Relay Cropping for Improved Air and Water Quality

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Using plants to extract excess nitrate from soil is important in protecting against eutrophication of standing water, hypoxic conditions in lakes and oceans, or elevated nitrate concentrations in domestic water supplies. Global climate change issues have raised new concerns about nitrogen (N) management as it relates to crop production even though there may not be an immediate threat to water quality. Carbon dioxide (CO_2) emissions are frequently considered the primary cause of global climate change, but under anaerobic conditions, animals can contribute by expelling methane (CH_4) as do soil microbes. In terms of the potential for global climate change, CH_4 is ~ 25 times more harmful than CO_2. This differential effect is minuscule compared to when nitrous oxide (N_2O) is released into the atmosphere because it is ~ 300 times more harmful than CO_2. N_2O losses from soil have been positively correlated with residual N (nitrate, NO_3^-) concentrations in soil. It stands to reason that phytoremediation via nitrate scavenger crops is one approach to help protect air quality, as well as soil and water quality. Winter wheat was inserted into a seed corn/soybean rotation to utilize soil nitrate and thereby reduce the potential for nitrate leaching and N_2O emissions. The net effect of the 2001–2003 relay cropping sequence was to produce three crops in two years, scavenge 130 kg N/ha from the root zone, produce an extra 2 Mg residue/ha, and increase producer profitability by ~ $ 250/ha.

Key words: Agriculture, Air Quality, Nitrogen Management

Introduction

Nutrients required for crop growth may hardly seem like viable candidates for phytoremediation efforts, but such is actually the case with nitrogen (N) and phosphorus (P). Excess amounts of N or P in soil can have significant adverse impacts on surface and ground water quality. Removing the source of these potential contaminants from soil to some critical level requires special consideration because both are dynamic in soil. Phosphorus in soil is in equilibrium between the adsorbed and solution phases and thus can exist in both soluble and nonsoluble forms. While soluble P is the form that promotes eutrophication in standing water (*e.g.*, lakes and ponds), it is the nonsoluble P that perpetually contributes to the problem. As such, erosion control has long been recognized as a key factor in controlling eutrophication. Controlling soil erosion is a noble and esthetically desirable goal, but nearly impossible to achieve. Therefore, making the most of crop removal (*i.e.*, phytoremediation from an environmental perspective), when excess nutrients exist, is an important aspect of both agronomic and environmental sustainability.

Assessing the effects of a phytoremediation effort should realistically involve a holistic evaluation of the production system because many processes can be involved. In the case of N, farmers grow legumes to enrich the soil and use cover crops to protect the soil from erosion and build organic matter. The interesting thing is that both types of crops (*i.e.*, legumes and cover crops) can serve as a scavenger of residual soil N (*i.e.*, nitrate). This is because legumes only fix N when they need it for growth and otherwise prefer to utilize inorganic forms of N (nitrate or ammonium) in soil when available because less energy is expended in the acquisition process.

The challenge when dealing with environmental issues that are confounded by crop production and profitability requirements is in knowing which pieces of the puzzle are available and understanding how to put them together in the best way possible. Identifying environmental problems is a natural process that may take years before it becomes a viable concern. By that time, simple solutions are frequently not an option because of the infrastructure that has developed over the years. Therefore, more complex and integrated solutions are usually required, but formulating effective and practical solutions that consider other constraints (*e.g.*, climate, labor, cost) is sometimes difficult.

Relay Cropping

The case study presented in this paper illustrates how the seed corn production industry in the United States has evolved into being perceived as an environmentally unfriendly enterprise (*i.e.*, groundwater contamination with nitrate) and how other crops in a rotation are starting to be used to remediate the problem. Producers consider seed corn a high-value crop and so risk aversion is a key consideration when making management decisions. This includes N fertilizer and water applications, but in excess these two inputs can seriously threaten the environment. Nitrogen fertilizers applied to crops are readily transformed into nitrate by soil microorganisms. Plants readily use nitrate, but the presence of excess water causes percolation through the root zone. Since nitrate is soluble in water, any leachate leaving the root zone carries some of the nitrate that is not used by plants. This infiltrating water eventually reaches the ground water or emerges in streams.

The scenario leading to the current environmental challenge is that several major seed corn companies have gradually moved more of their production to the Midwest because the region offers irrigation, which helps to stabilize production. Irrigation is made possible via groundwater (typically 5 to 50 m depth) that also provides domestic water for local residents. Therefore, crop production practices that result in nitrate leaching also threaten the livelihood of the community. The situation in parts of Nebraska is that the shallow groundwater aquifer contains 20 to 30 mg/l of nitrate-N or more. The safe drinking water standard in the U.S. is 10 mg nitrate-N/l. An annual groundwater quality reporting system initiated in 1988 has documented changes in nitrate-N concentrations and generally delineates fields producing seed corn, popcorn, and potatoes and those receiving multiple applications of manure. Limitations already exist on when fertilizer can be applied and producers are required to use soil and water testing procedures to make better-informed nutrient and water management decisions, but there are no restrictions on how much water, N fertilizer, or manure that can be applied.

