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Comparative effectiveness of two nitrogen sources for corn fertilization

Efectividad comparativa de dos fuentes nitrogenadas para la fertilización del maíz

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Abstract. Corn has not only a high growth potential and a great capacity of biological response to suitable crop management but also may contribute to a better match of crops with environmental offer in Argentina. Nitrogen (N) fertilization must make provision for eventual N losses, and fertilization strategies must be designed so as to minimize their global incidence. The different quick-release N sources show similar efficiencies when they are incorporated, but in surface applications, sources that contain little or no amidic N have a better performance than urea (U). The objective of this paper was to make an evaluation of corn response to N applied in V6 without incorporation, using two different solid N sources. A field experiment was carried out during 2004, in a farm located 30 km away from General Pico (La Pampa, Argentina), to evaluate corn response to N rates (0 - 120 kg/ha) sidedressed in V6 without incorporation, using U or a commercial mixture of ammonium nitrate and dolomite (ND). Rainfall and temperatures were ideal during the crop cycle. The excellent growing conditions reflected in high corn yields. The results showed that N fertilization affected virtually all yield components. Yield was on average 2417 kg of grain/ha greater in the ND than in the U treatments. For a N rate below 85 kg/ha, agronomic efficiency was of 65 and 87 kg of corn per kg of applied N for U and ND, respectively. Apparent fertilizer N recovery was 1.14 and 1.34 kg absorbed N per kg applied N for U and ND, respectively. For the kind of soil, cultivar and growing conditions of the experiment, a substitution value of 1.6 can be used to estimate ND-N rates from models developed for U-N.

Keywords: Fertilizer technology; Nitrogen recovery; Substitution value.

Resumen. El maíz no sólo tiene un alto potencial de crecimiento y una gran capacidad de respuesta biológica a un manejo adecuado, sino que también puede contribuir a un mejor ajuste de la agricultura con la oferta ambiental en la Argentina. Para la fertilización del cultivo las diversas fuentes de liberación rápida de nitrógeno (N) muestran eficiencias similares cuando se incorporan, pero en aplicaciones superficiales los productos sin N amídico se comportan mejor que la urea (U). El objetivo de este trabajo fue evaluar la respuesta del maíz a N aplicado en V6 sin incorporación, usando dos fuentes sólidas diferentes. En 2004/05 se llevó a cabo un ensayo en un establecimiento situado a 30 km de General Pico (provincia de La Pampa, Argentina) para evaluar la respuesta a dosis de N (0 - 120 kg/ha) aplicado entre líneas en V6 sin incorporación, como U o una mezcla comercial de nitrato de amonio y dolomita (ND). Durante el ciclo del cultivo las precipitaciones y las temperaturas fueron ideales y se reflejaron en los altos rendimientos del maíz. Los resultados demostraron que la fertilización con N afectó virtualmente todos los componentes de la producción. El rendimiento en los tratamientos con ND fue en promedio 2417 kg de grano/ha mayor que para U. Para una dosis de N menor a 85 kg/ha, la eficiencia agronómica fue de 65 y 87 kg de maíz por kg de N aplicado como U y ND, respectivamente. La recuperación aparente del fertilizante fue de 1,14 y 1,34 kg de N absorbidos por kg N aplicado para U y ND, respectivamente. Para la clase de suelo, cultivar y condiciones del experimento, se puede utilizar un valor de sustitución de 1,6 para estimar dosis de N como ND a partir de los modelos desarrollados para U.

Palabras clave: Tecnología de fertilización; Recuperación de nitrógeno; Valor de sustitución.

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INTRODUCTION

Corn (*Zea mays* L.) is the most important cereal crop in the world, yearly contributing with more than one third to the total world cereal production (USDA, 2012). Corn is a traditional source of food and feed. However, global interest in the crop has increased significantly due to an escalating demand for biofuel energy. In the past five years, Argentine corn planting area, mainly located in the temperate regions of the country, has been over three million ha (MinAgri, 2012). The annual output is less than 0.5% of the world's total.

If agriculture is to be intensified in Argentinean Pampas, corn inclusion in crop sequences will both have a positive effect on soil carbon balance (Studdert & Echeverría, 1998) and contribute to a better match of crops with the environmental conditions, particularly through an increment in water use efficiency (Caviglia & Andrade, 2010).

