Limiting factors for pasture and cereal production in marginal soils of the southwestern Pampas in the province of Buenos Aires, Argentina

Campaña, D.H[1], Airasca A.O.[2], Andrade Couce M.L.[3]

[1,2]GEAQB, Universidad Tecnológica Nacional, Argentina
[3]Universidad de Vigo. España

Abstract— *Typical soils of Southwestern Buenos Aires Province were evaluated to determine quality and capability for cereal and forage production having in mind potential improvements due to amendment with organic residual from agroindustrial wastes process. Studied soils from Mollisol order were, Argiudoll and Argiustol suborder, of marginal area of Pampa Argentina. The organic matter content of those soils corresponded to weakly humic soils which shows the transition from the Pampas zone to the semi-arid zone and indicates a major limiting factor. Granulometric analyses were similar, with a sandy loam texture for the Tres Arroyos soil and a borderline sandy silt loam for the Cabildo soil. Anycase the results were below the limit that indicates salinity problems. Low availability of essential micronutrient like Copper and Molibdenum were another limiting factor of the Tres Arroyos soil, where the cultivation of winter grains, such as wheat and barley is very important for regional economy. The availability of the micronutrients Zn and Cu are strongly dependent on the soil pH; therefore, the more alkaline the conditions (such as for the Cabildo soil), as a limiting factor mainly for cereals sensitive to Cinc deficiencies like maize and sorghum. Soils from this marginal areas of the Pampas (Argentina), could be improved with respect to the factors that limit soil quality and productivity.*

Keywords— Soil, properties, limiting factors, degradation.

I. INTRODUCTION

Soils from semi-arid zones, such as the southern boundary of the Argentine Pampas, have low resilience values and are therefore fragile because they are subject to natural erosion processes, such as wind, and anthropogenic degradation, i.e., monoculture (Iacobucci, 2000). The province of Buenos Aires is also affected by varying degrees of erosion. The processes of wind erosion are observed in western and southern regions of Buenos Aires with an intensity that varies locally. In the south of the province, there is also the development of desertification processes that are mainly attributable to the overuse of soil resources in a transitional area located between the Pampas region and the Patagonia region.

Soil degradation results in a series of negative effects. Structural deterioration hampers the rooting of plants and their ability to absorb water and nutrients; at the same time, this deterioration greatly exacerbates the risk of erosion. A deficient structure results in decreased soil permeability, increased difficulty in water infiltration, increased runoff and less efficient use of the soil structure. The decrease in organic matter and the degradation of the exchange complex causes a loss of nutrients that accelerates the degradation of the vegetation. In recent decades, Argentine agriculture underwent a transformation from mixed farming-based production systems to intensive agriculture. This change resulted in nutrients being extracted at high rates but not replaced in equal magnitudes, generating degradation and depletion processes that threaten the sustainability of production systems (Casas, 2000; Martínez, 2002). Soil quality can be defined as the ability of the soil to function within the surrounding ecosystems such that it maintains biological productivity and environmental quality and promotes the health of plants and animals (Doran and Parkin, 1994). The soil has an essential role in the carbon cycle, acting as a source and/or sink, depending on the conditions. More than 50% of the carbon that "circulates" is contained in soil organic matter. The carbon in soil organic matter (OM) is almost double the content of the gas phase (atmosphere), where it is found primarily as CO_2, and surpasses the carbon contained in plant matter to an even greater extent. Nitrogen fertilisation favours the increase in soil organic carbon and improves its quality and productivity, thereby increasing the efficiency of atmospheric carbon sequestration (Halvorson et al., 1999). Continuous agriculture promotes the least amount of OM. Fertilisation has been suggested to increase the level of OM by increasing the crop yield and thereby increasing volume of waste (Diaz et al., 1980).

