Spring Wheat Stand and Yield Losses From Applying Urea-N Fertilizer With The Seed

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Since urea is becoming a primary source of N-fertilizer in dry-granular blends and in liquid formulations, there is reason to be concerned whether such urea-containing fertilizers should be used for grain-drill application with the seed. We found germination damage and root pruning increased progressively 27 days after seeding as the rate of urea-N applied with the seed increased. For every 10 lbs/acre of actual N applied with the seed, spring wheat stands decreased about 13 percent and grain yields decreased 3.1 bu/acre. To prevent such losses, liquid or dry-granular N-fertilizer materials that contain urea-N should be broadcasted and incorporated before seeding or banded to the side and below the seed.

Some nitrogen (N) fertilizer materials can damage seedlings and reduce grain yields when applied with the seed. Urea (46-0-0) causes more damage to seedlings than ammonium nitrate (34-0-0), as was shown by Devine and Holmes (5), Olson and Preier (10), and Hunter and Rosenau (8). Seedling damage is attributed to either urea [$CO(NH_2)_2$] itself or to one of its transformation products, such as ammonium cyanate (NH_4OCN), ammonium carbonate [$(NH_4)_2CO_3$], free ammonia (NH_3), or nitrite (NO_2^-). For a given N rate, Towes and Soper (13) found an inverse relationship between spring barley seedling damage resulting from drilling urea with the seed and soil-cation-exchange capacity for eight soils with a wide range in soil pH and cation exchange capacity. The quantity of NH_3 produced from ammonium- and urea-containing fertilizer materials, like diammonium phosphate (18-46-0) and urea-ammonium phosphate (24-42-0), increased as soil calcium carbonate increased, but less NH_3 was produced at high than at low soil water levels (12). Concentrations of NH_3, in the range of 0.3 to 0.5 ppm inhibited seedling development, particularly root growth of spring wheat (12).

The amounts of N as urea recommended by the Montana and North Dakota Agricultural Experiment Stations for application with small grain planted in 6-inch rows range from 0 to 15 lb of N/acre (4, 9). Since urea is becoming the primary N source used in dry-granular fertilizer blends there is reason for concern whether N-P-K fertilizer blends containing urea (46-0-0) should be used for grain drill applications with the seed.

Our study was designed to determine the influence of urea-N rate, when drilled with the seed, on spring wheat stand and grain yields while periodically determining soil ammonium (NH_4^+), nitrite (NO_2^-), and nitrate (NO_3^-) forms of N within the 0- to 3-, 3- to 6-, and 6- to 12-inch soil depths for 48 days after seeding.

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Methods and Materials

Spring wheat (*Triticum aestivum* L. 'Lew') was planted on April 26, 1978 in 7-inch rows at a seeding rate of 60 lb/acre, using a double disk press wheel drill with fertilizer attachment. The drill was equipped with 2-inch depth bands which ensured uniform seed-depth placement. We applied 0, 10, 20, 30, 40, 50, and 60 lb/acre of actual N as urea with the seed at planting. Each fertilizer treatment was one drill-width wide (12 feet) and 130 feet long, randomly arranged with four replications.

The soil is a Williams loam (fine-loamy, mixed, Typic Argiborolls) which had been fallow the previous year. At the 0- to 6-inch soil depth, this soil is slightly calcareous with a pH near 7.0, but below 6 inches it is strongly calcareous with a pH of 8.2. The loam surface soil, bordering on a sandy loam, has a CEC of 15 and a water holding capacity of 6.8 and 13.7 percent by volume at 15 and 0.5 bar suction, respectively. Soil phosphorus availability, as measured by the sodium bicarbonate method (11), was adequate at 16 ppm. Total soil NO_3-N to a 4-foot depth was initially 112 lb/acre, which is estimated to be sufficient N for a 50 bu/acre wheat yield (1).

