



Soybean nutrition with soil and foliar application.

INTA EEA PERGAMINO
2021/22 Growing Season

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Introduction:

In Argentina, soybean production continues to improve year by year. Better varieties, biotechnology with increasing diversity in insect and herbicide tolerance, and highly efficient mechanization characterize current production systems.

One aspect that could provide a remarkable boost in yields is the optimization of fertilization. Chronic phosphorus deficiencies, soil acidification, and moderate deficiencies of several elements—often overlooked—limit full yield expression. New inputs have also been incorporated, occupying an intermediate space between nutrition and physiology. A possible mitigation measure for adverse effects caused by biotic agents (diseases, insects) or abiotic factors (herbicides, environmental stress) is the use of biostimulants.

The term biostimulant refers to a functional grouping rather than a biochemical one. It includes molecules with very diverse characteristics, yet all of them stimulate plant growth and help the crop overcome stages of restriction. Their effectiveness depends on the crop's growth stage, its growth rate, external stimuli, and the plant tissue reached by the application. The most common components of biostimulants are plant growth hormones—auxins, gibberellins, and cytokinins—which promote root, shoot, and reproductive growth, respectively. Other molecules often included in this category are amino acids, chitosans, vitamins, and enzymes.

The positive effect of biostimulants on growth can be complemented and enhanced by the addition of nutrients. In particular, foliar application is especially suitable for supplying micronutrients. Since crops require micronutrients in small amounts, the quantity delivered through a foliar spray may be sufficient to cover their demand.

The objective of this study was to evaluate fertilization systems that combine soil-applied treatments with foliar applications. We hypothesized that:

1. Intensified nutrition systems—including new technologies—optimize crop growth and yield; and
2. It is possible to identify combinations with superior agronomic performance.

Keywords: soybean, phytohormones, physiology, fertilization, foliar treatments, micronutrients.

Materials and Methods

During the 2021/22 growing season, a field experiment was conducted to evaluate integrated nutrition strategies. The trial was established at INTA Pergamino Experimental Station, on a Pergamino Series soil, Typic Argiudoll, mixed, loamy, thermic, Class I-2, PI = 85. Sowing took place on November 11, using the variety DM 46I20 RR STS, with 0.40 m row spacing.

The previous crop was soybean.

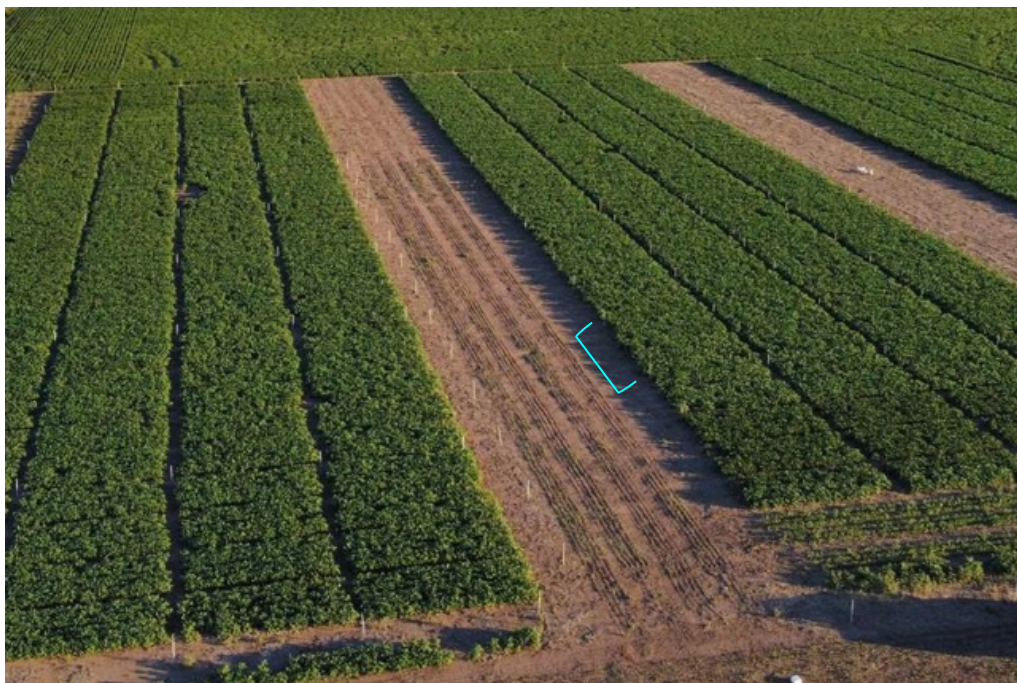
Throughout the crop cycle, herbicides, insecticides, and fungicides were applied to prevent weed presence, velvetbean caterpillar, stink bugs, and foliar diseases. Experimental plots were kept completely free of these biotic stresses.



