CORN YIELD RESPONSE TO THE UREASE INHIBITOR N-(n-BUTYL)THIOPHOSPHORIC TRIAMIDE (NBPT) WHEN APPLIED WITH UREA[1]

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ABSTRACT

Urease inhibitors are applied to reduce ammonia volatilization and immobilization losses from surface-applied urea or urea-ammonium nitrate solutions (UAN). The urease inhibitor N-(n-butyl)thiophosphoric triamide (NBPT) was evaluated at rates of 0.25 to 1.0 % (w/w) in 78 U.S. trials conducted with corn (Zea mays L.) during the period 1984 to 1989. When averaged over N rates for all locations and years, NBPT increased grain yields by 4.3 bu/acre when compared to similar rates of unamended urea. Average NBPT responses were higher on sites that were able to respond to N conserved by NBPT (5.0 bu/acre). Average NBPT responses were also greater on sites where non-volatile N treatments gave higher yields than unamended urea (6.6 bu/acre for urea). Results from 21 trials employing multiple N rates showed that maximum grain yields could be obtained using an average of 74 lb/acre less N when NBPT was included with surface-applied urea. These results demonstrate that NBPT provides an effective alternative to the excessive rates of surface-applied urea that are currently used to ensure that N will not limit grain yields.

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INTRODUCTION

The concept of urease inhibition is described in Figure 1. When urea or UAN are applied to the soil surface, the urea is converted within a few days to ammonium carbonate due to the action of urease enzymes that are present both in the soil and in plant residues. This conversion gives rise to both high ammonium levels and elevated soil pH, conditions that are conducive to volatilization of ammonia. Since many agricultural systems favor the accumulation of plant residues at the soil surface, the ammonium may also be made unavailable via immobilization, as soil microorganisms use the N to decompose the low N plant residues. Urease inhibitors temporarily reduce the activity of these enzymes, maintaining most of the applied N as urea for several days. Since urea is quite mobile in the soil, rainfall received within this period will move the urea into the soil, beyond the zone of residue accumulation, where it can hydrolyze normally with less opportunity for N losses via ammonia volatilization or immobilization.

