# Performance-Based Evaluations of Guidelines for Nitrogen Fertilizer Application after Animal Manure

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## ABSTRACT

**Nitrogen fertilizer needs for corn (*Zea mays* L.) in fields already treated with animal manure can be estimated by using general guidelines or soil testing for inorganic N. Although the soil-testing approach has been extensively evaluated for ability to predict yield responses to applied N under field conditions, the general-guideline approach has not been subjected to comparable performance-based evaluations. Fertilizer response trials were conducted in 205 manured fields to (i) compare the two approaches for ability to predict corn yield responses to fertilizer N applied after animal manure, (ii) identify reasons for differences in predictive ability, and (iii) explore the benefits of performance-based comparisons of the alternative approaches. Analyses showed that 34% of the observed variability in response could be explained by inorganic N concentrations whereas less than 5% of this variability could be explained by the general-guideline approach. The soil-testing approach, therefore, had greater ability to integrate the effects of all factors affecting yield responses across the range of conditions studied. Mean yield responses (0.55 Mg ha$^{-1}$) were smaller than are usually detectable in individual trials, but they were great enough to prompt farmers to fertilize. Results of this study indicate that the most commonly accepted approach to estimating N fertilizer needs is less reliable than generally believed and, therefore, that superior approaches are likely to remain unrecognized unless the performance of the commonly accepted approach is objectively evaluated under realistic field conditions.**

Land application of animal manure provides N needed for corn production, but there is great uncertainty in the amount of N a given application of animal manure will supply for plant growth (Bouldin et al., 1984; Bouldin and Klausner, 1998; Sharpley et al., 1998; Klausner et al., 1994; Blackmer, 2000). Schepers and Fox (1989) attributed this uncertainty to (i) inaccurate and vague estimates by farmers concerning amounts of manure applied, (ii) extreme variation in N concentrations in manure, (iii) variable amounts of N lost by $NH_3$ volatilization following unincorporated surface applications, (iv) uncertainty concerning the proportion of the manure N that will become available for plant uptake, and (v) the possibility that manure additions will increase N losses due to denitrification.

This uncertainty causes problems when selecting rates at which commercially prepared fertilizer N should be applied after the manure. These problems usually are addressed by encouraging farmers to follow general guidelines that estimate amounts of N needed by the crop and amounts of N supplied by the manure and the soil (Midwest Planning Service Livestock Waste Subcommittee, 1985; Miller, 1986; Killorn, 1995; Schmitt et al., 1997; Killorn and Lorimor, 1999; USDA Nat. Resour. Conserv. Serv., 1999, 2001; Iowa Dep. of Nat. Resour., 2000; Jackson et al., 2000). Estimates of N need by the crop are based on expected N removal by the crop, which is based on expected yield level or published yield potentials of soil map units. Amounts of N supplied by the manure are estimated by analyzing the manure for N content and adjusting for expected losses of N by $NH_3$ volatilization soon after application and for percentages of organic N expected to be mineralized.

Soil testing for inorganic N when plants are 15 to 30 cm tall (i.e., in late spring) offers an alternative approach for selecting rates of N fertilization (Magdoff et al., 1984; Blackmer et al., 1989; Fox et al., 1989; Magdoff, 1990; Binford et al., 1992; Bundy and Meisinger, 1994). Such testing gives site-specific estimates of the sufficiency of N for plant growth where sufficiency indicates supply relative to needs of the plants on a scale ranging from below to above optimal (Blackmer, 2000). Balkcom et al. (2003) recently showed that testing soils for inorganic N after fertilization offers an effective way to evaluate N management practices and guidelines given to farmers.

Performance of the soil-testing approach to estimating fertilizer need is usually evaluated by considering ability to predict yield responses (often expressed as relative yields) to fertilizer N under field conditions. Such evaluations are reasonable because fertilizers are applied to increase yields. The problem addressed in this paper is that we can find no published studies that provide comparable evaluations of the performance of the general-guideline approach (i.e., estimating N fertilizer needs by following general guidelines that do not include soil testing for $NO_3$). There is need for such evaluations because reports indicate that most farmers make little or no downward adjustment in rates of N fertilization for N already applied as animal manure (Duffy and White, 1998; Nowak et al., 1998; Balkcom et al., 2003). Balkcom et al. (2003) found that farmers may have valid reasons for not making these adjustments. The reliability of methods for estimating N fertilizer needs is more important than ever before because land application of animal manure and fertilizer N has been identified as a major source of $NO_3$ in rivers, and therefore, many farmers are now being required to develop nutrient management plans (Jackson et al., 2000; Kalkhoff et al., 2000; USEPA, 2001).

