# Effect of elemental and soluble sulphur sources on grain yield of wheat (*Triticum aestivum* L) in Mollisols of Pampas Region of Argentina

Martin Torres Duggan[A], Mónica B. Rodriguez[B], Raúl.S. Lavado[B] and Ricardo Melgar[C]

[A]Tecnoagro S.R.L and Argentinean Soil Science Association, Buenos Aires, Argentina, Email torresduggan@tecnoagro.com.ar
[B]Faculty of Agronomy, University of Buenos Aires, Buenos Aires, Argentina, Email rodrigu@agro.uba.ar and lavado@agro.uba.ar
[C]INTA (National Institute of Agricultural Technology). Pergamino Experimental Station, Pergamino, Buenos Aires province, Argentina, Email rmelgar@pergamino.inta.gov.ar

## Abstract

Field experiments were conducted in different sites of the humid area of the Argentine Pampas Region during two successive years. The objective was to evaluate the influence of different sulphur sources (elemental and sulphate form) on grain yield of wheat (*Triticum aestivum* L.). This region has a temperate climate; average annual rainfall is 980 mm and mean annual temperature 16°C. The S sources used in the experiments were: micronized elemental sulphur (ES, 95% of S) and standard ammonium sulphate (AS, 21-0-0+24% of S). A randomized complete block experimental design with 4 or 6 replications was used with factorial arrangement. Factor 1 was sulphur source and factor 2 was the S rate. Sulphur rates were 10 and 30 kg/ha (year 1) and 15 and 30 kg/ha (year 2). A check treatment was included. Data were analyzed through factorial analysis of the variance (ANOVA). There was a significative fertilization effect ($p<0.05$) in 80 % of sites and response was in the range of 231-857 kg/ha (mean response=600 kg/ha) during the first year. During second year a significant response was observed in all sites, with a range of 702-2119 kg/ha (mean response=1228 kg/ha). As a general trend, no significant source effects on S response were detected. Thus, in most sites S fertilizer effectiveness was not significatively affected by sulphur form or water solubility. However, in few sites, better behavior of S as sulphate was found. There was not S rate effect, and lower rate of S (10 or 15 kg/ha) was enough to provide S for the levels of yields obtained in present experiments.

## Key Words

Elemental sulphur, sulphate sulphur source, sulphur fertilization.

## Introduction

Sulphur fertilization has grown sharply in last years in Argentina. Experimental evidences of S response in different crops like wheat, maize and soybean were reported (Torres Duggan and Rodriguez 2009). Although there is not a general diagnostic system based in S soil or plant testing, S deficiency is associated with long cropping history soils; decreases in soil organic matter or with physical or chemical degradation, no-tillage management and high N and P responses. Because of progressive evidence of S responses and the relative low cost of S sources compared with N or P fertilizers, farmers began to apply S in last years. Thus, S replenishment increase form 5% in 1998 to 30% in 2007 four mains crops of Pampas Region (IPNI 2007). Wheat is one of the most important cereal crop of Pampas Region. In this region average S response range from 200 to 500 kg/ha (FAO 2004). Although S fertilization research has expanded in recently years, most experiments applied S soluble sources (e.g. ammonium sulphate, gypsum, etc.) or elemental S sources alone. Thus, there is little experimental information about the agronomic effectiveness of elemental S sources compared with soluble S fertilizers in annual crops. The oxidation requirements of ES sources could be a limitation in annual crops but the use of reactive sources can decrease their period of time to produce $SO_4^2$ and increase S bioavailability. In last years there was an important progress in ES product development in different countries. Taking into account that ES consumption has shown a sharply increase as a S source for crops, it is necessary to increase the knowledge about the behavior of reactive elemental S sources in soils and the relative effectiveness to soluble S sources. The aim of tihis work is to evaluate the S fertilizer response of wheat with ES (insoluble S) in relation with a soluble S source ($S\text{-}SO_4^2$).

## Materials and methods

### *Study area and experimental sites information*

Field experiments were conducted during two successive years in wheat at different fields of north and central area of Pampas Region (n=5 year 1; n=3 year 2). This region has a template climate. Mean annual temperature ranges from 14 to 18°C and annual rain-fall is almost 1000 mm (FAO 2004). The entire area is covered by Mollisols developed on eolian sediments (loess) with grassland vegetation (Hall *et al.* 1992). The experiments were established in farmer's fields. Mains rotations include wheat/soybean (double crop) with maize and full season soybean sequences. In Figure 1 are presented the geographical location of sites. Latitude and longitude range were between 32° 25´S, 60° 52´W and 36° 25´S, 61 52´W. Table 1 shows means of some chemical and fertility soil properties and standard deviation of means (0-20 cm).