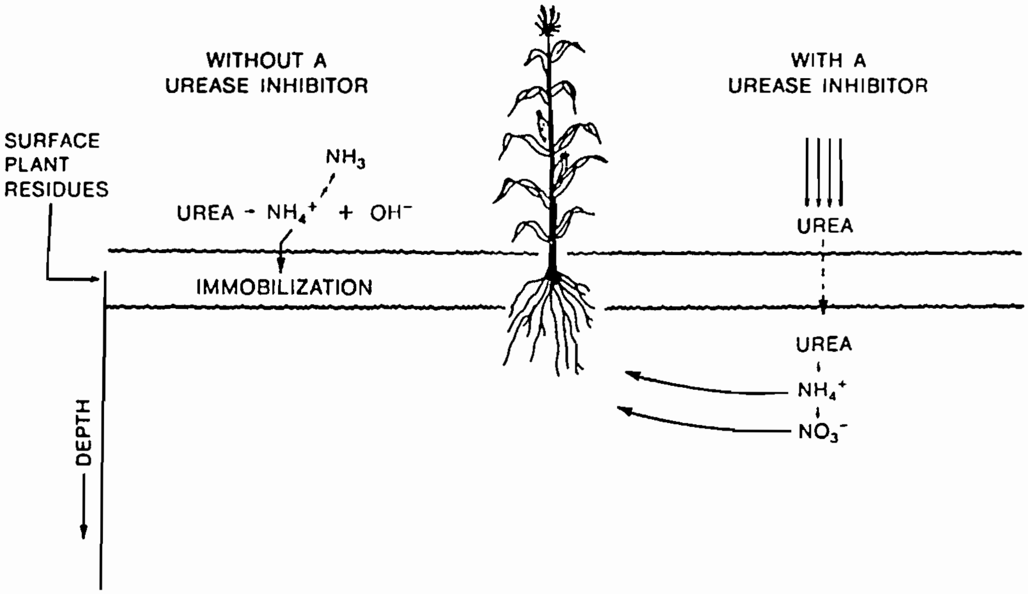

Figure 1. Application of urease inhibitors with surface applied urea fertilizers

Although many compounds have been evaluated as urease inhibitors within the past 10 years, the most active compound identified to date is N-(n-butyl)thiophosphoric triamide, generally referred to as NBPT. NBPT provides excellent control of urea hydrolysis when applied at very low concentrations (Bremner and Chai, 1986; Beyrouty, et al.,1988). In addition to these laboratory studies, NBPT has been extensively evaluated in field trials conducted over the past 6 years. Unfortunately only a small fraction of the available yield data have been published to date (Schlegel et al., 1986; Hoeft, 1986; Varsa et al., 1989; Goodroad and Wilson, 1989). The purpose of this paper is to summarize corn yield responses to NBPT over the period 1984 to 1989 in a manner that will not compromise future publication of results from individual trials.

MATERIALS AND METHODS

NBPT was evaluated in the U.S. in 78 trials with corn over the period 1984 to 1989 (Table 1). All of the experiments were conducted by university scientists using replicated treatments. NBPT was introduced into the urea using a variety of impregnation and incorporation techniques. Concentrations of NBPT in the urea varied from year to year as shown in Table 2 and the per-acre application rates of NBPT varied with N application rate. For example, application of urea containing 0.5% (w/w) NBPT at rates of 50 and 100 lb N/acre would provide approximately 0.55 and 1.1 lb/acre NBPT, respectively. A detailed comparison of the various NBPT rates is beyond the scope of this discussion, but the yield results indicated that all rates of NBPT were generally quite effective.

Additional N treatments such as anhydrous ammonia, ammonium nitrate, ammonium sulfate, or subsurface applications of urea or UAN were generally employed as positive non-volatile N (NVN) controls to indicate the likelihood of significant N losses from surface-applied urea. A wide range of N rates was employed (40 to 280 lb N/acre), with some trials using multiple N rates and others employing only a single N rate. Since only a single rate of NBPT was applied in 1989, most collaborators employed multiple N rates, enabling an improved estimate of N conservation by NBPT. In addition, most of the trials also included a zero-N treatment to evaluate responsiveness to applied N.

It should be recognized that this summary includes data from trials where significant responses to NBPT and/or N were not observed. Since treatments were not uniform from trial to trial, a comprehensive statistical analysis of the complete data set is not possible. Most of the following results are presented using yield differentials between two treatments, rather than as specific mean yields for each treatment. This allows many statistically valid comparisons to be made using only those portions of the data where pair-wise comparisons are possible.

Table 1. Locations of U.S. field trials evaluating NBPT.

State	Collaborator	Years
Illinois	R.G. Hoeft	5
Illinois	E.C. Varsa	4
Indiana	D.B. Mengel	5
Nebraska	D.H. Sander	5
Wisconsin	L.G. Bundy	5
Colorado	D.G. Westfall	4
Alabama	J.T. Touchton	3
Georgia	L.L. Goodroad	3
Kansas	A.J. Schlegel	2
Iowa	A.M. Blackmer/R. Killorn	2
Ohio	J.W. Johnson/D.J. Eckert	2
Minnesota	G.W. Randall/G.L. Malzer	2
North Carolina	J.V. Baird/E.J. Kamprath	2
Kentucky	W.W. Frye/L.W. Murdock	2
Pennsylvania	R.H. Fox	1
Michigan	M.L. Vitosh	1
New Jersey	J. Walworth	1
Maryland	J.A. Bandel	1

RESULTS & DISCUSSION

NBPT was evaluated in 78 field trials conducted in 17 states over the past 6 years. This resulted in a total of 295 distinct comparisons (years x sites x application times x N rates) over a wide range of climates, soils, tillage practices, preceding crops, etc. When averaged over all years of the study, NBPT increased grain yields by 4.3 bu/acre when applied with urea (Table 2).