The seed corn industry generally recognizes that the lower production level of seed corn (~ 50%) compared to commercial corn requires less N fertilizer, but has no control over producer N practices. Even though the seed industry may recommend reduced rates of N application for seed fields, producers know that modestly elevated levels of N fertilizer do not adversely affect yields. The tendency is to apply extra N because inbred seedlings are less vigorous than hybrid seedlings and so producers feel that extra N might enhance their growth. This is in spite of the fact that most seed corn companies now require that soybeans are grown as the previous crop to avoid possible problems with off-breed carryover from a previous crop. At the end of the growing season, residual N levels are frequently high and thus represent a considerable risk to the environment because fall and spring precipitation frequently exceeds the water hold capacity of the soil. Indirectly, seed companies have strong general control over contract producers through their payment system that is based on productivity relative to other seed producers growing the same cultivar and commercial corn yields in the area. Therefore, there is a tendency not to skimp on any input that might enhance yields. This scenario is common and supports the need for modified cropping systems and management practices to reduce the risk of nitrate leaching. A complementary benefit of reduced soil nitrate levels would be the reduced potential for N_2O emission.

Finding a crop that would be a good scavenger of soil nitrate and still fit within the realm of the standard two-year seed corn/soybean rotation requires a winter annual like wheat or barley. Both crops take up reasonable amounts of soil N in the fall and spring before conventional summer annuals become established. One challenge is to get the winter cover crop established in the corn residue well enough to survive the winter conditions. A second hurdle arises in the spring when it is time to plant soybeans in that a winter cover crop will not mature until early July, but soybeans are usually planted in mid May. Treating the winter scavenger crop as a green manure in the spring would make it possible to plant soybeans in a timely manner, but requires that the cover crop be killed or otherwise destroyed by incorporation into the soil. Allowing the cover crop to reach maturity and be harvested for grain offers another source of income if delayed planting of the soybean crop does not reduce yield too much.

An alternative to 1) treating the scavenger crop as a green manure and thus planting soybean in May or 2) harvesting the scavenger crop in July and then planting soybeans in hope of a late frost that would allow the soybeans to mature is to work out a compromise using a relay cropping strategy. Such a system has good potential because the second crop is inter-seeded into the first crop as it approaches maturity. This strategy effectively extends the growing season of the second crop, but means that ways must be developed to seed the second crop into the first with minimal damage. A second prerequisite is that machines used to harvest the first crop must do so while causing minimal damage to the second crop. To successfully accomplish these feats, a careful strategy must be planned before planting the first crop to include fertilization, weed control, and irrigation of both crops when necessary. Timely irrigation with small amounts of water is essential, which basically requires sprinkler irrigation. Seedling establishment has traditionally been a concern with inter-seeded crops when soil-based herbicides are used. The introduction of Roundup Ready soybeans has greatly simplified weed control for soybean producers where such crops are allowed. This is especially true in relay cropping because weeds can get an early start within the wheat canopy and soon become larger than the soybeans.

Various combinations of equipment and management practices can be modified to accomplish the relay cropping scheme described above. Aside from the need for sprinkler irrigation and glyphosate-tolerant soybeans is the need for planting equipment for the cover crop that will function well with modest amounts of corn residue. The strategy being developed in Nebraska typically involves planting winter wheat into corn stubble in early October (seed corn harvest is usually completed before frost which usually occurs in late September). Most seed corn is produced using 76-cm rows and many commercial grain drills have 25-cm row spacings. This arrangement makes it convenient to plant two rows of wheat between the corn rows and leave the area previously occupied by the corn vacant for the soybean crop to be planted in the spring. The net result is a 50-cm opening between the double wheat rows to accommodate the soybean planting equipment. The difficulty arises when it comes to planting the soybeans without destroying some of the wheat crop that is growing between the old corn rows. This area is normally reserved for tractor and implement tires. The solution is to adjust the spacing of the tractor tires or tracks to drive on top of the old corn rows. Another alternative is to move the planter units over one-half row when seeding the soybeans and driving on top of the old corn rows. This later approach results in a planter with an odd number of units rather than the traditional even number of units. Soybeans are planted about one month before wheat harvest. Irrigation is usually required after planting soybeans to facilitate uniform germination in that the wheat crop is likely to have depleted the surface soil water. Wheat harvest is accomplished with a conventional combine equipped with duals so that the tires fit between the soybean rows (soybeans are usually 15–25 cm tall when the wheat is harvested). After the upper half or so of the wheat plant is removed during harvest, the young soybean plants emerge from the remaining stover to grow and mature as normal (usually slightly delayed).