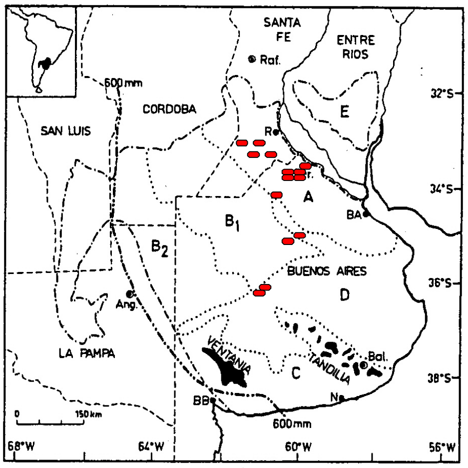

**Figure 1. Geographical distribution of experimental locations. A: Rolling Pampas; B: Inland Pampa ($B_1$: Flat Pampa; $B_2$: Western Pampa); C: Southern Pampas; D: Flooding Pampa; E: Mesopotamic Pampa. Map reproduced from Hall *et al.* (1992).**

**Table 1. Mean soil fertility properties (n=5, year 1 and n=3 year 2) for 0-20 cm layer. Standard deviations of means are presented between parentheses.**

| | pH | OM | CEC | $S\text{-}SO_4^{2-*}$ | P Bray 1 |
|---|---|---|---|---|---|
| | | g/kg | Meq/100 g | mg/kg | |
| Year 1 | 6 (0.20) | 30.6 (5.3) | 13.1 (2.9) | 5.8 (1.5) | 19.4 (8.6) |
| Year 2 | 6 (0.06) | 38.3 (2.31) | 16 (2.76) | 5.5 (4.53) | 29.3 (22.9) |

*extraction with $KH_2PO_4$ and turbidimetry determination (Lisle *et al.*1994).

*Treatments, experimental design and statistical analysis*

The experimental design was a randomized complete block design, with 4 replicates during year 1 and 6 replicates during year 2 and factorial arrangement. Independent and interactive effects were evaluated. Factor 1 was sulphur source and factor 2, the S rate. Factor 1 was split into two levels: (i) elemental sulphur (ES), (ii) soluble S source. Factor 2 contained two levels: (i) medium rate of S (10 and 15 kg/ha in year 1), (ii) high rate of S (30 kg/ha in both years). The soluble S source used was a standard grade of ammonium sulphate (AS, 21-0-0+24% of S). The ES source was a granulated reactive form (micronized with particles size below 200 µm) and inert agglomerating agent, provided by Sulferworks ®. Sulphur content of ES was 95%. A control treatment (C) without S fertilization was included. All plots received N and P fertilization. Fertilizers were applied at sowing (broadcasted and then incorporated). The data were analyzed by factorial ANOVA. When interaction between main factors (S source and S rate) was not significant ($p<0.05$) and a significant treatment effect was found, orthogonal contrast was used to evaluate S source and rate effects. When the interaction was significant, the treatment comparison was performed for each S rate.

*Soil and plant determinations*

Soil testing was performed on composite samples collected from topsoil (0-20 cm) before seeding. Exchangeable soil cations were extracted with neutral N ammonium acetate and determined with atomic absorption spectrometry. Soil P was measured by the Bray 1 extractant (1: 7 soil to solution ratio with 1 minute shaking) and evaluated by colorimetry. Total organic soil carbon was determined by the Walkley - Black method. Soil pH was evaluated in a 1:2.5 soil water ratio. Available S was evaluated by extracting soluble and adsorbed S with a 1 M $KH_2PO_4$ solution at a 1:5 soil to solution ratio, after 1 hour shaking. The S was determined by turbidimetry in a clean filtrate using activated charcoal, at 450 nm of wavelength spectrophotometer (Lisle *et al.* 1994). The grain yield was determined by mechanical harvest at physiological maturity, referring results on wheat grain (grain biomass) in kg/ha at 14 % of humidity.

*Climate date recording*

Rainfall and temperature were recording for each site from experimental stations of INTA (National Institute of Agriculture Technology) and Climatic Data Center (NOAA Satellite and Information Service).

## Results and discussion

*Yield and environmental during the study*

Mean wheat yield ranged from 3287 to 4724 kg/ha (mean 3907 kg/ha) during the first year of evaluation and from 2116 to 4389 kg/ha (mean 3457 kg/ha) in the second year. The average yield were higher than mean yield production of the study region (around 2700 kg/ha). Mean rainfalls were different between years, (year 1=1377 mm, year 2=730 mm) but there weren't water stress events during the crop cycle and water availability was sufficient to cover requirements. Mean temperatures were similar to historical data. Mean, minimum and maximum temperature on tillering stage of wheat (july-september) were 11, 8 and 14°C during first year and 8,6 and 12°C during second year. Those temperatures were higher than 4°C, which is considered a critical temperature for ES oxidation (Mc Caskill and Blair 1989).

