USE OF YIELD GOALS FOR PROVIDING N RATE SUGGESTIONS: GENERAL CONCEPT

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Recent studies in the North Central region have shown a poor relationship between optimum yield of individual sites and optimum fertilizer N rate (Sawyer et al., 2006). The outcome has been the development of fertilizer recommendation approaches that do not consider site yield goal (Vanotti and Bundy, 1994a; Sawyer and Nafziger, 2005). This causes one to ponder how so many recommendation programs utilizing yield goal were developed in the first place and have continued in use for more than 40 years. It appears to be an appropriate time to review the general concept of use of yield goals in N recommendations. That will be the primary objective of this narrative with a secondary objective of relating the traditional concept to the recent studies suggesting a very limited role for yield goal in predicting N fertilizer need.

History of Using Yield Goals in N Recommendations

Use of yield goals in N recommendations dates back at least to the 1960s. Common practice at that time was to associate set attainable yields with given regions of a state based on climate or soil considerations (Anonymous, 1969). As computerized recommendations were developed, programs shifted toward user-defined yield goals. More recently, several states have gone back to regionalized N recommendations. Another recent relevant development has been sophisticated, yet user-friendly, tools such as Hybrid Maize (Yang et al., 2004) that have the potential to assist users in estimating realistic attainable yields for a given site and set of cultural practices.

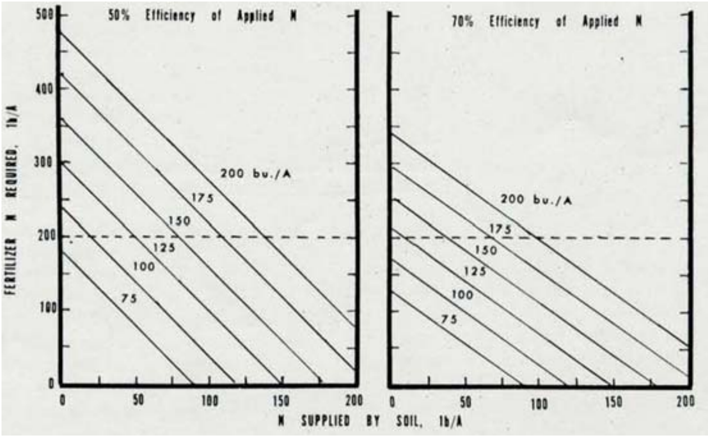
Initial justification for early yield goal approaches was likely quite intuitive. It simply made sense that a larger crop would require more N from either indigenous or supplemental sources. Stanford was one of the first to write somewhat mechanistically about N recommendations in his paper of 1973 (Stanford, 1973). The purpose stated by Stanford for the paper was *"to develop a rational basis for maintaining the levels of N fertilizer use within bounds that not only are optimum for crop production, but also provide for an acceptable balance between N inputs and losses of nitrate to surface and ground waters."* Over thirty years later, that remains an appropriate objective for N recommendations with the possible addition of atmospheric losses to the balance consideration. At the 1985 Soil/Plant Analyst's Workshop, I reported on a 1983 NCR-13 subcommittee study on N recommendations of 13 North Central region universities (Fixen, 1985). With reasonable assumptions implicit in the recommendations of the time, Stanford's basic mass balance algorithm essentially reproduced North Central recommendations … strong evidence of the pervasive application of this basic concept.

Stanford offered the following mass balance expression and explanation for estimating N fertilizer needs: $\mathbf{N_f = (N_y - N_s)/E_f}$, where …

- $\mathbf{N_f}$ is fertilizer N needed (including N from non soil sources … manure, irrig. water, etc.).

