

The relationship between soil characteristics and vegetation as a function of landform position in an area of the Flooding Pampa

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Abstract

The Flooding Pampa is a grassland with gentle slopes (<1%) and a completely flat appearance. Nevertheless, the unevenness of the land at the local scale conditions differences in the runoff, leading to the formation of swampy areas. A thematic grassland map was produced, correlating the soils and plant communities via variables that condition their presence. The working methodology included the analysis of a geomorphologically homogeneous area using cartographic materials and aerial photographs. Based on data obtained from the analysed sampling units, the system used allows extrapolations to be made at the landscape scale. The soils show important changes over the toposequence. The vegetation alters with changes in the soil, leading to the appearance of species groups with hydromorphic, hydrohalomorphic or halomorphic characteristics. The worsening of natural drainage is related to variations in the organic carbon content, an increase in pH and the percentage of exchangeable sodium, more intense signs of hydromorphism, and the appearance of characteristic species groups.

Additional key words: cartography, edaphic characteristics, grassland, hydromorphism, landscape.

Resumen

Relación suelo-vegetación en función de la posición topográfica en un área de la Pampa Deprimida

La Pampa Deprimida constituye un notable ejemplo de pastizal de baja pendiente, con una apariencia completamente llana. No obstante, existen desniveles en el terreno a escala local que ocasionan diferencias en el escurrimiento y originan encharcamientos. Se realizó un mapa temático de pastizales a partir de estudios detallados, correlacionando suelos y comunidades vegetales a través de parámetros de importancia que condicionan su presencia. El método de trabajo incluyó el análisis de un área geomorfológicamente homogénea mediante el uso de material cartográfico y fotografías aéreas. El sistema utilizado permitió formular extrapolaciones a la gran unidad de paisaje considerada a partir de datos obtenidos en las unidades muestrales analizadas. Los suelos revelan importantes cambios a lo largo de la toposequencia. La vegetación acompaña los cambios en el suelo a través de grupos de especies con características hidromórficas, hidrohalomórficas o halomórficas. El empeoramiento de las condiciones de drenaje natural está relacionado con la variación del contenido de carbono orgánico, incremento de los valores de pH, y porcentaje de sodio de intercambio, mayor intensidad de rasgos de hidromorfismo y aparición de grupos de especies característicos.

Palabras clave: características edáficas, cartografía, hidromorfismo, paisaje, pastizal.

Introduction

The Flooding Pampa is a broad depression forming a 58,000 km² triangle in the Buenos Aires Province of Argentina. The climate is wet, with a mean annual temperature of 13-16°C and a mean annual precipitation of 850-950 mm. The region is characterised by very

mild slopes and an extremely low morphogenetic potential, which can make runoff difficult during periods of flooding. The local groundwater drainage supplies the base discharge of surface waters and the perennial discharge of streambeds (Miretzky *et al.*, 2000). The many water bodies that exist act as giant evaporators that concentrate the salts contained in soil minerals derived from past marine incursions. This causes the salinization and alkalization of the soils, factors that restrain agricultural development in

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Received: 02-04-04; Accepted: 03-03-05.

the Flooding Pampa (Solbrig, 2002). As a result of topographic heterogeneity, more than 60% of the soils of the Flooding Pampa are halo-hydromorphic complexes and associations strongly influenced by flooding (Natraquolls, Natraqualfs, Natralbolls, and Argialbolls); well-drained soils (Hapludols and Argiudolls) are restricted to the highest areas.

An ecological interplay occurs between the native and introduced plants growing in the area, grazing effects, and the consequences of flooding (León, 1975; Sala *et al.*, 1986). The unevenness of the land at the local scale conditions differences in the runoff, leading to the formation of swampy areas, and the hydromorphic soils of the depressions and flat areas show their own, particular features. The importance of water dynamics on landscape development has been indicated by Hall and Olson (1991), who studied their influence on soil genesis.

The above factors highlight the importance of topography in explaining the variation in soil properties and composition among different stretches of land, and their provocation of modifications in the genetic processes of the soil (Brubaker *et al.*, 1993), in its hydrological features, and the distribution of plants.

When soil heterogeneity increases in temporarily saturated soils, the depth of the saturated stretch of the profile becomes variable, which affects the plant cover (Richardson *et al.*, 1994). Thompson *et al.* (1998) illustrated the relationship between soil properties and landscape in hydric soils, Khan and Fenton (1994) studied the soil morphology and the saturated zones of a Mollisol catena, and Seelig and Richardson (1994) examined the processes of sodic soils in relation to landform position. The spatial patterns of soil features have also been determined in relation to the elevational gradient of a wetland area (Reese and Moorhead, 1996).

