H. Yacoub, and P.J. Barnes.
by endogenous nitric oxide
Clin. Invest. 92: 736–742.
osby, St. Louis, MO.
nitric oxide synthases early

ɔrmal and clinical nutrition,

–150. *In* Advanced Human

mia: Etiology pharmacology

'n D. Heber, G.L. Blackburn,
San Diego, CA.
b. Co, New York, NY.
k, and A. Zajícová. 1997.
ions of bulls. Veterinarni

Nitrogen in the Environment: Sources, Problems, and Management
J.L. Hatfield and R.F. Follett (Eds)

Chapter 5. Nitrogen Management in Field Crops of the Southern Cone of Latin America

This chapter describes N management for field crops in representative regions of the Southern Cone of South America. Part A refers to the Pampas region of Argentina and includes some references about the western area of Uruguay. Part B addresses the regions of Southern Brazil and Eastern Paraguay.

PART A. NITROGEN MANAGEMENT IN THE PAMPAS OF ARGENTINA

A. Bianchini[a], F. García[b], and R. Melchiori[c]

[a]AAPRESID (Argentinean No-Till Farmers Association), Rosario, Santa Fe, Argentina

[b]IPNI, Latin America-Southern Cone Program (International Plant Nutrition Institute), Acassuso, Buenos Aires, Argentina

[c]INTA EEA Paraná (National Institute for Agricultural Technology), Parana, Entre Rios, Argentina

1. AGRO ECOLOGICAL CHARACTERISTICS OF THE PAMPAS REGION

The Pampas eco-region of Argentina covers an area of approximately 83,000,000 ha (INTA RIAP, 2007), including Buenos Aires, Santa Fe, Córdoba, Entre Rios, San Luis, and La Pampa provinces (Figure 1). Central Santa Fe and east central Cordoba represent the most important and typical productive area of the Argentinean Pampas. The region is the most developed with 67% of total population of the country and a density of 27.1 inhabitants/km^2, higher than the country average (13 inhabitants/km^2).

Crops and forest production occupy 84% of this area. In this region, cereal, oilseed, and forage occupy 90%, 87%, and 91% of the national production area. Soybean (*Glycine max* (L) Merril), wheat (*Triticum aestivum* L.), maize (*Zea mays* L.), and sunflower (*Helianthus annus* L.) are the most important crop.

A brief description of the climate and the major soil types is presented to contribute to a better understanding of common management practices.

Subhumid and temperate weather prevails in the region. Average annual temperature ranges from 14°C to 18°C. Average annual precipitation increases from the Southwest (300 mm) to the Northeast (1,100 mm) (Figure 2).

Figure 1. Geographical location of the area of interest (colored area) (INTA, 2007).

Mollisols occupy important areas of the Pampas plains and constitute the dominant soils among those with the best aptitude for agriculture. The Pampas Region, both humid and semiarid, is characterized, respectively, by Udolls and Ustolls with minor occurrence of Aquolls in flat areas utilized for cattle production (Moscatelli and Pazos, 2000). The most important soils from the agricultural standpoint are developed on the aeolian quaternary sediments. This sediment is known as Pampean loess. From the mineralogical standpoint, the loess is rich in weatherable minerals with conspicuous amounts of calcium (Ca), potassium (K), phosphorus (P) and microelements, and amorphous materials of volcanic origin (Scoppa, 1974). The physical characteristics of the Pampean loess favor the formation of well-structured, deep, dark surface horizons, adequate for root development (Moscatelli, 1991).

In general, soils of the Pampean region are deficient in nitrogen (N) and P, but well provided with K, Ca, and magnesium (Mg) under native conditions. In recent years, sulfur (S) responses have been observed in several crops, mainly in areas under intensive cropping (high grain yields and longer periods under row crops agriculture) (Garcia et al., 2000).

The most representative and productive is the Central Santa Fe region. In this area, a climatic water balance (WB) calculated as the difference between rainfalls (R) and potential evapotranspiration (PET) presents two different periods along the year (Figure 3). Spring and summer rainfalls represent 70% of annual rainfall.

lored area) (INTA, 2007).

s and constitute the domi-
ture. The Pampas Region,
y Udolls and Ustolls with
tle production (Moscatelli
gricultural standpoint are
nent is known as Pampean
ich in weatherable miner-
n (K), phosphorus (P) and
igin (Scoppa, 1974). The
mation of well-structured,
nt (Moscatelli, 1991).
in nitrogen (N) and P, but
ative conditions. In recent
ral crops, mainly in areas
periods under row crops

al Santa Fe region. In this
fference between rainfalls
o different periods along
nt 70% of annual rainfall,

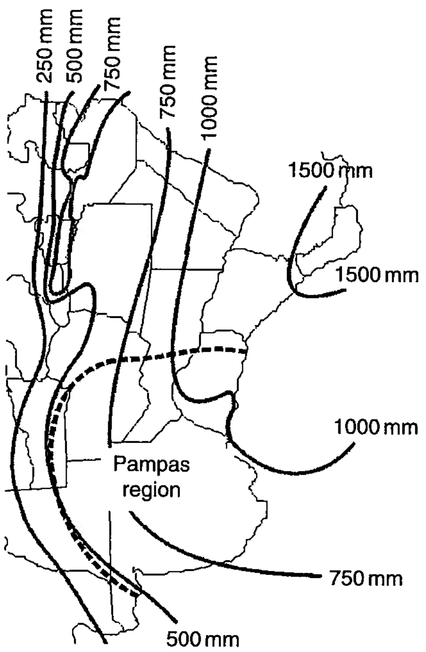


Figure 2. Isolines of annual average precipitation in the Pampas region (Genini, 2000).

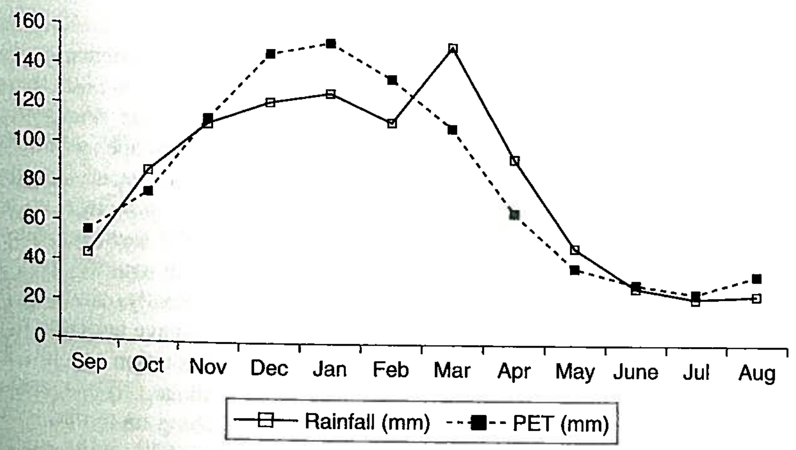


Figure 3. Rainfall and PET in Central region of Santa Fe province (Rafaela). (Unpublished data from Agrometeorology, INTA Rafaela.)

whereas winter and fall accumulate 30%. A positive balance, in terms of water accumulation, occurs during the spring and fall months, and a negative one during the winter period. Irrespective of positive annual climatic WBs, the variability of the rainfall regime occasionally causes local short droughts. Droughts in the December–February, and May–July periods are common in the region and increase the risk of production in drought sensitive crops (i.e., corn).

