



Evaluation of liquid fertilization with MIST macro- and micronutrients on soil properties and its impact on sunflower yield.

Objective:

The experiment aimed to evaluate the performance of MIST liquid fertilizers — formulated with macro and micronutrients — on soil chemical properties and on sunflower crop performance (yield and oil content).

Materials and Methods:

To achieve this objective, a field trial was conducted during the 2022/23 growing season at “Las Marías” Farm (Lat: -28.656741 / Long: -62.476639), located approximately 25 km west of the city of Bandera, in Santiago del Estero Province, Argentina.

Sunflower was direct-seeded on August 19 following a maize crop, at a planting density of 57,000 seeds ha^{-1} and a row spacing of 52.5 cm. The hybrid used was MG 360, a long-cycle hybrid.

At sowing, the crop was fertilized with 120 kg ha^{-1} of urea, supplying the equivalent of 55.2 kg N ha^{-1} . No chemical applications were performed for pest or disease control during the crop cycle, as pest incidence remained below the economic threshold.

A total of five treatments were evaluated (Table 1). Applications were carried out using a CO_2 -pressurized backpack sprayer at a constant pressure and volume. Two foliar applications were made at different phenological stages: the first at V8 (November 1) and the second at R1 (November 15). Details of each application are provided in the Annex (Table 4).

Table 1. Products, rates, and timing of MIST liquid fertilizer applications (macro and micronutrients) evaluated in sunflower via foliar applications during the 2022/23 growing season.

Treatment	Product	Rate (L ha^{-1})	Application stage / Phenology
1	Control	-	-
2	Mist Boro	1	R1
3	Mist N	5	V8
4	Mist N + Mist Boro	5+1	V8 + R1
5	Mist N + Mist Boro	5+1	V8

Before harvest, defoliation was performed using 2 L ha^{-1} of glyphosate. Harvest took place manually on January 23, cutting the heads from the two central rows and processing them with a stationary thresher. The harvested grain mass was weighed and sent to the laboratory for grain moisture and quality parameter determinations.

The experimental design was a completely randomized block design (RCBD) with three replications per treatment. Each experimental unit (EU) consisted of microplots 2 m wide \times 12 m long (24 m^2 treated area per EU).

Measurements included: a) Soil fertility: At sowing, parameters measured were OM, total nitrogen, nitrates, sulfates, Bray-1 phosphorus, total phosphorus, cation exchange capacity (CEC), cations (Ca, Mg, K, Na), pH, EC, and boron. At harvest, OM (T1-T5), total N (T1, T3), nitrates (T1, T3), and B (T1, T2) were analyzed.

Meteorological records: Throughout the crop cycle.

- Crop measurements:
- a) Plant population 60 days after sowing.
- b) Plant vigor (scale 1-5, where 1 = minimum and 5 = maximum, considering health, height, and uniformity).
- c) Number of plants (heads) at harvest.
- d) Grain yield adjusted to commercial moisture (11.0%).
- e) Oil content: determined in the laboratory (base 42%).
- f) Yield adjusted by bonus or discount based on 42% oil content.

Data were analyzed using InfoStat software (Di Rienzo et al., 2018). Analysis of variance (ANOVA) and LSD Fisher's test ($\alpha = 0.05$) were performed.

Results and Discussion
Soil and Climatic Characteristics

Table 2 shows the results of the soil chemical analyses conducted at sowing and harvest at 20 cm depth. At sowing, the site exhibited medium values of OM, total nitrogen, CEC, and boron. Although considered medium, these values are adequate and typical for the site where the study was conducted.

At harvest, these parameters remained unchanged. Nitrate, calcium, and magnesium contents were high at sowing, while nitrate decreased to 8 ppm in the control treatment and 6.5 ppm in the Mist-N treatment by harvest. This reduction may be due to the additional nitrogen fertilization received by this treatment, combined with the base fertilization.