Adequate nutrient supply is essential for corn profitable production. Nitrogen (N) deficiencies, in particular, affect crop growth and development, potential kernel set and grain yield. However, N use in agriculture has become an issue of great concern due to its potential negative externalities. It is important therefore to avoid N losses because of economical and environmental reasons (Cassman et al., 2002).

Over a decade ago, Raun & Johnson (1999) reviewed production practices that resulted in an increased N use efficiency in cereal crops. They included aspects of fertilization technology, such as rate, timing, application form and N source.

Sidedress N addition or fractionation is usually more efficient than a single rate of application at sowing. This is because the N amount exposed to potential early season losses is reduced (Magdoff, 1992). This advantage may be counteracted by a greater potential for losses through ammonia volatilization due to higher air temperatures at the V6 stage.

Regarding the different quick-release N sources, they usually display similar efficiencies when incorporated (Keller & Mengel, 1986). In surface applications, however, nitrate based products show a better performance than fertilizers containing urea (U). During U hydrolysis, soil pH increases. This favors ammonia volatilization, which is also influenced by the surface residue amounts (Andraski & Bundy, 2008).

In the Pampean region (Argentina), factors conditioning corn response to N have been studied since 1945 (Zaffanella, 1971). Most of the literature reports experiments in the more productive areas of the Rolling Pampas and eastern Southern Pampas (Calviño et al., 2003; Alvarez & Grigera, 2005). N losses from U have been measured directly (Rimski-Korsakov et al., 2007) and indirectly by various researchers and compared with N losses from non-amidic sources (García et al., 1999; Fontanetto, 1999; Barbieri et al., 2003; Ferraris et al., 2009) and slow release U (Sainz Rozas et al., 1999; Barbieri et al., 2010).

Research in the Inland Pampas is comparatively more recent and consistent with the expansion of summer crops in the last decade (Díaz-Zorita, 2000). Productivity of rainfed corn has been related to water and N availability in La Pampa Province (Quiroga et al., 2006). Barraco & Díaz-Zorita (2005) studied the effects of the timing of N application over a rate range in the north west of Buenos Aires Province. We are not aware of any reports dealing with corn responses to different N sources and their respective efficiencies in that region.

For comparing this aspect of fertilization technology over a range of N rates, different parameters can be used. For example, Rajan et al. (1996) contrasted the effectiveness of phosphate rock with that of hydrosoluble fertilizers. The methods have been applied to alternative techniques for wheat fertilization in the semiarid region, such as forms of phosphorus application (Ron & Loewy, 2000a), timing of N application (Ron & Loewy, 2000b) and N sources (Ron & Loewy, 2007).

Therefore, we thought that it was possible to extend the existing information on corn response to U by setting up a bridging experiment with another N product. The objective of this paper was to make an evaluation of corn response to N rates applied in V6 - without incorporation - using two different solid N sources.

MATERIALS AND METHODS

An experiment was carried out in a commercial production field located 30 km away from the city of General Pico (Province of La Pampa, Argentina) during the growing season of 2004/2005 (Fig. 1). The area is a transition between semiarid and subhumid climate and has been described by Lorda et al. (2008). The previous crop was soybean (1500 kg/ha).

The soil at the experimental site is an Entic Haplustoll of sandy loam texture, well drained and with a depth ranging between 60 and 90 cm. Prior to sowing, a composite soil sample of the site was taken for routine analysis. Initial and pre sidedress soil nitrate-N (at the V6 six leaf stage) were also determined (Table 1).

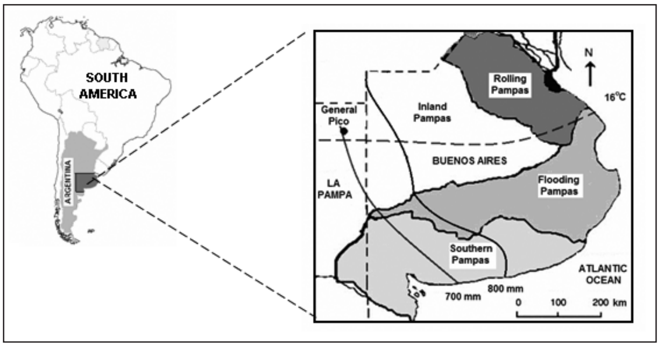

Fig. 1. Location of General Pico, in the inland pampas sector of La Pampa and Buenos Aires provinces, Argentina. Adapted from Díaz-Zorita & Buschiazzo (2006) and Viglizzo et al. (2001).