Annual global solar radiation, photoperiodic period and temperature evolution show the possibility of making use of an extended productive season (Figure 4).

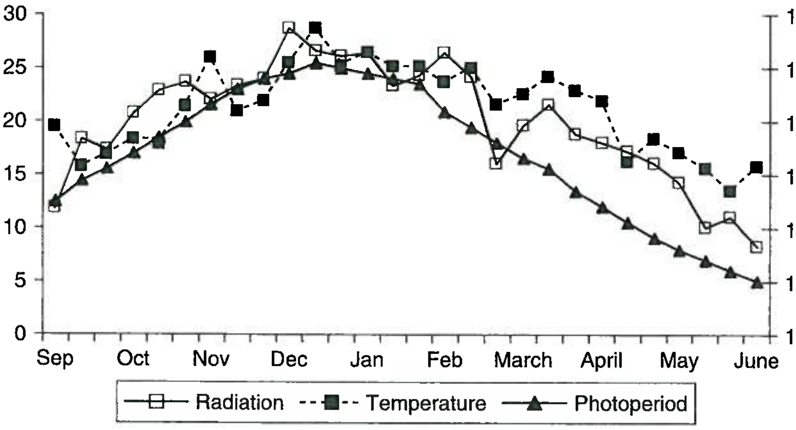


Figure 4. Global solar radiation, photoperiod, and mean monthly temperature in Central region of Santa Fe Province (Rafaela). (Unpublished data from Agrometeorology, INTA Rafaela.)

Full season crops are planted in this area and double cropping systems, generally wheat/double crop soybean, is a very common productive practice.

The central area of Santa Fe province, named Plain Pampas (Panigatti and Mosconi, 1979), is characterized by a slightly undulated landscape, with normal and subnormal relieves and slopes of 0.3–0.6%. Dominant soils are Mollisolls (Argiudolls and Argialbolls) and some soil type variability is associated to topographic position. Very high silt content (70%) induces a natural low aggregate stability and susceptibility to soil crusting. Soil fertility levels were naturally very high (5% organic matter and >50 ppm of P; Bray and Kurtz 1). Presently, extensive areas show soil degradation in moderate to severe grade due to intensive agricultural use, excessive and continuous conventional tillage without crop rotation and low fertilization rates. During the last decade, the adoption of no-tillage (NT) systems has been increasing at a rate of 1 million hectare per year, reaching more than 19 million hectare in the 2004/2005 season, and covering more than 67% of the country's arable land (AAPRESID, 2007). The adoption of no-till allowed farmers to increase their yields due to higher water use efficiency.

more than 90% of the wheat area receives an average rate of 45 kg/ha of N fertilizer, and more than 85% of the corn area receives an average rate of 50 kg/ha of N fertilizer.

2.1. Fertilizer Sources

Farmers utilize dry and liquid fertilizers as N sources. Dry sources include simple and composed fertilizers. Simple fertilizers constitute the products that only contain one nutrient and the composed fertilizers those that contain at least two nutrients. The composed fertilizers are presented as chemical or physical blends. The most common dry N fertilizer sources used in the Southern Cone of South America for extensive crops (corn, grain sorghum, wheat, barley, oats) are urea (46% N), ammonium sulfate (21% N, 24% S), ammonium nitrate (32% N), and calcareous ammonium nitrate (27% N, 12% CaO) (Figure 5). Also, other fertilizers like di-ammonium phosphate (DAP) or mono-ammonium phosphate (MAP) are used as starters and provide 18% and 11% of N, respectively.

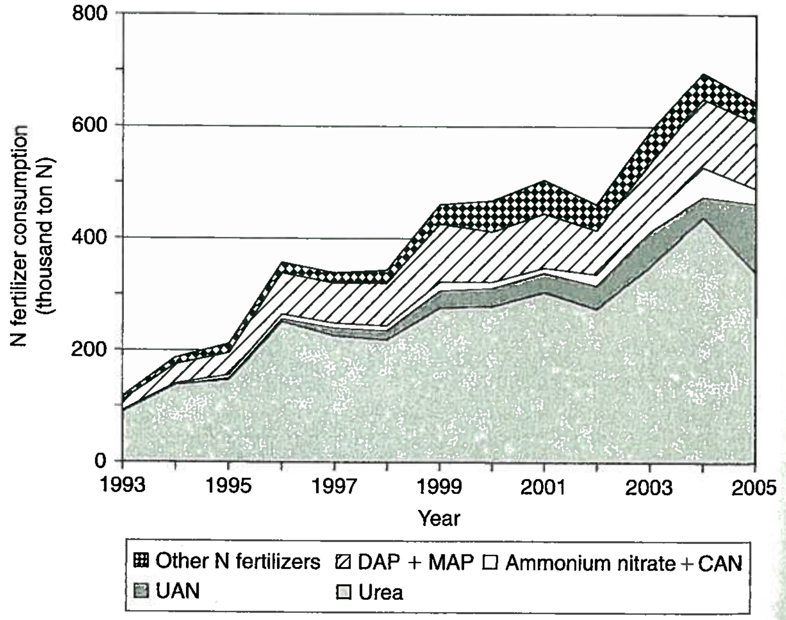


Figure 5. Evolution of consumption of N fertilizers in Argentina between 1993 and 2005 expressed in thousand metric tones of N. CAN stands for calcium ammonium nitrate. DAP + MAP includes the N applied in di-ammonium and MAP. Other fertilizers include ammonium sulfate, potassium nitrate, ammonium thiosulfate, and others. (IPNI Southern Cone; compiled from data of SAGPyA, Fertilizar AC Fundación Producir Conservando and fertilizer companies).

where N_f = Fertilizer N

N_c = Crop N demand
N_r = residual inorganic N at harvest
N_i = inorganic N at planting time
N_{min} = mineralized N
e_i, e_{min}, and e_f = use efficiencies of N_i, N_{min}, and N_f, respectively.