The fertilisation of soils is a common practice to compensate for the absence or deficiency of essential nutrients in the agro-ecosystem (Deacon et al., 2010). Nitrogen is the main element required for the production of winter grains, such as wheat, a typical crop in the southwest of the province of Buenos Aires in Argentina. Deficiencies in this nutrient affect the yield and protein content. Certain environmental factors reduce the efficiency of nitrogen use in such regions as southwestern Buenos

Aires, which is in the marginal zone of the Argentine Pampas. In this region, the cultivation of winter grains, such as wheat and barley, is limited in productivity, due to such factors as the presence of limestone at shallow depths, deficiencies in organic matter, and water stress. Therefore, low doses of nitrogen fertiliser are required (Ferraris, 2008). Organic fertilisers that have the ability to regulate the release of inorganic forms of nitrogen, which are available to plants, are preferred. The lack of water can limit the absorption of nitrogen by the crop; therefore, the availability of nitrogen as related to the water situation of the soil is important (Cáseres et al., 2005). For cereals, such as wheat, significant amounts of P, K, S, Ca, and Mg are also required as nutrients in addition to the micronutrients B, Cu, Mn, Fe, Cu, and Zn (Ciampitti and Garcia, 2007). For the particular case of the production of winter forage cereals (e.g., rye, oats, triticale), the demands of N, P, and S have been specifically confirmed. These nutrients have increased the dry-matter yields in sub-humid and semi-arid zones with fertilisation (Diaz-Zorita et al., 1997; Quiroga et al., 2007). The incorporation of organic matter into the soil increases the movement of P in calcareous soils, which consequently increases the organic P in the soil solution. The soil solution is mobilised by the microbial population, which, in turn, can physically move and aid in the redistribution of P, thereby increasing the efficiency of the P use compared to organic fertilisation with minerals (Hannapel et al., 1964; Aguirre et al., 2007). However, meat production, especially beef cattle production, is a production alternative that is suitable for marginal regions of the Pampas, such as in the southwestern zone of the province of Buenos Aires. It has also been confirmed that winter-cycle species of forage plants have limited growth as a result of the severe nitrogen deficiency (Echeverría and Bergonzi, 1995). Nitrogen fertilisation of perennial pasture and forage is a rarely adopted practice that would affect plant production, ease the forage shortage, and make it possible to sustain a higher animal load (Fernández Grecco et al., 1995).

Nutrient depletion is a major form of soil degradation. The sludge from effluent treatment plants in agro-industrial processes is a potential source of organic fertilisers (Roy et al., 2003) that can be used to restore the fertility of agricultural soils with better prospects than even inorganic or conventional fertilisation. When biosolids are incorporated as an amendment, many micronutrients that are not incorporated with conventional (synthetic) fertilisation are provided. This incorporation is an advantage, given that the design of fertiliser dosages at the micro-level would be notably costly. The bioavailability of trace elements, such as micronutrients or toxic elements, is not determined by the total concentrations of the elements in question; rather, it depends directly on the chemical properties of the soil, particularly the pH and cation exchange capacity. The oxidation states of the element and the type of complex formed also affect the bioavailability (Myers et al., 1996; Andrade et al., 2005; Lair et al., 2007).

The application of sludge and organic (plant/animal) waste to the soil should be reconsidered as an economic practice, both from the standpoint of operating costs (the current analysis) and from the standpoint of the environment, given the facts that matter is recycled and it can effectively compete with chemical fertilisers at lower environmental costs. All of these factors support the pursuit of an effectively sustainable agricultural-livestock production method. The use of organic waste would also be an advantage for countries with relatively low industrialisation that could more easily "close" the cycle of nutrient recycling in contrast to highly industrialised countries, where in certain cases, the surface availability is small. Ideally, sustainable agricultural-livestock production would be stable when organic waste arising from the study area is reused within the same area (Schulz et al., 1997). This stability is possible when the surface areas of agricultural land are large, and the generation of agribusiness and domestic waste is not excessive, as is the case in Argentina. One way to improve or restore long-term soil quality is to intervene in the complex processes of agro-ecosystem biocycles.

Taking into account the limiting soil factors for plant production in marginal zones of the Argentine Pampas, such as the southwestern regions of the province of Buenos Aires (sub-humid – semi-arid zones), the chemical and physical characterisation of two typical soils is shown. The objective is to propose practices, such as amendment with organic waste, that would improve the soil quality and increase the sustainable productivity of cereals and fodder to prevent deterioration of the ecosystem.