A cropping system similar to the one described above was observed in Argentina in 2001. The farmer in Argentina had been developing the strategy to increase profitability of his operation. He was growing commercial corn in rotation with wheat and inter-seeded soybeans in a growing season that is about 20 days longer than in Nebraska. Yield levels for corn (maize), wheat, and soybeans were ~ 9, 5, and 3 Mg/ha, respectively, in their two year rotation. Yields of the wheat and soybean crops in Argentina were 80 to 90% of full yield compared to when only one crop was planted.

The challenge in bringing the concept to Nebraska has been determining how to adapt the relay cropping system for our crops, equipment, and climate. The concept was successfully demonstrated on a single seed corn/soybean rotation field (60 ha) in Nebraska in 2002. Three more producers tried the system in 2003 (~ 500 ha). The seed corn/wheat/soybean relay cropping system was used on ~ 2000 ha in 2004. Several producers are trying the system with commercial corn that is typically harvested 2 to 3 weeks later than seed corn.

First year results with seed corn rotation showed the wheat crop yielded 4.57 Mg/ha and removed 146 kg N/ha from the soil (~ 101 kg N/ha in grain) that could have leached beneath the root zone (Table I). The additional residue produced by the wheat straw (~ 2 Mg/ha) will build soil organic matter content. First year results showed that the producer increased his profitability by about $ 250/ha, even after experiencing a 25% reduction in soybean yields (~ 1.2 Mg/ha).

The scavenger effect of winter wheat following seed corn is well timed to minimize the potential

Table I. Yield and estimated nitrogen removal in grain by wheat and soybean following seed corn production in Nebraska.

Year	Yield [Mg/ha]		N uptake [kg N/ha]		
	Wheat	Soybean	Wheat grain	Wheat stover	Soybean grain
2002	4.57	3.70	101	45	118
2003	4.97	3.03	110	47	97
2004	5.78	3.36	126	54	108

for nitrate leaching for two reasons. First, the young wheat crop uses fall and spring precipitation that might otherwise result in nitrate leaching. By removing the driving force (excess water) from the soil, nitrate is more likely to remain within the root zone for utilization by the scavenger crop. It follows that N uptake by the scavenger crop further reduces the potential for nitrate leaching in case of excess precipitation.

Although the concept of planting wheat as a scavenger crop after seed corn production has environmental merits, considerable uncertainty is associated with the scheme in terms of contributing to producer profitability. This is because adequate N must be supplied by the soil or made available from fertilizer to grow the crop and develop the grain to be harvested. Nitrogen carry-over after seed corn production is expected to be variable depending on previous management practices and weather conditions. Likewise, mineralization in the fall and spring is largely driven by weather and soil properties, so N availability to the crop is sure to be spatially variable. In the case of the wheat crop that was planted in the fall of 2001, the soil residual N (nitrate-N) level to a depth of 90 cm was 165 kg N/ha after seed corn harvest. After soybean harvest in 2002 the level had been reduced to 39 kg N/ha. The low levels of residual N observed in this case are considered as the base line for root extraction. In terms of an N budget in this case, residual soil N supplied 126 kg N/ha of the 264 kg N/ha taken by the wheat crop and in the soybean grain. Another 25–30 kg N/ha would have remained in the soybean residue. In total, residual soil N only supplied about one third of the total N taken up by the two crops (wheat and soybeans). The remainder of the N was supplied by mineralization and nitrogen fixation.

It is advantageous that soybean can fix N if needed because residual N carry-over after wheat is uncertain. In fact, producers are likely to take advantage of the fact that soybeans can also function as a scavenger crop and therefore are inclined to apply N fertilizer to wheat in the spring to maximize yields. Even with spring N application to wheat, there is little likelihood of nitrate leaching because the crop utilizes the spring precipitation and sometimes even requires supplemental irrigation.

Factors influencing gaseous N losses from soil include water status, temperature, and availability of soluble carbon (Firestone, 1982). The influence of a growing crop on N_2O emission from soil is largely unknown, but expected to have some influence in that root exudates are known to enhance mineralization (Denmead *et al.*, 1979). In that nitrate production is a product of mineralization, it is therefore possible that the presence of vegetation enhances N_2O production if other conditions (*e.g.*, temperature, aeration, pH, and electrical conductivity) are conducive (Davidson, 1991; Williams *et al.*, 1992).

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