Our objectives in this paper are (i) to compare the soil-testing and the general-guideline approaches for ability to predict corn yield responses to fertilizer N applied af-

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ter animal manure across a range of conditions generally representative of those found in Iowa, (ii) to identify reasons for differences in ability to predict yield responses, and (iii) to explore the possible benefits of performance-based comparisons of alternative approaches to estimating N fertilizer needs. Efforts to establish relationships between soil-test values and optimal rates of N application require substantially different analyses and will be presented elsewhere.

## MATERIALS AND METHODS

Corn yield responses to commercially prepared fertilizer N were measured in 205 trials in cornfields that had been treated with animal manure by farmers using their normal practices. The trials were distributed across 28 counties in Iowa, with approximately equal numbers each year from 1992 through 1997. Sites were selected to include variety with respect to soil type, manure type, and rate, method, and time of application. Soil and crop management practices (except N fertilization) were those normally used by each farmer.

The manure came from beef cows (*Bos taurus*) at 22 sites, dairy cows at 9 sites, swine (*Sus scrofa*) at 149 sites, and poultry at 9 sites. Sixteen sites received two or more forms of animal manure. Approximately equal numbers of sites were manured in the fall, winter, and spring before planting. Farmers provided information concerning amounts, type, and time of manure application. Manure analyses were available for about one-third of the sites. At the remainder of the sites, N content of the manure was estimated by using information given by Killorn (1995).

Each trial consisted of 16 plots arranged in a randomized complete block design with four replications. Plots were 12.2 m long and six rows (separated by 76 cm) or four rows (separated by 91–97 cm) wide. The experimental sites were selected on different areas of seemingly uniform soil each year. Experimental areas were prominently marked early enough to avoid unwanted application of N by farmers. Yield potential for the soil map unit for each trial was obtained from the appropriate county soil survey manual and from an updated soils database (Fenton and Miller, 1996).

Soil samples were collected from each block within each site when corn plants were 15 to 30 cm tall (usually within 1 wk of 1 June). Each sample was derived from a composite of 32 soil cores. The soils were air-dried, ground, and extracted with 2 *M* KCl. The extracts were analyzed for $NO_3$ and exchangeable $NH_4$ by the Lachat flow-injection procedure (Method 12-107-4-1-B, Lachat Instruments, Milwaukee, WI). Composite samples from each site were used for determination of (Bray and Kurtz P-1) P, ammonium acetate–exchangeable K, soil organic matter concentration, and pH (in water) as described by Brown (1998). Rainfall amounts (county averages) were obtained from the National Climatic Data Center (http://www.ncdc.noaa.gov; verified 23 Oct. 2003).

Within 7 d after soil samples were collected, four rates of N (0, 33, 67, and 100 kg N $ha^{-1}$) were broadcast (by hand) on the soil surface. In 1992, 1993, and 1994, N was applied as ammonium nitrate ($NH_4NO_3$). In 1995, 1996, and 1997, N was applied as urea [$(NH_2)_2CO$]. Grain was hand-harvested from 7.6-m sections of the center two rows of each plot. Yields were adjusted to 15.5% moisture content. Yield responses to N fertilization were calculated by subtracting the yields of the nonfertilized plots from the yield of the fertilized plots within each site. Although analyses were conducted for all rates of N applied, data usually are presented only for the highest rate of N application because presenting data for all rates would substantially increase the numbers of figures required and add essentially no additional relevant information.

Mean yield responses to fertilizer N were related to site conditions by using a linear function or a curvilinear function described by Nelson and Anderson (1977). All statistical analyses were conducted using the regression (REG), means (MEANS), or nonlinear regression (NLIN) procedures of the SAS package (SAS Inst., 1996). Relationships were considered statistically significant at $P = 0.05$. Protected least significant difference (LSD) values for yield responses for pooled data were calculated as described by Snedecor and Cochran (1980).

## RESULTS AND DISCUSSION

### Comparison of Abilities to Explain Yield Responses

Concentrations of $NO_3$ found in the surface 30-cm layer of soil explained 26% of the variability in yield response observed across all sites (Fig. 1A). Concentra-

