Plant-Soil-Microbe N Relationships in High Residue Management Systems

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Introduction

The importance of supplying nitrogen (N) to optimize crop production has been known for over 150 years. The use of legumes in crop rotations was the only practical method of rebuilding soil-N supplies for row crops until the advent of industrial N fertilizer production following WWII. Much research has been conducted over the past century on the topic of N fertility for agronomic crops. Many studies concentrated on rates of applied N to optimize economic yield in conventional tillage, while fewer studies focused on understanding of the complex cycle of N in the soil environment. Only in relatively recent times have research studies investigated N cycling within native prairie and no-till soils. Although some important relationships have been discovered in these experiments, much remains to be learned.

Tilled and no-till soils can vary dramatically in carbon (C), oxygen (O_2), water content and temperature because of the tillage process. Tillage breaks bonds between soil particles and mixes air and plant residues throughout the tilled zone. This increases soil temperature, evaporative losses, and the amount of available oxygen. The overall effect of tillage is a soil environment that stimulates aerobic microbial activity, eventually leading to increased decomposition rates of plant residue-C and accelerated cycling of soil-N compared with no-till and native prairie soils. We will briefly describe how plant residues and soil microbes interact and their effects on soil-N, and provide some recommendations on how to manage N for no-till crop production.

Plant Residue and Microbial Interactions

Tillage affects plant residues and N cycling in soils because plant tissue is a primary source and sink for C and N. Normally, when plant residues with C:N ratios greater than approximately 20 parts C to one part N are added to the soil available N is immobilized during the first few weeks of decomposition (Sinha et al., 1977; Doran and Smith, 1991; Somda et al., 1991; Green and Blackmer, 1995). Green et al. (1995) observed that incorporation of corn stover into soil resulted in rapid immobilization of all available inorganic N during the rapid decomposition period. This occurred because the microbial population decomposing the plant residue had increased exponentially in response to the C source and tillage, essentially needing the N much like cattle require protein in a balanced feed ration. If N immobilization occurs when a crop needs N for growth and development, the growth and yield may be reduced. Eventually, as residue decomposition proceeds, the C:N ratio will begin to approach that of soil organic matter (~10 or 12 to 1), microbial populations will decrease, and N from plant residues that was taken up by the microbes will once again be released into the soil. However, if temperature, water content, or other factors slow the residue decomposition process, N may not be released from the plant residue or microbes until the primary crop has matured and stopped assimilating N. In a Nebraska study, Varvel and Peterson (1990) determined that in continuous corn production 80% of the applied N fertilizer was still immobilized in crop residues, soil organic matter, and microbial biomass at the end of the growing season. This emphasizes the importance of understanding all the factors affecting plant residue decomposition along with fertilizer additions and how they might be manipulated to reduce losses of N without decreasing availability of N to the primary crop, or adversely affecting the soil C and N pools.

Incorporation of shoot residues by tillage can significantly increase the decomposition rates (Douglas et al., 1980; Doran, 1987; Holland and Coleman, 1987; Aulakh et al., 1991). Root residues, however, may respond differently to tillage or disturbance than shoot residues. For example, Martin (1989) observed that decomposition of root residues was more rapid and more complete when they were left undisturbed in the soil than when air-dried roots were mixed with moist or air-dried soil.

Even in the absence of disturbance, root and shoot residues appear to have inherent differences in decomposition rates. In a laboratory simulated no-till experiment, Gale and Cambardella (2000) found differences in the partitioned amounts of shoot-derived C and root-derived C during decomposition. They concluded that accrual of soil organic C associated with no-till is primarily due to the increased retention of root-derived C in the soil and that shoot-derived C did not have much of an effect. This is largely due to shoot residue remaining on the surface with no-till and that this simulation did not include earthworm activity.

The increased amount of plant residues at the surface and within the soil with no-till creates an environment that is wetter, cooler (during the growing season) and less aerobic than tilled soils (Allmaras et al., 1964). The greater amount of available C with no-till may lead to N limited conditions for plants even though the no-till soil has more total N than tilled. Soil organic matter (SOM) content is greater in no-till despite having higher microbial populations because the cooler early season soil temperatures and a more anaerobic soil condition results in reduced microbial activity and SOM decomposition. During the period of increasing SOM content (i.e., first few years after conversion from tillage to no-till), the soil's C content increases and the N cycle is shifted towards inorganic N being immobilized into organic N. At this stage the timing, placement and rate of N applications are critical to minimize the risk of N deficiencies for the crop. Once the SOM level comes to a new equilibrium, N immobilization and mineralization processes become more balanced. This results in a reduced crop response to N additions and N fertilization rates may be able to be reduced without diminishing economic yields.

TIMING AND PLACEMENT OF N FERTILIZER FOR NO-TILL

Due to the accelerated decomposition rates with tillage, fall and early spring tillage may lead to mineralization of residue- and microbial-N before the crop is able to assimilate the N. The mineralized N is then vulnerable to loss from leaching and denitrification. In contrast, no-till often delays decomposition and mineralization, and residue-N may not be mineralized fast enough nor soon enough to optimize crop production.

