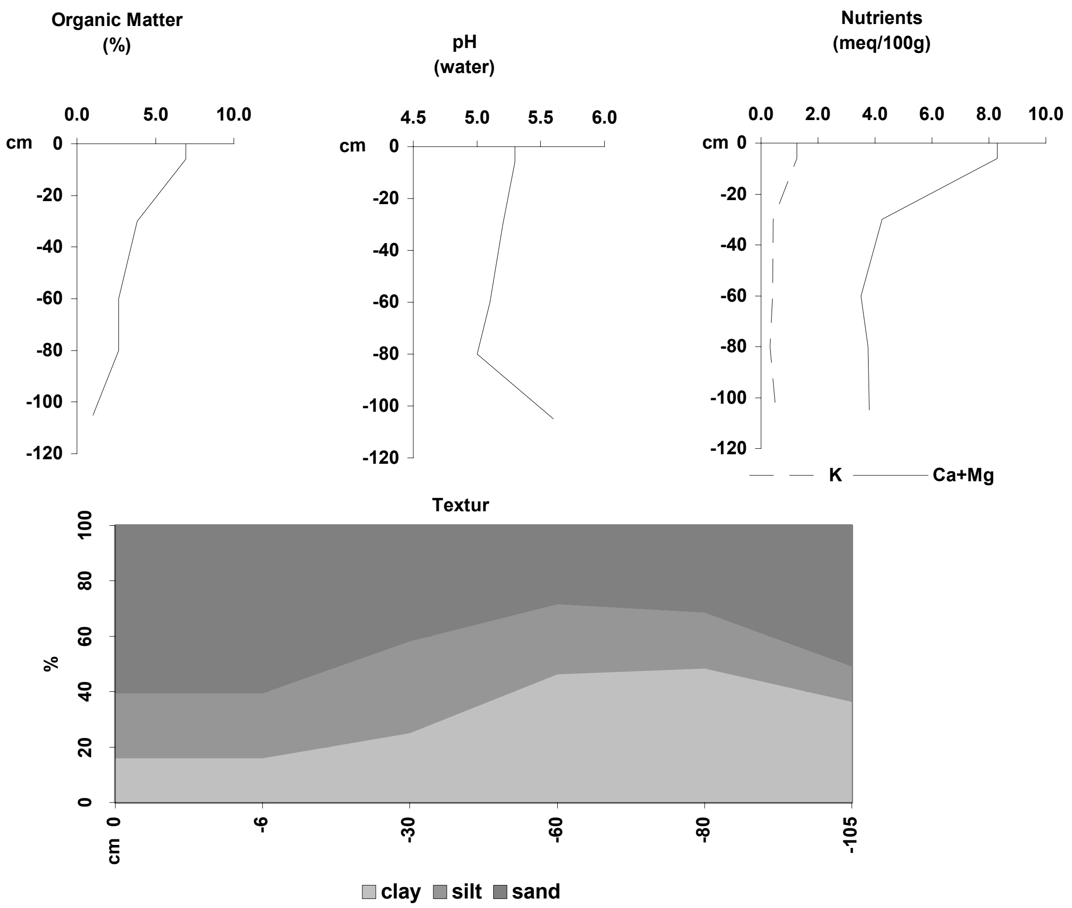
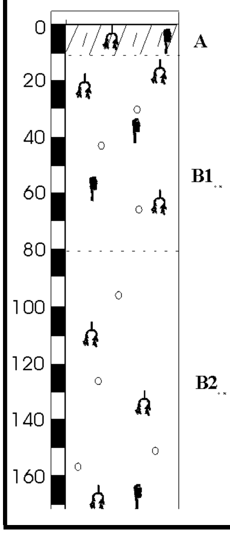


Fig. 5-15: Profile Bdo. Irigoyen (Bdo. de Irigoyen)

OCrd Rhodic Hapludox

Sample: CB 1
Elevation: 585 masl
Slope: 9%
Aspect: W

Landform: hilly
Slope position:backslope
Land use/land cover: degraded forest
Cover: 100 %

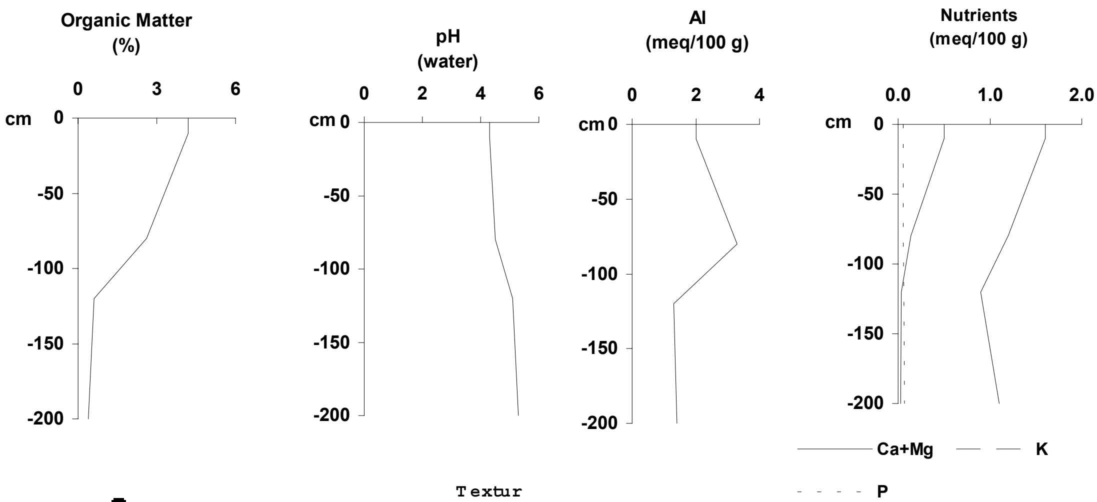


O1/O2:0-0.1 cm. Partially descomposed litter

A 10 R 3/6 (moist):clay, fine granular structure; moist; plastic, very sticky; many pores; well drained; diffuse boundary; medium biological activity and common roots.

B1 10 R 4/6 (moist):clay; moderate granular structure;moist; plastic, very sticky; many pores, well drained; small quarz pebbles; diffuse boundary; medium biological activity and common roots.

B2 10 R 4/6 (moist):clay; moderate granular structure; moist; plastic, very sticky; common pores;well drained; small quarz pebbels; diffuse boundary; low biological activity and few roots.



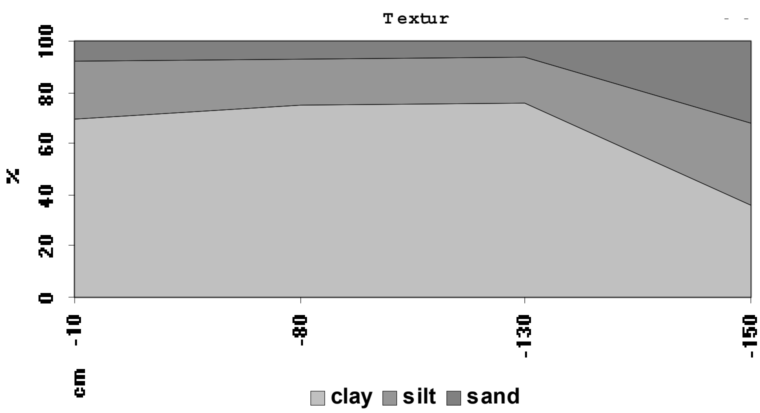


Fig. 5-16: Profile CB1 (San Pedro)

5.4.2 Infiltration Rate Determination

The theoretical analyses outlined above imply that the steady infiltration rate is a function of the pore configuration of the soil. Soils derived from basalt containing mainly clay mineral Kaolinite and little or none of the swelling clay mineral montmorillonite, are predominant in the study area. Consequently, the steady infiltration rate should remain stable over time unless the soil structure is altered by animal or machine traffic.
With the objective to evaluate the infiltration capacity of major soil under different land use series measurements were done.

Measurements were performed on six plots under the following land use/land cover: a) semideciduous dense rainforest; b) maize crop (10 years, without rotation and with conventional tillage (disk plow)); c) manioc crop (6 years, without rotation and with reduce tillage (chisel plough)); d) yerba mate crop (10 years scarce cover soil); e) pasture (10 years, four Livestock per hectare without suitable management practices, being the carrying capacity of natural pastures of 0.8 Livestock per hectare), and f) bare soil. The soil of these plots is classified as Rhodic Hapludox. Moreover, it measured the infiltration in other three sites after different heavy machinery use for land clearance in order to evaluate the effect of these in the infiltration process: a) machete and skidder; b) bulldozer and skidder; c) skidders (more than 10 passes). On the other hand, at test plots, undisturbed core samples (five repetitions) were taken at three different depths (0-5, 5-10, 10-15 cm) to determine the bulk density (r_b). In the bare soil a sample for r_b could not obtain due the extreme hardness of the soil. A sixth core sample was taken from the topsoil near the ring, before the beginning of the infiltration rate mensuration, to determine the initial moisture content. In both case a metallic cylinder of 53.76 cm^3 was used to obtain the samples. All soils samples were sieved through a 2-mm sieve, weighed and oven dried at 105°C for 24 hours. Bulk density was calculated by dividing the mass of soil by the volume of soil collected (Blake and Hartge, 1986). The classification, drainage and texture characteristics of both soil types are given in Table 5-4.

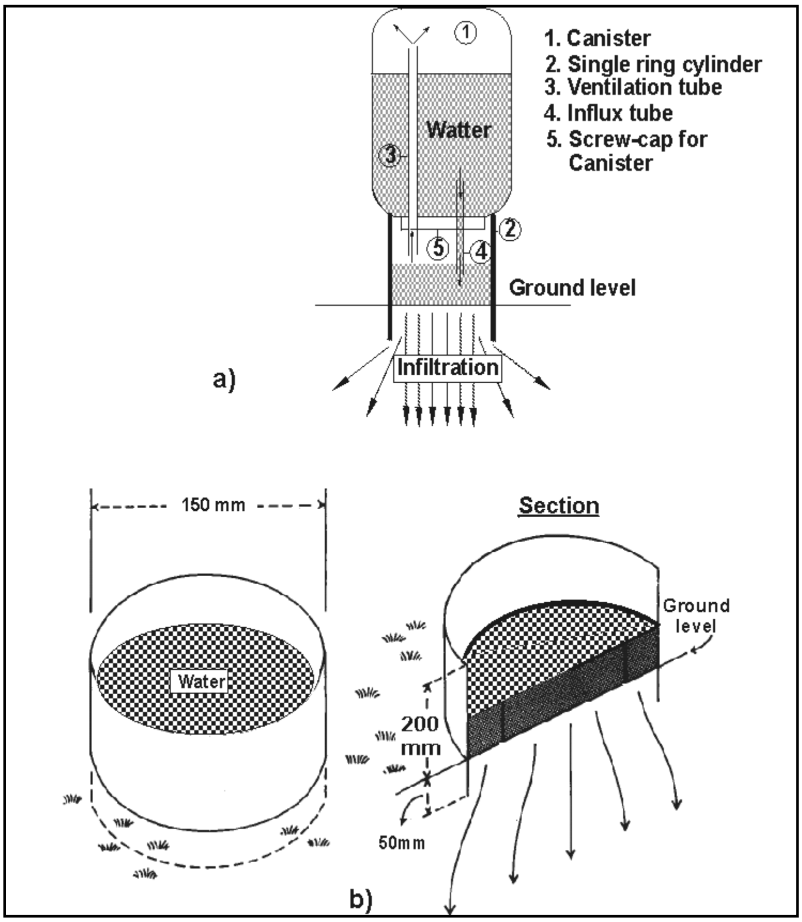


Fig. 5-17: Single ring infiltrometer (a and b).

Table 5-4: Classification, drainage and texture characteristics of plot sites.

Soil[1]	Drainage class[2]	Texture (horizon)		Structure (horizon)	
		A	B	A	B
Rhodic hapludox	Well	Clay	Clay	fine granular	moderate granular
Distric eutochrepts	Well	Sandy loam	Sandy clay loam	fine granular	moderate granular

[1] Definitions according to Soils Taxonomy, USDA 1998; [2] INTA, 1990.

For the infiltration, a single-ring infiltrometers, according HILLS (1970), were used. The diameter of the ring is 150 mm (145 mm inside ring) and 200 mm high (Fig.5-17). The ring was driven into the ground 50 mm depth. Grass was cut to near soil level. The edge was tamped to seal possible cracking. Generally, the water level was kept at or above 50 mm depth. The rate of fall of the water level in the cylinder was measured at 2, 4, 6, 8, 10, 12, 14, 16, 18, 20, and after that at 5-minute intervals until 60 minutes and at 10-minute intervals thereafter. Three repetitions of each measurement, with 3 m distance among infiltrometer were performed. The measurements were carried out at same slope degree. The choice of this method was determined by practical considerations and common use at the APT (Applied Physiogeography to the Tropics and Subtropics). The data were analysed through an analysis of variance (ANOVA).

5.5 Erosion Model USLE

The Universal Soil Loss Equation (USLE), developed by WISCHMEIER and SMITH (1978), has been widely accepted and utilized for over 30 years. The equation is used as a method to predict average annual soil loss caused by sheet and rill erosion resulting from overland flow (US DEPARTMENT of AGRICULTURE, 2002). Each of the major components of soil erosion by water, are considered by the USLE. The USLE has been found to give realistic estimates of soil erosion over small and large areas (WISCHMEIER and SMITH, 1978). The USLE was chosen for this particular research project because of its ability to accurately estimate soil erosion for both practical and theoretical situations and because of its simplicity. It is easy to understand and employ. Moreover, the user has the possibility to manipulate variables for prediction of different circumstances.

This erosion prediction equation is composed from five sub-equations:

$$A = R \cdot K \cdot L \cdot S \cdot C \cdot P$$

where:

- A = average annual soil loss in (t ha^{-1} yr^{-1})
- R = rainfall erosivity index (in MJ mm ha^{-1} h^{-1} yr^{-1})
- K = soil erodibility factor (in t h MJ^{-1} mm^{-1})
- LS = topographic factor – slope-length factor (dimensionless)
- C = cropping factor (dimensionless)
- P = conservation practice factor (dimensionless)

After selection the USLE as the erosion model for this study, data was collected from GIS data basis for each variable within the equation. Layers of the study area were created for each of these variables of the USLE. Using Idrisi GIS software, each layer was multiplied together by performing an overlay analysis to determine the rate of average annual soil loss. Figure 5-18 represents the steps that took in developing a GIS approach to model the risk of soil erosion for the study area.

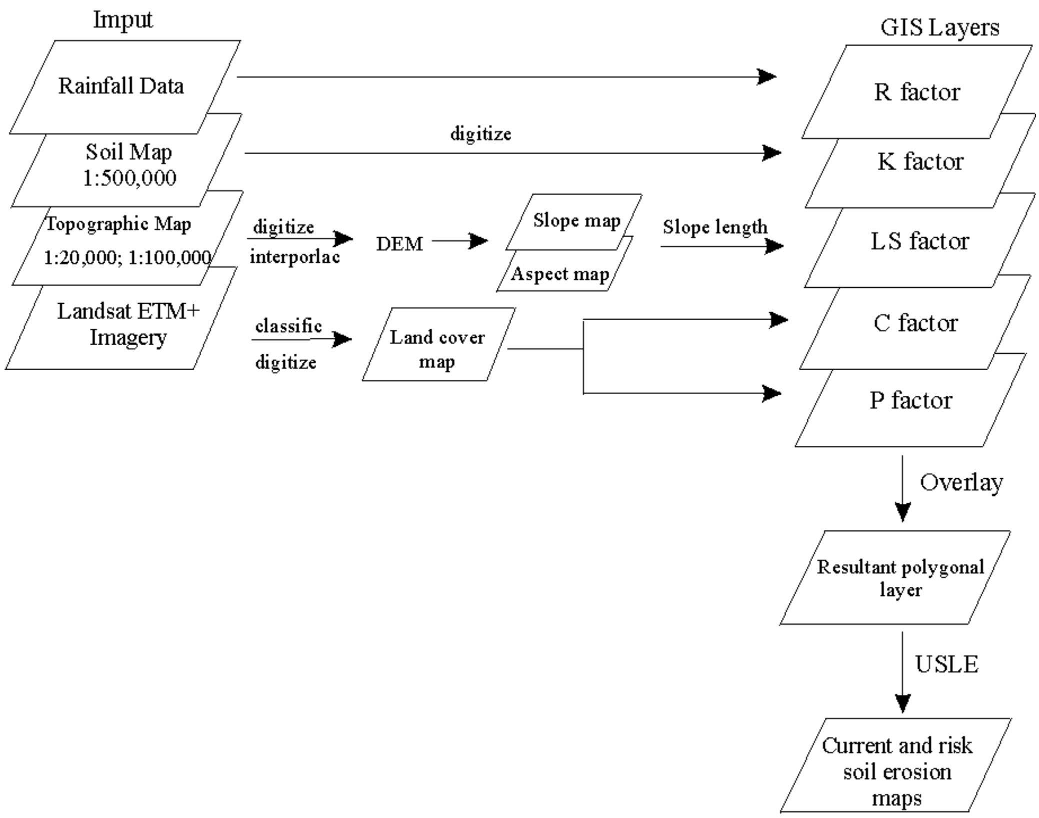


Fig. 5-18: Flowchart illustrating the followed steps to obtain the actual soil erosion and risk of soil erosion maps.

5.5.1 R-Factor

This is the rainfall erosivity index which is equal to the mean annual erosivity value divided by 100: R = $EI_{30}/100$. By definition, the value of EI for a given rainstorm equals the product: total storm energy (E) times the maximum 30-min intensity (I_{30}), where E is in tn m h^{-1} and cm of rain and I_{30} is in cm h^{-1}. By evaluating long-term rainfall figures in the USA, WISCHMEIER and SMITH (1978) concluded that the bulk of soil loss is not only caused by a few exceptional rain storms with high intensities, but also by the cumulative effect of many average rain falls which contribute equally to the average yearly soil loss. However, WISCHMEIER and SMITH (1978) only consider precipitations with at least 12.5 mm of rain. The same authors found that soil loss is directly proportional to the index EI_{30} (R factor), if all other factors are kept constant. This relationship is linear and the single precipitation values are additive. Therefore, the sum of EI_{30}-values over a certain period (e.g. one year) is a numeric measure of the erosive potential of the rainfall during this time interval.

The R-Factor varies with climate and geographic location. In the practice, it is very difficult to obtain the data that this expression requires to estimate the territorial distribution of the erosivity index. Due to this, efforts have been done to find out relationships between simple parameters such as the rainfall amount and the R-factor of the USLE. These relationships can be applied to data gathered from the region and give a more complete view to the region's erosivity (BERGSMA, 1996 in SONDER, 2002). With this purpose, FOURNIER (1960) established the index of climatic aggressiveness or Fournier Index that it shows a high correlation with the quantity of transported yields by runoff. Since detailed 30-min rain intensity data are not available for the study area, therefore the R-Factor was estimated using the Fournier index modified by ARNOLDUS (1978):

$$R = \sum_{1}^{12} p^2/P$$

p = average monthly rainfall amount in mm
P = average annual precipitation in mm

Arnoldus verified that this equation is correlated better than the Fournier index with the EI_{30} value in tropical areas of Africa. Other authors verified this fact in other parts of the world (BOLLINE *et al.*, 1980; SONDER, 2002). Although if the data of a short period of time are extrapolated, the results will be less precise (WISCHMEIER and SMITH, 1978), to verify the application of this equation in this work, the EI_{30} and R, according Fournier modified, for a 5-year rainfall data (1998-2002) of a station located near Montecarlo city - 65 km west of San Pedro, and to 200 masl- were calculated. For the calculation of the erosivity index rains above 12.5 mm were taken and it was considered as the only event the fallen rain in a period of 6 hours. For both estimates it was: EI_{30}=167 and R (Fournier)=159.

A long-term rainfall data from four meteorological stations (San Pedro, B. de Irigoyen, San Antonio and Cuartel Victoria) were analysed. 26 years of rainfall data, comprised the period from 1977 to 2001, were analysed for the San Pedro station, 15 years for the San Antonio and B. de Irigoyen station and 32 years for the Cuartel Victoria station (approx. 550 masl). Cuartel Victoria is located 55 km southwest from San Pedro, at the Guarani Department. Since when considering the monthly means rainfall values to obtain the R-valued the erosivity capacity of the heavy subtropical rain can be underestimated and when considering the maximum monthly rainfall, the same one can be overestimated, it was opted to consider both values (207.6 and 1300 respectively), obtaining two erosion risk maps. I suppose as more convenient to consider an overestimation of the erosion values in order to apply this model as a base for future planning of soil conservation and due to high occurrence of heavy rains in the region.