Fig. 1. Ubicación de General Pico, en el sector de la pampa interior de las provincias de La Pampa y Buenos Aires, Argentina. Adaptado de Díaz-Zorita & Buschiazzo (2006) y Viglizzo et al. (2001).

Table 1. Soil test results at the experimental site.
Tabla 1. Resultados de análisis de suelos en el sitio experimental.

Soil test	Sampling depth (cm)	Value	Method	Reference
pH	0-12 [a]	6.9	Potentiometric in water 1:2.5	Vázquez, 2005
Organic matter	0-12 [a]	17 g/kg	Walkley & Black	Carreira, 2005
Extractable phosphorus	0-12 [a]	9 mg/kg	Bray & Kurtz	Boschetti & Quintero, 2005
Nitrate- N	0-20 [a]	18 mg/kg	Steam distillation with Devarda alloy	Bremner & Keeney, 1965
Nitrate- N	20-40 [a]	16 mg/kg		
Nitrate- N	0-20 [b]	5 mg/kg		
Nitrate- N	20-40 [b]	4 mg/kg		

Time of sampling: [a] preplant; [b] V6.

Corn cultivar Nidera AX 952 was planted in rows spaced 52 cm apart under conventional tillage on 20 October 2004. The crop was supplied with a starter rate of 40 kg diammonium phosphate/ha. The site was kept free of weeds and insects through the application of 2,4-D concentration 100% (0.2 L/ha) of atrazine (3 L/ha), metolachlor and cypermethrin insecticide (0.2 L/ha).

The experiment included 7 treatments arranged in a randomized complete block design (n = 3). Each experimental unit was 5 rows wide by 5 m long. Treatments were check and N rates (40 - 80 - 120 kg/ha) applied as U (46-0-0) or a commercial mixture of ammonium nitrate and dolomite (Nitrodoble®= ND) with grade 27-0-0 (4Mg-6Ca). Fertilizer N was sidedressed between the rows at V6 (Ritchie & Hanway, 1982) on 1 December 2004, without incorporation.

At physiological maturity, yield components were estimated in each plot. Plants and harvestable ears per plant were counted on 5 lineal randomly selected 1 m segments from the three central rows to determine the number of plants per m^2 (PNm^2) and the number of ears per plant (ENp). From the same plot area, 15 randomly selected ears were collected and dried under ambient air temperature. Ears were shelled, pooled grain from the 15 ears was weighed, and average grain weight per ear (GWe) was calculated. To estimate grain weight (GW), 5 subsamples of 100 grains each were weighed. Grain yield (GY) and other components and subcomponents such as number of ears per m^2 (ENm^2), grains per ear (GNe) and grains per m^2 (GNm^2) were estimated through calculation. Bulk density was determined by weighing a 250 cm^3 grain sample and the result was expressed as volume weight (VW), in kg/hL (SENASA, 2012).

For each treatment grain samples from the two blocks with a similar GY range were pooled and ground using a laboratory mill to uniform fineness. Grain N concentration was determined by Kjeldahl method. This was combined with GY (mean of the two blocks) to estimate N yield (NY).

Statistical procedures

Analysis of variance and comparisons. Analyses of variance were performed to study the effects of treatments. In order to partition N sources and N rate effects and evaluate interactions, orthogonal contrasts were used (Table 2). When the F-test from the ANOVA was significant for treatment effects, a critical least significant difference (LSD) value ($p<0.05$) was calculated for planned mean comparisons: U vs. ND, for the same N rate.

Table 2. Coefficients for orthogonal contrasts.
Tabla 2. Coeficientes para los contrastes ortogonales.

N rates/source	0	40 (U)	80 (U)	120 (U)	40 (ND)	80 (ND)	120 (ND)
Contrast effects							
1 Fertilization	-6	1	1	1	1	1	1
2 N source	0	1	1	1	-1	-1	-1
3 N rate	0	2	-1	-1	2	-1	-1
4 source x rate	0	2	-1	-1	-2	1	1

U urea; ND ammonium nitrate mixture with dolomite.
1: Check vs fertilized; 2: U vs ND; 3: 40 kg N /ha vs 80 and 120 kg N/ha; 4: interaction.

Substitution value. In a continuous analysis for the comparison of the two sources, we used regressions of the form:

$GY = b_0 + b_1\ FN + b_2\ FN^2$ (1)

where GY is yield in kg/ha, FN, fertilizer rate in kg N/ha applied with either source, and b_0, b_1 and b_2, coefficients.

