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In Search of Nitrogen Efficiency

Nebraska MSEA project explores ways to improve crop N use efficiency.

Summary: *Nitrate contamination of ground water is often attributed to the nitrogen (N) fertilizer that producers apply to crops. Efforts to minimize nitrate leaching can take many forms, de-pending on the cropping system. Management practices that improve N use efficiency by crops will be a major component of environmentally sound and profitable cropping systems of the future.*

The Nebraska Management System Evaluation Area (MSEA) project is an example of how N and water management practices can be modified to improve crop N use efficiency. The objective of this demonstration/research project is to develop and implement cropping systems that reduce the potential for nitrate contamination of ground water in the Platte River Valley of Central Nebraska. This project near Shelton, Nebraska, is one of five such lo-cations (Ohio, Missouri, Iowa, Minnesota and Nebraska) in the U.S. that are part of the President's Water Quality Initiative. The scope of each project and the approach taken at each location are unique because of the different climatic conditions, soil characteristics and cropping systems for the areas.

Nitrogen management options avail-able to producers vary by regions, but to be practical they must be compatible with existing cropping systems. Producers with irrigation may have the opportunity to fertigate, which extends the traditional window for fertilizer applications. Dryland producers can also apply N fertilizer after sidedressing by using high-clearance vehicles (i.e. spoke injectors), but this approach is less convenient than fertigation and is plagued with the uncertainty about N availability to the roots when applied in dry soil.

Irrigated corn producers who choose to rely on fertigation to apply part or all of their N fertilizer expose themselves to the risk of not needing to irrigate at times when the crop requires N. However, environmental considerations and a shift toward more automated irrigation systems (sprinkler and gated pipe with surge-flow control valves) have prompted more and more producers to consider fertigation for part of their N needs. Any discussion of fertigation requires one to consider the uniformity of water application, because an irrigation system that has poor water distribution will not apply fertilizer uniformly and could even enhance ground water contamination by nitrate.

Considering the water management options available to producers, the Nebraska MSEA project was designed to compare nitrate leaching, productivity and profitability of a conventional irrigated corn cropping system with a somewhat more costly alternative using surge-flow irrigation and a more costly center-pivot irrigation system. Each of these cropping systems offers unique features that can be viewed as either an opportunity or a limitation. Fertigation is one of the primary N management options associated with irrigation systems, provided water is distributed uniformly. Therefore, fertigation was considered a viable management practice for the surge-flow and sprinkler irrigation systems above. Other management practices imposed on the cropping systems as appropriate were:

Conventional Furrow
- soil testing
- furrow irrigation
- diked-end furrows
- preplant N fertilizer

Surge-flow Furrow
- soil testing
- laser grading
- runoff recovery pit
- irrigation scheduling
- limited sidedress N or fertigation

Sprinkler
- soil testing
- tissue testing
- fertigation
- irrigation scheduling

Table 1. Nitogen characteristics of the Nebraska MSEA site.

Irrigation system	Residual Soil N* (lb/acre)	Starter N (lb/acre)	Other N fertilizer (lb/acre)	Fertilizer Method	Irrigation water N** (lb/acre)
1991					
Conventional	95	30	150	preplant (NH_3)	269
Surge-Flow	154	30	80	sidedress (NH_3)	129
Center-Pivot	85	30	0	fertigation (NH_3)	97
1992					
Conventional	108	19	140	preplant (NH_3)	212
Surge-Flow	121	19	46	sidedress (NH_3)	66
Center-Pivot	70	19	23	fertigation (NH_3)	60

* Total residual N (nitrate-N) to a depth of 3 ft.

** Estimated credit for nitrate-N in irrigation water for the purpose of making fertilizer N recommendations was 69 lbs N/acre (9.5 inches average application at 32 ppm (mg/L) nitrate-N or approximately 7 lb N/acre-inch.

Table 2. Production characteristics at the Neraska MSEA site.

Irrigation system	Water applied* (in)	Fertilizer N (lb/acre)	Fertilizer N cost** ($/acre)	Total N efficiency (%)	Grain yield (bu/acre)	Return*** after fert ($/acre)
1991						
Conventional	37	180	$27.50	28	199	$470.50
Surge-Flow	18	110	$20.50	35	196	$469.50
Center-Pivot	13	30	$6.00	58	194	$479.00
1992						
Conventional	29	159	$24.30	30	207	$493.20
Surge-Flow	9	65	$13.00	48	200	$487.00
Center-Pivot	8	42	$8.40	48	175	$429.10

* Growing season rainfall roraled 3 and 12 inches in 1991 and 1992, respectively.