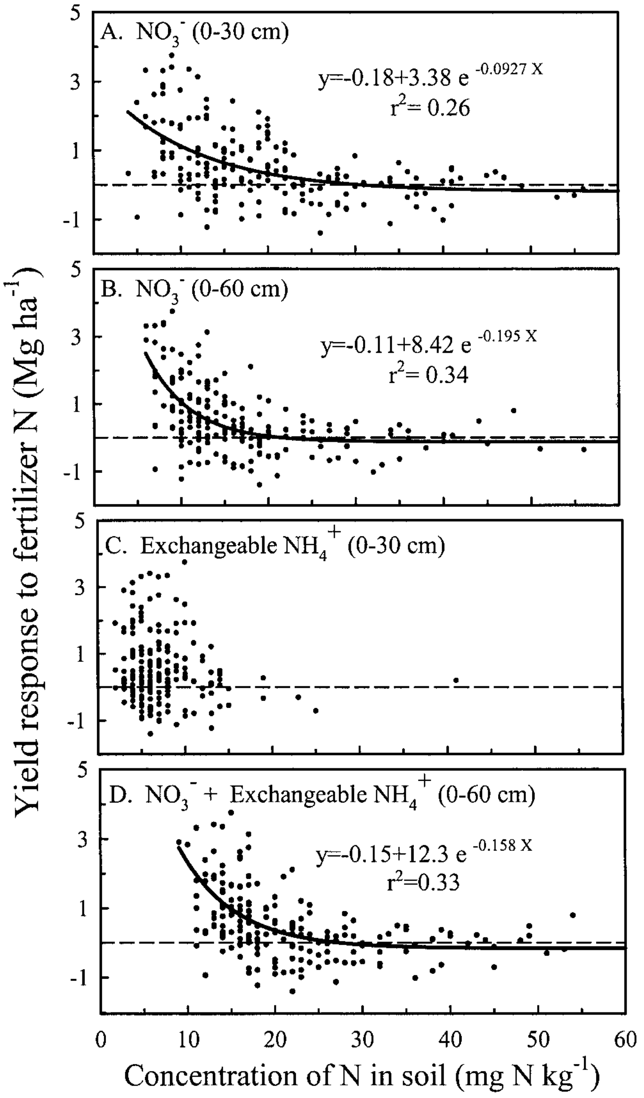

**Fig. 1. Relationships between corn yield responses to fertilizer N applied at 100 kg $ha^{-1}$ and concentrations of soil (A) $NO_3$–N to a depth of 30 cm, (B) $NO_3$–N to a depth of 60 cm, (C) exchangeable $NH_4$–N to a depth of 30 cm, and (D) exchangeable $NH_4$–N and $NO_3$–N to a depth of 60 cm.**

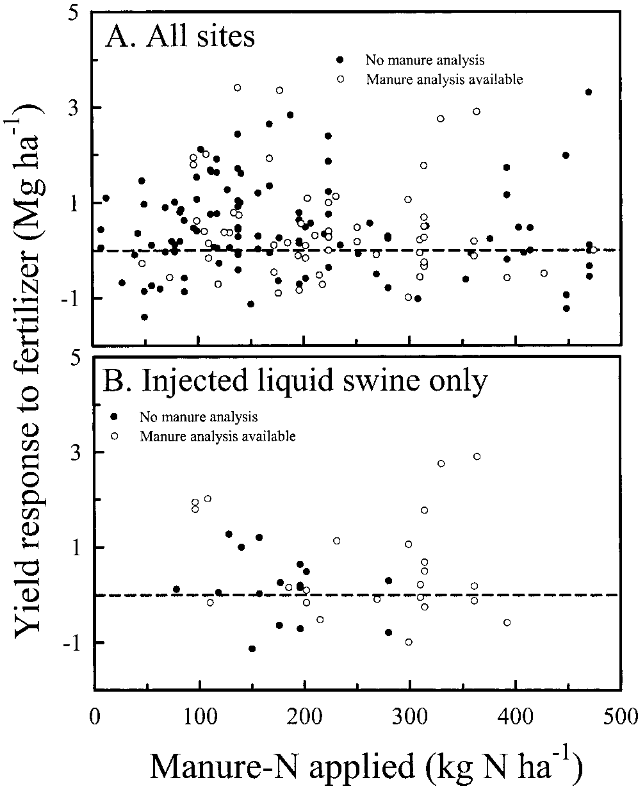

**Fig. 2. Relationships between rates of manure-N application and corn yield responses to fertilizer N applied at 100 kg ha$^{-1}$ across (A) all sites and (B) sites treated with liquid swine manure that was injected into the soil.**

tions of $NO_3$ found in the surface 60-cm layer of soil explained 34% of this variability (Fig. 1B). Concentrations of $NO_3$ in the 30- to 60-cm layer of soil (not shown) explained 22% of the variability in yield response. Concentrations of exchangeable $NH_4$ in the surface layers were not significantly related to observed yield responses (Fig. 1C). Exchangeable $NH_4$–N plus $NO_3$–N in each layer explained no more of the variability than was explained by $NO_3$–N alone (Fig. 1D). The finding that $NH_4$ concentrations were relatively unimportant is consistent with results of earlier studies (Binford et al., 1992; Sims et al., 1995).

No significant relationship was found between rates of manure-N application and yield responses to fertilizer N (Fig. 2A). Significant relationships were not found even when only the most common types of manure (liquid swine) and placement (injection) were considered (Fig. 2B). Analyses (not presented) showed that significant relationships were not attained by considering only sites where the manure was analyzed or by adjusting rates of application for expected losses by using published guidelines (Killorn, 1995). Significant relationships similar to those in Fig. 2 could not be attained by considering yield responses observed when fertilizer N was applied at rates of 33 or 67 kg ha$^{-1}$ or those observed for the highest-yielding treatment mean.

