YIELD GOAL VERSUS DELTA YIELD TO PREDICT NITROGEN NEED IN CORN

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Abstract

Fertilizer nitrogen (N) needs of corn can vary widely both among and within fields. Many states use a yield goal to identify differences in fertilizer N need combined with an N credit system to adjust for N provided by the soil from sources such as soil organic matter, residual inorganic N and crop residues. Some have questioned yield-goal derived fertilizer N recommendations because of its poor correlation with fertilizer N need, leading some states to eliminate yield goal from their N recommendation system.

In this study, grain yield at responsive sites was positively but poorly correlated with fertilizer N need (r^2=0.04). This result was consistent with others that have observed that maximum or optimum yield is a poor predictor of fertilizer N need. Our analysis indicated most locations required a reduction in recommended N to account for N supplied by the soil.

Delta yield (grain yield at optimum N rate minus grain yield with 0N applied) was positively correlated with fertilizer N need and a much better predictor of fertilizer N need than grain yield (r^2=0.48). A theoretically derived equation to predict fertilizer N need in corn grain based on the delta yield concept agreed well with the empirically derived regression formula.

Our results demonstrate that yield is an important component of an accurate fertilizer N recommendation. Locations that have a greater ability to increase yield with additions of fertilizer N required higher fertilizer N rates to attain optimum yield.

The close association of delta yield with fertilizer N requirement suggests an alternative approach for developing fertilizer N recommendations. Farmers should be trained to assess the potential for increasing yield with fertilizer N, not the total yield potential. Instead of asking the question "what yield do I expect from this field" farmers should be trained to ask the question "how much more yield can I expect if I apply fertilizer N."

The strength of the delta yield approach is that it focuses producers on the components of yield that directly affect fertilizer N need. The delta yield equation also incorporates fertilizer nitrogen efficiency (FNUE) directly into the calculation of fertilizer N need. This provides an opportunity to incorporate differences in FNUE among locations into fertilizer N recommendations as we become more sophisticated at predicting FNUE.

Introduction

Nitrogen fertilizer needs of corn can vary widely, both among fields (Schmitt and Randall, 1994; Bundy and Andraski, 1995, Scharf and Lory, 2001) and within fields (Malzer et al., 1996; Blackmer and White, 1998). This variation in corn N response has been attributed to differences in soil N supply, corn nitrogen use efficiency and crop N need (Meisinger, 1984). For example, high inorganic N concentration in the soil profile at the start of the growing season can reduce fertilizer N need in low-rainfall regions (Olson, 1984) and humid regions of the U.S. (Schmitt and Randall, 1994; Blackmer et al., 1989). Legumes, such as alfalfa, preceding corn in a crop rotation can also reduce fertilizer N need (Shrader et al., 1966; Lory et al., 1995).

The accuracy of corn N fertilizer recommendations has important water quality implications. Fertilizer N application in excess of crop need dramatically increases residual N in the soil profile at the end of the growing season (Olsen et al, 1970; Schuman et al., 1975; Andraski et al, 2000). Excess residual nitrate in the soil profile in the fall is likely to move into ground or surface waters in humid regions of the U.S. (Olsen et al., 1970; Schuman et al., 1975; Andraski et al., 2000). Accurate fertilizer N recommendations can reduce residual N in the soil profile.

Under-application of N fertilizer N is costly to the corn grower (Black, 1993). Investment in fertilizer on a field that needs N is returned many times over in the value of the increased grain yield. Fertilizer recommendations must balance the risk of over application to our water resources with the risk of under application to the profitability of the farmer.

Yield goal is a component of many U.S. corn grain fertilizer N recommendations with most follow the general form:

$$N_f = 1.2 \text{ X } YG - N_s \quad [1]$$

where N_f is the fertilizer requirement for a selected yield goal, N_s is the quantity of N supplied by the soil and YG is the expected grain yield in bu/ac. States following this general approach include Illinois (Hoeft and Peck, 2000, Minnesota (Schmitt et al, 1998), Missouri, Nebraska (Hergert et al., 1995), North Dakota (Dahnke et al., 1992), Pennsylvania (Beagle and Wolf, undated), South Dakota (Gerwig and Gelderman, 1996). Indiana, Michigan and Ohio follow the same approach but uses the equation 1.36 X YG - N_s - 27 (Vitosh et al., 1995). Yield goal-based N recommendation methods also have been incorporated into many regulatory and technical standards (NRCS, 1999; USEPA, 2001).