Table 2. Corn grain yield increases due to NBPT application.

Year	NBPT Rate Low	NBPT Rate High	NBPT Response	Uninhibited Urea Yield
	%(w/w)		bu/A	bu/A
1984	0.25	1.0	2.3 (50)	107
1985	0.25	1.0	3.0 (29)	115
1987	0.25	0.5	5.9 (52)	116
1988	0.25	0.5	3.2 (79)	86
1989	0.5		5.9 (85)	130
Average			4.3 (295)	113

( ) indicates number of comparisons.

The responses to NBPT varied from year to year, likely reflecting prevailing environmental conditions. The most positive responses to NBPT were obtained in 1987 and 1989, years with generally favorable growing conditions, as indicated by higher average grain yields (Table 2). Conversely, less favorable responses to NBPT were obtained during years with more adverse growing conditions, such as 1988, when there was a severe drought. Some of this annual variability in NBPT response might be due to differences in the rates of NBPT or to the method of NBPT introduction, but such effects cannot be separated from the overall yield responses.

The frequency distribution of NBPT responses is shown in Fig. 2. Increases in excess of 10 bu/acre were obtained for 25 % of the comparisons and over 40 % of the responses were in excess of 5 bu/acre. Negative responses to NBPT were observed in approximately one-third of the trials and are discussed later.

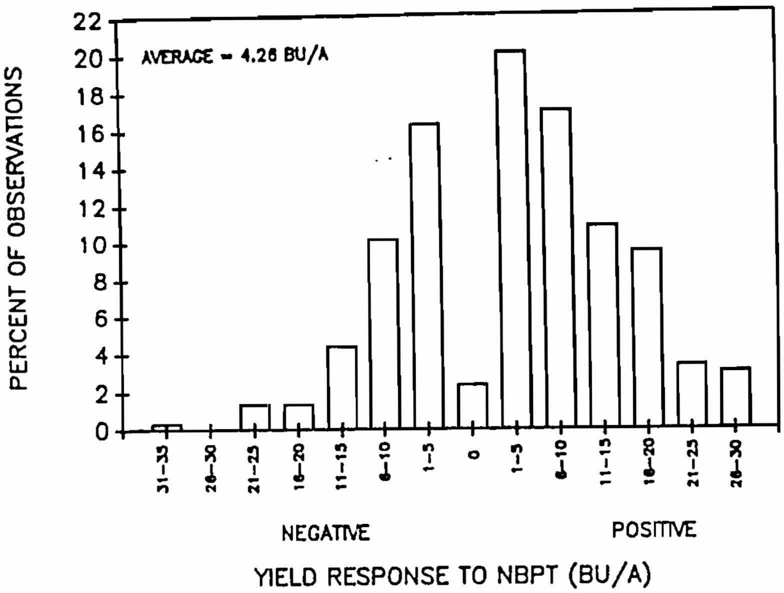

Figure 2. Frequency distribution of yield responses to NBPT applied with urea on all sites.

Some sites did not respond to applied N, due either to high inherent N fertility or to other limitations on yield such as drought, thus precluding positive responses to NBPT. An additional comparison was made using only those experiments that were able to respond to N conserved by NBPT. As such, data from 10 of the 78 experiments were excluded because of extremely low yields (less than 80 bu/acre at the highest N rates), and data from four additional experiments were excluded since equivalent yields were obtained with and without applied N. Ten of the 14 experiments were conducted in 1988 and likely reflected the extreme drought conditions prevalent throughout much of the U.S. Following elimination of these 14 experiments, (51 out of 298 comparisons),the average response to NBPT increased to 5.0 bu/acre. This average likely provides a better estimate of NBPT effectiveness. Many of the other comparisons may have also been made at sites or N rates where N did not limit yields, but these could not be reliably identified.