Comparisons of the relationships in Fig. 1 and 2 are meaningful because the soil-testing and general-guideline approaches are used as alternative methods to estimate N fertilizer needs in fields already treated with animal manure. Ability to explain variability in yield responses (i.e., $r^2$ values) offers a rational estimate of ability to estimate fertilizer needs because fertilizers are applied to increase yields of grain and because fertilizer needs tend to increase as magnitude of yield response increase. Ability to *explain* observed variability in yield responses across a wide range of field conditions provides a reasonable estimate of ability to *predict* fertilizer responses across the same range of conditions.

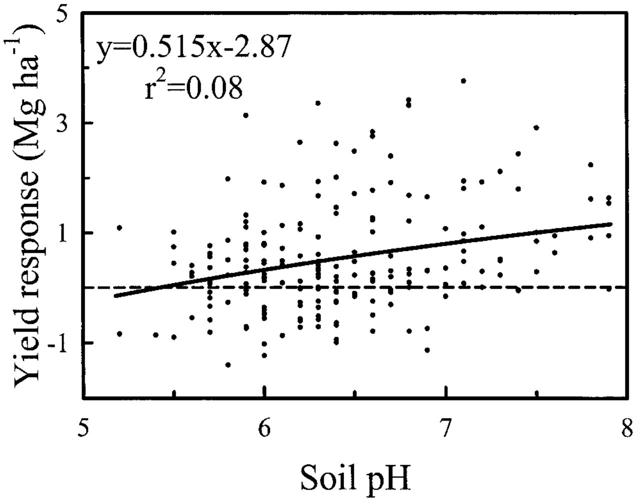

**Fig. 3. Relationship between soil pH and corn yield responses to fertilizer N applied at 100 kg ha$^{-1}$.**

Figure 1 evaluates a basic assumption of the soil-testing approach, namely that yield responses to fertilizer should tend to decrease as concentrations of soil inorganic N increase. Figure 2 evaluates a basic assumption of the general-guidelines approach, namely that yield responses to fertilizer should tend to decrease as rates of manure-N application increase. The finding that the relationship in Fig. 1 is better than that in Fig. 2 indicates that the soil-testing approach performed better than the general-guideline approach. The general-guideline approach to estimating N fertilizer needs did not meet the standards of performance normally expected of the soil-testing approach.

The finding that rates of manure-N application did not show useful relationships with yield responses to fertilizer N was not expected because sites were selected to include an unusually wide range in rates of manure-N application. This unexpected finding cannot be attributed to errors in farmer-derived estimates of manure application rates or amounts of manure-N applied because similar soil $NO_3$ concentrations and yield responses were observed at the highest and lowest rates of manure application. It is unlikely that farmers lacked ability to distinguish between the highest and the lowest rates of manure-N application.

## Other Predictors of Yield Response

Several additional factors were found to show significant relationships with yield responses, and these factors deserve attention when trying to explain differences in performance of the alternative approaches to estimating

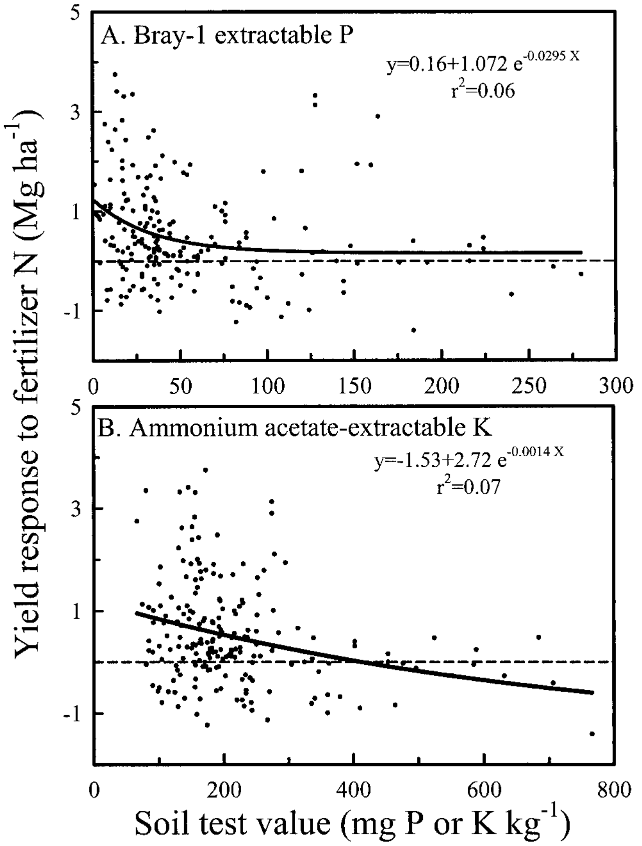

**Fig. 4. Relationships between corn yield response to fertilizer N applied at 100 kg ha$^{-1}$ and soil test (A) P and (B) K in the surface 30-cm layer.**

