



# Combined nutrition strategies in wheat.

## Nitrogen nutrition in wheat.

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### Introduction:

Nitrogen (N) is the most important element for the nutrition of grasses. Its deficiencies affect growth, leaf expansion, and photosynthetic efficiency. Industrial and baking quality of wheat flour is strongly impacted. This element shows a strong interaction with the crop's water status.

A water deficit impairs the acquisition and transformation of nitrogen (N).

On one hand, lower yields determine a reduced plant demand. As a result, the nutrient follows alternative pathways instead of being absorbed by the crop, remaining in the soil or being lost to the atmosphere. Losses usually increase, mainly through volatilization.

The incorporation of more efficient N sources or the use of inhibitors helps reduce the intensity of nitrogen losses to the environment, or at least keeps them at manageable levels. Under drought conditions, foliar application of N is an alternative. As soil water availability becomes depleted, root absorption is interrupted. The canopy then becomes the alternative organ for nutrient uptake.

The limitation often lies in the restricted leaf surface area and the low concentration of foliar-applied sources. However, low-biuret foliar urea is typically a viable option because its concentration, affordability, solubility, and tolerance by the leaf tissue allow the crop to receive relatively high doses.

Zinc (Zn) plays a primary role as an enzyme activator, catalyzing numerous metabolic reactions such as respiration, chlorophyll synthesis, and protein synthesis. It is also a precursor of tryptophan and indole-acetic acid. Zinc deficiency is a worldwide problem affecting almost all crops, with nearly 50% of soils

used for cereal production exhibit low levels of available Zn, which not only reduces crop yields but also their nutritional value. International literature reports critical thresholds ranging from 0.5 to 1 mg kg<sup>-1</sup>, depending on the author and region. In Argentina, a critical limit of 1 mg kg<sup>-1</sup> extracted by DTPA in the 0-20 cm layer has been proposed. Values below this range indicate low availability, and values above it indicate adequate availability.

The objective of this research was to evaluate the effect of different fertilization strategies—alternating solid sources combined with biostimulants and foliar treatments—on wheat yield. We hypothesized that:

It is possible to identify combinations of sources, rates, and application timings with greater agronomic efficiency and nitrogen (N) use efficiency; and

Combined strategies reduce environmental N losses and increase nitrogen use efficiency (NUE), generating a positive impact on yield under conditions of severe water stress.

**Keywords:** wheat, nitrogen, zinc, foliar treatments, enhanced efficiency, nitrogen losses, drought, environment.

### Materials and Methods:

During 2022, a field experiment was conducted at INTA Pergamino Experimental Station (EEA INTA Pergamino), on a Pergamino soil series, Class I-2, Typic Argiudoll, fine illitic, thermic family (USDA Soil Taxonomy V. 2006). On June 18, the short-cycle cultivar Don Mario Aromo, characterized by good sanitary behavior and high yield potential, was sown.

Fertilization treatments included both soil and foliar applications. Fertilizers were applied at different growth stages. Due to the absence of diseases, no foliar fungicides were applied. The evaluated treatments are described in Table 1. The soil analysis for the site is presented in Table 2.

Table 1. Fertilization treatments evaluated in the experiment. INTA Pergamino, 2022 season.

| T | Treatments                  | Fert. at sowing<br>(dose kg ha <sup>-1</sup> ) | Fert. Zadoks13<br>(dosie 1 ha <sup>-1</sup> ) | Fert. Zadoks 30<br>(dose 1 kg ha <sup>-1</sup> ) | Fert. Zadoks 30<br>(dose 1 kg ha <sup>-1</sup> ) |
|---|-----------------------------|--|---|--|--|
| 1 | Absolut control             |  |   |  |  |
| 2 | Producer's control          | MAP 100 / Urea 100                             |   | Urea 100   |  |
| 3 | N + Zn                      | MAP 100 / Urea 100                             | Mist Zn 1 l                                   | Urea 100   |  |
| 4 | N + N foliar Z30            | MAP 100 / Urea 100                             |   | Mist N 6 l                                       |  |
| 4 | N + N foliar Z30 + Z39      | MAP 100 / Urea 100                             |   | Mist N 4 l                                       | Mist N 4 l                                       |
| 4 | N + N foliar Z30 + Kuma Z39 | MAP 100 / Urea 100                             |   | Mist N 4 l                                       | Mist Kuma 4 l                                    |

Table 2. Soil data at sowing time.