Assuming the effect of ND relative to that of U was constant for any level of yield within the range covered by the experiment, the data for the two sources were combined to estimate a yield function of the form:

$GY = b_0 + b_1\ sv\ FN + b_2\ (sv\ FN)^2$ (2)

where sv = 1 for U, and sv = SV for ND. SV was termed a substitution value of ND for U corresponding to the substitution rates described by Colwell & Goedert (1988) for the representation of the relative effectiveness of various forms of P fertilizer relative to a standard fertilizer. Estimates of SV were obtained by successive approximation by fitting regressions of form (2) with sv = 1 for U and successive values for sv = SV for ND.

To test for the statistical significance of the estimate of SV, the difference between the sums of squares for equations (2) and (1) was calculated. This was divided by the residual mean square for eq. (2) deducting a degree of freedom to allow for the estimate of SV. The contribution of SV was given by the F ratio obtained.

A statistical test of the adequacy of the model in eq. (2) was made by comparing the residual mean square for this form with the alternative:

$GY = b_0 + b_1\ U\text{-}N + b_2\ U\text{-}N^2 + b_3\ ND\text{-}N + b_4\ ND\text{-}N^2$ (3)

where GY is grain yield in kg/ha; U-N and ND-N fertilizer rate in kg N/ha applied as U and ND, in that order, and b_0 to b_4, coefficients.

Fertilizer efficiency. For each N source, linear-plateau equations were fitted for GY and NY as a function of N rates. The slopes of the linear phases in these equations provided estimates of N agronomic efficiency (A_E) and apparent recovery fraction (R_F), respectively. N utilization efficiency (N_{UE}) was calculated as the quotient between A_E and R_F (Delogu et al., 1998).

For statistical analysis, INFOSTAT software was used (Di Rienzo et al., 2008).

RESULTS

During the growing season, the temperature was higher from December to February and then decreased towards maturity of the crop (Fig. 2). Precipitation occurred mostly from November to January, matching crop requirements. December rains were twice the average and provided high soil water availability around corn flowering period.

Statistical analysis showed significant overall effects of fertilizer treatments existed for GY and all the components and subcomponents except for GNe (Table 3). Unfertilized plots produced the lowest GY. In general GY and its components increased with N rate. VW ranged from 75.9 to 79.7 kg/hL but was not significantly affected by N fertilization. Corn receiving ND had greater values of ENp, ENm^2, GWe, GNm^2 and GY than plots fertilized with U. The only significant interaction found between N rates and sources was for PNm^2. This is consistent with individual treatment comparisons for this variable, which showed significant ND superiority only for the lowest N rate. For ENp, ENm^2, GNm^2 and GY the least significance difference only detected source effects at certain N rates, giving a narrower view than contrasts (Table 4). Simple linear correlation analysis between GY and different components showed significant or highly significant positive associations in almost all cases (Table 5).

Estimation of SV for GY was 1.6. The regression in Fig. 3 accounted for a large proportion of yield variation. Addition of SV to equation (1) was found to be statistically highly