** Nitrogen at $0.10/lb, plus $6.50/acre application cost; UAN in starter and for fertigation at $0.20/lb.

*** Market value of grain at $2.50/bu minus fertilizer N expenses.

N dynamics

Three nearly square 33-acre irrigated corn fields with individual irrigation wells were established in 1990 to demonstrate the impact of the above cropping systems on ground water quality. The predominant soil type was a nearly level Hall silt loam. Each of the fields received a preplant application of 150 lb N/acre in 1990. Planted corn received 30 lb N/acre as a starter fertilizer. Flow meters were installed on the wells and fields were furrow irrigated according to traditional producer practices. Grain yields were similar for all three fields (averaging 196 bu/acre) and irrigation application ranged from 36 to 48 inches in 1990.

After installation of the irrigation systems in the Spring of 1991 and before planting, soils from each field were sampled to a depth of 4 feet for residual soil N. Yield expectations for the fields were set at 200 bu/acre and used to calculate fertilizer N recommendations according to University of Nebraska procedures. The conventional cropping system is common to the area, which is under a N management program imposed on producers by the Central Platte Natural Resource District (CPNRD). Soil test data, fertilizer applications and nitrate contained in irrigation water for 1991 are shown in Table 1. Three adequately fertilized test strips (six rows wide receiving 150 lb/acre as sidedress N) were established in each field for comparison purposes to evaluate crop N status in the surge-flow and sprinkler irrigated fields. Chlorophyll meters (SPAD ***502*** manufactured by Minolta Corp.) were used to routinely monitor crop N status of fields on a weekly basis by comparing meter readings from the bulk field with those from adequately fertilized test strips.

An N sufficiency index of 95% was established as the threshold level to trigger fertigation (20 to 30 lb N/acre as UAN). Comparison data from the sprinkler irrigated field never indicated crop N stress, therefore no fertilizer N was applied via fertigation in 1991. Similarly, chlorophyll meter data collected from the surge-flow irrigated field never indicated an N stress. Provisions and procedures were not available to fertigate the surge-flow irrigated field in 1991. These two improved N and water management strategies were able to maintain productivity in 1991 without statistically reducing yields (Table 2). Slight apparent yield reductions for the surge-flow and sprinkler irrigated fields are attributed to minor equipment problems resulting in delayed application of the first irrigation in late June when climactic conditions were unusually hot and dry.

Grain yields in 1992 were slightly lower (approximately 3%) under surge-flow irrigation than under conventional practices (Table 2). Yields determined at 12-row intervals across both fields indicated that the reduction occurred in the area of the surge-flow irrigated field where laser grading removed up to 8 cm of topsoil in the fall of 1990. These areas were visible in aerial photographs taken at silking, but only one of the three producer test strips that received extra fertilizer N could be detected in the photo. Nevertheless, average yield from the three test strips in the surge-flow irrigated field was 206 bu/acre, compared to 209 bu/acre for adjacent strips that only received starter fertilizer and fertigation applied N (Table 1).

Yield reductions of 15% under the sprinkler irrigation strategy in 1992 are attributed to 1) lower levels of residual soil N in the spring compared to the surge-flow irrigated field and 2) a lower rate of starter fertilizer application than in 1991 (Table 1). Inadequate N availability during the rapid growth stages (four weeks prior to silking) could also contribute to the lower yield under sprinkler irrigation in 1992. However, chlorophyll meter data indicated that the average crop N sufficiency level was never lower than 95%, compared to the adequately fertilized reference strips, except just prior to the single fertigation application. Yield reductions under the sprinkler system in 1992 suggest an apparent failure of the chlorophyll meter strategy to schedule fertigation, but aerial photographs showed the problem was with locating the adequately fertilized test strips. Unfortunately, one of the old 1991 test strips confounded interpretation of the 1992 chlorophyll meter data, which resulted in the erroneous decision to limit fertigation.

Yields and grain protein contents (averaged 8.3%) were similar for the three fields in 1991, resulting in grain N removal of approximately 124 lb N/acre. Grain N removal averaged 123, 117 and 90 lb N/acre in 1992 for the conventional, surge-flow and sprinkler irrigated fields, respectively. Comparing grain N removal with the sum of N availability for each irrigation system, including mineralized N, illustrates why N use efficiency would tend to be greater for the sprinkler system. Mineralized N is expected to be similar for each field, since cropping histories were similar prior to this study, but leaching and de-nitrification would lead to greater N losses under the conventional system. Estimated N mineralization at an annual rate of 3% of the organic N (soil with 2% organic matter) in the surface foot amounts to approximately 138 lb amounts to approximately 138 lb N/acre/yr. Assuming that only two-thirds of the N that mineralized annually would be available during the growing season, then one could add about 90 lb N/acre to the estimate of N availability. Interpretation of such comparisons involves several assumptions that are not easily documented, but estimates (data from Tables 1 and 2, plus mineralization estimate) show that approximately 632, 482 and 301 lb N/acre would be avail-able at various times during the growing season for the conventional, surge-flow and sprinkler irrigation systems in 1991, respectively. Similar values for 1992 are 568, 341 and 261 lb N/acre, respectively.

