INSIGHTS
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Capturing Residual Soil Nitrogen with Winter Cereal Cover Crops

The enduring and widespread drought this summer has resulted in reduced crop growth, poor yields, crop failures, and anticipated increases in residual nitrate-nitrogen (RSN) in the soil profile. When no nitrogen (N) is applied to productive Midwestern soils that have subsurface or tile-drains, nitrate-N losses commonly range from 8 to 20 lbs/A with nitrate-N concentrations in the drainage of 3 to 10 mg/L or ppm. Corresponding nitrate-N losses from recommended fertilization rates are often between 25 to 50 lbs N/A and 10 to 30 ppm (Sawyer and Randall, 2008). Many are asking if winter cereal cover crops (cereal rye, wheat, oats, or annual ryegrass) could help capture the RSN this fall and early winter, help prevent leaching and subsurface/tile drainage losses, and return some of that recovered N during the growing season of the crop planted next spring.

To help answer some of these cover crop N retention questions, we have referred to several important publications in preparing the information presented in this brief. Those review papers and book chapters (e.g. Kaspar et al., 2008; Dabney et al., 2010) and other cover crop management resources are shown in the reference list at the end of this brief. We will only use selected highlights, because the effects of cover crops on N in cropping system productivity and on environmental impacts have been reviewed by others.

We will consider two general approaches for managing RSN after a drought. The first is to use a cover crop and the second is to monitor RSN and adjust N addition.

To understand the potential to capture RSN following a drought in soils supporting either continuous corn, or corn-soybean systems, it is helpful to look back and consider observations from scientists who experienced the last major drought in 1988. The approach of using a cereal rye cover crop in the 1988 drought has been reported from Maryland by Brinsfield and Staver (1991), and the approach of monitoring and adjusting N additions has been reported from southwestern Minnesota by Randall et al. (1997).

Like much of the rest of the nation in the 1988 drought, Maryland's corn suffered, achieving only 50% of normal yields as a result of rainfall which was 48% below normal from the late-vegetative through early-grain fill period. Fortunately, an existing long-term study was underway in small watersheds in the Atlantic Coastal Plain (Brinsfield and Staver, 1991; Staver and Brinsfield, 1998), which provided data to compare the ability of a cereal rye cover crop versus no winter cover crop to capture RSN. The study used a continuous corn system receiving 140 lbs of fertilizer UAN-N/yr, with the cereal rye planted on October 1 of 1988, about two weeks before the average frost date. Soil samples were collected in 6-inch increments to a depth of five feet on November 1 and again on December 1, 1988, and analyzed for nitrate-N. Total above-ground rye samples were also collected and analyzed for total N. **Figure 1** summarizes these data and shows that the soil contained 191 lbs of RSN/A in the no cover crop treatment, while the soil under the rye cover crop contained 34 lbs/A less on November 1, 1988, which is consistent with the measured rye N uptake of 39 lbs of N/A on November 1. Most of this N came from the surface six inches of soil. A month later (December 1), the soil without a cereal rye cover crop had not lost any RSN (although the nitrate-N had moved deeper in the soil profile), but the rye cover crop had taken up 75 lbs of N/A, with most of that N absorbed from the surface two feet of the soil (**Figure 1**). These data clearly show the ability of a simple cereal rye cover crop to convert mobile soil nitrate-N into immobile plant protein and thereby sequester RSN within the soil N cycle.

The ability of a cereal rye cover crop to prevent nitrate-N leaching in a corn-soybean system was also shown in a study using large replicated plots on a subsurface-drained field (tile at 4 feet) in Iowa, which contained Canisteo and Nicol-