We counted plant stands in each plot on May 11, 16, and 22, and on June 5. On May 11 and 22, whole plant samples (tops plus roots) were also obtained with a shovel from 1 foot of row during the seedling growth stages for photographic recordings. Soil cores, 2 inches in diameter, were periodically obtained on May 11, 15, 17, 22, and 26 and on June 5 and 9 from the 0- to 3-, 3- to 6-, and 6- to 12-inch soil depths, centered on the drill-row. These samples were placed in plastic bags and frozen immediately to prevent any changes in N-forms. The soil samples were extracted with 2 M KCL. An autoanalyzer was used to determine the concentration of ammonium (NH_4-N), nitrite (NO_2-N), and nitrate (NO_3-N) in the extracts. All soil N levels are expressed on a dry soil basis.

Grain yields were determined by hand harvesting the plants from 14 square feet of each plot and also by small combine harvesting an 8-foot swath, 130 feet in length in each 12-foot drill width. Grain yields were similar between the two harvest methods.

Results and Discussion

Soil water in the seed zone, after seedbed preparation with a tandem disk operated at the 3- to 4-inch soil depth, was adequate for seed germination. The surface-tilled soil layer continued to dry during the first 6 days after seeding. After a 0.97 inch rain on May 3, the soil in the seed-placement zone remained moist because of frequent rainfall throughout May (Figure 1). Cool soil temperatures during this rainy period minimized soil drying (Figure 1) and, except for the surface 1 inch of soil, soil water conditions were considered good. The fact that average soil temperature at the 3-inch depth did not reach 50°F until late May (Figure 1) may have influenced the microbial conversion of NH_4^+ to other available forms of N, which will be discussed later.

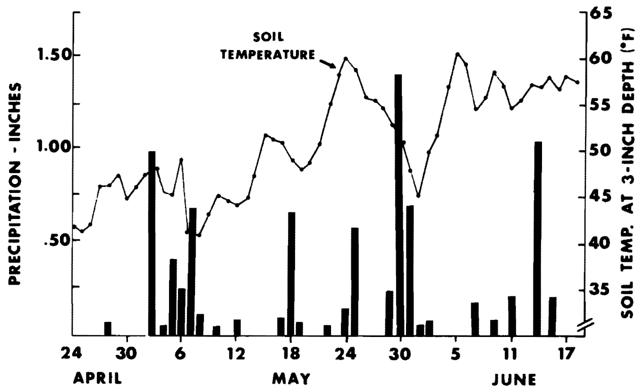

Fig. 1. Precipitation and average soil temperature at the 3-inch soil depth from seeding to jointing growth stage.

Conversion of Urea to Plant Available Forms:

Hydrolysis of urea involves the conversion of urea, $CO(NH_2)_2$, to ammonia (NH_3), and then to ammonium (NH_4^+). Subsequent transformations involve the microbial conversion of NH_4^+, to nitrite (NO_2^-), and then to nitrate (NO_3^-). Therefore, release of plant-available forms of N (NH_4^+ and NO_3^-) from urea is governed by factors that control the rates of hydrolysis and mineralization. Aside from source, rate, and placement of N-fertilizer, these available N forms are influenced primarily by soil water, temperature, aeration, and soil pH (acidity or alkalinity).

During urea hydrolysis in the soil, NH_3 is the first and most toxic N form produced before the N is transformed to NH_4^+. Pairintra (12) reported that as little as 0.3 to 0.5 ppm NH_3 adsorbed in spring wheat seeds prevented germination. The progressive negative effect of increasing rates of N on seedling vigor, number and length of roots, and germination, at the highest N rate, 27 days after seeding in our study is shown in Figures 2A through 2G. As the rate of N increased, root growth and development was increasingly inhibited, which is characteristic of NH_3 damage to roots and seeds in soils.