Yield goal alone typically does not correlate well with optimum fertilizer rate (Vanotti and Bundy, 1994; Fox and Piekielek, 1995; Kachanoski et al., 1996; Bundy, 2000). Vanotti and Bundy (1994) found no correlation between yield and optimum N rate (r^2=0.02) in 24-year N rate study. Fox and Piekielek (1995) found no correlation with yield goal and optimum fertilizer N rate in a summary of 57 site-years in Pennsylvania (r^2=0.08). Bundy (2000) found no correlation of yield goal and optimum fertilizer N rate in 101site-years of data summarizing Wisconsin experiments from 1989 to 1999. A summary of 300 N fertilizer experiments in Ontario concluded that maximum yield explained less than 15% of the variability in the optimum N rate (Kachanoski et al., 1996).

The limited ability of yield goal alone to predict fertilizer N need is anticipated in yield-goal based N recommendation systems. Fertilizer N need is a function of yield goal and N_s in equation 1. Yield goal will be poorly correlated with fertilizer N need if N_s is variable among years and locations and is a significant source of grain N in at least some years and locations.

Soil N supply is expected to vary among years and location. Corn N recommendations typically include a system of N credits to account for conditions that increase the quantity N_s available to the crop. Components of N_s include soil organic matter, residual organic and inorganic N from previous N applications, atmospheric N fixed by legumes and free-living N-fixing bacteria and atmospheric deposition (Legg and Meisinger, 1982). Typically N credits are given for elevated inorganic N in the profile, recent cropping history that includes legumes, recent applications of manure and, in a few cases, high soil organic matter (e.g. Vitosh et al., 1995; Gerwig and Gelderman, 1996; Hergert et al., 1995; Schmitt et al., 1998).

Yield goal has been eliminated from N recommendations in at least 2 states (Vanotti and Bundy, 1994; Bundy, 2000; Blackmer et al., 1997). In Wisconsin, recommended fertilizer N rate is based on regional soil characteristics (Vanotti and Bundy, 1994). The state was divided into 4 regions based on soil characteristics anticipated to affect productivity and nitrogen use efficiency. A standard corn fertilizer N rate was determined for each soil region based on fertilizer N response experiments. These recommendations are further adjusted for annual and location variations in soil organic matter, residual N levels in the soil and other management factors that affect N_s. Iowa also developed state-wide recommendations independent of yield goal. The recommendation is based only on cropping system. Soil N tests can be used to hone the recommendation to field-specific N_s conditions. Information supporting the Iowa and Wisconsin recommendation systems both cite the lack of correlation between yield goal and fertilizer N need as one of the reasons for adopting the current recommendation system (Vanotti and Bundy, 1994; Blackmer et al., 1997).

Most fertilizer recommendations in the US are predicated on the assumption that among sites that are responsive to fertilizer N, more fertilizer N is needed at locations where there is a greater response to applied N. The elimination of a yield component from the recommendations system is a fundamental shift away from the away from this yield-based system. In the Iowa and Wisconsin systems, a site that has potential for a large increase in yield from fertilizer N can have the same recommendation a site that has only a small potential for increasing yield.

Our primary objective is to determine the importance of yield in developing an accurate corn fertilizer N recommendation. We will test the hypothesis that locations that have greater yield response to applied N require more fertilizer N. To accomplish this assessment we evaluated 197 N response experiments from 4 states in the humid region of the U.S.

Materials and Methods

We used data from 197 fertilizer N response experiments in Illinois (n=54), Minnesota (n=54), Missouri (n=32) and Pennsylvania (n=57). These sites represented a wide range of management systems, soil types and climate conditions within the humid region of the US. Tillage systems included no till, moldboard plow and chisel plow. Previous crops included corn (n=110), soybean (n=63), small grain (n=15), and alfalfa (n=9); 38 locations had a recent application of animal manure. Further details of the experiment locations and the management of the fertilizer N response experiments can be found in Brown (1996), Schmitt and Randall (1994), Scharf and Lory (2001), Scharf and Lory (*in press*) and Fox and Piekielek (1995).

We obtained an estimate of control grain yield (no fertilizer N applied), the economic optimum fertilizer N rate and the yield at the economic for each experimental site-year. Typically, the quadratic plateau model had been used by the authors to model fertilizer N response at most sites responsive to applied N. For the Missouri and Pennsylvania data we had access to the regression coefficients and calculated economic optimum fertilizer N rate and the associated optimum yield based on a fertilizer:crop value ratio of 0.1. In the remaining 2 states we relied on reported economic optimum fertilizer N rates and control yield.

Regression methods were used to determine best fit models (SAS Inst., 1987) and to test the hypothesis that regression lines from different states had the same slope and intercept (Weisberg, 1985).

Results and Discussion

Economic optimum yield for corn grain yield at the 197 locations in Pennsylvania, Missouri, Minnesota and Illinois had a mean of 155 bu/ac (SD=30), a range from 68 to 226 bu/ac and a normal distribution (P<W=0.41). Yield did not respond to fertilizer at 50 of 197 locations (optimum N rate =0). Across the 147 responsive locations, the mean optimum N fertilizer rate was 116 lb N/ac (SD=37) and ranged from 38 to 198 lb N/ac. Grain yield of the control plot (plots that received no fertilizer N) had a mean of 116 bu/ac (SD=38) and a range from 30 to 223 bu/ac.