Estimated crop yield allowed estimating N_c. Generally, N_r was considered 0 or as a fraction of N_i. N_i has been determined at 60-cm depth at pre-planting. Estimations of N_{min} include a fixed percentage of the organic N content, or referenced values obtained from laboratory incubations or regionalized field experiments (Echeverría and Bergonzi, 1995; Gonzalez Montaner et al., 1997; Alvarez, 1999; Melchiori, 2002). Efficiency factors are highly variable according to crop, soil, climate, and management conditions and might vary between 0.4 and 0.8.

In Chile, Rodriguez et al. (2001) have developed an adaptation of the N balance methodology in which the soil supply of N is estimated from the N availability of residues of previous crops.

3.2. Soil Available N at Planting or During the Growing Season

The evaluation of available (inorganic) N at planting time has been a useful tool to determine fertilizer N needs in subhumid and semiarid regions of the world. This methodology has been calibrated in several areas of the Pampas region of Argentina with good success. Critical available N levels at planting vary according to the crop (wheat or corn), expected yield, soil and climate conditions of the area, and cropping systems. Table 2 shows critical levels for wheat across several areas of the Pampas.

The N fertilization recommendation is estimated from the critical level and the amount of NO_3^--N determined at the pre-planting sampling:

$$N_f = CL - X$$

where N_f is the amount of fertilizer N to be applied, CL is the critical level, and X is the amount of NO_3^--N in the soil at 60-cm depth.

Field experimentation in corn has also allowed determining critical levels of available N at planting (Ruiz et al., 1997). Figure 6 shows a calibration of this methodology for trials carried out between 2000 and 2004 at Córdoba, Santa Fe and Buenos Aires provinces. Recent evaluations indicated that available N critical levels of 150–170 kg N/ha, according to yield potential, maximize economic return of corn N fertilization in the region (Alvarez et al., 2003; García et al., 2006).

Soil N determinations during the growing season have also been calibrated to estimate N fertilization needs for small grains and corn. In Uruguay, the availability of NO_3^--N (20-cm depth) at two tillers stage (Zadoks 2.2; Zadoks et al., 1974) is d N_f, respectively.

rally, N_r was considered
cm depth at pre-planting.
ganic N content, or refer-
regionalized field experi-
ner et al., 1997; Alvarez,
riable according to crop,
between 0.4 and 0.8.
daptation of the N balance
from the N availability of

g Season

ime has been a useful tool
regions of the world. This
mpas region of Argentina
vary according to the crop
s of the area, and cropping
eral areas of the Pampas.
n the critical level and the
g:

L is the critical level, and

rmining critical levels of
hows a calibration of this
004 at Córdoba, Santa Fe
d that available N critical
naximize economic return
García et al., 2006).
ve also been calibrated to
n Uruguay, the availability
.2; Zadoks et al., 1974) is

Table 2.
Critical levels of available N at wheat planting (NO_3^--N, 60-cm depth) in different areas of the Pampas with different expected yields.

Area	Critical level NO_3^--N 60 cm (kg/ha)	Expected yield (kg/ha)	Reference
Southeastern Buenos Aires	125	3,500	González Montaner et al., 1991.
Sierras areas of Buenos Aires	110	4,000–4,500	García et al., 1998.
Western Buenos Aires	90	3,000	González Montaner (pers.com.)
South-Central Santa Fe	70	2,500	González Montaner (pers.com.)
Northern Buenos Aires	100–140	3,500–4,000	Satorre (pers. com.)
Southeastern Buenos Aires	175	5,000–5,500	González Montaner et al., 2003.
Southern Santa Fe and Córdoba	100–150	3,200–4,400	García et al., 2006.

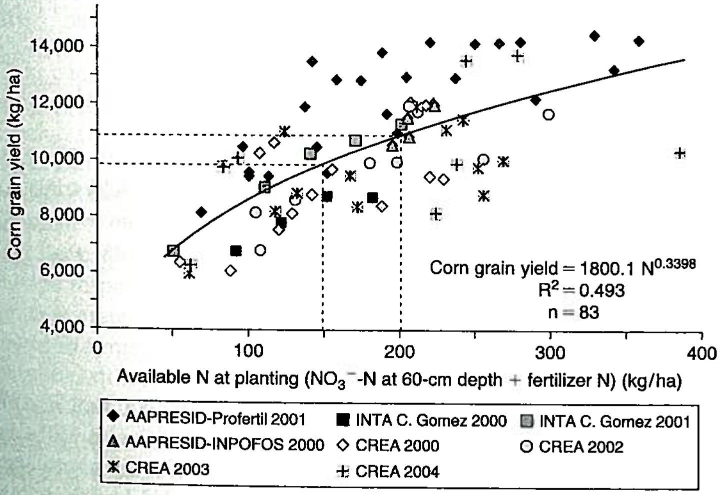


Figure 6. Corn yield as a function of available N at planting (NO_3^--N at 60-cm depth + fertilizer N). Field trials carried out between 2000 and 2004 at Córdoba, Santa Fe, and Buenos Aires provinces (Argentina) by several research groups.

utilized with NO_3^--N (20-cm depth) availability at planting to determine N fertilization needs in small grains (Bordoli and Perdomo, 2005).

For corn, the pre-sidedress soil nitrate test (PSNT) developed by Magdoff et al. (1984) has been calibrated in several areas. Critical NO_3^--N (0–30 cm depth) levels at V5–V6 stage (Ritchie et al., 1993) varied between 16 and 27 mg/kg according to corn yields, crop and soil management, and soil and climate conditions (Melchiori et al., 1996; García et al., 1997; Perdomo et al., 1998; Ferrari et al., 2000; Sainz Rozas et al., 2000; Bianchini et al., 2005 (Figure 7); Bordoli and Perdomo, 2005). Field research has estimated that, to reach the critical level, 8–12 kg N/ha should be applied to increase 1 mg/kg (Bianchini et al., 2005; Echeverría and Sainz Rozas, 2005b).