Very high values were recorded for sulfates, Bray-1 phosphorus, and potassium, which remained high at harvest. Sodium content decreased by 51% from sowing to harvest, dropping from a high to a medium category. Soil pH remained suitable, reaching a neutral value.

Table 2. Soil analysis at sowing and harvest (0-20 cm depth) at the experimental site.

Parameter	Unit	Sowing		Harvest			
		1-5	1	2	3	4	5
Organic matter	%	2.20	2.07	2.06	2.15	2.10	2.04
Total nitrogen	%	0.111	0.108	---	0.113	---	---
Nitrates	ppm	19.5	11.5	---	13.0	---	---
Sulfates	ppm	18.0	10.1	---	---	---	---
Bray-1 phosphorus	ppm	62.3	45.1	---	---	---	---
Total phosphorus	ppm	777.5	695	---	---	---	---
CEC	meq/100	15.7	15.3	---	---	---	---
Calcium	ppm	2091	2069	---	---	---	---
Magnesium	ppm	299	295	---	---	---	---
Potassium	ppm	805	790	---	---	---	---
Sodium*	ppm	160	82	---	---	---	---
Base saturation	%	100	99.2	---	---	---	---
pH*	----	7.00	7.05	---	---	---	---
EC*	uS/cm	166	109	0.91	---	---	---
Boron	ppm	0.95	0.88	---	---	---	---

Reference (except for Na -pH-EC):

Very high	High	Medium	Low
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*** Reference**

Low/Very Low
Adequate
High/ Very high

Precipitation during the crop cycle, from sowing to harvest, totaled only 239 mm, whereas the historical average for the same period is around 428 mm (Fig. 1). Low rainfall coincided with the crop establishment phase up to mid-October and again during the grain formation period in November.

Regarding temperature conditions throughout the crop cycle, average values were very similar to the historical mean. However, a late frost event (3 °C or lower measured in a meteorological shelter) was recorded on November 1, coinciding with the onset of the reproductive stage. Due to the crop's sensitivity to this climatic phenomenon, a loss of photosynthetically active leaf area and apical death in a percentage of plants were observed, both of which negatively affected the yield potential of the crop.

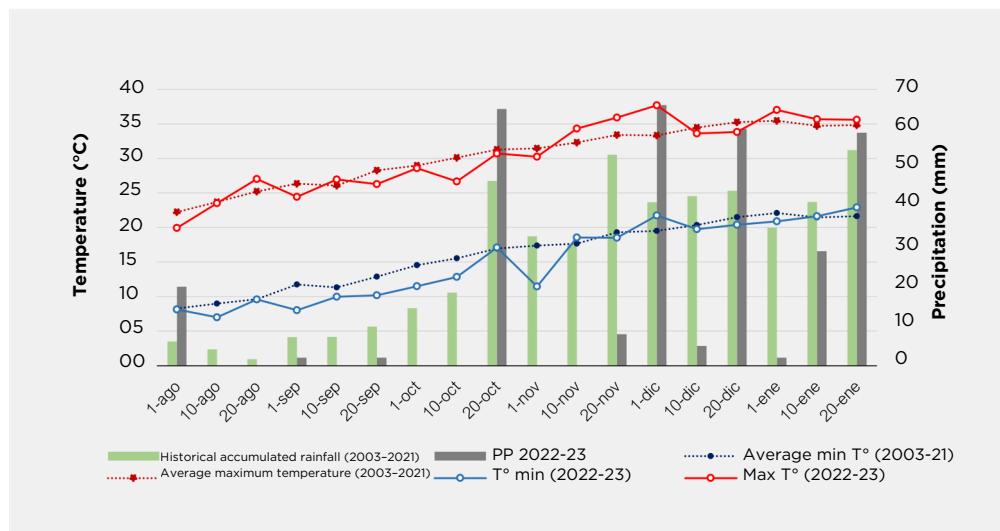


Figure 1. Accumulated rainfall every 10 days from August 2022 to January 2023 and historical accumulated average; average minimum and maximum decadal temperature for the 2022-23 growing season and its comparison with the historical mean for the city of Bandera. Source: AER INTA Bandera Series 2003-2021.