Grain yield at responsive sites was positively but poorly correlated with fertilizer need (Fig. 1). This result was consistent with others that have observed that maximum or optimum yield is a poor predictor of fertilizer N need (Vanotti and Bundy, 1994; Fox and Piekielek, 1995; Kachanoski et al., 1996; Bundy, 2000).

Delta grain yield was highly correlated with economic optimum N fertilizer rate (Fig. 2). The best-fit model for responsive locations (r^2 = 0.48) was a positive, linear relationship with an intercept significantly greater than 0. There was little evidence of curvilinearity (P=0.23). Separate regression lines for each state also did not significantly improve model fit (P=0.21). This implies a universal linear relationship describing the effect of delta yield on the amount of fertilizer N required in cornfields responsive to N among all 4 states.

The standard recommendation of 1.2 lbs N/bu yield recommended more N than needed at most locations (Fig. 3). Application of 1.2 lbs N/bu is a strategy that will rarely leave you short of N; almost all data points in Fig. 3 fall above the 1:1 line implying this strategy recommended more than the optimum N rate. This implies that most fertilizer N recommendations using the standard approach (Eq. 1) would need some adjustment for N_s. The majority of N recommendations in this system require some form of an N credit to accurately assess fertilizer N need.

The yield of the 0N control is a measure of the magnitude of soil N available to the crop. Grain yield with no fertilizer applied at 147 sites that responded to fertilizer N had a mean of 104 bu/ac (SD=31) and a range from 30 to 199 bu/ac. Yield with 0N applied exceeded 70 b/ac at 90% of the responsive locations. Most locations have significant sources of soil N other than fertilizer that must be accounted for in order to accurately estimate fertilizer N need. Failure to adjust for soil N contributions will likely result in over application of fertilizer N.

Sites that had low yields with no fertilizer tended to require more fertilizer to attain optimum yield among the 78 locations that had no recent history of manure and corn as a previous crop. The relationship was linear but limited in its ability to predict optimum N rate (r^2=0.22). Some sites that had a high control yield (high N_s) were highly responsive to fertilizer N. This result emphasizes that yield of the 0N control provides information about soil nitrogen supply but may not necessarily be a good predictor of fertilizer N response.

Our results demonstrate yield is an important component of an accurate fertilizer N recommendation. Locations that have a greater ability to increase yield with additions of fertilizer N required higher fertilizer N rates to attain optimum yield. Consequently our fertilizer N recommendations at these more responsive sites should be greater than recommendations at less responsive sites.

The close association of delta yield with fertilizer N requirement suggests an alternative approach for developing fertilizer N recommendations. Farmers should be trained to assess the potential for increasing yield with fertilizer N, not the total yield potential. Instead of asking the question "what yield do I expect from this field" farmers should be trained to ask the question "how much more yield can I expect if I apply fertilizer N." This focuses the farmer's fertilizer assessment on the component of yield most associated with fertilizer N need.

Delta yield can be determined in-field by applying no fertilizer N to patches of a corn field. This can be done by shutting off the fertilizer N applicator at predetermined locations within a field. Location of the 0N strip should change each year corn is grown. Comparing yield in these 0N areas with yield in the surrounding fertilized areas is a direct measure of delta yield. Yields can be determined from a yield map generated with a yield monitor or by hand harvesting a known length of row in the 0N and full N areas of the field.

The measure of variation in delta yield will be much more predictive than yield (r^2=0.48 vs. r^2=0.04). A history of delta yields for a field over time is a rough estimate of the quantity of fertilizer N needed and the variability in need over years. Variation of delta yield within a field is an estimate of the variation in fertilizer N need within a field. Delta yield is a relatively simple measurement and maintaining records of delta yield within a field and over years would provide a more effective predictor of fertilizer N need in the field than yields. Kachanoski et al. (1996) also suggested that delta yield has potential to improve fertilizer N recommendations within a field.

Delta yield also has potential as a diagnostic tool evaluating past year fertilizer N management. This is a relatively insensitive tool for evaluating over or under application of fertilizer N because of the relatively large variation about the best-fit line (Fig.2). The optimum fertilizer N rate can be estimated from delta yield within ± 54 lbs N/acre within the range of reported data 95% of the time.