Total N uptake by irrigated corn is approximately 41% more than grain N uptake, so on this basis the 1991 corn crop would be expected to use about 175 lb N/acre. Excluding N losses and based on the above annual estimates of N availability, inorganic N use for these cropping systems ranged from 28 to ***58%*** (Table 2). The numeric value of these estimates is probably less important than the relative ranking, because it helps to identify cropping systems that intuitively should reduce the potential for nitrate leaching and ground water contamination. These data illustrate that N management practices that ultimately reduce yields can also reduce N use efficiency (Table 2). Nitrogen use efficiency of fertilizer alone cannot be calculated from this data, because check plot yields were not available.

Cost of N fertilizer is only one factor that producers must consider when making N management decisions. The 1991 production data (Table 2) illustrate that reducing fertilizer N costs can add to profitability provided yields do not de-crease significantly. But once yields de-cline very much so does profitability (as in 1992). Profitability considerations also need to include irrigation costs and how the equipment costs are amortized, which are beyond the scope of this article. These data illustrate that a "fertilization-as-needed" strategy can maintain productivity and perhaps even increase profitability. They also show that marginal or N deficient conditions can significantly reduce yields and profits.

The above scenarios are an obvious oversimplification of the N dynamics involved in irrigated corn production. At the very least, N availability and crop needs (i.e. synchronization) should be considered for key times during the growing season. When this is done, it will become apparent why producers develop preferences for certain fertilizer practices (i.e. preplant, starter, nitrification inhibitors, etc.) that they find to work well for their soils, climatic conditions and tillage systems. Unknowingly, producers put priorities on the various N sources, based on how they manage fertilizer N inputs. Awareness of the various N sources and how they contribute to the available N pool in soil compared to crop N needs can lead to N and water management practices that improve fertilizer N use efficiency and protect the environment.

Why BMPs

Improving N use efficiency of crop-ping systems seems to be an implied goal of producers and society alike. Although the reasons we strive to improve N use efficiency of crops may differ, most people intuitively agree that it should help protect drinking water from contamination by nitrate. Implementing management practices that improve crop N use efficiency would seem to be the natural thing to do, but many factors tend to impede adoption of what are commonly termed best management practices (BMPs).

Producer priorities affect the implementation of BMPs because adoption requires individuals to make trade-offs. These trade-offs take many forms and are influenced by factors that are hope-fully based on sound scientific facts and prudent economic consideration. Built into all of these considerations is a risk factor that may place producers in a real or perceived state of vulnerability. These risks are the integration of many factors that can, in some way, be quantified, but include other considerations, such as peer pressure, that can only be described or characterized.

Perhaps the most immediate concern of producers, when considering modifying a management practice, is that of economics. The combination of short-and long-term economic implications weighs heavily with producers because cropping systems must be sustainable. Beyond that, producers must be able to deal with modified time commitments of any new cropping system and they must have the technical expertise to successfully integrate the ever-increasing number of management considerations. These needs open the door for crop consultants and others who can provide information to help producers make higher-level management decisions. For N management decisions, the options may seem to be quite extensive. But, in reality, changing one management practice can impact a number of subsequent management decisions and can even limit the options available to producers.

Nearly all N management decisions affect crop N use efficiency in some way. Traditionally, scientists use tagged-N fertilizers or compare crop N uptake from plots receiving N fertilizer with unfertilized check plots to calculate how much of the fertilizer was used by the crop. Both of these methods require special considerations when interpreting data, because there are other sources of N (i.e. manure, residual N, mineralization, irrigation water) in addition to fertilizer. There are also other demands for N fertilizer within the soil system (i.e. microbial immobilization). These considerations all tend to decrease the measured N use efficiency because they either dilute the fertilizer with other N sources or temporarily reduce the fertilizer availability to the crop. Interpretation of crop N use efficiency data also requires some knowledge of synchronization between crop N needs and soil N availability for the different stages of crop growth.

Another way to think about crop N use efficiency is to simply compare N inputs from all sources with crop N removal. This approach to N budgeting is generally thought to be less precise than the above fertilizer N use efficiency calculations, but tends to integrate the various N transformations that take place in soil. The latter approach requires some assumptions and/or estimations to quantify the N inputs, but this concept is frequently adequate to evaluate the economic and environmental implications of a cropping system.

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