5.5.2 K-Factor

The erodibility of a soil, in contrast to the erosivity of the rain, is governed by its surface texture, its content of organic matter, its aggregation status (all of the topsoil), its bulk density of the topsoil and the subsoil, its acidity and its permeability. Of all these parameter, grain size distribution and organic matter (O.M) content were the most important factors determining the erodibility. For the erodibility of clay soils, besides de grain size distribution, the contents of free iron and aluminium oxides are the most important characteristic (ROTH *et al.*, 1974, cit. by WISCHMEIER and SMITH, 1978). In the USLE, erodibility is considered as factor K, a quantitative value that is determined experimentally. The K-Factor is a measure of the cohesive or bonding character of a soil type and its resistance to dislodging and transport due to raindrop impact and overland flow. It is the combined effect of processes that regulate rainfall infiltration and the resistance of soil to particle detachment and subsequent transport (HASLEY, 1980 in SIMPSON and TRACEY, 2003). Once these soil properties are known, the K-factor can either be calculated according to:

$$100 \times K = 2{,}1 \times M^{1{,}14} \times 10^{-4} \times (12 - O.M.) + 3{,}25\,(b-2) + 2{,}5\,(c-3) \qquad (1)$$

$$M = (\%\ \text{silt} + \%\ \text{very fine sand}) \times (100 - \%\ \text{clay})$$

or estimated using the nomograph shown in Fig. 5-19. This relation-ships are only valid for soils, in which silt and very fine sand (0.1 - 0.002 mm) make up less than 70% of the soil material. The true erodibility of a soil may, however, deviate from this determination due to specific soil properties favouring or hindering soil dispersion or aggregate breakdown. E.g. high content of exchangeable sodium, high content of iron oxides or some types of clay minerals (kaolinite) (BECHER, 2003).

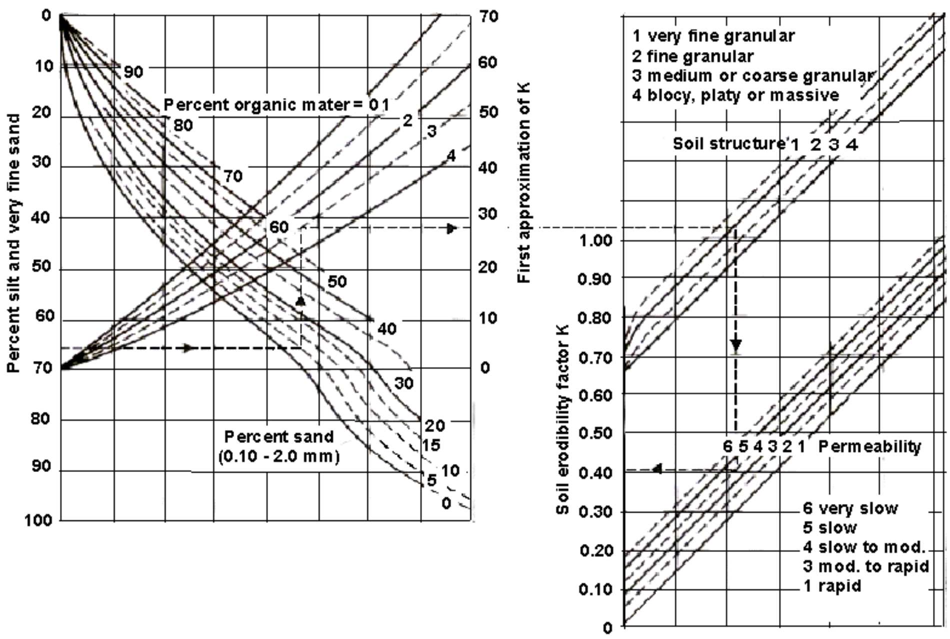


Fig. 5-19: Nomograph for estimating the K-factor (Wischmeier and Smith, 1978).

Table 5-5: Erodibility factor correction (Source: ISRIC, 1988).

Fragments (%)	Coefficient
0 -2	1
3 -14	0.85
15 - 49	0.48
50 - 89	0.18
> 90	0.05

The K values in this research were determined from field soil samples for each soil class and supplemented with those reports by LIGIER (1989), applying the equation 1.

The equation proposed by WISCHMEIER and SMITH (1978) it doesn't consider the presence of fragments. Since several soil types of the study area present fragments in the first centimetres of soil, a correction factor (table 5-5) was applied. The K values estimated for the main types soil are given in table 5-6.

Table 5-6: K-value estimated of main type soils of the study area

Sample	Ks	f x ks	Class	Soils type
CM1	0.06		Light	Rhodic Hapludox (Ocrd)
CB1	0.07		Light	Rhodic Hapludox (Ocrd)
CB2	0.24	0.11	Light	Entic Hapludolls (Mjen)
R22 Km3	0.15		Light	Rhodic Kandiudalfs, moderatly deep (Alrd)
Tob1	0.14	0.12	Light	Humic Eutrudepts
R14 P.Ale	0.22		Moderate	Rhodic Kandiudalfs, moderatly deep (Alrd)
R22 Km 10	0.32	0.32	Mod.high	Typic Eutrudepts
Tob2	0.17		Light	Rhodic Kandiudults (Utrd)
R14 Km50	0.06		Light	Rhodic Kanhapludults (Uvrd)
GR2	0.07		Light	Rhodic Hapludox (Ocrd)
B. de Irigoyen	0.31	0.26	Moderate	Distric Eutocrepts (Iqdi)
R.16 Km 71	0.24		Moderate	Typic Udorthents (Eotc)

For the obtaining of the K-layer the soil map of the study area was digitised. Through identifying the soil type and given K-Factor data, the K-layer was completed within the GIS. Due to the soil map is represented only by soil units, the corresponding K-value according to the dominance percentage of each soil type was pondered. The thematic layer (Fig. 5-20) illustrates the erodibility of the soils in the study area.

5.5.3 LS-Factor

The slope length (L) and slope steepness (S) are generally known as the topographic LS-Factor within the USLE. The effective slope length for erosion "L" corresponds to the distance between the point where runoff starts at the tops of the slope and the point where sedimentation begins further down the slope (ARBEITSGRUPPE BODENKUNDE, 1982). His research has shown that both increased slope length and steepness produce higher overland flow velocities and correspondingly higher erosion (VAN REMORTEL *et al.* , 2001; JAIN, 2001 in SIMPSON and TRACEY, 2003). Thus, both factors result in increased erosion potential. For convenience, L and S are frequently combined into a single term. In order to determine the LS-Factor the following equation developed by WISCHMEIER and SMITH, (1978) will be used.

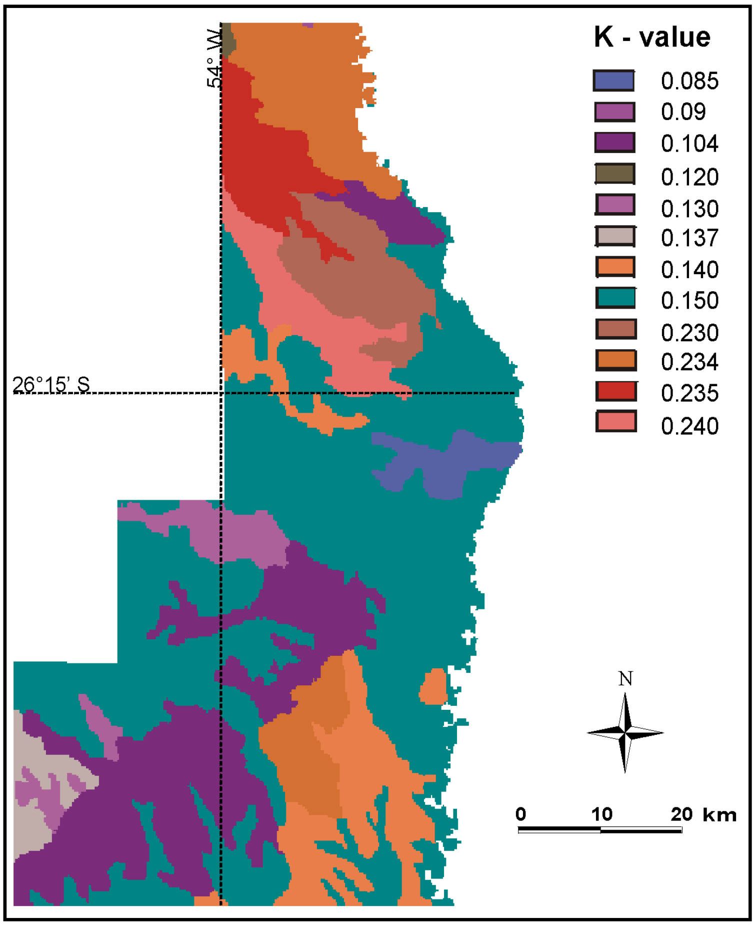


Fig. 5-20: K-factor layer.

$$LS = [0.065 + 0.04569\ s + 0.006541\ (s)^2]\ (x / 22.13\ m)^n \qquad (2)$$

Where: s = slope gradient (%), x = length of slope (m), and n= constant (Table 5-7)

Table 5-7: N-values (Source: WISCHMEIER and SMITH, 1978)

S	< 1	1 < Slope < 3	3 < Slope < 5	> 5
N	2	3	4	5

In order to derive LS-factor values, a 10 m digital elevation model (DEM) worked out from digitised topographic maps (scale 1:20.000 and 1:100.000), and subsequently used in the final calculations (Fig. 5-21). Slope steepness (%) was calculated from DEM for each pixel (Fig. 5-22). The slope length can be also calculate from DEM, but it is impossible know if the slope is continuous or not. Therefore, the slope length value was obtained from 500 measurements (slope degree and slope length) carried out during field campaigns (the slope degree each 30 m was measured). According to the histogram obtained from data of both parameters, 95% of the cases slope steepness greater than 10% didn't overcome 120 m, the mean value of slope was 80 m. For smaller slopes steepness up to 10%, the mean slope length value was 140 m. Since the value of the exponential constant "n" is discriminated according to slope degree, five different layers were generated considering slope steepness and slope length applying the equation (2). Finally, these five layers were overlaid obtaining the LS-factor as a result (Fig. 5-23).

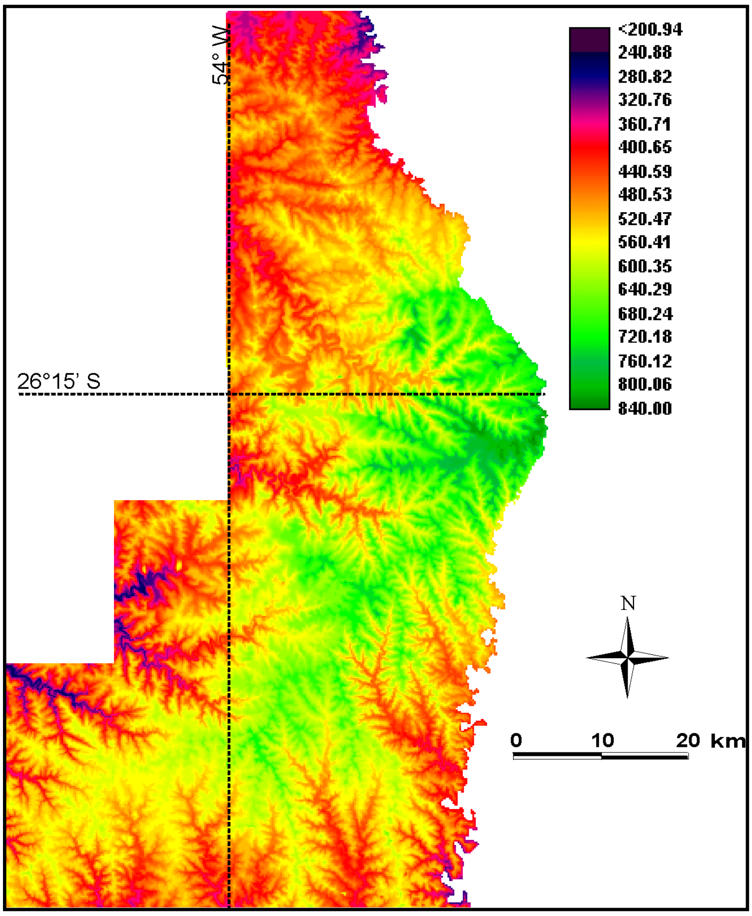


Fig. 5-21: 10 m DGM of the study area.

5.5.4 C-Factor

The complex relationships between ground cover and soil tillage, crop rotation, and type of crops, crops residues, and crop growth stage are considered in the USLE as the C-factor for soil cover and management. The problem of quantifying these relationships makes the C-factor as the most complicated factor of the USLE. C-factor represents the

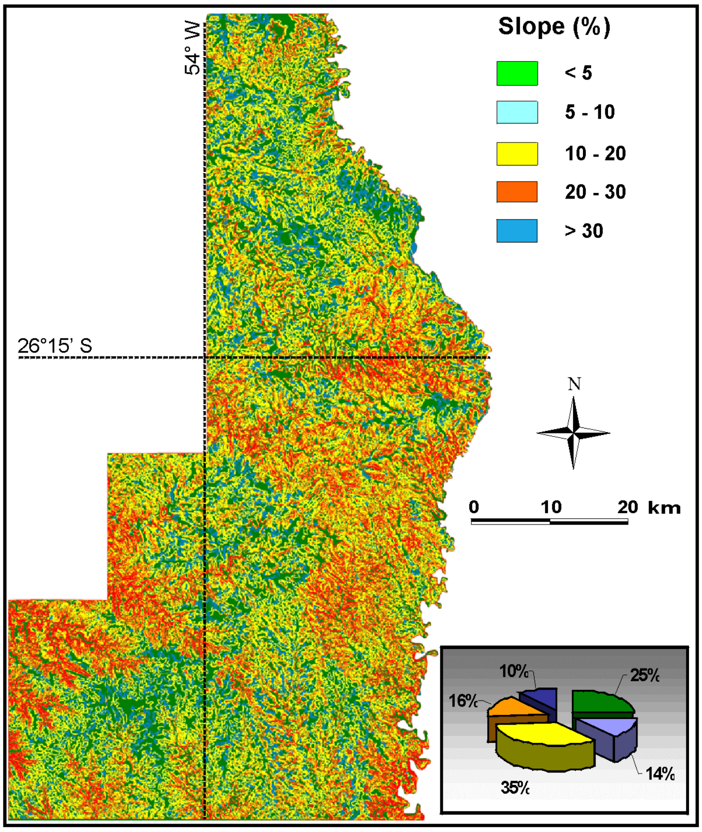


Fig. 5-22: Slope steepness calculated from DGM.

ratio of soil loss from land cropped under specified conditions to corresponding loss under tilled, continuous follow conditions. Soil loss from permanent bare fallow (or bare soil) is generally much higher than that from cropping systems. The vulnerability of a cropping system in relation to erosion hazards comprises the effects and interactions of soil cover, the crops used and general management practices. The most complicated of USLE factors, it incorporates effects of tillage management, crops, land use, cropping history, and crop yield (USDA, 1980). Additionally, the actual soil loss during a certain period also depends on the typical erosivity of the rainfall of an area at the particular time. Therefore, the relative soil loss of a definite period has to be seen in relation to the portion of the yearly R-value relevant to that very period. This portion (in percent) of the yearly R-value is called the erosion index (WISCHMEIER and SMITH, 1978).

In this research, the C-factor was extracted from land use/land cover digital classification map 2001 (Ch. 4) and field data. Shares of different land use/land cover are shown in figure 5-24.

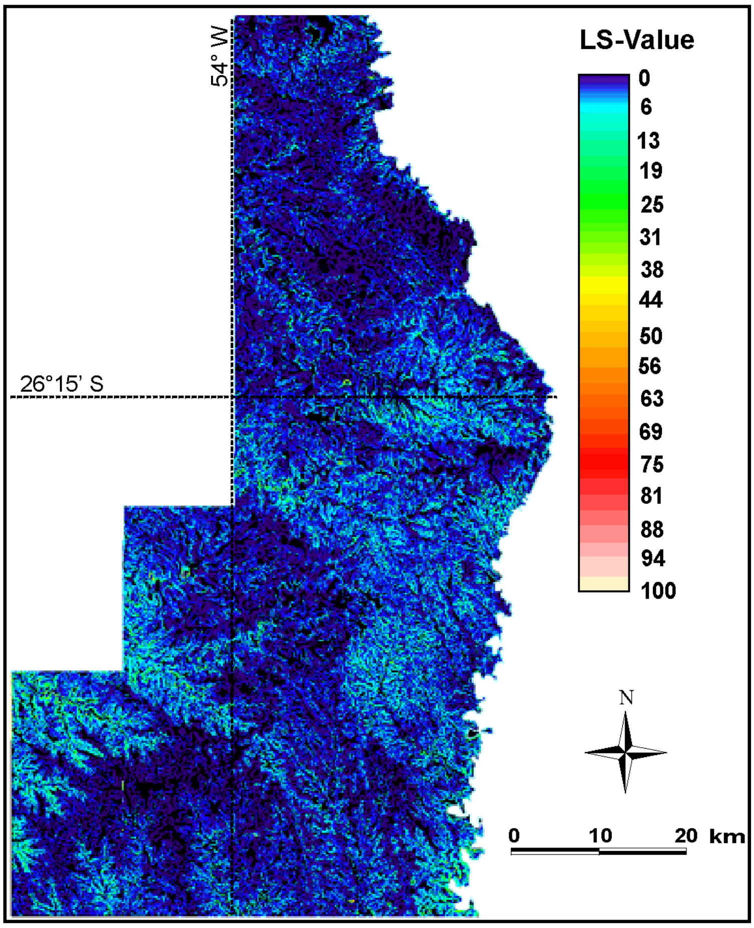


Fig. 5-23: LS-factor layer of study area.

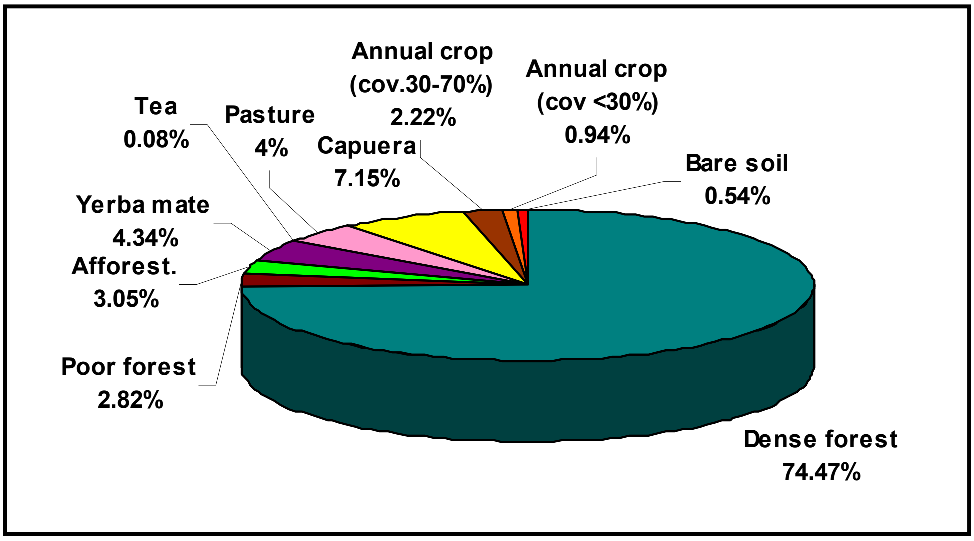


Fig. 5-24: Soil cover in the investigated area in 2001.

Values for the various vegetative cover types (C-factor) were assigned as follows

Land use/land cover	Annual average Factor C
Semideciduous mixed dense forest	0.001
Semideciduous mixed poor forest	0.01
Reforestation	0.02
Yerba mate crop	0.1 -0.3
Tea crop	0.1 - 0.3
Pasture	0.01 - 0.1
Capuera	0.01 - 0.025
Non-permanent crops (soil cover 30-70%)	0.3 - 0.9
Bare soil	1

(Source: ROOSE (1977); WISCHMEIER and SMITH (1978); MORGAN (1986); LIGIER (1989)).

By assigning each land use in the study area from the land use/land cover classification map, a C layer was created for the analysis with GIS. In the case of the pastures, because the factor C values vary from unused pastures to overgrazing pastures, the mean value was taken.

Since the soil losses vary with the erosivity and the morphology of the cover vegetation, it is necessary to consider the changes that take place in these along the year to obtain the annual value. The year is divided in periods corresponding to the crops development stages. The individual values for every period are pondered of agreement with the percentage of the annual mean rain (R) that falls in that period and add to obtain the annual value of C (MORGAN, 1986). Thus, for example, the C-value was calculated for a parcel with maize crop without crop rotation:

Months	C value	Adjustment factor	Pondered C value
Jun-Oct	0.9	0.42	0.38
Nov	0.8	0.08	0.06
Dec	0.4	0.08	0.03
Jan	0.6	0.08	0.05
Feb	0.7	0.11	0.08
Mar-Mai	0.7	0.26	0.18
		C-value	0.73

5.5.5 P-factor

All erosion control measures such as contour cropping, terracing, grass strips and all other measures that main purpose is to reduce slope length and thus runoff water velocity and sediment transport are included in the USLE in the form of the P-factor. This factor represents the ratio of soil loss by a support practice to that of straight row farming up and down the slope (MARTINEZ-CASASNOVAS and SANCHEZ-BOSCH, 2000). The P-Factor determines the effect of strip cropping, contour cultivation, and other conservation practices applied to agriculture. In this research, for all vegetative cover types, no erosion control was found, therefore value 1 was assigned.