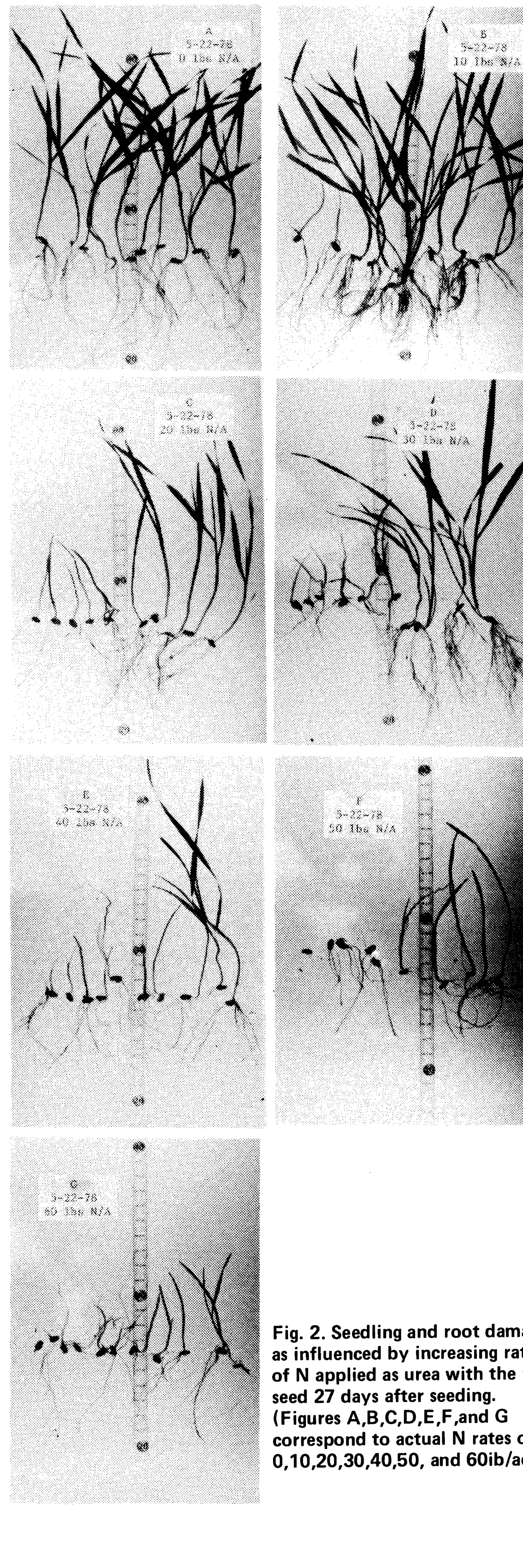

Fig. 2. Seedling and root damage as influenced by increasing rate of N applied as urea with the seed 27 days after seeding. (Figures A,B,C,D,E,F,and G correspond to actual N rates of 0,10,20,30,40,50, and 60ib/acre.)

Since the amount of NH_4-N and NO_3-N produced was similar for the high (50 and 60 lb N/A), medium (30 and 40 lb N/A) and low (10 and 20 lb N/A) rates of N, we plotted the average NH_4-N and NO_3-N accumulations in Figures 3 and 4, respectively. These values show the relative effect of rate of N applied and time on NH_4-N and NO_3-N accumulation within and below the fertilizer placement zone. These values do not reflect the absolute amount of NH_4-N and NO_3-N on an area basis.

Ammonium is formed during hydrolysis of urea. The data in Figure 3 show that hydrolysis was not completed until sometime between May 15 to 22. As the rate of fertilizer N increased, hydrolysis was completed progressively later.

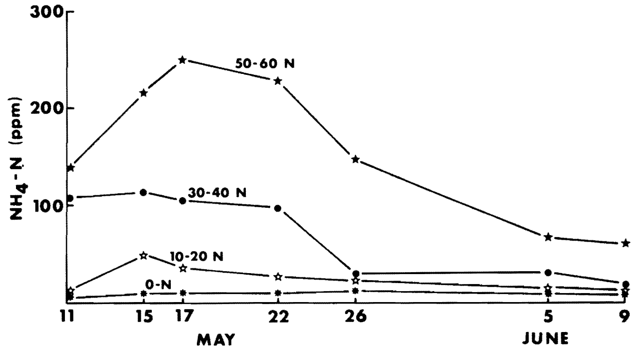

Fig. 3. Accumulation of ammonium (NH_4) in the 0- to 12-inch soil depth in relation to rate of urea-N applied.