The aim of the present work was to examine the relationships between the topographical variation, the soils, and the pasture land of the Flooding Pampa. A thematic map was developed to provide information on the distribution of the herbaceous vegetation growing on soils belonging to a geomorphological unit of the northern part of these grasslands. When taking management decisions in this region, where stock raising is the main economic activity, the knowledge of the relationship between soil and plant cover is important. Remote sensing data are of limited use because of the difficulties in interpreting differences in the signals produced by variations in soil charac-

teristics and plant cover-which may or may not be associated with soil wetness (Thompson *et al.*, 1997). The same problem has been reported in areas dominated by Mollisols, where the surface horizons of the soil are dark due to their high content in organic matter (Stolt and Baker, 1995). The collection of field data is therefore very important for detailed studies of basic landscape units.

Material and Methods

This study was performed at Chascomús in the Province of Buenos Aires, Argentina. The geomorphology of the area corresponds to a zone of sea abrasion with deflation depressions that extends over some 1,600 km² (Tricart, 1973). The climate is warm and humid, with a mean temperature of 13–16°C. The mean annual precipitation is 850–950 mm, with higher values in the summer when the precipitation–evaporation balance is negative.

The site has very gentle slopes (<1%), and the surface hydrology is therefore characterised by the presence of several lentic water bodies and the absence of streams (due to the lack of runoff energy).

The main economic activity in the Flooding Pampa area is stock raising. The cow-calf system is the chief production method, which is mainly based on the grazing of the grasslands that occupy 70% of the Flooding Pampa. These areas sustain 4,036,000 cattle (54% cows; calving percentage 80%) (INDEC, 2002). The high quality of these temperate pastures renders the meat produced healthier (in terms of human consumption) than meat produced in feedlots (Rearte, 1998).

Crops occupy only 17% of the area (980,000 ha). The small proportion of arable land available for this use is sown either with perennial pasture or cereal crops. Species of the genera *Dactylis*, *Lolium*, *Festuca* and *Trifolium* are the most commonly cultivated forage crops. In topographically lower and alkaline soils, *Agropyrum* is the main species, associated with *Trifolium*, *Lotus* and *Melilotus*. A representative holding in this area yields a net income of US\$ 57.55 ha⁻¹ with a margin of US\$ 9.74 ha⁻¹.

A detailed study of the vegetation and soil profiles was undertaken, comparing different sampling points within similar map units. The characteristics of the soils over representative transects were assessed at six sites distributed across the Chascomús district.

Transects were preferred to scattered sampling points since this is the main method of data collection used in soil surveys (Young *et al.*, 1997).

A topographical study of the sample area was performed to determine the direction of the surface runoff in the toposequence. After levelling by transects, topographical positions ranging from normal to concave were measured. The sampling points were located 20 m apart on a straight line extending over 1,000 m. The photointerpretation of the soils, performed using photographic mosaics (1:50,000) and aerial photographs (1:20,000), allowed the borders of the existing sub-landscapes to be defined. The thematic map of the grassland was based on the 1:50,000 «Laguna Yalca» topographic chart (35° 30' - 35° 40' S / 57° 45' - 58° 00' W) (*Instituto Geográfico Militar*, Chart 3557-26-3) and a 1:50,000 photographic mosaic (INTA, 1989). The phytosociological studies that have been carried out at different latitudes in this subregion describe plant heterogeneity at the landscape scale (León *et al.*, 1979; Burkart *et al.*, 1990). The vegetation patterns of the Flooding Pampa at both the landscape and regional scales have been examined by Perelman *et al.* (2001).

The morphology of the profiles at each position of the toposequence was described according to standard methods (Soil Survey Staff, 1951) and relevant analytical data. Soil pits were dug down to 1.20 m, and the pedons sampled by horizon. Seventy samples were air dried and then passed through a 2 mm diameter

