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Use of diammonium phosphate on wheat grown in southwestern Buenos Aires (Argentina)

Uso de fosfato diamónico en trigo cultivado en el sudoeste de Buenos Aires (Argentina)

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Abstract. In the southwest of Buenos Aires Province (Argentina), nitrogen (N) and phosphorus (P) deficiencies are important wheat yield limiting factors. There is an information gap regarding differences between single element and binary N-P sources. The objective of this paper was to develop a general model for N-P fertilization in the area that also quantified diammonium phosphate (DAP) effect and its interactions with N-urea, applied at sowing or tillering, as compared with triple superphosphate (TSP). Between 1984 and 1985, 13 experiments were carried out in farmer's fields N. With the yield data for each experiment, a yield function was fitted which included terms for single effects of urea (0, 30 and 60 kg N/ha) and 80 kg/ha of either DAP or TSP. Yield response variables were derived from the equation. Measured site variables were pH, organic matter (OM) and soil extractable phosphorus (Bray-P). Categorical variables of soil texture, wheat cycle and previous soil use were also included. Regressions were developed between dependent and site variables. The set of equations constituted a model that explained 31 to 75% of the variation in the yield response variables. Agronomic efficiency of N-urea for soils with agricultural use was around 12 kg wheat/kg N for both times of application. Response to DAP and TSP was related to Bray-P and soil texture. The bridging experiments between these two P sources estimated a superiority of DAP of around 180 and 90 kg wheat/ 80 kg of fertilizer on coarse and medium textured soils, respectively. Although it is physically impossible to isolate N-P effects in a binary fertilizer, this may be attributed to additional N. The data also suggested synergism between DAP and urea applied at sowing after their interaction in the soil.

Keywords: Fertilization; Phosphorus sources; Models.

Resumen. En el sudoeste de la provincia de Buenos Aires (Argentina) las deficiencias de nitrógeno (N) y fósforo (P) son factores limitantes del rendimiento de trigo. Hay una brecha de información con respecto a las diferencias entre fuentes de P monoelemento y binarias (N-P). El objetivo de este trabajo fue desarrollar un modelo general para la fertilización nitrogenada en la zona que también cuantifique el efecto del fosfato diamónico (DAP) y sus interacciones con N-urea, aplicada a la siembra o macollaje, en comparación con el superfosfato triple (SFT). Entre 1984 y 1985 se llevaron a cabo 13 experimentos en campos de productores. Con los datos de rendimiento, se ajustó, para cada ensayo, una función que incluyó términos para los efectos simples de la urea (0, 30 y 60 kg N/ha), y de una dosis de 80 kg/ha de DAP o TSP y para las interacciones entre estos fertilizantes. De la ecuación se derivaron variables de la respuesta. Las características medidas en cada sitio fueron pH, materia orgánica (OM) y fósforo extraíble (Bray-P). También se incluyeron variables de clase para la textura del suelo, el ciclo de trigo y el uso previo del suelo. Se desarrollaron regresiones de las variables de la respuesta en función de variables seleccionadas de sitio. El conjunto de ecuaciones obtenido nos permitió obtener un modelo que explicó entre el 31 y el 75% de la variación en las variables de respuesta. La eficiencia agronómica del N de urea en los suelos con uso agrícola fue de alrededor de 12 kg de trigo/kg N para las dos épocas de aplicación. La respuesta a DAP y a TSP se relacionó con Bray-P y la textura del suelo. Los experimentos puente entre estas dos fuentes fosforadas estimaron una superioridad aproximada del DAP de 180 y 90 kg trigo/80 kg de fertilizante, en suelos de textura gruesa y media, respectivamente. Esto se puede atribuir al N del DAP, aunque es físicamente imposible aislar los efectos de los nutrientes en una fuente binaria. Los datos también sugirieron sinergismo entre DAP y urea aplicada a la siembra, a través de su reacción en el suelo.

Palabras clave: Fertilización; Fuentes de fósforo; Modelos.

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INTRODUCTION

Wheat (*Triticum aestivum* L.) is one of the most important crops in the world, yearly contributing with approximately 30% of the total world crop grain production (USDA, 2015). In Argentina, wheat is still a major crop despite expansion of the soybean area (Barberis, 2015). It is also one of the most fertilized crops in the country together with corn (González Sanjuán et al., 2013).

In the south west of the Buenos Aires province, soybean expansion has been limited by climatic constraints and wheat is still the main crop as a result. Nitrogen (N) and phosphorus (P) deficiencies are important wheat yield limiting factors. Available information for fertilization in the area includes predictive response models that have been developed for N-P fertilization. Both single nutrient and two nutrient equations have been used (Loewy & Ron, 1995; Ron & Loewy 1996, Ron & Loewy, 2000). Interaction effects between N and P have been studied, as well as single effects.