Results and Discussion of the Experiments

Table 3 details the results of plant population at harvest, grain moisture content, grain yield, oil content, yield adjusted by oil content (42% base), and yield differences relative to the control treatment (grain and adjusted yield).

Table 3. Plant population at harvest, grain moisture at harvest, grain yield corrected to commercial moisture (MC = 11%), oil content, yield adjusted by premium or discount based on 42% oil content, and yield differences (grain and adjusted) relative to the control.

Nº	Treatment	Plants established (l ha ⁻¹)	Grain moisture (%)	Grain yield (Kg ha ⁻¹)	Grain yield difference		Oil content (%)	Adjusted yield (Kg ha ⁻¹)	Adjusted yield difference Kg ha ⁻¹ %
					Kg ha ⁻¹	%			
1	Control	42064	8.2	1464	----	----	50.4 a	1711 a	----
2	Mist Boro	41667	7.8	1470	6	0.4	50.8 ab	1731 a	20 1.2
3	Mist N	42460	9.4	1475	11	0.8	50.7 ab	1730 a	19 1.1
4	Mist N (V6) + Mist Boro (R1)	41270	7.9	1534	70	4.8	50.6 ab	1797 ab	86 5.0
5	Mist N (V6) + Mist Boro (V6)	42857	6.9	1637	173	11.8	51.4 b	1946 b	235 13.7
	Statistical diff.	ns	ns	ns	----	----	*	*	----
	CV (%)	7.1	28.1	6.3	----	----	0.9	6.2	----
	DMS	----	----	----	----	----	0.86	202,3	----

ns indicates that the evaluated effect is not significant at the 0.05 probability level.

LSD indicates the Least Significant Difference.

No statistically significant differences ($P > 0.05$) were found among treatments and variables evaluated, except for oil content and consequently the adjusted yield. However, from an agronomic standpoint, positive trends were observed in response to the foliar application of fertilizers, showing increases in grain yield compared with the control treatment.

The average number of plants at harvest (heads) was 42,063 plants ha^{-1} . The treatment Mist-N + Mist-Boron applied at V6 produced the highest grain yield (1,637 kg ha^{-1}), followed by Mist-N (V6) + Mist-Boron (R1) with 1,534 kg ha^{-1} , Mist-N with 1,475 kg ha^{-1} , and Mist-Boron with 1,470 kg ha^{-1} , representing yield increases of 173, 70, 11, and 6 kg ha^{-1} , respectively, compared to the control.

The adjusted yield, calculated with the oil content bonus, averaged 1,783 kg ha^{-1} , which was 267 kg ha^{-1} higher than the unadjusted grain yield (1,516 kg ha^{-1}). As shown in Figure 2, all treatments exhibited higher oil-adjusted yields than grain yields.

The average oil content was 50.78%, exceeding the 42% base by 8.78%, resulting in an average bonus of 17.6%. As previously mentioned, there were statistically significant differences for oil content and adjusted yield; therefore, it can be stated that the treatment combining Mist-N + Mist-Boron applied at V6 differed statistically from the control, Mist-N, and Mist-Boron, but showed no significant difference compared to Mist-N (V6) + Mist-Boron (R1). The percentage of adjusted yield compared to the control treatment increased by 13.7%, 5.0%, 1.2%, and 1.0% for the treatments Mist-N + Mist-Boron (V6), Mist-N (V6) + Mist-Boron (R1), Mist-Boron, and Mist-N, respectively.