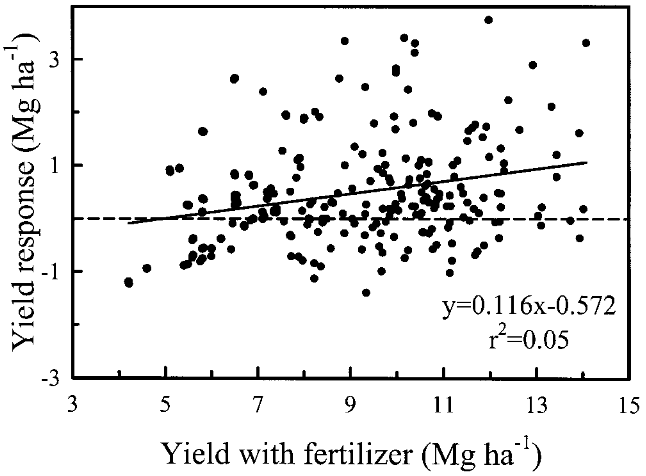

**Fig. 5. Relationship between corn yield responses to fertilizer N applied at 100 kg ha$^{-1}$ and corn yield levels with the applied fertilizer.**

fertilizer needs. These factors are listed in order of decreasing ability to explain yield responses.

Soil pH values were significantly related to yield response, and this relationship explained 8% of the variability in response (Fig. 3). The greatest responses tended to occur at the higher pH values. A possible explanation for this effect is greater volatilization of $NH_3$ soon after manure application to soils having relatively high pH values (Nelson, 1982; Fenn and Hossner, 1985). Another possible explanation is provided by the recent observation (Kyveryga and Blackmer, 2001) that higher soil pH values within the range of 6 to 8 promote more rapid nitrification and, therefore, increase losses of N by leaching or denitrification of $NO_3$.

Soil-test values for P and K were significantly related to yield responses to applied N, and these relationships explained 6 and 7% of the variability in yield response (Fig. 4). The greatest responses tended to occur at the lowest soil-test values. One possible explanation for these relationships is that the higher P and K soil-test values resulted from previous applications of animal manure and that these applications also increased rates of N mineralization in the soils. Linear relationships indicated that soil-test P explained 4% of the variability in soil $NO_3$ concentrations and that soil-test K explained 7% of this variability. Soil-test values for P and K were linearly related ($r^2$ = 0.56). Soil-test values for P and K were not significantly correlated with manure N applied for the years studied. Inadequate data were collected to assess the effects of earlier applications of manure N.

Yields observed on fertilized plots were significantly related to yield responses to fertilizer N (Fig. 5), but this relationship explained only 5% of the variability in yield response. Yield potentials in soil survey manuals were not significantly related to yield responses to added N (Fig. 6). The yield potentials showed statistically significant linear relationships with yields observed on the fertilized plots, but this relationship explained only 2% of the variability in yields. Essentially identical results were obtained when yield potentials were taken from an updated soils database (Fenton and Miller, 1996).

Analyses (not shown) revealed no significant relationship between yield responses to fertilizer N and rainfall during May or March through May. Rainfall during these periods, however, explained 11% (slope = −0.14) and 17% (slope = −0.12) of the variability in yields on fertilized plots. Rainfall during the growing season (April through September) explained 28% (slope = −0.17) of the variability in yields observed on fertilized plots, but it was not significantly related to yield responses. The observation that rainfall was more impor-

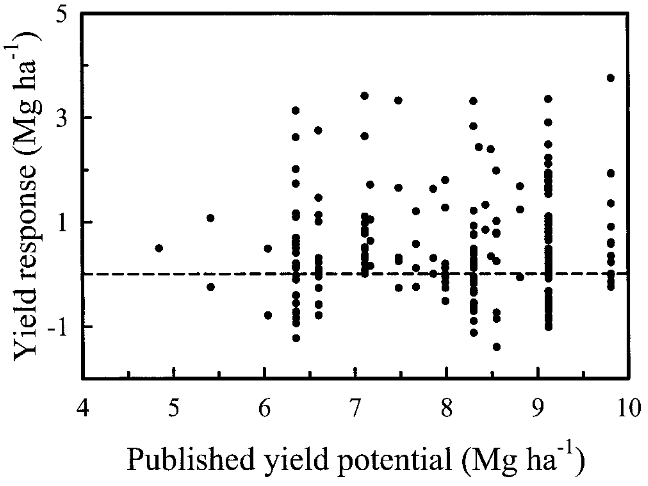

**Fig. 6. Relationship between published yield potentials of soils and corn yield responses to fertilizer N applied at 100 kg ha$^{-1}$.**

