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(Research Article)

Effect of nitrogen rate and urease inhibitors on wheat yield in the Yaqui Valley, Sonora, Mexico

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Abstract

Nitrogen use efficiency (NUE) is a key determinant factor for wheat yield and quality in northwestern Mexico, where urea is the main nitrogen source. However, its rapid hydrolysis leads to losses through NH_3 volatilization. Urease inhibitors are an alternative to reduce losses. During the 2023–2024 fall–winter growing season, the effect of inhibitor-treated fertilizers (NitroPerfecto: NBPT + Duromide) versus conventional urea was evaluated in two field studies established in the Yaqui Valley, Sonora, Mexico. In Study 1, 253 kg ha^{-1} were applied at sowing and 300 kg ha^{-1} at the first supplemental irrigation; in Study 2, late applications before the second supplemental irrigation were evaluated with doses of 0–200-400-600 kg ha^{-1}. In Study 1, no significant differences were observed between nitrogen sources in grain yield; NitroPerfecto yielded 8.309 t ha^{-1} and urea 7.969 t ha^{-1}. In Study 2, conventional urea yielded 8.792 t ha^{-1} with 600 kg ha^{-1}, while NitroPerfecto did not show significant increases between 200–600 kg ha^{-1}, and a maximum yield of 7.527 t ha^{-1}. The above suggests an unfavorable synchrony between nitrogen release and crop demand in late applications. Protein content increased with nitrogen dosage from both sources. It was concluded that urease inhibitors work best at the beginning of the crop cycle, but are not recommended in later crop stages when nitrogen demand is higher.

Keywords: Inhibitors; Urease; Yield; Nitrogen

1 Introduction

In 2024, a total of 468,036 ha of wheat were planted in Mexico, yielding 2.648 million tons of grain with an average yield of 5.66 t ha^{-1}. In southern Sonora, particularly in the Yaqui and Mayo valleys, 237,963 ha were established, representing 50.84% of the national area and 95.16% of the state's wheat production [1]. Wheat is grown under irrigated conditions and, in years with favorable climate and adequate management, average yields exceed 7.0 t ha^{-1}. Globally, when water and climate are not limiting, nitrogen fertilization is often the most influential factor affecting wheat yield and quality [2, 3, 4]. Urea is the most widely used nitrogen fertilizer worldwide. Its hydrolysis, catalyzed by the urease enzyme, increases soil pH around the granules and leads to NH_3 volatilization losses averaging 16% of the applied N globally, and reaching or exceeding 40% in warm, humid climates [5]. Improving nitrogen use efficiency (NUE) without compromising yield remains a fundamental agroecological challenge, both theoretically and in practice [6]. Anthropogenic NH_3 emissions, mainly from agriculture, have caused significant harm to human health and ecosystems [7]. Beginning in 2030, the European Union will allow the use of fertilizers such as urea only if at least a 30% reduction in ammonia emissions is achieved [8]. In alignment with this regulation, Spain issued Royal Decree 1051/2022, which establishes standards for the sustainable nutrition of agricultural soils [9]. The risk of NH_3 volatilization from ammonium-based fertilizers has been widely recognized in the context of nitrogen management [10]. Urea ($CO(NH_2)_2$)

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accounts for approximately half of the mineral nitrogen applied globally. It is the mineral fertilizer with the highest N concentration (≈46%) and is accessible, economical, safe, and easy to transport, making it a key component of agricultural productivity and food security. However, when applied to the soil in the presence of water and urease, the carbon dioxide fixed during its manufacturing is released through hydrolysis; these emissions are intrinsic to its chemical structure and thus unavoidable [11]. One alternative to reduce losses is soil incorporation or the use of urease inhibitors. Slow-release urea is used to decrease volatilization losses after hydrolysis and leaching losses following ammonium nitrification. Several agronomic management strategies have been evaluated to reduce volatilization and maintain adequate soil N availability. Among them, N-(n-butyl) thiophosphoric triamide (NBPT), a urease inhibitor that temporarily delays enzymatic degradation of urea, reduces NH_3 volatilization, and enhances crop nitrogen uptake, is particularly notable [12]. In southern Sonora, urea is the main nitrogen source used in wheat production. It is broadcast pre-sowing and incorporated with a harrow or during furrow formation. Prior to the first supplemental irrigation, it is also broadcast and incorporated with irrigation water. The aim of the present study was to evaluate the effect of urease inhibitors in split fertilization applied at pre-sowing and the first supplemental irrigation, as well as in late-season nitrogen applications, on yield, protein content, biomass, and harvest index of wheat in the Yaqui Valley, Sonora.