Most of the trials included a non-volatile N (NVN) control to enable quantification of the N loss potential. The NVN treatments averaged 6.45 bu/acre higher than the corresponding rate of surface-applied urea, with yield differences exceeding 20 bu/acre in 15 % of the comparisons and 10 bu/acre in one-third of the trials (Fig. 3). Surface-applied urea gave higher yields than the NVN treatments in nearly one-third of the comparisons. This was not expected as most previous research comparing N sources has shown with few exceptions, that yields are generally higher for NVN treatments than for surface-applied urea (Bandel et al., 1980; Mengel et al., 1982; Touchton and Hargrove, 1982; Eckert et al., 1986; Fox et al., 1986).

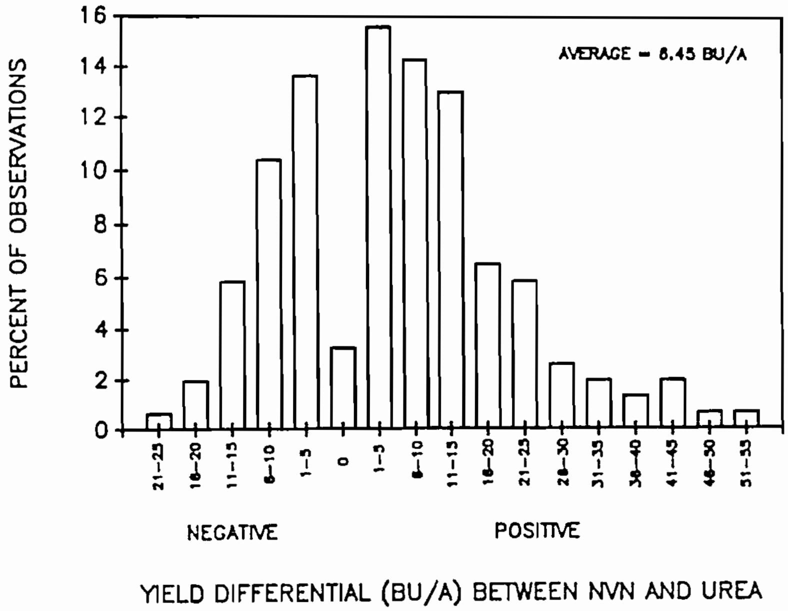

Figure 3. Frequency distribution of the yield differential between non-volatile N treatments (NVN) and surface-applied urea.

A consistent pattern emerges when NBPT response is plotted against the yield differential between the NVN treatments and surface-applied urea (Fig. 4). In those cases where surface-applied urea was inferior to NVN treatments (right side of Fig. 4), application of NBPT generally increased grain yields. Conversely, when surface-applied urea was superior to NVN treatments, NBPT decreased yields as often as it increased yields. Although a few significantly negative NBPT responses (greater than 5 bu/acre) were observed on the right side of

Fig. 4, most appeared anomalous, as evidenced by positive responses to NBPT obtained for other N or NBPT rates at the same site. This pattern suggests that the NBPT was generally quite effective in inhibiting urea hydrolysis, but in some of the trial environments (left side of Fig. 4), such inhibition was not desirable.