| Depth   | Organic matter | Total N | Extractable phosphorus | pH                  | Soil nitrate-N (0-60 cm, December) | Soil sulfate-S      | Soil water          |
|---------|----------------|---------|------------------------|---------------------|------------------------------------|---------------------|---------------------|
|         | %              | %       | mg kg <sup>-1</sup>    | water 1:2,5         | kg ha <sup>-1</sup>                | mg kg <sup>-1</sup> | 150 cm - sowing     |
| Pergam  | 2,73           | 0,14    | 13,4                   | 5,6                 | 45,7                               | 16,7                | 89 mm               |
| 0-20 cm | low            | low     | low                    | Slightly acidic     | low                                | low                 | low                 |
| Depth   | Potassium      | Calcium | Magnesium              | Zinc                | Boron                              | Mn                  | Copper              |
|         |                |         |                        | mg kg <sup>-1</sup> | mg kg <sup>-1</sup>                | mg kg <sup>-1</sup> | mg kg <sup>-1</sup> |
| Pergam  | 359            | 1245    | 154                    | 0,50                | 0,50                               | 139,4               | 0,94                |
| 0-20 cm | MOD. HIGH      | HIGH    | MOD. HIGH              | VERY LOW            | LOW                                | HIGH                | MEDIUM              |

The applications of Solum were carried out using an electric, constant-pressure manual backpack sprayer equipped with nozzles suitable for fertilizer streaming. The sprayer applies 100 L ha<sup>-1</sup> per pass; the required dose was obtained by adjusting the number of passes and the fertilizer dilution.

The Fronda treatments were performed with an electric, constant-pressure manual backpack sprayer. It was equipped with a 200-cm boom fitted with four nozzles spaced 50 cm apart, using 80015 hollow-cone tips. Application conditions are described in Tables 4 and 5.

At Zadoks Z41, canopy cover, NDVI (GreenSeeker), vigor, and SPAD readings (Leaf Greenness Index) were determined. At anthesis (Z65), plant height and accumulated dry matter were measured. Harvest was carried out mechanically, collecting the entire plot. Spikes were counted, and grain yield components — grain number (GN) and grain weight (GW) — were evaluated on a grain subsample. Results were analyzed through variance partitioning and correlation analysis.

## Results

### a) Environmental conditions of the season

At sowing, the soil profile had low water storage (89 mm, 40% of plant-available water at 150 cm depth). Rainfall was practically absent until October (Figure 1), even below the already limited 2020 and 2021 seasons, exhausting water reserves throughout the crop cycle. The crop reached and went through most of its cycle with soil moisture levels close to the permanent wilting point (Figure 2). Only 92.8 mm of rainfall were recorded between sowing and harvest, with barely 10.7 mm until October 10 (Figure 1).

With no moderating effect from soil moisture, thermal amplitude increased: maximum temperatures were above average, while minimums were below (Figure 3). The most significant climatic event of the season was the severe frost that occurred early on October 9. The minimum air temperature reached -3.2 °C. Although this was an extreme event for the region, limited damage was observed in the experimental field.

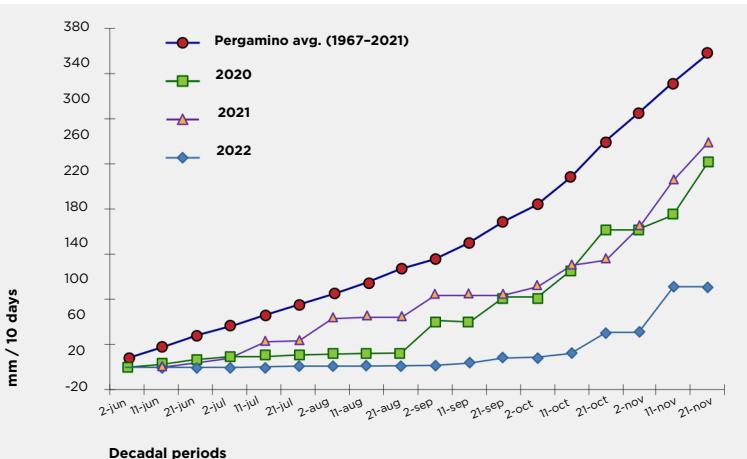


Figure 1. Rainfall between June and November for the 2022 season, compared with the historical average and the two previous cycles. Values accumulated every 10 days in mm. Note the persistence of a dry cycle, with rainfall below the historical average during the last three seasons, and very pronounced during the most recent one.

