CREATING THE SCIENCE BASE FOR NUTRIENT MANAGEMNT GUIDELINES AND POLICY: SUCCESSES AND FUTURE NEEDS

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Introduction

The goal of this paper is to review some of the soil fertility research projects I have contributed to and to make some comments about what results were successful and what areas have continuing research and education needs. In general, the purpose of much of this work was to create new knowledge and build upon existing information to provide a sound science base for nutrient management guidelines and recommendations for producers and the industry. In fact, many of the projects were initiated to answer questions or solve problems brought to our attention by farmers and the agricultural industry. The maintenance of a credible science base supporting nutrient management recommendations is made even more important when these recommendations are widely used as the basis for nutrient management regulatory policy.

Nitrogen Management

Nitrogen Rate Recommendations – Selecting the optimum N rate for a specific corn production situation is the most important N management decision for both agronomic and environmental reasons. Since 1982, more than 200 N rate response experiments with corn have been conducted under a wide range of soil, management, and climatic conditions in Wisconsin. Results from many of these experiments form the basis for our current corn N rate guidelines. Development of these guidelines emerged from work showing that optimum N rates for corn are a soil specific characteristic and are not well related to expected yield or yield goal (Vanotti and Bundy, 1994a;1994b). Recommendations introduced in 1989, were based on economically optimum N rates determined from corn N response experiments conducted on major soil groups used for corn production in the state. Recently, a regional approach to corn N rate guidelines was developed (Sawyer et al., 2006) in which corn N rate recommendations are calculated from N rate response experiments to maximize economic return to the N applied (MRTN). This MRTN approach has been incorporated into corn N rate guidelines for Wisconsin (Laboski et al., 2006), and 22 N response experiments were conducted throughout the state in 2006 to evaluate the MRTN rate guidelines and to further enhance the N response database.

Educational programs must continue to emphasize that yield expectations or yield goals are not a good predictor of corn N needs. This erroneous concept is apparently strongly engrained with corn producers. Future needs also include building the N response database through additional N rate response experiments conducted throughout the state to recognize the effects of changing production practices on corn N needs and to keep the database current. Historic data indicate that corn N use efficiency continues to increase, and this change should be reflected in future corn N rate guidelines.

Diagnostic Tests for Nitrogen – An essential component for accurate prediction of crop N needs is to account for the amounts of N supplied by the soil and other non-fertilizer N sources. Research in Wisconsin has shown that preplant soil nitrate testing (Bundy and Malone, 1988; Bundy and Andraski, 1995) and use of the presidedress soil nitrate test (PSNT) can be useful for

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improving N rate recommendations. Work based on historic data from the Lancaster Crop Rotation Experiment showed that nitrate carryover is likely in most years on medium-textured, well-drained soils in Wisconsin (Vanotti and Bundy, 1994c) and that the preplant soil nitrate test can be used to measure this N contribution. The sampling procedure for the preplant nitrate test was simplified based on work showing that the amounts of nitrate-N in the 2- to 3-ft soil depth could be reliably predicted using soil nitrate data from shallower soil depths (Ehrhardt and Bundy, 1995). The PSNT developed in Vermont and Iowa was calibrated for Wisconsin conditions and shown to be a reliable predictor of available N contributions from organic sources such as manure and previous legume crops (Bundy and Andraski, 1995; Andraski and Bundy, 2002). The more recent work (Andraski and Bundy, 2002) also identified the temperature dependency of the PSNT and that organic N credits were likely to be underestimated if early spring temperatures were more that $1^{o}F$ below the long-term average normal temperature. Work with the end-of-season corn stalk nitrate test confirmed critical values from Iowa research and showed that the test can identify sites with deficient, adequate, or excessive N supplies during the growing season (Bundy and Andraski, 1993).

Many attempts have been made to develop a diagnostic test for soil N availability, but none have proven satisfactory. The important influence of soil N supplying capability on estimating corn N needs is illustrated by a recent compilation of data on corn yield response to N fertilization from over 300 experiments in Illinois, Iowa, Minnesota, and Wisconsin showing that 50 to 70% of the observed corn yield was produced with N supplied by the soil alone (Sawyer et al., 2006). Wisconsin research to evaluate various tests for predicting soil N availability has yielded inconsistent results (Vanotti et al., 1995; Schoessow et al., 1996). Recently, a test based on soil amino sugar-N content (Illinois soil nitrogen test) received substantial publicity for its ability to predict soil N supplying capability. However, when this test was evaluated in Wisconsin and other states in the North Central Region, it was found to be ineffective in predicting soil N mineralization or corn N fertilizer needs (Osterhaus and Bundy, 2005; Osterhaus et al., 200_).