Photograph 1: General view of the experiment at growth stage R4.



Photograph 2: View of the experiment at INTA Pergamino. The arc indicates the front of the experiment reported in this document. 2021/22 growing season.



Photograph 3: Aerial view of the soybean nutrition experiments at INTA Pergamino. The arc indicates the experiment. final del 2021/22 growing season.

The experimental design corresponded to a randomized complete block design with four replications. Details of the evaluated treatments are described in Table 1. The soil analysis is presented in Table 2.

Table 1: Soil and foliar fertilization treatments in soybean, INTA Pergamino. 2021/22 growing season.

Treatment	Planting treatment	Foliar treatments at V5	Foliar treatments at R2
1	Control SPT 70 % + SPS 30 % 100		
2	kg ha-1 SPT 70 % + SPS 30 % 100		
3	kg ha-1 SPT 70 % + SPS 30 % 100	Mist B 600 ml ha-1	Mist BLC 1500 ml ha-1
4	kg ha-1 SPT 70 % + SPS 30 % 100	Mist BLC 1500 ml ha-1	Mist BLC 1500 ml ha-1
5	kg ha-1	Mist BLC 1500 ml ha-1	Mist B 600 ml ha-1

Table 2: Soil analysis at planting time, average of four replications. Pergamino, 2021/22 growing season.

Depth	pH	OM	N total	Available phosphorus	Calcium	Magnesium	Potassium	S-Sulfates	Zn
	water 1:2,5	%	%	mg kg-1	mg kg-1	mg kg-1	mg kg-1	ppm	mg kg-1
Perga 1ra 0-20	5,5	3,36	0,168	7,3	1332	212	469	8,5	0,65
	SLIGHTLY ACIDIC	MEDIUM	MEDIUM	VERY LOW	HIGH	HIGH	VERY HIGH	MEDIUM	VERY LOW

Foliar applications were carried out using an electric, constant-pressure backpack sprayer.

The equipment was fitted with a 200-cm boom with four nozzles spaced 50 cm apart and hollow-cone 80015 tips which, at a pressure of 3 kg, allow spraying at 100 L ha⁻¹. Application details are presented in the Appendix (Tables 5 and 6). Treatments were applied together with a chemical fungicide.

Biomass accumulation was measured at R4. At the same stage, NDVI was determined using a GreenSeeker sensor, and canopy cover was assessed through digital image processing with specialized software. Nitrogen content was estimated with a Minolta SPAD-502 chlorophyll meter, and crop vigor was rated based on the overall condition of the plot, uniformity, and health status. Harvest was performed with an experimental self-propelled combine on April 19.

From a harvest subsample, yield components were determined: number of nodes, pods, grain number (GN), and grain weight (GW). Results were analyzed by analysis of variance, mean comparisons, and regression analysis.

Results and Discussion

Environmental conditions during the season

Figure 1 shows rainfall recorded at the experimental site, compared with historical values and the last three growing seasons. Summer rainfall was scarce, especially until mid-January. Two periods of severe drought were observed: one in December-January and a second from late January to mid-February. In the second half of summer, rainfall totals exceeded the historical average (Figure 1). In addition, temperatures reached very high levels in the region (Figure 3).

This situation caused a reduction in soil water reserves during pod formation (Figure 2). However, rainfall recovered during grain filling (Figures 1 and 2). This reversal in precipitation proved to be key for final yields.