- $\mathbf{N_y}$ is the quantity of N in the crop defined as a product of the attainable yield of dry matter and the critical internal N concentration. In a review of N uptake vs above ground dry matter yield relationships for corn from studies conducted at diverse locations across the U.S., Stanford concluded that the critical concentration for corn was unaffected by variety, location, climate, or level of attainable yield, and remained essentially constant at 1.2%. Since corn typically has a harvest index of 50% and a bushel of shell corn contains 47.3 lbs dry matter, the total above ground dry matter on a per bushel basis is 94.6 lbs and N_y becomes 1.1 lb N/bu (94.6 x 1.2%). Since the critical N concentration (1.2%) is influence by crop to fertilizer price ratio, an adjustment in this coefficient can be included for market conditions if so desired. As crop management continues to be more cognizant of crop end use, this factor may be tied to an increasing degree to the characteristics of the hybrid grown, unlike in Stanford's time. For example, the coefficient may be different for a high starch hybrid developed for bioenergy than it is for a feed hybrid. The recent development of commercially available grain protein sensors for combines may offer another means of gathering information for more site-specific estimation of this coefficient (Long and Rosenthal, 2005).
- $\mathbf{N_s}$ is the amount of N obtained by the crop from the soil itself, consisting of residual mineral N and N mineralized from soil organic matter. In a later paper, $\mathbf{N_s}$ was split into separate sources for mineral N and N mineralized during the season with specific efficiency factors for each (Stanford, 1982). Stanford also demonstrated that mineralization is usually at its maximum when soil water content is near field capacity and declines in linear fashion to the soil's permanent wilting point where it approaches zero (Stanford and Epstein, 1973). Thus, soil moisture conditions conducive to high yields also typically result in high soil N mineralization.
- $\mathbf{E_f}$ is the fraction of fertilizer N recovered by the crop defined as the difference in N uptake by plants receiving fertilizer N and plants receiving no fertilizer N divided by the amount of fertilizer N applied. Stanford indicated that $\mathbf{E_f}$ is influenced by rate of N application, time of N application, and growing conditions affecting yield potential such as soil properties, other essential nutrients, soil management, climate, rainfall, and irrigation practices. As in the case of $\mathbf{N_s}$, Stanford again points out how factors influencing attainable yield can also influence another factor in the recommendation algorithm, in this case $\mathbf{E_f}$. He indicated $\mathbf{E_f}$ values of 50-70% encompassed the range normally encountered with proper application timing.

Fig. 1. Fertilizer N required for various attainable yields of corn in relation to amount of N supplied by soil and fertilizer N efficiency (Stanford, 1973).

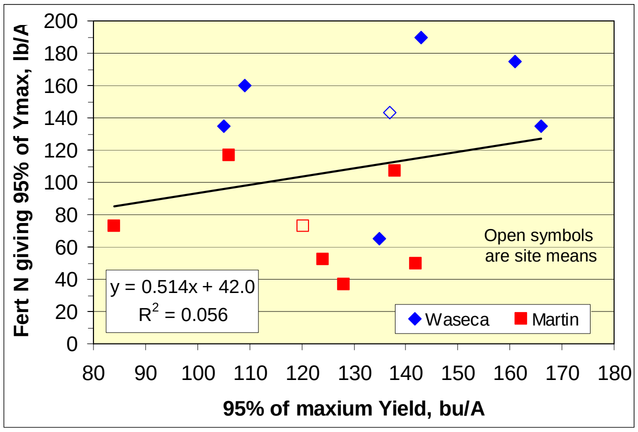


Key to understanding Stanford's message was his figure 5 reproduced here as **Figure 1**. In this figure he shows how fertilizer N need can vary markedly at any given attainable yield as N supplied by soil varies and that the slope is steeper with lower efficiency. He mentioned that the range in amounts of soil N shown in the figure were realistic in terms of experimental evidence. Therefore, fertilizer N required with 70% efficiency for a 200 bu/A yield could vary from 57 to 343 lb/A depending on soil N supply. From this analysis it becomes apparent that, if Ns varies among sites, Stanford would not expect a high correlation between attainable yield and fertilizer N need unless soil N supply could be reliably estimated and a reasonable assumption about fertilizer efficiency could be made.