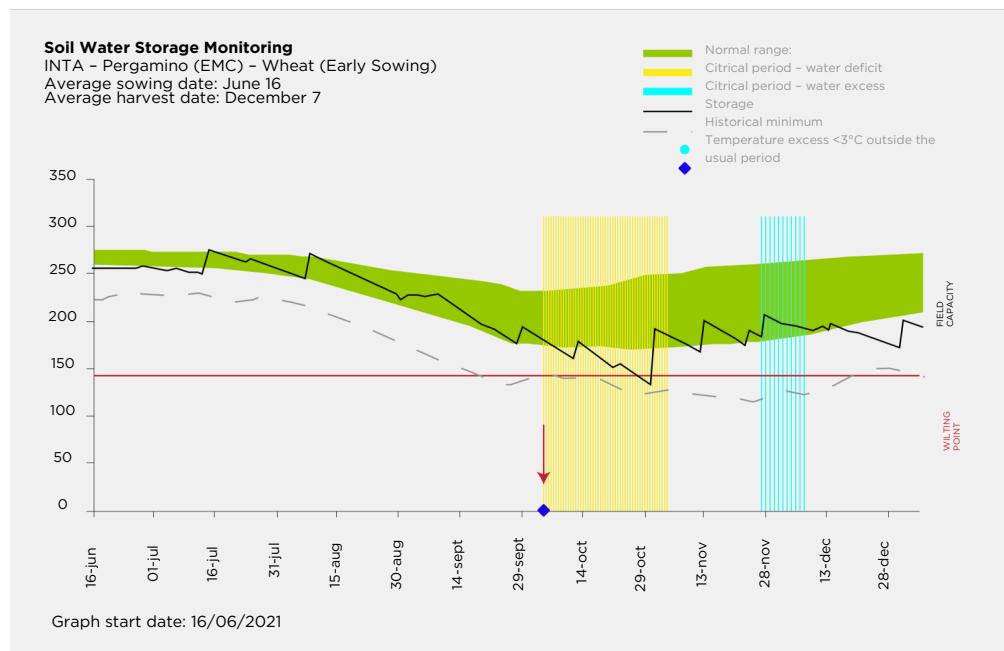


Figure 2. Evolution of soil water availability in a wheat crop during the 2022 season. The storage simulation was carried out starting from a level higher than the one observed in the experiment. Prepared by the Agricultural Risk Office (ORA) based on data from the INTA Pergamino Experimental Station.

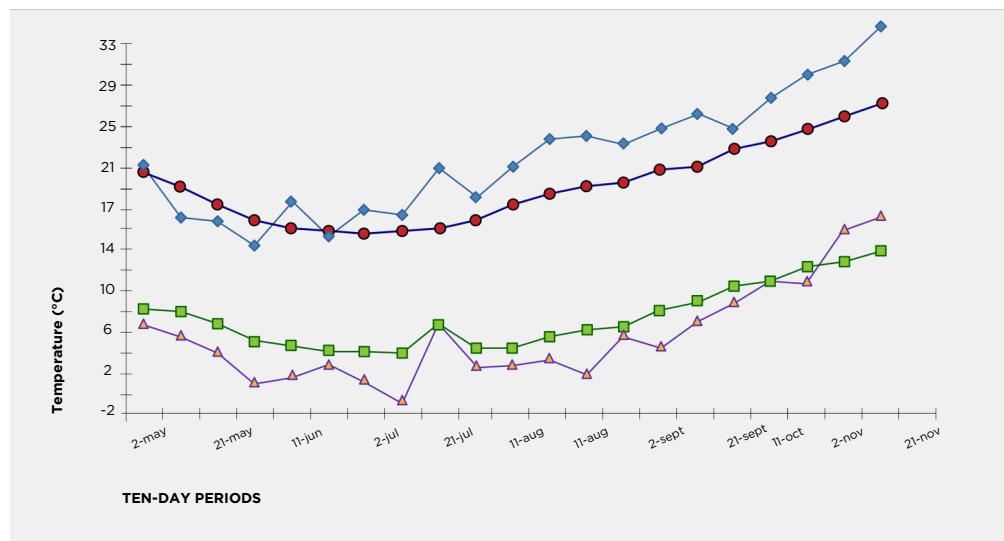


Figure 3. Mean decadal maximum and minimum temperatures between May 1 and November 31, 2022. Arrows indicate the periods with the most intense frosts. Data from the INTA Pergamino weather station.

**b) Experimental results**

Table 3 presents the observations recorded during the crop cycle, and Figure 1 shows the grain yields grouped by treatment.