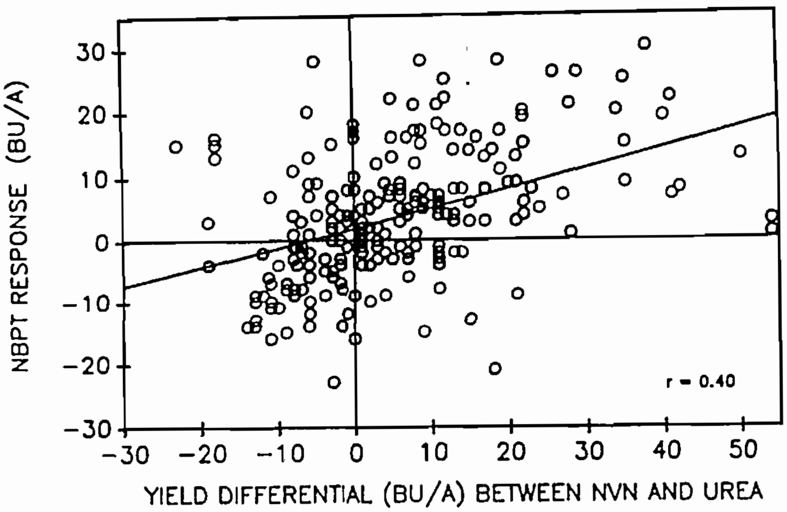

Figure 4. Relationship between the yield response to NBPT applied with urea and the yield differential between non-volatile N treatments (NVN) and surface-applied urea.

As noted above, most published information comparing N sources has consistently shown that non-volatile N treatments out-yield broadcast urea. Although exceptions to this pattern are probably more prevalent than are noted in the published literature, the conditions present in these NBPT studies would appear to be less than representative of the real world. If all comparisons where surface-applied urea was more efficient than the NVN treatments are eliminated from the analysis, the average NBPT response for urea becomes 6.6 bu/acre. As shown in the resultant frequency distribution (Fig. 5), 30 % of the comparisons demonstrated NBPT responses in excess of 10 bu/acre and more than half of the comparisons gave NBPT responses of over 5 bu/acre. Only 8 % of the comparisons from this reduced data set gave negative NBPT responses exceeding 5 bu/acre. Although additional studies will be necessary to better define NBPT responses in the real world, the distribution shown in Fig. 5 may provide a more accurate indication of the value of NBPT than the data set as a whole.

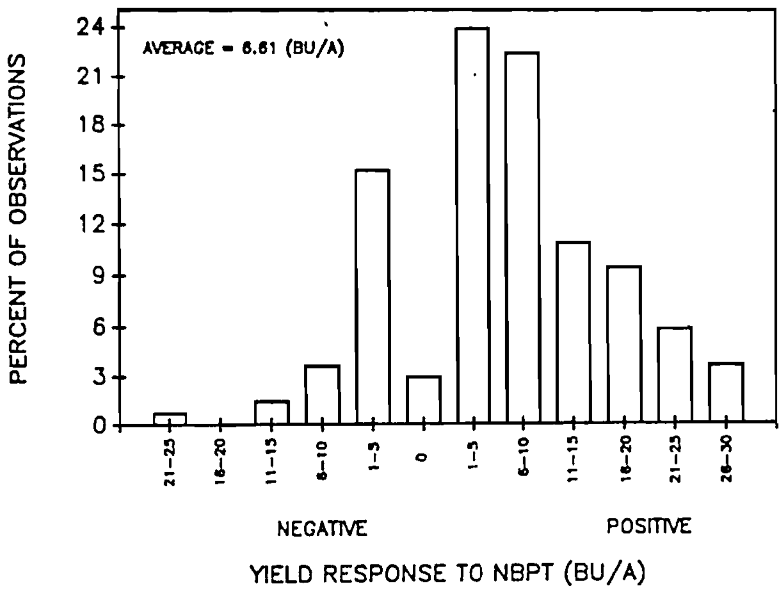

Figure 5. Frequency distribution of yield responses to NBPT applied with urea for comparisons where non-volatile N treatments had greater yields than surface-applied urea.

NITROGEN CONSERVATION

The preceding discussion described the yield differential due to NBPT application at equivalent rates of applied N. At this time of increasing concern over groundwater pollution by nitrates, it may be more important to evaluate the ability of NBPT to enable maintenance of current grain yields using reduced inputs of N fertilizers.

As previously noted, most of the experiments conducted in 1989 employed at least three non-zero N rates and results from these 21 experiments (18 sites plus an additional application time at 3 sites) are summarized in Fig. 6. Average yields were determined for the maximum N rate used in each experiment (mean of 166 lb N/acre) and for an intermediate N rate (lowest rate between 80 and 110 lb/acre; mean of 92 lb N/acre). In the absence of NBPT, the application of an additional 74 lb N/acre increased yields from 130 to 142 bu/acre. NBPT enabled attainment of that same yield without application of additional N. When NBPT was applied along with the additional N, yields were increased by an additional 6 bu/acre.