5.6 Results and Discussion of Soil Degradation

5.6.1 Concept of Soil Loss Tolerance

In order to achieve a sustainable management of the soil resource, it is necessary that the soil loss is kept within certain sustainable limits so that this resource is not degraded further. For this purpose, the concept of soil loss tolerance was adopted, as the maximum soil loss value that can be permitted for a given land without causing degradation of the soil. Different authors have taken the values of soil loss tolerance differently. In the USA, soil loss tolerances ranging from 11.2 to 4.48 tn ha^{-1} y^{-1} were derived by various researchers (WISCHMEIER and SMITH, 1978). PAHARI (1996), in the context of Nepal, considered not practical to use the same value because of different conditions, having taken as 15 to 20 tn ha^{-1} y^{-1} soil loss tolerance for steep slopes. FAO-UNESCO-PNUMA estimates the following erosion rates:

Soil Loss (tn $ha^{-1}y^{-1}$)	Water erosion degree
< 10	Low
10 - 50	Moderate
50 -200	High
> 200	Very high

For lack of representative data referred to the study area, it was used as reference value proposed by WISCHMEIER and SMITH (1978) for deep soils, of moderate texture and permeability, around the 12 tn ha^{-1} y^{-1}. In the hillsides of deep slope, where the soils have a scarce depth and they are especially sensitive to the erosion, I consider that there are not acceptable rates above the 10 tn ha^{-1} y^{-1}. For the rest of the area, with deep soils, fine texture and scarce organic matter content, mainly of those areas under agricultural use, the acceptable threshold can be located, in the best of cases, around 20 tn ha^{-1} y^{-1}. Above this value, the conservation of the soil is not guaranteed, since the destruction is quicker than the soil formation.

5.6.2 Soil Erosion Risk

After completing data input procedure and preparation of the appropriate maps as data layers, they were multiplied in the GIS, to provide a estimate both risk erosion map, with R=207.6 and R=1300, shown in figure 5-25 and 5-26 respectively. With the USLE procedures and factor units, the numbers in the legend are formally the average annual erosion intensities in tons/ha. Table 5-8 show the estimated soil loss rate for parcels under different land cover/land use where the soil samples for this study were obtained.

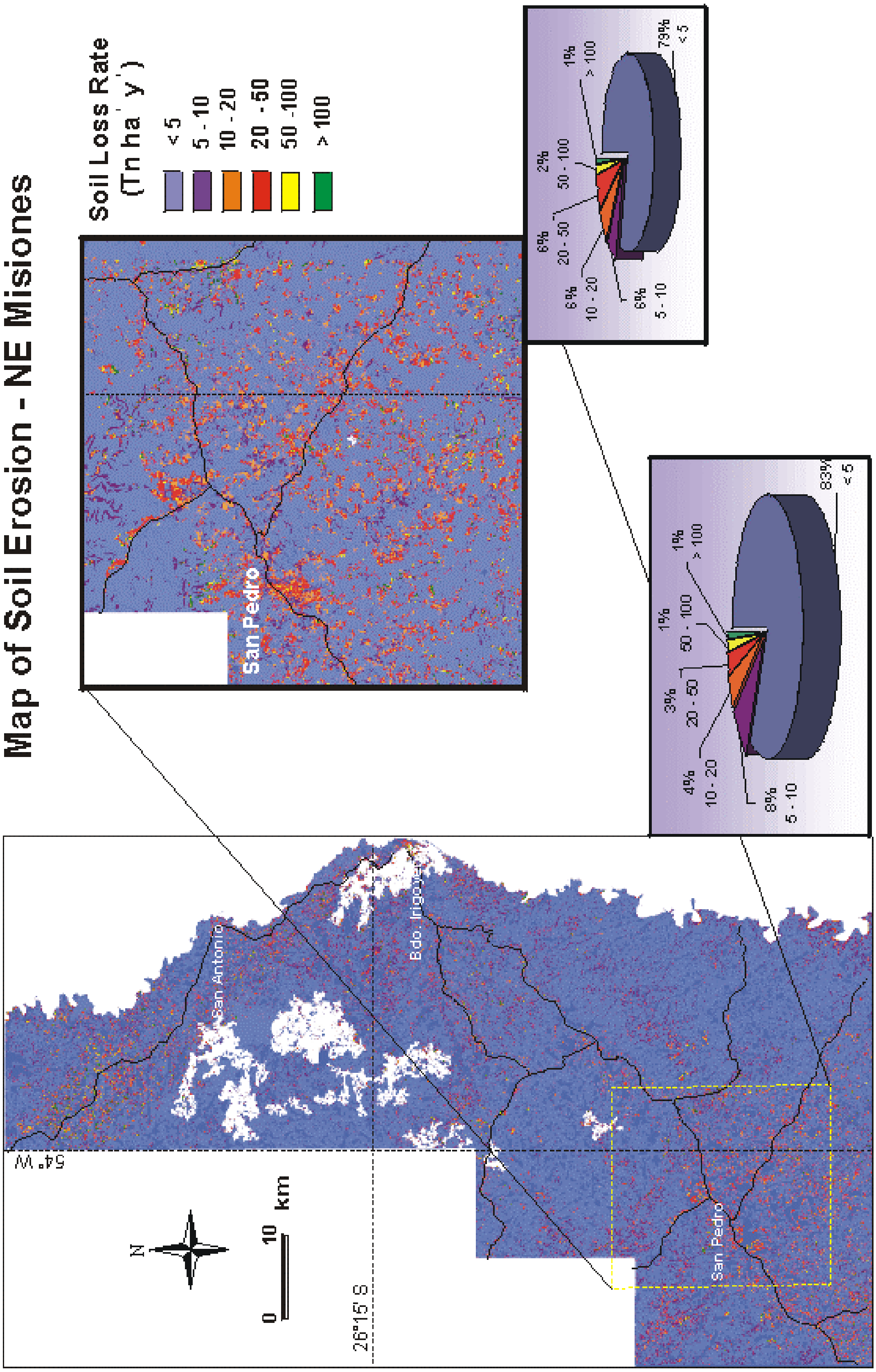


Fig. 5-25: Soil erosion risk map NE Misiones, R=208.

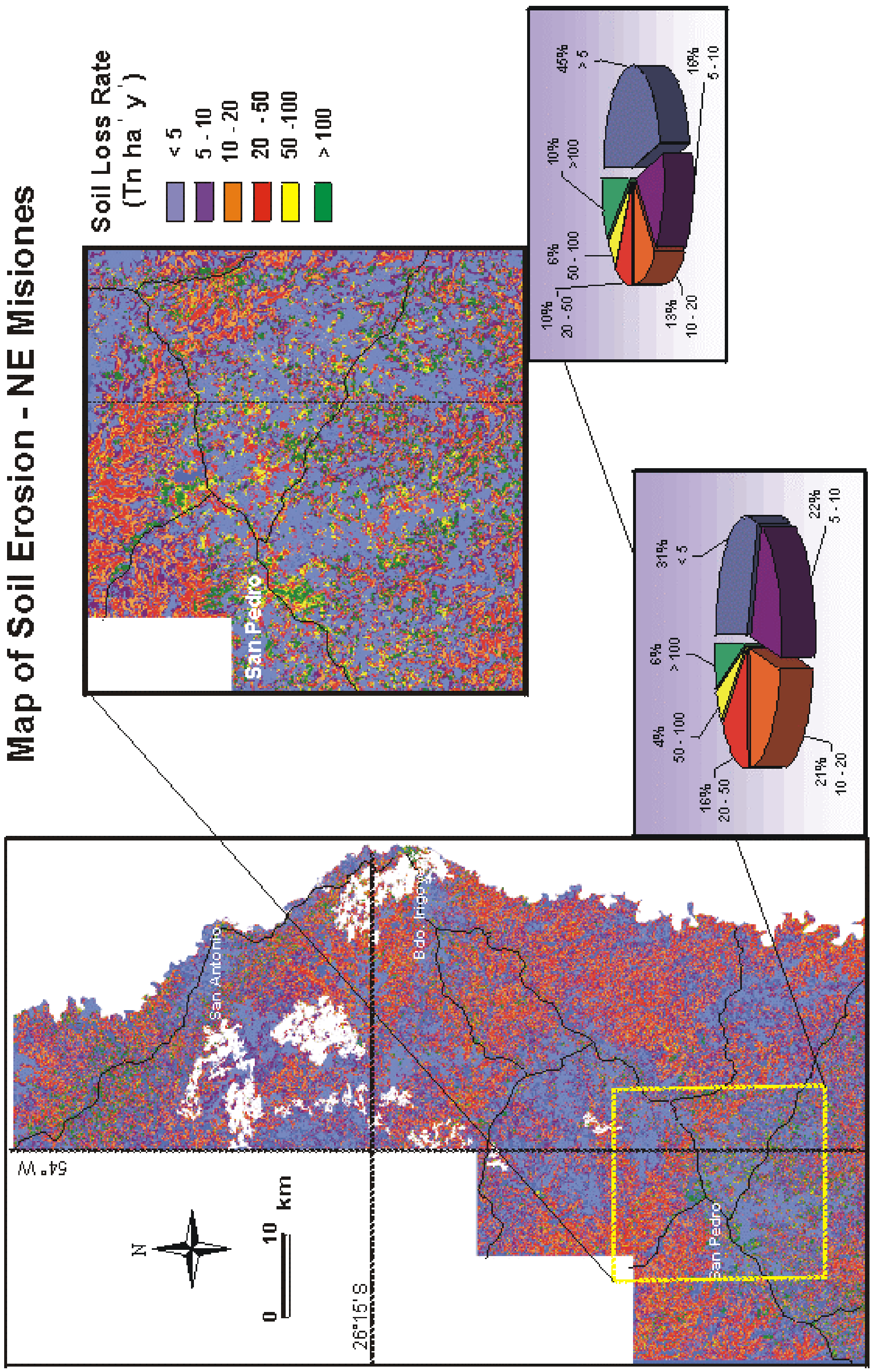


Fig. 5-26: Soil erosion risk map NE Misiones, R=1300.

Table 5-8: Annual soil loss rate using USLE for different land use/land cover. R= 208 and R=1300 respectively.

Sample	Soil	L (m)	S (%)	LS	Ks	R	C*	P	A (tn/ha/y)	A (m^3/ha/y)	Topsoil
CM-1	Rhodic Hapludox	80	13	3,32	0,06	208	0,73	1	**30,29**	**20,62**	**0,21**
CB-1	Rhodic Hapludox	100	10	2,48	0,07	208	0,001	1	**0,04**	**0,05**	**0,0005**
CB-2	Entic Hapludox	30	5	0,51	0,11	208	0,05	1	**0,58**	**0,46**	**0,0045**
R16 Km71	Typic Udorthents	130	23	13,13	0,24	208	0,05	1	**32,77**	**28,43**	**0,28**
TOB-1	Humic Eutrudepts	80	13	3,32	0,12	208	0,001	1	**0,08**	**0,06**	**0,0006**
TOB-2	Rhodic Kandiudalfs moderatly deep	190	13	6,35	0,17	208	0,3	1	**67,38**	**45,29**	**0,45**
R14 Pje.Ale	Rhodic Kandiudalfs moderatly deep	150	19	10,30	0,22	208	0,1	1	**47,12**	**31,67**	**0,32**
GR2	Rhodic Hapludox	150	13	5,51	0,07	208	0,2	1	**16,05**	**12,51**	**0,12**
R22-Km3	Rhodic Kandiudults	250	20	15,27	0,15	208	0,001	1	**0,48**	**0,32**	**0,0032**
R22-Km10	Typic Eutrudepts	170	25	17,85	0,27	208	0,001	1	**1,00**	**0,67**	**0,0068**
Manioc	Rhodic Hapludox	80	13	3,78	0,06	208	0,4	1	**18,87**	**13,98**	**0,14**
B.de Irigoyen	Distric Eutocrpets	20	5	0,43	0,26	208	0,001	1	**0,02**	**0,02**	**0,0002**
Sample	**Soil**	**L (m)**	**S (%)**	**LS**	**Ks**	**R**	**C***	**P**	**A (tn/ha/y)**	**A (m^3/ha/y)**	**Topsoil**
CM-1	Rhodic Hapludox	80	13	3,32	0,06	1300	0,73	1	**189,29**	**128,86**	**0,21**
CB-1	Rhodic Hapludox	100	10	2,48	0,07	1300	0,001	1	**0,23**	**0,29**	**0,0005**
CB-2	Entic Hapludox	30	5	0,51	0,11	1300	0,05	1	**3,65**	**2,85**	**0,0045**
R16 Km71	Typic Udorthents	130	23	13,13	0,24	1300	0,05	1	**204,84**	**177,66**	**0,28**
TOB-1	Humic Eutrudepts	80	13	3,32	0,12	1300	0,001	1	**0,52**	**0,35**	**0,0039**
TOB-2	Rhodic Kandiudalfs moderatly deep	190	13	6,35	0,17	1300	0,3	1	**421,16**	**283,03**	**0,45**
R14 Pje.Ale	Rhodic Kandiudalfs moderatly deep	150	19	10,30	0,22	1300	0,1	1	**294,52**	**197,93**	**0,32**
GR2	Rhodic Hapludox	150	13	5,51	0,07	1300	0,2	1	**100,32**	**78,19**	**0,75**
R22-Km3	Rhodic Kandiudults	250	20	15,27	0,15	1300	0,001	1	**2,98**	**2,00**	**0,0032**
R22-Km10	Typic Eutrudepts	170	25	17,85	0,27	1300	0,001	1	**6,27**	**4,21**	**0,0068**
Manioc	Rhodic Hapludox	80	13	3,78	0,06	1300	0,4	1	**117,95**	**87,37**	**0,88**
B.de Irigoyen	Distric Eutocrpets	20	5	0,43	0,26	1300	0,001	1	**0,15**	**0,10**	**0,0011**

* mean pondered value

It can be seen that the low erosion class dominates, for both R estimates, due to dense forest and rangeland vegetation on slopes. This is confirmed by the field observations. It was also observed that on cultivated sloping lands a lot of both sheet and rill erosions occur (Fig. 5-27 and 5-28), and most of these area are shown in the higher erosion classes on the map of figure 5-29. Therefore, the map can be used as an indicator of areas where priority to soil conservation of restriction of cultivation should be given.

Fig. 5-27: Linear erosion in manioc field after 132.5 mm rainfall. San Pedro, Misiones. (Photo: M. F. Rau, 17/09/2000)

Fig. 5-28: Sheet erosion in yerba mate field. It can be seen the bare roots after erosion processes. At the backdrop can be observed the line where it is deepened the erosive process and the decrease of the vegetation cover. This erosion type is very common in the yerba mate fields and it has taken the abandonment of great plantations, due to loss of the fertility, in the south of county. San Pedro, Misiones. (Photo: M.F. Rau, 2004)

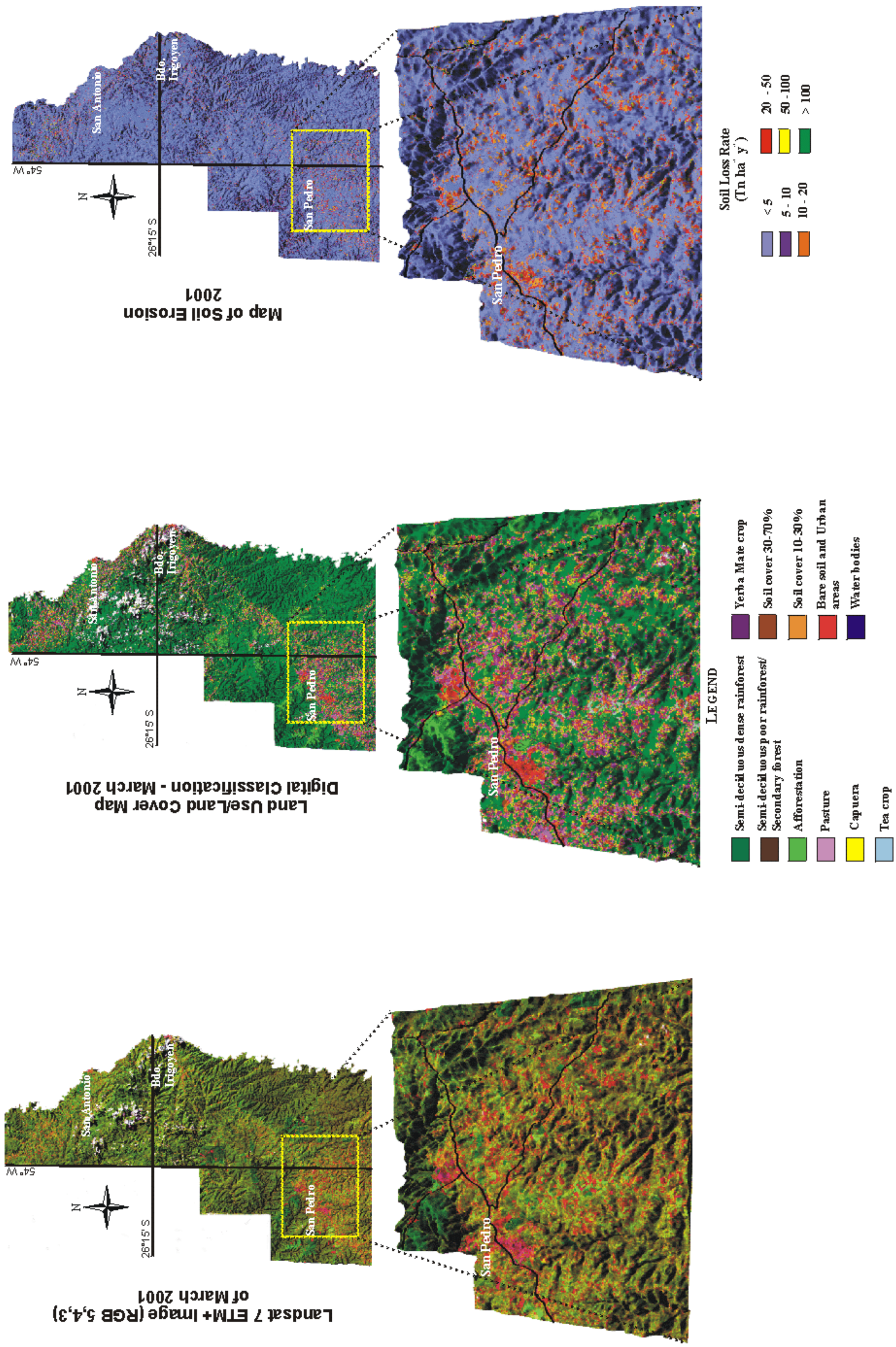


Fig. 5-29: 3D images of Landsat 7 ETM+ image, land use/land cover classification map and soil erosion risk of study area. In the sequence of partial scenes clearly can be distinguished that most of the areas with high erosion risk corresponds to agricultural and bareland areas.

The quantitative output of predicted soil loss was collapsed into six ordinal classes as shown in table 5-9.

Table 5-9: Derivation of the ordinal categories of soil erosion risk.

Erosion Class	Numeric range tn ha^{-1} y^{-1}	Erosion risk
1	<5	Very low
2	5 a 10	Low
3	10 a 20	Moderate
4	20 a 50	High
5	50 a 100	Very heigh
6	>100	Extrem

Table 5-10 shows the area of different erosion risk classes in the study area. In this table can be seen that nearly 5% and 26.5% (R= 207.6 and R=1300, respectively) land of the study area has high to extreme erosion. These areas should be treated as the erosion hazards and the soil management practices should be adopted in this area to prevent the erosion.

Table 5-10: Area of different erosion classes in the study area.

Erosion Class	R=207.6		R=1300	
	Ha	%	Ha	%
1	226058.76	83.24	83786.44	30.85
2	21665.16	7.98	59294.12	21.83
3	10071.68	3.71	57236.00	21.08
4	7553.48	2.78	42826.80	15.77
5	3766.00	1.39	11835.36	4.36
6	2455.60	0.90	16591.96	6.11

Total erosion risk in the study area in tn ha^{-1} y^{-1} is calculated for each major land uses and presented in Table 5-11. These results showed that there is a greater amount of hectare vulnerable to moderate, high or very high soil erosion under agricultural use. Considering the R-value=207.6, soil losses are comparatively lower (82% less than 5 tn ha^{-1} y^{-1} or 3.5 m^3 ha^{-1} y^{-1}) under land cover types, such degraded forest, reforestations and capuera, while grazing lands had only 45% at this level. The maximum annual soil loss rates are in areas under cultivation (annual and/or permanent), low soil cover and bare soil. The 52% of these areas has a potential annual soil loss between 20 and 100 tn ha^{-1} y^{-1} (13.5 to 68 m^3 ha^{-1} y^{-1}) and was considered high to very high. The lowest soil losses (less than 1 tn ha^{-1} y^{-1} or 0.7 m^3 ha^{-1} y^{-1}) are recorded in areas under dense forest.

Table 5-11: Ranking estimated erosion risk by water (R=207.6).

Estimated Soil Loss	Potential soil loss (tn h-1 y-1)	Dense forest		Crops- Bare soil		Grazing land		Deg.forest - Afforest. - Capuera	
		ha	%	ha	%	ha	%	ha	%
Very low	< 5	179466	91.52	981.56	5.33	4810.32	45.23	26173.68	82.30
Low	5 to 10	13244.3	6.75	1475.16	8.01	3046.08	28.64	3899.64	12.26
Moderate	10 to 20	2816.44	1.44	4021.48	21.84	1868.4	17.57	1365.36	4.29
High	20 to 50	567.2	0.29	5925.4	32.18	790.2	7.43	326.12	1.03
Very high	50 to 100	0	0.00	3592.52	19.51	100.36	0.94	30.28	0.10
Extrem	> 100	0	0.00	2416.08	13.12	19.12	0.18	7.8	0.02

Considering areas of deep slopes, and taking 10 tn ha^{-1} y^{-1} as limit of tolerance, it is observed that the erosion rate in 3.47% of these areas exceeds this limit (Table 5-12).

