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Enhanced-efficiency urea fertilizer use for wheat in the Rolling Plains of Texas

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Introduction

Most wheat grown in the Rolling Plains of Texas is managed in conventionally tilled dryland production systems, although no- or reduced-tillage operations are gaining attention among producers to improve soil health, reduce erosion, and improve moisture retention. In these systems, nitrogen (N) fertilizer can be applied in a variety of forms, though urea is one of the most common forms utilized by producers. Urea is popular because the material is typically less expensive than other options, has a relatively high N content (lower application costs), and is easier to handle. Urea is often surface-applied in no-till operations and in split in-season applications, and producers rely on unpredictable precipitation to incorporate it into the soil. This practice puts producers at great risk for losing N through multiple pathways, especially ammonia volatilization. Nitrogen (N) fertilizer accounts for a large portion of expenses in dryland wheat production, approximately 25% of total variable costs (Texas Crop and Livestock Budgets, 2017), and is critical to obtaining desired yield goals. Due to all these factors, N loss to the environment should be minimized and N-use efficiency should be optimized for profitable wheat production in the Rolling Plains of Texas.

Pathways for N Loss

Ammonia Volatilization

Ammonia (NH_3) volatilization refers to the loss of N through gaseous emission of NH_3 from the soil surface. When urea [$(NH_2)_2CO$] is applied to the soil and comes in contact with moisture, a chemical reaction called urea hydrolysis converts it to NH_3 very rapidly when environmental conditions are favorable. Specialized microorganisms that are abundant in most soils produce an enzyme called urease that drives the breakdown process. Loss of the N in urea through NH_3 volatilization occurs in every soil type, but the rate of loss is accelerated at high soil temperatures and high soil pH, and when the urea is not rapidly incorporated into the soil. Each of these conditions is prevalent in the Rolling Plains of Texas. The N lost through NH_3 volatilization can be as high as 65% of total applied urea within a week, depending on the environmental conditions, if the urea is not incorporated into the soil (Cameron et al., 2013). When urea is incorporated into the soil, NH_3 is converted into ammonium (NH_4^+), a non-gaseous form of the molecule that is more stable in the soil. Therefore, it is important that urea is incorporated into soil immediately after the application or stabilized to prevent volatilization until it can be incorporated.

Urea Hydrolysis:

$$(NH_2)_2CO + H_2O \rightarrow CO_2 + 2NH_{3(g)}$$

Ammonia-Ammonium Equilibrium:

$$NH_{3(g)} + H_2O \leftrightarrow OH^- + NH_4^+$$

Leaching

Ammonia volatilization is not the only process through which the N in urea may be lost that may affect Texas wheat producers. Once urea has been converted into NH_3 and or NH_4^+, soil microbes convert the NH_3/NH_4^+ to nitrate (NO_3), a process called nitrification. Nitrate is a water-soluble form of N and is susceptible to leaching under certain conditions. Leaching of NO_3 occurs when precipitation and/or irrigation water inputs are great enough to drive deep water percolation and N is driven beyond the reach of plant roots.

Denitrification

Nitrogen loss in the field also occurs through the process of denitrification, which converts NO_3 to nitrous oxide gas (N_2O) and dinitrogen gas (N_2) under wet soil conditions that limit oxygen availability to soil microorganisms. These gaseous forms of N are lost by emission from the soil.

Enhanced-efficiency urea fertilizers are commercially available products designed to reduce the loss of N from urea fertilizer and improve N uptake by the crop. There are a variety of enhanced-efficiency fertilizer technologies available, which are described in the following section.

Enhanced Efficiency Fertilizers

There are two basic classes of enhanced efficiency fertilizers: 1) controlled- and slow-release fertilizers, and 2) stabilized fertilizer products. Controlled- and slow-release fertilizers include low solubility materials (e.g. magnesium and ammonium phosphate), and materials coated with a physical barrier that control fertilizer release, such as polymer- and sulfur-coated fertilizers. There are polymer- and sulfur-coated options for urea fertilizer, though sulfur-coated urea technologies are older and considered less effective than newer and higher-tech polymer-coated urea fertilizers. Stabilized fertilizers include materials chemically treated with microbial inhibitors, including urease and nitrification inhibitors. Here we focus on polymer-coated urea and urea stabilized with urease and nitrification inhibitors.