*Treatment effects and S responses*

Mean of grain yield for each treatment and a summary of the ANOVA, interactions and mains contrast, are shown in Table 2. There were significant fertilization effects ($p<0.05$) at 80% of sites in year 1 and in all sites during second year. Mean grain S response (difference between Control and Fertilized treatment) was 600 kg/ha during the first year. This information agreed with results obtained by other authors (FAO, 2004; Reussi Calvo *et al.* 2006). Mean S responses during second year were highest than year 1. Minimum response was 702 kg/ha of grain and maximum was 2119 kg/ha. The high response in this site could be accredited to the low S-$SO_4^{2-}$ available in soil (the lowest one of all sites evaluated). Yield of control treatment was 2119 kg/ha in this location, which is considered low according with yield averages in the area. Probably a low capacity to provide S from soil during tillering wheat stage and a very low initial S availability could explain these results. Anderson *et al.* (2006) reported similar results, showing very high S grain responses in wheat (between 36 and 112% over control) with similar levels of S rates that ours experiments.

**Table 2. Wheat grain yield (kg/ha) and summary of ANOVA, and treatment interactions (p values).**

| | | | | | | Year 1 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Site | Control | $AS_1$ | $AS_2$ | $ES_1$ | $ES_2$ | LSD ($\alpha$=0.05) | AS vs. ES | C vs Fert. | Int. Source x Rate | p ANOVA |
| 1 | 3245 | 3777 | 3712 | 3926 | 3759 | 233 | 0.057 | 0.012 | 0.40 | <0.001 |
| 2 | 3367 | 3822 | 4117 | 4208 | 4201 | 403 | 0.24 | <0.001 | 0.52 | 0.002 |
| 3 | 3867 | 4959 | 5323 | 4443 | 3973 | 782 | 0.11 | <0.001 | 0.28 | 0.003 |
| 4 | 3513 | 4959 | 3935 | 4641 | 3635 | 607 | 0.33(0.012)* | <0.001 | 0.02 | 0.029 |
| 5 | 4186 | 4459 | 4489 | 4353 | 4368 | - | - | - | - | 0.519 |
| | | | | | | Year 2 | | | | |
| 6 | 2777 | 3257 | 3686 | 3560 | 3686 | 798 | 0.21 | 0.011 | 0.90 | 0.0418 |
| 7 | 3686 | 4368 | 4406 | 4381 | 4406 | 430 | 0.94 | <0.001 | 0.86 | 0.0126 |
| 8 | 2146 | 4141 | 4620 | 3863 | 4014 | 848 | 0.14 | 0.005 | 0.97 | 0.0004 |

* First p value corresponds to first level of S rate and between parentheses are indicated p value of second S rate level.

*Source and rate effects*

No significant ($p<0.05$) S source effect on grain yields was observed, as a general trend, (Table 1). The exception was site 4. This location showed significant interaction source x rate treatment ($p=0.02$) and source S effects was dependent on S rate. In the high S rate (30 kg/ha of S), AS effectiveness was higher than ES ($p=0.012$). Analysis of whether conditions (e.g. temperature during tillering, water availability, etc.) indicate little variations between sites. Consequently, the lowest S responses with ES could be related to a local fertilizer x soil interaction. As reported Deng and Dick (1990), the lowest relative performance of ES was possibly due to an accumulation of toxic products or acids that reduce oxidations rates of ES. Another possible cause could be a low microbian accessibility to the granules of ES (Chien *et al.* 1988). In site 1, it was observed a trend ($p=0,057$), where ES presented a moderated better response compared ES, at two levels of S evaluated, but significantly superior to control treatment. This site presented the lowest soil organic matter (SOM) content of evaluated locations and could reduce oxidation rate of ES and possibly generated less S-$SO_4^{2-}$ available for crop. According to Horowitz and Meurer (2007) the SOM is the most important chemical soil attribute associated with oxidation rates of ES in soils and there are an inverse relationship between SOM and ES oxidation rate.

## Conclusion

Agronomic effectiveness of S sources was similar in most sites and there wasn't S rate effect. The application of 10-15 kg/ha of S was enough to cover S requirements of wheat. Our results suggested that the reactive ES was a suitable S source to provide S bioavailability for wheat. The similar agronomic effectiveness of ES compared with soluble S source, derived in agronomic implications. The micronized ES source used in experiments produced available S-$SO_4^{2-}$ during tillering wheat stage. Associated with previous affirmation, environmental conditions (e.g. temperature, water content, oxidation capacity of soils, etc.) were adequate to oxidate the ES and to provide S bioavailable to the crop.

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