Table 5-12: Inadmissible erosion in the study area.

Inadmissible erosion	
Surface	Percentaje
9421.88	3.47

5.6.3 Infiltration capacity

To compare the capacity of infiltration values of the soil under different uses were carried out the corresponding measurements according to the explained methodology. Tables 5-13 and 5-14 summarize the results of infiltration rate, satured hydraulic conductivity (Ks), bulk density, porosity and moisture content of the sampled soils.

In all the sites, the initial moisture content at 0-15 cm depth was similar, without significant differences. The coefficient of variation (CV) was 0.056 and 0.023 respectively. Bulk density measurements showed significant differences between plots; pasture, maize, manioc, bare soil yerba mate and forest clearance by skidder plots had a bulk density substantially higher than that of natural forest. At the Rhodic hapludox, the highest r_b registered at the pasture and maize treatments. This probably indicates compactation by overgrazing at the pasture treatments and structure loss and change of soil porosity by tillage practice at the maize plot. At the Distric eutochrepts, higher r_b was registered where only the skidder for the area clearing was used. However, the other two sites, where heavy machinery was also used, greater density that the forest has been registered. This denotes the compactation generated by use of heavy machinery.

Table 5-13: Mean infiltration rate (mm h^{-1}), bulk density (0-15 cm), porosity and moisture content of each treatment at a Rhodic Hapludox. Ks: saturated hydraulic conductivity. (ND: no data).

Site	Infiltration rate[1] mm h^{-1}	Ks mm h^{-1}	Bulk density[2] g cm^{-3}	Porosity[3] (%)	Moisture cont. kg kg^{-1}
Forest	25.59	2.49	0.87	67.21	0.41
Yerba Mate	13.98	1.38	1.09	58.91	0.33
Maize	5.76	0.24	1.19	55.21	0.36
Manioc	17.51	1.20	1.04	60.87	0.39
Pasture	4.35	0.48	1.08	59.40	0.42
Bare soil	2.70	0.08	N/D	N/D	N/D

[1] $\alpha=0.05$ F=139.9 $p<0.001$; [2] $\alpha=0.05$ F=8.325 $p<0.001$;
[3] Particle density=2.65 g/cm^3

Table 5-14: Mean infiltration rate (mm h^{-1}), bulk density (0-15 cm), porosity and moisture content of each treatment at a Distric Eutochrepts. Ks: saturated hydraulic conductivity. (ND: no data).

Site	Infiltration rate[1] mm h^{-1}	Ks mm h^{-1}	Bulk density[2] g cm^{-3}	Porosity[3] (%)	Moisture cont. kg kg^{-1}
Forest	37.39	1.80	0.77	71.13	0.48
Skid + Buldoz.	1.27	0.24	0.99	62.79	0.50
Mach.+ Buldoz.	4.93	0.36	0.94	64.38	0.48
Skid.	0.91	0.12	1.05	60.42	0.51

[1] $\alpha=0.05$ F=295.6 $p<0.001$; [2] $\alpha=0.05$ F=19.32 $p<0.001$;
[3] Particle density=2.65 g/cm^3

The infiltration rates were very variable in both groups of measurement. This variability has given a range of values, in the evaluated cases, which go from 37 to 0.9 mm h^{-1}. Figures 5-30 and 5-31 shows the infiltration rate for different land use/land cover soil and under different heavy machinery use for clearance of parcels. There is a wide difference between the infiltration rate of the forest soil and the infiltration at the other site soils, as an evidence the human intervention in these sites. In both the cases, the forest obtained the highest accumulated infiltrated rate, although in the Dystric eutochrepts it was slightly higher. This can be due to the greater sand content in the first 50 cm of the soil. Intra-site variation in infiltration rates was substantial and varied widely between sites, evidencing modifications of the soil physical properties. In the rhodic hapludox, the sites corresponding to bare soil, pasture and maize crop registered the smallest infiltration rate (2.60, 4.35 and 5.76 mm h^{-1} respectively), being the last two cases those of greater soil physical properties modification by man-made activity (overgrazing and tillage practice).

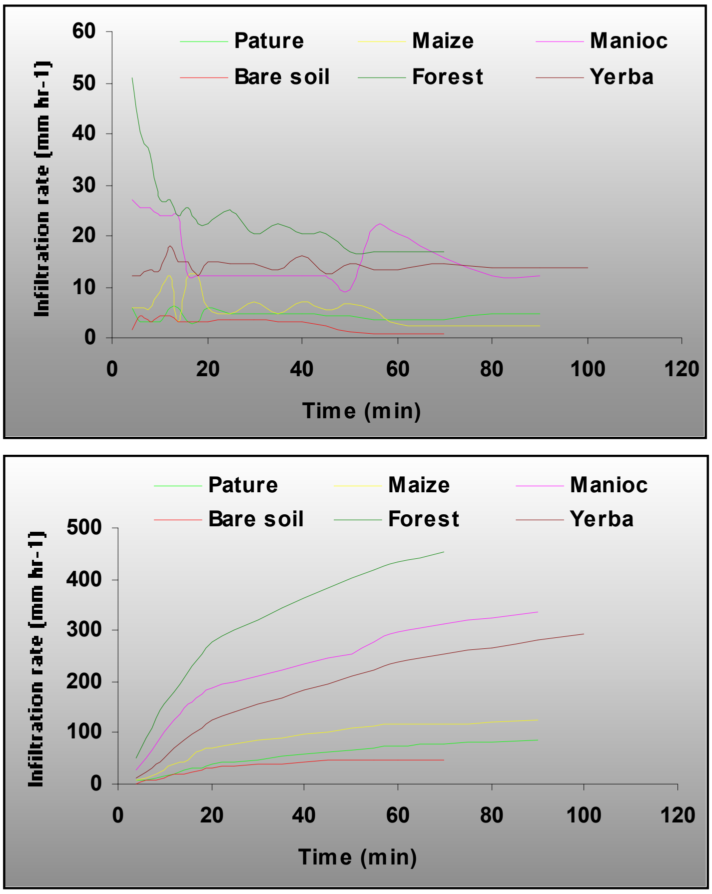


Fig. 5-30: Infiltration rate under different land use/land cover in a rhodic hapludox soil (below, cumulative infiltration rate). The lateral movement of water underneath the cylinder is not considered. The true infiltration rate can be calculated using the $f_c = f_m (V_c/V_t)$ formula, where f_c = true (vertical) infiltration capacity; f_m = measured infiltration capacity; V_c wetted volume beneath the cylinder; and V_t = total wetted volume (TRICKER, 1978).

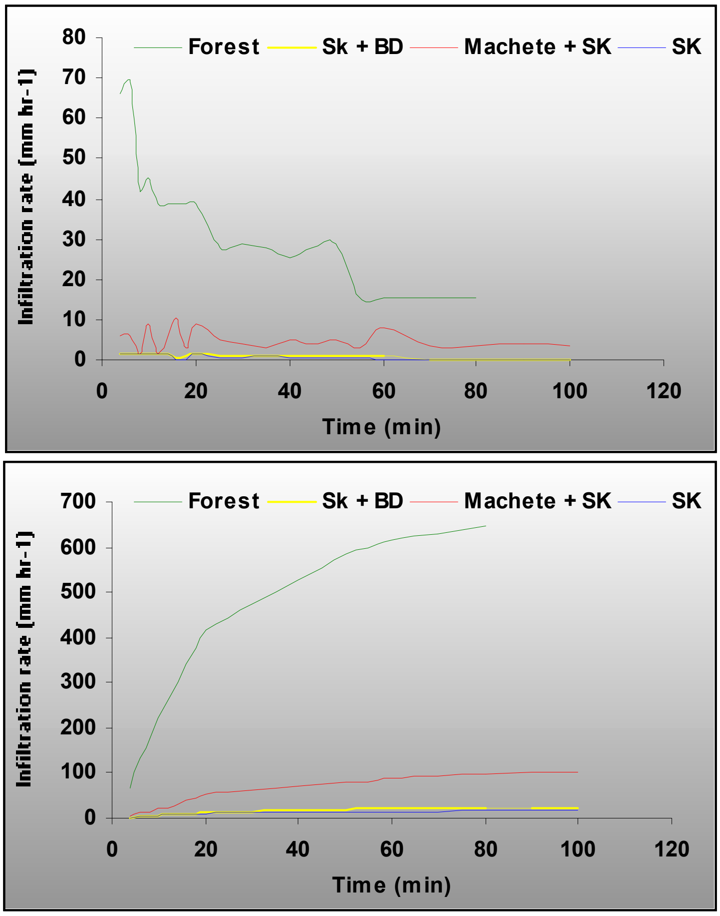


Fig. 5-31: Cumulative infiltration rate under different heavy machinery use in a distric eutochrepts soil. The lateral movement of water beneath the cylinder is not considered. SK: Skidder and BD: Bulldozer

FREITAS (1994) and SILVA *et al.* (1994) showed that water-stable soil aggregates, infiltration rate and organic matter decline in tropical soils under conventional tillage (offset disks and disk plow). The lower Infiltration rate at the bare soil can be due to the surface crusting. The high infiltration rate at the manioc treatments responds, possibly, to the lowest time lapsed from the forest clearing and the reduced tillage practice. The high infiltration rate at the yerba mate treatments, in spite of the relatively low porosity, could be explained by lowest initial moisture content of the soil. In the Distric eutochrepts, the three sites under use of heavy machinery obtained very low infiltration rates that agree with the values of bulk density registered for these sites. However, a greater infiltration rate was registered in the site where the machete was used like alternative for the area clearing.

Low values of r_b reported in this study, although may seem to be unreasonably low compared with to global averages, which usually exceed 1.0 g/cm3, are characteristic of those found in the field for these soils.

5.6.4 Discussion

Aim of this investigation section was to assess the potential soil erosion and possible causes of this erosion after deforestation, using satellite imagery, geographic information systems and erosion models. Hereto, in a first step different soils profiles were determined and soil samples obtained of these profiles were analysed; slope length and slope steepness field measurements were performed. Finally, the obtained data were multiplied in a GIS and the soil erosion rate was estimated.

The infiltration rate is an important parameter characterizing soil structure. According to the field investigations, there were significant differences between the infiltration rates of the different treatments at both sites. The infiltration rates were approx. 10, 6, 5, 2 and 1.5 times higher in the bare soil, pasture, maize, manioc and yerba mate treatments than natural forest. Significant differences also were observed between the bulk densities in all the sites.

There was a high correlation between the infiltration rate and the bulk density for all the treatments (r=0.82 and r=0.92 at the rhodic hapludox and distric eutochrepts respectively). Figure 5-32 shows the variation of the infiltration rate according to the increase of the bulk density. This behavior is possibly because the increase of the bulk density takes with a decrease in the total soil pores volume (see table 5-3 and 5-4). Furthermore, the initial soil moisture contents in the treatments were not statistically different, I interpret that the difference in the infiltration rate was caused by the different total porosity of the all the sites. Consequently, it can be said that the land use change toward agricultural use after deforestation influenced the soil physical properties measured that would suggest soil physical conditions degradation. While runoff measurements

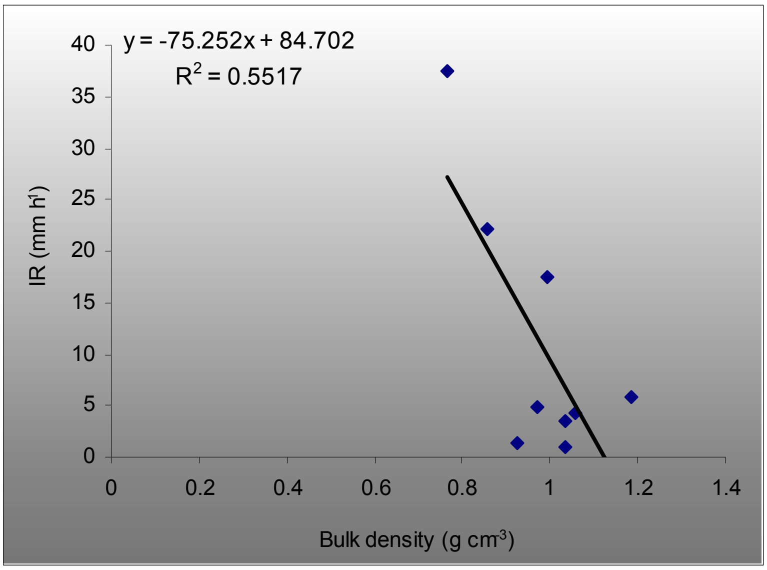


Fig. 5-32: Variation of the infiltration rate according to increase of the bulk density.

runoff measurements were not carried out, it can be confirmed that the descent of the capacity of soil infiltration produces the increase in the runoff and of soil loss. Likewise, it is necessary to considerer the low permeability of these soils when dry; therefore, heavy rainfalls on dry soils cause greater runoff for lack of immediate infiltration.

Most of the tropical soils, particularly those with high content of kaolinite clays, like the Oxisols, develop a stable microstructure as a result of strong binding between these clays, the oxyhydroxides and the organic matter (NEUFELDT, 2001). This stability explains why such soils are less prone to erosion. According to data of Table 2, in the first 10 cm of depth, soils under forest cover presented an average organic matter contents of 4.2% against 2.3% and 2.7% that presented those soils under agricultural use or rangeland, respectively. The loss or decrease of the organic matter content, either by tillage or by overgrazing and decrease of the roots volume or by loss of vegetation cover, cause a decrease in the aggregate stability and consequently an increase in the erosion probability. To this would be necessary to add the decrease of organic matter by burns practice, that according pointed out by GIOVANNINI and LUCCHESI (1993) (cit. by BOIX FAYOS, 1997), this significantly decrease in the superficial layers when the soils is heated above 220°C.

Regarding to erosion risk, the results for this study showed low erosion rates in areas under permanent vegetation cover with the use of the USLE. On the two final soil erosion maps, agricultural lands are at a higher potential of erosion possibilities. As shown in the final estimation maps (Figures 5-24, 5-25 and 5-29) there is considerably lower levels of soil erosion under forest cover. The agriculture land generates 93% of the total erosion. If the erosion from agriculture land is minimized then it will minimize the total erosion. In the calculations carried out through the application of the USLE, exaggerated values of erosion in areas of deep slopes can be seen.

6. CONCLUSIONS

This presented study deals with the actual state of the natural araucaria forest in the Province of Misiones (NE - Argentina), with emphasis on the state of the *A. angustifolia* population, the land use and land cover change during the last forty years and the subsequent land degradation. The opinion differences on agroforestry in the Province of Misiones is strong and appears to be led as well by social-environmental concerns as by political interests. Likewise, this dissertation undertakes an integrated assessment between deforestation and land use change with the aim of getting past the argumentative barriers by providing empirical evidence and "balanced" analysis. Finally, its scientific contribution has not only to be seen in the ecological exploration of these forests but also in the methodological progress.

Actual state of *A. angustifolia* population

In Chapter 3 the chronological process of the intensive exploitation that had been carried out during the last four decades on the *A. angustifolia,* was described. This exploitation and the use of the best individuals for the timber and paper industry left almost desolated its population and have led inevitably to a negative selection. Today only few small groups and isolated individuals, predominantly of very poor quality, remain. They are located mostly in areas under agricultural use and are exposed year after year to fires as consequences of slash and burn practices.

The law 2380 and its modifications promulgated as probably only measure to protect and to conserve the already reduced population of araucarias has not been found to be effective at all. The contemplation of the araucaria as an individual and not as an important part of a complex and threatened ecosystem led to the physical isolation of almost randomly distributed, individual trees. Today, it is common to see adult individuals isolated in field crops or in populated areas damaged by the man's hand and with profusion of great quantity of branches of scarce development along its trunk as well as a smaller development of their crowns. Both possibly play an important roll against their reproductive possibilities.

Even when the regeneration in the forest as well as in cleared areas would be satisfactory, the actions against the survival of Araucaria a. perpetrated by the local rural population and the lack of a clear conservation policy from the provincial authorities, makes the continuity of this species in the Province of Misiones difficult.

Deforestation, Land use change and Land Degradation

The extensive deforestation and the subsequent land use change processes induced mainly by expansion of the agricultural frontier and the soil degradation as direct consequence of the vast clearings were described and analysed in Chapters 4 and 5.

The obtained results show that the northeastern region of the Province of Misiones, an area of approximately 3.800 km^2 has experienced significant land use changes during the period 1962–2001. There has been a loss of 740 km^2 of forest, which amounts to 18.55% of the former forest area. The changes in the forest and land cover in this region exhibit great spatial variation; the areas near towns and extensive parallel fringes to main routes experienced the highest losses of dense forest stands. The estimated annual rate of deforestation was 0.50% during 1962-2001 period and 0.88% during the period 1986-2001. Hereby it is noteworthy, that these high values even exceed the estimates by FAO (1993) for tropical rainforests (0.60%) during the period 1981-1990.

Although it is known that the selective logging normally does not lead to the disappearance of forests, the strong removal of trees, no matter how carefully done, obviously alters the spatial pattern and size class distribution of tree species in a forest. In the investigated study area, the absence of several marketable species of the timber market and the appearance of other ones of lower quality and economic value, as well as the reiterated decrease of minimum girth limit allows for all marketable species to infer about the improper logging and the lack of an appropriate stand management.

Results of this study also showed that several forest soils cleared for agriculture displayed indications of degradation within few years of subsequent cultivation after deforestation. Major declines were observed for soil organic matter, bulk density and infiltration capacity. Likewise, the results showed that these areas are characterised by moderate to very high soil erosion risk. Despite the clear land degradation and the loss of soil fertility, local farmers continue to cultivate the lands for a prolonged time under low input systems in accordance to the demographic and economic pressures in this region. Therefore, this process of prolonged use with low inputs may ultimately lead to the abandonment of land.

The depletion of Misiones forest ecosystems, less than 1% of the country's land area, implies that horizontal expansion of croplands to forest sites is no longer an option. Therefore, strategies to nourish the expanding population in the province have to be implemented on basis of a sustainable management plan addressing the current issues of soil degradation and land use changes. More research on nutrient management (e.g. traditional agroforestry, composting, crop rotation) and improved cultivation techniques should be integrated into a strategy for sustainable agricultural development in the province. In addition, improvement in the management of the soil resources for sustainable agricultural use would be one of the most useful strategies that could help to protect the remnant patches of these unique forest ecosystems and their biological diversity from the aggressive agricultural land expansion in Misiones.

On the other hand, agricultural land expansion and intensification threatens the native forest flora not only through the outright destruction of the forest, but also through the impact on the soil seed bank, the future of the forest flora. Besides the depletion of the soil seed banks, vegetation recovery after slash and burn practices and intensive agricultural land use is hindered due to the depletion of other resources needed for natural regeneration such as soil fertility, abiotic and biotic site conditions at degraded agricultural sites, and lack of sufficient seed dispersal due to increasing isolation from nearby natural forests. This will ultimately lead to a permanent destruction of the native forest flora. As a conclusion, there is an urgent need for the protection and the sustainable management of the natural forests remnants and their biodiversity in Misiones to save these vulnerable and unique ecosystems from the threat of extinction.

Finally, the ability to successfully restore the degraded lands will contribute significantly to the economic and rural development. In Misiones, with a predominantly rural structure and economy mainly based on natural resources for livelihood, afforestations activities may have several advantages. Some of these advantages may include (i) supplying forest products, particularly for timber industry; (ii) augmenting rural income and provincial economy by making productive use of the degraded lands; (iii) slowing down the increasing pressure on the degraded forests that have high significance for their biodiversity; and (iv) enhancing the greenness and improving the recreational values and panorama of the degraded landscapes and making them attractive and hospitable for the community.

7. SUMMARY

Originally, araucaria forest was characteristic of the northeast Misiones landscape, covering around 210.000 hectares. The broad variety of possible uses for araucarian timber, as well as a growing need for agricultural land, however, leads to the circumstance that since the middle of the past century these forests were strongly exploited and cleared. In only 50 years, of the original existence of *A. angustifolia* in the Province of Misiones, from about 500.000 individuals before de exploitation, a mere 5% were left in 1992. After the depletion of the araucaria stands a timber industry was established in the region. From this and with the local population's growth other valuable species were selectively logged and a fast expansion of the agricultural frontier and the encroachment farming into the forest took place. Despite their natural and economic value, until now the araucarian forests in the Province of Misiones have poorly been studied.
The aims of this study was an evaluation of the actual state of the Araucaria forests and the land use/land cover changes after deforestation and their impacts on soil resource in the Province of Misiones. From the results conclusions a contribution was made in finding concepts for future planning and sustainable resources management. Hereto, main points following thematic areas were processed:

– Evaluation *A. angustifolia* population
– Land use/land cover change
– Land degradation

The research was performed at the NE of the Misiones Province, between 25°40' and 26°50' S and 54°15' W and the Brazil frontier.

Evaluation of *A. angustifolia* population

With the goal to evaluate the actual state of the Araucaria forest and the *A. angustifolia* population, processes combining air photography interpretation and air and terrestrial recognition were carried out. The data of the original existence of *A. angustifolia* were based on the work of COZZO (1960). In addition, with the purpose to obtain information of the natural regeneration of *A.angustifolia*, both adult and young trees inventory was performed in a parcel of 2 hectares of a little perturbed native forest.