Polymer-Coated Fertilizers

Polymer-coated fertilizers are coated with synthetic polymers. When placed in a high-humidity environment, such as moist soil, water vapor diffuses through the polymer coating, dissolving fertilizer. Once hydrated, fertilizer solution diffuses outward through the coating and is expected to be more slowly available to plants than readily soluble uncoated urea. In wetter environments, polymer-coated fertilizer can be surface broadcast, but fertilizer release is severely limited when the soil surface is dry, as is often the case in Texas. The release of fertilizer solution into the soil depends on several environmental factors beyond moisture, but temperature is the most important. The rate of release increases with temperature. In field applications, polymer-coated fertilizers have been more extensively tested and used in cooler northern regions of the United States and Canada, while limited testing has occurred in the warmer southern United States.

Stabilized Urea Fertilizers

Stabilized urea fertilizers are treated with urease and/or nitrification inhibitors. These products protect the N in urea from loss by inhibiting the natural activity of soil microbes or enzymes. Urease inhibitors delay the breakdown of urea, allowing more time for it to become fully incorporated into the soil, thus reducing the loss of N through NH_3 volatilization. Once urea has broken down to NH_3/NH_4^+, a nitrification inhibitor can prevent further microbial transformation of NH_4^+ into NO_3, which can be lost by leaching, or further transformed into nitrous oxide or dinitrogen gasses and emitted from soil.

Field Trial on Enhanced-Efficiency Urea Fertilizers

A set of field experiments were conducted in dryland and no-till conditions in the Rolling Plains of Texas during the 2016 – 2017 winter growing season. One location was south of Chillicothe, TX and the other near Lockett, TX at Texas A&M AgriLife Research Stations. The trials were planted on 16 November 2016. Soil types were Rowena clay loam and Miles loamy fine sand in the Chillicothe and Vernon, respectively (Table 1). The wheat variety planted was cv "Gallagher". There were four experimental treatments: 'Environmentally Smart Nitrogen or ESN' (Agrium, Calgary, AB, Canada) (44-0-0) polymer-coated urea (PCU), SUPERU (46-0-0) stabilized urea (SU) (Koch Agronomic Services, Wichita, KS), untreated urea (46-0-0) as a control, and no fertilizer as an additional control. All fertilizers were applied at planting at 60 lbs N/ac. Wheat was drilled on 10-inch row spacing at approximately 1-inch depth. Dry granular forms of urea were tested, but application methods were customized based on technological constraints. In semi-arid environments where the soil surface is typically dry, like central and west Texas, PCU must be placed sub-surface for fertilizer to be released, therefore it was drilled directly in the seed row by the planter through a fertilizer box. The polymer coating of PCU is intended to reduce the solubility and plant-availability of the urea, preventing stand loss when used in this way. The SU and untreated urea were broadcast on the soil surface, as they would be expected to cause stand loss due to their high solubility if drilled directly in the seed row. The plots were harvested on 15 May 2017. Economic analysis of the results was conducted across a range of possible wheat price points, from $3/bu to $7/bu at $0.50/bu increments, to estimate net profit values. Net revenue was calculated using the Texas A&M University enterprise budget for dryland wheat for Rolling Plains Extension District-3 (Texas Crop and Livestock Budgets, 2017). Variable expense estimations in the budget were used, except in experimental treatment-related expenses (e.g. fertilizer costs, application costs), which were modified according to the treatment. Another economic analysis was conducted for SU based on yield goals. Net revenue calculations were made for yield goals from 25 bu/ac to 50 bu/ac at 5 bu/ac increments, with N rates corresponding to the yield goals calculated as 1.5 lbs N/ac per bushel of yield expected.

Table 1: Soil NO_3 and NH_4^+ levels at planting. Soil samples were collected from 0 to 18-inch depth for analysis.

Nitrogen Source	Soil Concentration (lbs/ac)
Lockett	
NO_3-N	2.1
NH_4-N	13.8
Total N	15.9
Chillicothe	
NO_3-N	3.9
NH_4-N	22.8
Total N	26.7

Yield and Grain Protein Results

The stabilized urea product (SU) had a positive impact on yield. Wheat fertilized with SU yielded 34 bu/ac, 26% more than wheat fertilized with untreated urea (27 bu/ac) and 36% more than wheat without fertilizer (25 bu/ac). Wheat fertilized with untreated urea yielded only a marginal amount more than unfertilized wheat, indicating that most of the untreated urea was lost to the environment or not taken up by wheat roots. The yield results show that the SU product was effective in increasing N availability to the crop. Given the environmental conditions of the region, it is likely that the urease inhibitor present in the SU, rather than the nitrification inhibitor, played the largest role in improving nitrogen availability, possibly through a reduction in NH_3 volatilization.