2 Material and method

During the 2023–2024 fall–winter growing season, two studies were established at the Norman E. Borlaug Experimental Station of INIFAP, located in the Yaqui Valley, Sonora, Mexico (27°22'4.9'' N; 109°55'36.86'' W; 40 m asl). The site is characterized by a warm arid climate [BW(h)] with episodes of extreme heat, according to the Köppen classification modified by Garcia [13]. The objective was to evaluate the effect of fertilizers containing urease inhibitors in comparison with conventional urea; both materials contain 46% nitrogen. Wheat was the preceding crop. Land preparation included one pass with a chisel plow, three passes with a disk harrow, leveling, and furrow formation at 0.80 m spacing. Sowing was carried out on 25 November 2023 using 100 kg ha^{-1} of seed of the variety CIRNO C2008 [14]. No phosphorus fertilizer was applied, based on soil test results.

1.1 Study 1

The experiment was established in 24 rows, each 110 m long and spaced 0.80 m apart (2,112 m^2 total area), with two plant lines per row spaced 0.30 m apart. A pre-sowing irrigation and three supplemental irrigations were applied. Total fertilization consisted of 553 kg ha^{-1} of urea, split into 253 kg ha^{-1} applied before sowing and incorporated with a cultivator pass, and 300 kg ha^{-1} applied prior to the first supplemental irrigation and incorporated with the irrigation water. The same fertilizer rate was applied for the urease inhibitor treatment containing NBPT and Duromide (commercial name NitroPerfecto). In both treatments, the fertilizer remained on the soil surface for five days. The total nitrogen rate was 254 kg ha^{-1}. The useful plot area was 0.8 m^2, harvested manually using a sickle; four samples were collected for every 12 treatment rows. Threshing was carried out with a stationary Pullman-type thresher. Grain was cleaned, weighed, and its moisture content determined. A randomized complete block design with eight replications per treatment was used. The variables evaluated were total biomass, grain yield, and harvest index

1.2 Study 2

The experimental unit consisted of eight rows, each 7 m long and spaced 0.80 m apart (44.8 m^2 total area), with two plant lines spaced 0.30 m apart. A pre-sowing irrigation and four supplemental irrigations were applied. Prior to the second supplemental irrigation (59 days after sowing), broadcast applications of 0, 200, 400, and 600 kg ha^{-1} of conventional urea and NitroPerfecto fertilizer—treated with the urease inhibitors NBPT and Duromide (ANVOL®)—were manually applied. The fertilizers were left on the soil surface for five days and subsequently incorporated with irrigation water. The useful plot area consisted of two 3-m rows (4.8 m^2), harvested manually using a sickle. Threshing was performed with a stationary Pullman-type thresher. The grain was cleaned, weighed, and its moisture content determined. A randomized complete block design arranged in split plots with four replications was used. The evaluated variables were grain yield adjusted to 12% moisture and protein content on a dry basis.

3 Results and discusión

3.1 Study 1

No significant differences were observed for the use of urease inhibitors in NitroPerfecto compared with conventional urea for any of the evaluated variables. The yield difference was 0.34 t ha^{-1} in favor of the urease inhibitor treatment. Likewise, the harvest index increased with NitroPerfecto use, although this increase was not significant (Table 1).