The models reported above were based on experiments carried out 30 years ago, and predictions derived from them were validated with results obtained in the '90s (Ron & Loewy, 2003). At present, N recommendations based on these models might be considered "a priori" fairly conservative, because new varieties with increased yield potential are currently used. However, wheat yields in the area have not increased substantially in the past 30 years because water stress is very often the main limiting factor. Regarding P, early calibrations (Ron & Loewy, 1990) were recently ratified for environments of similar productivity in a neighbouring area (Ross & Elgart, 2014). This agrees with findings of Valkama et al. (2009), who analyzed results of experiments carried out over 80 years in Finland and did not find significant differences in crop response to P between recent and earlier experiments. Therefore, the data base developed in the past can still be used despite some changes in farming systems and practices.

In southwestern Buenos Aires there is an information gap regarding differences between single element and binary N-P sources. At present, due to agronomic and commercial reasons, there is widespread use of ammonium phosphates as P sources, mainly as diammonium phosphate (DAP). Although DAP is mostly thought of as a P source, N addition is relevant in basal applications of this fertilizer. This includes not only its single effect but also its possible interaction with P and N applied broadcast as urea.

In our earlier reports, the P source was as a triple superphosphate (TSP) to discriminate between N and P effects (Ron & Loewy, 2000). The objective of this paper was to develop a general model for N-P fertilization in the area that also quantified DAP effect and its interactions with N-urea, applied at sowing or tillering, as compared with TSP.

MATERIALS AND METHODS

Experiments. Information from 13 fertilization experiments in wheat carried out in farmers' fields between 1984 and 1985 was used. Growing seasons were considered average to wet. Mean rainfall from September to November was around 300 and 550 mm for 1984 and 1985, respectively. Soils included Udolls and Ustolls. Soil nitrogen fertility in 12 of the sites was diagnosed as deficient because annual crops other than legumes had been grown for at least 5 years prior to the experiment. The remaining experiment was preceded by a mixed pasture (Loewy, 1990). Sites covered a wide range of soil texture and extractable phosphorus (Table 1).

The design was of 3 complete randomized split blocks. A factorial combination of N rates (control, 30 and 60 kg/ha) and time of fertilization (sowing or tillering) were conducted in horizontal plots. N source was urea broadcast in single applications. P fertilization was applied in vertical plots, consisting of a control and 80 kg/ha of DAP or TSP in the seed row. The following wheat cultivars were used: Chasicó INTA (35.7% of the experiments), Cochicó INTA (35.7 %) and Klein Chamaco (28.6%) of early, intermediate and late growing cycles, respectively. Further details about characteristics of the area and experiments may be found in previous reports mentioned above.

Data analysis. For the statistical analysis ANOVA of individual experiments, regressions and correlations were used. Study of wheat response to fertilization was based on the method proposed by Colwell (1994). The yield data for each experiment were combined to estimate yield functions of the forms:

$$y = b_0 + b_1 Ns + b_2 Nt + b_3 Ns^2 + b_4 Nt^2 + b_5 P_{DAP} + b_6 P_{TSP} + b_7 NsxP_{DAP} + b_8 NtxP_{DAP} + b_9 NsxP_{TSP} + b_{10} NtxP_{TSP} + b_{11} Lb + b_{12} Qb \quad \text{(Eq. 1)}$$

$$y = b_0 + b_1 Ns + b_2 Nt + b_3 Ns^2 + b_4 Nt^2 + b_5 P_{DAP} + b_6 P_{TSP} + b_7 Lb + b_8 Qb \quad \text{(Eq. 2)}$$

where y: yield; Ns and Nt: N-urea rates at sowing and tillering, P_{DAP} and P_{TSP}: P rates applied as DAP and TSP (0 – 16 kg/ha), Lb and Qb categorical variables for blocks, $b_0 ... b_{12}$ coefficients. Lb and Qb, for linear and quadratic orthogonal trends, account for variation in yield levels across the experimental site with values of –1, 0, +1 and +1, -2, +1 for blocks 1, 2 or 3, respectively.

Dependent variables of yield response to fertilization (representing linear, curvature and interaction effects) were derived from Eq.1 as shown in Table 2. Independent variables were routine soil tests and categorical variables included soil texture, wheat cycle and previous crops (Table 1). Regressions were developed between dependent and independent variables. Selection of predictor variables was based on statistic and agronomic criteria. Equations con-

Table 1. Site and crop variables.
Tabla 1. Variables de sitio y del cultivo.