The results showed that at the moment the *A.angustifolia* population is completely fragmented, mostly composed from isolated individuals or of very poor growth or ones overmature or ill, remaining less than 4 percent of its original existence. The regeneration of the araucaria (plant > 1 m height) into the forest with its mere 7 individuals per hectare is satisfactory and would be enough -comparing these results with those obtained by SEITZ (1982)- to perpetuate the species.
Nevertheless the satisfactory natural regeneration, the inefficient application of the Law 2380 and the continuous illegal felling, people's growing resentment against the araucaria, the scarce remainder individuals numbers and poor sanitary state or overmaturity of these tress, make almost impossible, without an appropriate management the natural continuity of the araucaria in the Province of Misiones.

Land cover/land use change

The use of medium spatial-resolution (5–30 m) satellite images, as a land cover-mapping tool has been growing steadily. The digital nature of satellite images allows an advanced computer-assisted analysis, classification, and compatibility with geographic information systems (GIS).
With the goal to identify and quantify the land cover/land use change during the last forty years in the study area, a multi-temporal analysis from Landsat Thematic Mapper (TM) and Landsat Enhanced Thematic Mapper plus (ETM+) imagery was performed. A time series of Landsat-5 image and Landsat-7 image spanning 1986–2001 was analyzed to detect changes in the forest cover. To analyze properly this time series, a set of corrections was undertaken, which included noise-reduction correction, atmospheric correction, and TM–ETM+ data normalization. Both images were classified with a Maximun Likelihood classifier using training sites for the 2001 image and statistics from this image to identify the different classes in the 1986 image. A KAPPA analysis and overall accuracy analysis were used to perform a classification accuracy assessment from 47 training sites and about 800 random points for each image. Land cover types of 1962 were obtained from vegetation maps and historical aerial photographs. Post-classification caparison change detection and Normalized Index of Vegetation (NDVI) image differencing were employed. Five Levels I land use categories, according US Geological Survey, were selected for analysis: a) Forest land (Semideciduous dense rainforest, Semideciduous poor rainforest and Reforestation), b) Agricultural land (Yerba mate crop, Tea crop, Pasture, Annual crops -soil cover 30-70 % and soil cover 10-30 %), c) Rangeland, c) Bareland and d) Water. The accuracy assessment of both classifications was high, with an overall accuracy and K_{hat} greater to 90 % and about 0.9 respectively. All data sets provided consistent results, with a noticeable loss in the forest cover between 1962 and 2001 about 19 %, while the agricultural land nearly quadruplicated. The average deforestation rate (by clear-cutting) between 1962 and 2001 was approx. 1908 ha year^{-1}, while in the period between 1986 and 2001 of 3515 ha year^{-1}.

Nevertheless the high dynamic of the landscape, which sometimes hindered the distinction of one or several classes in the temporary series, this study demonstrates the feasibility and utility of combining Landsat-5 TM and Landsat-7 ETM+ images in a great scale change detection study.

Land degradation

The aims of this part of the work were to evaluate and determine the soil erosion risk and possible causes of soil erosion for the study area, using satellite imagery, geographic information systems and Universal Soil Loss Equation (USLE) model. The overall methodology comprised several parts involving first field observations and following, measurements of infiltration capacity and bulk density, and then spatial data capture for erosion risk prediction. Laboratory analysis, statistical analysis and spatial modelling of erosion risk in a GIS followed the first three steps. The first step involved dug of profiles and obtaining of soil sample data. Eleven soils profiles were dugs and 41 samples were collected. Infiltration capacity and bulk density were measured on six plots under different land use/land cover in a Rhodic hapludox and three plots under different heavy machinery use in Dystric eutochrepts. Infiltration capacity was measured using single-ring infiltrometer. On average, three replicates were performed at each treatment. One core sample was taken to determine the initial moisture content. Bulk density samples were taken from three different depths (0-5, 5-10, 10-15 cm) with five replicates in each depth. Collected spatial data involved measuring slope length and slope degree. The eleven soil profiles and the slope length and slope degree were geopositioned by mean of a GPS. The infiltration and bulk density data were analysed using Analysis of Variance (ANOVA) between groups to examine effects of different land use on soil physical properties. For the USLE prediction model, five layers were created. In order to derive LS-factor values, a 10 m digital elevation model (DEM) was generated. C-factor was extracted from land use/land cover digital classification map 2001 and field data.

The results revealed that the soil organic matter (SOM) content in the first 10 cm depth considerably decreased after deforestation, ranging from 4.2 % to 2.3 % at soils under forest cover and agricultural use, respectively. Significant differences were observed between bulk densities (r_b) at all treatments ($P < 0.001$). The r_b increased as intensive use increased at the Rhodic hapludox, whit levels between 0.87 g cm^{-3} at forest cover and 1.19 g cm^{-3} at maize crop. At the Dystric eutochrepts, higher rb was registered where skidder was used. The infiltration rate was very variable in both groups of measurement ranging from 37 mm h-1 at the forest to 0.9 mm h^{-1} at the bare soil treatments. There was a high correlation between the infiltration rate and the bulk density for all treatments ($r=0.82$ and $r=0.92$ at the Rhodic hapludox and Dystric eutochrepts respectively).

Results provided by running a soil erosion assessment model (USLE) in a GIS environment showed that there are a greater amount of hectare vulnerable to moderate, high or very high erosion under agricultural use. Considering R-value=207.6, the 52% of these areas has a potential annual soil loss between 20 and 100 tn ha^{-1} y^{-1} (13.5 to 68 m^3 ha^{-1} y^{-1}) while soil losses are comparatively lower (82% less than 5 tn ha^{-1} y^{-1} or 3.5 m^3 ha^{-1} y^{-1}) under degraded forest, reforestations and capuera. The lowest soil losses (less than 1 tn ha^{-1} y^{-1} or 0.7 m^3 ha-1 y^{-1}) are recorded in areas under dense forest. The 3.47% of deep slope areas exceeds 10 tn ha^{-1} y^{-1}.

In summary, the results of the field observations and the analysis of satellite imagery indicate clearly that the population of *A. angustifolia* in the Province of Misiones is almost destroyed due to an ongoing overexploitation. In particular, the last 2 decades were characterised by a very high deforestation rate and a rapidly advancing agricultural frontier. Vast areas in north-eastern Misiones, especially agricultural crop land, show clear indications of soil degradation due to inadequate soil use practices and, as a consequence, were found to be highly susceptible to erosion.

The presented findings reveal that the survival of *A. angustifolia* depends on an urgent revision of the conservation policy as well as the regional agricultural and forest policies. Likewise, in the face of the ignorance observed in the rural population about management techniques and resource conservation, it is also indispensable to generate better futures information channels and appropriate technical advice in order to a better sustainable natural resources use. Based on the methodology developed in this study, a consistent monitoring program using satellite imagery has to be implemented to control the application of a revised conservation policy and, therefore, to ensure the protection of the Araucaria forests in the future.

8. ZUSAMMENFASSUNG

Ausgedehnte Araukarienwälder (*Araucaria angustifolia*) bedeckten im Nordosten der Provinz Misiones (Argentinien) noch bis vor wenigen Jahrzehnten rund 210.000 Hektar und bildeten damit die landschaftsprägende Vegetationsformation. Die weitreichenden Nutzungsmöglichkeiten des Araukarienholzes und der steigende Bedarf an landwirtschaftlichen Nutzflächen führten jedoch in der zweiten Hälfte des 20. Jahrhundert zu einer intensiven Nutzung und rücksichtslosen Ausbeutung dieser subtropischen Waldökosysteme. Hierbei wurde in lediglich 50 Jahren bis zum Jahr 1992 der geschätzte ursprüngliche Araukarienbestand von rund 500.000 Individuen um 95% reduziert. Nach der weitgehenden Erschöpfung dieser wertvollen Ressource verblieb in der Region eine etablierte holzverarbeitende Industrie, die sich in der Folge vermehrt in der Erschließung weiterer Gebiete und der Ausbeutung alternativer Nutzholzarten engagierte. Im Zusammenspiel mit einem raschen Bevölkerungswachstum wurden dabei die natürlichen Wälder weiter reduziert und auf ihre heutigen Restareale zurückgedrängt.

Trotz ihres ökologischen und ökonomischen Potentials liegen über die natürlichen Araukarienwälder der Provinz Misiones bislang nur vereinzelte und lückenhafte Studien vor. Der aktuelle Kenntnisstand über Verbreitung und Beschaffenheit rezenter Araukarienbestände sowie die Folgen des dramatischen Holzeinschlags in der zweiten Hälfte des zwanzigsten Jahrhunderts ist als defizitär einzustufen. Ziel dieser vorliegenden, interdisziplinär angelegten Arbeit ist daher die Evaluation des aktuellen Zustandes der Araukarienwälder sowie die Erfassung und Dokumentation des Landnutzungswandels und dessen Auswirkungen auf die Ressource Boden in der Provinz Misiones. Aufbauend auf den dabei erzielten Ergebnissen und Erkenntnissen sollen Entscheidungshilfen für die Planung sowie Durchführung einer nachhaltigen Nutzung der natürlichen Ressourcen im Zusammenhang mit der lokalen, regionalen und nationalen Entwicklung hergeleitet werden. Dieser Zielsetzung folgend ist die Arbeit in die folgenden drei thematischen Forschungsfelder untergliedert:

- Erfassung der aktuellen Population von *Araucaria angustifolia*
- Dokumentation des Landnutzungs- und Landschaftswandels
- Erfassung der Bodendegradation

Die Geländearbeiten für diese Studie wurden im Nordosten der Provinz Misiones (Argentinien) zwischen 25°40' und 26°50′ südlicher Breite sowie zwischen 54°15' westlicher Länge und der argentinisch – brasilianischen Grenze durchgeführt.

Erfassung der aktuellen Population von *Araucaria angustifolia*

Die GIS-gestützte Kartierung der gegenwärtigen Verbreitung der Araukarienbestände und die Erfassung ihrer Beschaffenheit erfolgte anhand von Luftbildauswertungen sowie durch terrestrische und flugzeuggestützte Erkundungen. Als Grundlage der früheren Verbreitung von *Araucaria angustifolia* diente die detaillierte Kartierung von Cozzo (1960). Die natürliche Regeneration von Araukarienbeständen wurde anhand von Vegetationsaufnahmen exemplarisch auf einer 2 Hektar großen Untersuchungsfläche in einem weitgehend naturnahen und wenig gestörten Waldareal untersucht.

Die Ergebnisse der Untersuchungen belegen, daß die ehemals landschaftsprägenden natürlichen Araukarienwälder gegenwärtig auf geringe Restbestände reduziert sind, die überwiegend mit vereinzelten, häufig überalterten und schwachen Individuen bestockt sind. Insgesamt verblieben gegenüber der Erhebung von Cozzo (1960) nur noch rund 4% der ursprünglichen Bestände. Die Untersuchungen zur Regenerationsfähigkeit der *Araucaria angustifolia* zeigen entgegen den Schlußfolgerungen von Seitz (1982), daß diese in naturnahen Beständen mit mehr als sieben Juvenilpflanzen (> 1 m) pro Hektar durchaus ausreichend ist, um eine Verjüngung und somit den Erhalt der Spezies zu gewährleisten. Dennoch erscheint offensichtlich, daß aufgrund der unzureichenden Anwendung des Gesetzes zum Schutze der Araukarien (Gesetz 2380), der fortgesetzten illegalen Abholzung verbliebener Individuen sowie der geringen Restbestände, die sich zumeist aus schwachen oder kranken und überalterten Bäumen zusammensetzen, der Fortbestand der natürlichen Araukarienwälder in der Provinz Misiones ohne ein angepaßtes Managementkonzept kaum zu gewährleisten sein wird.

Dokumentation des Landnutzungs- und Landschaftswandels

Zur Kartierung der aktuellen Landnutzung hat sich in den vergangenen Jahren verstärkt die GIS-gestützte Auswertung von Satellitenbilddaten mittlerer Auflösung (5 – 30 m) mittels fortschrittlicher Klassifikationsverfahren durchgesetzt. Die Untersuchung des Landnutzungswandels im Untersuchungsgebiet im Verlauf der vergangenen vier Jahrzehnte wurde durch Luftbildauswertungen und die Analyse multi-temporaler Satellitenbilder der Sensoren Landsat Thematic Mapper (TM) und Landsat Enhanced Thematic Mapper plus (ETM+) realisiert.

Eine zwischen 1986 und 2001 aufgezeichnete Satellitenbildzeitreihe mit Szenen von Landsat 5 (TM) und Landsat 7 (ETM+) wurde zur Erfassung der Veränderungen der Waldbedeckung ausgewertet. Die Prozessierung der dazu verwendeten Einzelszenen umfaßte neben einer präzisen Georeferenzierung diverse Korrektur- und Normalisierungsschritte (Rauschunterdrückung, Atmosphärenkorrektur, etc.). Daran anschließend wurden die Bilddaten mittels eines überwachten Klassifikationsalgorithmus (Maximum Likelihood) prozessiert. Hierbei flossen die Ergebnisse von Geländekartierungen in Form georeferenzierter Trainingsgebiete und Nutzungsstatistiken als Bodenkontrolldaten in die Klassifikation ein. Die Qualität der Klassifikationsergebnisse wurde anhand einer KAPPA-Analyse und einer globalen Genauigkeitsuntersuchung evaluiert. Hierzu wurden 47 Kontrollflächen und rund 800 zufällig verteilte Meßpunkte in den klassifizierten Datensätzen ausgewertet. Diese Evaluation belegt mit $K_{hat} > 0.9$ % die allgemeine Güte der Klassifikationsergebnisse.

Die Vegetationsbedeckung des Jahres 1962 wurde anhand von Vegetationskarten und historischen Luftbildern ermittelt.

Zeitliche Veränderungen der Vegetationsdecke wurden durch Analysen der Klassifikationsergebnisse sowie differentielle Auswertungen des normalisierten Vegetationsindex (Normalised Differential Vegetation Index, NDVI) untersucht. Dazu wurden die erfaßten Vegetationstypen zu fünf Landnutzungsklassen zusammengefaßt:

- Waldflächen (natürliche und degradierte Wälder, Aufforstungsflächen und Baumplantagen)
- Landwirtschaftliche Nutzflächen (Acker- und Weideland, Mate- und Teeplantagen)
- Brachflächen
- Vegetationsfreie Flächen
- Wasserflächen

Die Auswertung der Datensätze belegt übereinstimmend die drastische Reduktion der Waldflächen im Untersuchungsgebiet um rund 19% zwischen 1962 und 2001. Im gleichen Zeitraum hat sich der Anteil der landwirtschaftlichen Nutzflächen annähernd vervierfacht. Die durchschnittliche Verlustrate an Waldflächen lag im Gesamtzeitraum 1962 – 2001 bei 1908 ha a^{-1}, wohingegen allein in den Jahren zwischen 1986 und 2001 jährlich mehr als 3500 ha entwaldet wurden.

Erfassung der Bodendegradation

Die Erfassung aktueller Bodendegradationsprozesse im Untersuchungsgebiet und die Ermittlung deren Ursachen bildeten zusammen mit der Abschätzung des potentiellen Risikos einer fortschreitenden Bodenerosion die wesentlichen Schwerpunkte dieses Arbeitsabschnitts. Die im Untersuchungsgebiet durchgeführten Geländearbeiten setzten sich aus der Kartierung aktueller Erosionsphänomene, der Aufnahme von Bodenprofilen und Messungen der Infiltrationskapazität sowie der Erhebung räumlicher Daten zur Abschätzung des Erosionsrisikos zusammen. Neben diesen umfangreichen Geländeerhebungen wurden unter Nutzung eines geographischen Informationssystems Satellitenbilder ausgewertet und Bodenerosionsprozesse unter Anwendung eines auf der Bodenabtragsgleichung Universal Soil Loss Equation (USLE) basierenden Erosionsmodells simuliert.

Zur Messung bodenphysikalischer und -chemischer Parameter wurden an elf, für den Untersuchungsraum charakteristischen Bodenprofilen Proben gesammelt, die anschließend labortechnisch analysiert und statistisch ausgewertet wurden. Die Infiltrations- und Bodendichtemessungen wurden auf sechs durch den Bodentyp Rhodic hapludox charakterisierten Standorten unterschiedlicher Nutzung (Wald, Mateplantage, Weideland, Ackerflächen und vegetationsfreier Boden) beziehungsweise auf drei durch Distric eutochreptes – Böden geprägten Waldparzellen, die mit unterschiedlichen forstlichen Bearbeitungsmethoden bewirtschaftet werden, durchgeführt. Die Messungen der Infiltrationskapazität erfolgten mit einem Ringinfiltrometer. Nach der Bestimmung der initialen Boden-feuchte wurden jeweils drei Einzelmessungen zur Bestimmung der Infiltrationsrate durchgeführt. An den gleichen Standorten erfolgte die Bestimmung der Bodendichte in drei Tiefenniveaus (0-5, 5-10, 10-15 cm). Die Meßdaten wurden durch eine Varianzanalyse (ANOVA) statistisch ausgewertet um die Auswirkungen der unterschiedlichen Nutzungsklassen und Bewirtschaftungsmethoden auf die Bodenbeschaffenheit zu untersuchen.

Die Meßergebnisse belegen, daß der Anteil organischer Materie in den obersten 10 cm auf entwaldeten Flächen deutlich abnimmt. Während auf Waldstandorten hierbei der Anteil organischen Materials bei rund 4.2% liegt, werden auf landwirtschaftlichen Nutzflächen lediglich 2.3% gemessen. Signifikante Unterschiede konnten bei der Auswertung der Dichtemessungen unterschiedlicher Standorte beobachtet werden ($P < 0.001$). Hierbei zeigte es sich auf den Rhodic hapludox – Standorten, daß die oberflächennahe Bodendichte mit der Intensität der Bodenbewirtschaftung stark zunimmt. Gegenüber den Waldstandorten mit einer durchschnittlichen Bodendichte von 0.87 g cm^{-3} stieg der Wert auf rund 1.19 g cm^{-3} auf Maisfeldern. Die Ergebnisse der Infiltrationsmessungen zeigten auf allen Standorten hohe Variabilitäten. Dabei wurden maximale Infiltrationsraten von 37 mm h-1 auf Waldböden gemessen, wohingegen minimale Werte von lediglich 0.9 mm h-1 auf degradierten, vegetationsfreien Standorten ermittelt wurden. Generell zeigte sich bei allen Messungen eine hohe Korrelation zwischen den gemessenen Infiltrationsraten und den jeweiligen Bodendichtewerten ($r=0.82$ auf Rhodic Hapludox – Böden beziehungsweise $r=0.92$ auf den Distric Eutocreptes –Standorten).

Das GIS-gestützte Modellierung zur Risikoabschätzung des Erosionspotentials basierte auf fünf Informationsebenen (Niederschlag, Bodeninformationen, Bodennutzungsdaten, Relief und Bewirtschaftungform). Zur Berechnung des Hanglängen- und Hangneigungsfaktors LS des verwendeten USLE-Models wurde ein digitales Geländemodel des Untersuchungsgebietes (Bodenauflösung 10 m) erzeugt. Darüber hinaus standen eingemessene Hangprofile zur Verfügung. Neben den im Gelände erhobenen, mittels GPS-Messungen geo-referenzierten Bodenmeßdaten diente die auf den Landsat ETM+ Daten basierende Landnutzungsklassifikation 2001 als Eingangsdatensatz für die Modellierung. Neben den im Gelände erhobenen, mittels GPS-Messungen georeferenzierten Bodenmeßdaten diente die auf den Landsat ETM+ Daten basierende Landnutzungsklassifikation 2001 als Eingangsdatensatz für die Modellierung des Faktors C.

Die Modellierungsergebnisse zeigen, daß ein hoher Anteil landwirtschaftlicher Nutzflächen einem mittleren bis sehr hohen Erosionsrisiko ausgesetzt sind: Unter Berücksichtigung eines R-Wertes von 207.6 mm weisen 52% dieser Flächen potentielle Bodenverlustraten zwischen 20 und 100 tn ha^{-1} y^{-1} auf (13.5 bis 68.0 m^3 ha^{-1} y^{-1}). Demgegenüber weisen die locker mit Bäumen bestockten Areale (degradierter Wald, Aufforstungen, Capuera) vergleichsweise geringe potentielle Abtragsraten auf (82% der Flächen weniger als 5 tn ha^{-1} y^{-1} beziehungsweise 3.5 m^3 ha^{-1} y^{-1}). Niedrigste Werte mit weniger als 1 tn ha^{-1} y^{-1} (0.7 m^3 ha^{-1} y^{-1}) wurden auf dicht bestockten Waldstandorten ermittelt.