II. MATERIAL AND METHOD

2.1 Soils

To carry out the present study, from the southern province of Buenos Aires, two soil samples belonging to the order of Mollisols were used. The topsoil of both soils was used after surface cleaning (removal of plant cover). The soil samples were air-dried, adequately homogenised, and sifted with a 2-mm light mesh. The soil description includes data on the sampling site, general soil information, and the general details of typical profiles (SAGyP-INTA, 1989).

General information on the location of the Cabildo sample	
Soil type	Typic Argiustoll
Location	From Bahía Blanca–Cabildo, 38º 30' S, 62º 50' W
Altitude	152 m
Geomorphologic unit	Plateau
Surrounding landform	Gently rolling or nearly horizontal
Slope	Class 0 plain
Use	Agricultural and livestock

General information regarding the Cabildo soil	
Starting material	Quaternary sediments (Holocene).
Plot area	162 ha
Drainage	Poor (slow permeability), class III (USDA, 1960)
Stoniness	Less than 0.01%, class II (USDA, 1960)
Climate	Ustic regime
Effective depth	60 cm
Depth of arable layer	20 cm
Rocky outcroppings	None, class 0 (USDA, 1960)
Evidence of erosion	Light (USDA, 1960), moderately susceptible to wind and water erosion.

The Cabildo soil, of the typic Argiustoll subgroup, had a sandy clay-loam texture and was shallow to very shallow in certain areas, given that the calcareous appeared at depths between 40 and 60 cm. The A1 surface horizon had a thickness of 15 cm to 20 cm, an organic matter content of approximately 3%, sandy clay-loam texture, and a weak reaction of carbonates in the mass. The B2t subsurface horizon was 20 cm to 25 cm thick, had a clay loam texture, and was loosely structured in blocks.

The colour of the surface soil used for the present study according to Munsell's notation was 10YR 4/2 dark greyish brown when dry and 10YR 2/2 very dark brown when wet (Munsell, 1975). The colouration had the characteristic tinge (10YR) and variation of wet-dry intensity (2 units higher as a typical value) of temperate regions with the same colour (Palmer et al., 1989). For the tests in the present study, the A1 horizon was used.

The "Tres Arroyos" soil corresponded to the typical, thin, shallow Argiudoll taxonomic unit, which is preferentially found in upper regions, where the calcareous is at a shallower depth. The Argiudolls are the most representative group of the Udolls.

General information on the location of the Tres Arroyos sample	
Soil type	Typic Argiudoll
Location	From Tres Arroyos – 38º 16' S, 60º 33' O
Altitude	115 m
Geomorphologic unit	Plain
Surrounding landform	Rolling
Slope	Gently rolling, 1-2 % (USDA)
Use	Agricultural
General information concerning the Tres Arroyos soil	
Parent material	Predominant loess
Plot area	15 ha
Drainage	Poor (slow permeability), class III (USDA, 1960)
Stoniness	Less than 0.01%, class II (USDA, 1960)
Climate	Udic regime
Effective depth	50 cm
Depth of the arable layer	15 cm
Rocky outcroppings	Stoniness < 0.01% (USDA, 1960)
Evidence of erosion	Slight (USDA, 1960)
Human influence and land management	Pasture and afforestation

The Tres Arroyos soil had a fine texture with shallow phases and, given that the calcareus appears at 80 cm or less in depth, was well-developed (Ap, B2t, B3ca), without alkalinity, without salinity, and with a slow permeability. The surface horizon (Ap) was 15 cm to 20 cm thick, had an organic matter content of approximately 3-4%, had clay loam texture, and had a good structure and was porous. The subsurface horizon (B2t) was 25 to 30 cm thick, had a clay texture, was moderately structured in prisms, and had few clay-humic coatings. The B3ca horizon had a thickness similar to the previous horizon and a loamy texture that was unstructured with abundant calcium carbonate. The colouration of the surface soil according to Munsell's notation was 10YR 3.5/1 very dark grey to dark grey when dry and 10YR 2/1 black when wet (Munsell, 1975). This colouration coincided with the characteristic tinge of temperate regions (10YR) and the variation of the wet-dry intensity (1.5 units higher) while maintaining the same tinge (Palmer et al., 1989). In the present study, the soil from the Ap horizon was utilised.