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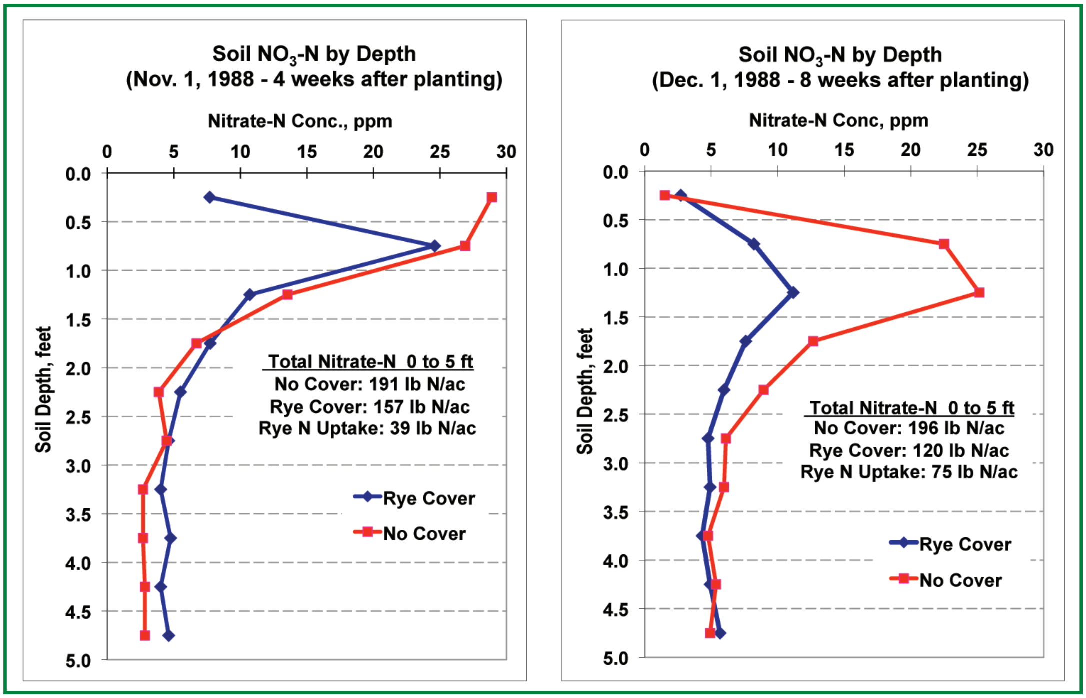

Figure 1. Fall soil profile nitrate-N at two dates following the growing season drought of 1988 in a continuous corn system, with and without a cereal rye cover crop in Maryland (adapted from Brinsfield and Staver, 1991; Staver and Brinsfield, 1998).

let soils (Kaspar et al., 2007). The goal was to evaluate the effects of a rye cover crop versus no cover crop on RSN, and on tile drainage nitrate-N concentration and load over four years. Rye was planted annually after the corn and the soybean harvest. Crop yields and rye N uptake were measured, tile drainage was continuously monitored and analyzed for nitrate-N, and soil samples were collected in early to mid-November each year to a depth of four feet and analyzed for nitrate-N. The data from this Iowa study are summarized in **Figure 2**. The rye cover crop was an effective scavenger of the RSN (**Figure 2a**), even though none of the years was a significant drought year. The low rye N uptake in 2003 was due to a poor aerially seeded stand that germinated in the midst of a warm-dry fall, causing seedling mortality. The rye cover crop took up considerable N, which resulted in lower nitrate-N concentrations (**Figure 2b**) and lower tile drainage nitrate-N loads compared to no cover crop (**Figure 2c**). The ability of a well-established rye cover crop to scavenge and take up N in amounts within the common range of RSN in this Iowa study (**Figure 2a**), illustrates the flexibility of this cover crop to conserve RSN and the potential to help protect water quality with grass cover crops.

Managing residual soil N after a drought by monitoring and adjusting fertilizer N

In a southwestern Minnesota study, Randall et al. (1997) measured: soil profile RSN (spring and fall), crop yields (see corn yields in **Figure 3a**), total above-ground N uptake, and nitrate-N losses to tile drainage in continuous corn and corn-soybean systems. Their measurements occurred between 1988 and 1993, and included drought years 1988 and 1989, which received 64 and 73% of long-term normal rainfall during the growing season, respectively. In 1990, the growing season rainfall was normal (approx. 21 inches), while subsequent years experienced above-normal rainfall during the growing season. The annual N application rates for corn followed the University of Minnesota Extension recommendations at the time, and were adjusted in consideration of: the nitrate-N content in soil samples taken from 0 to 48 inches in April, the previous crop (corn or soybean), moldboard plow primary tillage, and a yield goal of 140 bu/A (Randall et al., 1997). The fertilizer N source was urea, broadcast each spring and incorporated within 24 hours by tillage. Corn yields and total N uptake were significantly reduced by drought in 1988, with increased yields in the subsequent two years, and more typical yields and N uptake in 1991 and 1992 (**Figure 3a**). Significant RSN was observed in the soil profile beginning in the fall (measured in late October) of 1989, the spring of 1990, and continuing into the spring of 1991 (**Figure 3b**). This significant rise in RSN after drought is especially noteworthy, since only 50 lbs of N/A had been applied to corn plots in the study area from 1980 to 1987, in order to reduce the effects of residual nitrate-N and residual organic-N from prior studies before these studies began in the spring of 1988.