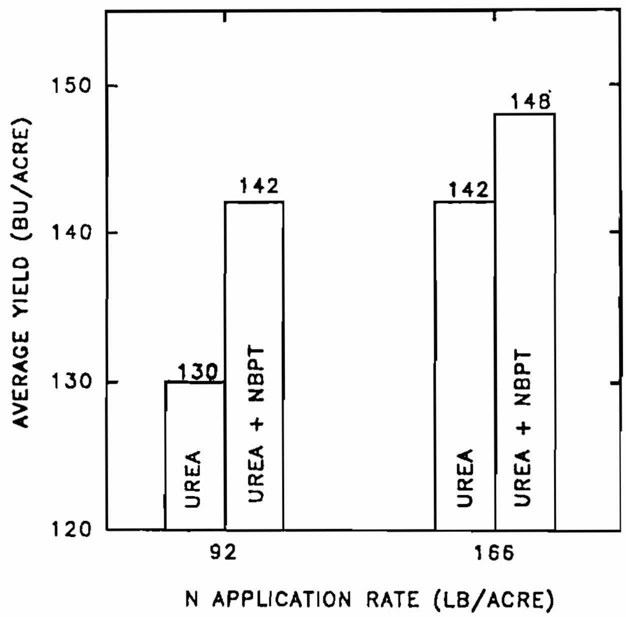

Figure 6. Average grain yields for intermediate (mean = 92 lb/acre) and maximum (mean = 166 lb/acre) N application rates ($LSD_{.05}$ = 5.8 bu/acre)

This demonstrates that an average of 74 lb/acre of additional unamended urea-N would be required to overcome the apparently large losses of N that are prevented by NBPT. Undoubtedly, such losses do not occur at all locations every year, but as noted by Fowler and Brydon (1989), the presence of conditions giving rise to large N losses are as unpredictable as the weather. If conditions leading to large yield losses do not prevail, NBPT will be an unnecessary input. On the other hand, if such conditions do exist, a considerable quantity of additional unamended urea will be required to prevent significant yield decreases. Application of an additional 74 lb N/acre during years of high N losses would bridge the differential to some extent, but would probably not attain the same yields as if the N losses did not occur. In years when N losses are not severe, application of an additional 74 lb

N/acre will be unnecessary, thereby wasting money on fertilizer. More importantly, this additional N will not be utilized by the crop and will instead be lost from the root zone where it will eventually make its way to groundwater.

Importantly, the additional N required would actually be greater than the 74 lb/acre average difference, since this average includes all of the sites where N losses were low or negligible. This is illustrated by the fact that on six of the 21 sites the yield differential between the high and intermediate N levels was 5 bu/acre or less. Therefore, estimates of N losses and additional N requirements on the basis of average yield data may be erroneous. As stated by Fowler and Brydon (1989), potential losses with broadcast urea cannot be corrected for by simply increasing application rates to compensate for average losses. Similarly, the value of urease inhibitors, when based upon the average yield differential between N sources or on average NBPT responses, may be greatly underestimated for conditions where N losses are most severe.

SUMMARY

In general, a urease inhibitor will be of limited value in situations where urea can be easily and inexpensively incorporated into the soil during or immediately after application. When rapid incorporation is impossible due to the presence of a crop or undesirable due to the presence of residue or time constraints, it offers one of the few technologies that can ensure full value for surface-applied urea. Even in those situations where the applied N can be incorporated, a urease inhibitor may still offer a very useful tool to increase the flexibility for timing and placement of N. As we become more aware of the impact of N fertilizers on the environment, it becomes apparent that we can no longer afford to use excessive N rates as insurance against the high N losses that are often encountered. Urease inhibitors would appear to offer an environmentally safe alternative to excessive N fertilization.

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