Table 3. Morphological parameters of the crop: final number of spikes, total dry matter (Z45), vigor (Z45), canopy cover and light interception (Z45), NDVI measured with GreenSeeker (Z45), final plant height (Z65), green intensity readings in SPAD units (Z45), grain yield and its components, number of grains (NG) and grain weight (PG). Fertilization with nitrogen, zinc, and biostimulants in wheat. Pergamino, 2022.

| T     | Treatments                    | Spikes m <sup>-2</sup> | Dry Matter Z45 (kg ha <sup>-1</sup> ) | Vigor Z45 (1-5) | Canopy Cover and Interception Z45 | NDVI GS 45 |
|-------|-------------------------------|------------------------|---------------------------------------|-----------------|-----------------------------------|------------|
| Wheat | 1 Absolut control             | 312                    | 5430                                  | 2,5             | 57,4                              | 0,49       |
|       | 2 Producer's control          | 318                    | 6440                                  | 3,5             | 69,1                              | 0,54       |
|       | 3 N + Zn                      | 325                    | 8235                                  | 3,2             | 64,3                              | 0,56       |
|       | 4 N + N foliar Z30            | 354                    | 7360                                  | 2,8             | 63,2                              | 0,55       |
|       | 5 N + N foliar Z30 + Z39      | 297                    | 7250                                  | 3,0             | 62,4                              | 0,54       |
|       | 6 N + N foliar Z30 + Kuma Z39 | 297                    | 6530                                  | 2,8             | 67,0                              | 0,54       |
|       | R2 vs Yield                   | 0,1<br>3               | 0,58                                  | 0,78            | 0,44                              | 0,71       |

| T     | Treatment                     | Plant Height (cm) | Spad Z45 | Grains m <sup>-2</sup> | Grain Weight | Yield kg ha <sup>-1</sup> |
|-------|-------------------------------|-------------------|----------|------------------------|--------------|---------------------------|
| Wheat | 1 Absolut control             | 57,5              | 41,2     | 6293,2                 | 31,4         | 1976,1                    |
|       | 2 Producer's control          | 63,0              | 45,3     | 8847,5                 | 30,          | 2725,0                    |
|       | 3 N + Zn                      | 64,0              | 47,4     | 9003,9                 | 8            | 2809,2                    |
|       | 4 N + N foliar Z30            | 63,5              | 43,2     | 7446,5                 | 31,2         | 2494,6                    |
|       | 5 N + N foliar Z30 + Z39      | 61,5              | 45,1     | 7345,2                 | 33,5         | 2409,2                    |
|       | 6 N + N foliar Z30 + Kuma Z39 | 63,0              | 43,9     | 7209,6                 | 32,8         | 2263,8                    |
|       | R2 vs Yield                   | 0,41              | 0,29     | 0,94                   | 31,4         |                           |
| P=    |                               |                   |          |                        |              | 0,01                      |
| CV=   |                               |                   |          |                        |              | 7,7 %                     |

**Vigor Index:** 1 minimum - 5 maximum. It considers growth, uniformity, plant health, and general appearance of the crop in the evaluated plot. **NDVI:** Normalized Difference Vegetation Index, measured with a GreenSeeker.

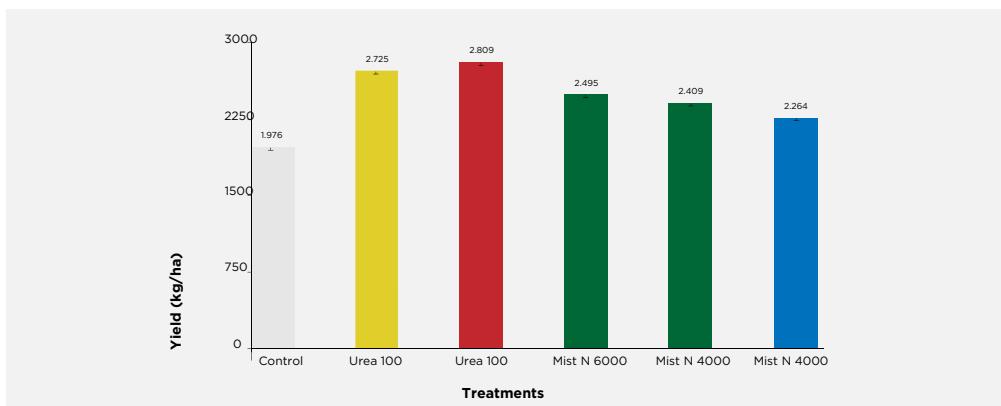


Figure 4. Average wheat yield according to sources, rates, and application timings of nitrogen fertilizers, zinc, and biostimulants. Different letters above the bars indicate significant differences between treatments (LSD  $\alpha = 0.0001$ , LSD = 282 kg ha $^{-1}$ ). Error bars represent the standard deviation of the mean. INTA Pergamino, 2022.