Possibly the greatest future need in this area is to continue work to develop a reliable procedure for predicting soil N mineralization on a site-specific basis. Since one-dimensional tests or procedures addressing this topic have not been successful in the past, the greatest benefits are likely to come from integrating information from several procedures to yield comprehensive information about soil N availability. This could include greater use of soil nitrate tests, which are currently under-utilized, accumulation of aerobic soil N mineralization data on a field-by-field basis, and use of an applied modeling approach that attempts to integrate some of the factors contributing to soil N supplying capability.

Corn N Response in Soybean-Corn Systems – Wisconsin's soybean acreage has increased dramatically in the last 20 years making prediction of corn N needs following soybean a critical question. Early work (Bundy et al., 1993) showed that N needs of corn following soybean were lower than those for corn following corn on medium-textured soils but that no adjustment in N rates was needed on sands and loamy sand soils. Further work (Vanotti and Bundy, 1995) indicated that a major component of the soybean effect on corn N needs was an increase in mineralization of the readily available N fraction of stable soil organic matter. Shoessow et al. (1996; 1998) found that tillage and residue management variables had little effect on N availability to corn following soybean. Collectively, these studies provided an adequate soybean-corn N response database to allow development of separate MRTN rate guidelines for this cropping system (Laboski et al., 2006). Future needs include monitoring of soil organic matter and N availability in long-term corn soybean cropping systems to measure potential declines in soil productivity due to enhanced organic matter decomposition in this cropping system. As was noted above for all cropping systems that include corn, additional N rate response experiments in soybean-corn systems are needed to enhance the N response database and to reflect the influence of changing production practices on corn N needs.

Tillage and Fertilizer Source Effects on Nitrogen Efficiency – Cropping systems with large amounts of corn residue (over 50% cover) often have increased N needs. Research in these systems showed that the increase in N requirement was largely due lower soil temperatures in high-residue systems that reduced the amount of N mineralized from organic matter during the growing season (Bundy and Andraski, 1997). Artificial cover providing the same coverage as corn residue had similar effects on N availability. In no-till corn systems, N applications to the residue in fall did not influence the rate of residue decomposition or N availability to subsequent crops (Bundy, 2001).

Ammonia volatilization losses from surface-applied urea can be a key factor affecting N use efficiency. In Wisconsin, maximum losses from urea-containing fertilizers applied to corn or grass pastures range from 20 to 25% of the applied N (Oberle and Bundy, 1987; Bundy and Oberle, 1988). Typical losses are usually substantially less than this due to climatic effects that influence these losses. However, these losses are often large enough to influence yields. For example, surface applications of 28% N solution were less effective than ammonium sulfate in no-till corn systems in two of three years (Bundy, 2001).

Nitrate leaching losses can also have major effects on N efficiency and potential losses of nitrate to groundwater, especially on coarse-textured soils. Timing of N applications (sidedress and split applications) and use of nitrification inhibitors with ammonium N sources can help control these losses. Polymer-coated urea materials can also reduce leaching losses especially where N is applied early in the growing season. Future needs include continued development and evaluation of fertilizers, fertilizer amendments, and application techniques to control ammonia loss from urea-containing fertilizers. It will also be increasingly important to recognize tillage and residue combinations that may affect N availability and use effective N application strategies to avoid N deficiencies.

Nitrogen Management for Winter Wheat – Studies to determine optimum N rates for wheat and to evaluate diagnostic tests to predict wheat N needs were conducted at 21 site-years (Bundy and Andraski, 2004). Results helped to establish current wheat N rate recommendations and showed that excess N fertilization lowered yields and economic return. The preplant soil nitrate test (conducted in August or September) was the best predictor of wheat N needs, and results supported the idea that winter wheat accumulates a substantial portion of its N requirement before dormancy. Future needs include expanding the wheat N response database to allow extension of the MRTN approach to N rate guidelines to include wheat. Additional work is necessary to identify optimum timing and N source effects on wheat N response including use of urease inhibitors and polymer-coated urea. Research is also needed to identify the mechanisms responsible for the decline in wheat yields with excess N.

Long-term Nitrogen Response Experiments – The value of long-term experiments is that they can often provide answers to current questions that were not being asked when the experiments were started years earlier. For example, the long-term continuous corn experiment at Arlington (established in 1958) and the Lancaster crop rotation experiment (established in 1967) have provided research environments for studies on long-term effects of N fertilization on soil N availability (Motavalli et al., 1992; Vanotti and Bundy, 1996; Vanotti et al., 1997), nitrogen carryover potential (Vanotti and Bundy, 1994c), long-term N use effects on soil productivity (Bundy et al., 2000), soybean N contributions to subsequent crops (Vanotti and Bundy, 1995), and N credits from legumes grown in crop rotations. Numerous studies in disciplines other than soil science have also utilized these experimental sites. An obvious need is to secure adequate permanent funding to maintain these long-term studies for use in future research.