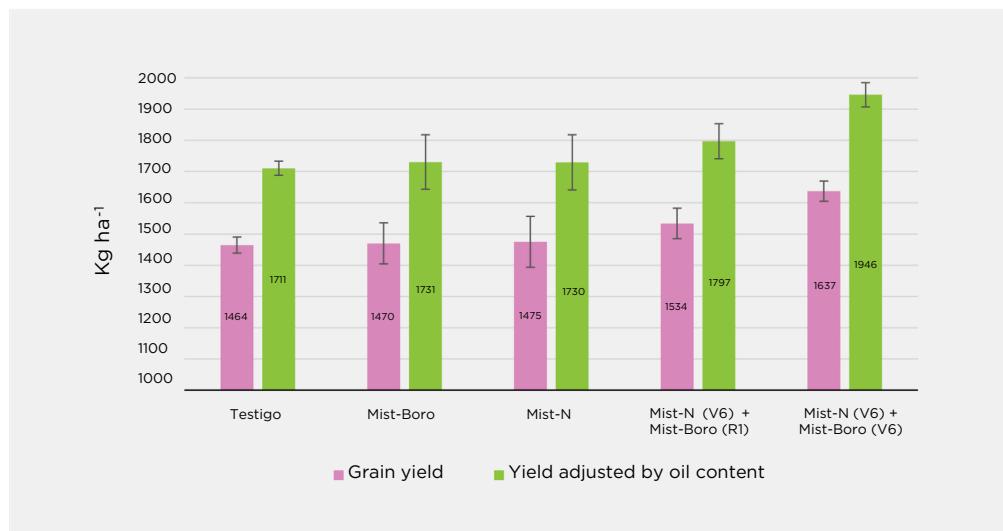
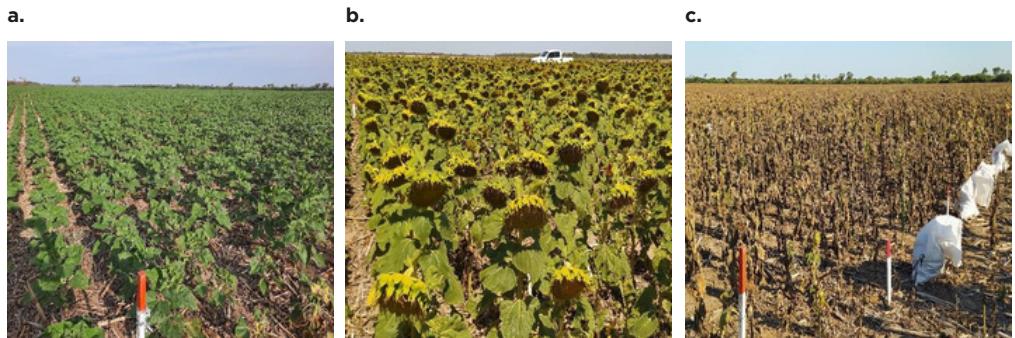


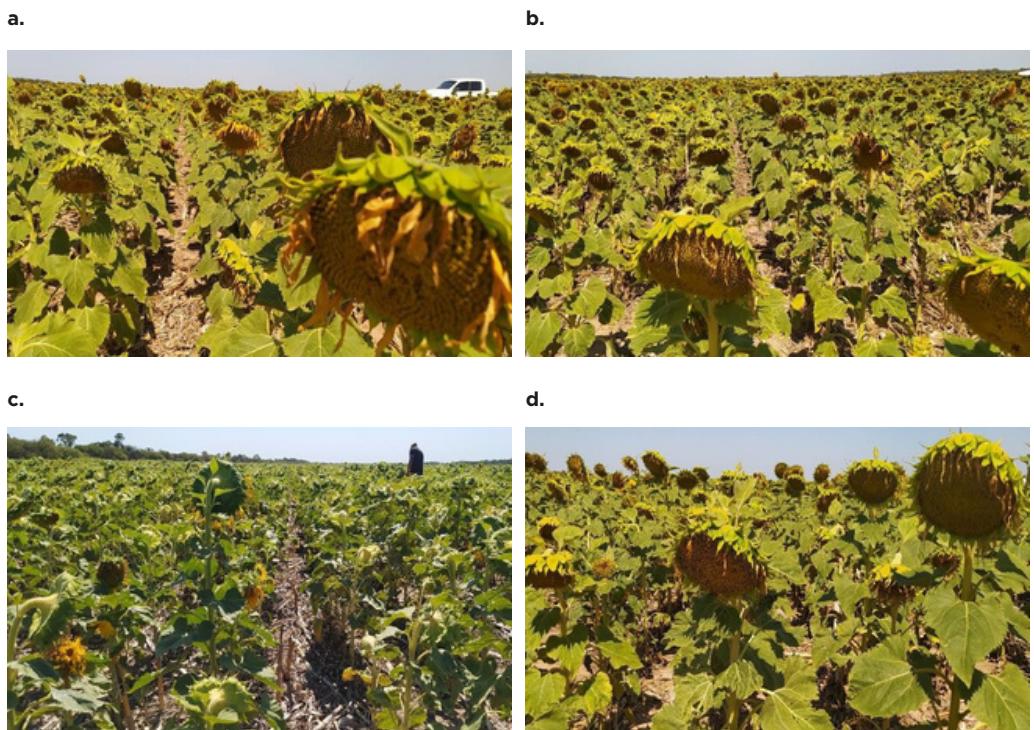
Fig. 2. Grain yield and oil content-adjusted yield in sunflower crops for the different treatments evaluated in Bandera (SE) during the 2022-23 growing season. The error bars on each column represent the standard error of the mean.