Mineralization of NH_4^+ to NO_2^- and then to NO_3^- is a microbial process, dependent primarily upon soil water and temperature. Nitrite is converted to NO_3^- very rapidly. At none of the seven sampling dates did we find more than 4 ppm NO_2-N within the 0- to 3-inch soil depth for the highest N rate. At no time did we find more than 1 ppm NO_2-N for N rates of 50 lb/acre, or less. However, at fertilizer N rates greater than 30 lb/acre, the NO_3-N increased rather rapidly from May 26 to June 5 (Figure 4). By June 5, the spring wheat crop was utilizing considerable soil NO_3-N. This explains why soil NO_3-N decreased in the soil with the low fertilizer N rates. The rather rapid decrease in the NH_4-N between May 22 and 26 coincided with the rather marked increase in the NO_3-N. Microbial

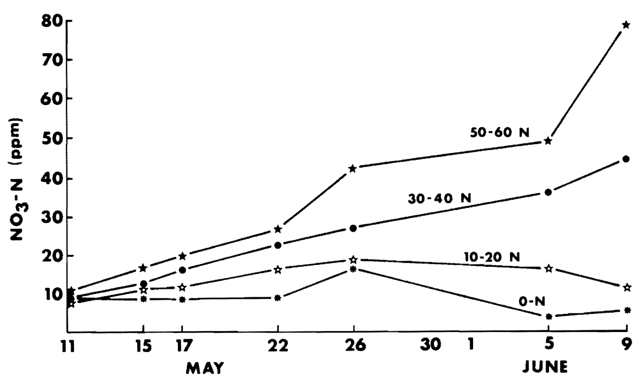

Fig. 4. Accumulation of nitrate (NO_3-) in the 0- to 12-inch soil depth in relation to rate of urea-N applied.

conversion of the NH_4^+ to NO_3^- likely was restricted during early May until average soil temperature at the 3-inch soil depth increased above 50°F about May 20. Previous research in northeastern Montana also showed no significant amount of NO_3-N production from urea applied at 40 and 80 lb of N/acre when surface incorporated or band-applied at 4- and 8-inch soil depths, until average soil temperature reached about 50°F at each application depth (6).

Spring Wheat Stand

Stands counted on May 11, 16, and 22, and June 5 (Table 1) showed emergence decreased progressively on all observation dates as rate of N applied increased. Stand reductions were relatively consistent with time at N rates of 30 lb/acre or less. Even though stands were drastically reduced at N rates of 40 lb/acre or more, stands improved somewhat with time. As shown in the photographs taken on May 22, 27 days after seeding (Figures 2A through 2G), germination was inhibited and/or delayed, but a small percentage of the seedlings were near emergence at that time. Seeds and seedlings which had not germinated or emerged by June 5 were beginning to decompose.

Table 1. Spring wheat emergence on four successive dates as affected by rate of urea-N applied with the seed.

Nitrogen Rate	Sampling Date May 11	May 16	May 22	June 6
lb/acre	Plants/yd²*			
0	134	130	126	129
10	103	99	105	113
20	88	90	87	92
30	65	64	71	69
40	30	36	48	59
50	21	25	34	47
60	17	20	22	28

*Plants/yd² divided by 15.4 gives the number of plants per foot of row in a 7-inch spacing.

The correlation between number of plants per unit area and rate of N applied was highly significant and negative (Figure 5). Each pound of N added reduced stands by 1.7 plants/yd². So, if 40 lbs of N were applied, the predicted stand loss would be 67 plants/yd² (53% loss of stand).

Grain yields decreased as rate of N applied increased (Figure 6). This significant, negative correlation predicts a yield loss of 0.31 bu/acre for each pound of N added or 3.1 bu/acre for every 10 lb N/acre added. As mentioned earlier, this soil contained 112 lb of N/acre to a 4-foot soil depth at seeding. At this N level, no yield response to N fertilization was expected, unless the yield potential exceeded 50 bu/acre (1).

