ADVANCES IN SLOW-RELEASE NITROGEN FERTILIZERS

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ABSTRACT

Controlled- and slow-release nitrogen (N) fertilizers have been commonly used in high-value applications, such as horticultural production. Traditional controlled-release products have not been economical for use in major grain crops because of high cost and low crop prices. New economical, controlled-release fertilizers are available for use in field crops such as corn (*Zea mays* L.), wheat (*Triticum aestivum* L.), potato (*Solanum tuberosum* L.) and other commodity grains. Technology improvements have reduced manufacturing costs, while high N prices and interest in improved N-use efficiency have increased demand for new products. Polymer-coated fertilizers seem to offer the most promise. Nutrients are released from polymer-coated fertilizers by diffusion, which responds to soil temperature. Coupling N release with soil temperature, a primary factor in crop growth rate and N demand, allows N release to be programmed to better match crop needs. Research shows that controlled N release improves crop output per unit of applied N and reduces N losses.

INTRODUCTION

Nitrogen-recovery efficiency for cereal production worldwide has been estimated at only 33% (Raun and Johnson, 1999). Some of the N not used by the crop is presumed lost through denitrification, runoff, volatilization, and leaching. Low use efficiency of fertilizer N also reduces economic returns from fertilizer inputs. Nitrogen-use efficiency can be improved by reducing N losses (Englesjord et al., 1997). New fertilizer products – controlled-release N fertilizers or CRN – that release N at controlled rates to maintain maximum growth and minimize losses have been developed (Goertz, 1991; Hauck, 1985; Waddington, 1990).

Controlled or slow-release fertilizers can be classified in two basic groups: compounds of low solubility and coated water-soluble fertilizers. Products known as N stabilizers or bio-inhibitors reduce N losses by slowing N transformations but are not true slow-release products. Polymer-coated CRN fertilizers look promising for use in agriculture because they can be designed to release nutrients in a controlled manner. The polymers exhibit predictable release rates when temperature and moisture conditions can be estimated. A more detailed review was provided in Hauck, (1985). Some salient points from that review are described below.

Fertilizers delaying N release through reduced solubility include both inorganic salts and slowly soluble organic compounds. Magnesium ammonium phosphate, first proposed for use in 1858, is an example of a slowly soluble inorganic N salt. Most slowly soluble organic N fertilizers, constituting most of the commercial CRN fertilizers available in the U.S. are urea-aldehyde reaction products. They typically contain about 30-35% N and decompose in soil by chemical and/or biological processes. Solubility and N release are varied by altering the molecular weight and cross-linking of the urea polymers. Ureaform, first patented in 1924 in

Germany, was first commercially produced in 1955. Another common product, isobutylidene diurea (IBDU), regulates solubility and N release by particle size and surface area.

The most common coated slow/controlled-release fertilizers are sulfur- and polymer-coated products. Sulfur-coated urea was first produced in 1972. Sulfur-coated urea releases N by biological oxidation of the S coating, physical rupture or fracture of the coating, and diffusion thru the somewhat porous S coating. It is commonly used in turf formulations.

Polymer-coated fertilizers were manufactured as early as the 1960s in Japan. A variety of polymers are used to form semi-permeable coatings on soluble N sources, usually urea. Release is regulated by polymer chemistry, coating thickness, soil moisture, and soil temperature. Because of high cost, CRN use in agriculture is limited, accounting for less than 1% of worldwide fertilizer consumption (Englesjord et al., 1997). Recent advancements have decreased production costs to an economical level for commodity grain crops.

Limited studies of CRN on large acreage agricultural crops generally indicate there is significant value in using CRN under most conditions. Howard and Oosterhuis (1997) showed that N application rates on cotton may be reduced by 40% when CRN is used. Trials using CRN on winter wheat indicated a 20% yield increase compared with growers' standard practice; research on potatoes (*Solanum tuberosum* L.), onions (*Allium cepa* L.), and garlic (*Allium sativum* L.) also showed an increase in yield and quality with CRN (Tindall and Detrick, 1999). In potatoes, CRN produced less nitrate leaching, greater fertilizer-N recovery, and greater marketable yields than conventional split applications (Zyomuya, 2003). In western Canada, fall application of polymer-coated urea on barley resulted in decreased nitrate accumulation and fertilizer-N loss, while spring application of CRN increased crop N uptake (Nyborg et al., 1993).

Potential for CRN use in North America and Europe is high if cost can be reduced and benefits consistently demonstrated. Adoption will be most rapid where N loss is large, in-season N applications are common, and in crops with shallow root systems. In the U.S. Corn Belt, much of the required N is applied in advance of crop uptake. Winter and spring precipitation in this geography often exceeds evapotranspiration, and N-loss potential is high (Balkcom, 2003). CRN use can significantly improve N use-efficiency in these production systems.