Fertilizer use efficiency (fertilizer N in the grain/optimum fertilizer N rate) is also positively related to delta yield (Fig. 4). It typically took more fertilizer N per bushel to increase yield at locations with low potential to increase yields than locations with a high potential. Locations that have small delta yields are anticipated to have lower FNUE than highly responsive locations because of the concept of diminishing returns. Extensive literature has demonstrated that FNUE for this last increment of yield increase is usually low (Black, 1993). Predicted fertilizer efficiency increased from 31% (delta yield =20 bu/ac) to 57% (delta yield =120 bu/ac). However, many locations had significantly higher than predicted FNUE.

Accurate fertilizer N recommendations require determining the grain fertilizer N requirement and determining the FNUE of the plant at recovering applied fertilizer N from the soil and utilized in the plant to make grain. We have demonstrated that locations that have greater potential to increase yield require more fertilizer N. This result is compatible with most current fertilizer N recommendation systems based on Eq. 1 if a comprehensive N credit system is in place.

Most fertilizer recommendation systems assume a constant FNUE as reflected by the constant 1.2 lbs. N/bu. Yet there is ample evidence that FNUE varies with delta yield (Fig. 4) as well as many other soil, management and climate factors. Our inability to predict variations in FNUE among locations and years has hampered incorporating FNUE into N fertilizer recommendations.

Wisconsin has adopted a fertilizer N recommendations system that assumes different FNUE's for different regions of the state (Vanotti and Bundy, 1994). However this system does not provide for adjustments in fertilizer N rate based on yield potential. Our analysis indicates that both yield and FNUE components must be incorporated into accurate fertilizer N recommendations. Both are significant sources of variation in fertilizer N need for corn grain.

We developed a fertilizer N equation based on the delta yield concept that includes an adjustment for variability in FNUE with delta yield:

$$N_f = (\Delta_{Yg} \text{ X } CN_{OPTN} + Y_{gON} \text{ X } \Delta_{NC}) / \text{FNUE} \quad [2]$$

where ΔY_g is delta grain yield from fertilizer N application, C_{NOPTN} is the grain N content at the optimum N rate assumed here to be 0.65 lbs N/bu, Y_{g0N} is the yield with no fertilizer N applied, Δ_{NC} is the change in grain N content between corn with no N applied and optimum N rate applied and FNUE is the ratio of fertilizer N in the grain and applied fertilizer N. We estimated Δ_{NC} from the equation:

$$\Delta_{NC} = 0.757 + 0.579 \text{ X } Y_{g0N} \quad [3]$$

that was developed from assessing the relationship between grain N concentration in the 0N control plots and grain N concentration at the optimum fertilizer N rate for 38 Minnesota studies that were responsive to fertilizer N.

Fertilizer N recommendations developed from Equation 2 are derived from the mass balance approach to fertilizer N recommendations translated into the delta yield format. The theoretically derived formula (Eq. 2) and the empirically derived formula (Fig. 2) result in similar predictions of fertilizer N need (Fig. 5).

The strength of the delta yield approach is that it focuses producers on the components of yield that directly affect fertilizer N need. Farmers using this approach would be rewarded for tracking the magnitude of fertilizer N response within and among their fields. This information would lead directly to more accurate fertilizer N recommendations. Equation 2 also incorporates FNUE directly into the calculation of fertilizer N need. This provides an opportunity to incorporate differences in FNUE among locations into fertilizer N recommendations as we become more sophisticated at predicting FNUE.