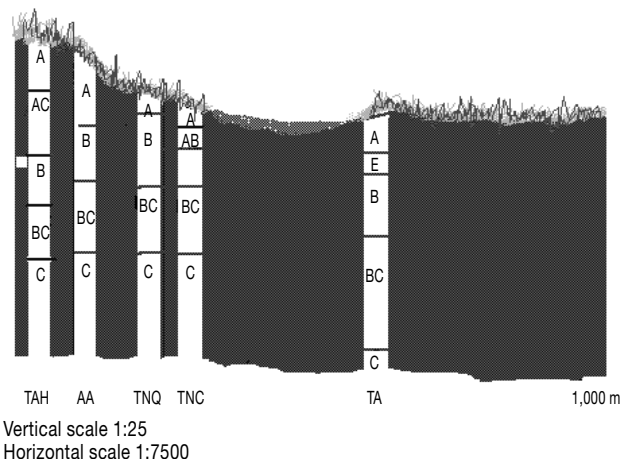


Figure 1. Localisation of soil subgroups at each landform position. AA: Aquic Argiudoll. TA: Typic Argialboll. TAH: Thapto Argic Hapludoll. TNC: Typic Natracuoll. TNQ: Typic Natracuall.

sieve. The soil pH was measured in solution (1:2.5) and its electrical conductivity (EC) analysed in saturation extracts. Total organic carbon (TOC) was measured according to the method of Walkley and Black (1934); total nitrogen (TN) was measured using the Kjeldahl method. Exchangeable cations (Ca, Mg, Na, and K) were determined in 1N ammonium acetate extracts of soil samples and then analysed by atomic absorption spectrophotometry. Cation exchange capacity (CEC) was measured according to Chapman and Pratt

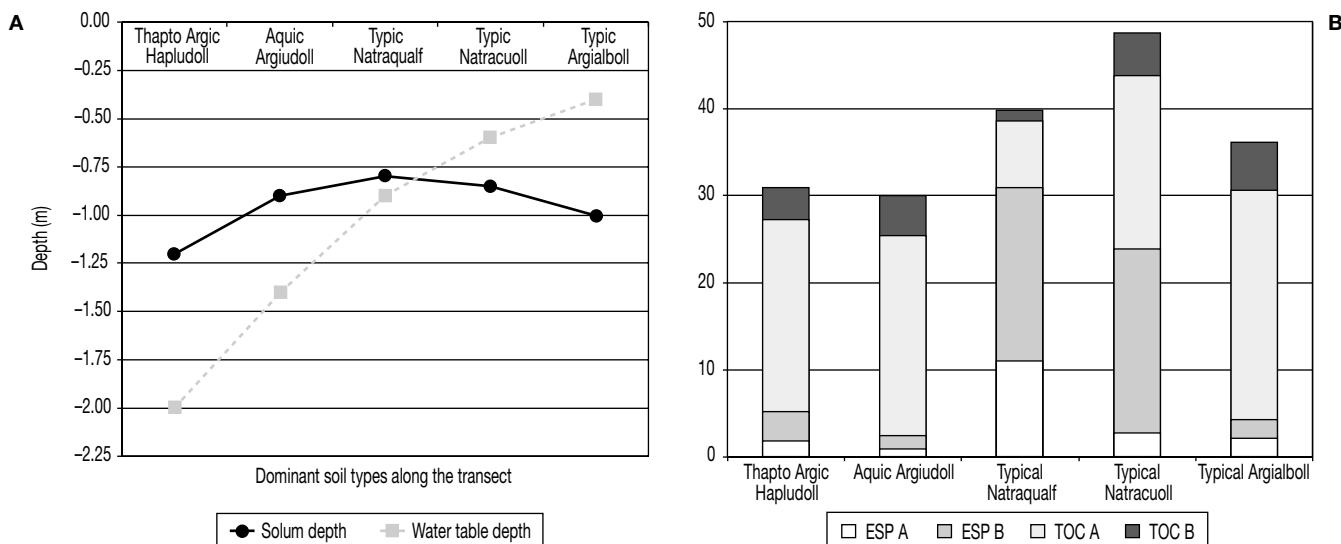


Figure 2. A) Soil and water table depth at each topographic position. B) Percentage of exchangeable sodium (ESP) and g kg⁻¹ of total organic carbon (TOC) in horizons A and B of the dominant soil types.

(1991). Particle size analysis was performed using a modification of the hydrometer method (SAGyP, 1990). Sands were dried, and then fractionated by dry sieving through a nest of sieves.

The taxonomic classification of the soils (Soil Survey Staff, 1992) allows the extrapolation of the results within the same geomorphological area (INTA, 1989).

Following a criterion of homogeneity, six zones of the study area were sampled. A transect following a topographic gradient was examined within each sampling area. Four topographic positions were determined along each transect, following a stratified random sampling design. Sampling sites along transects were

determined subjectively to reflect the full range of soil variability.