This paper will review results from a large number of studies conducted in the U.S. Corn Belt from 2000-2004. The studies constitute comparisons of CRN with a variety of conventional N fertilizers and application practices on commodity grain crops. The results summarized represent both small-plot studies and field-scale grower trials over a wide range of environments. The objectives of the studies were to demonstrate improved N-use efficiency and crop productivity and CRN suitability for commodity grain crops.

METHODS

This paper uses corn studies to illustrate CRN's potential for commodity crops. Corn response to CRN was evaluated by comparison with similar applications of conventional N sources in many soil and weather conditions. Response, or yield difference, is yield with ESN minus yield with a conventional N treatment. Most CRN treatments were a single pre-plant application. Conventional applications included pre-plant, side-dress, and split applications. Data from replicated plot studies and grower strip trials are pooled together and subjected to two analyses. The first analysis evaluates all comparisons of CRN with conventional N at the same N rate. In studies with multiple N rates and products, each rate-product combination is considered as a single comparison. We classified the data by the magnitude of yield increase and determined the frequency in each yield-increase range.

Preliminary analysis of comparisons with individual conventional N fertilizers revealed that comparisons with ammonium nitrate represented a different population than comparisons with urea and UAN (non-homogenous variances), so yield differences are analyzed and presented for individual conventional products. There were insufficient comparisons with ammonium sulfate and anhydrous ammonia to analyze performance versus those sources individually. For comparisons of pre-plant ESN with split or side-dress applications of conventional fertilizers, yield comparisons among conventional N sources did not represent different populations. These comparisons were pooled together for further analysis.

The frequency distribution of yield differences from each conventional N source or application time was then analyzed using a one-way classification Chi-square test with three response classes to test if the response frequency distribution was significantly different from a normal distribution centered on zero. The null hypothesis is that ESN is not different from other N fertilizers and observed yield differences are distributed normally around zero. If ESN performs differently than other N sources and yield differences are due to ESN treatments, a Chi-square test would indicate the distribution is significantly different from normal.

The second analysis consists of comparing the relative yield response to conventional N sources with the response to CRN. Relative-yield responses were modeled as quadratic-response-and-plateau (QRP) responses using SAS PROC NLIN (SAS Institute, 1996). QRP models were parameterized for all data combined and for comparisons with urea and urea-ammonium nitrate solution (UAN) individually. There were insufficient comparisons with ammonium nitrate (NH_4NO_3), ammonium sulfate ($(NH_4)_2SO_4$), and anhydrous ammonia (NH_3) to accurately model response to those products individually.

RESULTS AND DISCUSSION

Controlled-release N produced greater yields in the majority of comparisons when applied pre-plant at the same N rate as pre-plant applications of conventional N sources (Fig. 1). The data represent both responsive and non-responsive sites. Yield increases in excess of 24 bu/acre generally coincide with conditions conducive to high N-loss potential, although actual N loss was not measured in these studies. Over all trials, pre-plant CRN increased corn yields by about seven to ten bu/acre over pre-plant urea or UAN at equal N rates (Table 1).

Some negative responses to CRN were observed, but there are few logical explanations for these observations. If the controlled-release properties of CRN offered no protection for N and did not increase N uptake or reduce N losses, then CRN would be expected to perform no worse than conventional N fertilizers. One possible explanation is that CRN did not release soon enough to meet plant needs. Our release data give no indication that this would occur and indicate N release from CRN applied before planting precedes plant demand. About 20% of responses less than five bu/acre and almost 40% of significant negative responses were observed in comparisons of surface-applied CRN with surface-applied NH_4NO_3. Ammonium nitrate is considered non-volatile in most conditions. It is possible that some N was lost by ammonia volatilization from the urea as it diffused through the coating. Conversely, it is interesting to note that some of the largest yield increases observed with CRN was in comparison with surface-applied urea and UAN where volatilizing conditions were present.