2.2 Sampling and analysis methods

The soil sampling was conducted by collecting 10 sub-samples to form a composite sample that was representative of the plot (Jackson, 1970). In the field, sampling was performed using a semi-closed cylindrical bore of 50 mm in diameter. The Munsell key (1975) was used to determine the wet and dry colours, and the methodology proposed by the USDA (1960) was followed to characterise and classify the morphology. For the bulk density, the grammes per cm^3 of undisturbed samples were obtained in the field in steel cylinders with a bevelled edge, and the maximum capacity of water was analysed by the weight difference in PVC cylinders (Guitián and Carballas, 1976). For the granulometric analysis, the organic material was oxidised with hydrogen peroxide, and then the soil sample was treated with HCl. Next, dispersion of the clays was performed with Calgon (sodium hexametaphosphate). Once the percentage distribution of soil mineral particles was obtained, the USDA criteria were followed (SSS, 1975) to determine the texture.

The pH was measured with a pH metre by suspending the sample in double-distilled water at a ratio of 1:2.5, the electrical conductivity (the soluble salt content) was measured with a conductivity metre, the maximum capacity of water was measured using a cylinder of PVC, and the humidity was calculated by the weight difference after evaporation at 110 °C (Guitián and Carballas, 1976). The method of Walkley and Black (1934) was used to determine the organic matter in soils in which the soil organic matter was wet-oxidised. The total N was determined by the Kjeldahl method (Bremner and Mulvaney, 1982) as modified by Guitián and Carballas (1976), and the content of ammonia nitrogen and of nitrates + nitrites was determined by visible absorption spectrophotometry using Hach equipment (Model DR 2010) as described by Bremner and Mulvaney (1982). The exchange capacity and exchangeable cations were determined as described by Hendershot and Duquette (1986). The cations were analysed with inductively coupled plasma atomic emission spectroscopy (ICP –AES) using the 200.7 method (Rev 4.4) of the EPA (1994). The available phosphorus was determined by the method of Olsen et al. (1954), which is recommended for calcareous, alkaline, or neutral soils (Watanabe, 1965). After acid digestion of the samples, the content of total phosphorus and the other nutrients, micronutrients, and trace elements were determined by ICP-AES according to the 200.7 method (Rev 4.4) of the EPA (1994).

One-way analysis of variance (ANOVA) was performed to test for significant differences in certain variables. In all cases, the physical and chemical properties were determined using triplicate samples, taking into account the minimum requirements of Student’s t-test, which requires at least three replicates of the samples for each case.

III. RESULTS AND DISCUSSION

The results of granulometric analysis were similar in both soils with a sandy loam texture for the Tres Arroyos soil and a borderline sandy silt loam for the Cabildo soil. The textures that were found are in agreement with literature data for soils typical of the province of Buenos Aires, Argentina (SAGyP and INTA, 1989). The densities were in the range of values for soils poor in organic matter (Peinemann, 1998). The pH values of the soils were alkaline. The electrical conductivities, however, showed differences of less than 20% with a higher value in the Tres Arroyos soil. In both cases, the values were below the limit that indicates salinity problems (<2 mS cm^{-1}). The organic matter (and therefore the organic carbon) content of the soils used in the present study corresponded to weakly humic soils (Peinemann, 1998). There was <10% difference in the OM content of the Tres Arroyos soil with respect to Cabildo soil, which clearly shows the transition from the Pampas zone to the semi-arid zone and indicates a major limiting factor (Table 1).

The total nitrogen content of the Tres Arroyos soil was more than 20% different than the Cabildo soil. The inorganic fractions of N in both soils showed normal concentrations of ammonium and nitrates, with the greatest proportion being observed in the Tres Arroyos soil.

The C/N ratios showed typical values for soils in temperate zones in transition to low temperatures. The contents of organic matter, organic carbon, and total N coincided with the literature data for soils typical of the province of Buenos Aires, Argentina (SAGyP and INTA, 1989).