Three samples were taken at each sampling site (topographical position). Herbage accumulation and floristic composition were recorded in each using a 0.25 m² quadrat. The above-ground herbage mass was cut 2.5 cm above the ground, as it would be if grazed. This herbage mass was dried in an oven at 110°C until a constant weight was reached. The dry matter accumulation (kg DM ha⁻¹) was estimated from the plant communities used for livestock grazing.

Plant collections were prepared in spring and summer, and identified according to Cabrera and Zardini (1993). Censuses were performed following the methodology

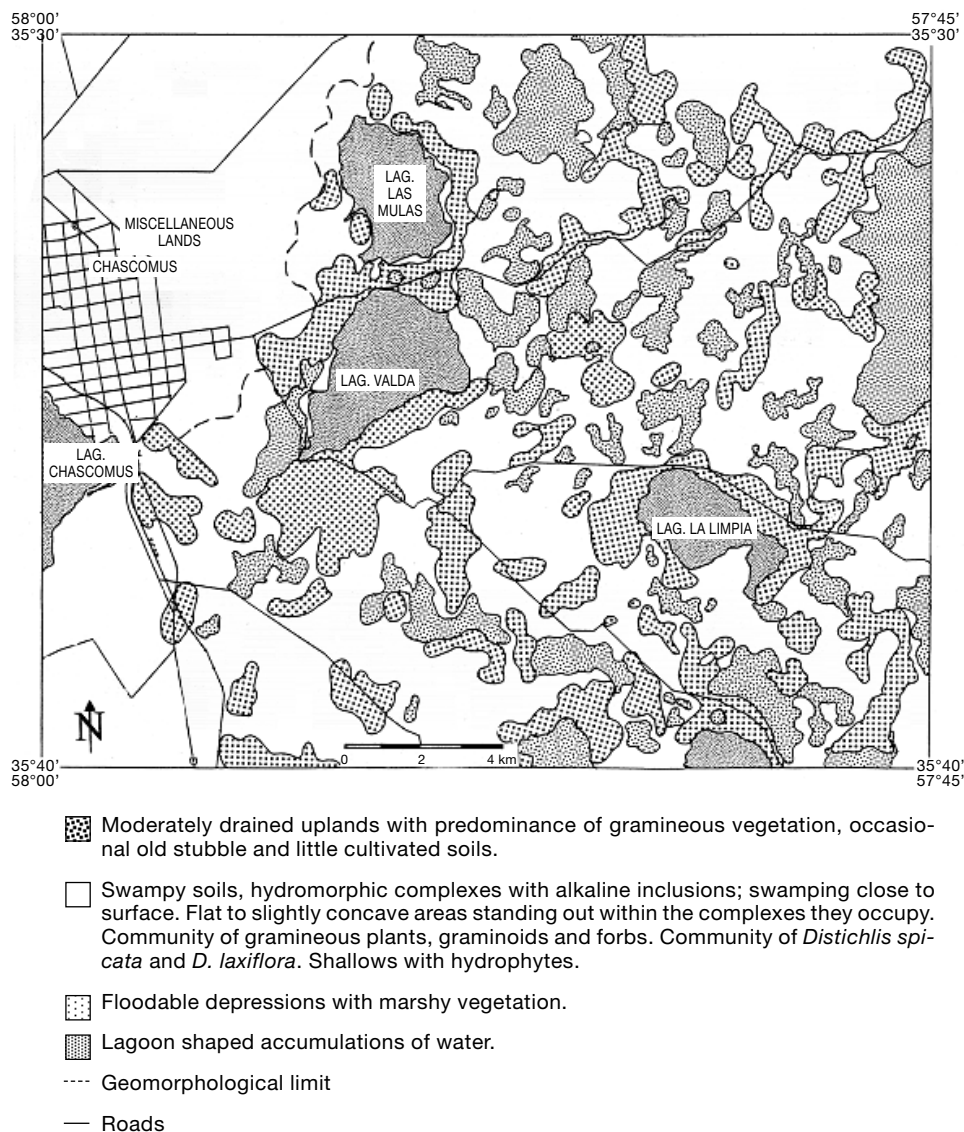


Figure 3. Grassland mapping units (Laguna Yalca chart, Chascomús).

of Braun-Blanquet (1950) to establish species groups. These determinations were performed in April and December, prior to grazing.

The results were analysed by one-way ANOVA (SAS, 2001). The Tukey test for the comparison of means was used to detect differences in herbage accumulation productivity between the sites.

