Measuring Corn Response to Fertilization in the Northern Pampas

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Phosphorus (P) and sulfur (S) responses were most prevalent and their application most critical to maintain optimal growth rates and higher corn grain yield. Increases have been related to higher grain number. Deficiencies of P and/or S reduced crop growth rate around flowering. Potassium (K) responses have not been observed in these high K testing soils.

The northern Pampas is the main corn production region in Argentina. Nitrogen (N) and P deficiencies are frequently observed in cereals grown in this region. Yield increases due to S addition are becoming increasingly common. This is especially true for soils with many years of continuous cropping, partial loss of soil surface horizons through erosion, and reduced organic matter contents. No responses to K fertilization are reported in grain crops, but continuous negative nutrient balances may cause this to change. It is important to periodically re-examine nutrient responses and deficiencies within the region.

Objectives of this study were: i) to determine corn response to P, S, and K fertilization; ii) to analyze the effects of P, S, and their interaction on mechanisms involved in yield determination of corn; and iii) to evaluate the effects of P and S fertilization on grain N, P, and S content.

Thirteen on-farm experiments were conducted during 2 years (7 during 2003/04 season, and 6 during 2004/05 season), on Argiudoll and Hapludoll soils in southern Santa Fe Province and northern Buenos Aires Province. Soil properties at each experimental site are provided in **Table 1**. Five treatments were arranged in a randomized complete block design with four replicates (**Table 2**). Phosphorus fertilizer (triple superphosphate) was placed in a band below and to the side of the seed, while S (gypsum) and K (potassium chloride) were broadcast. All treatments received 150 kg N/ha as urea. All fertilizers were applied at sowing. Other crop management followed current farmer technology.

Potassium addition did not affect grain yield. No significant differences were observed between $P_{30}S_{30}K_0$ and $P_{30}S_{30}K_{100}$ treatments at any experimental site. Soil exchangeable K at every site was high compared with critical values reported in the literature. These values usually vary between 110 and 200 parts per million (ppm) (Haby et al., 1990).

Most of the experiments showed yield increases. Yield increased significantly in 7, 4, and 2 sites due to the addition of P, S, or both, respectively. The average yield in-

Grain number per surface area is a major factor in corn yields.

crease from P fertilization was 1,631 kg/ha (19% over the control). Mean yield increase due to S fertilization was 1,145 kg/ha (11% over the control). Phosphorus and S effects were additive, as no significant interaction was observed at any site. Yield increase due to S addition was not related to measured soil characteristics (i.e., sulfate concentration, soil organic matter content), management practices (i.e., previous crop, years from last pasture), or maximum yield achieved at the site.

Table 1. Soil characteristics at the experimental sites (0 to 20 cm depth), Argentina.

Site	Organic matter, %	Bray 1 P, ppm	Exchangeable K, ppm	pH	SO_4-S, ppm	SO_4-S, 0-60 cm, ppm
1	2.9	13.2	449	5.7	13.5	17.1
2	2.2	11.8	507	5.8	8.2	5.8
3	2.0	21.1	536	5.6	5.7	4.9
4	2.2	6.3	595	6.2	12.5	10.6
5	1.7	7.3	566	5.9	5.3	2.8
6	3.2	11.4	663	5.6	12.0	10.0
7	3.0	11.9	692	5.6	8.0	6.8
8	2.8	7.2	585	5.8	7.2	7.7
9	2.7	9.3	546	5.6	7.0	5.8
10	3.5	10.1	585	5.9	12.0	7.6
11	2.8	5.2	569	5.8	7.6	6.7
12	2.4	6.0	566	5.4	8.9	7.4
13	2.4	4.9	663	5.5	10.6	8.2

In corn, like other cereal crops, grain yield is mainly determined by grain number per surface area (GN). Andrade (1995) has observed that grain number is strongly associated with the crop growth rate (CGR) during a 40-day period around flowering. Thus, when the crop suffers water or radiation stress during this period, the grain number is reduced due to a lower biomass accumulation rate. Similarly, we hypothesized that a P or S deficiency would reduce the crop growth rate during this period, and therefore, grain number and yield.

Table 2. Rates of P, S, and K applied (kg/ha) in each treatment.