Environmental Impacts of Nitrogen Management – Although it is well known that N management variables can influence the potential for N losses from cropland, few studies have actually measured N losses occurring under different N management regimes. Research with several cropping systems and N application rates in corn production showed that soil water nitrate-N concentrations at the bottom of the corn root zone increased as the amount of N applied in excess of the observed optimum N rate increased (Andraski et al., 2000). Results indicated that the amount of excess N applied and not the total N rate was the major factor controlling nitrate N losses. Subsequent work using isotopically labeled N fertilizer for sweet corn and potato on sandy irrigated soils showed that whole plant N recovery at recommended N application rates averaged 54 and 34% for sweet corn and potato, respectively (Bundy and Andraski, 2005). Very little fertilizer N was recovered by a winter rye cover crop or by a subsequent corn crop indicating that fertilizer N not recovered by the crop during the growing season is likely lost by leaching on these soils.

Corn Response to Starter Fertilizer

Use of starter fertilizer in corn production is a widespread and often profitable practice in Wisconsin. With increasing state-wide average soil test P levels and growing concerns about excess soil P contributing to P losses in runoff, the importance of starter fertilizer use needed evaluation. An initial examination of tillage, planting date, and starter fertilizer composition showed that the largest responses to starter fertilizer occurred in no-till systems with late planting dates (Bundy and Widen, 1992). This work also showed that the most consistent responses were obtained when starter fertilizers contained all three major nutrients (N, P, and K). Later work at 100 on-farm sites throughout the state showed that 40% of these sites gave a profitable response to side-placed starter fertilizer containing N, P and K, although most had excessively high soil test P and K levels (Bundy and Andraski, 1999). The major factors affecting starter response were planting date, hybrid relative maturity, and soil test K. The probability of response to starter on high-testing soils can be predicted based on planting date and hybrid relative maturity with the more frequent responses occurring at late planting dates with long-season hybrids (higher relative maturity). The starter fertilizer response with late planting dates and long-season hybrids is probably due to stimulation of early season corn growth rates by the starter fertilizer resulting in a realization of more of the crop's yield potential by the end of the growing season.

Implications and future needs emerging from this work include the following. The trend away from starter fertilizer use due in part to larger planters and time considerations probably means that growers are giving up yield increases that could be provided by starter fertilizer. The response to a side-placed N-P-K starter fertilizer usually cannot be obtained with other fertilizer application methods including broadcast treatments and use of low rates of fertilizer placed with the seed. Trends toward low rate starter applications that contain little or no K probably contribute to a growing problem with K deficiency. Potassium fertilizer use in Wisconsin has decreased substantially in recent years, and this trend needs to be reversed if major problems with K deficiency are to be avoided. Research needs include development of starter fertilizer application technologies that are compatible with large planters and minimize time requirements.

Management Practice Effects on Phosphorus Losses in Runoff

In 1998, a research effort was initiated to provide the research base to support phosphorus-based nutrient management planning in Wisconsin. These studies established the interactive effects of variables including soil test P, tillage, and manure applications on the relative risk of P losses in runoff from cropland (Bundy et al., 2001; Andraski and Bundy, 2003; Andraski et al., 2003). Additional work showed that excessive P levels in dairy diets resulted in higher manure P concentrations and substantially higher P losses in runoff when these manures were land applied (Ebeling et al., 2002). Roberson et al. (2007) showed that P losses from plant residues, such as alfalfa, could contribute to P in runoff from cropland, particularly after freezing or drying of the plant materials, but that these losses were strongly influenced by climatic variables.

Results from these and other studies were used to construct the Wisconsin P index, which is a semi-quantitative model for predicting the risk of runoff P losses on a field specific basis http://wpindex.soils.wisc.edu/. The P index is one of the options for P-based nutrient management planning included in the NRCS Nutrient Management Standard (590) which contains the requirements for nutrient management planning in the state. The effectiveness of the P index in identifying the risk of P losses in runoff was evaluated by comparing P-index values with field-scale annual P loss measurements. Results showed that the P-index was very effective in predicting the P losses that were observed in the field (Good and Bundy, 2005; 2006). To facilitate use of the P index in nutrient management planning, the index was incorporated into the SNAP-Plus nutrient management software program http://www.snapplus.net. This program calculates field-by-field P index values and provides nutrient application guidelines according to University of Wisconsin recommendations and the NRCS 590 nutrient management standard. It also provides a RUSLE2-based soil loss assessment that will allow producers to determine whether fields which receive fertilizer or manure applications meet tolerable soil loss (T) requirements.

Since much of the data base used to construct the P-index was obtained in small plot research, the effect of scale of measurement on observed P losses was compared at the plot and sub-watershed scale (Bohl et al., 2006). Results showed that P concentrations in runoff were usually similar between the two scales of measurement, thus confirming the validity of using small plot research data to develop P loss risk assessment tools like the P-index.

Future research needs include continued expansion of the P-index to include additional cropping systems and management scenarios. Since P loss risk is highly climate sensitive, further validation studies comparing predicted and observed P runoff losses under various climatic conditions are needed. The SNAP–Plus nutrient management planning software requires frequent updating to incorporate emerging research results.

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