Variable		Not.	Mean	Mín.	Máx.	S.D.
Routine Soil tests (+)						
pH		pH	6.55	6.05	7.25	0.28
Organic matter in g/kg		OM	31.4	12.5	53.0	10.8
Available P in mg/kg		Bray-P	15	6	25	7
Wheat Cycle	early	E		Categorical variables		
	intermediate	I				
	late	L				
Soil Texture	coarse	C				
	medium	M				
	fine	F		0: not applicable; 1 applicable		
Previous Use	agriculture	A				
	pasture	NA				

(+) pH, potentiometric in water (1:2.5); OM, Walkley & Black (1934); Bray-P, Boschetti et al., 2003.

Table 2. Description and calculation of yield response variables.
Table 2. Descripción y cálculo de las variables de la respuesta.

Variable/Effect/Calculation	Response to
Linear effects	
$A_{Ns} = b_1 + 56.25\ b_3 + 5.33\ b_7 + 5.33\ b_9$	N-urea at sowing
$A_{Nt} = b_2 + 56.25\ b_4 + 5.33\ b_8 + 5.33\ b_{10}$	N-urea at tillering
$A_{P\text{-}DAP} = b_5 + 18\ b_7 + 18\ b_8$	P-DAP
$A_{P\text{-}TSP} = b_6 + 18\ b_9 + 18\ b_{10}$	P-TSP
Curvature effects	
$B_{Ns} = b_3$	N-urea at sowing
$B_{Nt} = b_4$	N-urea at tillering
Interactions	
$B_{NsxP\text{-}DAP} = b_7$	P-DAP x N-urea at sowing
$B_{NtxP\text{-}DAP} = b_8$	P-DAP x N-urea at tillering
$B_{NsxP\text{-}TSP} = b_9$	P-TSP x N-urea at sowing
$B_{NtxP\text{-}TSP} = b_{10}$	P-TSP x N-urea at tillering

Mean value for Ns and Nt rates = 18, Mean value for P-DAP and P-TSP rates = 5.33, conversion factor for linear trend = 56.25, b_1 … b_{10} coefficients from Eq. 1

verting estimates of the yield variables into estimates of fertilizer-yield functions were derived from Table 2. Yield response was then estimated for expected values for the site variables.

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

RESULTS

Effects of horizontal and vertical treatments were highly significant in 13 and 8 experiments, respectively, as tested by ANOVA (results not shown). Interactions between horizontal and vertical treatments were not significant. In 12 out of 13 experiments, Eq. (1) gave significant regressions with coefficients of determination ranging from 45.7 to 89.0%. At least one of the N coefficients (b_1 to b_4) was significant in 8 of the experiments, and b_5 (P-DAP) and b_6 (P-TSP) were significant in 9 and 3 experiments, respectively. Addition of the 4 interaction coefficients to Eq. (2) was significant in 21% of the experiments.

Table 3 summarizes the characteristics of the yield response variables for the 13 experiments. Yield response to N (both linear and curvature effects) was similar for the two times of application. The linear effects represented by A_{Ns}, A_{Nt}, $A_{P\text{-}DAP}$ and $A_{P\text{-}TSP}$ provide an estimation of the agronomic efficiency of the highest N and P rates. DAP-P agronomic efficiency was 50 % greater than P-TSP. This may be accounted for the effect of N in DAP, which was not included in Eq. 1 or Eq. 2. Similarly, interaction effects with N-urea were higher for DAP than for TSP, particularly when urea was applied at sowing.

As yield response variables are orthogonal it is possible to compare them by correlation. Linear yield response to N-urea at either time of application was positive and significantly correlated ($P<0.01$). The same happened between P-DAP and P-TSP effects ($P<0.01$). B_{Nt} had a positive correlation with A_{Ns} ($P<0.05$) and a negative one with $B_{NtxP\text{-}DAP}$ and $B_{NtxP\text{-}TSP}$ ($P<0.01$). These interaction variables were, in turn, highly significantly associated ($P<0.01$).

Table 3. Characteristics of yield response variables calculated as in Table 2 (n=13).
Tabla 3. Características de las variables de la respuesta calculadas como se muestra en la Tabla 2 (n=13).

