A review of sulphur fertilizer use and technology management in Pampas Region of Argentina

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Abstract
The Pampas Region, located at east central plains of Argentina, is the main grain producing area of the country. Although, sulphur fertilization has been expanded in recent years, there is little field research on S source effectiveness and S technology management. The aim of this work is to review actual field research information on S fertilization in the Pampas Region of Argentina.

Key Words
Sulphur, sulphur sources effectiveness, sulphur fertilization

Introduction
Argentina is one of most outstanding temperate crop producer of the Southern Hemisphere. The Pampas Region is the main grain producing area of the country. The area of the Pampas in which cropping is a frequent feature of land use covers about 34 Mha of agriculturally useful land (Figure 1). This area excludes the Flooding Pampa where the crop production is limited by poor drainage and saline-alkaline soils (Hall *et al.* 1992). Climate is temperate (i.e. mean annual temperatures range from 14 to 17°C) with annual rainfall ranging from 600 to almost 1000 mm.

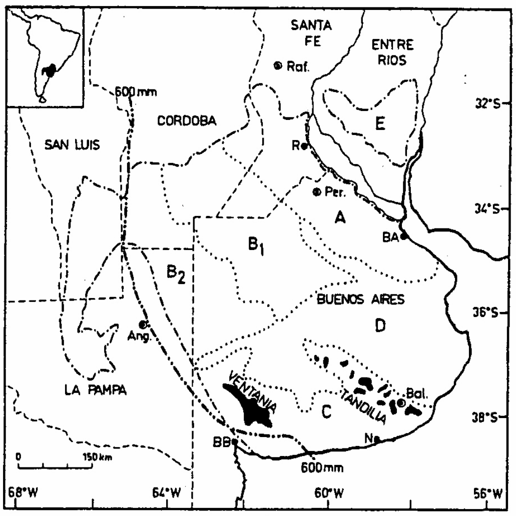

Figure 1. Subdivisions of Pampean grasslands. A: Rolling Pampas; B: Inland Pampa (B_1: Flat Pampa; B_2: Western Pampa); C: Southern Pampas; D: Fooding Pampa; E: Mesopotamic Pampa. Map reproduced from Hall *et al.* (1992).

Humid Pampas integrates areas of the Pampas Region with mean annual rainfalls of almost 1000 mm (e.g. Rolling Pampas and part of Inland Pampa). In the west side of the region, where rainfall becomes lower (600 mm per year or lower), there are more limitations to crop production. Most important rotations of the Pampas Region are: double wheat/soybean double crop; continuous soybean; corn- wheat/soybean and soybean-wheat/soybean. Main nutrient deficiencies in Humid Pampas are N and P, but recently field research showed S response in different crops and pastures at many locations (Gutierrez Boem *et al.* 2007; Torres Duggan and Rodriguez 2009). Yield responses to S were observed in the following conditions: low organic matter or degraded soils; fields with long cropping history; no till tillage systems; high N and P fertilizer responses. As a consequence of a progressive evidence of significant grain yield response to S fertilization and the relative low cost of S fertilizers as compared with N or P sources, S fertilization became a frequent practice in Humid Pampas agro-ecosystems. Sulphur replenishment (i.e. S application/removal ratio) increase from

5% in 1998 to 30% in 2007, taking into account mains annual crops of Pampas Region (IPNI 2007). Although S fertilization research has expanded in last years, little information is available of S sources agronomic effectiveness evaluation and fertilization technology issues. The aim of this work is to review actual field research information on S fertilization in Humid Pampas of Argentina with an emphasis on effectiveness of S sources and technology management.