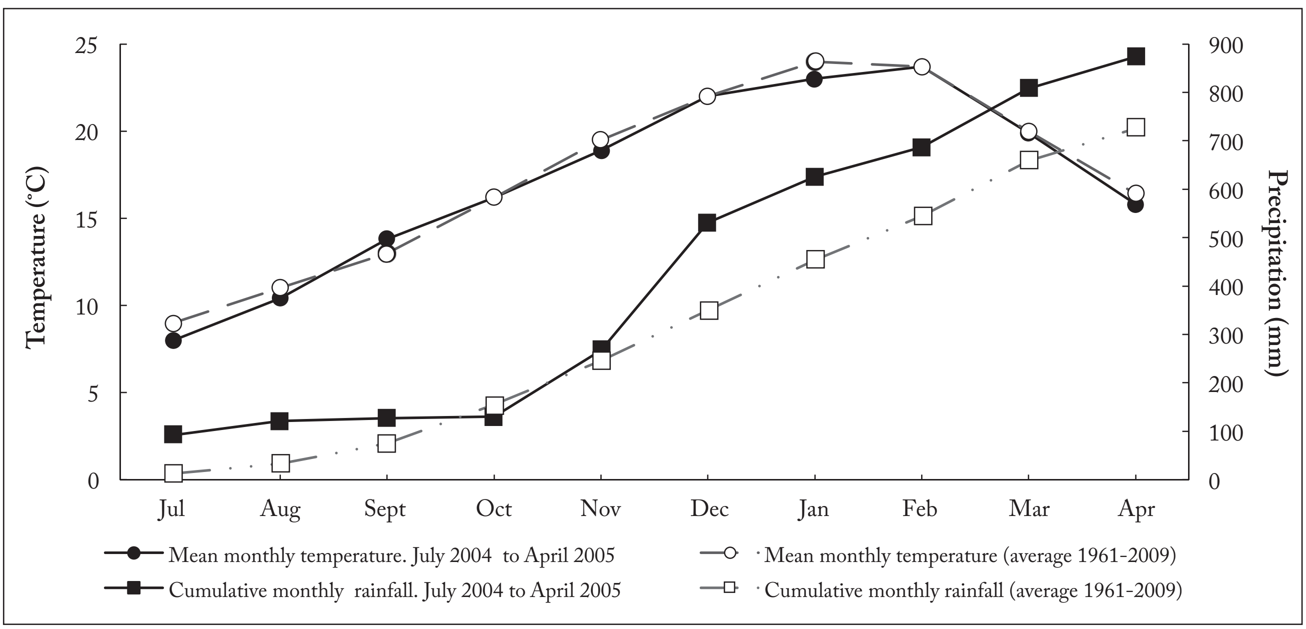

Fig. 2. Mean monthly temperature and cumulative precipitation in 2004-2005 compared with average values for a 49-year period (1961-2009).
Fig. 2. Temperatura mensual y precipitaciones mensuales acumuladas en 2004-2005, comparadas con los valores promedio de un periodo de 49 años (1961-2009).

Table 3. Significance for block, treatment and orthogonal contrast effects.
Tabla 3. Significancia de los efectos de bloques, tratamientos y contrastes ortogonales.

	PNm^2	ENp	ENm^2	GWe	GNe	GNm^2	GW	GY	VW
Block	ns	ns	ns	ns	ns	ns	ns	ns	ns
Treatment	**	**	**	***	ns	***	***	***	ns
Contrast effects									
Fertilization	***	***	***	***	ns	***	***	***	ns
Source	ns	**	*	*	ns	**	ns	**	ns
Rates	ns	**	*	**	ns	**	***	***	ns
Interaction	ns	ns	ns	ns	ns	ns	ns	ns	ns

***, ** or * indicate, respectively, significance at 0.001, 0.01 or 0.05 p level; ns: non significant. Contrasts see Table 2. PNm^2: plant number per m^2, ENp and ENm^2: ear number per plant and per m^2, GWe: grain weight per ear, GNe and GNm^2: grain number per ear and per m^2, GW: grain weight, GY: grain yield, VW: volume weight.

Table 4. Individual and group mean comparison and coefficients of variation.
Tabla 4. Comparación individual y grupal de medias y coeficientes de variación.

N rate (kg/ha)	N source	n	PNm^2	ENp	ENm^2	GWe (g)	GNe	GNm^2	GW (mg)	GY (kg/ha)	VW (kg/hL)
0		3	5.9	0.85	5.0	419	96	2092	229	4787	78.0
40	U	3	6.9	0.84	5.8	400	102	2277	256	5825	77.7
80	U	3	8.0	0.88	7.0	496	138	3486	279	9676	78.2
120	U	3	8.7	0.90	7.3	513	153	3718	297	11936	78.3
40	ND	3	8.6	0.91	7.9	484	125	3818	259	9907	77.3
80	ND	3	7.8	0.93	7.9	514	151	4016	295	10975	77.8
120	ND	3	8.3	1.04	8.7	540	169	4630	314	14511	78.7
LSD			1.3	0.09	1.7	106	29	935	25	2708	2.3
Mean of 3 rates	U	9	7.9	0.87	6.7	470	131	3160	277	8469	78.1
	ND	9	8.2	0,96	8.1	513	149	4155	289	12474	77.9
CV	%		9.8	5.4	13.3	12.2	12.5	15.3	5.2	15.8	1.7

Crop variables, U and ND see Table 3. LSD: least significant difference (p=0.05).
CV: coefficient of variation.

Table 5. Correlation coefficients and significance.
Tabla 5. Coeficientes de correlación y significancia.