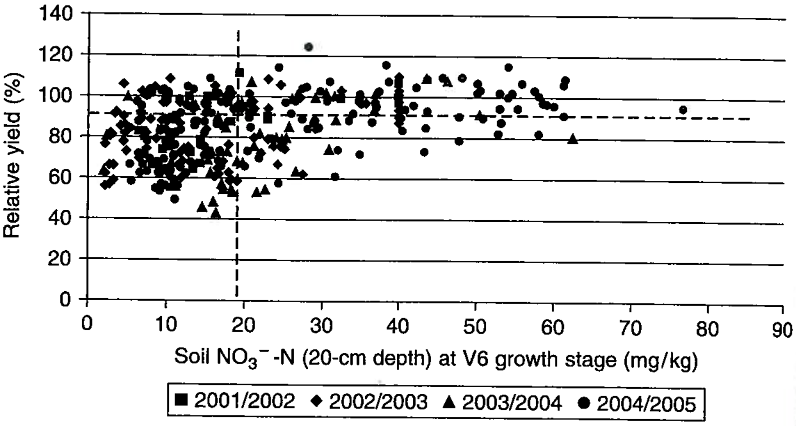


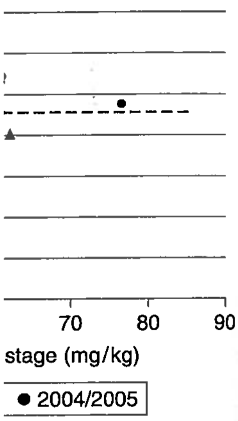
Figure 7. Relative corn yield as a function of NO_3^--N availability (0–20 cm depth) at V5–V6 stage. Network AAPRESID 2001–2005 ($n = 384$). Field trials carried at Buenos Aires, Córdoba, Entre Ríos and Santa Fe Aires provinces (Argentina). The vertical line indicates NO_3^--N = 19 ppm and the horizontal one Relative yield = 0.95 (Bianchini et al., 2005).

3.3. Plant Analysis

Concentration of total N is not frequently used as a diagnostic tool in deciding N fertilization in corn or wheat. In Uruguay, total N concentration at Z30 (Zadoks scale; Zadoks et al., 1974) complements a diagnostic tool in a recommendation model for fertilization of malting barley (Baethgen, 1992).

The determination of sap NO_3^- concentration (SNC) in stems of wheat (González Montaner et al., 1987; Justes et al., 1997) and corn has been calibrated for different situations of the Pampas region. Critical levels of SNC in pseudo-stems of wheat

ng to determine N fertili-
.
) developed by Magdoff
NO_3^--N (0–30 cm depth)
tween 16 and 27 mg/kg
oil and climate conditions
1998; Ferrari et al., 2000;
7); Bordoli and Perdomo,
itical level, 8–12 kg N/ha
005; Echeverría and Sainz



ailability (0–20 cm depth
384). Field trials carried
es provinces (Argentina
horizontal one Relative

diagnostic tool in deciding
centration at Z30 (Zadoks
ool in a recommendation
).
stems of wheat (González
een calibrated for different
in pseudo-stems of wheat

at tillering vary according to growth stage, time of the day, plant density, and soil and climate conditions. For wheat, critical levels range from 1,000 to 2,500 mg/L NO_3^- at tillering stages, and for corn, from 1,200 to 4,500 mg/L NO_3^- at V6 stage (González Montaner and Di Napoli, 1997; Ferrari et al., 2001; Sainz Rozas et al., 2001; García et al., 2006).

Concentrations of NO_3^- in dry stems of corn at 400–800 mg/kg, at physiological maturity, have been reported as optimal to achieve 90% of maximum corn yield (Sainz Rozas et al., 2001; Bianchini et al., 2005).

3.4. Remote Sensing

Determinations of greenness index (GI) using the chlorophyll meter Minolta SPAD 502® have been carried out to determine N status in corn and wheat crops. The GI varies according to genotype, growth stage, water availability, and soil and climate conditions, as it has been shown in numerous researches across the world. To avoid this variability, a sufficiency index (SI) (SI = GI of the test field/GI of a nonnitrogen limited field) is used.

In wheat, the SI relates closely to wheat yield at advanced stages (after jointing), thus the potential use of this tool for recommending N fertilization is limited (León et al., 2001; Gandrup et al., 2004). The SI levels also correlated with grain protein content, and its determination could be used in determining the need of late foliar N applications to improve protein levels (Bergh et al., 2001; Bergh et al., 2004).

In corn, the sensitivity of the GI or SI determinations has not been able to differentiate crop N status after V5–V6 stage, limiting its use in dryland conditions. In advanced stages, pre- and post-anthesis, critical levels of SI were of 0.97–0.98 to reach 95% corn maximum yield (Sainz Rozas and Echeverría, 1998).

Crop canopy sensors should sense a large area, which integrates the amount of living plant biomass into the reflectance reading and subsequent vegetation index value (NDVI). Comparing the NDVI value from an area in the field to the value from an adequately fertilized area provides a measure of relative N status (Schepers, 2002). Research evaluating remote sensing to determine crop N status and develop N fertilization strategies is underway. Several algorithms have been derived that calculate N fertilizer application rates based on the crops yield potential and the response to additional fertilizer (Raun et al., 2004). Extensive field tests have demonstrated the validity of the algorithm and the performance of the sensors/applicator in Argentina. Urricarriet and Zubillaga (2001) demonstrated that aerial photos could differentiate areas with different corn N status at R4. Also in corn, Melchiori et al. (2001) compared uniform and variable N applications with the N-Sensor® of Yara® The site-specific N management allowed obtaining greater corn yields and higher N use efficiency (NUE) than the uniform N management. Current work by EEA INTA Paraná and AAPRESID is evaluating the sensors Crop Circle® (Holland Scientific) and GreenSeeker® (NTech Industries). Preliminary results have shown a great increase in the NUE using variable rate applications (Table 3) (Melchiori et al., 2005).

Table 3.
Corn grain yield and components with fertilization at planting, splitted with fixed rate and with a rate based on the SBNC[1] (Melchiori et al., 2005).

Treatments	Grain yield (kg/ha)	Kernel weight (mg)	Kernels (m^2)	Yield response (kg/ha)	NUE[2] (kg grain/kg of applied N)
Control	5,595	215	2,620	–	–
N 140	8,725	204	4,281	2,474	18
N 70 + N 70	9,219	226	4,075	3,623	26
N 70 + SBNC[1]	8,660	224	3,773	3,064	44

[1] SBNRC: Sensor Based Nitrogen Rate Calculator.

[2] NUE: Nitrogen Use Efficiency.

3.5. Agronomic Simulation Models (ASM)

The ASM constitute a promissory tool to manage N efficiently since they allow to integrate soil, plant, and climatic factors with management decisions. Work developed by researchers of the Faculty of Agronomy (University of Buenos Aires) and AACREA (Satorre et al., 2001; Satorre et al., 2005) resulted in the release of the software *Triguero* (FAUBA-AACREA, 2005). *Triguero* is an interactive software for decision-making support in wheat, N, and irrigation management in the Pampas region of Argentina. Similarly, *Maicero* is a corn model currently under development (Ruiz et al., 1997; Mercau et al., 2001; Satorre and Mercau 2001).

