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Comparative effectiveness of two phosphorus sources for wheat in southwestern Buenos Aires (Argentina)

Efectividad comparativa de dos fuentes de fósforo para trigo en el sudoeste bonaerense (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. The objective of this paper was to report on the comparative effectiveness of diammonium phosphate (DAP) and triple superphosphate (TSP) in the area covering a range of soils and years. Between 1983 and 1992, 13 experiments were carried out in farmer's fields. Soils were classified as Ustolls and Udolls. The design of the experiments was of complete randomized split blocks. Horizontal treatments were P-sources (DAP and TSP) and rates (0 to 135 kg/ha). Vertical treatments were check and a single rate of urea N applied at sowing or tillering. Yield response to horizontal treatments was significant in four experiments carried out in the Ustolls. DAP and TSP were compared by the calculation of efficiency ratio (ER) and substitution value (SV), defined as the ratio of TSP/DAP rates rendering the same yield response. ER of DAP to TSP was between 0.82 and 1.28. In two of the four experiments, the SV value was above the quotient between their respective prices, estimated in around 1.1. This means that, in those sites, DAP was not only more effective than TSP but also a more profitable source. SV seems a more useful parameter than ER because it applies to the full range of fertilizer rates. Regardless of statistical significance yields were around 60 kg/ha higher for DAP on an average of all experiments and fertilizer rates.

Keywords: Fertilization; Diammonium phosphate: Triple superphosphate.

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. El objetivo de este trabajo fue informar sobre la efectividad comparativa de fosfato diamónico (DAP) y superfosfato triple (TSP) en una variedad de suelos y años. Entre 1983 y 1992, 13 experimentos se llevaron a cabo en lotes de productores del área. El diseño de los experimentos fue de bloques divididos completos aleatorizados. Los tratamientos horizontales fueron dosis (0 a 135 kg producto/ha) y fuentes de fósforo (DAP y TSP). Los suelos pertenecen a los subórdenes Ustoles y Udoles. Los tratamientos verticales fueron testigo y una dosis única de urea aplicada a la siembra o macollaje. La respuesta del trigo a los tratamientos horizontales fue significativa en cuatro experimentos llevados a cabo en los Ustoles. DAP y TSP se compararon mediante el cálculo del índice de la relación de eficiencias (ER) y el valor de sustitución (SV), que se define como la relación entre las dosis de TSP/DAP a las que se obtiene la misma respuesta en rendimiento. ER del DAP con respecto a TSP estuvo entre 0,82 y 1,28. En dos de los cuatro experimentos, el valor SV estuvo por encima del cociente entre los respectivos precios de DAP y TSP, que se estima en alrededor de 1.1. Esto significa que, en esos casos, DAP no sólo fue más eficaz que TSP sino también una fuente más rentable. SV parece ser un parámetro más útil que ER porque cubre un rango mayor de dosis. Independientemente de la significación, los rendimientos con DAP fueron alrededor de 60 kg/ha superiores que para TSP, en un promedio de todos los experimentos y las dosis de fertilizantes.

Palabras clave: Fertilización; Fosfato diamónico; Superfosfato triple.

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INTRODUCTION

Wheat (*Triticum aestivum* L.) is a traditional crop in Argentina and current production areas are expected to increase al least by 20% in 2016. This cereal is also one of the most fertilized crops in the country. In the south west of Buenos Aires province, wheat is the main crop. Because of the semiarid and subhumid conditions in the area, the main limiting factor is very often water stress. When this constraint is not severe, other limiting factors may affect the yield. Nitrogen (N) and phosphorus (P) deficiencies are relevant among these.

Fertilizer N-P recommendations in southwestern Buenos Aires are based on predictive response models developed for the area (Loewy & Ron, 1995; Ron & Loewy 1996, Ron & Loewy, 2000a). These include single nutrient effects and interactions. In order to bridge the information gap regarding differences between P sources, several field experiments were carried out. In a recent paper, a general model for N-P fertilization that quantified response to diammonium phosphate (DAP) and its interactions with N-urea, as compared with triple superphosphate (TSP) was reported (Ron & Loewy, 2016). DAP effect was superior to that of TSP in around 180 and 90 kg wheat/80 kg fertilizer for coarse and medium textured soils, respectively. However, this generalization only applies to rates used for basal fertilization. A thorough comparison of the two products implies experimenting over a range of P rates and N availability and contrasting fertilizers effectiveness using suitable parameters, as those shown by Rajan et al. (1996). The methods have been applied to compare alternative techniques for wheat fertilization in southwestern Buenos Aires, such as forms of phosphorus application (Ron & Loewy, 2000b), and N sources (Ron & Loewy, 2007).