	PNm^2	ENp	ENm^2	GNe	GWe	GNm^2	GW	GY
PNm^2	1	*	***	*	**	***	**	***
ENp	0.45	1	***	ns	*	***	**	***
ENm^2	0.92	0.77	1	*	**	***	***	***
GNe	0.43	0.33	0.44	1	***	***	**	***
GWe	0.55	0.50	0.60	0.90	1	***	***	***
GNm^2	0.82	0.69	0.89	0.79	0.85	1	***	***
GW	0.58	0.58	0.67	0.53	0.84	0.70	1	***
GY	0.78	0.72	0.88	0.76	0.91	0.97	0.84	1

(*, * *, *** and crop variables see Table 3).

significant. According to this, N rates applied as U should be 60% greater than N rates as ND, to attain the same yield response in the N range of 40 to 120 kg/ha. The comparison of the residual mean squares for equations (2) and (3) showed that SV was close to constant in the N rate range studied.

Efficiency analysis for the mean of two blocks is shown in Table 6. Equations show the plateau was only reached for ND-N. For the rate range of 0 to 85 kg N/ha, A_E was around 65 and 87 kg grain/kg N applied as U and ND, respectively. R_F was above 1 for the two N sources. Estimated N_{UE} was 57 and 65 kg grain/kg absorbed N for U and ND, respectively.

Table 6. Linear-plateau equations for grain yield and nitrogen yield as a function of N rates for two N sources.
Tabla 6. Ecuaciones lineales y de meseta del rendimiento en grano y de nitrógeno en función de las dosis de N para dos fuentes nitrogenadas.

N source	Grain yield (GY) kg/ha	R^2	N yield (NY) kg/ha	R^2
U	GY = 4112 + 65.28 FN	0.97	NY = 40.0 + 1.14 FN	0.98
ND	GY = 5518 + 87.17 FN; FN< 85	0.87	NY = 53.3 + 1.34 FN; FN<94	0.97

Equations fitted over means of two blocks. FN: N fertilizer rates (kg/ha). U and ND see Table 3.
Ecuaciones efectuadas desde el promedio de 2 bloques. FN: Tasa de fertilización con nitrógeno (kg/ha). U y ND ver Tabla 3.

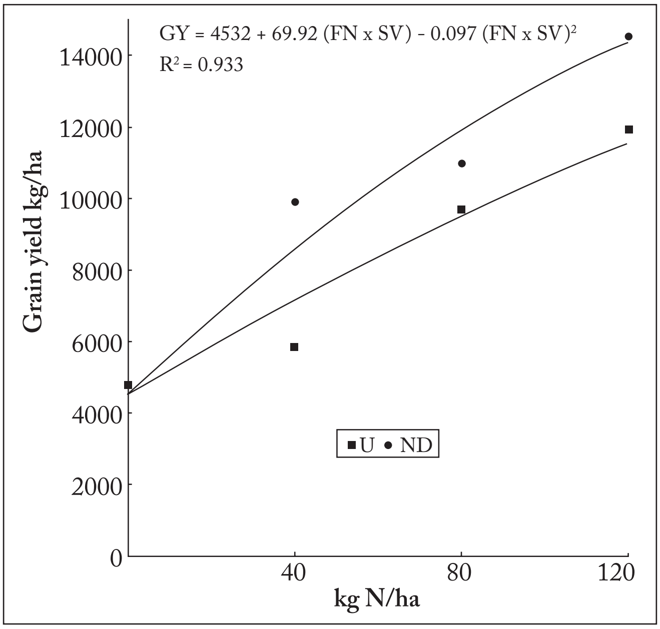

Fig. 3. Model for crop response to nitrogen applied from two different sources.
GY, U and ND see Table 3. FN: N fertilizer rate. SV substitution value = 1.6 for ND and 1 for U. Equation fitted over means of 3 blocks.
Fig. 3. Modelo para la respuesta del cultivo a nitrógeno aplicado de dos fuentes diferentes.
GY, U y ND ver Tabla 3. FN: dosis de N. SV: valor de substitución = 1.6 para ND y 1 para U. Ecuación ajustada sobre las medias de 3 bloques.

DISCUSSION

Rainfall and temperatures were ideal during the crop cycle. The excellent growing conditions reflected in high corn yields. The results respond to the wide N availability range obtained through fertilization. Highest GY was over 15000 kg/ha, nearly three times greater than the check. This response index (Johnson & Raun, 2003) is about twice the factor of 1.6, reported by Tremblay et al. (2012) for medium and coarse textured soils, across studies involving a diversity of North American locations.