Delta Yield as a Surrogate for Soil N Supply

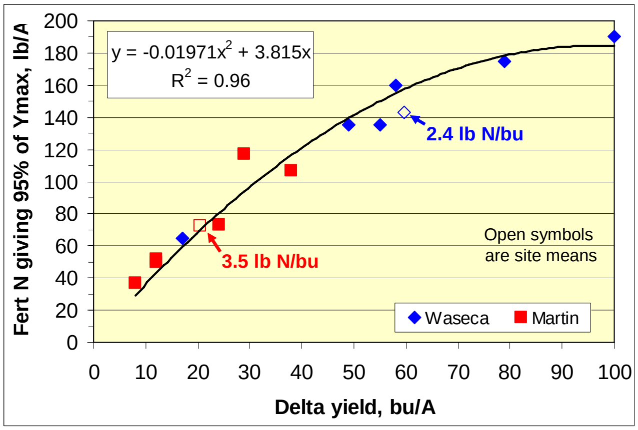
A southern Minnesota study conducted during the time of Stanford's papers is typical of many of that era in showing differences in N need due to factors other than attainable yield (**Figure 2**; Fenster et al., 1978). The Waseca County site had a higher average attainable yield than the Martin County site, but only by 15 to 20 bu/A and the relationship for individual site years was indeed quite poor. However, the average estimated optimum fertilizer N rate for the Waseca site was approximately 70 lb/A higher. In this case, the higher optimum N rate was thought to be largely due to poorer drainage of the soil at the Waseca site (Argiaquoll) compared to the Martin site (Hapludoll). The drainage impairment was thought to have increased N losses and decreased soil N mineralization. This study also illustrates the tremendous range in N need across years for a given site as weather patterns potentially influence all factors determining fertilizer N need.

Fig. 2. Relationship between estimated optimum corn yields and fertilizer N rates for six years at two Minnesota locations.



Data source: Fenster et al., 1978.

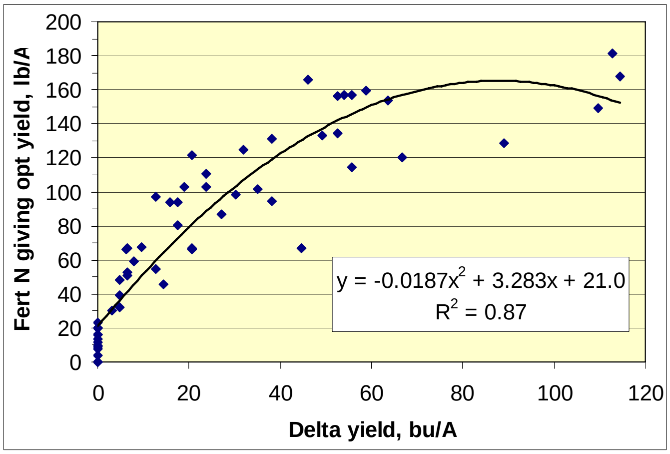
Fig. 3. Relationship between delta yield (optimum minus check) of corn and fertilizer N rates for six years at two Minnesota locations.



Data source: Fenster et al., 1978.

The same Minnesota data are graphed in **Figure 3** using delta yield, optimum yield minus the check yield as suggested by Kachanoski et al. (1996), rather than attainable yield. The improvement in relationship between the yield expression and optimum N rate is impressive and quite consistent with what Stanford would likely have expected as the check yield in this case is serving as a surrogate for soil N supply and the slope of the curve reflects fertilizer N efficiency. It is

Fig. 4. Relationship between delta yield of corn and optimum fertilizer N rates for 60 sites in Pennsylvania.



Data source: Fox and Piekielek, 1983.

interesting to note the curvilinear nature of the relationship among these 12 site-years, suggesting that fertilizer efficiency is higher when delta yield values are higher. This implies that $\mathbf{E_f}$ increases as $\mathbf{N_s}$ decreases. A similar relationship occurred across 60 trials in Pennsylvania (**Figure 4**; Fox and Piekielek, 1983), and for 300 Ontario trials (Kachanoski et al., 1996). However, Lory and Scharf (2003) reported a linear relationship in their study of 298 locations from five north central states. Regardless of the specific shape of the relationship, the delta yield approach appears to have promise as a means of incorporating yield information into N fertilizer recommendation algorithms where soil N supply is not being measured by soil tests. Requesting from farmers or their advisers both attainable yield and estimates of yield without N fertilizer applied would appear to be an improvement over current yield goal only approaches (Lory and Scharf, 2003). Precision technologies common today should make local databases of this kind of information relatively easy to develop. Though yearly yield variability with no fertilizer N applied is great due to weather, with time localized typical yields and yield ranges can be defined.

Yields, Yield Goals, and Attainable Yield

The process of setting yield goals and how they relate to attainable yield is a critical aspect of yield-based N recommendations and one on which numerous articles and papers have focused. Most universities and agronomic organizations have fact sheets, or have had fact sheets in the past, devoted to the topic. Recommended approaches include: a 5 or 6-year average; an average plus 5 to 20%; 5-year average with the lowest yield excluded; average plus one standard deviation; or based on 80 to 90% of a simulation model-estimated attainable yield for the location. Review of yield goal guidelines indicates a trend towards more conservative approaches in recent years. The most appropriate approach will be influenced by the specific algorithm in which the goal will be used, just as appropriate procedures for soil sampling or plant sampling are determined by the procedures used in calibrating the analytical tests. It's likely that more explicit instructions for setting yield goals based on careful simulation of profitability using the data generating the recommendations would be beneficial.