4. SYSTEMS FOR FERTILIZER APPLICATION

When a fertilizer application method is selected, the general objective is to maximize the use efficiency of the N applied as fertilizer, reducing energetic and time costs, and minimizing environmental aspects. To maximize the use efficiency, N should be available to the crop at the beginning of the highest uptake period. The specific objectives are:

- To minimize the nutrient losses in the system.
- To avoid that the fertilizer affects germination and the following crop development (phyto-toxicity).
- To achieve the most simple and economic application method.

The achievement of these objectives depends on the following aspects:

- Fertilizer characteristics: chemical form of the nutrient, accompanying compounds, acidity or alkalinity, physical form, solubility.

g, splitted with fixed
05).

ield esponse kg/ha)	NUE^2 (kg grain/kg of applied N)
-	–
2,474	18
3,623	26
3,064	44

ciently since they allow
ement decisions. Work
ersity of Buenos Aires)
lted in the release of the
an interactive software
agement in the Pampas
urrently under develop-
rcau 2001).

general objective is to
reducing energetic and
imize the use efficiency,
ghest uptake period. The

e following crop devel-

method.

lowing aspects:

ent, accompanying com-

- Soil conditions and properties: pH, buffer capacity, texture, cation exchange capacity, surface residue cover, moisture, temperature, and others.
- Phenological stage and root development of the crop.
- Type and availability of the application equipment.

There are important differences between nutrients regarding the mobility and reactions of the different chemical forms in the soil. In general, the nutrients are classified depending on the mobility in the soil in mobile and nonmobile. Nitrogen is the example of the mobile nutrient, because the inorganic form of nitrate, the most frequent to find in agricultural soils, is very soluble.

The soil and management conditions should be considered when selecting the application method. For example, reduced tillage and NT result in a surface residue accumulation that favors the ammonia volatilization losses with surface applications of urea, mainly due to the high urease activity of the residue (García et al., 1999; Sainz Rozas et al., 1999; Fontanetto and Keller, 2003). The presence of surface residues also favors microbial immobilization of applied N, P, and S. Other factors like surface residue quality (C:N ratio, lignin content) and quantity should be considered because they affect the fertilizer N immobilization. To improve NUE of the applied fertilizers, the fertilizer incorporation below the residues layer has been suggested (Fontanetto, 1999; Ferrari et al., 2000).

The most common application methods of N fertilizers in Argentina and Uruguay are discussed below.

4.1. Surface Applications

Surface applications are associated to pre-plant applications, post-emergence with the crop under development (i.e., wheat at tillering, corn at 5–6 leaves) or with the irrigation water. The surface or broadcast applications are more frequent for mobile nutrients like N. If the surface applications are done with UAN solutions with the corn at advanced growth stages, the applicator should include devices that direct the fertilizer to the soil surface to reduce the corn leaf damage.

Dry N fertilizers, mainly urea, are usually applied by broadcasting at pre-plant, top dressing at wheat tillering and corn at V3–V6 stage (Ritchie et al., 1993), or side-dressing at V3–V7 corn. Liquid fertilizers, UAN or UAN + ATS blends, are mainly applied by top dressing at wheat tillering, or surface dribbling at wheat tillering and V3–V7 corn. These applications of liquid N fertilizers could be carried out including some pesticides such as herbicides.

The actual area under surface irrigation for extensive crops in the Central Pampas Region is less than 2% of the total arable land (Martellotto et al., 2005). The diffusion of this technology allows to incorporate fertilizers in the irrigation water with the advantage that the nutrients can be applied in growth stages of more crop demand, when it will be difficult to apply with traditional methods. Additionally, the application with the irrigation water reduces the application costs. Soluble dry or liquid fertilizers are the most used. The dissolved fertilizer is injected in the irrigation line using a centrifuge or high-pressure pump. Security systems that avoid the return of the fertilizer to aquifer should be used. It is very important that the fertilizer is injected in the area with highest turbulence to optimize the mixture with the irrigation water.

4.2. Subsurface Applications

Application of N fertilizers in bulk blends with P and/or S fertilizers at planting is a very frequent practice in Argentina and Uruguay. These applications could be considered as starters, but the rates used are commonly higher than those considered in starter applications in the United States. Fertilizer applications close to the seeds and roots can generate phyto-toxicity problems. These effects are mainly due to the salt effect and the presence of toxic compounds for the crops like ammonia, applied as anhydrous ammonia or generated by the hydrolysis of the urea in the soil.

Due to the toxic effects of the high ammonia concentrations generated around the urea granule, it is not recommended to apply high rates of urea with the seed at planting. In wheat, rates up to 25–30 kg N/ha as urea applied with the seed can be used in soils of medium to fine texture without toxicity problems, and in soils of coarser textures more than 15–20 kg N/ha should not be applied as urea with the seed. In corn, the maximum N rates vary between 20 and 10 kg N/ha, in row widths of 70 cm, for soils with fine and coarse textures, respectively. These maximum reference rates decrease rapidly when the soil moisture content decreases (Gudelj et al., 2001) (Figure 8). The DAP also produces ammonia in the reaction zone

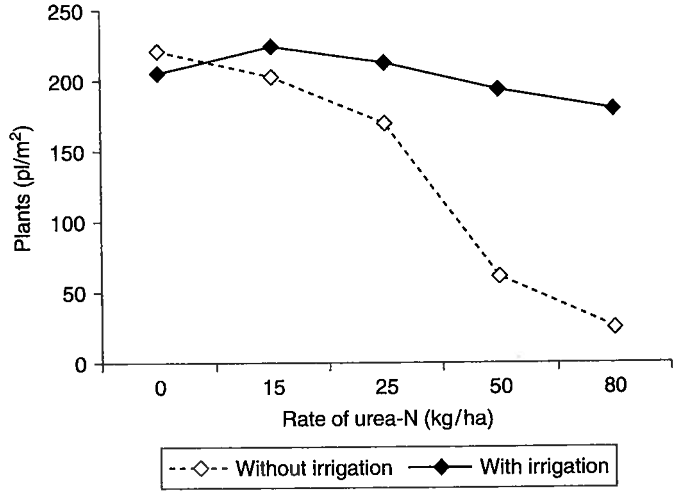


Figure 8. Wheat plants emerged at 25 days after planting with different N rates applied as urea in the furrow with the seed, with and without irrigation (Gudelj et al., 2001).

and the same maximum N rates should be considered. The side-dress fertilizer N applications in post-emergence generally do not generate toxicity problems to the crop.

4.3. Foliar Applications

The foliar applications involve the use of soluble liquids in sprayings over the canopy. The nutrients are rapidly absorbed, so the nutrient deficiency can be immediately corrected. The foliar fertilizers do not permit to apply great amounts of nutrients, so it is considered as a supplemental application in the fertilization program. High salt concentrations in the fertilizer can result in leaf burning.