In this southwest Minnesota study (Randall et al., 1997), higher RSN levels in the upper 48 to 60 inches of the soil in the fall of 1989 and the spring and fall of 1990 (**Figure 3b**) were generally reflective of the lower total above-ground N uptake in the cropping systems in 1988 and 1989 (**Figure 3a**), but did not result in increased nitrate-N loss to tile drainage until 1991 (**Figure 3c**) because the drought stopped tile drainage. The magnitude of this RSN following 1988 is striking, but in agreement with the yield and N uptake data shown in **Figure 3a**. It is important to note again that spring RSN levels were used to downward adjust spring fertilizer N rates in this Minnesota study (**Figure 3c**), which illustrates the second approach that farmers and their crop advisers can use to reduce the risks of inefficient N utilization and N loss to water resources.

According to Randall and Mulla (2001), *"Noncontrollable factors such as climate and soil organic matter have a profound influence on nitrate-N concentrations and loadings in subsurface drainage water. The dynamics of N behavior in drained agricultural soils during these periodic climatic events and the management of both crops and nutrient inputs (controllable factors) must be considered carefully by agriculturalists as they manage the land. Furthermore, these factors must be understood by scientists and policymakers as they educate the public and develop environmental guidelines regarding nitrate loading to surface waters."*

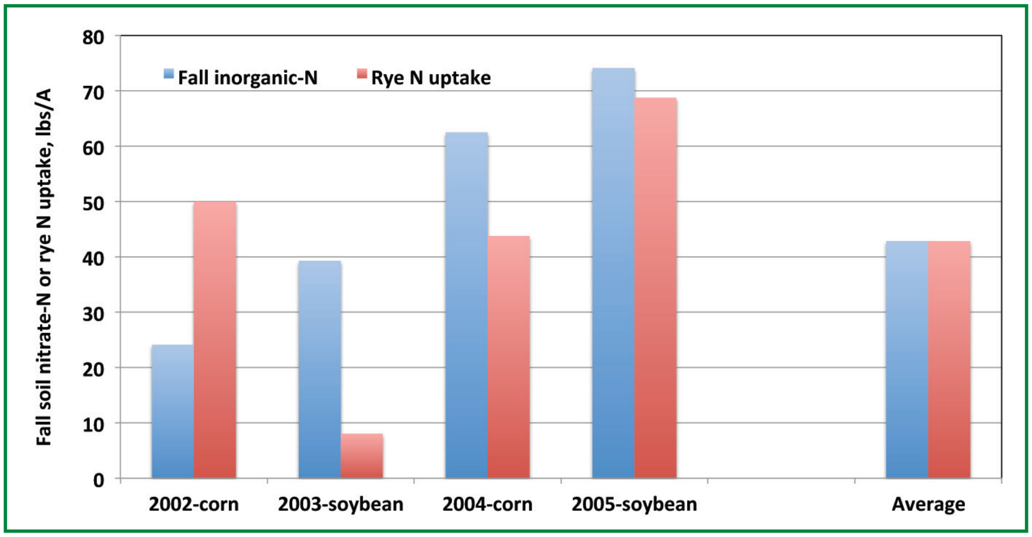

Figure 2a. Effects of a cereal rye cover crop on fall soil N and rye N uptake in corn-soybean production systems in Iowa (Kaspar et al, 2007).