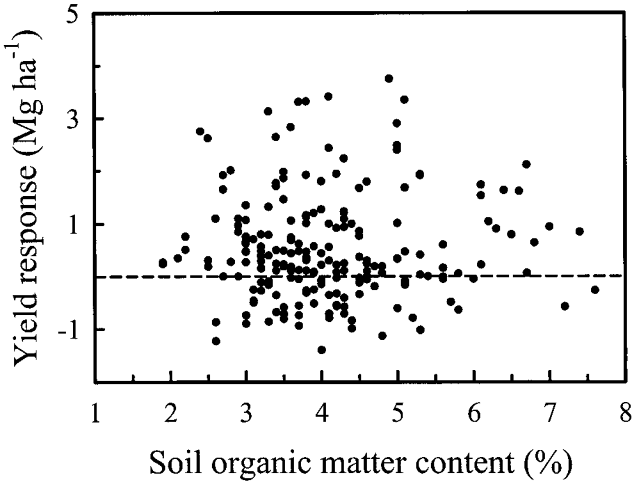

**Fig. 7. Relationship between soil organic matter concentrations and corn yield response to fertilizer N applied at 100 kg ha$^{-1}$.**

tant as a factor affecting yields than as a factor influencing yield response helps to explain why yields were not a good predictor of yield response.

Soil organic matter concentrations were not significantly related to observed yield responses to applied N (Fig. 7). Multiple-regression techniques failed to identify any models that could explain more than 10% of the observed variability in yield response by simultaneously considering rates of manure-N application, yield potential or level, soil organic matter concentrations, and interactions of these factors. Because these are the factors normally considered in the general-guideline approach, the results of these analyses offer little hope for improving the performance of this approach.

The foregoing analyses indicate that factors that explained only 5% of the observed variability in yield response could be detected at the 0.05 level of confidence by the methods used in this study. The lack of a relationship that was significant at this level in Fig. 2, therefore, suggests that general-guideline approach as would be used by farmers explained less than 5% of the observed variability in yield response.

## Factors Affecting Inorganic Nitrogen Concentrations

Concentrations of $NO_3$–N and ($NO_3$ plus $NH_4$)-N in the surface 60-cm layer of soil showed a statistically significant linear trend to increase with increasing rates of manure-N application (Fig. 8). These relationships, however, explained only 4% of the variability in inorganic-N concentrations. There was no useful relationship between soil $NO_3$ concentrations and rates of liquid swine manure N injected into the soil. The finding that amounts of manure N explained relatively little of the variability in $NO_3$ concentrations was not expected because the sites were selected to include an unusually wide range in rates of manure N application.

The observed relationships between concentrations of inorganic N and corn yield responses to fertilizer N (Fig. 1) suggest that soil testing would have detected effects of rate of manure-N application if they were consistent and important. Because it is clear that manure often has important effects on concentrations of inorganic N in soils, it must be concluded that manure N did not have consistent effects across the sites studied. Lack of consistent effects of manure N on supplies of N for plant growth could explain the poor performance of the general-guideline approach.

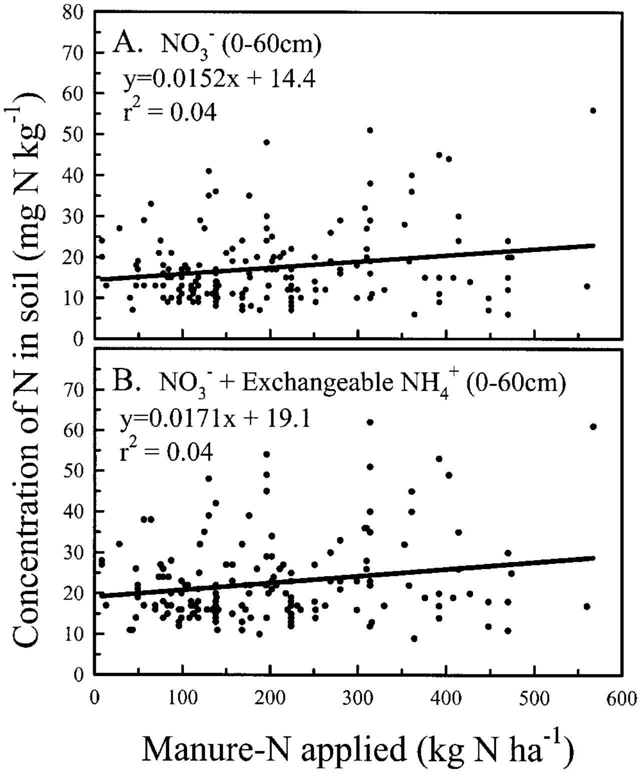

**Fig. 8. Relationships between rates of manure-N application and soil (A) $NO_3$–N to a depth of 60 cm and (B) exchangeable $NH_4$–N and $NO_3$–N to a depth of 60 cm.**