	Mean	Minimum	Maximum	SD
A_{Ns}	10.95	-2.26	18.50	5.87
A_{Nt}	10.72	-0.79	17.33	5.11
$A_{P\text{-}DAP}$	37.18	8.86	82.72	20.75
$A_{P\text{-}TSP}$	24.56	1.22	66.40	18.09
B_{Ns}	-0.12	-0.50	0.07	0.16
B_{Nt}	-0.09	-0.32	0.29	0.16
$B_{NsxP\text{-}DAP}$	0.15	-0.26	0.65	0.27
$B_{NtxP\text{-}DAP}$	0.08	-0.41	0.60	0.28
$B_{NsxP\text{-}TSP}$	0.01	-0.66	0.42	0.28
$B_{NtxP\text{-}TSP}$	0.04	-0.40	0.34	0.25

Table 4. Selected regressions relating yield response variables to predictor variables.
Tabla 4. Regresiones seleccionadas entre variables de la respuesta y variables predictivas.

Regression Equation	R^2 (%)
A_{Ns} = -2.263 + 14.366 A	46.0 **
A_{Nt} = -0.790 + 12.770 A	45.1 **
$A_{P\text{-}DAP}$ = 71.837 – 2.741 Bray-P (G+M) +26.458 G –41.528F	63.0 *
$A_{P\text{-}TSP}$ = 62.310 – 2.686 Bray-P (G+M)+14.792 G –48.140 F	74.9 **
B_{Ns} = - 0.107	
B_{Nt} = - 0.071	
$B_{NsxPDAP}$ = 0.736 - 0.156 $(\text{Bray-P})^{1/2}$	31.5 *
$B_{NtxPDAP}$ = 0.309 - 0.019 Bray-P + 0.292 L	41.7 *
$B_{NsxPTSP}$ = 0.449 - 0.017 Bray-P - 0.413 E	58.3 **
$B_{NtxPTSP}$ = 0.578 - 0.013 OM - 0.311 E	47.3 *

Abbreviations see Tables 1 and 2.
** and * indicate significance at P<0.01 and 0.05, respectively.

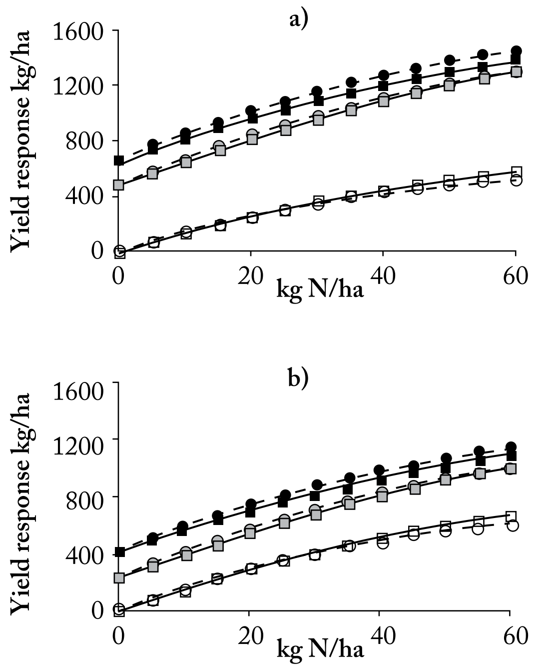

Fig. 1. Estimates of yield response to 80 kg/ha of DAP or TSP over a range of N rates applied at sowing or tillering, for intermediate cycle cultivars and medium textured soils of (a) low fertility (25 g OM/kg and 8 mg Bray-P/kg) and (b) moderate fertility (35 g OM/kg and 16 mg Bray-P/kg).
Dashed and solid lines represent N-urea applied at sowing or tillering, respectively. Open, grey and solid symbols stand for urea, urea + TSP and urea + DAP, respectively.
Fig. 1. Estimaciones de la respuesta a 80 kg/ha de DAP o TSP en un rango de dosis de N aplicadas a la siembra o macollaje, para cultivares de ciclo intermedio y suelos de textura media de (a) fertilidad baja (25 g OM/kg y 8 mg Bray- P/kg) y (b) fertilidad moderada (35 g OM/kg y 16 mg Bray-P/kg).
Líneas cortadas y continuas representan N-urea aplicada a la siembra o en macollaje, respectivamente. Símbolos blancos, grises y negros representan urea, urea + TSP y urea + DAP, respectivamente.

Correlation of response variables with routine soil tests did not show significant associations with linear effects or curvature adjustments of N-urea or interactions of P sources with urea applied at tillering. As might be expected, linear effect of P fertilizer (both DAP and TSP) was negatively correlated with Bray-P (P<0.05). $B_{NsxP\text{-}DAP}$ was related to Bray-P in the same way as $A_{P\text{-}DAP}$, as well as positively associated with pH (P<0.05).