Zusammenfassend zeigen die auf den Geländeerhebungen und der Satellitenbildanalyse basierenden Ergebnisse deutlich, daß die Population von *A. angustifolia* in der Provinz Misiones aufgrund der starken Übernutzung weitgehend zerstört ist. Insbesondere die vergangen zwei Jahrzehnte waren dabei durch sehr intensive Rodungsaktivitäten und eine rasche Ausdehnung landwirtschaftlicher Nutzflächen geprägt. Beträchtliche Gebiete, darunter vorrangig agrarisch genutzte Flächen, zeigen deutliche Anzeichen einer fortschreitenden Bodendegradation und sind folglich dadurch einem hohen Erosionsrisiko ausgesetzt. Die dargelegten Erkenntnisse weisen eindeutig darauf hin, daß für das Überleben der Araukarien-wälder eine rasche Revision sowohl der unmittelbaren Schutzmaßnahmen als auch der regionalen Agrar- und Forstpolitik erforderlich ist. Gleichermaßen erscheint es in Anbetracht der in der lokalen Landbevölkerung weitverbreiteten Unkenntnis hinsichtlich angepaßter Managementmethoden und einem effektiven Ressourcenschutz unerläßlich, wirkungsvollere Verfahren der Informationsvermittlung und technischen Beratung zu etablieren, um zukünftig eine nachhaltige Nutzung der wertvollen Ressourcen Wald und Boden zu gewährleisten. Aufbauend auf der im Rahmen dieser Studie entwickelten Methodik wird zur Kontrolle zukünftiger Schutzmaßnahmen die regelmäßige und großräumige Überwachung der Araukarienwälder im Rahmen eines auf multi-temporalen und multi-sensoralen Satellitenbilddaten basierenden Monitoringprogramms empfohlen.

9. RESUMEN

Originalmente, los bosques de araucaria fueron paisaje característico del nordeste de Misiones, cubriendo aproximadamente 210.000 hectáreas. La amplia variedad de posibles usos de la madera de araucaria, así como la creciente necesidad de tierras para uso agrícola, llevaron, sin embargo, al hecho de que estos bosques fueran durante el pasado siglo fuertemente explotados. En tan sólo 50 años, de la existencia original de A. angustifolia en la Provincia de Misiones, estimada aproximadamente en 500.000 individuos previo a la explotación, fueron dejados apenas el 5 % en 1992. Posterior al agotamiento de los rodales de araucaria, una industria maderera quedó establecida en la región, a partir del cual y junto al crecimiento de la población local, continuó la tala selectiva sobre otras especies maderables, produciéndose una rápida expansión de la frontera. A pesar de su valor económico y natural, hasta hoy los bosques de araucaria en la Provincia de Misiones han sido escasamente estudiados.

El objetivo del presente estudio fue evaluar el estado actual del bosque de araucarias, cambios del uso del suelo posterior a la deforestación y su impacto en el recurso suelo en la Provincia de Misiones. A partir de los resultados obtenidos se derivaron coclusiones tendientes a contribuir con futuras planificaciones y tomas de decisiones en el manejo sustentable de los recursos. A este fin, las siguientes áreas temáticas fueron investigadas:

– Estimación de la de *A. angustifolia*
– Cambios del uso del suelo
– Degradación de suelos

Las investigaciones para este estudio fueron desarrolladas al NE de la Provincia de Misiones, entre los 25°40' S y 26°50' y entre los 54°15' O y la frontera con Brasil.

Estimación de la población de A. *angustifolia*

Con el objetivo de evaluar el actual estado del bosque de araucarias y el estado poblacional de *A. angustifolia*, se llevaron a cabo procesos combinando la interpretación de fotografías aéreas y reconocimientos aéreos y terrestres. Los datos de la existencia original de *A. angustifolia* se basaron en aquellos publicados por COZZO (1960). Asimismo, con el propósito de obtener información sobre regeneración natral de *A. angustifolia*, se llevó a cabo un inventario de vegetación, tanto de individuos adultos como renovales, en una parcela de 2 hectáreas en un bosque escasamente perturbado. Los resultados mostraron que actualmente la población de *A. angustifolia* se encuentra completamente fragmentada, compuesta principalmente por individuos aislados, ya sea de escaso porte o sobremaduros, quedando menos del 4 % de su existencia original. La regeneración de la araucaria (plantas > 1 m) dentro de bosque, con más de 7 individuos por hectárea, es satisfactoria y sería suficiente, comparando los resultados con los obtenidos por SEITZ (1982), para perpetuar la especie. A pesar de estos resultados satisfactorios, la ineficiente aplicación de la Ley 2380 y la continua tala ilegal de los ejemplares de araucaria, el creciente resentimiento de la gente contra ésta, el escaso número de individuos remanentes y el mal estado sanitario o sobremadurez de los mismo, hace casi imposible, sin un apropiado manejo, la continuidad natural de la araucaria en la Provincia de Misiones.

Cambio del Uso del Suelo

Las imágenes satelitales de resolución espacial media (5-30 m) son cada vez más utilizadas como herramientas para el mapeo de coberturas de suelo. La naturaleza digital de éstas permiten un avanzado análisis computarizado, clasificación y compatibilidad con sistemas de información geográficos (SIG).

A fin de identificar y cuantificar los cambios en el uso del suelo durante las últimas cuatro décadas en el área de estudio, se realizó un análisis multitemporal a partir de imágenes Landsat Thematic Mapper (TM) and Landsat Enhanced Thematic Mapper plus (ETM+). Una serie temporal de imágenes Landsat 5 y Landsat 7 entre 1986 y 2001 fue analizada con el objetivo de detectar cambios en la cobertura del bosque. Para analizar apropiadamente esta serie temporal, se llevó a cabo un conjunto de correcciones, las cuales incluyeron reducción de ruidos, corrección atmosférica y normalización de los datos de ambas imágenes. Posteriormente estas imágenes fueron clasificadas por medio del algoritmo Maximun Likelihood, usando como referencia, para la imagen del 2001, áreas de entrenamiento obtenidas y geoposicionadas a campo, mientras que para la imagen de 1982 se usaron estadísticas de la imagen 2001. Un análisis KAPPA y un análisis global de exactitud fueron realizados a fin de evaluar la exactitud de las clasificaciones. Para esto se utilizaron 47 áreas de entrenamiento destinadas a tal fin y aproximadamente 800 puntos seleccionados al azar en ambas imágenes clasificadas. Los tipos de coberturas vegetales correspondientes al año 1962 se obtuvieron a partir de mapas de vegetación y fotografía aérea histórica. Métodos de comparación post-clasificación e imagen diferencia del Índice Normalizado de Vegetación (NDVI) fueron empleados como medio de detección de cambios. Para el análisis se seleccionaron cinco categorías principales de tipos de usos de suelo, acorde a los niveles propuestos por el US Geological Survey: a) Tierras forestales (bosque semidec. denso, bosque semidec. degradado y reforestaciones), b) Tierras agrícolas-ganaderas (cultivos de yerba mate, cultivos de te, cultivos anuales y pastura), c) Tierras yermas, d) Suelo desnudo y d) Cuerpos de agua. Ambas clasificaciones mostraron una alta exactitud, con una exactitud global y K_{hat} mayores al 90 % y 0.9 respectivamente. El análisis de todos los datos proporcionaron resultados consistentes, con una notable pérdida de cubierta boscosa entre 1962 y el 2001 de aprox. el 19 %, mientras que las áreas agrícolas prácticamente cuadruplicaron su superficie. La tasa promedio de deforestación (por tala rasa) fue entre 1962 y 2001 de alrededor de 1908 ha año^{-1}, mientras que en el período entre 1986 y 2001 fue de 3515 ha año^{-1}.

Degradación del suelo

El objetivo de esta parte del estudio fue evaluar y determinar el riesgo de erosión y las posibles causas de la erosión del suelo por agua, utilizando imágenes satelitales, sistemas de información geográfica y la Ecuación Universal para Pérdidas de Suelos (modelo USLE). Globalmente, la metodología comprendió observaciones de campo, mediciones de capacidad de infiltración y densidad aparente, y la obtención de datos espaciales para la predicción del riesgo de erosión. A estos tres pasos les siguió análisis de laboratorio, análisis estadísticos y el modelado espacial del riesgo de erosión en un SIG. El primer paso involucró el cavado de perfiles y la obtención de muestras de suelo. Para esto, se cavaron 11 perfiles de suelo y en total, 41 muestras fueron colectadas. Las mediciones de capacidad de infiltración y densidad aparente se llevaron a cabo, por un lado, en 6 parcelas bajo cinco diferentes tipos de coberturas/usos de suelo (bosque, yerba mate, pastura, maíz, mandioca, suelo desnudo) en un Hapludox ródico y por otro, en tres parcelas bajo el uso de diferentes tipos mecanizados de deforestación (machete, topadora y zanello) en un Eutocreptes dístrico. La capacidad de infiltración fue medida por medio de un infiltrómetro de anillo simple. En promedio, se realizaron tres repeticiones por tratamiento. Otra muestra fue obtenida a fin de determinar el contenido de humedad inicial. Las muestras para determinar densidad aparente fueron tomadas a tres profundidades (0-5, 5-10, 10-15 cm), con cinco repeticiones por tratamientos. La obtención de datos espaciales involucró la medición de largo y grado de pendiente. Los once perfiles de suelo y largo y grado de pendiente fueron geoposicionados por medio de un GPS. Los datos de infiltración y densidad aparente fueron analizados estadísticamente por medio de un Análisis de Varianza (ANOVA) entre grupos, a fin de examinar efectos entre los diferentes usos del suelo y propiedades físicas del suelo. Para el modelo de predicción del riesgo de erosión, se crearon cinco capas de información. Asimismo, se generó un 10 m modelo digital de elevaciones a fin de derivar los valores para el factor LS del modelo USLE. Los valores para obtener el factor C fueron extraídos del mapa de usos del suelo del 2001 obtenido a partir de la clasificación de la imagen satelital Landsat 7 ETM+ y de datos obtenidos a campo.

Los resultados revelaron que el contenido de materia orgánica del suelo (MOS) en los primeros 10 cm decreció considerablemente luego de la deforestación, yendo de 4.2 en suelos bajo bosque a 2.3 % en suelo bajo uso agrícola. Diferencias significativas fueron observadas entre la densidad aparente (r_b) en todos los tratamientos ($P < 0.001$). La r_b en el Hapludox ródico aumentó con el incremento del uso intensivo del suelo, con valores entre 0.87 g cm^{-3} en suelos cubierta forestal y 1.19 g cm^{-3} en suelos bajo cultivos de maíz. En el Eutocreptes dístrico la mayor r_b fue registrada en suelos bajo uso sólo de zanello. La tasa de infiltración fue muy variable en ambos grupos de mediciones, oscilando entre 37 mm h^{-1} en suelos bajo bosque y 0.9 mm h^{-1} en suelos desnudos. Hubo una alta correlación entre la tasa de infiltración y la densidad aparente en todos los tratamientos ($r=0.82$ and $r=0.92$ en el Hapludox ródico y Eutocreptes dístrico respectivamente).

Los resultados obtenidos a partir del modelo de erosión mostraron que hay una gran cantidad de hectáreas vulnerables a moderado, alto y muy alto riesgo de erosión en tierras bajo uso agrícola. Considerando el valor R = 207.6, el 52 % de estas áreas tienen una potencial pérdida anual de suelo entre 20 y 100 tn ha^{-1} y^{-1} (13.5 a 68 m^3 ha^{-1} y^{-1}), mientras que la perdida de suelo es comparativamente baja (82% menos que 5 tn ha-1 y-1 o 3.5 m^3 ha-1 y-1) en suelos bajo bosque degradado, reforestaciones y capuera. La más baja tasa de pérdida de suelo (menos que 1 tn ha^{-1} y^{-1} o 0.7 m^3 ha^{-1} y^{-1}) fue registrada en áreas bajo bosque denso. El 3.47 % de las áreas con profundas laderas exceden las 10 tn ha^{-1} y^{-1}.

En resumen, se observó que la población de *A. angustifolia* se encuentra casi devastada como consecuencia de una extrema sobreexplotación. Una alta tasa de deforestación y un rápido avance de la frontera agrícola tomaron lugar particularmente durante los últimos 20 años. Vastas áreas, especialmente bajo agricultura fueron encontradas con alto grado de riesgo de erosión y con claros indicios de degradación del suelo por inadecuadas prácticas de uso del suelo. Todo esto conduce a una urgente revisión de políticas, tanto de conservación como agrícolas y forestales de la provincia. Asimismo, ante el desconocimiento observado en la población rural de mejores técnicas de manejo y conservación de los recursos, es también indispensable generar en el futuro mejores canales de información y la llegada de adecuado asesoramiento técnico en vistas de un verdadero aprovechamiento sustentable de los recursos. Finalmente, y basado en la metodología desarrollada en este estudio, un consistente programa de monitoreo a través del uso de imágenes satelitalres tendría que ser llevado a cabo, a fin de controlar la aplicación de póliticas de conservación y, por consiguiente, para asegurar la protección del bosque de araucarias en el futuro.

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11. APPENDIX

Appendix I: Methods of data-analysis

1) Estimate of variables of the inventoried vegetation

In many studies, the vegetable communities are described and compared assisting the presence or the absence of certain categories. The variables describe the behavior, yield, abundance or dominance of these categories in the community. The following variables were described from the census of vegetation:

- Relative abundance a specie:

$$rA_i = \frac{N_i}{N} * 100$$

where N_i – number a specie
N – number total individuals
i - specie

- Percentage frequency a specie:

$$F_i = \frac{m_i}{M} * 100$$

where m_i - number of parcels in that the species occur
M – total number of parcels
i - specie

- Relative frequency a specie:

$$rF_i = \frac{F_i}{\sum_{i=1}^{n} F_i} * 100$$

where $F\%_i$ – percentage frequency a specie
i - specie

2) Diversity indexes

In the strictest ecological sense, the diversity is a measure of the heterogeneity of the system that means the quantity and proportion of the different elements that it contains. Besides the meaning that has the diversity itself, it is also a very useful parameter in the research, describing and comparing the ecological communities.

Numerous measures of diversity somehow boil rank abundance data reduce to one number, being variously influenced by species richness, species evenness, or both. Common diversity measures are sample species richness, Alpha, the Shannon-Wiener Index (H), the Simpson's Diversity Index (D), Margalef (Da) and the Berger-Parker index (d). These measures vary due to how they are influenced by the species abundance distribution. For this research, the Reciprocal Simpson (1/D) and the Shannon-Wiener indexes were used. The first is strongly influenced by the few most abundant species ("Dominance index") and the second is influenced by both species richness and by the dominant species.

- Shannon-Wiener Index: $H = -\sum (p_i \ln p_i)$

Where p_i - proportion of the total number of specimens i expressed as a proportion of the total number of species for all species in the ecosystem.

- Simpson diversity index: $D = \sum \left[\frac{n_i(n_i - 1)}{N(N - 1)} \right]$

where n_i - total number of organisms of a particular species
N - total number of organisms of all the species

The higher D the lower the diversity, so the reciprocal of D the higher number means higher diversity.

- Evenness (E): $E = \frac{H}{H_{max}}$

where H_{max} - the maximum possible value of H, and is equivalent to ln S

Thus $H_{max} = \ln S$

S – species richness

The Evenness index can fluctuate between 0 and 1, corresponding the first one to the total dominance of one species, while a value of 1 expressed an individuals uniform distribution among the species.

APPENDIX II: List of Species

Table 9-1: List of species

Familie	Nr.	Specie	Common Name	Growth-form
ACHATOCARPACEAE	1	*Achatacarpus bicornutus*	Talera	2
AMARANTACEAE	2	*Chamissoa acunimata*		6
ANNONACEAE	3	*Annona longifolia*	Ariticum	2
APOCINACEAE	4	*Aspidosperma australe*	Guatambú amarillo	1
AQUIFOLIACEAE	5	*Ilex paraguariensis*	Yerba mate	1
ARALIACEAE	6	*Didymopanx morototoni*	Cacheta or Ambaí guazú	1
	7	*Pentapanax warmigiana*	Sabuguero	1
ARAUCARIACEAE	8	*Araucaria angustifolia*	Pino paraná	1
ARECACEAE	9	*Syagrus romanzoffiana*	Pindó	7
	10	*Aristolochia elegans*	Isipó de Cobra	8
	11	*Aristolochia triangularis*	Isipó mil hombres	8
	12	*Muticia coccinea*	Clavo divino blanco	8
	13	*Pseudogynoxys benthamii*		8
BIGNONACEAE	14	*Jacaranda serratifolia*	Caroba	1
	15	*Adenocalymma marginatum*	Isipó vaquero	8
	16	*Adenocalymma paulistarum*		8
	17	*Arrabidaea chica var. cuprea*	Carajuru	8
	18	*Arrabidaea mutabilis*	Cipó-camarao	8
	19	*Clystotoma sciuripabulum*	Cipó-pau	8
	20	*Macfadyena unguis-cati*	Uña de gato	8
	21	*Macfadyena dentata*	Isipó de canoa	8
	22	*Pithecoctenium echinatum*	Peine de mono	8
	23	*Pyrostegia venusta*	San Juan	8
BOMBACACEAE	24	*Chorisia speciosa*	Samohú	1
BORRAGINACEAE	25	*Cordia trichotoma*	Loro negro o Peteribi	1
	26	*Patagonula americana*	Guayubira	1
CARICACEAE	27	*Jacaratia sp.*	Yacaratiá	2
CELESTRACEAE	28	*Maytenus elicifolia*	Cancorosa	6
CESALPINACEAE	29	*Gleditzia amorphoides*	Espina de Corona	2
	30	*Myroxilon perviferum*	Quina o Palo amargo	2
COMELINACEAE	31	*Dichorisandra aubletiana var. intermedia*		6
CONVOLVULACEAE	32	*Calonyction aculeatum*	Dama de noche	8
	33	*Ipomoea cairica*	Campanilla	8
CYATHEACEAE	34	*Alsophila procera*	Chachi bravo	4
	35	*Diksonia sellowiana*	Chachí manso	4
EUFORBIACEAE	36	*Manihot tweediana*	Mandioca brava	3
FABACEAE	37	*Machaerium stipitatum*	Canela breya o isapuí	2
	38	*Albizzia hassleri*	Anchico blanco	1
	39	*Apuleia leiocarpa*	Grapia	1
	40	*Enterolobium contortisiliquum*	Timbó	1

1 = Tree, 2 = Small tree, 3 = Shrub, 4 = Arboreal fern, 5 = Bambus, 6 = Herbaceus, 7 = Palm, 8 = Liana

Familie	Nr.	Specie	Common Name	Growth-form
	40	*Enterolobium contortisiliquum*	Timbó	1
	41	*Holocalyx balansae*	Alecrin	1
	42	*Lonchocarpus leucanthus*	Rabo itá	1
	43	*lonchocarpus muehlbergianus*	Rabo molle	1
	44	*Peltophorum dubium*	Canafístula o Ibira pitá	1
	45	*Erythrina falcata*	Seibo	1
	46	*Myrocarpus frondosus*	Incienso	1
	47	*Parapiptadenia rigida*	Anchico colorado	1
	48	*Acacia velutina var. monadena*	Yuquerí	3
	49	*Inga affinis*	Ingay	2
FLACOURTIACEAE	50	*Banara bernadinensis*	Guazatumba	1
LAUREACEAE	51	*Nectandra lanceolata*	Laurel amarillo	1
	52	*Ocotea dyospirifolia*	Laurel ayuy	1
	53	*Ocotea puberula*	Laurel guaicá	1
	54	*Nectandra saligna*	Laurel negro	1
LOGANIACEAE	55	*Strychnos niederleinii*	Espolón de Gallo	2
	56	*Spigelia humboldtiana*		6
MALVACEAE	57	*Bastardiopsis densiflora*	Loro blanco	1
	58	*Cabralea canjerana*	Cancharana	1
	59	*Cedrela fissilis*	Cedro	1
	60	*Ficus enormis*	Higuerón	1
MARANTACEAE	61	*Ctenanthe casupoides var. subtropicalis*		6
MORACEAE	62	*Alcornia sp.*	Mora blanca	1
	63	*Cecropia adenopus*	Ambay	1
	64	*Clorophora tinctoria*	Mora amarilla	1
	65	*Sorocea bonplandi*	Ñandipá	2
MYRSINACEAE	66	*Rapanea ferruginea*	Caá pororo	2
	67	*Rapanea lorentziana*	Canelon	2
MYRTACEAE	68	*Campomanesia xanthocarpa*	Guabirá o Guabiroba	1
	69	*Eugenia involucrata*	Guabiyú	1
	70	*Myrciaria cauliflora*	Yabuticaba	2
	71	*Plinia baporeti*	Guaporoití	2
PIPERACEAE	72	*Piper geniculatum*	Pariparoba	2
POACECAE	73	*Chusquea ramosissima*	Tacuarembó o crisiuma	5
	74	*Guadua angustifolia*	Tacuara	5
	75	*Guadua trinii*	Yatebó o tacuaruzu	5
	76	*Merostachys clausseni*	Tacuapí	5
POLIGNOACEAE	77	*Ruprecchtia laxiflora*	Marmelero	1
POLIPODACEAE	78	*Blechnum polypodioides*		6
	79	*Didymochlaena truncatula*		6
	80	*Doryopteris concolor*		6
	81	*Doryopteris palmata*		6

1 = Tree, 2 = Small tree, 3 = Shrub, 4 = Arboreal fern, 5 = Bambus, 6 = Herbaceus, 7 = Palm, 8 = Liana

Familie	Nr.	Specie	Common Name	Growth-form
	82	*Dryopteris submarginalis*		6
ROSACEAE	83	*Prunus subcoriacea*	Persiguero	1
RUBIACEAE	84	*Coussarea contracta*		3
	85	*Psychotria leiocarpa*		3
	86	*Psychotria brevicollis*		6
RUTACEAE	87	*Balfourodendron riedelianum*	Guatambú blanco	1
	88	*Fagara naranjillo*	Naranjillo	3
	89	*Fagara sp.*	Mamica de caela	2
	90	*Helietta cuspidata*	Canela de venado	2
SAPINDACEAE	91	*Diatenopteryx sorbifolia*	María Preta	1
	92	*Allophylus edulis*	Cocu	2
	93	*Matayba eleagnoides*	Camboatá	2
	94	*Cardiospermun grandiflorum*	Isipó timbó miúdo	8
	95	*Paullinia elegans*	Isipó timbó	8
SAPOTACEAE	96	*Chrysophyllum marginatum*	Vasuriña	1
	97	*Chrysophyllum gonocarpum*	Aguai	2
SOLANACEAE	98	*Solanum verbascifolium*	Fumo bravo	2
STYRACEAE	99	*Styrax leprosus*	Carne de vaca	2
TITILACEAE	100	*Luehea divaricata*	Azota caballo	1
ULMACEAE	101	*Celtis tala*	Tala	2
	102	*Trema micrantha*	Palo pólvora	2
UMBELIFERAE	103	*Hydrocotyle leucocephala*		6
URTICACEAE	104	*Urera baccifera*	Ortiga brava	3
VERBENACEAE	105	*Vitex montevidensis*	Tarumá	2
	106	*Trichilia catigua*	Pitanga	2

1 = Tree, 2 = Small tree, 3 = Shrub, 4 = Arboreal fern, 5 = Bambus, 6 = Herbaceus, 7 = Palm, 8 = Liana

Table 9-2: List of species at the sampled plots.