Lack of consistent effects should be expected because, as noted by Schepers and Fox (1989), ammonia volatilization soon after application, denitrification of $NO_3$, and variability in rates at which organic N in manure is mineralized should be expected to vary greatly among sites and years. Leaching of $NO_3$ during spring rainfalls also should vary greatly among sites and years because manure was applied weeks to months before soil $NO_3$ concentrations were measured. Indeed, concern about leaching of manure-derived $NO_3$ to water supplies is great enough to prompt regulatory action (Jackson et al., 2000; USEPA, 2001). Recent studies in Iowa show that $NO_3$ concentrations in rivers tend to be higher in areas having intensive livestock production (Kalkhoff et al., 2000). Studies reported by Balkcom et al. (2003) indicate that late-spring concentrations of $NO_3$ in cornfields treated with animal manure tend to decrease with increases in amounts of spring rainfall and be inversely related to $NO_3$ loads in rivers.

Immobilization of N by soil microorganisms decomposing organic compounds from manure may help explain why rates of manure-N application showed poor relationships with soil $NO_3$ concentrations and yield responses to fertilizer N. This possibility is supported by observations of Balkcom et al. (2003), who found that normal applications of animal manure by Iowa farmers supplied less $NO_3$ than was supplied by normal applications of commercial fertilizer. Although C/N ratios are known to influence amounts of N immobilized, these ratios are not considered in general guidelines for N management. Isotope studies indicate that relatively little of the N immobilized during the decomposition of organic materials in manure would be available for the first crop (Broadbent and Nakashima, 1965; Legg et al., 1970; Green and Blackmer, 1995). The cumulative effects of immobilization from previous applications of manure, however, would increase soil N mineralization rates and thereby influence measured soil $NO_3$ concentrations and yield responses to added N in ways that would be difficult to predict from general guidelines.

The preceding discussion illustrates that the performance of any method of estimating N fertilizer need depends on ability to correctly *integrate* the effects of many different interacting factors. Evaluations of performance, therefore, can be made without knowledge of which specific factors or processes were most important.

The finding that the soil-testing approach performed better than the general-guideline approach suggests that factors affecting the N transformations and movement after application of manure N were not adequately addressed by the general-guideline approach. This finding illustrates that performance-based evaluations can often suggest why one approach works better. Soil testing for inorganic N in late spring avoids the difficult task of *predicting* transformations and movement of N before the plants begin rapid growth because it *measures the net effects* of all processes that influence supplies of N before this time.

## Importance of Predicting Responsive Sites

Simple calculations suggest that fertilization would have been profitable at more than a third of the sites. Fertilization would have been profitable at 37% of the sites, for example, if the costs of fertilization were equivalent to 0.61 Mg of grain (0.11 Mg ha$^{-1}$ for application, 0.50 Mg ha$^{-1}$ for 100 kg of N). At sites where yield responses were greater than 2.5 Mg ha$^{-1}$, fertilization would have provided more than \$4 in grain for each dollar invested in fertilizer. Large profits at a few sites are noteworthy because they prompt many farmers to regard fertilization of all sites as necessary insurance against large economic losses (Fox et al., 1989; Babcock, 1992; Schroder et al., 2000). Information provided by the cooperating farmers indicates that the mean rate of N applied outside the experimental areas was 143 kg N ha$^{-1}$.

The mean yield without addition of fertilizer N across all sites was 9.13 Mg ha$^{-1}$, and the mean yield with 100 kg N ha$^{-1}$ was 9.68 Mg ha$^{-1}$. Simple calculations, therefore, indicate that fertilization of all sites at this rate would have resulted in overall economic losses. The profitability of applying fertilizer N after animal manure, therefore, depends largely on ability to predict the responsive sites before fertilizers are applied.

Current guidelines for using the soil test in Iowa (Blackmer et al., 1997) indicate that fertilizer N should not be applied when $NO_3$ concentrations in the surface 30-cm layer of soil exceed 20 mg N kg$^{-1}$. The mean yield response for all sites testing higher than this critical concentration was –0.03 Mg ha$^{-1}$ whereas the mean yield response for all lower-testing sites was 0.93 Mg ha$^{-1}$. Unlike the general-guideline approach, therefore, soil testing for inorganic N in late spring showed potential for resolving the dilemma that N fertilization after applications of manure is very profitable at some sites but not profitable at most sites. The extent to which benefits of soil testing can be increased by establishing relationships between soil test values and optimal rates of N application is beyond the scope of this paper and will be addressed elsewhere.