Table 1 Mean comparisons for total biomass, grain yield, and harvest index in the evaluation of urea treated with urease inhibitors. CENEB-INIFAP. Fall–Winter 2023–2024 growing season.

Tratament	Biomass t ha^{-1}	Grain t ha^{-1}	Harvest index
Urea	17.369 a	7.969 a	0.458 a
NitroPerfecto	17.125 a	8.309 a	0.485 a
DMS	1.433	1.213	0.058

The cost of NitroPerfecto is USD 70 per ton higher than that of conventional urea, representing a 14.0% increase. Therefore, the yield or quality response of wheat to fertilizers containing urease inhibitors should exceed that obtained with conventional urea. In this study, both conventional urea and NitroPerfecto were sourced from the same company. The crop appearance under both treatments is shown in Figure 1.

Figure 1 Left: urea with two urease inhibitors. Right: conventional urea. CENEB-INIFAP. Fall–Winter 2023/2024 growing season.

Urea ($CO(NH_2)_2$) is the most widely used mineral nitrogen fertilizer worldwide, accounting for approximately half of all mineral nitrogen applied. It has the highest nitrogen content among mineral fertilizers (≈46%), is widely available, affordable, and safe to handle and transport. Consequently, it plays a critical role in agricultural productivity and food security. However, when urea is applied to the soil in the presence of water and urease enzymes, the carbon dioxide fixed in the urea molecule during manufacturing is released through hydrolysis. These emissions are intrinsic to urea's chemical structure and are unavoidable [11]. One solution is to incorporate urea into the soil or treat it with urease inhibitors. To meet field requirements, additional factors must also be considered, including application rate and timing, application method, soil type, crop type, soil pH, and atmospheric conditions [15].

3.1.1 Study 2

In this evaluation, significant differences were observed for grain yield between nitrogen sources, fertilizer rates, and their interaction (Table 2). On average, grain yield with conventional urea was 461 kg ha^{-1} higher than that obtained with NitroPerfecto (NPTO). When examining the interaction between fertilizer rate and source, no significant differences were found among the 200, 400, and 600 kg ha^{-1} rates of NitroPerfecto; the only significant difference was between these three rates and the unfertilized control. In contrast, with conventional urea, a significant yield increase was observed when applying 200 and 400 kg ha^{-1}; the 400 and 600 kg ha^{-1} rates were statistically similar, and 600 kg ha^{-1} was superior to 200 kg ha^{-1} and the unfertilized control. The observed coefficient of variation in this study was 4.08%, indicating high experimental precision. The highest grain yield was obtained with 600 kg ha^{-1} of conventional urea.

Table 2 Fertilizer rate, nitrogen source, and wheat grain yield. CENEB-INIFAP. Fall–Winter 2023/2024 growing season.

Fertilizer kg ha-1	Yield t ha-1		Mean t ha-1
	Urea	NitroPerfecto	
0	6.663 a	6.616 a	6.639 a
200	7.998 b	7.764 b	7.881 b
400	8.499 bc	7.996 b	8.247 bc
600	8.792 c	7.730 b	8.261 c
Mean	7.988 a	7.527 b	

These results contrast with those obtained in Study 1. The lack of response to the application of NitroPerfecto in the second supplementary irrigation is considered indirect evidence that nitrogen availability is lower in this fertilizer compared to urea, likely due to the effect of urease inhibitors. This pattern could be explained by the delayed release of nitrogen caused by the inhibitor: the slower hydrolysis of urea may have desynchronized nitrogen availability relative to crop demand during the grain-filling stage, particularly in the case of a late application. Under these conditions, conventional urea, with its rapid release, may provide a more favorable synchronization between available nitrogen and crop demand [16]. Similarly, recent studies report that under well-managed water conditions (irrigation or rainfall), the agronomic advantage of urease inhibitors decreases or disappears [17]. Field studies have shown that the use of inhibitors can reduce ammonia (NH_3) emissions by up to 50–60% compared to standard urea, but yield increases were modest or absent [18]. This indicates that the agronomic efficiency of inhibitors strongly depends on irrigation management, timing of application, and soil conditions. The results obtained suggest that NitroPerfecto can be recommended for broadcasting at sowing and at the first supplementary irrigation but not at later stages when crop nitrogen demand increases.