Familie	Nr.	Specie	Common Name	Growth-form
ACHATOCARPACEAE	1	*Achatacarpus bicornutus*	Talera	2
ANNONACEAE	3	*Annona longifolia*	Ariticum	2
AQUIFOLIACEAE	5	*Ilex paraguariensis*	Yerba mate	1
ARALIACEAE	6	*Didymopanx morototoni*	Cacheta or Ambaí guazú	1
	7	*Pentapanax warmigiana*	Sabuguero	1
ARAUCARIACEAE	8	*Araucaria angustifolia*	Pino paraná	1
BIGNONACEAE	14	*Jacaranda serratifolia*	Caroba	1
BORRAGINACEAE	25	*Cordia trichotoma*	Loro negro o Peteribi	1
	26	*Patagonula americana*	Guayubira	1
CARICACEAE	27	*Jacaratia sp.*	Yacaratiá	2
	30	*Myroxilon perviferum*	Quina o Palo amargo	2
CYATHEACEAE	34	*Alsophila procera*	Chachi bravo	4
FABACEAE	38	*Albizzia hassleri*	Anchico blanco	1
	39	*Apuleia leiocarpa*	Grapia	1
	40	*Enterolobium contortisiliquum*	Timbó	1
	41	*Holocalyx balansae*	Alecrin	1
	42	*Lonchocarpus leucanthus*	Rabo itá	1
	44	*Peltophorum dubium*	Canafístula o Ibira pitá	1
	45	*Erythrina falcata*	Seibo	1
	46	*Myrocarpus frondosus*	Incienso	1
	47	*Parapiptadenia rigida*	Anchico colorado	1
	49	*Inga affinis*	Ingay	2
LAUREACEAE	51	*Nectandra lanceolata*	Laurel amarillo	1
	52	*Ocotea dyospirifolia*	Laurel ayuy	1
	53	*Ocotea puberula*	Laurel guaicá	1
	54	*Nectandra saligna*	Laurel negro	1
LOGANIACEAE	55	*Strychnos niederleinii*	Espolón de Gallo	2
MALVACEAE	58	*Cabralea canjerana*	Cancharana	1
	59	*Cedrela fissilis*	Cedro	1
	60	*Ficus enormis*	Higuerón	1
MORACEAE	63	*Cecropia adenopus*	Ambay	1
	64	*Clorophora tinctoria*	Mora amarilla	1
MYRSINACEAE	66	*Rapanea ferruginea*	Caá pororo	2
MYRTACEAE	68	*Campomanesia xanthocarpa*	Guabirá o Guabiroba	1
	69	*Eugenia involucrata*	Guabiyú	1
	71	*Plinia baporeti*	Guaporoití	2
ROSACEAE	83	*Prunus subcoriacea*	Persiguero	1
RUTACEAE	87	*Balfourodendron riedelianum*	Guatambú blanco	1

1 = Tree, 2 = Small tree, 3 = Shrub, 4 = Arboreal fern, 5 = Bambus, 6 = Herbaceus, 7 = Palm, 8 = Liana

Familie	Nr.	Specie	Common Name	Growth-form
RUTACEAE	88	*Fagara naranjillo*	Naranjillo	3
	89	*Fagara sp.*	Mamica de caela	2
	90	*Helietta cuspidata*	Canela de venado	2
SAPINDACEAE	91	*Diatenopteryx sorbifolia*	María Preta	1
	92	*Allophylus edulis*	Cocu	2
	93	*Matayba eleagnoides*	Camboatá	2
SAPOTACEAE	96	*Chrysophyllum marginatum*	Vasuriña	1
	97	*Chrysophyllum gonocarpum*	Aguai	2
STYRACEAE	99	*Styrax leprosus*	Carne de vaca	2
TITILACEAE	100	*Luehea divaricata*	Azota caballo	1
VERBENACEAE	105	*Vitex montevidensis*	Tarumá	2

1 = Tree, 2 = Small tree, 3 = Shrub, 4 = Arboreal fern, 5 = Bambus, 6 = Herbaceus, 7 = Palm, 8 = Liana

APPENDIX III: Relative Abundance and Relative Frequency of Arboreal Vegetation at Sampled Plots

Table 9-3: Abundance by height class, relative abundance and relative frequency at the sampled plots.

		Abundance by height class						
Common Name	Scientific Name	< 2 m	2 - 4 m	4 - 8 m	> 8 m	abs. Abundance	rel. Abundance	rel. Frequency
Aguai	*Chrysophyllum gonocarpum*	2	1			3	0.28	1.67
Alecrin	*Holocalyx balansae*	8			1	9	0.83	2.78
Ambai	*Cecropia adenopus*	1	2			3	0.28	0.56
Anchico bco.	*Albizzia hassleri*	4	2	2	1	9	0.83	1.67
Anchico colorado	*Parapiptadenia rigida*	16	3	1	3	23	2.12	5
Araucaria	*Araucaria angustifolia*	34		2	4	40	3.69	5.56
Ariticum	*Annona longifolia*	1	2		3	6	0.55	2.78
Azota	*Luehea divaricata*				2	2	0.18	1.11
Cacheta	*Didymopanx morototoni*	5	4	3	2	14	1.29	4.44
Camboata	*Matayba eleagnoides*	40	2	1	1	44	4.06	5
Cañafistula	*Peltophorum dubium*	4	1	1	5	11	1.02	2.78
Cancharana	*Cabralea canjerana*	36	14	23	11	84	7.76	5.56
Canela de venado	*Helietta cuspidata*	1	11	11	3	26	2.4	5
Carne de vaca	*Styrax leprosus*	1				1	0.09	0.56
Caroba	*Jacaranda serratifolia*		2	2	1	5	0.46	2.22
Cedro	*Cedrela fissilis*	11	1	3	5	20	1.85	5
Cocu blanco	*Allophylus edulis*	8	7	13	5	33	3.05	4.44
Epolon de gallo	*Strychnos niederleinii*	3	1	1	2	7	0.65	1.11
Grapia	*Apuleia leiocarpa*	59	11	3	4	77	7.11	4.44
Guabiroba	*Campomanesia xanthocarpa*	10	3		2	15	1.39	4.44
Guaporoití	*Plinia baporeti*	7	3		1	11	1.02	4.44
Guatambu bco.	*Balfourodendron riedelianum*	86	39	14	9	148	13.7	5.56
Guayubira	*Patagonula americana*	4	2	4	2	12	1.11	3.33
Higueron	*Ficus enormis*	0			1	1	0.09	0.56
Incienso	*Myrocarpus frondosus*	6	1	2	2	11	1.02	3.33
Inga	*Inga affinis*	1				1	0.09	0.56
Lapacho amarillo		6	2	3	1	12	1.11	2.78
Laurel Amarillo	*Nectandra lanceolata*	21	6	8	17	52	4.8	3.89
Laurel ayui	*Ocotea dyospirifolia*	4	8	4		16	1.48	2.22
Laurel guaica	*Ocotea puberula*		1		3	4	0.37	2.78
Laurel Negro	*Nectandra saligna*				6	6	0.55	2.78
Laurel pimienta		7	11	7	22	47	4.34	5.56
Mamica de caela	*Fagara sp.*	1				1	0.09	0.56
Maria preta	*Diatenopteryx sorbifolia*	75	24	15	4	118	10.9	5.56

Common Name	Scientific Name	Abundance by height class						
		< 2 m	2 - 4 m	4 - 8 m	> 8 m	abs. Abundance	rel. Abundance	rel. Frequency
Mora amarilla	*Clorophora tinctoria*	1		2	4	7	0.65	2.22
Naranjillo	*Fagara naranjillo*	50	29	4		83	7.66	5.56
Palo amargo	*Myroxilon perviferum*	2	1	3	2	8	0.74	2.22
Palo de canga		5	4	1	4	14	1.29	3.33
Persiguero	*Prunus subcoriacea*	4	1	2	6	13	1.2	4.44
Peteribi	*Cordia trichotoma*			1	1	2	0.18	1.11
Pororo	*Rapanea ferruginea*	6	2	1	2	11	1.02	2.22
Rabo ita	*Lonchocarpus leucanthus*	6				6	0.55	2.78
Sabuguero	*Pentapanax warmigiana*	1				1	0.09	0.56
seibo	*Erythrina falcata*				1	1	0.09	0.56
Talera	*Achatacarpus bicornutus*			1		1	0.09	0.56
Taruma	*Vitex montevidensis*				2	2	0.18	0.56
Timbo bco.	*Enterolobium contortisiliquum*	2	1	1	1	5	0.46	2.22
Vasuriña	*Chrysophyllum marginatum*	2	2	4	3	11	1.02	3.33
Yacaratia	*Jacaratia sp.*			1		1	0.09	0.56
Yerba cauna		6	8	11	11	36	3.32	5.56
Yerba mate	*Ilex paraguariensis*	3		4	2	9	0.83	3.89

APPENDIX IV: Distribution of Abundance of Forest Arboreal Vegetation Separated by Height Classes at each Sampled Plots.

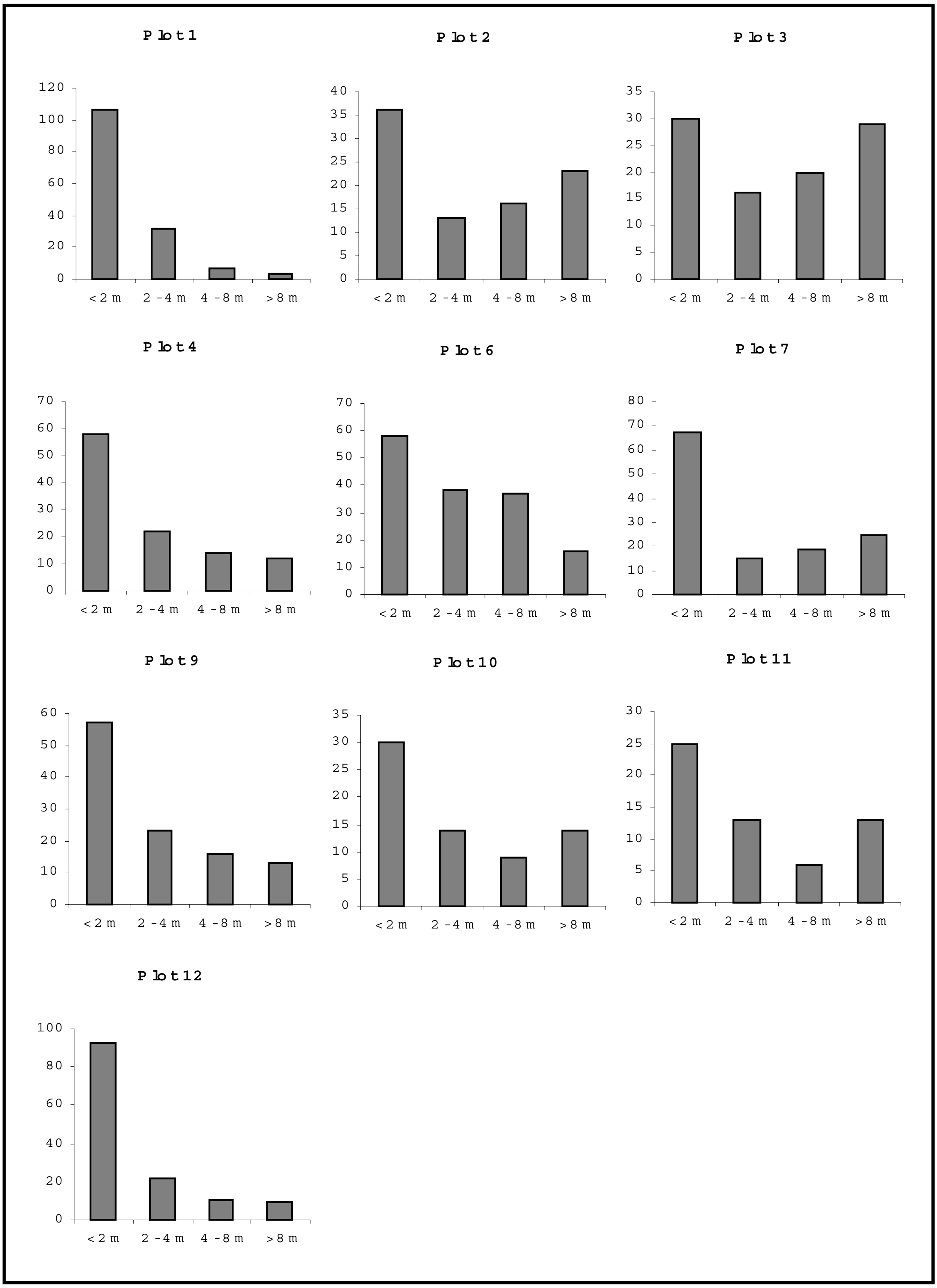

Fig. 9-1: Abundance distribution according height class.

APPENDIX V: Major tropics soils according FAO-UNESCO and US Soil Taxonomy

Table 9-4: Comparicion table amtong the major tropics soils according FAO-UNESCO and US Soil Taxonomy.

FAO-UNESCO Soil name: Soil Unit & Subunit	US Soil Taxonomy Name	FAO-UNESCO Soil name: Soil Unit & Subunit	US Soil Taxonomy Name

Acrisols
- orthic
- ferric
- humic
- plinthic
	Ultisol
	[orthic=Hapludults;
	ferric=Palexerults;
	humic=Humults;
	plinthic=plinthudults]
		Nitosols
		- eutric
		- dystric
		- humic
			Alfisols & Ultisols
			[eutric=Tropudalfs;
			dystric=Tropudults;
			humic=Trophumults]

Andosols - ochric - mollic - humic - vitric	Inceptisols - Andepts [ochric & humic=Dystrandepts mollic=Eutrandepts]	Phaeozems - haplic - calcaric - luvic	Mollisols [haplic=Hapludolls; calcaric=Vermudolls; luvic=Argiudolls]
Arenosols - cambic - luvic - ferralic - albic	Entisols - Psamments	Rendzinas	Mollisols - Rendolls

Cambisols
- eutric
- dystric
- humic
- calcic
- chromic
- vertic
- ferralic
	Inceptisols
	[eutric and
	calcic=Eutrochrepts;
	dystric=Dystrochrept;
	humic=Haplumbrepts
	vertic=Vertic Topepts;
	ferralic=Oxic
	Tropepts]
		Solonchaks
		- orthic
		- mollic
			Aridisol
			- Salorthid

Ferrasols
- orthic
- xanthic
- rhodic
- humic
- acric
- plinthic
	Oxisols
	[orthic, xanthic &
	rhodic =Orthox;
	humic=Humox;
	acric=Acrox;
	plinthic=Plinthaquox]
		Solonetz
		- orthic
			Alfisol
			- Natrustalf

Fluvisols - eutric - calcaric - dystric - thionic	Inceptisols - Fluvents [thionic=Sulphaquept or acid sulphate]	Vertisols - pellic - chromic	Vertisols [pellic=Pelluderts; chromic=Chromudert]
Histosols - eutric - dystric	Histosols	Xerosols	Aridisols
Luvisols - orthic - chromic - calcic - vertic - ferric - plinthic	Alfisols [orthic=Hapludalfs; chromic=Rhodexeralf calcic=Haplustalf; vertic=Vertic Haploxeralfs]	Yermosols	Aridisols

APPENDIX VI: Socio-economic and Cultural Interview

Data: Interviewer:

Demographic data

1. Number members family

	Relationship	Age	Sex	Education level	Profession
1					
2					
3					
4					
5					
6					
7					

For more 7 persons, indicate only quantity

2. Nationality

3. Family revenues (monthly or annual): $

4. Antiquity in the region: ....years

5. Antiquity in the property/farm: ....years

6. Size and type property (farm, sawmill, etc.)
Size (ha):

7. Property location
District:............................... Parcel:.......................

Socio-economic data

9. You are 1 = renter; 2 = landowner 3 = licensee 4 = occupier
If 1, go to 10 - if 2 go to 14

10. Who is the landowner?

11. Do you pay for the use of the property? Yes / No
If yes, go to 12; if not go 13

12. How do you pay the rent? 1 = cash; 2 = products; 3 = other (to specify)

1 2 3

13. Do you plan to buy the property in the future? Yes / No

14. Do you have more than this property? Yes / No

15. If yes, how many?

16. What class of property?

Antecedents of the property

17. Do you know how were the parcel physical conditions before your settling? Yes / No

18. If yes, what was there?

    a) natural forest (go to 19)
    b) crops
    c) bareland
    d) capuera (go to 19)
    e) other (to specify)

19. Did you have to clear the forest or the capuera? Yes / No
    If yes, go to 20

20. When? How much? (surface)

Objectives of the property

21.Which is the purpose of its property?

    a) agricultural (yerba, maize, tea, tung, manioc, etc.)
    b) timber products
        sawed timber cellulose
        carpentry
        fuelwood
    c) both
    d) tobacco e) forestry f) other (to specify)

22. How is the property distributed? (in ha.)

    forest: capuera: reforestation:
    crops: pasture: garden:

23. Do you sell the products at the market? Yes / No
    If yes, go to 25 - if not go to 24

24. Why don't you sell the products?

    a) there are not available facilities
    b) there are not available roads
    c) there are not available transports
    d) the costs are very high
    e) other (to specify)

25. Where do you sell their products? (town)

26. What transport do you use?

27. How far is the market? (in km.)

28. How much money do you monthly perceive for the sale your products?

29. Which is the more important product that your property takes place?

30. Which is it the less important one?

31. Do you use bank credits or subsidy? Yes / No

Practical of use

32. What work of tools do you use?

a) manpower
b) mechanization
c) both

33. Who work in the property (who does carry out the works in the field)?

a) the family woman children men
b) journeymen

34. Do you buy the seeds or the plants? Yes / No

35. Do you use seeds of the last crop? Yes / No

37. Do you use fertilizers? Yes / No
If yes, what type of fertilizers?

38. Do you use organic fertilizers? Yes / No
If yes, what type?

39. Do you have problems with pests and/or illnesses in your farm? Yes / No
if yes, what class and in that products?

40. Do you use insecticides? Yes / No

41. Do you have problems with robberies or vandalisms? Yes / No

42. You combat the overgrowth (bad grasses; capuera)? Yes / No

If yes, how you the combat?
a) using herbicides
b) manually
c) other (specify)

43. Do you practice crops rotation? Yes / No

44. Do you practice selective cutting? Yes / No

45. Which is your water source for watering and/or private use?

46. How is this water of its property far?

47. Do you have storage facilities for the products? Yes / No

48. Do you have erosion problems in your farm? Yes / No

49. did you abandon lands due to the erosion? Yes / No

50. If yes, after how many years of the land use?

51. Do you carry out some type of soil management? If yes, which? Yes / No

a) erosion (to specify what type)

c) tillage (traditional, reduced, conservation, no-till)
d) other (to specify)

52. How many hours do you dedicate to the farm work?

53. Do you receive help or information for better cultivation ways? Yes / No

54. Where did you obtain the knowledge of agrarian l, forestry or industrial practical?

a) school
b) family
c) friends
d) own experience
e) other (to specify)

General knowledge on environment, nature and their protection

55. Do you have knowledge about environment? Yes / No

56. Do you have knowledge about ecology? Yes / No

57. Do you have knowledge about erosion Yes / No

58. Do you know that sustainable managements it is? Yes / No

59. How are you informed frequently of the environmental problems through the following means?

newspapers and magazines	1 2 3 4 5 6 7
radio and television	1 2 3 4 5 6 7
books	1 2 3 4 5 6 7
neighbours' comment	1 2 3 4 5 6 7
associations	1 2 3 4 5 6 7
other (to specify)	

60. How do you believe to be informed on the environmental problems?

very bad 1 2 3 4 5 6 7 very good

61. How do you believe to be informed on the protection of the natural forest?

very bad 1 2 3 4 5 6 7 very good

62. Do you know about the state of the natural araucaria forest?

very low 1 2 3 4 5 6 7 a lot

63. Are you according with the environmental politics?

don't conform 1 2 3 4 5 6 7 very according

64. In your opinion, what is it more important to solve the environmental problems?

1- scientific and technician develop or 2- Changes in the politics and the society

65. What opinion you have on the environmental activities (private, municipal initiative, etc.)

against 1 2 3 4 5 6 7 in favour

66. What opinion do you have on the natural forest conservation through a controlled exploitation?
against 1 2 3 4 5 6 7 in favour

67. Is it important for you the extinction of the flora and the fauna? Yes / No

68. Do you make use of the forest? Yes / No
a) recreation
b) educational
c) exploitation
d) hunt and fishing e) other (to specify)

69. How important it is for you the natural forest?

low 1 2 3 4 5 6 7 high

70. How important it is for you the natural araucaria forest?

low 1 2 3 4 5 6 7 high

71. How important are in their opinion the following problems?

a) erosion	very low	1 2 3 4 5 6 7	very high
b) soil degradation	very low	1 2 3 4 5 6 7	very high
c) water contamination	very low	1 2 3 4 5 6 7	very high
d) forest degradation	very low	1 2 3 4 5 6 7	very high
f) flora and fauna extinction	very low	1 2 3 4 5 6 7	very high
g) lack of information	very low	1 2 3 4 5 6 7	very high
h) lacks of scientific and technician support	very low	1 2 3 4 5 6 7	very high

72. In their opinion that would be important to be able to conserve the native forest (to choose maximum three possibilities)

a) to fight against the contamination of the air and the water
b) to limit the hunt
c) to limit the cutting
d) to create more protected natural areas
e) to control the tourism
f) to legislate the use of the forest
g) implement a sustainable management system
h) to implement and/or to improve a environmental education plan
i) more and/or better information
j) financial, technician, productive and commercial support toward a less aggressive agricultural and forestry practice

73. According to their opinion, which is the responsibility degree that has the following groups in solving the environmental problems, especially those of the natural forest?

a) unions	1 2 3 4 5 6 7
b) privates	1 2 3 4 5 6 7
c) municipality	1 2 3 4 5 6 7
d) the provincial govern	1 2 3 4 5 6 7
e) the national govern	1 2 3 4 5 6 7
f) political parties	1 2 3 4 5 6 7
g) the industrial sector	1 2 3 4 5 6 7
h) scientific and technicians	1 2 3 4 5 6 7
i) the inhabitant	1 2 3 4 5 6 7

j) the church 1 2 3 4 5 6 7

Is there something that you want to add and that you believe that it lacks in this survey?