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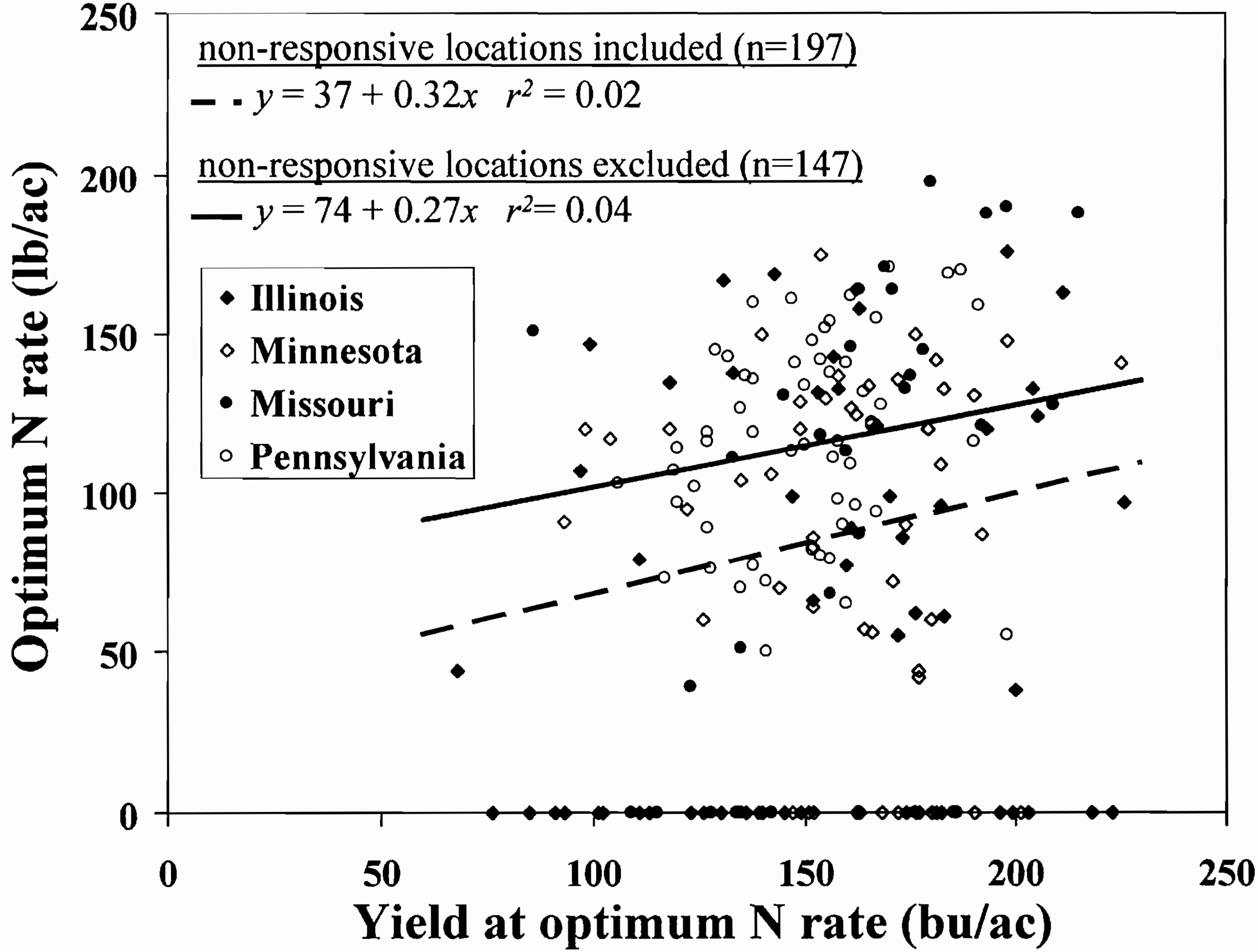

Figure 1. The effectiveness of yield at the optimum fertilizer N rate as a predictor of optimum fertilizer N rates.