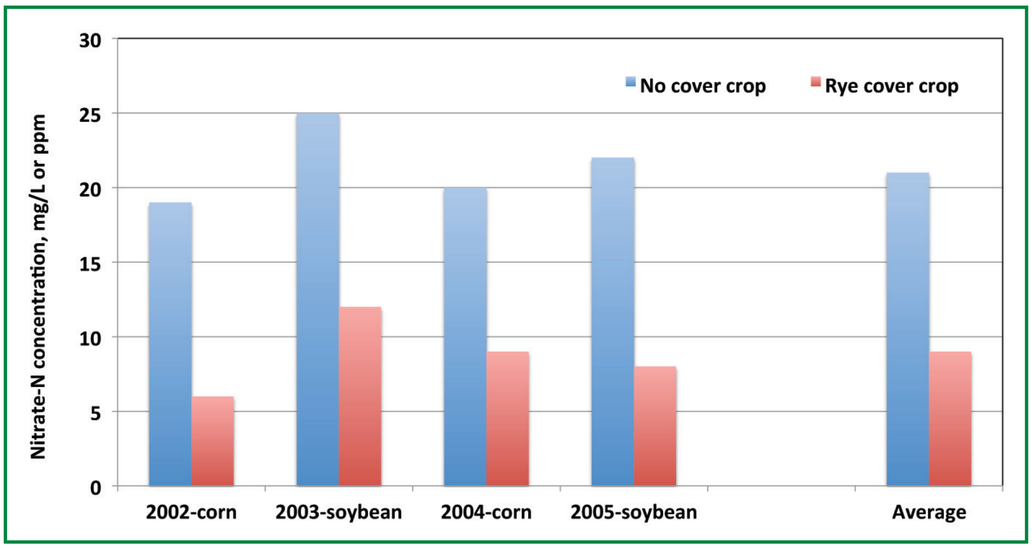

Figure 2b. Effects of a cereal rye cover crop on subsurface tile drainage nitrate-N concentrations in corn-soybean production systems in Iowa (Kaspar et al, 2007).

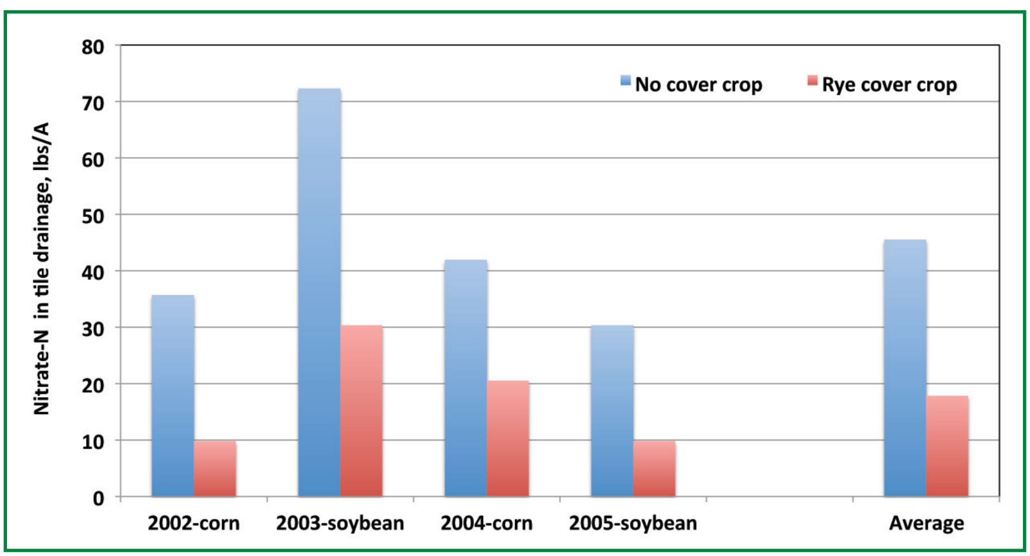

Figure 2c. Effects of a cereal rye cover crop on nitrate-N loads in corn-soybean production systems in Iowa (Kaspar et al, 2007).