Most guidelines for setting yield goals involve using a sufficient number of years to average across weather variation or simulation models which incorporate long-term weather data. Therefore, evaluation of the efficacy of recommendation approaches employing yield goals is best accomplished using studies where each site has multiple years of optimum yield vs optimum

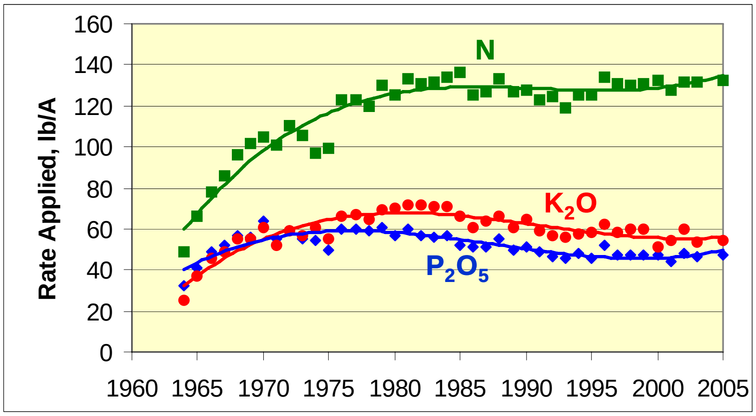
Table 1 . Example of the influence a cultural practice can have on yield and N requirement.

Population	Opt. yield	Opt. N	N/bu
plants/A	bu/A	lb/A	lb/bu
16,000	125	92	0.74
24,000	142	100	0.70
32,000	155	118	0.76
Avg			0.73

Data source: Thomison et al., 1992; Avg of the two single-ear hybrids (Pioneer 3379 & Countrymark 747 AX); interaction LSD $_{0.05}$ = 11 bu/A.

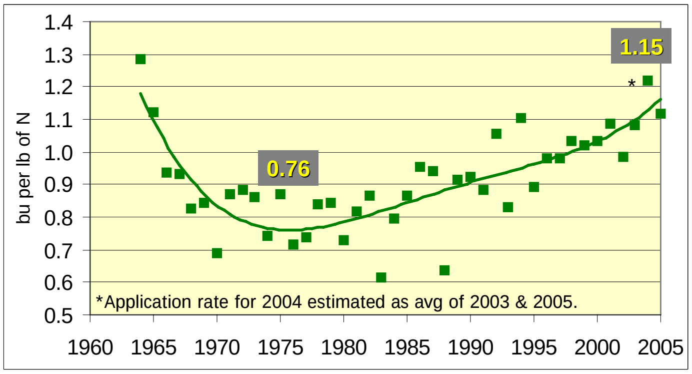
N rate determination. Differences in appropriately defined yield goals in a region of similar climate are due primarily to soil differences and cultural practices. Soil differences have already been discussed. Cultural practices can clearly influence yield and the resulting N need. Plant population is one such factor and is illustrated in the Ohio study summarized in **Table 1** (Thomison et al., 1992). In this hybrid x population by N rate study, increasing population increased optimum yield and optimum N rate such that N required per bushel remained essentially constant. A recent summary of extensive N trials in Illinois also showed higher N requirements where higher corn plant populations were present (Mulvaney et al., 2006).

Fig. 5. Fertilizer use on corn in the U.S.



Data source: USDA Ag Chemical Use Survey

Fig. 6. Corn grain produced in the U.S. per unit of fertilizer N used, 1964 to 2005.



Since 1975: 12% increase in N fertilizer use
60% increase in corn yield
51% increase in N efficiency

Data sources: USDA Ag Chem Use Survey & Annual Crop Production.