There was a notable difference in the effective cation-exchange capacity (CEC) of both soils (Table 2), with the Cabildo soil almost double that of Tres Arroyos. The latter had a moderate adsorption capacity, whereas the Cabildo soil had a high adsorption capacity, which was in agreement with Reed et al. (1988).

TABLE 1
PHYSICAL AND CHEMICAL CHARACTERISTICS OF THE TESTED SOILS

	Soil	Soil
	Cabildo	**Tres Arroyos**
pH H_2O		7.3^{a}
Electrical conductivity (mS cm^{-1})	0.3^{a}	0.35^{a}
OM (g kg^{-1})	29.1^{a}	33.2^{b}
C (g kg^{-1})	16.9^{a}	19.3^{b}
N (g kg^{-1})	1.1^{a}	1.4^{a}
$NO3^{-}$ and $NO2^{-}$ (mg kg^{-1})	60^{a}	115^{b}
$NH4^{+}$ (mg kg^{-1})	20^{a}	22^{a}
C/N	16^{a}	14^{b}
□ real (Mg m^{-3})	2.56^{a}	2.61^{a}
□ apparent (Mg m^{-3})	1.33^{b}	1.35^{b}
Sand (%)	60^{a}	69^{a}
Silt (%)	20^{a}	11^{b}
Clay (%)	20^{a}	20^{a}
Water-retention capacity %	35^{a}	30^{b}

For each parameter, different letters for the different soils indicate significant differences ($p<0.05$)

The values of the pH, EC, and CEC agreed with literature data from various authors for soils typical of the province of Buenos Aires, Argentina (SAGyP and INTA, 1989). The Tres Arroyos soil had a lower content of exchangeable Ca and K, thereby showing a limitation in the availability of essential nutrients.

There were significant differences in the total P content; the Tres Arroyos soil had a lower total P content, which was also clearly observed in the lower levels of available P.

The total Cu contents were low and coincided with the average concentrations for the soils in the zone (Peinemann, 1998). The crops most susceptible to copper deficiency are cereals (Davies et al., 1987). In plants, Cu participates in oxidation-reduction processes, which associated with enzymes that, for example, generate lignin and melanin (Prasad et al., 1997). The low availability of this essential micronutrient is another limiting factor of the Tres Arroyos soil, where the cultivation of winter grains, such as wheat and barley, is notably important for the regional economy. The content of available Cu in the Tres Arroyos soil was very low, as was the available molybdenum (Table 2).

TABLE 2
THE TOTAL METAL CONTENT IN THE SOILS

mg kg^{-1} SS	Cabildo Soil	Tres Arroyos Soil
Na	330^a	450^a
Mg	3294^a	2610^a
K	2679^a	1300^b
Ca	5637^a	3100^b
P	302^a	189^b
Al	22810^a	10100^b
Fe	33690^a	25054^b
Mn	455^a	385^b
B	11^a	4^b
Co	8^a	1^b
Mo	3^a	3^a
V	11^a	4^b
Cr	8^a	1^b
Ni	6^a	3^b
Cu	11^a	5^b
Cd	5^a	$<1^b$
Zn	65^a	35^b
Pb	27^a	14^b
As	$< 1^a$	$<0.1^b$
Se	$< 1^a$	$<0.1^b$
S	223^a	210^a
Ag	$< 0.1^a$	$<0.1^a$
Sn	6^a	4^a
Ba	39^a	93^b

For each element, different letters for the different soils indicate significant differences ($p<0.05$)

The soil precursor material in the southern regions of the province of Buenos Aires has a large percentage of carbonate rocks with a notably low Cu content (Alloway, 1995). The total Cu content of the Tres Arroyos soil (5 mg kg^{-1}) was lower than that of the Cabildo soil (11 mg kg^{-1}).

The total Zn content of the Cabildo and Tres Arroyos soils was 65 and 35 mg kg^{-1}, respectively. These values were within the normal range and are suitable for plant nutrition (Peinemann, 1998). The availability of Zn, similar to that of Cu, is affected by several factors, such as the pH, amount and type of organic matter, interaction with other elements in the soil solution, fertiliser use, and flooding (Covelo et al., 2007; Vega et al., 2009; Vega et al., 2010; Cerqueira et al., 2010).