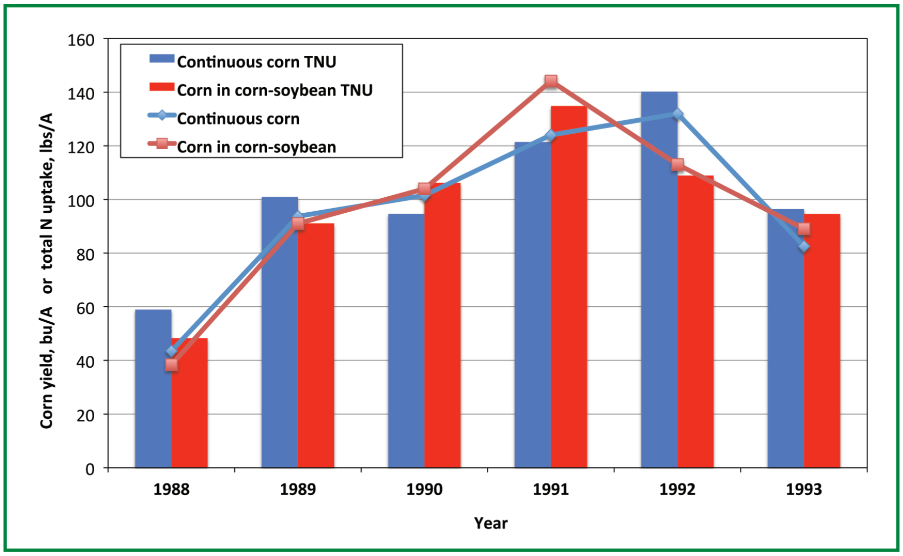

Figure 3a. Effects of the 1988 and 1989 drought years on corn yields and total N uptake (TNU) in southwestern Minnesota (Randall et al., 1997). Note: spring nitrate-N samples were collected in April at 0 to 60 inches and fall samples were collected in October at 0 to 48 inches.

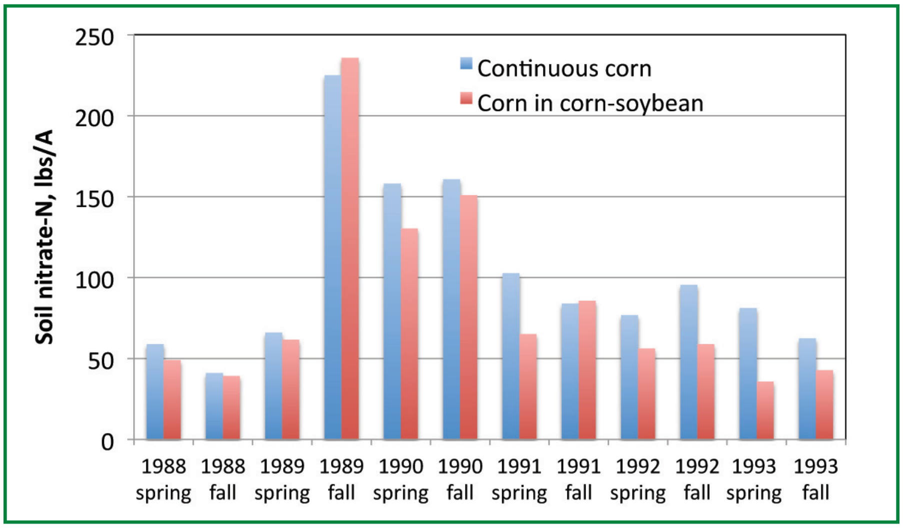

Figure 3b. Effects of the 1988 and 1989 drought years on fall and spring soil nitrate-N in the root zone in southwestern Minnesota (Randall et al., 1997). Note: spring nitrate-N samples were collected in April at 0 to 60 inches and fall samples were collected in October at 0 to 48 inches.