Treatment	P	S	K
$P_0S_0K_0$	0	0	0
$P_0S_{30}K_0$	0	30	0
$P_{30}S_0K_0$	30	0	0
$P_{30}S_{30}K_0$	30	30	0
$P_{30}S_{30}K_{100}$	30	30	100

Grain yield was related to grain number: [Yield (kg/ha) = 3.05 GN (number/m^2) + 1,958; r^2 = 0.52]. Crop growth rate did not show a close relationship with grain number across sites (r^2=0.034), even when only data from treatments with high P and S availability was used (r^2=0.029). These results suggest that changes in grain number across sites could not be explained by variation in CGR. Since it may be possible that each hybrid had a different GN-CGR relationship, normalized GN and CGR values were calculated in order to avoid hybrid or site effects on this relationship. Normalized GN (GNn) was calculated by dividing the GN of each treatment by the average GN of the site. Normalized CGR (CGRn) was calculated by dividing the CGR of each treatment by the average CGR of the site. Normalized values varied around 1 and reflected variation due to fertilization treatments applied within each site. Analysis of these data found a relationship between GNn and CGRn (**Figure 1**). This association suggests that changes in GN due to P and S fertilization

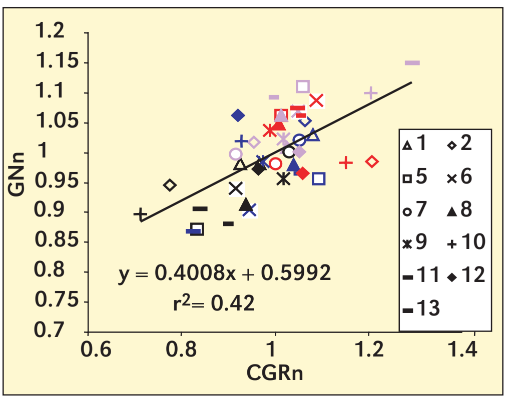

Figure 1. Relationship between normalized grain number (GNn) and normalized crop growth rate (CGRn). Symbol color denotes treatment: $P_0S_0K_0$ (black), $P_0S_{30}K_0$ (blue), $P_{30}S_0K_0$ (red), and $P_{30}S_{30}K_0$ (violet). Symbol shape denotes experimental site (see legend). Each point is the mean of four replications. Data from sites 3 and 4 were not determined.

Table 3. Concentration of N, P, and S in grain (mg/g), and N:S ratio. Range and mean values for all experimental sites for each treatment, Argentina.

	N			P			S			N:S		
	Min.	Max.	Avg.	Min.	Max.	Avg.	Min.	Max.	Avg.	Min.	Max.	Avg.
$P_0S_0K_0$	11.6	15.3	12.8	1.68	2.93	2.41	0.61	1.33	0.97	9.21	29.34	15.83
$P_0S_{30}K_0$	10.8	16.1	12.8	1.57	2.79	2.32	0.72	1.37	1.05	9.72	25.29	13.88
$P_{30}S_0K_0$	11.4	16.1	13.2	1.93	3.24	2.63	0.71	1.09	0.84	12.02	34.80	18.78
$P_{30}S_{30}K_0$	11.2	15.1	13.1	1.75	3.21	2.63	0.79	1.36	1.07	8.25	19.61	13.30

were in part explained by their effects on the CGR around flowering.

Nitrogen, P, and S concentration were determined in grain from the four treatments without K addition. Phosphorus fertilization increased N concentration in grain slightly (**Table 3**). Across all sites, N concentration increased by 3% (from 12.8 to 13.2 mg/g). Nitrogen exported with grain was 13 kg N/tonne of grain. This value was similar to the previously reported number of 14.5 kg N/tonne (INPOFOS, 1999).

Phosphorus fertilization increased P concentration in grain, regardless of soil P availability or crop response to P fertilization (**Table 3**). Across all sites and S treatments, P concentration increased by 11% (from 2.36 to 2.63 mg P/g). Phosphorus exported with grain was 2.5 kg P/tonne, a value slightly lower than the previously reported value of 3 kg P/tonne (INPOFOS, 1999). Phosphorus fertilization also affected S grain concentration at several sites, but effects were small and inconsistent (S concentration was higher, lower or remained unaffected). These variations were not related to yield response to P fertilization.

Sulfur fertilization increased S concentration in grain, while it did not affect N or P concentration. Thus the grain N:S ratio was also reduced (**Table 3**). The mean increase in S concentration, across all sites and P treatments, was 17% (from 0.90 to 1.06 mg S/g). The N:S ratio is associated with the proportion of S containing amino acids (i.e., cysteine, methionine) which are present within grain protein. These results suggest that S does not affect protein concentration, but modifies its composition. Sulfur exported from the grain of crops fertilized with S was 1 kg S/tonne, a value lower than the previously reported number of 2 kg S/tonne (INPOFOS, 1999).

These experiments showed evidence about the relevance of P and S deficiencies in corn production in the Pampas. On the other hand, K deficiencies have not been detected. Crop response to S fertilization was not related to soil or management variables. Yield increases due to S or P fertilization were associated with changes in the crop growth rate during the period around flowering. Grain P content increased with P fertilization. Sulfur fertilization increased S concentration in grain, but it did not affect N and P content. BC

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