Grain yields increased as number of plants per unit area increased (Figure 7). Once the plant population decreased below 70 plants/yd², grain yields decreased more than when the population ranged from 70 to 130 plants/yd². Growing season precipitation was 13.3 inches from seeding to harvest, about 70% above average. Pre-

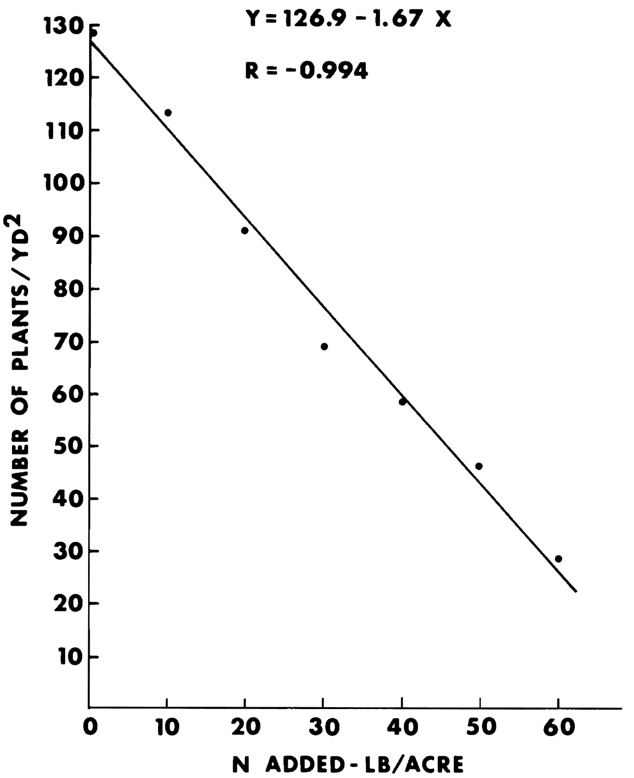

Fig. 5. Stand losses as affected by increasing rate of urea-N applied with the seed.

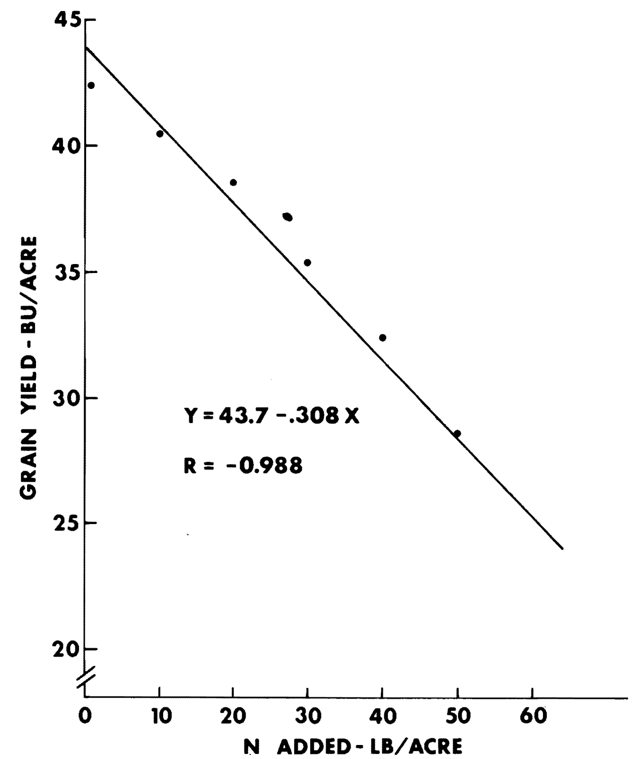

Fig. 6. Grain yield loss as affected by increasing rate of urea-N applied with the seed.