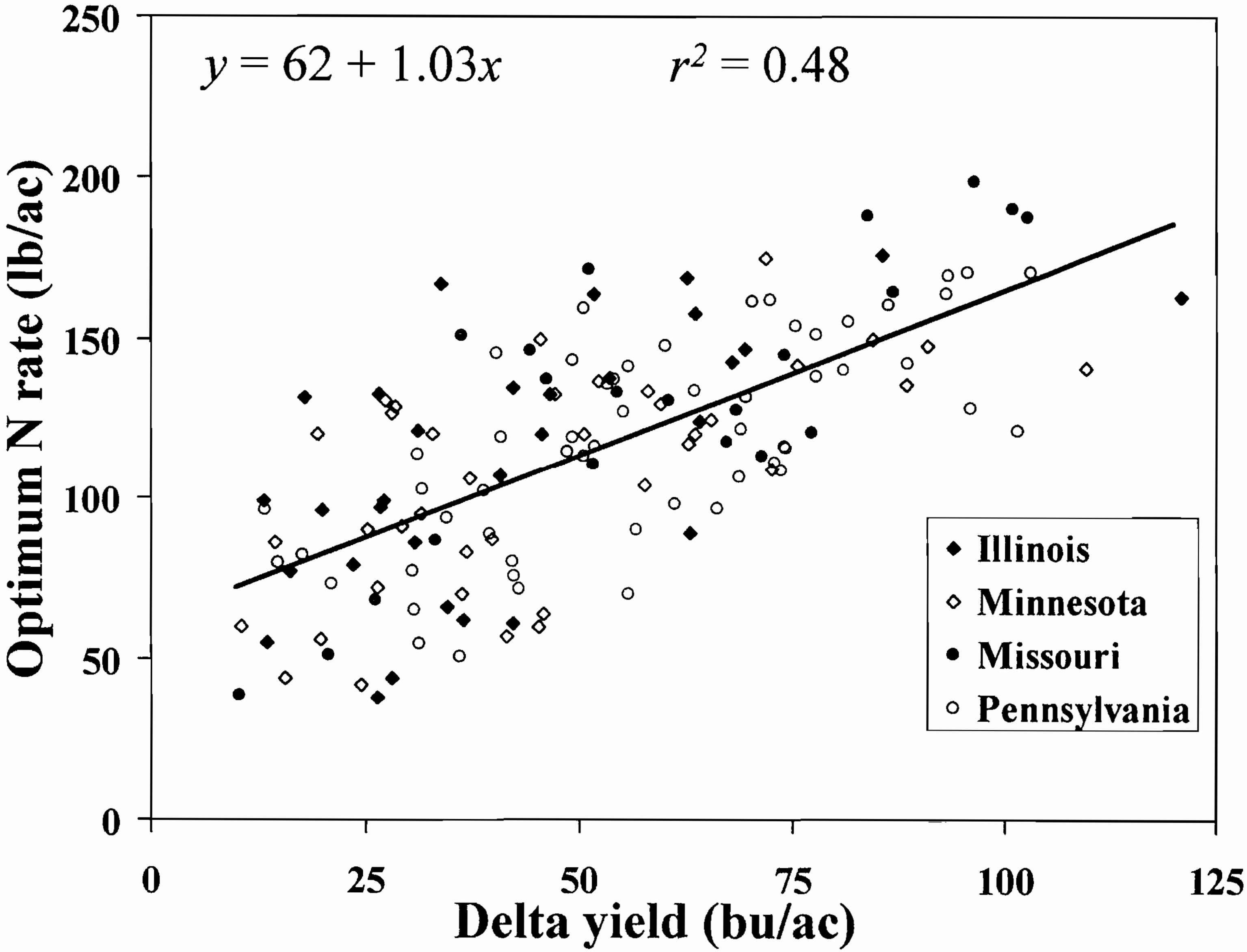

Figure 2. The effectiveness of delta yield (Grain yield at the optimum fertilizer N rate minus grain yield of the 0N control) as a predictor of optimum fertilizer N rates. Data summarizes 147 fertilizer N response experiments in 4 states where fertilizer N increased yield.