Results

Rangeland conditions (including herbage accumulation, floristic composition and points of natural drainage of the soils at the topographic positions

evaluated) were used as the main criteria for producing the map units (Fig. 3). Some associated features were also emphasised. The map scale selected allows the inclusion of species groups whose botanical composition and productivity differ among the different map units.

Description of the map units of the study area

Moderately well drained uplands (1): soil complexes and associations with mollic epipedons, well-defined Bt horizon, neutral to slightly acidic, with mottling and/or ferromanganese concretions; land capability class IIw (Soil Survey Staff, 1973).

Table 1. Morphological data for representative pedons of the major taxonomic units of each landform position

Hz	Depth (m)	Color	Texture	Structure ¹	Fe-Mn coner ²	Mottling ²
<i>Thapto Argic Hapludoll</i>						
A	0-0.30	Dark grey 10YR4/1	Silt loam	gr	a	a
AC	0.30-0.50	Brown 10YR5/3	Loam	m	m	c
2Bt	0.50-0.90	Dark brown 10YR3/3	Clay	pr	f	c
2BC	0.90-1.20	Pale brown 10YR6/3	Silty clay loam	sbk	f	m
3C	> 1.20	Very pale brown 10YR7/3	Loam	m	f	c
<i>Aquic Argiudoll</i>						
A	0-0.30	Dark greyish brown 10YR4/2	Clay loam	sbk	f	c
2Bt	0.30-0.60	Brown 7.5YR5/4	Silty clay	pr	f	m
2BC	0.60-0.90	Light brown 7.5YR 6/4	Clay loam	pr	c	c
3C	> 0.90	Light brown 7.5YR 6/4	Loam	m	m	c
<i>Typic Natraqualf</i>						
AB	0-0.15	Grey 10YR6/1	Silt loam	sbk	c	m
2Bt	0.15-0.50	Dark brown 7.5YR3/2	Clay	sbk	m	c
3BC	0.50-0.80	Brown 7.5YR4/4	Clay loam	sbk	m	m
3C	> 0.80	Pinkish grey 7.5YR7/2	Silt loam	m	m	m
<i>Typic Natracuoll</i>						
A	0-0.2	Greyish brown 10YR5/2	Silt loam	sbk	f	f
AB	0.2-0.35	Greyish brown 10YR5/2	Silt loam	sbk	c	c
2Bt	0.35-0.65	Dark greyish brown 10YR4/2	Clay	pr	m	m
2BC	0.65-0.85	Brown 7.5YR5/4	Silt loam	sbk	m	f
2C	> 0.85	Brown 7.5YR5/4	Loam	m	f	
<i>Typic Argialboll</i>						
A	0-0.20	Greyish brown 10YR5/2	Silt loam	sbk	a	f
E	0.20-0.30	Light grey 10YR7/2	Silt loam	pl	c	m
2Bt	0.30-0.70	Very dark brown 10YR2/2	Clay	pr	m	m
2BC	0.70-1.00	Pale brown 10YR6/3	Silt loam	sbk	m	c
2C	> 1.00	Pale brown 10YR6/3	Loam	m	f	f

Hz: horizon. ¹ Structure: granular (gr), massive (m), platy (pl), prismatic (pr), subangular blocky (sbk). ² Fe-Mn concretions and Mottling: absent (a), common (c), few (f), many (m).

Swampy alkaline soils (2): soil complexes with high risk of winter flooding and swamping, non-sodic to sodic, with irregular distribution patterns formed by small polypedons; land capability class VIws.

Floodable soils (3): hydrohalomorph complex, undifferentiated flooding complexes at lower relief position; land capability class VIII.

Relationships between soil morphology and landform in the sampling area

The upland positions were dominated by moderately well drained Thapto Argic Hapludoll soil. These soils

showed the best drainage in this landscape, as revealed by their morphology and the depth to the water table (Fig. 2A). Their A horizon was 0.30 m thick and well supplied with organic matter. This was followed by a transitional AC horizon of variable thickness (0.15–0.30 m) with mottled ferromanganesic concretions. In this position of the toposequence, the epipedon showed the greatest development. The solum was over 1 m thick. The pH of the whole profile was close to neutral. The maximum flooding level does not cover these sectors.