Foliar applications are not commonly used in Argentina and Uruguay. Recent developments have shown promissory results in improving wheat protein concentration using a liquid urea (20% N) of low biuret content (Loewy et al., 2004).

5. FINAL COMMENTS

The Southern Cone of Latin America has adopted NT systems in more than 65% of the arable land, and the trend shows that this adoption will continue in the next years. The presence of crop residues in the soil surface increases the water use efficiency and thus, grain yield potential of extensive crops. Average soybean, corn, and wheat yields have been significantly increased during the past years, partially due to higher fertilizer consumption (N, P, and S use was tripled in the last 10 years). The challenge for the next decades is to produce a higher amount of food, feed, fuel, and fiber by increasing the use efficiency of all the resources involved in crop production (nutrients, water, etc.), and minimizing the impact to the environment for the well-being of future generations. Management of N through right rates, right timing, and right applications is a challenge in developing sustainable systems in the NT agriculture of the Southern Cone.

REFERENCES

AAPRESID. 2007. No-tillage evolution in Argentina. AAPRESID, Rosario, Santa Fe, Argentina. Available at www.aapresid.org.ar. Accessed February 1, 2007.

Alvarez, R. 1999. Uso de modelos de balance para estimar los requerimientos de fertilizante nitrogenado de trigo y maíz EUDEBA, Buenow Aires, Argentina. 58 pp.

Alvarez, R. (ed.). 2005. Fertilización de cultivos de granos y pasturas. Diagnóstico y recomendación en la Región Pampeana, Facultad de Agronomía, Universidad de Buenos Aires, Buenow Aires, Argentina, 174 pp.

Alvarez, R., H. Steinbach, C. Alvarez, and S. Grigera. 2003. Recomendaciones para la fertilización nitrogenada de trigo y maíz en la pampa ondulada. Informaciones Agronómicas. 18: 14–19. INPOFOS Cono Sur. Acassuso, Buenos Aires, Argentina.

Baethgen, W. 1992. Fertilización nitrogenada de cebada cervecera. Serie Técnica No. 24, INIA La Estanzuela, Uruguay.

Barberis, L., A. Nervi, H. del Campo, S. Urricariet, J. Sierra, P. Daniel, M. Vazquez, and D. Zourarakis. 1983. Análisis de la respuesta del trigo a la fertilización nitrogenada en la Pampa Ondulada y su predicción. Ciencia del suelo 1: 51–64.

Berardo, A. 1994. Aspectos generales de fertilización y manejo de trigo en el área de influencia de la Estación Experimental INTA-Balcarce. Boletín Técnico No. 128, EEA INTA Balcarce, Argentina.

Bergh, R., T. Loewy, and H. Echeverría. 2004. Nitrógeno en trigo: rendimiento y calidad panadera. III. Aplicaciones de las lecturas del índice de verdor. Actas VI Congreso Nacional de Trigo, Bahía Blanca, Buneos Aires.

Bergh, R.G., M.S. Zamora, M.L. Seghezzo, and E.R. Molfese. 2001. Nutrición nitrogenada y proteína de trigo candeal. *In* Proceedings V National Congress of Wheat. Villa Carlos Paz, Córdoba, 26–28 September.

Bianchini, A., M.E. Magnelli, D. Canova, S.N. Lorenzatti, D. Peruzzi, J. Rabasa, A. Sylvestre Begnis, and F.O. García. 2005. Diagnóstico de Fertilización Nitrogenada para Maíz en Siembra Directa. Proceedings VIII National Congress of Maize, pp. 230–233. AIANBA-Maizar, Rosario, 16–18 November 2005.

Bordoli, J.M. and C.H. Perdomo. 2005. Balance de nutrientes y principales criterios de fertilización de cultivos en Uruguay. Proceedings CD Symposium Uruguay–Argentina "Impact of agricultural intensification in the soil resource". Colonia, Uruguay, 6–7 October 2005.

Calviño, P. and H. Echeverría. 2003. Incubación anaeróbica del suelo como diagnóstico de la respuesta a nitrógeno del maíz bajo siembra directa. Ciencia del Suelo. 21: 24–29.

Echeverría, H. and R. Bergonzi. 1995. Estimación de la mineralización de nitrógeno en suelos del sudeste bonaerense. Tech. Bull. 135, EEA INTA Balcarce, Balcarce, Buenos Aires, Argentina.

Echeverría, H. and H. Sainz Rozas. 2005a. Nitrógeno, pp. 255–282. *In* H. Echeverría and F. García (eds) Fertilidad de Suelos y Fertilización de Cultivos. Editorial INTA, Buenos Aires, Argentina.

Echeverría, H. and H. Sainz Rozas. 2005b. Maíz, pp. 255–282. *In* H. Echeverría and F. García (eds) Fertilidad de Suelos y Fertilización de Cultivos. Editorial INTA, Buenos Aires, Argentina.

FAUBA-AACREA. 2005. Software Triguero (CD). Facultad de Agronomía (UBA)-AACREA. Buenos Aires, Argentina. Available at www.aacrea.org.ar. Accessed January 22, 2007.

Ferrari, M., J. Ostojic, L. Ventimiglia, H. Carta, G. Ferraris, S. Rillo, M. Galetto, and F. Rimatori. 2000. Fertilización de maíz: Buscando una mayor eficiencia en el manejo de nitrógeno y fósforo. Proceedings "Fertility 2000". PPI-PPIC Southern Cone, Acassuso. Buenos Aires, Argentina.

Ferrari, M., F. Rimatori, G. Ferraris, J. Ostojic, M. Galetto, and R. Gómez. 2001. Diagnóstico de deficiencias de N en maíz basado en la concentración de nitratos en savia. Proceedings VII National Congress of Maize. AIANBA, Pergamino, Buenos Aires, Argentina.