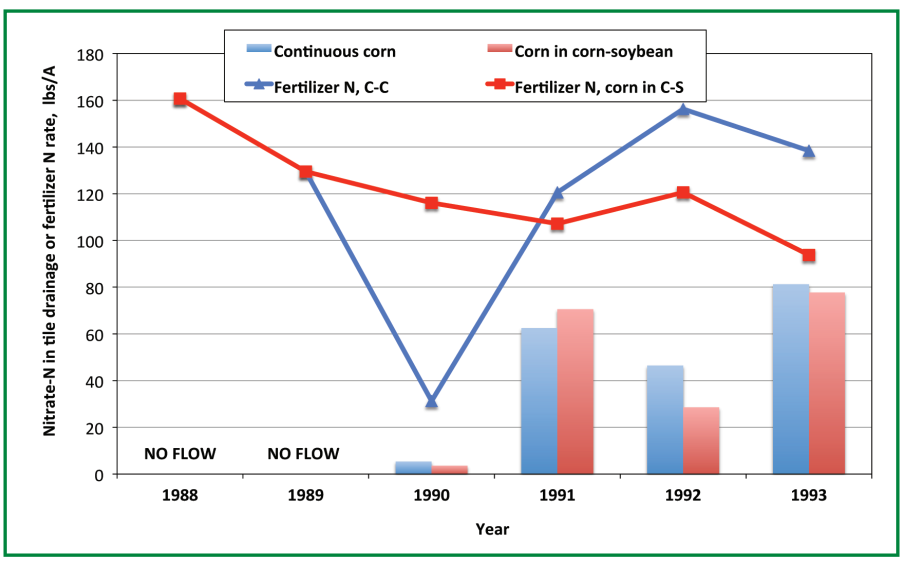

Figure 3c. Effects of the 1988 and 1989 drought years on tile drainage nitrate-N losses and adjustments to fertilizer N applied to continuous corn and corn in corn-soybean production systems in southwestern Minnesota (Randall et al., 1997).

Broad geographic potential to reduce soil N loss with winter grass cover crops

Cereal cover crops hold significant potential for reducing RSN leaching and drainage losses, with reductions often ranging above 60% (Kaspar et al., 2008), depending on the location, cropping system, amount of cover crop growth, and environmental conditions (**Table 1**). Additionally, winter cereal cover crops help reduce surface runoff loss of phosphorus (P), with reductions in loss ranging from 54 to 92% in several studies (Kaspar et al., 2008).

Table 1. Percent reduction in nitrate-N leaching losses with grass winter cover crops (adapted from Kaspar et al., 2008, including citations in Meisinger et al., 1991).

Location of cited study, (year published)	Cover crop	Reduction in nitrate-N leaching, %
California, U.S. (1996)	Rye	65 to 70
Connecticut, U.S. (1942)	Rye	66
Delaware, U.S. (1998)	Rye	30
Denmark (1985)	Ryegrass	62
France (1990)	Ryegrass	63
Indiana, U.S. (2004)	Winter wheat and less fertilizer	61
Iowa, U.S. (2007)	Rye	61
Kentucky, U.S. (1950)	Rye	74
Kentucky, U.S. (1994)	Rye	94
Maryland, U.S. (1990)	Rye	77
Minnesota, U.S. (2004)	Rye	13
Oregon, U.S. (1997)	Rye	32 to 42

Research has also shown that annual ryegrass is often superior to annual winter cereal grasses (oats, wheat, rye) in scavenging soil N. But any grass cover crop raises spring management challenges with termination of growth and risks of potential soil moisture deficits for the targeted cash crop. Conversely, in wet springs, grass cover crops may provide beneficial moisture draw-down and facilitate timely spring planting. Successful N scavenging from any winter cover crop heavily depends on timely fall planting, favorable weather, and the extent of root growth. Successfully established winter grass cover crops can take up more than 60 lbs of N/A in many central Midwest states, and more than 100 lbs of N/A in Atlantic Coast states, depending on the quantity of RSN. Isotopically-labeled N (^{15}N-RSN) studies in Maryland measured cover crop above-ground ^{15}N uptake and estimated root ^{15}N in the spring, and showed that a cereal rye cover crop recovered 50 to 60% of the labeled RSN, while annual ryegrass recovered 40 to 50%. The recovery of labeled RSN by these grass cover crops was substantially higher than the recoveries using hairy vetch, crimson clover, or native weeds; which amounted to less than 10% of the labeled RSN (Shipley et al., 1992).

N release from annual winter grass cover crops, plus other benefits of cover crops

Synchrony of N release from winter cereal cover crops is hard to predict and to manage, and release may not occur until well into the growing season of the spring-planted crop. The release of scavenged N from grass cover crops has been shown to be quite small (with negative releases often reported, i.e. somewhat higher N additions are needed for the next crop). This is because the vast majority of the scavenged N is returned to slowly decomposing components of the soil N cycle. However, the dynamics of cover crop decomposition and N mineralization will vary depending on the number of years the cover crop has been part of the cropping system, the cover crop residue carbon to nitrogen ratio (C:N), soil microbial activity, soil temperature and moisture, and also whether the cover crop has been soil-incorporated by tillage.