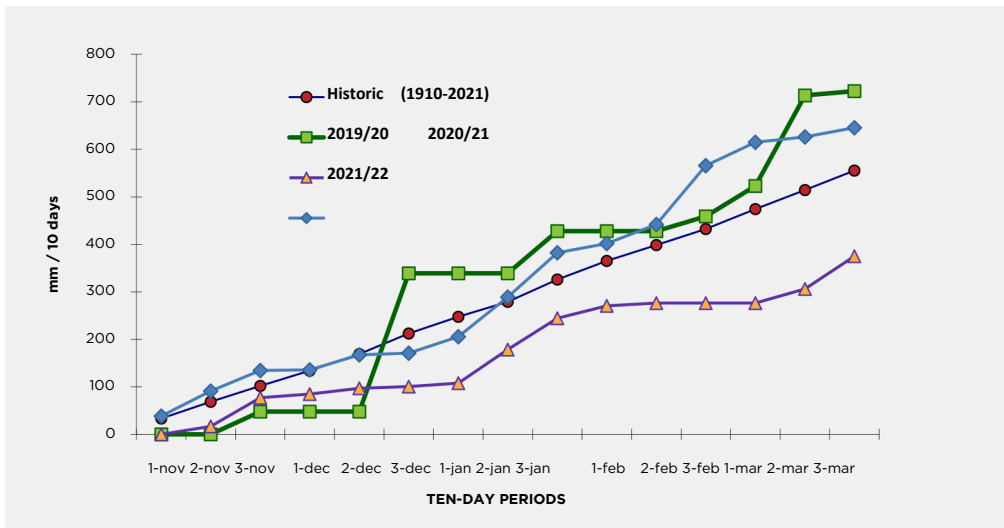


Figure 1. Ten-day rainfall totals for the 2021-22 growing cycle compared with the two previous seasons and the historical average. Soybean, INTA Pergamino Experimental Station. Initial available water (150 cm): 130 mm. Total rainfall during the cycle: 645.5 mm.

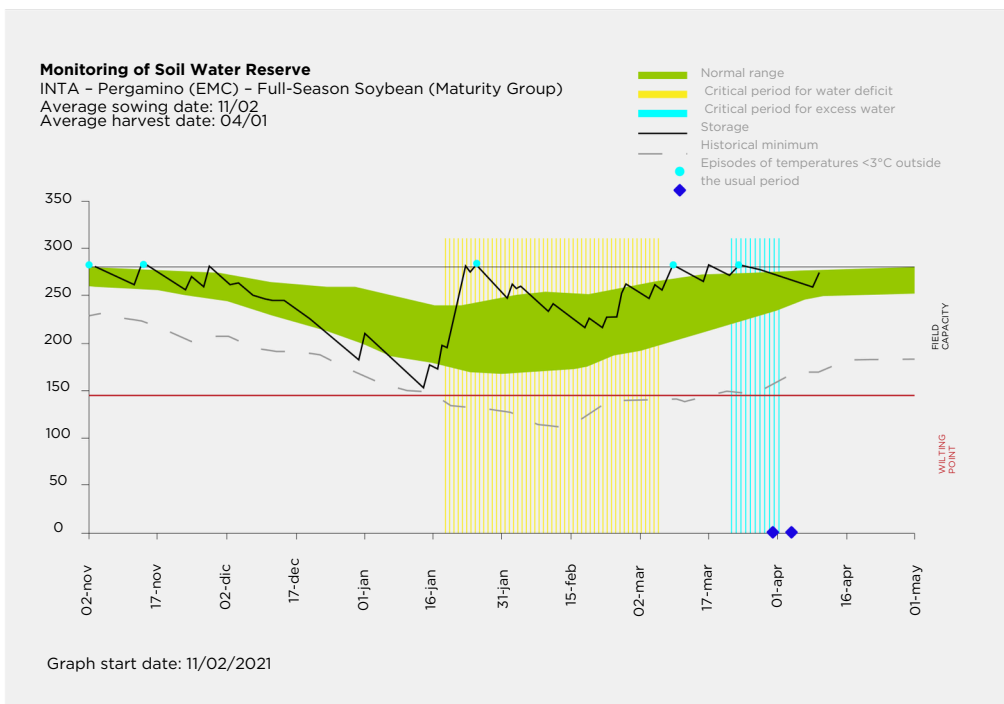


Figure 2. Evolution of soil water availability in a soybean crop during the 2021/22 season. Soil water storage was limited from the beginning, reaching values close to the permanent wilting point (PWP) in early January. Prepared by the Agricultural Risk Office (ORA) based on data from INTA Pergamino.