The objective of this paper was to report on the comparative effectiveness of DAP and TSP at different rates, over a range of years and soils in the area.

MATERIALS AND METHODS

Experiments. Information from 13 fertilization experiments in wheat carried out in farmers' fields between 1983 and 1992 was used. Growing seasons were considered average to wet. Site characteristics are summarized in Table 1. In all cases, except for experiment #5, annual crops had been grown for at least five years prior to the experiment.

The design was of complete randomized split blocks. Treatments in horizontal plots were check and a factorial combination of P sources (DAP or TSP) and rates. In the three vertical plots treatments were check and a single rate of N, applied broadcast as urea, at sowing or tillering. Fertilizer rates and other details are shown in Table 2. In 1983 and 1984 DAP and TSP were broadcast and incorporated prior to sowing. In the rest of the experiments P sources were applied in the seed row. Further information about characteristics of the area and experiments may be found in previous reports mentioned above.

Table 1. Site characteristics and soil variables.
Tabla 1. Características de los sitios y variables edáficas.

Experiment No.	Municipal district	Year	Organic matter g/kg	pH	Bray-P mg/kg	Soil suborder
1	Bahía Blanca	1983	22.7	6.30	6	Ustoll
2	Bahía Blanca	1984	22.1	6.21	5	Ustoll
3	Bahía Blanca	1989	22.0	6.20	11	Ustoll
4	Puan a	1989	18.5	6.35	9	Ustoll
5	Puan b	1989	20.0	6.30	9	Ustoll
6	Cnel Suarez a	1990	37.8	6.00	8	Udoll
7	Cnel Suarez b	1990	38.3	5.65	7	Udoll
8	Cnel Suarez a	1991	38.4	6.00	8	Udoll
9	Cnel Suarez b	1991	41.3	5.90	7	Udoll
10	Cnel Suarez c	1991	42.4	6.00	10	Udoll
11	Cnel Suarez a	1992	27.0	6.25	6	Udoll
12	Cnel Suarez b	1992	28.0	6.62	7	Udoll
13	Puan	1992	22.6	6.33	11	Ustoll

(+) pH, potentiometric in water (1:2.5); organic matter, Walkley & Black (1934); extractable Bray-P, Boschetti et al., 2003.
Cnel Suarez adjacent sites with different previous crops. 1990 and 1992 a) soybean and b) sunflower; 1991 a) and b) soybean, c) sunflower.

Table 2. Fertilizer rates and number of blocks in the different experiments.
Tabla 2. Dosis de fertilizante y número de bloques en los distintos experimentos.

Experiment No.	Number of blocks	TSP and PDA rates kg/ha			Urea rates kg/ha
		Starter	Basal 1	Basal 2	
1 & 2	3	---------	80	135	100
3, 4 & 5	4	40	80	120	87
6 & 7	2	30	60	90	100
8 & 9	2	30	60	90	100
10, 11 & 12	2	30	60	90	100
13	3	30	60	90	100

Data analysis. Analyses of variance were performed to study the effects of horizontal and vertical treatments and the interactions between the two. When interactions were not significant, the results of the vertical plots were pooled to compare the DAP and TSP treatments. A critical least significant difference value (LSD P<0.05) was calculated for planned mean comparisons of yield with TSP vs. DAP, for the same rate.

In experiments with significant response to DAP and TSP treatments, results were further analyzed by the calculation of two parameters i) efficiency ratio (ER) and ii) substitution value (SV).

For the estimation of ER, lineal plateau models were fitted for the relation between wheat yield and fertilizer rate (either DAP or TSP).

$$GY = a_0 + a_1 F \text{ for } F < XL \quad (1)$$

where GY is wheat grain yield in kg/ha, F, fertilizer rate in kg N/ha applied with either DAP or TSP, a_0 and a_1, coefficients and XL, the fertilizer rate for the inflexion point of the model, above which yield estimate is constant. ER was calculated as the quotient of the respective slopes (a_1 for DAP/a_1 for TSP) and considered applicable to the fertilizer rate range between 0 and XL.

A continuous analysis was also used to estimate SV, following the procedure described by Colwell & Goedert (1988). We used regressions of the form:

$$GY = b_0 + b_1 F + b_2 F^2 \quad (2)$$

where GY is yield in kg/ha, F, fertilizer rate in kg N/ha applied with either fertilizer, and b_0, b_1 and b_2, coefficients. The data for the two fertilizers were combined to estimate a yield function of the form:

$$GY = b_0 + b_1 \text{ sv } F + b_2 (\text{sv } F)^2 \quad (3)$$

where sv = 1 for TSP, and sv = SV for DAP. Estimates of SV were obtained iteratively by fitting regressions of form (3) with sv = 1 for TSP and successive values for sv = SV for DAP.