## Discussion and Conclusions

Yields reached 2446.3 kg ha $^{-1}$ , below the historical average for the northern Buenos Aires region. The water use efficiency was 26.3 kg grain per mm of rainfall during the crop cycle, a value close to that of a normal crop. This indicates that the low yields of the season can be attributed almost entirely to the lack of precipitation rather than to reduced crop efficiency or functionality.

Initial soil fertility ranged from medium to low, particularly due to poor levels of organic matter (OM), phosphorus (P), sulfur (S), boron (B), and nitrate-N, and very low zinc (Zn), characterizing an environment with high expected responsiveness to both N and Zn fertilization.

Significant differences were observed in grain yield ( $P = 0.0002$ ; CV = 7.7%) (Table 3). This indicates a ceiling effect in the crop's response to fertilization and N use efficiency, leveling the yields among treatments. Overall, two urea applications were required to achieve maximum productivity (Figure 4). When this occurred, the addition of Zn generated an additional yield increase (Table 3 and Figure 4). Although not reaching the yield level of urea, foliar application strategies, especially early applications, also increased yields compared to the control.

Most crop variables were affected by the severe water deficit, except grain weight and leaf N content measured by SPAD. For instance, plant height ranged only 60–65 cm, and radiation interception around 60% (Table 3). Other parameters highly impacted by the harsh environmental conditions were those related to crop growth and structure, such as accumulated dry matter and NDVI. The plots without added nitrogen (T1) quickly lost canopy cover and reached physiological maturity with almost no green tissue remaining (Table 3).

Many evaluated variables anticipated yield performance, including: Exposed awn biomass ( $r^2 = 0.58$ ), Plant vigor rating ( $r^2 = 0.78$ ), Radiation interception ( $r^2 = 0.44$ ), NDVI (GreenSeeker) ( $r^2 = 0.71$ ), Grains per m $^2$  (NG) ( $r^2 = 0.94$ ) (Table 3)

In an extremely dry season, exploring alternatives based on enhanced-efficiency fertilizers or distributing N or Zn throughout the crop cycle, combining sources and application methods, is a viable strategy. However, it should not involve strong reductions in baseline soil fertilization. The limited yields imposed a ceiling on crop response and on the potential increases in nitrogen use efficiency offered by these new alternatives. Zinc, meanwhile, confirms its role as a strategic and relevant nutrient for grass crops.

## Appendix: Application Conditions

Table 4. Crop stage at the time of application.

| Application timing | Application date | Crop stage | Height (cm) | Canopy cover (%) |
|--------------------|------------------|------------|-------------|------------------|
| Zadoks 13          | 28-Jul           | Z13        | 10          | 15               |
| Zadoks 30          | 29-Aug           | Z30        | 30          | 40               |
| Zadoks 39          | 04-Oct           | Z39        | 55          | 58               |

Table 5. Environmental conditions during the application.

| Application timing | Soil moisture (0–2 cm) | Soil moisture (3–18 cm) | Air temperature (°C) | Relative humidity (%) | Wind speed (km h $^{-1}$ ) | Cloud cover | Precipitation 24 h after application |
|--------------------|------------------------|-------------------------|----------------------|-----------------------|----------------------------|-------------|--------------------------------------|
| Zadoks 13          | S                      | SH                      | 14,5                 | 96                    | SW 14,7                    | 5           | 0                                    |
| Zadoks 30          | S                      | SH                      | 15,4                 | 36                    | NE 10,0                    | 0           | 0                                    |
| Zadoks 39          | S                      | S                       | 17,5                 | 45                    | E 1,1                      | 4           | 0                                    |

Cloud cover scale: 0 completely clear, 9 completely overcast.

daa: days after application.



Photograph 1. Sowing of the experiment. Year 2022. INTA Pergamino, Buenos Aires, Argentina.



Photograph 2. Nutrition experiments during the vegetative growth phase.



Photograph 3. View of the experimental plots on harvest day. Top row, from left to right: T1, T2, and T3. Bottom row, from left to right: T4, T5, and T6. INTA Pergamino, Buenos Aires, Argentina.

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