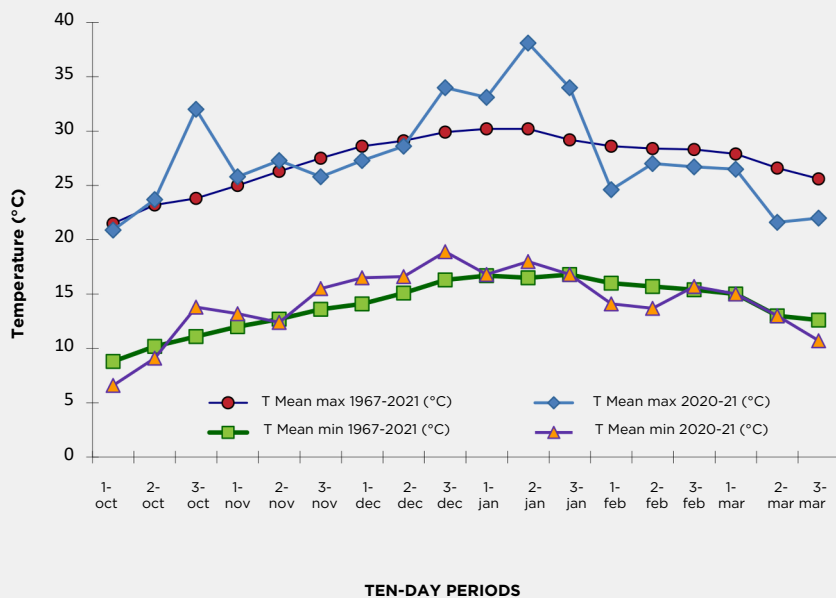


Figure 3. Decadal temperatures during the 2021/22 cycle compared with the historical values (1967-2021). The mean maximum temperature was 0.6 °C higher than the historical average, and the mean minimum temperature was 0.2 °C lower, resulting in a greater thermal amplitude. Data from INTA Pergamino Experimental Station.

Experimental results

Table 3 presents grain yield, its components, and other variables measured throughout the crop cycle. Finally, Figure 4 illustrates the yields, including standard deviations and statistical significance.

Table 3. Dry matter at R4, plant height (cm), leaf N content estimated by SPAD, NDVI by GreenSeeker, canopy cover and light interception, vigor rating, number of nodes and pods, grain yield, yield components, and response relative to the control. Soil and foliar fertilization treatments in soybean. Pergamino, 2021/22 season.

T	Treatments	Dry matter R4 (kg ha ⁻¹)	Plant height	Spad	Green Seeker R4	Interception R4 (%)	Vigor
1	Control	3610	108	44,2	0,86	91,3	3,9
2	SPT + SPS	4770	111	42,1	0,87	94,8	4,2
3	SPT + SPS + Mist B	4490	111	41,4	0,85	93,9	4,5
4	SPT + SPS + Mist BLC + Mist BLC	4715	110	43,6	0,87	96,2	4,3
5	SPT + SPS + M BLC + M BLC + M B	4390	107	43,9	0,85	93,8	4,5
	R2 vs Yield	0,74	0,37	0,41	0,00	0,67	0,68

T	Treatments	Nodes plant ⁻¹	Pods plant ⁻¹	Yield (kg ha ⁻¹)	NG	PG	Difference vs. T1 (kg ha ⁻¹)
1	Control	16	44	5197,9	3131,3	166	
2	SPT + SPS	17	53	5765,6	3342,4	173	567,7
3	SPT + SPS + Mist B	18	54	6069,4	3549,4	171	871,5
4	SPT + SPS + Mist BLC + Mist BLC	17	51	5984,5	3551,6	169	786,6
5	SPT + SPS + M BLC + M BLC + M B	17	59	5727,4	3310,7	173	529,5
	R2 vs yield	0,82	0,40		0,93	0,29	
	P=			0,02			
	CV(%)			5,7			

R4 (full pod) according to the Fehr and Caviness scale, 1974. Vigor Index: Scale from 1 (minimum) to 5 (maximum).

Evaluates plant health, plant size, and plot uniformity.

Interception: Evaluated as the percentage of maximum incident radiation.