Both Zn and Cu have Zn^{2+} and Cu^{2+} ions in bioavailable forms in the soil solution, with Zn concentrations almost always being higher (Prasad et al., 1997). The cereals that are particularly sensitive to Zn deficiencies are maize and sorghum. The availability of the micronutrients Zn and Cu are strongly dependent on the soil pH; therefore, the more alkaline the conditions (such as for the Cabildo soil), the more important the pH is as a limiting factor.

IV. CONCLUSION

The soils were slightly alkaline, which is a typical condition of the Pampas region of Argentina, and the Cabildo soil was more alkaline. The alkalinity was a limiting factor for the availability of nutrients and micronutrients.

The contents of organic matter and N were either low (Tres Arroyos soil) or very low (Cabildo soil), constituting a limiting factor that determines various soil processes, such as nutrient availability, water retention, and porosity.

The soils had significantly different contents of organic matter. The organic matter was higher in the Tres Arroyos soil with a higher content of total N and nitrates and therefore a lower C/N ratio; the Cabildo soil had a lower organic matter content and a higher C/N ratio.

The low availability of P in both soils constituted a limiting factor associated more with the alkalinity than with the P supply.

The effective cation exchange capacities were significantly different with higher contents of calcium and potassium and lower exchangeable sodium in the Cabildo soil. The lower availability of Ca and K were limiting in the Tres Arroyos soil.

The availability of Zn and Cu in both soils depended on the pH, with greater limitations being observed for the Cabildo soil.

The lower amount of Cu in the Tres Arroyos soil would be a limiting factor for the cultivation of cereals, such as wheat and barley.

Both soils could be improved with respect to the factors that limit soil quality and productivity, for example, by amendment with organic waste.

REFERENCES

[1] Aguirre, M.E. Bussetti S.G., Santamaría R.M. (2007). Fósforo hidrosoluble y disponible en el suelo por el agregado de cáscara de girasol [Water-soluble and available phosphorus in soil through the addition of sunflower husks]. *Revista de investigaciones de Ciencias Agrarias – UNS*

[2] Alloway, B.J. 1995. Heavy metal in soils. Blackie Academic and Professional Press. London

[3] Andrade, L., Alonso Vega, F., Marcet, P., Fernández Covelo, E. 2005. Heavy metal contents of soils from semiarid Pampa, Buenos Aires Province (Argentina). In: Faz Cano, A., Ortiz, R., Mermut, A.R. (eds.) Sustainable Use and Management of Soils- Arid and Semiarid Regions. Chapter 11. Soil Contamination and Remediation. *Adv. Geoecol.* 36: 477-492. A Cooperating Series of the International Union of Soil Science (IUSS) Catena Verlag. Germany.

[4] Bremner, J.M., Mulvaney, C.S. 1982. Nitrogen total: 621-622, in A.L. Page, editor. Methods of soil analysis Part 2 chemical and microbiological properties. Second edition. American Society of Agronomy and Soil Science Society of America, Madison, WI.

[5] Casas, R. 2003. Sustainability of agriculture in the Pampas region. Climate and Water Institute. Rev. *INTA.* (11): 57-65.Castelar-Argentina.

[6] Casas R. A. 2000. La Conservación de los Suelos y la Sustentabilidad de los Sistemas Agrícolas [Soil conservation and sustainability of agricultural systems]. Disertación acto entrega premio Antonio Prego.

[7] Cáseres L., Bast, R., Mendez M., Currie H. (2005). Fertilización en trigo en condiciones óptimas de disponibilidad hídrica [Wheat fertilisation under optimal conditions of water availability]. Resumen A 039- UNNE- Comunicaciones C y T [Abstract 039 - UNNE- Communications C and T]

[8] Cerqueira, B., Covelo, E.F., Andrade, M.L., Vega, F.A. 2010. The influence of soil properties on the individual and competitive sorption and desorption of Cu and Cd. *Geoderma* (Accepted for publication 30-8-2010).