APPENDIX VI: Results of the Interview

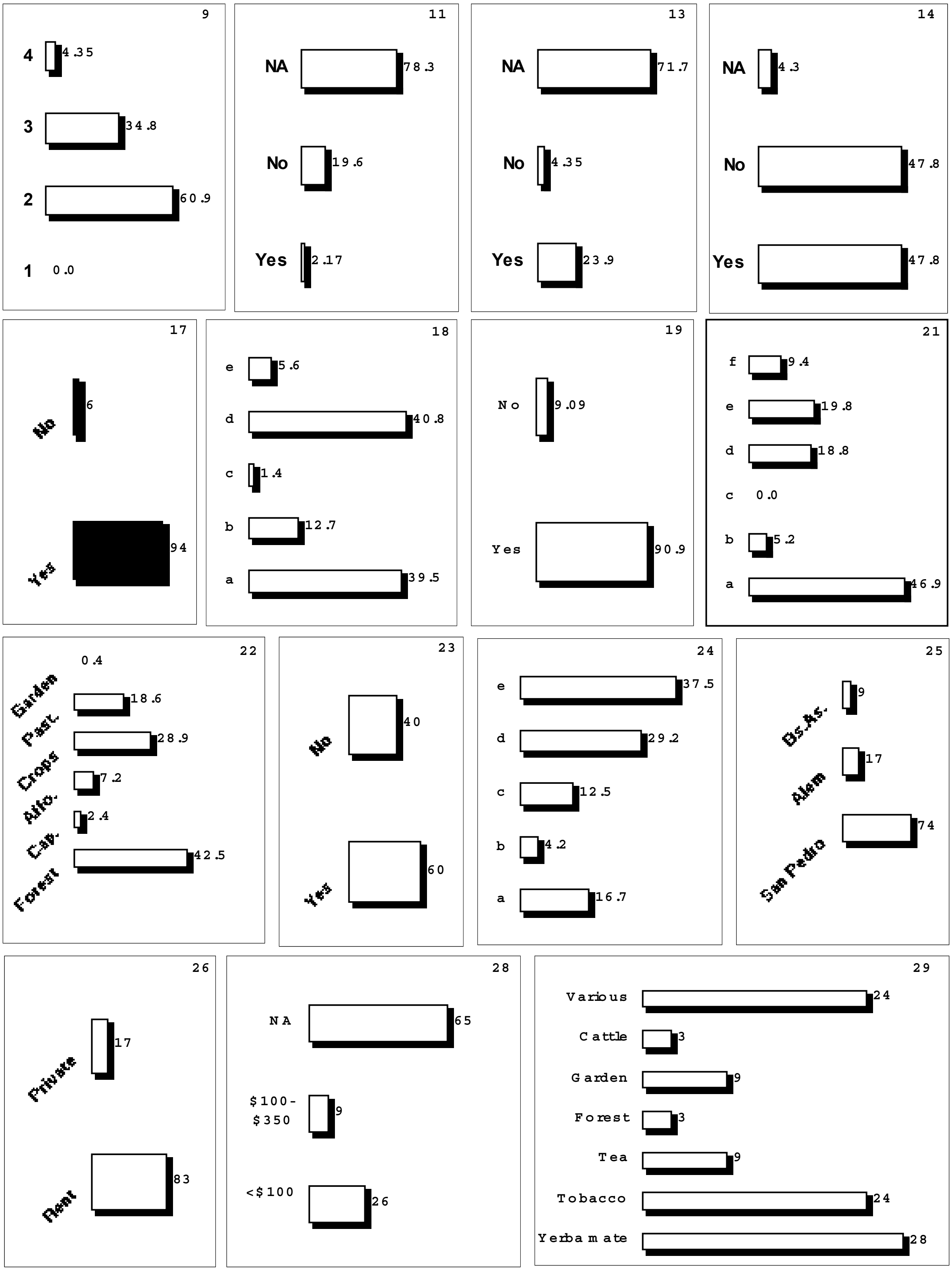

Fig. 9-2: Answers of the interview carried out to the farmers (N=102). The values are indicated in percentage. Answer 9 to 29.

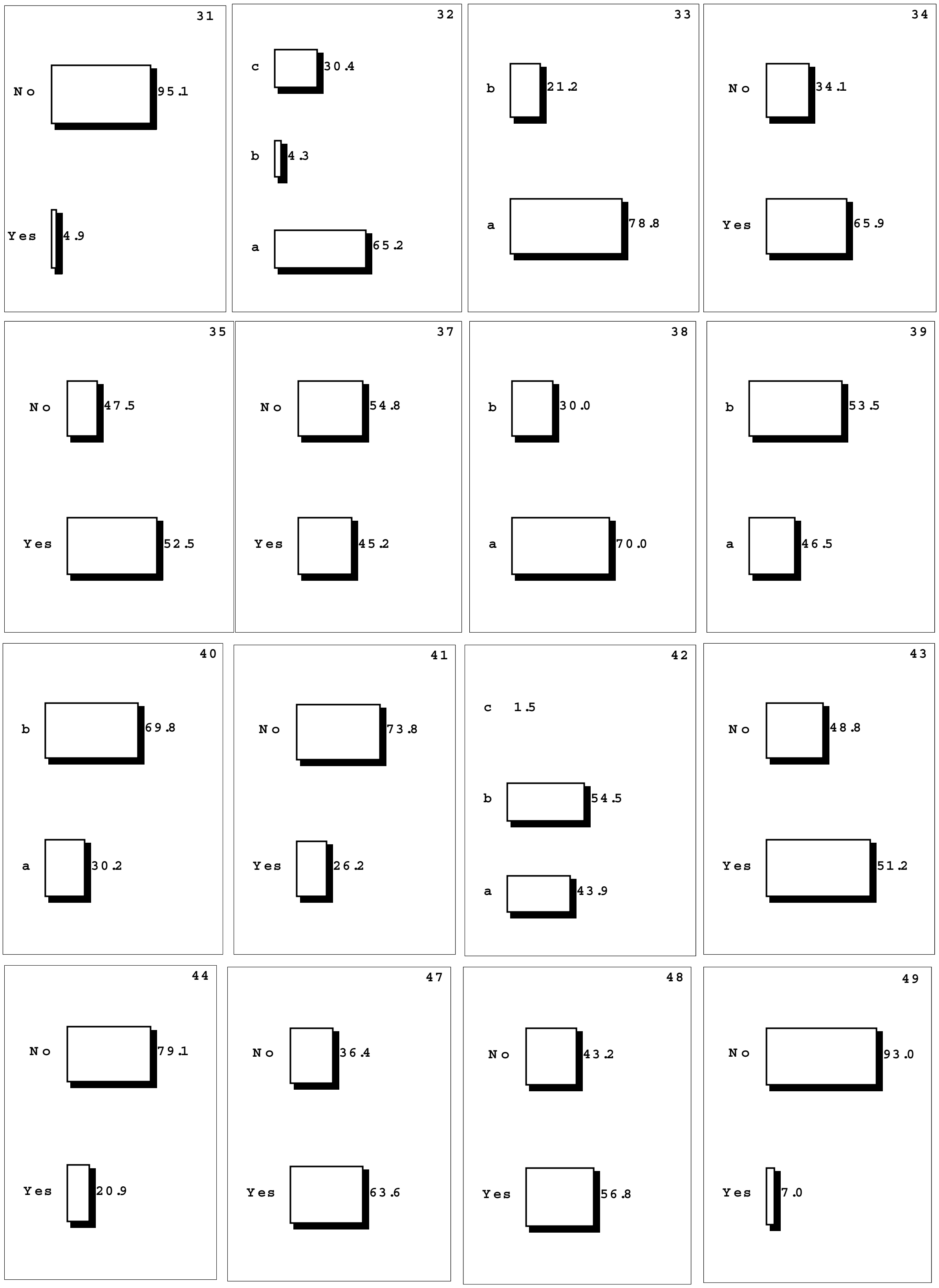

Fig. 9-3: Answers of the interview carried out to the farmers. The values are indicated in percentage. Answer 31 to 49.

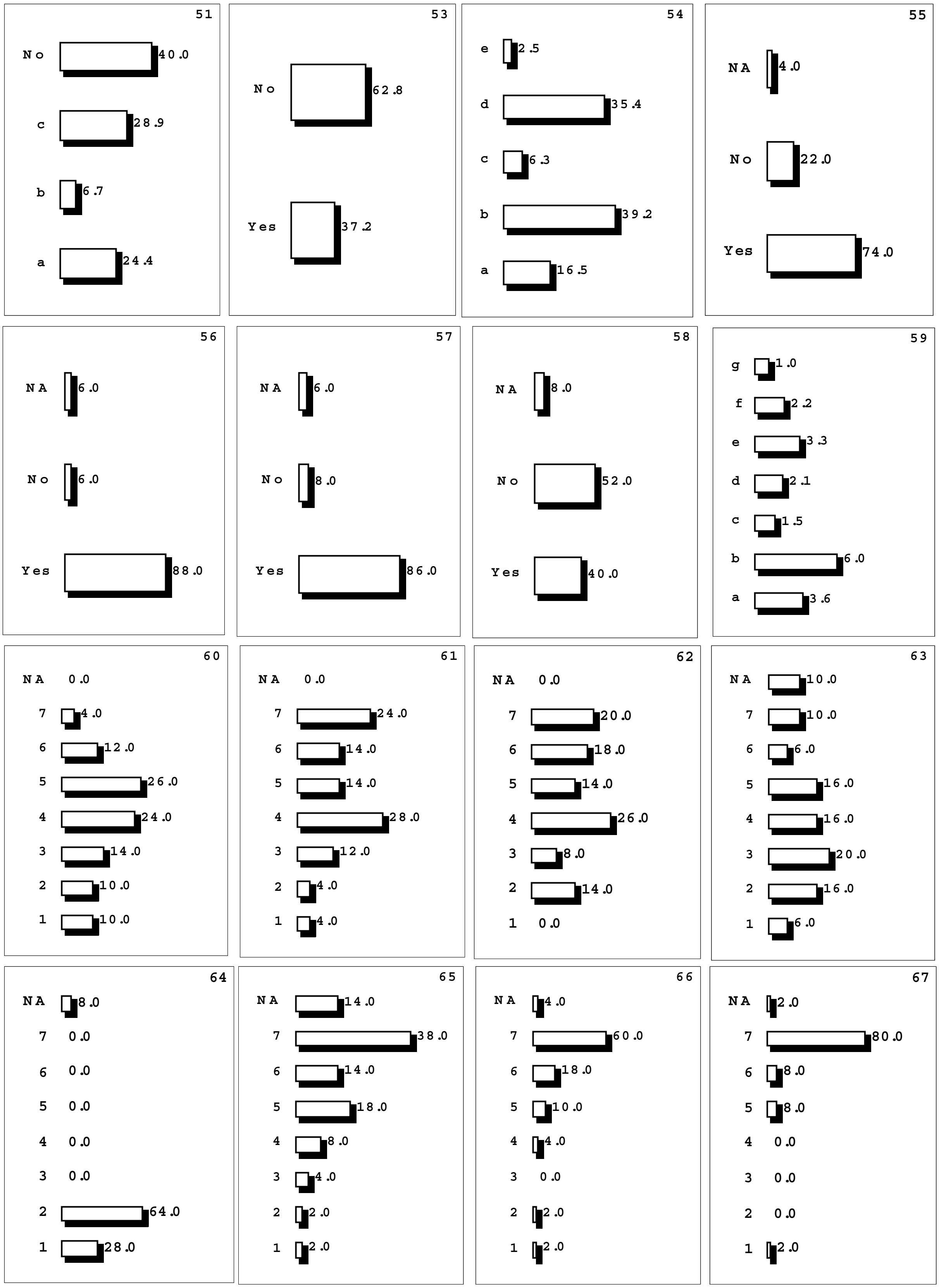

Fig. 9-4: Answers of the interview carried out to the farmers. The values are indicated in percentage; answers 59 correspond to averages values. Answer 51 to 67. (NA=no answer).

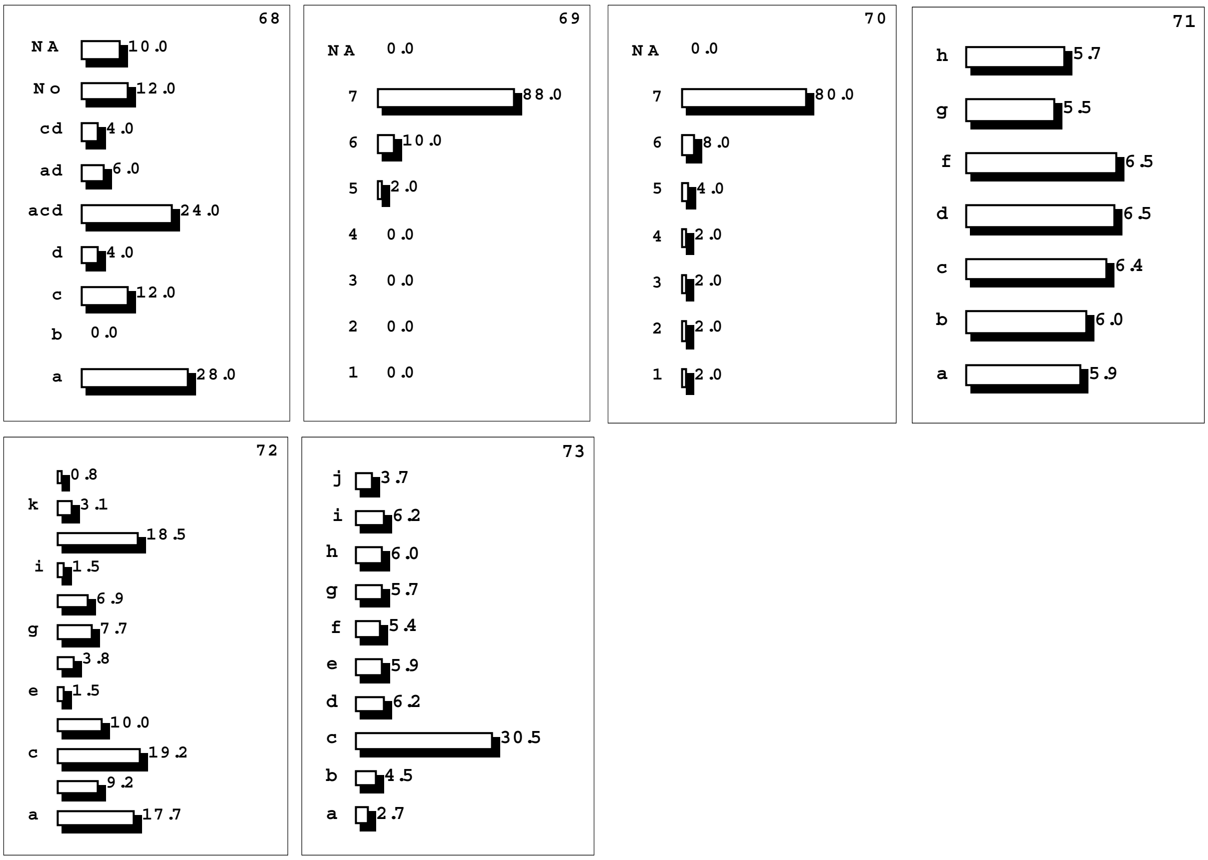

Fig. 9-5: Answers of the interview carried out to the farmers. The values are indicated in percentage; answers 71 and 73 correspond to averages values. Answer 68 to 73. (NA=no answer).

APPENDIX VII: List of Maps serie CARTA 1962 used for this work

Table 9-5: List of maps used for this work (serie CARTA 1962).

Map Series Number	Area	Map Series Number	Area
2754-10-4a	Celulosa Argentina	2754-4-3c	Intercontinental
2754-9-2d	Celulosa Argentina	2754-4-3d	Intercontinental
2754-9-4a	Celulosa Argentina	2754-15-2a1	Laharrage - San Pedro
2754-9-4b	Celulosa Argentina	2754-15-1b	Laharrague
2754-9-4c1	Celulosa Argentina	2754-9-4c3	Laharrague
2754-4-4c1	Colonia Bernardo de Irigoyen	2754-15-4a	Laharrague y Harriet
2754-4-4c2	Colonia Bernardo de Irigoyen	2754-10-4c	Luis Lorefice
2754-4-4c3	Colonia Bernardo de Irigoyen	2754-4-4a3	Maderera Grecar
2754-4-4c4	Colonia Bernardo de Irigoyen	2754-4-1c	Manuel Belgrano
2754-4-4a4	Colonia Bernardo de Irigoyen	2754-4-1d1	Manuel Belgrano
2754-4-1a	Colonia Manuel Belgrano	2754-4-1d2	Manuel Belgrano
2754-4-3b	Colonia Manuel Belgrano	2754-4-1d3	Manuel Belgrano
2554-34-1a	Colonia Manuel Belgrano	2754-4-1d4	Manuel Belgrano
2554-34-1b	Colonia Manuel Belgrano	2754-4-2c1	Manuel Belgrano
2554-34-1c	Colonia Manuel Belgrano	2754-4-2c3	Manuel Belgrano
2554-34-1d	Colonia Manuel Belgrano	2754-4-2c4	Manuel Belgrano
2554-34-3a	Colonia Manuel Belgrano	2754-4-4a1	Manuel Belgrano
2554-34-3b	Colonia Manuel Belgrano	2754-4-4a2	Manuel Belgrano
2554-34-3c	Colonia Manuel Belgrano	2754-10-2c	Piñalito
2554-34-3c	Colonia Manuel Belgrano	2754-4-1b1	San Antonio
2754-15-2a2	Colonia San Pedro	2754-4-1b2	San Antonio
2754-15-2a3	Colonia San Pedro	2754-4-1b3	San Antonio
2754-15-2a4	Colonia San Pedro	2754-4-1b4	San Antonio
2754-15-2b1	Colonia San Pedro	2754-4-2a3	San Antonio
2754-15-2b2	Colonia San Pedro	2754-16-1a	San Pedro
2754-15-2b3	Colonia San Pedro	2754-9-4d1	San Pedro
2754-15-2b4	Colonia San Pedro	2754-9-4d2	San Pedro
2754-9-4c4	Colonia San Pedro	2754-9-4d3	San Pedro
2754-10-1a	Colonizadora Misionera	2754-9-4d4	San Pedro
2754-10-1b	Colonizadora Misionera	2754-10-3b	San Pedro - Celulosa Argentina
2754-9-2b	Colonizadora Misionera	2754-10-3a	San Pedro - Cruce Caballero
2754-16-2a	D.J. Y J.M.Echeverz Harriet	2754-10-3d	San Pedro - Luis Lorefice
2754-16-1b	Echeverz Harriet	2754-10-3c	San Pedro - Luis Lorefice Pado-van y Santinelli
2754-10-2a	Facomate	2754-9-4c2	San Pedro Km. 81
2754-15-1d	Guarani	2754-10-1c	Tobuna
2754-15-4b	Guarani -Prosper	2754-10-1d	Tobuna-Angriman y Lavintman
2754-4-3a	Intercontinental		