Fertilizer Efficiency in Yield Goal Approaches

Because of the change in fertilizer efficiency that has occurred since Stanford's time, the impact of increasing fertilizer efficiency on the effect of attainable yield on fertilizer need is worth highlighting. Estimated fertilizer use per acre on corn has increased only 12% since the mid 1970s (**Figure 5**), while corn yields have climbed 60%, resulting in an increase of 51% in the bu of corn produced per lb of fertilizer N (**Figure 6**). Increases in removal efficiencies as high as shown in **Figure 6**, imply that improvements in recovery efficiency have very likely occurred. This higher N efficiency of today's systems conceptually means that attainable yield should have less impact on fertilizer N needed (**Figure 1**). Vanotti and Bundy (1994b), based on their studies in Wisconsin, concluded that mass balance approaches using attainable yield will probably result in overapplication if the N efficiency factor remains set for average conditions.

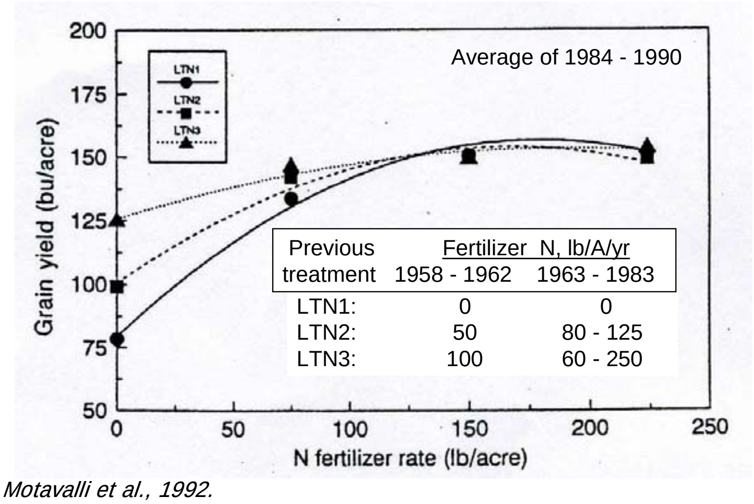
It is possible that at least a portion of the increase in apparent N removal efficiency of corn systems discussed above is due to factors other than improvement in fertilizer uptake efficiency. For example, use of conservation tillage in corn production has increased substantially in the last 30 years. Though tillage reduction initially likely reduced apparent N efficiency due to N immobilization, it is possible that conservation tillage today is enhancing efficiency of soil N use if mineralization is occurring later in the growing season compared to fall moldboard plowing (pure speculation). While a shift to later N mineralization is speculative, research comparing older and newer hybrids has shown a trend to increased N uptake later in the season (Tollenaar, 1997). Such a trait could lead to more complete utilization of the N mineralized from the soil. However, whether due to improved fertilizer uptake efficiency or soil N uptake efficiency, more corn is produced today per unit of fertilizer N used than in the past.

Long-term Stability of Recommendation Approaches

A particular fertilizer recommendation approach is often adopted by a crop adviser or farmer and used for many years. Therefore, the approach should generate stable results over time. One of the advantages to studies conducted for many years with the same treatments applied to specific areas is that the data can be queried for the best treatment over time. When residual effects of fertilizers are expected, long-term studies are invaluable. We have traditionally considered these long-term effects to be important for P and K, but have not been as concerned about them in N recommendations. However, residual effects do occur with N as well. Due to residual effects, care should be taken in relating check yields in long-term studies to delta yield approaches.

A Wisconsin study clearly illustrated residual N effects (**Figure 7**; Motavalli, et al., 1992). The average optimum N rate across a 7-year period was not influenced greatly by N fertilization history, but the yield penalty for dropping below optimum was clearly greater where less N had been historically applied.

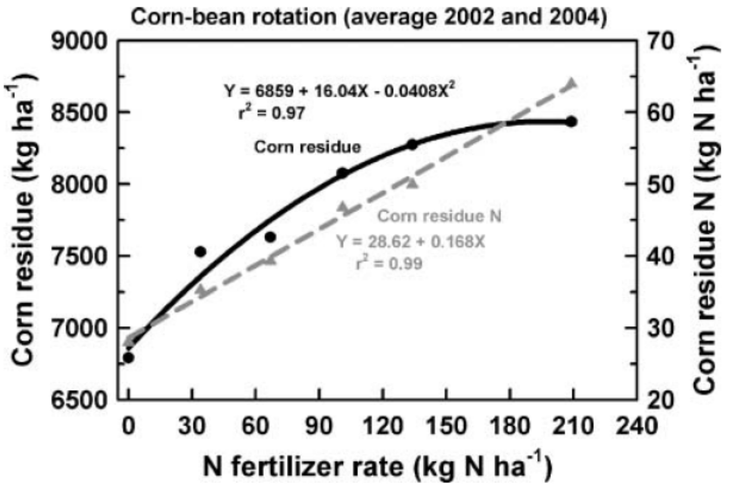
Fig. 7. Effects of long-term N fertilization treatments on grain yield N response to additional N fertilizer over a 7-year period.