Other crops like the brassicas, such as turnips or radishes, have also been successfully used as N scavengers although they require earlier planting than the grasses and will likely winter kill in the Midwest. Hairy vetch and clovers have also been used successfully as winter cover crops primarily to supply N to the following summer crop. When these brassica and legume cover crops are used alone, or in combination with grass cover crops, some N release may occur both early in the targeted field crop growing season (i.e. late spring) from the lower C:N residues (< 20 to 30:1) of the non-grass cover crops, and again later in the growing season as soil microbes release N from the decomposing grass cover crop residues.

It is also important to note that the positive contributions of winter cover crops are not restricted just to RSN capture and to improved water quality. These additional benefits include sequestering N and carbon into building soil organic matter, improving water infiltration, and lowering soil erosion. Farmers should also think about these other soil, cropping system, and the environment benefits when considering the use of cover crops. Further descriptions and discussions of the benefits of cover crops can be found at the Midwest Cover Crop Council website (see link below) and the USDA website for the publication "Managing Cover Crops Profitably" (see link below).

Summary

This brief has illustrated two key opportunities for many farmers to more efficiently manage RSN (i.e. residual soil nitrate-N), which may be elevated after drought in corn and other crop production systems:

1. use of a winter cover crop, and
2. spring monitoring of soil nitrate-N with adjustment of fertilizer N rates for corn when spring nitrate-N is elevated.

The advantages of a winter cover crop are: a rapid capture of RSN and a reduction in the soil nitrate-N pool, which enables appropriate adjustment of spring fertilizer

N rates, as well as a reduced risk of nitrate-N leaching and drainage losses.

It has been estimated that cover crops could be used on 70 to 80% of the U.S. corn and soybean acreage to help reduce soil nitrate-N losses. Kaspar et al. (2008) aptly summarized: "Establishment on some acres would be limited because of lack of rainfall in some years, late planting because of harvest delays, and poor soil conditions at time of planting." They also concluded that, 1) reductions in nitrate loss and cover crop growth would be diminished in the northern parts of the U.S. "because of cold temperatures and frozen soil between main crops and because of less growth of the cover crops", 2) Benefits and cover crop growth would also be limited in the drier regions west of the Mississippi river (unless irrigated) because of water limitations for cover crop growth and nitrate leaching, and 3) "Crop acres with more diverse rotations than a typical corn-soybean rotation may have even better opportunities for cover crops."

There is still a great deal of uncertainty in the estimation of the potential nitrate-N losses and N availability to crops next spring (2013), largely because of our inability to accurately predict the weather between fall and spring, and our current lack of knowledge about the RSN levels across broad and varied geographies (F. Fernandez – U. of Illinois, J. Camberato – Purdue University, R. Mullen – Potashcorp; and T. S. Murell and P. Fixen – IPNI; personal communication August 18, 2012). It is clear, however, that farmers will experience increased cropping system management challenges and initial investment costs when including winter cover crops as a component of their annual cropping systems. The costs, benefits, and local management guidance on winter cover crops need to be evaluated on a field-by- field or farm-by farm basis, in consultation with an experienced agronomist.

The expertise of a Certified Crop Adviser, university extension specialist, USDA soil conservationist or other skilled agronomic professional should be sought in making your winter cover crop management decisions. A helpful starting place to consider is the website of the Midwest Cover Crops Council: http://www.mccc.msu.edu/ and several of the references posted at that website; especially the Kaspar et al. (2008) article listed in the references below. The USDA website for the informative 2007 publication "Managing Cover Crops Profitably" is: http://www.sare.org/publications/covercrops.htm . The August 20, 2012 webinar - Dealing With Drought: Securing Nitrogen With Cover Crops, which was hosted by CropLife (see http://www.croplife.com/webinars and specifically http://www.croplife.com/register-video?forward=video/c:56/webinars/1304/) may also be of special interest to those considering winter cover crops, particularly for the first time.

Acknowledgement

There are numerous scientists whose work could have been mentioned in this brief. We express appreciation for their work and apologize if their reports were not included in this brief because of space limitation, unintentional oversight, and the limited time available to summarize studies and disseminate this information.