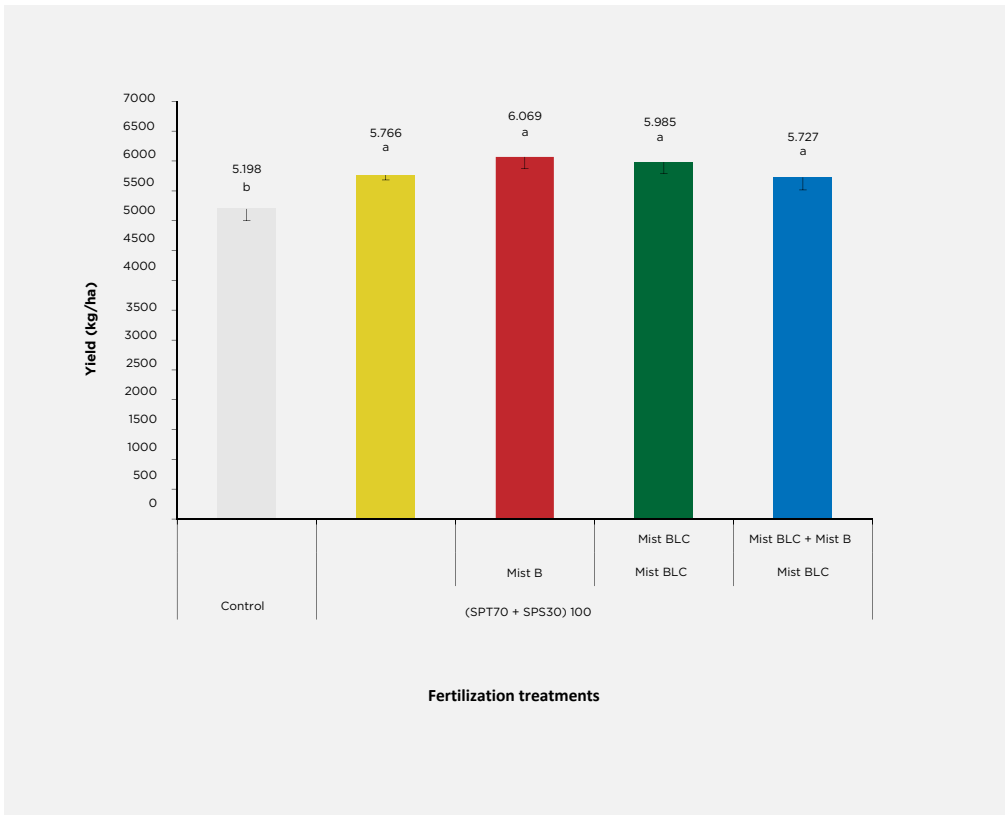


Figure 4. Grain yield according to soil and foliar nutrition treatments. Different letters above the columns represent significant differences among treatments (LSD $\alpha = 0.05$, LSD = 510.8 kg ha⁻¹). Error bars indicate the standard deviation of the mean. INTA EEA Pergamino, 2021/22 growing season.

Discussion and Conclusions

Rainfall during the 2021/22 summer season was scarce, although a period of moisture recovery occurred during pod formation and grain filling, in late February and March. This allowed for strong compensation in the yield components defined later in the cycle, such as pods per node, grains per pod, and grain weight.

The average yield of the experiment was very high, reaching 5,749 kg ha⁻¹. The variety's potential, the flat topography, and timely rainfall events explain the yield obtained (Table 3 and Figure 4).

Statistically significant yield differences were detected ($P = 0.02$; $CV = 5.7\%$) (Table 3 and Figure 4). The response ranged from 547.6 to 889.6 kg ha⁻¹ (Table 3), with increases of 218.9 kg ha⁻¹ (T4) and 303.8 kg ha⁻¹ (T3) attributable to foliar applications. The greatest impact corresponded to the early application of boron (T3), an essential element that may have been in limited availability due to the low soil organic matter content.

Several variables reflected treatment effects. Most notable were the effects on biomass accumulation, radiation interception, vigor, number of nodes per plant, and grains per plant. The variables most strongly associated with yield were biomass at R4 ($r^2 = 0.74$), radiation interception ($r^2 = 0.67$), vigor rating ($r^2 = 0.68$), nodes per plant ($r^2 = 0.82$), and grains per plant ($r^2 = 0.93$).

The results of this study support the proposed hypotheses. A clear and significant effect of base fertilization was determined. Foliar treatments complemented the fertilization strategy. The application of B at V5 showed the best performance. An early treatment likely encountered permeable membranes for absorption, all yield components yet to be defined, and prepared the plant for the high temperatures and environmental stress that it would face.

APPENDIX: APPLICATION CONDITIONS

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Table 5. Crop status at the time of application.

Application timing	Application date	Crop growth stage	Plant height (cm)	Canopy cover (%)
Pergamino V5	23-DEC	V6	60	68
Pergamino R2	07-JAN	R3	95	95

Table 6. Environmental conditions during application.

Application timing		Soil moisture (3-18 cm)	Air temperature (°C)	Relative humidity (%)	Wind speed (km h ⁻¹)	Cloudiness	Precipitation 24 h daa
Pergamino V5	S	S	27,4	55	6,2 NE	0	0
Pergamino R2	S	SH	18,8	64	5,0 NE	0	0

Cloudiness scale: 0 completely clear, 9 completely overcast.

S: dry. SH: moderately dry. H: wet.

daa: days after application.

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