Fontanetto, H. 1999. Maíz en la región central de Santa Fe. Proceedings of the "nitrogen phosphorous and sulphur diagnosis in crops of the Pampas Region Seminar". EEA INTA Balcarce, Balcarce, Buenos Aires Argentina.

ra. Serie Técnica No. 24,
. Daniel, M. Vazquez, and
ilización nitrogenada en la

le trigo en el área de influ-
cnico No. 128, EEA INTA

igo: rendimiento y calidad
erdor. Actas VI Congreso

001. Nutrición nitrogenada
ess of Wheat. Villa Carlos

). Peruzzi, J. Rabasa, A.
tilización Nitrogenada para
ss of Maize, pp. 230–233.

rincipales criterios de ferti-
Jruguay–Argentina "Impact
uguay, 6–7 October 2005.
ielo como diagnóstico de la
el Suelo. 21: 24–29.
ralización de nitrógeno en
Balcarce, Balcarce, Buenos

-282. *In* H. Echeverría and
os. Editorial INTA, Buenos

282. *In* H. Echeverría and
os. Editorial INTA, Buenos

gronomía (UBA)-AACREA.
cessed January 22, 2007.
S. Rillo, M. Galetto, and
r eficiencia en el manejo de
Southern Cone, Acassuso,

. Gómez. 2001. Diagnóstico
itratos en savia. Proceedings
os Aires, Argentina.
oceedings of the "nitrogen
egion Seminar". EEA INTA

Fontanetto, H. and O. Keller. 2003. Pérdidas de nitrógeno por volatilización de diferentes fuentes nitrogenadas aplicadas al voleo, Campaña 2002/03. *In* Maíz en Siembra Directa, pp. 88–91, AAPRESID, Rosario, Argentina.

Gandrup, M.E., F. García, K. Fabrizzi, and H. Echeverría. 2004. Evolución de un índice de verdor en hoja para evaluar el status nitrogenado en trigo. Rev. Inv. Agropecuarias 33(3): 101–117.

García, F. and A. Berardo. 2005. Trigo, pp. 233–253. *In* H. Echeverría and F. García (eds) Fertilidad de Suelos y Fertilización de Cultivos. Editorial INTA, Buenos Aires.

Garcia, F. and I. Daverede. 2007. Diagnóstico para recomendação de adubação nitrogenada em culturas de interesse agronômico. *In* G.C. Vitti (ed.) Nitrogenio e enxofre na agricultura. ESALQ-POTAFOS. (In press).

García, F., K. Fabrizzi, M. Ruffo, and P. Scarabicchi. 1997. Fertilización nitrogenada y fosfatada de maíz en el sudeste de Buenos Aires. *In* Proceedings VI National Congress of Maize. AIANBA, Pergamino, Buenos Aires, Argentina.

García, F., K. Fabrizzi, L. Picone, and F. Justel. 1999. Volatilización de amoniaco a partir de fertilizantes nitrogenados aplicados superficialmente bajo siembra directa y labranza convencional. 14, Latinamerican Congress of Soil Science, Pucón, Chile. 8–12 November 1999.

García, F., M. Ambrogio, and V. Trucco. May 2000. No-Tillage in the Pampas of Argentina: A Success Story. Better Crops International 14(1).

García, F., M. Boxler, J. Minteguiaga, R. Pozzi, L. Firpo, G. Deza Marin, and A. Berardo. 2006. La Red de Nutrición de la Región CREA Sur de Santa Fe: Resultados y conclusiones de los primeros seis años 2000–2005. AACREA, Buenos Aires, Argentina. 32pp.

García, F.O., K.P. Fabrizzi, A. Berardo, and F. Justel. 1998. Fertilización nitrogenada de trigo en el sudeste bonaerense: Respuesta, fuentes y momentos de aplicación. *In* Proceedings XVI National Soil Science Congress. AACS, pp. 26–28, Villa Carlos Paz, Córdoba, Argentina. September.

Genini, G.F. 2000. Riego, estado y legislacion en San Juan (Argentina) 1850–1914. In: Scripta Nova. Electronic magazine of geography and social sciences. University of Barcelona. Nº 66, 15 June, 2000.

González Montaner, J. and M. Di Napoli. 1997. Respuestas a nitrógeno del cultivo de maíz en el sur de la provincia de Santa Fe. *In* Proceedings VI National Congress of Maize. AIANBA, Pergamino, Buenos Aires, Argentina.

González Montaner, J., J.M. Meynard, and B. Mary. 1987. Contrôle de la nutrition azote du blé par l´analyse des teneurs en nitrates dans la plante. C.R. Acad. Agric. Fr. 73(3): 105–115.

González Montaner, J., G. Maddonni, N. Mailland, and M. Porsborg. 1991. Optimización de la respuesta a la fertilización nitrogenada en el cultivo de trigo a partir de un modelo de decisión para la Subregión IV (Sudeste de la Provincia de Buenos Aires). Ciencia del Suelo 9: 41–51.

González Montaner, J., G. Maddoni, and M.R. Di Napoli. 1997. Modeling grain yield and grain yield response to nitrogen in spring wheat crops in the Argentinean Southern Pampa. Field Crops Res. 51: 241–252.

González Montaner, J., M. Di Nápoli, P. Calviño, N. Mailland, M. Posborg, F. Dodorico, and J. Andenoche. 2003. Nitrógeno en trigo. CREA Magazine 272: 56–59.

Gudelj, V., C. Galarza, P. Vallone, and B. Massiero. 2001. Fitotoxicidad por fertilización en la línea en siembra directa de trigo. Informaciones Agronómicas 10: 12–13, INPOFOS Southern Cone. Acassuso, Argentina.

INTA. 2007. Proyecto Red de Informacion Agroeconomica de la Region Pampeana. INTA. Available at http://riap.inta.gov.ar/. Accessed February 7, 2007.

Justes, E., B. Mary, and J. Meynard. 1997. Evaluation of a nitrate test indicator to improve the nitrogen fertilization of winter wheat crops, pp. 93–110. *In* G. Lemaire and I. Burns (eds) Diagnostic procedures for crop N management. INRA, Paris, France.

Khan, S.A., R.L. Mulvaney, and R.G. Hoeft. 2001. A simple soil test for detecting sites that are non responsive to nitrogen fertilization. Soil Sci. Soc. Am. J. 65: 1751–1760.

León, M., M.F. Dreccer, and D. Rodríguez. 2001. Estimación del N foliar utilizando el SPAD en trigo creciendo con deficiencia de agua y de nitrógeno. *In* Proceedings V National Congress of Wheat. Villa Carlos Paz, Córdoba, Argentina.

Loewy, T., H. Echeverría, and R. Bergh. 2004. Nitrógeno en trigo: rendimiento y calidad panadera. II. Fertilización complementaria. *In* Proceedings VI National Congress of Wheat. pp. 153–154, Bahía Blanca, Ed. INTA, Argentina.

Magdoff, F.R., D. Ross, and J. Amdon. 1984. A soil test for nitrogen availability to corn. Soil Sci. Soc. Am. J. 48: 1301–1304.

Martellotto, E., A. Salinas, E. Lovera, P. Salas, C. Alvarez, J. Giubergia, and S. Lingua. 2005. Inventario y caracterización del riego suplementario en la Provincia de Córdoba. Tech. Bulletin No. 10. EEA INTA Manfredi, Manfredi, Córdoba, Argentina.