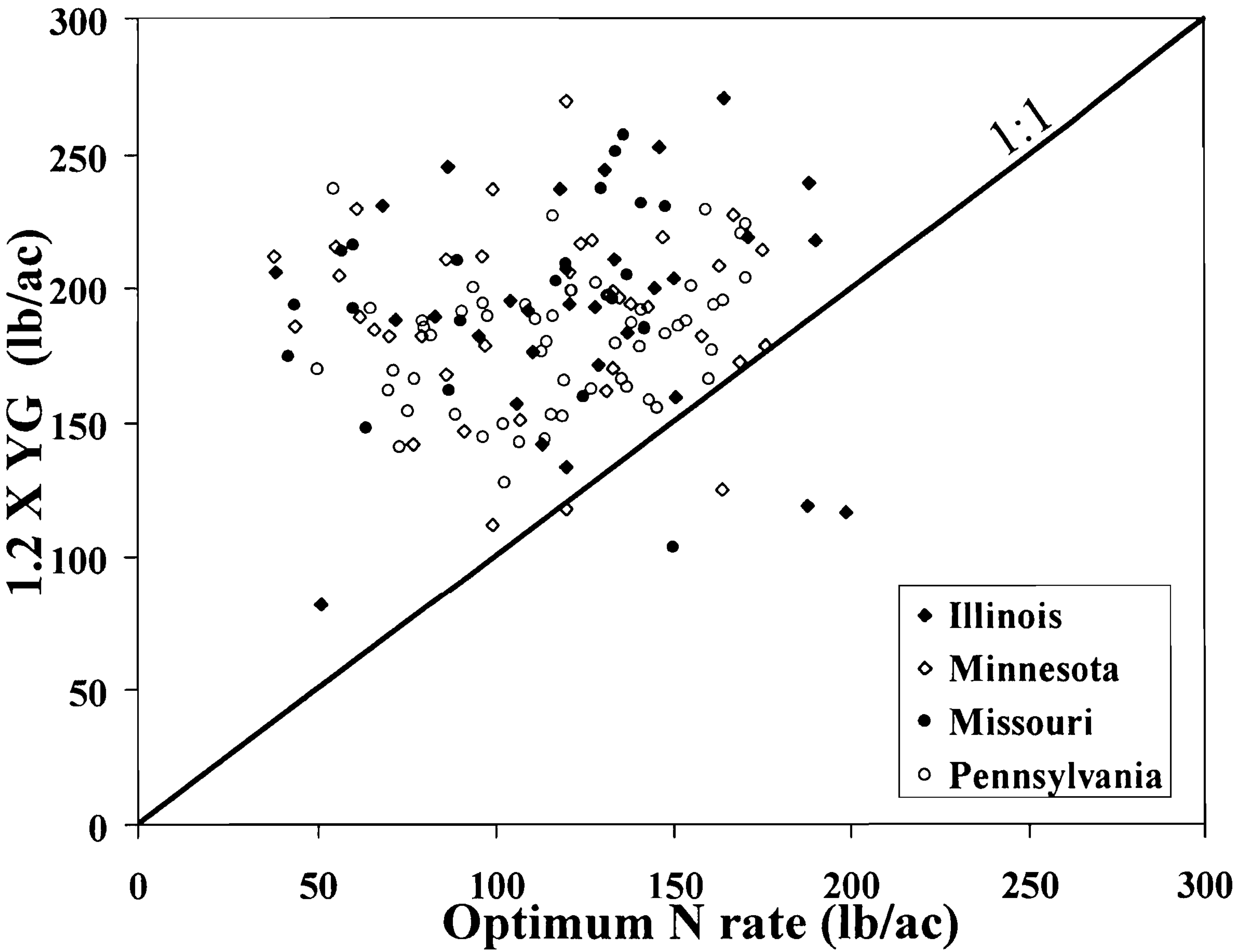

Figure 3. The correlation between optimum N rate and optimum N rate calculated as 1.2 X yield goal. The two approaches are equivalent at locations that fall on the 1:1 line. Data summarizes 147 fertilizer N response experiments in 4 states where fertilizer N increased yield.

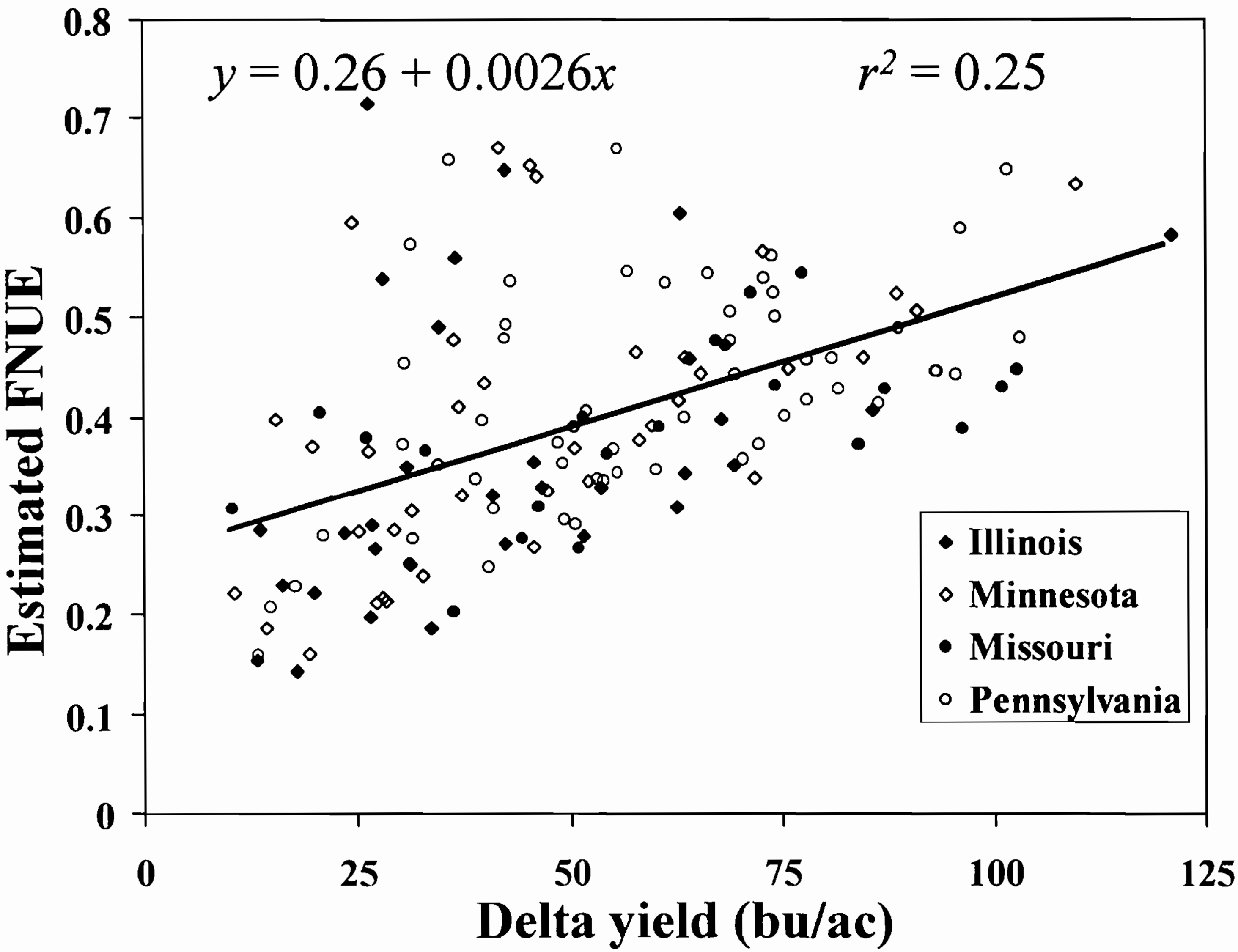

Figure 4. The effectiveness of delta yield (Grain yield at the optimum fertilizer N rate minus grain yield of the 0N control) as a predictor of fertilizer N use efficiency (FNUE=fertilizer N in grain/optimum fertilizer N rate). Fertilizer N in the grain N was estimated assuming grain N content is 0.65 lbs N/bu at optimum N rate and applying fertilizer N increased grain N content at responsive sites based on Eq. 3 in the text. Data summarizes 147 fertilizer N response experiments in 4 states where fertilizer N increased yield.