The challenge with any tillage or no-tillage system is to manipulate N availability before, during, and after peak crop demand. If N fertilizer is applied long before the crop is actively growing and taking up N from the soil profile, the N can be lost through leaching, denitrification, volatilization, or immobilization processes. The same is true for residual N remaining in soil after crop senescence (Magdoff, 1991; Karlen et al., 1998), especially in years that do not produce optimal yields (Power et al., 1998). A key factor to increasing N use efficiency and reducing nitrate (NO_3) leaching potential is to limit the amount of inorganic N within the soil at the end of the crop growing season and before the next crop has established a root system extensive enough to efficiently scavenge plant-available N from the soil profile. Therefore, timing and placement of N application and accounting for mineralizable soil-N are important for improving N management, whether one tills or no-tills.

Typical N fertilizer application for corn production in the sub-humid Midwest currently consists of a single pre-plant application, usually done in autumn prior to the year when corn is planted. This management practice was promoted by agricultural experts because the potential for soil compaction following harvest is generally less, labor is often more available, the window of opportunity for the operation is generally more favorable, and fertilizer prices are frequently lower than in the spring. However, fall application places the applied N in the soil several months before the crop needs it and thus increases the potential for leaching or other losses. Sanchez and Blackmer (1988) conducted a study of fall-applied N efficiency and found that 49 to 64% of the fall-applied fertilizer N was lost from the upper 1.5 m of the soil profile through pathways other than plant uptake.

Changing the timing of a single pre-plant fertilizer application from fall to spring could significantly decrease N loss and increase fertilizer use efficiency. This was demonstrated for southern Minnesota (Randall et al., 1992; Randall, 1997) where studies showed N use efficiency was improved by over 20% through spring rather than fall N application. Although fall strip tillage offers soil physical benefits for spring planting and deep placement of phosphorus and potassium, potential N losses with this operation can still be severe. Some farmers choose to apply most or all of their annual N fertilizer in a liquid form with their pre-plant herbicides, which may perform reasonably well as long as adequate rainfall occurs soon after application. However, a starter fertilizer application at planting followed by in-season application(s) tends to be most efficient.

Starter fertilizer application is more important for no-till than tilled conditions due to no-till's slower N mineralization in early season and tendency for N to be immobilized during the early years of conversion from tillage (Brouder, 1998). A starter fertilizer that supplies a form of N readily plant-available (such as nitrate-N) and is placed two to three inches away from the seed at the same depth of planting serves well in preventing seedling N stress. It is important to not place the starter fertilizer too far from the seed because cool early season soil temperatures limit the growth of seedling roots. In addition, it is important to not apply too high a rate of starter fertilizer because of the risk of salt damage to the seedling. The safe rate limits will vary upon soil type, but in general, lower rates should be used as the closer the starter fertilizer is placed to the seed and the coarser the soil texture (Brouder, 1998).

Rate recommendations for in-season N applications can be determined by monitoring N mineralization to better synchronize N availability with crop uptake using either a pre-sidedress soil nitrate test (PSNT) (Magdoff et al., 1984; Fox et al., 1989; Magdoff et al., 1990) or modifications such as the late-spring nitrate test (LSNT) (Blackmer et al., 1997). These tests are often implemented by sampling the soil after planting and are used to help account for the net effects of mineralization, leaching and other potential losses that may have occurred since the last crop was harvested. However, an in-season N application does not need to use a soil test to determine the applied N rate. An in-season rate may simply be chosen, much like any pre-plant application rate, by experience with one's own production system or guided by previous end-of-season stalk nitrate tests (Blackmer and Mallarino, 1994). But a PSNT test does allow a farmer to track plant available-N supplies in their no-till soil given the season's climate, which can be valuable management information in the future.

Placement of in-season N fertilizer application for no-till, like all other no-till N applications, is most efficient if it is knifed or injected. Broadcast applications tend to be the most inefficient, surface banded is better, but knife or injection performs best at minimizing N losses due to volatilization and immobilization by microbes on surface residues. Because a substantial amount of surface residues can accumulate on the soil surface, surface immobilization of N is more of a concern than in tilled soils. Knifing or injecting N fertilizer separates the N from the surface residues and reduces the risk of the added N being immobilized. Again, a readily plant-available form of N fertilizer (i.e., urea-ammonium nitrate as opposed to anhydrous ammonia) would likely perform best because the crop is actively growing and is near peak demand for N.

SUMMARY

No-till soils vary dramatically from tilled soils in C content, O_2 status, water content and temperature. Understanding that these and other factors affect the soil-N cycle can help to manage N fertilizer by accounting for the effects of high levels of surface residues on no-till's N mineralization and immobilization processes. With cool early season soil temperatures, the timing and placement of N fertilizer for no-till corn is critical. Readily plant-available N starter fertilizer placed near the seed at planting, and an additional in-season application, can provide an effective no-till N program. Also, because of high surface residue levels, knifing or injecting of N fertilizer is more effective than surface applications.

Improving N fertilizer use efficiency provides benefits not only to the environment, but also for farm economics. Historically, many farmers used rates of N greater than they perceived their corn crop required to maximize yield because the cost of N fertilizer made this practice a relatively cheap form of yield insurance in the event of excessive precipitation. However, with N fertilizer prices nearly doubling within the past year, there is now adequate economic pressure to minimize N fertilizer costs and make efforts to make one's crop production program as efficient as possible. Because much remains to be learned about the N cycle in no-till environments, it is very important for the no-till farmer to keep up-to-date on new knowledge and technologies from the soil sciences to improve their N management and farm profitability.

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