To test for the statistical significance of the estimate of SV, the difference between the sums of squares for equations (3) and (2) was calculated. This was divided by the residual mean square for eq. (3) deducting a degree of freedom to allow for the estimate of SV. The contribution of SV was given by the F ratio obtained.

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

RESULTS

According to ANOVA, fertilization with DAP or TSP had a significant effect in experiments #1, #2, #4 and #5. Wheat responded significantly to urea-N in four experiments. Interactions between horizontal and vertical treatments were not significant (Table 3). No significant differences were found between DAP and TSP treatments when the fertilizers were compared at the same rate (Table 4). Experimental precision was considered adequate, based on the coefficients of variation, which ranged from 4.9 to 11.8%.

Linear plateau fitted equations for the relation between grain yield and fertilizer rate in experiments #1, #2, #4 and #5 were all significant or highly significant (Table 5). The slopes of the linear phases were all higher than the current fertilizer/grain price ratio of around 4 for DAP and TSP (Halle, 2016). In experiments #2 and #4, DAP was 28 and 11% more efficient than TSP, respectively, the superiority applying to a wide range of fertilizer rates. Only in experiment 5 was DAP somewhat less efficient than TSP for fertilizer rates below 55 kg/ha.

Table 6 shows quadratic equations and estimates of SV for the same experiments. The SV values of 1.4 and 1.3 mean that in experiments #2 and #4 it was necessary to increase TSP rates by 40% and 30%, respectively, in order to attain the same wheat yield as with DAP. In the other two experiments DAP and TSP were equally effective. SV was significant only in #4.

Regardless of statistical significance yields were around 60 kg/ha higher for DAP than for TSP on an average of all experiments and fertilizer rates. This superiority applies to a wider rate range than the one of 90 kg/ha derived in a previous paper for a rate of 80 kg TSP or DAP/ha (Ron & Loewy, 2016).

Table 3. F probability for sources of variation and coefficients of variation (CV).
Tabla 3. Probabilidad del F para las fuentes de variación y coeficientes de variación (CV).

Experiment No.	Block	Factor A (DAP-TSP)	Factor B (urea)	Interaction AxB	CV (%)
1	0.0138	0.0003	0.7704	0.3797	8.3
2	0.0016	0.0068	0.0299	0.6621	6.9
3	0.0010	0.2174	0.4087	0.6212	11.2
4	0.3288	0.0099	0.8852	0.6194	11.8
5	0.0058	0.0207	0.6259	0.1303	6.7
6	0.0689	0.9494	0.0320	0.2070	8.7
7	0.5857	0.1135	0.0797	0.2355	4.9
8	0.7484	0.3189	0.1205	0.7128	5.3
9	0.2266	0.3826	0.0519	0.3768	5.4
10	0.2402	0.8861	0.3361	0.1789	3.8
11	0.0251	0.0610	0.7062	0.0827	5.6
12	0.0117	0.2076	0.2542	0.4713	5.2
13	0.7662	0.1348	0.0065	0.2987	9.8

Table 4. Effect of TSP and DAP rates on wheat yields (kg/ha) in a) Ustolls and b) Udolls (means of blocks and three urea-N treatments).
Tabla 4. Efecto de las dosis de TSP y DAP sobre el rendimiento del trigo (kg/ha) en a) Ustoles y b) Udoles (medias de bloques y tres tratamientos con N de urea).

a) Ustolls

		Experiment No.					
P rates	P sources	1	2	3	4	5	13
0		2152	3056	2655	2236	2777	1869
Starter	TSP	2941	3713	3002	2539	3047	1691
Basal 1	TSP	2606	3762	3119	2759	3230	2084
Basal 2	TSP	2712	3863	2880	2912	3106	1955
Starter	DAP	2994	3692	2797	2653	2997	1931
Basal 1	DAP	2581	3956	2939	2813	3110	2122
Basal 2	DAP	2696	4201	2959	2942	3052	2265
	LSD 0.05	259	470	356	256	225	336

b) Udolls

		Experiment No.						
P rates	P sources	6	7	8	9	10	11	12
0		3581	3825	3331	3250	3428	2875	2679
Starter	TSP	3661	4098	3296	3229	3548	3044	2868
Basal 1	TSP	3546	4163	3285	3260	3523	3219	3054
Basal 2	TSP	3763	4242	3590	3251	3584	3422	3234
Starter	DAP	3705	4099	3190	3398	3531	3100	3088
Basal 1	DAP	3721	4384	3390	3474	3482	3259	3244
Basal 2	DAP	3589	4575	3382	3419	3540	3574	3526
	LSD 0.05	283	487	353	307	297	411	956

Table 5. Linear-plateau equations for grain yield (GY) as a function of fertilizer rates (F) and efficiency ratios (ER).
Tabla 5. Ecuaciones lineales y de meseta para el rendimiento en grano (GY) en función de las dosis de fertilizante (F) y relación de eficiencias (ER).