Furthermore, the use of nitrogen fertilizers in wheat cultivation is a well-documented topic in the literature. For example, Kubar et al. [19] reported that an optimal nitrogen dose significantly increased photosynthetic rate, aboveground biomass, and wheat yield. Hnizil et al. [20] found significant variations in yield, thousand-kernel weight, and spike number per unit area associated with the rate of nitrogen applied. In addition, recent meta-analyses show average yield increases of 60–90% with nitrogen fertilization, particularly under appropriate dosing and split-application strategies [21].

Urease inhibition is a process that can last from five to ten days, depending on soil or environmental moisture conditions. If urea is applied after pre-sowing irrigation and before covering the seed furrow, soil moisture is very high, and urea hydrolysis can occur within hours. When broadcasting urea, immediate incorporation is recommended. Finally, given that the cost of NitroPerfecto is approximately USD 70 t^{-1} higher than conventional urea, any agronomic recommendation must consider a cost–benefit analysis, especially if there is no clear yield increase. However, if the use of inhibitors allows for reduced nitrogen losses and lower environmental impact, their use may be justified in agricultural systems that prioritize sustainability, grain quality, or mitigation of NH_3 emissions.

For the variable grain protein content on a dry matter basis, significant differences were found only for the average fertilizer doses applied. No differences were observed between conventional urea and NitroPerfecto, nor was there an interaction between the two factors (Table 3). Protein values increased in response to the nitrogen dose applied in both nitrogen sources. On average, protein content with NitroPerfecto was higher than that observed with urea. This behavior is consistent with the well-documented relationship between nitrogen supply and protein accumulation in wheat, particularly during grain filling, a stage in which nitrogen availability directly influences the synthesis of storage proteins [22, 23].

Table 3 Nitrogen dose, nitrogen source, and grain protein content (dry matter basis) in wheat. CENEB-INIFAP. 2023/2024 Fall-Winter Season.

Fertilizer kg ha-1	Proteín %		Media %
	Urea	**NitroPerfecto**	
0	9.54	9.66	9.60 a
200	10.78	11.11	10.94 b
400	12.08	12.31	12.19 c
600	12.64	12.63	12.63 c
media	11.26	11.43	11.34

A meta-analysis conducted in China demonstrated that the optimal nitrogen application rate (approximately 240–300 kg N ha^{-1}) significantly increases total protein content [24]. Another recent study reported that late nitrogen application can enhance protein concentration without necessarily compromising yield [25]. Beyond the amount of nitrogen applied, wheat variety and agronomic practices also influence protein response. For instance, a recent study showed that the combination of nitrogen fertilization with specific wheat varieties affects protein accumulation [26].

The results indicate that both conventional urea and urea with urease inhibitors were effective in improving grain quality, and that the protein response was marked and consistent with increasing nitrogen application. Furthermore, the fact that the inhibitors produced protein levels similar to or slightly higher than those of conventional urea at intermediate and high application rates supports the idea that their use can contribute to improving nitrogen recovery efficiency when optimizing grain quality, even though their impact on yield is not always positive.

4 Conclusion

In study 1, when fertilization was applied at planting and during the tillering stage, the use of urease inhibitors resulted in a favorable response in wheat yield. Conversely, in study 2, when fertilization was delayed until before the second supplemental irrigation, at a stage when the crop's nitrogen demand increases significantly, the grain yield response was significantly lower when using urease inhibitors. This was considered indirect evidence that the urease inhibitors fulfilled their purpose and prevented nitrogen from being available at the same time as that from conventional urea.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare that No conflict of interest.

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