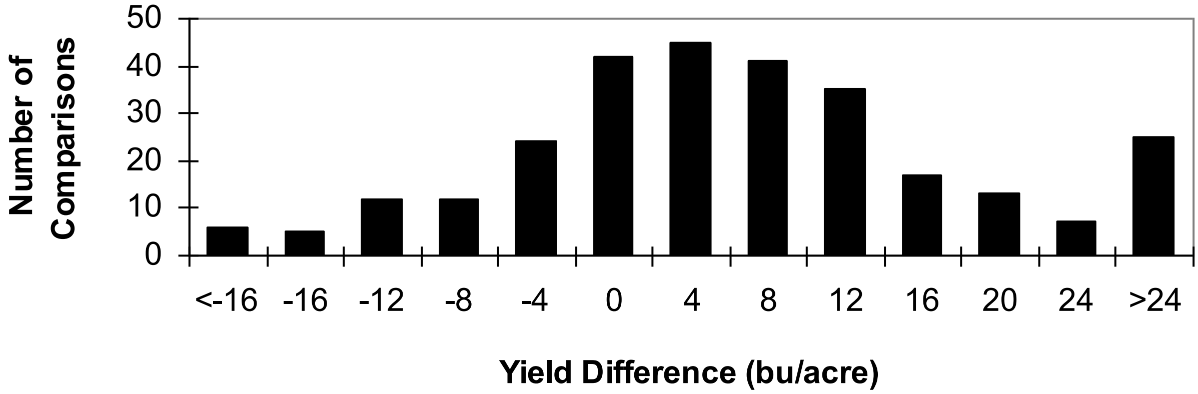

Figure 1. Frequency distribution of corn-yield response in comparisons of pre-plant CRN with pre-plant applications of conventional N fertilizers at equal N rates (U.S. Corn Belt, 2000-2004). Positive numbers denote greater yield with CRN than with conventional N sources.

Table 1. Summary statistics for comparisons of spring pre-plant CRN with pre-plant applications of conventional N sources at equal N rates.

	Yield Difference (ESN minus conventional, bu/acre)					
	<-5	-5 to 5	>5	>10	Total	Chi-sq. Pr > T
Urea						
Comparisons in group	15	45	64	43	124	<0.01
Group average yield difference (bu/acre)	-10.1	-0.5	16.6	21.1	7.2	
UAN						
Comparisons in group	4	16	42	26	62	<0.01
Group average yield difference (bu/acre)	-9.5	1.5	15.1	19.7	10.0	
Ammonium Nitrate						
Comparisons in group	17	27	14	7	58	ns
Group average yield difference (bu/acre)	-13.9	0.1	13.2	19.5	-0.9	

Some growers and dealers prefer fall N application, usually as anhydrous ammonia, to take advantage of seasonal N pricing and balance spring workloads, but it is discouraged because of potential N loss during wet periods of winter and spring. In limited studies, fall-applied CRN out-yielded fall applications of conventional N sources in some comparisons. Results of these comparisons indicate potential for fall CRN use, but data is insufficient to justify recommending fall CRN applications at. At this time, fall CRN applications should be considered experimental, although CRN may be superior to conventional N sources applied in the fall.

Side-dressing N is a best management practices for reducing N losses. Controlled-release N has potential to provide growers greater flexibility in timing and reduce costs by replacing side-dressing with a single pre-plant application. In studies comparing pre-plant CRN with side-dress and split N applications, pre-plant CRN produced yields similar to those of other N applications. In some comparisons under extremely high loss potential, CRN yielded less than conventional split or side-dress applications. Under these conditions, N applied later would have less exposure to loss, while N released from CRN would have some exposure, although less than conventional N sources applied at the same time. Under extreme loss potential, split applications of CRN significantly out-performed split applications of conventional N.

Table 2. Summary statistics for comparisons of ESN with split or side-dress applications of conventional N sources at equal N rates.

	Yield Difference (ESN minus conventional, bu/acre)					
	<-5	-5 to 5	>5	>10	Total	Chi-sq. Pr > T
Pre-plant ESN vs split or side-dress conventional N						
Comparisons in group	10	16	15	11	41	ns
Group average yield difference (bu/acre)	-1.15	0.07	1.07	1.29	0.14	
Split or side-dress ESN vs split or side-dress conventional N						
Comparisons in group	2	6	17	11	25	<0.01
Group average yield difference (bu/acre)	-1.03	0.04	0.89	1.12	0.53	

Nitrogen-use efficiency is of interest in reducing environmental risk. Greater recovery of N by the crop allows the grower to produce the same crop at a lower fertilizer-N rate. Less N is therefore exposed to loss, and the grower is less likely to apply more than is needed. In order to evaluate relative N-use efficiency of CRN and conventional N fertilizers, we compared relative yield responses of CRN with other fertilizers (Fig 2). CRN achieved about 5% greater plateau yields than conventional urea and UAN. Of greatest interest is the CRN rate that produces the same relative yield as other N sources. Urea and UAN produced a relative yield plateau of 93% at 174 lbs N/acre. Controlled-release N produced 98% relative yield at 120 lbs N/ac, a savings of 54 lbs N/acre. When taken as a percentage of average N rates of 120 to 200 lbs N/acre, this equals a savings of about 45 to 27%, respectively. These relative N savings are similar to improvements observed by Howard and Oosterhuis (1997) in cotton.