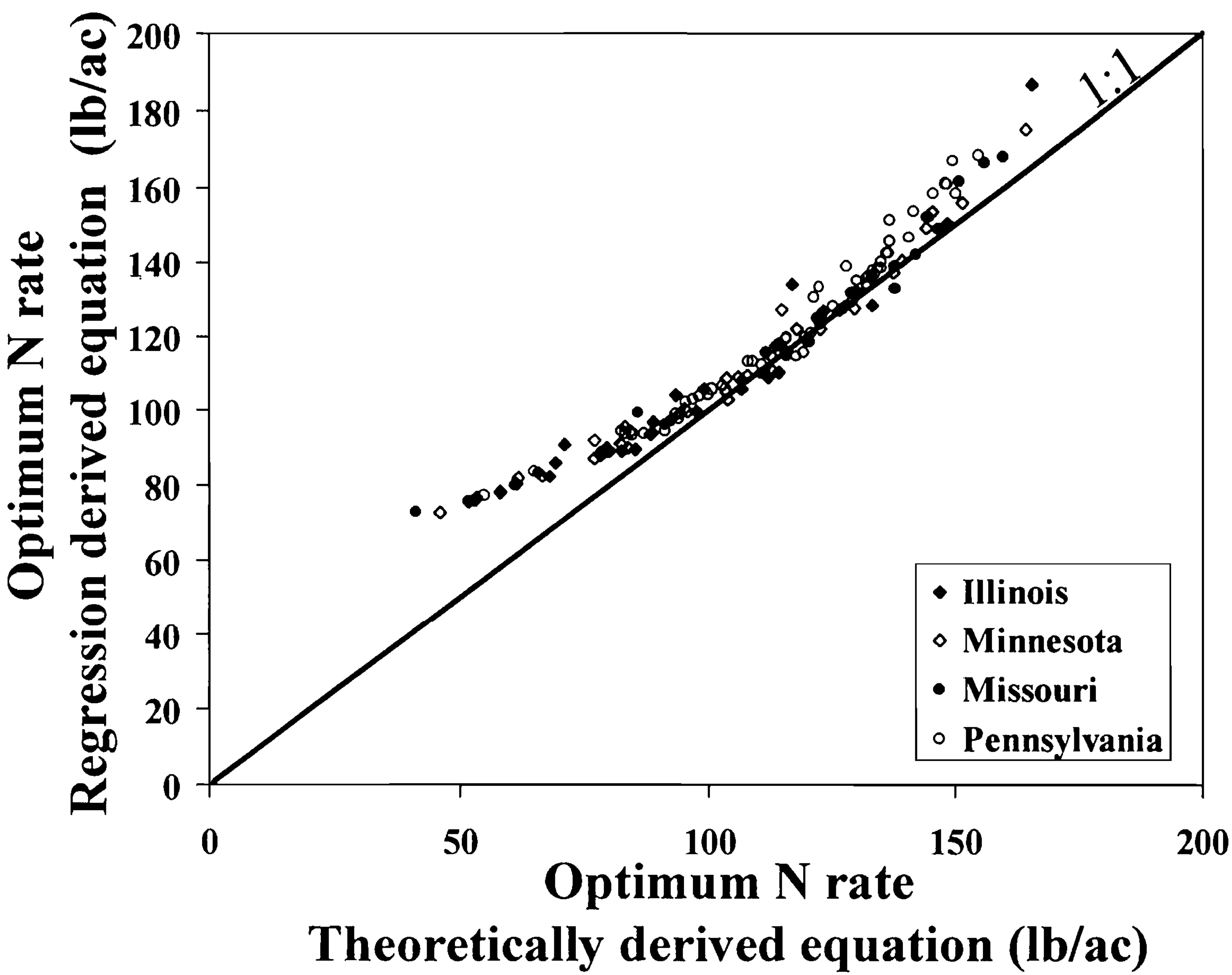

Figure 5. The correlation between optimum N rate calculated using the theoretical delta yield equation (Eq. 2) and the empirically derived equation (Fig. 2). The two approaches are equivalent at locations that fall on the 1:1 line. Data summarizes 147 fertilizer N response experiments in 4 states where fertilizer N increased yield.

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