The soils in the upland positions often followed a regular distribution pattern. Thapto Argic Hapludoll soil was most often located on the high upslope part

Table 2. Selected physical and chemical properties of the studied soils

Hz	TOC (g kg ⁻¹)	TN (g kg ⁻¹)	pH	EC (dS m ⁻¹)	CEC (cmol kg ⁻¹)	Ca (cmol kg ⁻¹)	Mg (cmol kg ⁻¹)	Na (cmol kg ⁻¹)	K (cmol kg ⁻¹)	ESP
<i>Thapto Argic Hapludoll</i>										
A	21.1	1.50	6.4	0.71	18.4	10.8	2.9	0.3	1.4	1.9
AC	3.6	0.39	6.8	0.43	7.7	4.7	3.0	0.3	0.8	3.4
2Bt	4.4	0.52	7.0	0.60	24.3	11.9	7.3	0.5	2.5	2.2
2BC	3.9	—	7.2	—	15.6	7.5	5.3	0.5	1.9	3.2
3C	1.2	—	8.2	—	14.9	7.2	5.4	1.2	2.7	7.2
<i>Aquic Argiudoll</i>										
A	23.0	2.10	6.3	0.62	21.0	13.8	3.4	0.2	2.8	0.9
2Bt	4.7	1.40	6.7	0.76	26.2	17.8	4.0	0.4	2.4	1.5
2BC	1.3	0.60	7.0	—	23.2	15.4	5.9	0.4	2.4	1.7
3C	0.4	0.40	8.3	—	19.7	—	—	—	—	—
<i>Typic Natraqalf</i>										
AB	7.5	0.81	9.5	2.19	8.5	3.7	2.5	0.9	2.6	11.0
2Bt	7.5	0.94	10.0	3.16	27.0	—	—	5.4	3.4	20.0
3BC	1.3	0.70	9.8	1.86	19.0	—	—	7.4	3.3	39.0
3C	0.4	0.60	9.6	2.20	11.0	—	—	4.9	2.9	44.0
<i>Typic Natracuoll</i>										
A	20.0	2.90	7.5	1.20	21.0	13.4	3.8	0.6	1.6	2.8
AB	5.0	0.60	7.8	3.50	15.0	10.3	3.6	1.4	1.1	9.0
2Bt	4.8	0.40	9.5	2.40	34.0	—	—	7.1	2.5	21.0
2BC	2.0	—	8.0	1.75	32.0	—	—	3.0	2.3	9.0
2C	1.2	—	8.0	2.00	26.0	—	—	1.6	2.3	6.5
<i>Typic Argialboll</i>										
A	26.5	2.52	6.0	0.84	22.0	13.3	2.4	0.5	1.9	2.3
E	5.5	0.65	6.5	0.33	8.1	5.6	2.5	0.4	1.1	4.9
Bt	4.6	0.30	6.7	0.60	28.0	16.0	7.5	0.6	2.6	2.0
BC	2.0	—	7.4	0.50	19.5	12.4	6.1	0.7	2.1	3.5
C	1.5	—	7.9	—	18.3	10.0	6.5	0.9	2.2	5.0

Hz: horizon. CEC: cation-exchange capacity. EC: electrical conductivity. ESP: exchangeable sodium percentage. TN: total nitrogen. TOC: total organic carbon.

of the landform, with Aquic Argiudoll soil below and halfway down the half slope. Although these soils were similar to the Thapto Argic Hapludoll, they differed in the absence of an AC horizon where the transition of the A horizon towards those underlying it showed an abrupt smooth boundary. The epipedon was dark in colour (10YR4/2), well supplied with organic matter and its exchange complex dominated by Ca and Mg. The solum was 1 m below the surface and calcium carbonate was frequently found in the BC horizon (>0.65 m). It showed signs of hydromorphism with ferromanganese concretions in the B horizon and frequent mottling in the A horizon. The pH of the whole profile was close to 7 and showed no trace of salinity.

The soils of the floodplain sectors with a 0.2% slope were organised in complex units with alkaline-hydromorphic characteristics. The solum reached down to a depth of approximately 0.80 m from the surface and the water table was close to 0.60 m from the surface in the winter. The soils were poorly

drained and showed abundant mottling and ferromanganese concretions starting at a depth of 0.30 m. Some profiles showed highly alkaline surface layers with an ocric epipedon (Typic Natraqualf), whereas others showed a mollic epipedon (Typic Natracuoll) with a high percentage of exchangeable sodium (ESP) (Fig. 2B) in the subsurface horizons (20-40%).

The higher water table and soil morphology of the soils in the intermediate position rendered them wetter than those in the upland position. Mottling was seen in most pedons (Table 1). An extended period of pedon saturation was also observed. The soils surrounding the depressions showed an A horizon with a high TOC content followed by an E horizon deeply lixiviated, platy, clear in colour, and with abundant mottling.