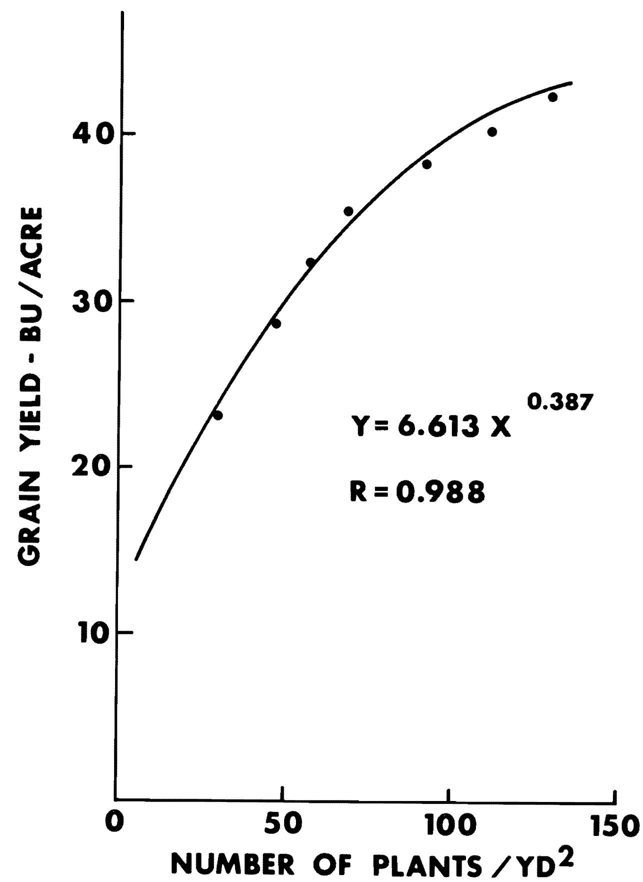

Fig. 7. Effect of stand loss on spring wheat grain yields.

cipitation during the tillering and jointing growth stages was exceptionally good (Figure 1). Therefore, any decrease in plant population was undoubtedly less serious to yields under these climatic conditions than the same stand loss would be under drier conditions because relative plant tiller production would be lower.

Components of Yield

Grain yield per unit area is the product of the number of heads per unit area, the number of kernels per head, and the weight per kernel. Grain yields calculated from independent measurements of each yield component for wheat samples harvested from eight different 8-foot row segments per N treatment agreed closely (within 1.4 bu/acre) with hand harvested and combine yields determined on a weight basis (Table 2). Of the individual components of yield, number of heads per unit area is the primary factor influencing yield. In this study, number of heads/yd^2 accounted for 98% of the yield variance due to N treatment ($Y = 667 + 5.62(X)$, $r = 0.99^{**}$); where Y is grain yield in lb/acre and X is the number of heads/yd^2. The number of heads per individual plant increased as number of plants/yd^2 decreased due to stand damage (Table 2). However, at the lowest plant population the 2-fold increase in number of heads per individual plant did not compensate for the 4.6-fold decrease in plant stand.

Table 2. Components of yield and other agronomic data as influenced by rate of urea-N applied with the seed.

Fertilizer N added	*Plants per yd^2	Heads per plant	Heads per yd^2	Kernels per head	1000-kernel wt.	**Yield (calculated)	**Yield (actual)	Test wt.	Protein Content
lb/acre	No.	No.	No.	No.	oz	lb/acre	lb/acre	lb/bu	%
0	129	2.68	345	23.8	1.037	2576	2546	64.0	12.8
10	113	2.81	318	25.1	1.008	2434	2438	63.7	13.2
20	92	3.13	288	26.3	1.026	2351	2318	63.4	13.5
30	69	3.49	242	28.2	1.023	2112	2120	63.5	13.7
40	59	3.77	221	28.3	1.026	1941	1940	63.2	14.0
50	47	3.96	186	28.9	1.019	1657	1717	63.2	14.8
60	28	5.23	149	29.6	1.009	1346	1429	61.8	15.2

*Plants/yd^2 or Heads/yd^2 multiplied by 4840.3 = Plants/acre, or Heads/acre.
**Yield (lb/acre) divided by 60 = bushels/acre.

Conclusions

Urea is a good N source for small grain crops if it is broadcasted and incorporated before seeding, or fall or early-spring topdressed when soil temperatures are cool (below 50°F) (2, 3, 7). However, urea should not be applied with the seed because of its potentially negative effect on germination and stand caused by its intermediate N-transformation products. Our data showed a 1.3% loss in stand for each pound of N applied with the seed. Grain yields also decreased about 1/3 bu/acre per lb of N applied with the seed.

Hydrolysis and mineralization of urea-N to available forms was influenced primarily by rate of N applied, time after application, soil water, and soil temperature. Ammonium (NH_4^+) was transformed to nitrate (NO_3^-) rather slowly, until the average soil temperature increased above 50°F.

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