Table 4 shows the set of equations that constituted the response model. The highly significant regressions for the response to N-urea at sowing and tillering (A_{Ns} and A_{Ns}) are not valid as such. This is because there was only one site in which wheat was preceded by a pasture. Equations for A_{Ns} and A_{Ns} gave an estimate of around 12 kg wheat/kg N for the average agronomic efficiency of N-urea at both times of application, for plots with a previous agricultural use. Response to fertilizer P was described as a function of soil test (Bray- P) for medium and coarse textured soils. For fine textured soils the effect was confounded with the year. No significant regressions were obtained for B_{Ns} and B_{Nt}; as a result, the average values were used for the model, as in Ron & Loewy (2000). Wheat cycle (late or early) was selected for 3 of the interactions, together with a routine soil test (OM or Bray-P). The latter was also chosen for interaction of DAP with urea applied at sowing.

To show the N-P effects as summarized by the model, the yield response was estimated for the intermediate wheat cycle and medium textured soils at two levels of N-P fertility (Fig.1). Estimates of the yield functions obtained from the models benefited from a smoothing of the error effects in the yield functions for the individual experiments.

DISCUSSION

Crop yield and yield responses to N in the southern Pampas are largely dependent on rainfall in the growing season, which is unknown at the time of fertilization. This variable has been used both in empirical and simulation models (Loewy & Ron, 1995); González Montaner et al., 1997. Models without site variables for weather effects like the one in this paper provide average estimates of relationships. The response curves to N-urea without P from DAP or TSP in Fig. 1 (a and b), are therefore identical, presenting only slight differences which are expected from the time of application.

Response to 16 kg P/ha (either from TSP or DAP) without urea can be read at 0 N on the Y-axis in Fig. 1 (a and b). In the comparison between the 2 P sources, the obvious factor is N from DAP, which was unaccounted for in the model. Not only does DAP-N increases available N in an early stage, but also P absorption by the plant. The effect would be independent of soil phosphate level when N is placed in a band together with phosphorus, according to classical references (Miller et. al., 1970). Increased nutrient acquisition due to ammonium in fertilizers has been related to acidification of both bulk solution and rhizophere (Thomson et al., 1993). This is consistent with DAP superiority over TSP in a range of P availability, as estimated from the equations in Table 4.

Urea x P source interactions are apparent from the slightly non-parallel curves in Fig.1. In this sense, it is important to consider the intermediate steps in the treatment-yield relationship, as described by Sumner (1987). A nutrient treatment usually reacts with the soil giving a soil response, which in turn causes a plant response in terms of nutrient content in plant tissues. Both soil and plant responses depend on the weather conditions and farming practices, and may result in yield responses as measured in the experiments. There are also differential plant responses to N-P in relation to wheat cycles: yield of late cycles is more dependent on fertilization while the reverse is true for early cycles

In plots with urea applied at tillering, plant responses in terms of root growth and balanced nutrition are mostly expected from the combined effects of urea and P sources. The marginal product declined faster in the curve for DAP, as compared to TSP, which may be attributed to the overall increase in the N-rate. Instead, simultaneous application of urea and P sources at sowing involves an interaction in soil and plant responses. Positive effects have been reported by Fan & Mackenzie (1993) and Fan and et al. (1996). Among these are reduced ammonia loss from urea hydrolysis for compound fertilizers, greater P diffusion to plant roots, improved residuality, and increased fertilizer availability in low Ca soils for urea banded with TSP. Interactions between urea broadcast at sowing and banded P-fertilizers in the soil are likely to be considerably lower than when the two fertilizers are applied in the same form. Nevertheless, synergism through soil response is suggested because the curve for DAP- N and urea applied at sowing remained parallel to its counterpart with TSP, showing no competition or addition effect of the two N- sources. It is unlikely, however, that this trend remains above 60 kg N-urea/ha (Loewy, 1996).

CONCLUSION

We have attempted to abstract essential details concerning the use of DAP as compared with a single P fertilizer (TSP). For this purpose it is physically impossible to isolate the effects of the two nutrientes in DAP (viz. N and P), and some of the possible interactions can only be guessed. Moreover, the set of equations that constitutes the response model deals with only some aspects of the system being studied, accounting for 31 to 75% of the variation in the yield response variables. However, it aims at playing a clarifying role by pointing out what is being described, and quantifying results. In this respect, the bridging experiments with TSP and DAP estimated an effect of additional N of around 180 and 90 kg wheat/80 kg DAP for coarse and medium textured soils, respectively.

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