[9] Ciampitti I., García, F. 2007. Requerimientos nutricionales. Absorción y extracción de macronutrientes y nutrientes secundarios: Cereales, Oleaginosos e Industriales [Nutritional requirements. Absorption and extraction of macronutrients and secondary nutrients: Cereals, oleaginous and industrial]. Informaciones Agronómicas No. 33 [Agricultural Report No. 33]. Archivo Agronómico No. 11 [Agriculture Archive No. 11]. pp. 1-4. IPNI Cono Sur. Acassuso, Buenos Aires.

[10] Covelo, E.F., Vega, F.A., Andrade, M.L. 2007. Competitive Sorption and Desorption of Heavy Metals by Individual Soil Components. *J. Hazard. Mater.* 140: 308-315.

[11] Davies, B., Tagle, D., Finney, B. 1987. Manejo del Suelo [Soil Management]. Ed. El Ateneo, Buenos Aires-Argentina.

[12] Diacono, M., Montemurro, F. 2010. Long-term effects of organic amendments on soil fertility. A review. *Agron. Sustain. Dev*. 30 (2): 401-422

[13] Diaz R.M., Garcia, F., Bozzano, A. I. 1980. Dinámica de la disponibilidad de nitrógeno y las propiedades físicas del suelo en rotaciones de pasturas y cultivos, Uruguay, Centro de Investigaciones Agrícolas Alberto Boerger [Dynamics of nitrogen availability and physical properties of soil in pasture and crop rotations, Uruguay, Alberto Boerger Centre for Agricultural Research]. Miscellanea No. 24, p. 25.

[14] Díaz-Zorita, M., Gonella, C. 1997. Nitrogen fertilisation in small grain pastures from the subhumid pampean region, Argentina Arch. Latinoam. Prod. Anim. 5(Supl. 1): 10-12

[15] Doran, J.W., Parkin, B.T. 1994. Defining Soil Quality for a Sustainable Environment. Soil Science Society of America, Inc. Special Publication. 35: 1367-1378. Madison, Wisconsin, USA.

[16] Echeverría, H., R. Bergonzi. 1995. Estimación de la mineralización de nitrógeno en suelos del sudeste bonaerense [Estimation of nitrogen mineralisation in soils from the southeast of Buenos Aires]. Boletín técnico N°135 [Technical Bulletin No. 135]. 16 p. Instituto Nacional de Tecnología Agropecuaria, Centro Regional Buenos Aires Sur, Estación Experimental Agropecuaria [National Institute of Agricultural and Livestock Technology, Buenos Aires South Regional Centre, Agricultural and Livestock Experimental Station], Balcarce, Argentina

[17] EPA–United States Environmental Protection Agency. 1993. Preparing Sewage Sludge For Land Application or Surface Disposal. EPA 831/B-93-002 a.

[18] Fernández Grecco, R., Mazzanti, A. E., Echeverría, H. 1995. Efecto de la fertilización nitrogenada sobre el crecimiento de forraje de un pastizal natural de la pampa deprimida bonaerense [Effect of nitrogen fertilisation on the growth of forage from a natural grassland of the Flooding Pampa of Buenos Aires]. p. 173-176. In Memorias XIV Reunión Latinoamericana de Producción Animal, 19º Congreso Argentino de Producción Animal [Proceedings of the XIV Latin American Meeting on Animal Production, 19º Argentine Congress of Animal Production], Mar del Plata, Argentina. November 26 to December 1.

[19] Ferraris, G., Mousegne, F. (eds.). 2008. Efecto de diferentes estrategias de fertilización sobre el rendimiento y la calidad de perfiles de genotipo de trigo pan en el norte, centro y oeste de la provincia de Buenos Aires. Campaña 2006/07 y 2007/08. Trigo. Resultados de Unidades Demostrativas. Proyecto Regional Agrícola [Effect of different fertilisation strategies on the yield and quality of bread-

wheat genotype profiles in the north, centre and west of the province of Buenos Aires. Season 2006/07 and 2007/08. Wheat. Results of demonstration units. Regional Agriculture Project]. pp 61-72.