Performance of conventional N is more subject to variability in weather and soil conditions than CRN. Less variability was observed in corn-yield response to CRN (R^2=0.48, Fig 3b) than in response to conventional N (R^2=0.39, Fig 3a), especially at rates approaching or above the plateau yield. Differences in the variability of yield response (Table 1 and Fig. 1) seem to indicate that when CRN does not out-perform other N sources, it is more frequently attributable to greater-than-expected efficiency of conventional N than to poor performance of CRN. If N-loss potential is low, little difference among products would be expected.

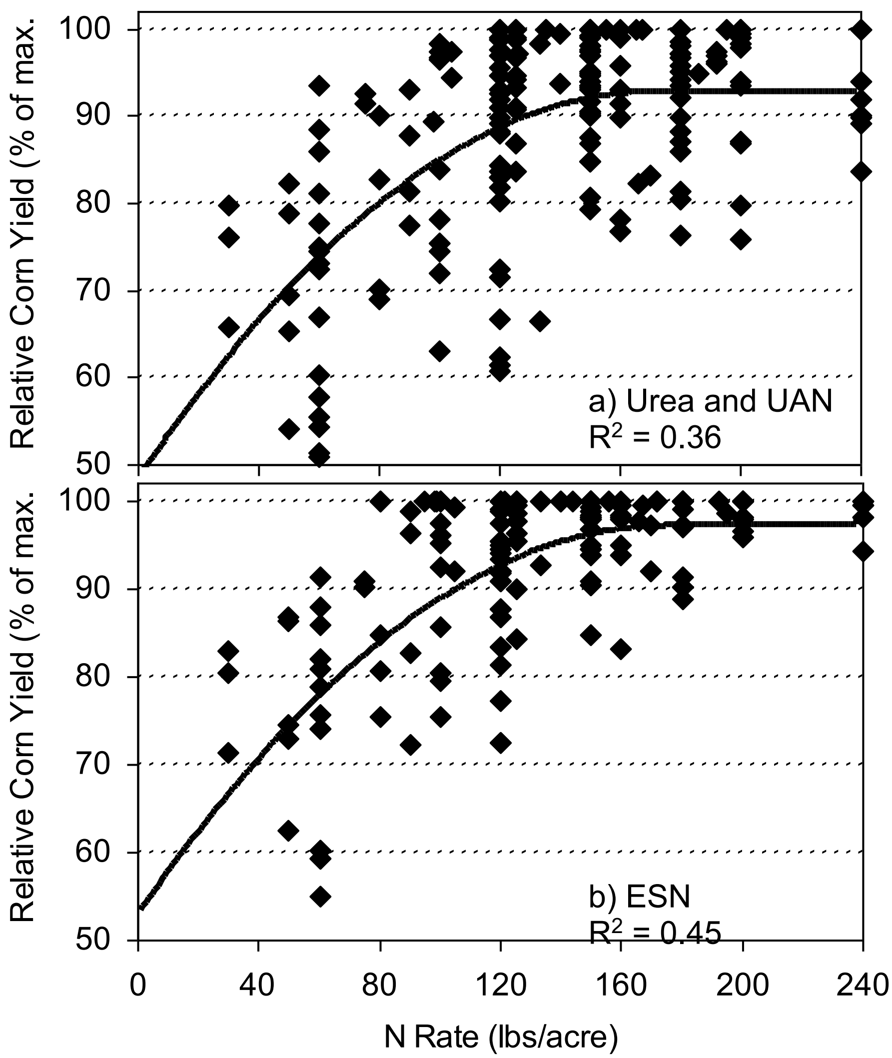

Figure 2. Relationship between relative yield (percent of the highest yielding treatment within an individual study) and rate of N applied. The plateau yield from the QRP model was 93% for conventional N (a) and 98% for CRN (b).

SUMMARY AND CONCLUSIONS

Controlled-release nitrogen fertilizers have the potential to significantly improve N-use efficiency while maintaining crop productivity. These studies demonstrate CRN to be a more efficient N source for grain crops without sacrificing yields. When applied at the same rate as conventional N sources, CRN increased corn yields sufficiently to offset additional cost of the product – in most cases increasing grower profit – while reducing risk of N loss. It was also demonstrated that CRN can be applied to corn at significantly lower rates, conservatively 25 to 35% less, than conventional N sources without sacrificing crop yield.

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