Motavalli et al., 1992.

In a study of irrigated corn in Colorado, N in corn residue increased linearly with increasing fertilizer applied beyond the rate resulting in optimum grain yield (**Figure 8**; Halvorson and Reule, 2006). The authors stated that the higher N rates had more N cycling back to the soil with

Fig. 8. Corn residue production and residue N uptake in an irrigated no-till corn-bean rotation as a function of N rate.



Halvorson and Reule, 2006.

the residue than did the lower N rates.

These studies raise some concern when recommendation approaches are developed based on single-year studies where measurements are made in fields where more N has been historically applied than the study shows is optimum. Nitrogen programs appearing adequate initially may with time result in N deficiencies as less N is cycled back to the soil. High yield growers would likely encounter problems sooner than others in approaches that do not include a yield expression.

Requirements for Use of Yield Goal Approaches

As one considers the role of yield goal in appropriate context, at least three requirements for its successful use become clear:

1) Yield goal approaches are based on mass balance and therefore require estimates of both N demand and soil N supply. If N demand is allowed to vary, N supply must be allowed to vary as well. The original concept of use of attainable yield in predicting fertilizer N need clearly shows the large error that would be encountered in recommendation algorithms in which yield is a variable when all other factors are fixed. If no test for soil N is available, a site-specific assumption for most probable soil N supply would be needed that is consistent with the assumptions made resulting in the attainable yield estimate. Delta yield approaches appear to have merit for providing surrogate information for soil N supply.
2) The impact of yield goal on fertilizer N need is influenced by fertilizer efficiency, making a reasonable estimate of efficiency critical to successful use of yield goals. Much is known about the impact of soil properties and fertilizer source, additive, timing, and placement on fertilizer efficiency. Considering the diversity in source and application technologies available today, site-specific estimation of fertilizer efficiency is more critical than ever and probably needs to be an additional variable in yield goal

approaches. Estimates of fertilizer efficiency can be made from delta yield, as illustrated in **Figure 3**.

3) Assumptions made in determination or estimation of yield goal, soil N supply, and fertilizer efficiency must be internally consistent. Recognition of the association between conditions leading to a given attainable yield, soil N supply, and fertilizer efficiency is essential to avoiding inappropriate fertilizer N need predictions.

Even when these requirements are met, evidence continues to grow of the benefit of near real-time approaches (sensors, weather driven models, etc.) for making season-specific estimates of attainable yield and N supply and delaying final N rate attenuation as long as application methods will allow (Derby et al., 2004). In this case, the pre-season recommendation becomes a preliminary estimate of fertilizer need with the expectation of refinement as season-specific information becomes available.

Summary

The relevancy and limitations of using yield goal in N recommendations does not appear to have significantly changed over the last 30 years. The requirements for its appropriate use as discussed earlier are as important today as they were in the past. While today's higher N efficiencies imply that fertilizer N need is less sensitive to attainable yield, the consequences of inaccuracy in estimating optimum rates has increased, owing to higher costs for fertilizers and greater appreciation of environmental impacts.

Since the time of Sir Francis Bacon, scientific understanding has evolved as data generated by repeated experimentation allowed acceptance or rejection of hypotheses. With time, conceptual understanding of many systems has become a reality. Due to more than a century of N-focused soil and plant science, the soil-plant system and how the N cycle operates within it is one such system. We have a wealth of empirical investigations that can help define critical coefficients for critical processes or predictive functions. We have amazing technology to respond to the treasury of knowledge developed across many decades and many dedicated careers.

Growers and their advisers today need more than averaged data-based recommendations, soil N-based recommendations, or yield goal-based recommendations. They need a robust approach to N recommendations that integrates all these elements and is responsive to variation in access to technology and management approaches, recognizes obvious differences among fields or soils, and is sensitive to regional changes in climate and seasonal changes in weather or other growing-season conditions. They need knowledge-based decision aids that provide a means of integrating local expertise and site or grower-specific information into the on-farm decision making process. The challenge to the applied scientist or private entrepreneur is to synthesize scientific understanding and deliver it in a package usable inside the farm gate.