[20] Guitián, F., Carballas, T. 1976. Técnicas de análisis de suelos [Techniques of soil analysis]. Editorial Pico Sacro. Santiago de Compostela

[21] Jackson, M. L. 1970. Análisis químico de los suelos [Chemical analysis of soils]. Ediciones Omega S.A. Barcelona-España

[22] Iacobucci, C. 2000. Informe Final. Programa Provincial de Desarrollo Agropecuario de la Provincia de Buenos Aires [Final Report. Provincial Agricultural Development Programme of the Province of Buenos Aires]. *PROSAP*. Argentina.

[23] Lair, G.J., Gerzabek, M.H., Haberhauer, G. 2007. Sorption of heavy metals on organic and inorganic soil constituents. *Environ. Chem. Lett*. 5: 23-27

[24] Hannapel R.J., Fuller W.H., Bosma S., Bullock J.S. 1964. Phosphorus movement in a calcareous soil. I Predominance of organic forms of phosphorus in phosphorus movement. *Soil Sci*. 97: 350-357.s

[25] Halvorson A.D., Reule C.A., Follett R.F. 1999**.** Nitrogen Fertilisation Effects on Soil Carbon and Nitrogen in a Dryland Cropping System. *Soil Science Society of America Journal* 63:912-917

[26] Hendershot and Duquette, 1986. Soil Sampling and Methods of Analysis. Canadian Society Of Soil Science. Carter, M. R. (Ed.).

[27] Lair, G.J., Gerzabek, M.H., Haberhauer, G. 2007. Sorption of heavy metals on organic and inorganic soil constituents. *Environ. Chem. Lett*. 5: 23-27

[28] Martinez, F. 2002. La soja en la Región Pampeana [Soybean in the Pampas Region]. IDIA Año II Nro 3 [IDIA Year II No 3].

[29] Munsell. 1975. Soil Color Charts. Ed.

[30] Myers, B.J., Polglase, P.J. 1996. Beneficial Use of Sewage Effluent and Biosolids in Plantations. Lessons for farm Forestry. *CSIRO*. Australia.

[31] Olsen, S.R., Cole, C.V., Watanabe, F.S., Dean, L.A. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. U.S. Dep. of Agric. Circ. 939.

[32] Peinemann, N, 1998. Conceptos de Edafología y Nutrición Mineral [Concepts of soil science and mineral nutrition]. Depto Agronomía UNS. Ed. UNS Bahía Blanca, Argentina

[33] Prasad, R., Power, J.F. 1997. Soil Fertility Management for sustainable agriculture. CRC Press. USA.

[34] Quiroga A, Fernandez R., Saks M., 2007. Verdeos de Invierno. INTA Anguil [Winter cereals for grazing. INTA Anguil]. www.produccion-animal.com.ar

[35] Reed, C.S., Middlebrooks, E.J., Crites, R.W. 1988. Natural systems for waste management and treatment. McGraw Hill Book Co. USA.

[36] Roy, R.N., Misra, R.V., Lesschen, J.P., Smaling, E.M. 2003. Assessment of soil nutrient balance. FAO. *Fertiliser and Plant nutrition Bulletin* 14

[37] SAGyP and INTA, 1989. Mapa de suelos de la Provincia de Buenos Aires, EDIPUBLI SA [Maps of the soils of the province of Buenos Aires, EDIPUBLI SA]. Buenos Aires, Argentina.

[38] Schulz, R., Romheld, V. 1997. Recycling of municipal and industrial organic wastes in Agriculture: benefits, limitations and means of improvements. Plant Nutrition-for Sustainable food production and environment. Kluwer Academic Pub (Japan): 581-586.

[39] SSS (Soil Survey Sataff). 1975. Soil Taxonomy: A basic system of making and interpreting soil surveys. Agriculture Handbook No 436. USDA. Washington D.C.

[40] Vega, F.A., Covelo, E.F., Andrade, M.L. 2009. The role of cation exchange in the sorption of cadmium, copper and lead by soils saturated with magnesium. *J. Hazar. Mat*. 171: 262-267.

[41] Vega, F.A., Andrade, M.L., Covelo, E.F. 2010. Influence of soil properties on the sorption and retention of Cadmium, Copper and Lead, separately and together, by 20 soil horizons: comparison of linear regression and tree regression analyses. *J. Hazar. Mat.* 174: 522–533.

[42] Walkey, Black. 1934. *Soil Sci.* 37:29