Melchiori, R. 2002. Fertilización de trigo, soja y maíz en Entre Ríos. Proceedings "Fertility 2002". PPI-PPIC Southern Cone, Acassuso, Buenos Aires, Argentina. pp. 24–30.

Melchiori, R., O. Paparotti, and W. Paul. 1996. Diagnóstico de la fertilización nitrogenada de maíz: Nitratos en preescardillada. Extensión Series No. 11, EEA INTA Paraná, Entre Ríos.

Melchiori, R., P. Barbagelata, C. Christiansen, and A. Von Martini. 2001. Manejo por sitios específicos del nitrógeno en maíz: Evaluación del N-sensor. *In* Proceedings VI National Congress of Maize. AUABVA, Pergamino, Buenos Aires Argentina.

Melchiori, R., O. Caviglia, A. Bianchini, N. Faccendini, and W. Raun. 2005. Avances en la utilización de sensores remotos para manejo de nitrógeno de maíz. *In* Proceedings of the XIV National Congress of AAPRESID. pp. 155–160.

Melgar, R. 2005. El mercado de fertilizantes en la Argentina y su relación con el sector agropecuario, pp. 489–502. *In* H. Echeverría and F. García (eds) Fertilidad de suelos y fertilización de cultivos, INTA, Buenos Aires, Argentina.

Mercau, J., E. Satorre, M. Otegui, G. Maddoni, J. Carcova, R. Ruiz, M. Uribelarrea, and F. Menendez. 2001. Evaluación a campo del comportamiento del modelo CERES en cultivos de maíz del norte de la provincia de Buenos Aires. *In* Proceedings VII National Congress of Maize. AIANBA, Pergamino, Buenos Aires, Argentina.

Moscatelli, G. 1991. Los suelos de la Región Pampeana, pp. 1–76. *In* Osvaldo Barsky (ed.) El desarrollo agropecuario pampeano. INDEC-INTA-IICA, Buenos Aires, Argentina.

Moscatelli, G. and M.S. Pazos. 2000. Soils of Argentina: Nature and use. *In* I. Kheoruenromne and S. Theerawong (eds). April 17–22, 2000, Bangkok, Thailand. Proceedings of the International Symposium on Soil Science: Accomplishments and Changing Paradigm towards the 21st Century, and IUSS Extraordinary Council Meeting 81-92. ISBN 974-87749-4-5.

Panigatti, J.L. and F. Mosconi. 1979. Arcillas de suelos del centro de Santa Fe y centro-este de Córdoba. RIA. Series 3, Vol. XII. No. 3. INTA, Buenos Aires.

Perdomo, C.H., V.S. Ciganda, E. Borghi, and G.Wornicov. 1998. Evaluación del test de nitrato en suelo para las condiciones de maíz en Uruguay. p. 337. En XXIII Reunao Brasileira Fertilidade de Solo e Nutricao de Plantas. FertBio 98. Resumos. Caxambu (MG). Brasil.

Raun, W.R., J.B. Solie, M.L. Stone, K.W. Freeman, K.L. Martin, R. Teal, B. Arnall, B. Tubana, C. Byungkyun, K.B. Morris, K. Girma, S. Moges, and C. Mack. 2004. Increasing Cereal Nitrogen Use Efficiency Using Sensor Based Technology, pp. 365–371. *In* Proceedings of the XII National Congress of AAPRESID.

Ritchie, S., J. Hanway, and G. Benson. 1993. How a corn plant develops. Special Report No. 48. Iowa State University. Ames, IA, USA.

Rodriguez, J., D. Pinochet, and F. Mathus. 2001. Fertilización de los cultivos. LOM Ediciones, Santiago, Chile, 117 pp.

Ruiz, R., E. Satorre, G. Maddoni, D. Calderini, D. Miralles, J. Carcova, and M. Di Napoli. 1997. Bases funcionales de la respuesta a la fertilización nitrogenada de cultivos de maíz en el norte de la provincia de Buenos Aires. *In* Proceedings VI National Congress of Maize. AIANBA, Pergamino, Buenos Aires, Argentina.

Sainz Rozas, H. and H. Echeverría. 1998. Relación entre las lecturas del medidor de clorofila (Minolta SPAD 502) en distintos estadios del ciclo del cultivo de maíz y el rendimiento en grano. Rev. Fac. Agron. La Plata 103(1): 37–44.

Sainz Rozas, H., H. Echeverría, G. Studdert, and F. Andrade. 1999. No-till maize nitrogen uptake and yield: Effect of urease inhibitor and application time. Agron. J. 91: 950–955.

Sainz Rozas, H., H. Echeverría, G. Studdert, and G. Dominguez. 2000. Evaluation of the presidedress soil nitrogen test for no-tillage maize fertilized at planting. Agron. J. 92: 1176–1183.

Sainz Rozas, H., H. Echeverría, E. Herfurt, and G. Studdert. 2001. Nitrato en la base del tallo de maíz. II. Diagnóstico de la nutrición nitrogenada. Ciencia del Suelo 19(2): 125–135.

Satorre, E. and J. Mercau. 2001. Bases de decisión para la fertilización nitrogenada en maíz. Report Project AACREA-FAUBA. Buenos Aires, Argentina.

Satorre, E., R. Ruiz, D. Miralles, D. Calderini, and G. Maddoni. 2001. Bases de decisión para la fertilización nitrogenada en las zonas Norte de Buenos Aires, Sur de Santa Fe y Centro de AACREA. *In* Wheat Tech. Bull, pp. 30–38, AACREA, Buenos Aires, Argentina.

Satorre, E., F. Menéndez, and G. Tinghitella. 2005. El modelo Triguero: Recomendaciones de fertilización nitrogenada en trigo. Proceedings "Fertility 2005". Rosario, 27–28 April. INPOFOS Cono Sur-Fertilizar A.C., pp. 3–11.

Schepers, J.S. (2002). Nitrogen management: New technologies for management and diagnosis of nitrogen fertilization. *In* Proceedings of the X National Congress of AAPRESID, Book.I, pp. 141–155.

Scoppa, C.O. 1974. The pedogenesis of a sequence of Mollisols in the Undulating Pampa (Argentina), D. Sc. Thesis, State University of Ghent, Belgium.

Urricarriet, S. and M. Zubillaga. 2001. Fotografía aérea color e índice de verdor en la detección de la respuesta a la fertilización nitrogenada en maíz. Proceedings VII national Congress of Maize. AIANBA, Pergamino, Buenos Aires, Argentina.

Zadoks, J., T. Chang, and C. Konzak. 1974. A decimal code for the growth stages of cereals. Weed Res. 14: 415–421.