The PCU negatively affected yield. The yield loss observed with PCU may be attributed to rapid release of the seed-placed urea fertilizer, which caused stand loss (33% reduction; data not shown). The rate of fertilizer release from polymer-coated urea is a function of temperature and, while PCU can be safely seed-placed at relatively high rates in cooler environments, this experiment suggest that the Rolling Plains of Texas may be too warm for seed-placement of PCU products, even in the winter growing season (Fig.1).

Application of N fertilizer is important in achieving yield goals, but it is also critical in achieving sufficient levels of grain protein. In many areas, wheat is subject to price dockages if protein falls below 12%. In our research, grain protein concentration ranged from 11.1% to 12.6%, with the lowest levels in unfertilized wheat and with all treatments receiving N fertilizer surpassing 12% protein. Grain protein levels were highest in the PCU treatment, which may have been elevated by seed placement of the fertilizer (direct N delivery to the plant) and stand loss (greater N availability per plant). Untreated urea and SU application generated grain protein concentrations of 12.1%, though the higher efficiency of N delivery with SU also brought higher yield. These results demonstrate the risk in going without fertilizer in wheat production and show an additional benefit of enhanced-efficiency fertilizers.

Nitrogen removal from the soil by grain, which is an indicator of the N-use efficiency of the crop, is a product of grain yield and grain protein concentration. With relatively high grain yield and protein, the grain N removal for wheat fertilized by SU was 44 lbs N/ac. This was 29% greater than with untreated urea (34 lb N/ac) and 47% greater than wheat without N fertilizer (30 lb N/ac) (Fig.1). Relatively low grain N removal by the wheat fertilized by PCU is attributed to low grain yields.