The Typic Argialboll met the light grey colour criterion (10YR7/2) for an albic horizon. The hydromorphic features were marked in a Bt horizon that showed abundant ferromanganese concretions and

Table 3. Grass composition of each community represented in the grassland chart

Community 1	Community 2.1	Community 2.2	Community 2.3	Community 3
Dominant				
<i>Lolium multiflorum</i> Lam	<i>Cynodon dactylon</i> L.	<i>Distichlis spicata</i> (L.) Greene	<i>Glyceria multiflora</i> Steudel	<i>Scirpus californicus</i> (C.A.Mey.) Steu
<i>Botriochloa</i> <i>laguroides</i> DC. Herter	<i>Panicum gouinii</i> Fournier	<i>Distichlis scoparia</i> (Kunth)	<i>Paspalidium</i> <i>paludivagum</i> (Hitchc. et Chase)	
<i>Bromus mollis</i> L.	<i>Panicum milioides</i> Nees	Arechavaleta	L.R.Parodi	
<i>Stenotaphrum</i> <i>secundatum</i> (Walt) O.K.	<i>Stenotaphrum</i> <i>secundatum</i> (Walt) O.K.	<i>Distichlis laxiflora</i> (Hackel)	<i>Leersia hexandra</i> Sw.	
<i>Paspalum dilatatum</i> Poiret				
Associated				
<i>Chaetotropis imberbis</i> (Kunth) Björkman	<i>Paspalum vaginatum</i> Sw.	<i>Hordeum</i> <i>stenostachys</i> Godr.	<i>Panicum milioides</i> Nees	
<i>Cynodon dactylon</i> L.	<i>Paspalidium</i> <i>paludivagum</i> (Hitchc. et Chase)	<i>Polypogon</i> <i>monspeliensis</i> L.	<i>Paspalum vaginatum</i> Sw.	
<i>Melica brasiliana</i> Arduinus	L.R.Parodi	<i>Sporobolus</i> <i>indicus</i> L.		
<i>Setaria geniculata</i> (Lam) Pal. Beauvois	<i>Sporobolus</i> <i>indicus</i> L.			
<i>Sporobolus indicus</i> L.	<i>Leersia hexandra</i> Sw.			
<i>Stipa papposa</i> Nees				
<i>Stipa hialina</i> Nees				

gleyed coloration. Throughout the study period, ponds formed only in the depressions. In the «wetland position», where the water table was closer to the surface than in the other positions, all the soils were poorly drained (Fig. 2A). These areas remain swamped for most of the year. From April onwards the water table came within 0.40 m of the surface and fluctuated throughout December. No salinity was detected in any horizon.

Plant communities

The plant communities (Tables 3, 4 and 5) clearly reflected the boundaries between areas of different soil characteristics. Five distinct groups of plants were represented in the thematic map. Only four of these communities were of forage value.

The upland vegetation (community 1) comprised several gramineous groups of forage plants. The dominant species was *Lolium multiflorum* (Lam.), followed by *Stenotaphrum secundatum* (Walt) O.K., *Bromus mollis* (L.), *Botriochloa laguroides* D.C. Herter, and *Paspalum dilatatum* Poiret.

The swampland alkaline soils showed less plant diversity than the upland sites. Alkaline pedons showed ample areas of bare ground with *Dystichlis spicata* (L.) Greene the dominant species (community 2.2). In the same topographic position, but in soils whose alkalinity was only evident in the deeper layers, there was poor gramineous cover dominated by graminoids and forbs (community 2.1) (Table 4).

In slight depressions of the swampland soils, *Solanum malacoxylon* Sendt was dominant but the plant diversity was reduced due to the presence of the temporary ponds (community 2.3). The marshy vegetation of the floodable depressions mainly consisted of *Scirpus californicus* (C. A. Mey.) Steud, *Ceratophyllum demersum* L. and *Myriophyllum brasiliense* Cambess. Community 3 had no forage value.