The importance of N nutrition to final yields has been emphasized by Greenwood et al. (1986). For maximum yields the crops must contain sufficient N at every stage of growth. Restricted growth, as a result of temporary N deficiency cannot be compensated. N demand has been modeled by Lindquist et al. (2007) and found to be driven by biomass accumulation. Making a rough balance the initial supply of 88 kg/ha of nitrate-N would be enough for a GY of 4000 kg/ha, close to that obtained in the check plots. It is reasonable to assume that this was adequate to meet crop demands until V6 (Karlen et al., 1988). At this stage, soil NO_3^--N had dropped to 23 kg/ha due to crop uptake, transformations and losses. Fertilizer application affected not only yield components defined from V6 onwards but also performance and survival of emerged plants, fixed much earlier, as shown by PNm^2 measured at harvest.

Correlations among crop yield variables show that there were cumulative increments in most yield components and no major compensation effects took place. The relationship between grain yield and plant-N accumulation in aboveground biomass at physiological maturity (estimated using a N harvest index of 0.67) places check and fertilized plots between maximum N dilution and the overall regression reported by Cassman et al. (2002), for data obtained across a wide range of agroecological environments in USA. This suggests that N was the factor that most limited crop growth and grain yield in corn receiving the lower N rates, consistent with high N_{UE} values obtained for both N sources.

The A_E values (65 to 87 kg grain/kg applied N) summarize GY response in the 0-85 kg N/ha rate range and provide further evidence of favorable growing conditions. It is an established fact that the greater the response index, the higher the likelihood of finding significant differences between standard and alternative fertilizer technologies. This is particularly true for the quick release nitrogen solid sources used in the experiment.

High A_E derives from good fertilizer recovery by crop. Estimated R_F of over 1 kg absorbed N/kg applied N is not unusual (Maddonni et al., 2003) and may be attributed to both priming effect and a greater N extraction zone for fertilized crop roots. R_F, in turn, is highly dependent on the proportion of applied N that remains available during crop growth (Steinbach, 2005). During the first 10 days of December rainfall exceeded the mean by 150 mm. This must have ensured fertilizer incorporation and reduced volatilization after U hydrolysis (García et al., 1999). However we can still argue that N losses due to this process took place, resulting in a smaller

R_F for U-N. Thus, around half the A_E difference between the N sources can be accounted for superior R_F for ND-N, the rest being ascribable to $N_{UE.}$ The fact that nitrate-N from ND is immediately available, as compared to amidic N, provides a clue to its greater N_{UE}. An indication in this direction is that, at the lowest N rate, PNm^2 was higher in plots receiving ND. Similar results have been obtained for wheat by Ron & Loewy (2007) when comparing U with calcium ammonium nitrate.

In a vertical comparison (Chien et al., 1990) between N sources, calculation of A_E ratio of 1.33 showed that in the range of 0-85 kg N/ha crop response was 33% greater when N was applied as ND.

SV provides a horizontal comparison over the complete N range. A SV of 1.6 for ND means that U-N rate must be increased in 60% to attain the same yield as with ND. For a simple economic analysis SV for GY can be compared with fertilizer price ratios. When SV equals 1.6, U would still be the cheaper source if ND: U price ratio is 1.07 or higher. For N rates lower than 94 kg/ha a R_F 17.5% greater for ND suggests it was the more environmentally friendly N source.

According to the literature, ND superiority might have been less important if fertilizer had been incorporated (Barbieri et al., 2003). Also, this evaluation should be carried out on a range of climate and soil characteristics to assess SV variation.

CONCLUSIONS

In an optimistic scenario of abundant and well distributed rainfall, high corn grain yield response to nitrogen can be expected in the coarse textured soils of the inland pampas. The superiority of the ammonium nitrate mixture (ND) over the standard fertilizer (urea) was attributed to smaller volatilization losses and earlier availability. This performance was characterized by estimating an agronomic efficiency ratio of 1.33 for the range of 0 - 85 kg N/ha and a substitution value (SV) of 1.6 for the complete experimental range. For the kind of soil, hybrid and growing conditions of the experiment, this SV can be used to estimate nitrogen rates as ND from models developed for U. Further research should focus in determining the SV variation due to soil and climate spatial variability across the region and between years.

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