Experiment No.	P source	Equation	XL kg/ha	P<	R^2	ER
1	TSP	GY = 2152 + 5.66 F	F<99	0.05	1	0.95
	DAP	GY = 2152 + 5.38 F	F<101	0.01	1	
2	TSP	GY = 3056 + 8.85 F	F<91	0.01	1	1.28
	DAP	GY = 3055 + 11.31 F	F<101	0.01	1	
4	TSP	GY = 2250 + 6.55 F	F<101	0.01	0.99	1.11
	DAP	GY = 2278 + 7.26 F	F<91	0.05	0.96	
5	TSP	GY = 2777 + 6.74 FP	F<58	0.05	0.93	0.82
	DAP	GY = 2777 + 5.53 F	F<55	0.05	0.97	

Table 6. Quadratic equations for grain yield (GY in kg/ha) as a function of fertilizer rate (F in kg of TSP and DAP/ha) and substitution values (SV).
Tabla 6. Ecuaciones cuadráticas para el rendimiento en grano (GY en kg/ha) en función de las dosis de fertilizante (F en kg de TSP y DAP/ha) y valores de sustitución (SV).

Experiment No	Equation	P<	R^2	DAP SV (+)	SV Significance
1	GY= 2152 + 7.60 (SV F) -0.026 (SV F)2	0.01	0.99	1.0	n.s.
2	GY= 3073 + 9.59 (SV F) -0.020 (SV F)2	0.05	0.96	1.4	n.s.
4	GY= 2243 + 8.64 (SV F) -0.027 (SV F)2	0.001	0.99	1.3	*
5	GY= 2764 +9.11 (SV F) -0.054 (SV F)2	0.01	0.90	1.0	n.s.

(+)SV=1 for TSP
ns and *: not significant and significant at P<0.05, respectively.

DISCUSSION

In southwestern Buenos Aires probability of response to P fertilization is high in soils with extractable Bray-P below 11 mg/kg. Also, in the range of 5 to 14 mg Bray-P/ kg, yield response has been reported to be 300 kg/ha greater in Ustolls than in fine textured Udolls (Ron & Loewy, 1990). These calibrations explain the lack of significant response to either DAP or TSP in nine out of 14 experiments.

On the other hand, significant effect of urea-N was more frequent in Udolls. This may be attributed to greater overall yields in this suborder, which in turn are related directly and indirectly to a higher soil organic matter content (Loewy & Ron, 1995; Díaz-Zorita et al.,1988). Differences between adjacent experiments in Cnel. Suarez can be partially explained by the effect of the previous crops (soybean vs sunflower), as reported by Loewy (1994).

Although ER and SV estimates were similar, their interpretation is different. ER is a measure of the relative efficiency and summarizes a vertical comparison (Chien et al., 1990). In this paper, values below 1 for ER (i.e. DAP less efficient than TSP) may be partly due to the nature of the linear plateau model used for their estimation. This model equation has an abrupt discontinuity at the inflection point and does not account for yield decline when fertilizer application rates are too high. Such characteristics are difficult to accept from a biological point of view. In experiment #5 the plateau was attained at a much lower rate than in the other experiments, including #4, carried out in a neighboring plot with the same Bray-P. This may be ascribed to the fact that in #5 wheat was grown after an alfalfa based pasture. Among other things, soil labile organic phosphorus, which is not assessed by the Bray-P test, may have been higher (Chater & Mattingly, 1980).

On the other hand, the quadratic models used for SV may indicate yield decrease of experimental data past the peak. This was the case with the equation for experiment #5 which peaked at 85 kg TSP or DAP/ha. The highest SV value was estimated for the only experiment with significant response to both P sources and urea-N (#2). This could be interpreted as a ratification of the importance of ammonia from DAP to enhance P uptake (Thomson et al., 1993), particularly because in this experiment the P-sources were broadcast and incorporated. This form of application for P has been reported to be less effective than placement in the seed row (Ron & Loewy, 2000b; Jiang et al., 2016).

In two of the four experiments, the SV value was above the quotient between their respective prices, estimated in around 1.1. This means that in those sites DAP was not only more effective than TSP but also a more profitable source. This simple economic analysis is one of the advantages of using this approach to compare fertilizers (Ratkowsky et al., 1997). Moreover, SV seems a more useful parameter than ER because it applies to the full range of fertilizer rates. Last but not least, efficiencies can often be misinterpreted if the values and objectives of the production system are not considered (Dibb, 2000).

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