References Cited

Brinsfield, R.B. and K.W. Staver. 1991. Use of cereal grain cover crops for reducing ground water nitrate contamination in the Chesapeake Bay region. pp 79-82. In W.L. Hargrove (ed.). Cover crops for clean water. Proc. Intl. Conf., April 9-11 1991, Jackson, TN. Soil and Water Conserv. Soc. Am., Ankeny, IA.

Dabney, S. M. J. A. Delgado, J.J. Meisinger, H.H. Schomberg, M.A. Liebig, T. Kaspar, J. Mitchell, and W. Reeves. 2010. Using cover crops and cropping systems for nitrogen management. Ch. 9, pp. 230-281 In JA. Delgado and R.F. Follett (eds.), Advances in Nitrogen Management for Water Quality. Soil and Water Conservation Society of America. Ankeny, IA.

Kaspar, T.C. D.B. Jaynes, T.B. Parkin, and T.B. Moorman. 2007. Rye cover crop and Gamagrass strip effects on NO3 concentration and load in tile drainage. J. Environ. Qual. 36:1503–1511.

Kaspar, T.C., E.J. Kladivko, J.W. Singer, S. Morse, and D. R. Mutch. 2008. Potential and limitations of cover crops, living mulches, and perennials to reduce nutrient losses to water sources from agricultural fields in the Upper Mississippi River Basin. pp. 127-148 in UMRSHNC (Upper Mississippi River Sub-basin Hypoxia Nutrient Committee). Final Report: Gulf Hypoxia and Local Water Quality Concerns Workshop. St. Joseph, Michigan: ASABE. Copyright 2008 by the American Society of Agricultural and Biological Engineers.

Meisinger, J. J., W. L. Hargrove, R. L. Mikkelsen, J. R. Williams, and V. W. Benson. 1991. Effects of cover crops on groundwater quality. pp. 57-68, In W. L. Hargrove (ed.), Cover Crops for Clean Water: Proc. Intl. Conference. Soil and Water Conservation Society of America. Ankeny, IA.

Randall, G. W., D. R. Huggins, M. P. Russelle, D. J. Fuchs, W. W. Nelson, and J. L. Anderson. 1997. Nitrate Losses through Subsurface Tile Drainage in Conservation Reserve Program, Alfalfa, and Row Crop Systems. J. Environ. Qual. 26:1240-1247.

Randall, G.W. and D.J. Mulla. 2001. Nitrate nitrogen in surface waters as influenced by climatic conditions and agricultural practices. J. Environ. Qual. 30:337–344.

Sawyer, J. E. and G.W. Randall. 2008. Nitrogen rates. pp. 59-71 in UMRSHNC (Upper Mississippi River Sub-basin Hypoxia Nutrient Committee). Final Report: Gulf Hypoxia and Local Water Quality Concerns Workshop. St. Joseph, Michigan: ASABE. Copyright 2008 by the American Society of Agricultural and Biological Engineers.

Shipley, P.R., J.J. Meisinger, and A.M. Decker. 1992. Conserving residual corn fertilizer nitrogen with winter cover crops. Agron. J. 84:869-876.

Staver, K.W. and R. B. Brinsfield. 1998. Using cereal grain winter cover crops to reduce groundwater nitrate contamination in the mid-Atlantic coastal plain. J. Soil Water Conserv. 53(3): 230-240.

Additional Suggested References

Dabney, S.M., J. A. Delgado, and D. W. Reeves. 2001. Using winter cover crops to improve soil and water quality. Commun. Soil Sci. Plant Anal. 32:7,1221-1250.

Dinnes, D.L., D.L. Karlen, D.B. Jaynes, T.C. Kaspar, J.L. Hatfield, T.S. Colvin, and C. A. Cambardella. 2002. Nitrogen management strategies to reduce nitrate leaching in tile-drained Midwestern soils. Agron. J. 94:153–171.

Strock, J.S., P. M. Porter, and M. P. Russelle. Cover cropping to reduce nitrate loss through subsurface drainage in the northern U.S. corn belt. J. Environ. Qual. 33:1010–1016.

Wagger, M.G., and D.B. Mengel. 1988. The role of nonleguminous cover crops in the efficient use of water and nitrogen. pp 115-127, In W.L. Hargrove (ed.) Cropping Strategies for Efficient Use of Water and Nitrogen. American Society of Agronomy. Madison, WI.

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