## Small Yield Responses and Poor Predictability

Although the yield responses observed in this study (0.55 Mg ha $^{-1}$) were large enough to influence the behavior of farmers, they were usually too small to be *statistically significant* in single trials. In this study, for example, $LSD_{0.05}$ values for yields in individual trials ranged from 0.3 to 3.9 Mg ha$^{-1}$ and had a mean of 1.09 Mg ha$^{-1}$. These LSD values are representative of those usually found in N-response trials (Blackmer, 1986; Fox et al., 2001). When it is recognized that a yield response of 1 Mg ha$^{-1}$ usually has value greater than the price of the normal annual application of fertilizer N for corn, it becomes obvious that ability to refine estimates of fertilizer needs requires an ability to measure smaller yield responses than are usually statistically significant in individual trails. Although increasing numbers of trials is an effective way to increase ability to detect statistically significant effects under conditions where yield responses are small, the percentage of variability in yield responses explained (i.e., $r^2$ values of models) is often considered too small to be of practical importance.

The finding that soil testing for inorganic N explained 34% of the variability in yield responses in this study has little practical value unless it is noted that the general guidelines given to farmers explained less than 5% of the variability under the same range of conditions. Observations that higher percentages of variability have been explained in other studies by restricting the range of conditions are irrelevant because ability to explain variability under a carefully restricted set of conditions does not give a valid estimate of ability to explain (or predict) yield responses across a much wider range of conditions. The analyses presented in this study, therefore, suggest that objective evaluations of current methods for predicting yield responses to fertilizer N within a region may require working with relationships that explain relatively small percentages of the observed variability in yield response.

The large number of trials in this study made it possible to identify factors that explained as little as 5% of the variability in yield response at the 95% level of confidence. It should be considered a matter for concern, therefore, that no single factor or combination of factors normally included in the general-guideline approach could explain as much as 10% of the observed variability in yield response in this study. This finding suggests that the performance of similar general guidelines needs to be objectively evaluated in regions where they are used. In absence of such evaluations, inflated and unrealistic perceptions concerning the performance of present guidelines pose a formidable barrier to the development and use of better guidelines.

Unlike the soil-testing approach, the general-guideline approach must be able to predict all N transformations and movement that influence concentrations of inorganic N in the soil when plants begin rapid growth in early summer. These predictions must address complex interactions of soil properties, weather (temperature and rainfall), characteristics of the manure, and effects of time and method of manure application. The general guidelines, however, usually include no reference to quantitative evaluations of the ability to predict transformations and movement of N in soils. Indeed, the guidelines usually include many numerical values without any statement of uncertainty and without any appropriate statement concerning their origin. The scientific basis for acceptance of the general-guideline approach requires re-evaluation as policy makers start requiring government regulatory agencies to use the guidelines as regulations that farmers must follow rather than merely as recommendations that farmers may follow.

## CONCLUSIONS

Agronomists have long been expected to develop N management guidelines without adequate amounts of experimental data, and widespread appreciation for the problems involved seems to have resulted in some reluctance to critically evaluate general guidelines developed under such conditions. It is often assumed that the performance of such guidelines cannot be quantitatively evaluated. Alternative guidelines based on soil testing for inorganic N, however, have been developed under conditions where critical evaluations of performance are expected. The expected evaluations are rightfully based on ability to predict yield responses to applied N under realistic field conditions. Our study demonstrates that the performance of the general-guideline approach to estimating fertilizer needs can be objectively evaluated by the same methods used to evaluate the soil-testing approach. The results give reason for concern that inadequate critical evaluation of the performance of the general-guideline approach may constitute a key barrier in efforts to improve N management on cornfields treated with animal manure. This possibility deserves attention by agronomists as the role of the guidelines is transformed from recommendations to regulations and the performance of the guidelines becomes more important to farmers and others working to protect environmental quality.

### ACKNOWLEDGMENTS

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## Statement of Ethics

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Members of the American Society of Agronomy acknowledge that they are scientifically and professionally involved with the interdependence of natural, social, and technological systems. They are dedicated to the acquisition and dissemination of knowledge that advances the sciences and professions involving plants, soils, and their environment.

In an effort to promote the highest quality of scientific and professional conduct among its members, the American Society of Agronomy endorses the following guiding principles, which represent basic scientific and professional values of our profession.

Members shall:

1. Uphold the highest standards of scientific investigation and professional comportment, and an uncompromising commitment to the advancement of knowledge.
2. Honor the rights and accomplishments of others and properly credit the work and ideas of others.
3. Strive to avoid conflicts of interest.
4. Demonstrate social responsibility in scientific and professional practice, by considering whom their scientific and professional activities benefit, and whom they neglect.
5. Provide honest and impartial advice on subjects about which they are informed and qualified.
6. As mentors of the next generation of scientific and professional leaders, strive to instill these ethical standards in students at all educational levels.

*Approved by the ASA Board of Directors, 1 Nov. 1992*