The assumptions of normality and homogeneity of variances were tested and shown to hold. ANOVA showed significant differences ($p < 0.05$) between communities 1 and 2. However, no significant differences ($p > 0.05$) were found in species productivity among the plant communities growing at intermediate positions (including the alkaline pedons). Therefore, for management purposes, they can be grouped

Table 4. Forbs and graminoids of each community represented in the grassland chart

Community 1	Community 2.1	Community 2.2	Community 2.3	Community 3
<i>Ambrosia tenuifolia</i> Spreng	<i>Adesmia bicolor</i> (Poir) DC.	<i>Melilotus indicus</i> L.	<i>Alternanthera philoxeroides</i> (Mart.) Griseb	<i>Ceratophyllum demersum</i> L.
<i>Adesmia incana</i> Vogel	<i>Carex sororia</i> Kunth	<i>Plantago myosurus</i> Lam.	<i>Cyperus</i> sp.	<i>Myriophyllum brasiliense</i> Cambess
<i>Carex sororia</i> Kunth	<i>Cyperus</i> sp.		<i>Juncus microcephalus</i> H.B.K.	
<i>Cyperus</i> sp.	<i>Lotus tenuis</i> Waldst et Kit		<i>Juncus imbricatus</i> Laharpe	
<i>Hipchoeris radicata</i> L.	<i>Dichondra repens</i> Forst et Forst		<i>Marsilea concinna</i> Baker	
<i>Juncus imbricatus</i> Laharpe	<i>Eleocharis viridans</i> Kükenth		<i>Solanum malacoxylon</i> Sendt.	
<i>Medicago lupulina</i> L.	<i>Hidrocotile bonariensis</i> Lam.			
<i>Pamphalea bupleurifolia</i> Less	<i>Juncus imbricatus</i> Laharpe			
<i>Trifolium repens</i> L.	<i>Juncus microcephalus</i> H.B.K.			
	<i>Jussiaea repens</i> L.			
	<i>Mentha pulegium</i> L.			
	<i>Sida leprosa</i> L.			

Table 5. Dry matter accumulation estimates for the communities used for grazing

Plant community	Dry matter (g ha ⁻¹)
Community 1	4,297 A
Community 2.1	1,820 B
Community 2.2	1,763 B
Community 2.3	1,155 B

Different letters indicate significant differences ($p < 0.05$).

as a single grassland unit with uniform production (Table 5).

Discussion

The soil profiles and the characteristics of this grassland emphasise the role of topography in the modification of soil genetic processes, in soil hydrological features, and the distribution of plant species. It is clear that topographic position governs soil variables such as pH and TOC as well as their differential distribution within the soil profile.

The worsening of natural drainage conditions is associated with an increase in pH and ESP, more intense signs of hydromorphism, and the appearance of characteristic groups of plants. Simonson and Boersma (1972) reported that the depth to mottling and the abundance of Fe-Mn concretions were a function of the depth of the water table.

The increase in TOC (associated with depressions) suggests the existence of a longer period of soil saturation, which results in slower decomposition rates (Richardson *et al.*, 1994; Reese and Moorhead, 1996; Thompson and Bell, 1996). The differences in soil variables in the A horizon may be a reflection of variations in vegetation patterns or hydrology (Reese and Moorhead, 1996).

The solum depth showed important differences along the transects (Fig. 1). The vegetation changed with alterations in the soil, leading to the appearance of species groups with hydromorphic, hydrohalomorphic or halomorphic characteristics. Landform position and plant communities were excellent indicators of the water regime and sodic content of the soil (Seelig *et al.*, 1990). Vegetation changes associated with soil gradients have been documented for other wetlands (Stewart and Kantrud, 1972; Cowardin *et al.*, 1979; Richardson *et al.*, 1994). As reported by Seelig

et al. (1990), the highest ESPs in the study area were found in soils located at intermediate positions, whose plant communities were dominated by *Distichlis spicata* spp. The sequence of horizons along the representative transects analysed were consistent with the regional pattern established in earlier reports (INTA, 1989).

Several researchers (Simonson and Boersma, 1972; Thompson *et al.*, 1998) have shown that water table fluctuations are related to landscape type, whereas soil morphology is related to saturation depth. Khan and Fenton (1994), Genthner *et al.* (1998) and He *et al.* (2003) indicate that the redoxymorphic features of the soil are the most easily observable sign of the presence and fluctuation of the water table. However, additional criteria such as thickness, surface colour (Reuter and Bell, 2001) and clayey textures (Megonigal *et al.*, 1993) should be used as supporting evidence in assigning land use.

In conclusion, it is clear that landscape recognition provides an orientational tool for differentiating different areas in grassland mapping. Although soils are mainly represented in complex map units, the analysis of soil features and properties —especially natural drainage— allows the definition of map units with different plant communities. Landform position and the plant communities present reflect variations in soil sodic properties and the soil water regime.

The methodology used in this study appears to be valid for the study of geomorphologically homogeneous flatlands.

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