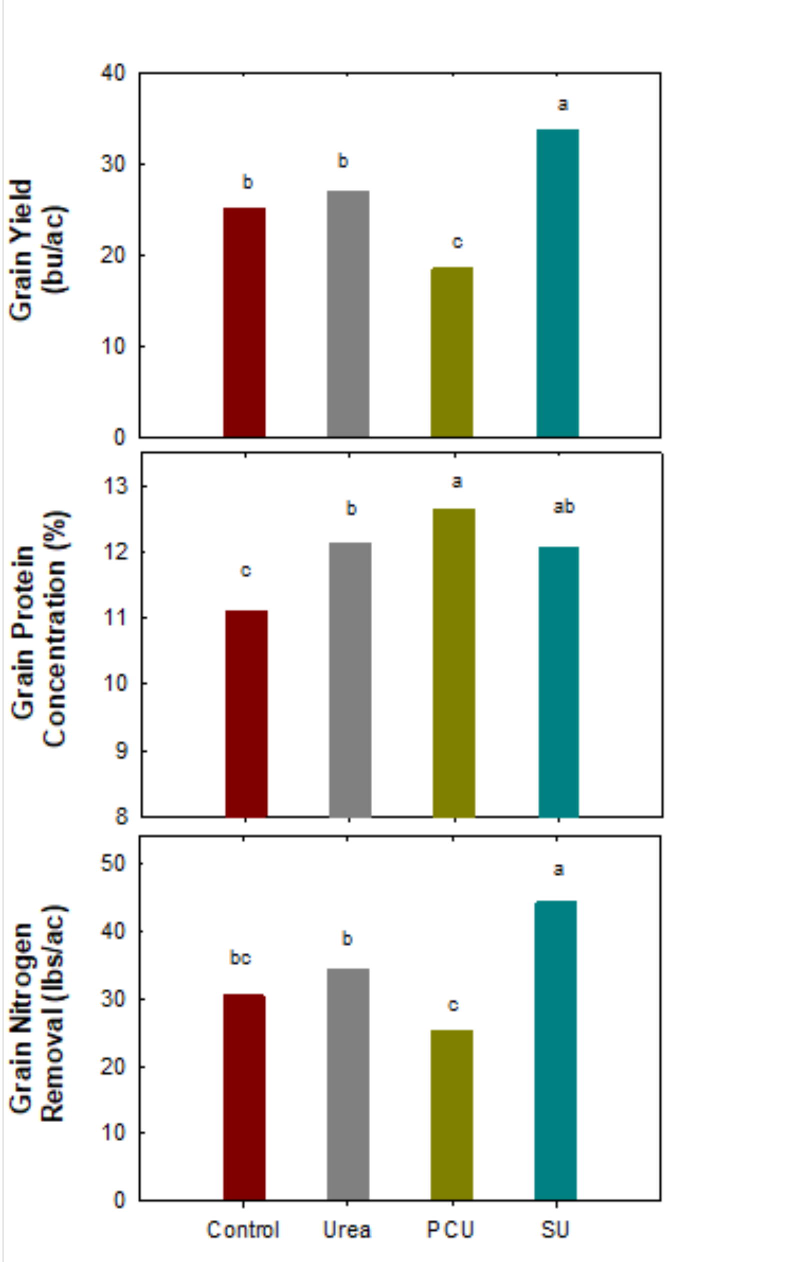

Fig. 1: Grain yield, grain protein concentration, and grain N removal in unfertilized wheat and wheat fertilized with untreated urea, polymer-coated urea (PCU), and stabilized urea (SU). Columns with the same letters within a graph are not statistically different at $P < 0.05$.

Economic Outcomes

Economic analysis of the results of the field trial showed that net revenue was greater with the SU product than untreated urea across all price points analyzed, despite the higher cost of SU relative to untreated urea. Net revenue values were negative at a price point of $4.50 and below for all fertilizers (Table 2), but as the price point increased, net revenue became increasingly positive for the SU product, because it increased yield relative to the other fertilizers. Economic analysis based on yield goals and corresponding N rates, given in Table 3, gives a better indication of tradeoffs in yield and price for achieving desired levels of crop income using SU (Table 3).

Table 2: Economic analysis of net profit for wheat fertilized with untreated urea, polymer-coated urea (PCU) and stabilized urea (SU) at wheat prices ranging from $3 to $7 bu/ac and the yields presented in Figure 1.

Price	Net Revenue		
	Urea	PCU	SU
($/bu)	($/ac)	($/ac)	($/ac)
3.00	-$68.94	-$106.43	-$57.96
3.50	-$55.56	-$97.21	-$41.16
4.00	-$42.17	-$87.98	-$24.35
4.50	-$28.9	-$78.77	-$7.55
5.00	-$15.41	-$69.55	$9.25
5.50	-$2.02	-$60.33	$26.05
6.00	$11.36	-$51.11	$42.85
6.50	$24.75	-$41.89	$59.66
7.00	$38.13	-$32.67	$67.32

Table 3. Theoretical net revenue of wheat fertilized with SU given a range of yield goals, corresponding N rates, and wheat prices ranging from $3 to $7 bu/ac.

Yield goals (bu/ac)	N rate for yield goal (lb/ac)[1]	Wheat price ($/bu)				
		3	4	5	6	7
		Net Revenue ($/ac)				
25	37.5	-72	-47	-22	2.8	28
30	45	-61	-31	-0.4	29	60
35	52.5	-49	-14	21	56	91
40	60	-38	2.4	42	82	122
45	67.5	-26	19	64	109	154
50	75	-15	35	85	135	185

[1]N rate was calculated with 1.5 lb N/ac for one bushel of yield goal. This calculation does not include residual N that can be credited toward the N rate based on soil test results.

Summary

When applied to the soil surface without rapid incorporation, the N in urea is extremely vulnerable to loss. In the Rolling Plains of Texas, most of this loss will occur by breakdown of the urea into NH_3, which is volatized to the atmosphere from the soil surface. Typical environmental conditions in the region, such as high temperatures and high pH soils, favor NH_3 volatilization and thus it is important to incorporate the N immediately after application or to stabile it until precipitation can incorporate it. The results of the field trial, described above, demonstrate that SU products can be effective in improving N availability to wheat, likely through reduced NH_3 volatilization, improving wheat yield and grain protein concertation in the Rolling Plains of Texas. Although SU fertilizers cost more than untreated urea, economic analysis of the field trial results showed that SU maintained higher net profit than untreated urea at all price points analyzed, including the lowest price points. Grain quality, in terms of protein concentration, was always better with N fertilizer (treated or untreated) rather than no fertilizer applied, showing the importance of proper nutrient management practices to maintain a high-quality product. Adjusting N rates for desired and achievable yield goals can help generate positive net revenue from wheat production. Use of enhanced-efficiency urea fertilizers, like SU products, can play an important role in achieving yield goals for wheat producers in the Rolling Plains region.

References

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