Final Comments

- The site where the experiment was conducted presented, at sowing time, nutrient levels considered adequate to high, which remained similar at harvest except for nitrate, which decreased.
- In early November, a late frost event was recorded, causing a reduction in plant stand and leaf area, thus affecting the crop's yield potential.
- The average number of plants at harvest (heads) in the trial was 42,063 plants ha^{-1} , reaching an average adjusted yield of 1,783 kg ha^{-1} , which represented 267 kg ha^{-1} more than the grain yield (1,516 kg ha^{-1}).
- Statistically, there were no significant differences among treatments and variables, except for oil content and adjusted yield. The treatment with Mist-N + Mist-Boron applied at V6 did not differ significantly from Mist-N + Mist-Boron applied at V6 and R1, respectively, but differed from the remaining treatments.
- The treatment combining Mist-N + Mist-Boron applied at V6 achieved the highest yield, both in grain (+173 kg ha^{-1}) and oil-adjusted yield (+235 kg ha^{-1}) compared with the control treatment.
- The percentage differences in adjusted yield compared with the control treatment followed an increasing order of 13.7%, 5%, 1.2%, and 1% for the treatments Mist-N + Mist-Boron (V6), Mist-N (V6) + Mist-Boron (R1), Mist-Boron, and Mist-N, respectively.



Photograph 1. General view of the experiment during the vegetative stage (a), reproductive stage (b), and at harvest (c).



Photograph 2. View of the treatments: Control (a); Mist-N (b); Mist-N applied at V8 + Mist-Boron applied at R1 (c); and Mist-N + Mist-Boron applied at V8 (d).

Annex

Table 4. General conditions of the applications performed according to treatment

Treatments		3-4-5	2-4
Application Date		01/11/2022	15/11/2022
Application Time		11:00	17:20
Application Stage		V8	R1
Application Pressure (bar)	3		
Forward speed (km h ⁻¹)		5.5	5.8
Flow rate (L ha ⁻¹)		133.33	121.21
Nozzle type	Hollow cone		
Nozzle model	ASJ 80015		
Weather conditions	Temperature (°C)	21.3	36.8
	Humidity (%)	24	16
	Wind speed (km h ⁻¹)	1.8	2.9

References

Di Rienzo, J. A., Casanoves, F., Balzarini, M. G., González, L., Tablada, M., & Robledo, C. W. (2018). InfoStat. Universidad Nacional de Córdoba, Córdoba, Argentina.



Administrative office and sales department:
Centenario Uruguayo 957 Lanús Este,
Provincia de Buenos Aires

Production Plant:
Parque Industrial Benito Juárez.

Phone numbers:
(+54) (11) 4230.2507
(+54) (11) 4058.3319