Summary of actual fertilizer use and trends in Pampas Region

In last 19 years, lots of technological improvements have been incorporated in cropping systems of this region: fertilization, direct seeding, new transgenic genotypes and best management practices. In this context, grain production of Pampas Region has increase from 35 Mt (1Mt=10^6 ton) of grains in 1991 to almost 90 Mt of grains in 2006. Fertilizer use has sharply increased in last years, from 250.000 in 1990 to 3.65 Mt in 2007. Before 1990, fertilization was not a common practice at Pampas Region. Most fertilizers applied are solids (80% approximately) and 20% liquid sources. However, in recent years fluid fertilizer growth was higher than solids.

Fertilizer global consumption distribution, estimated as the difference between fertilizer imports plus local manufacture production (fertilizers plants) and less export, is 48% of N sources, 45% of phosphate sources, 2% of potash sources and 6% of sulphur sources. In the case of S sources, the global estimation mentioned before, didn't consider sources which are not manufactured in any fertilizer plant or imported (e.g. gypsum). The lower potash (K) fertilizer consumption is due to high K content of parental material of soils (Mollisols) of the Pampas Region and, consequently, low K fertilizer response.

Sulphur sources and fertilizer technology

The main sulphur-containing fertilizer was ammonium sulphate locally manufactured (FAO 2004). After the progressive evidence of S responses in many crops, use of other S sources use has been increased. Thus, ammonium sulphate (21-0-0+24% of S) and single superphosphate (SPS, 0-21-0 + 12% of S) application has sharply increased during recent years. Recently, two SPS plants have been established in Pampas Region that supply to domestic markets of Argentina and also to the Southern Cone Region, mainly to supply the soybean market, where S and P are most important nutrient that limited grain yields.

Actually, the most popular S source is gypsum ($CaSO_4$. $2H_2O$) obtained from local geological resources. Although a pure gypsum mineral has 18.6% of S, there is a wide range of possible S content in gypsum available at marketplace depending on the purity of mineral. Torres Duggan and Ponce (2005) found important variations in mineralogical composition of samples of gypsum from different geological resources (Table 3). These gypsum sources are mainly applied in the Pampas Region as S sources and in some cases as an amendment to improve sodic soils.

Table 3. Chemical and mineralogical composition of a group of gypsum samples offered in the marketplace.

Origin (Province)	$CaSO_4$. $2H_2O$	S content
	%	
Catamarca	85.3	15.8
Entre Ríos	73.9	13.7
Mendoza	91.3	16.9

Elemental sulphur (ES) use is low, but it has increased in recent years. Main advantages are the high S concentration and consequently, less manufacture and transportation costs. However, ES must oxidize in soil to provide S-SO_4^2 available to plants. In the Argentina marketplace, many companies started to supply different ES contained products, mainly as complex products (e.g. NPS fertilizers). Fertilizer manufacture companies focused their research and development programs to obtain more reactive forms of ES and to mix S-SO_4^{2-} and S° chemical S forms into products. These strategies provide a short and medium term S release pattern in soil-plant system, suitable for a double crop sequence (e.g. wheat/soybean).

Physical presentation of solid chemical S sources (e.g. AS, SPS, et.) are granulated (2-4 or 1-5 mm particle size range). In case of minerals like gypsum, some companies provides S sources in form of pellets. Pelletization of fertilizers is the process of converting powdered fertilizers into granules, ranging from 1 to 5 mm in size (Gowariker *et al.* 2009). Mobility of S in soils allow great flexibility to apply S in different time or placement strategies. Thus, S could be applied with bulk blends mainly at planting, meanwhile in other

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cases applications of S are done broadcasting single S sources at pre-plant or after planting using liquid solutions sources. This S flexibility management allows S fertilization acccording to rotation. Recent research has shown similar agronomic responses applying all the S requirements of the annual double crop wheat/soybean at wheat plant time, compared with partition of the S application for each crop (Salvagiotti *et al.* 2004). This is interesting because, although S is a mobil nutrient in soil, there are residual effects in soybean planting after wheat, with S fertilization in wheat. There is field research in progress evaluating mechanisms in the soil-plant system associated with residual processes.