References

Anonymous. 1969. Soils and Fertilizer Guide. Agronomy Dept., South Dakota State U., Brookings.

Derby, Nathan E., Francis X.M. Casey, Raymond E. Knighton, and Dean D. Steele. 2004. Midseason nitrogen fertility management for corn based on weather and yield prediction. Agron. J. 96:494-501.

Fenster, W.E., C.J. Overdahl, G.W. Randall, and R.P Schoper. 1978. Effect of nitrogen fertilizer on corn yield and soil nitrates. Misc. Rept 153-1978. Agr. Exp. Station. U. of Minnesota, St. Paul.

Fixen, P.E. 1985. Nitrogen recommendations for corn in the North Central region. Proceedings of the 1985 Soil/Plant Analyst's Workshop. Bridgeton, MO.

Fox, Richard H., and Willam P. Piekielek. 1983. Response of corn to nitrogen fertilizer and the prediction of soil nitrogen availability with chemical tests in Pennsylvania. Bulletin 843. The Pennsylvania State U., Agr. Exp. Stat., University Park.

Kachanoski, R.G., I.P. O'Halloran, D. Aspinall, and P. Von Bertoldi. 1996. Delta yield: mapping fertilizer nitrogen requirement of crops. Better Crops 80(1):20-23.

Long, D. and T. Rosenthal. 2005. Evaluation of an on-combine wheat protein analyzer on Montana hard red spring wheat. Progress report, Zeltex, Inc., Hagerstown, MD 21740.

Lory, J.A. and P.C. Scharf. 2003. Yield goal versus delta yield for predicting fertilizer nitrogen need in corn. Agron. J. 95:994-999.

Halvorson, A.D. and C.A. Reule. 2006. Irrigated corn and soybean response to nitrogen under no-till in northern Colorado. Agron. J. 98:1367-1374.

Motavalli, P.P., L.G. Bundy, T.W. Andraski, and A.E. Peterson. 1992. Residual effects of long-term nitrogen fertilization on nitrogen availability. J. Prod. Agric. 5(3):363-368.

Mulvaney, R.L., S.A. Khan and T.R. Ellsworth. 2006. Need for a soil-based approach in managing nitrogen fertilizers for profitable corn production. Soil Sci. Soc. Amer. J. 70:172-182.

Sawyer, John E. and Emerson D. Nafziger. 2005. Regional approach to making nitrogen fertilizer rate decisions for corn. North Central Extension-Industry Conference Proceedings 21:16-24.

Sawyer, John, E. Nafziger, G. Randall, L. Bundy, G. Rehm, and B. Joern. 2006. Concepts and rationale for regional nitrogen rate guidelines for corn. PM 2015. Iowa State University, Ames, IA.

Stanford, George. 1973. Rationale for optimum nitrogen fertilization in corn production. J. Environ. Quality 2(2):159-166.

Stanford, George and Eliot Epstein. 1973. Nitrogen mineralization-water relationships in soils, Soil Sci. Soc. Amer. J. 38:103-107.

Stanford, George. 1982. Assessment of soil nitrogen availability. In F.J. Stevenson (ed) *Nitrogen in Agricultural Soils*. Agron. Monograph No. 22. Amer. Soc. Agron. Madison, WI.

Thomison, P.R., J.W. Johnson, and D.J. Eckert. 1992. Nitrogen fertility interactions with plant population and hybrid plant type in corn. In *Soil Fertility Research*. Agron. Dept. Series 219. Ohio State. U. pp 28-34.

Tollenaar, M. 1997. Yield response of old and new corn hybrids to nitrogen. Better Crops 81(4):3-5.

Vanotti, M.B. and L.G. Bundy. 1994a. An alternative rationale for corn nitrogen fertilizer recommendations. J. Prod. Agric. 7(2): 243-249.

Vanotti, M.B. and L.G. Bundy. 1994b. Corn nitrogen recommendations based on yield response data. J. Prod. Agric. 7(2): 249-256.

Yang, H.S., A. Dobermann, J.L. Lindquist, D.T. Waters, T.J. Arkebauer, and K.G. Cassman. 2004. Hybrid-maize – a maize simulation model that combines two crop modeling approaches. Field Crops Research 87:131-154.