Liquid S sources have steady increased in recent years in the Argentinan marketplace. Ammonium thiosulphate (ATS, 12-0-0+26%) mixed with UAN solutions (32-0-0) is the most common NS liquid fertilizer, enabling different "NS" formulations. These formulations are topdressed at tillering stage of wheat or at V6-7 completely expanded leaf of maize. Although growers apply liquid sources as a consequence of logistic advantages, field experiments conducted by experimental stations (e.g. INTA) observed lowest ammonia volatilization for corn (i.e. summer crop) when ATS-UAN solution was applied, compared with only UAN solutions. Thus, it seems that the inclusion of ATS into NS formulations operate like a urease and nitrification inhibitor. These results agree with international recent experimental evidence in fluid fertilizer development (Chien *et al.* 2009).

Sulphur fertilization rates and S source effectiveness evaluation
Table 2 shows a summary of some recent results on S rates and source evaluation obtained from field experiments. This review is not exhaustive, and considers only research that was published in peer reviewed papers or congress proceedings. Field research has indicated that, as a general trend, there are little differences in agronomic effectiveness among sulphate S sources, even between high water soluble ones (e.g. AS) and low water soluble ones (e.g. gypsum). Conversely, less information and varied results, have been reported in field research evaluation of ES sources or between these S sources and soluble S sources. Recent investigations show that S rates of 10-15 kg/ha of S are enough to cover S requirements of most annual crops. Oldest field trials tested higher S rates, between 10 to 40 kg/ha.

Table 2. Recent field research on S rates and sulphursources.

Crop	S source	S Rate	Grain response	Rate effect	Source effect	Reference
		Kg/ha of S	Kg/ha			
Double crop wheat/soybean	Gypsum	20 in sequence. 8 each crop.	Soybean=217-620 Wheat=130 (disease problems)	Not evaluated	Not evaluated	Salvagiotti *et al* (2004)
Wheat	Gypsum	15	625 kg/ha	Not evaluated	Not evaluated	Reussi Calvo *et al.* (2006)
Soybean	AS and Gypsum	15	160-500	Not evaluated	n.s	Gutierrez Boem *et al.* 2007
Wheat	AS, Agglomered Gypsum and SPS	15 and 30	495	n.s	n.s	Torres Duggan *et al.* 2006
Wheat	Elemental sulphur (reactive form)	24 and 40	208-465	n.s. in 4 of 5 sites sig. in 1 of 5 sites	n.s	Tysco and Rodriguez 2006

Notes: sig: statistically significant ($p<0.05$), ns: statistically not significant ($p>0.05$)

Results presented in Table 2 on the agronomic effectiveness of soluble S sources (i.e. similar performance) agree with international field research (Tisdale *et al.* 1993). Conversely, international research on ES has shown variable results, both in direct effects on annual crops, residual capacity and relative effectiveness to soluble S sources, depending on different factors: crop, environmental conditions, placement and application timing, physical and chemical form of ES (Lefroy *et al.* 1994; Girma *et al.* 2005; Horowits and Meurer 2007). Little field research has been done on the effectiveness of ES sources compared with soluble ones in the Humid Pampas. However, in recent years, promissing results has been observed in some field research using reactive forms of ES (e.g. fine particle size sources) even for winter annual crops like wheat (Tysko and Rodríguez 2006). Taking into account the progressive consumption and application of ES sources in world agriculture and in Argentina too, more experimental research information is needed to evaluate behavior of reactive and non reactive sources of ES under different soil and climate conditions.

Conclusion

Sulphur fertilization became a frequently practice in recent years for most crops and pastures in the Pampas Region. Most common S sources applied are ammonium sulphate, SPS and gypsum. Among liquid fertilizers, NS solutions are also frequently S sources. As a general trend, field research has indicated that there are little differences in agronomic effectiveness among sulphate S sources, even comparing high water soluble and low water soluble sources. Less information has been reported on field research evaluation on elemental sulphur sources or comparisons of these S sources with soluble S fertilizers.

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