THE ROLE OF PERENNIAL FORAGES IN PREVENTION AND REMEDIATION OF NITRATE IMPACTS

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Introduction

Perennial plants have always played crucial roles in protecting the environment – our soil, air, and water resources. Perennial forages provide these same services, and do a better job than annual crop plants, especially in the short growing season of the northern USA and southern Canada. In doing so, perennial forages improve the sustainability of farming systems.

The American public is increasingly interested in how farming affects the environment. According to a Gallup Organization poll in 2001, over 80% are concerned about water and air pollution and the loss of wildlife habitat. Another poll in 1999 by the Pew Research Center for the People and the Press showed that over 80% of the American public agreed with the statement: 'There need to be stricter laws and regulations to protect the environment.' Nearly 90% of Midwest respondents in a survey conducted by American Farmland Trust in 2001 said they would favor additional incentives for farms that put management practices in place to protect water quality, enhance wildlife habitat and protect ground water recharge systems.

Growing perennial forages, especially in strategically selected places on the landscape, can go a long way toward satisfying the public's demand for responsible farming, and in keeping farmers in business. This paper conveys ways that perennial forages help protect the environment, focusing on prevention of nitrate losses and remediation of nitrate-contaminated sites.

Nitrate leaching

Water that infiltrates the soil has four fates: 1) it moves into the plant, where a small amount becomes the cell cytoplasm, while the remainder evaporates inside the leaves and dissipates into the atmosphere, a process called transpiration; 2) it evaporates directly from the soil surface; 3) it moves below the root zone with the force of gravity; or 4) it remains in the soil. Coarse-textured soils hold less water than fine-textured soils, and water generally moves more quickly through sandy soils. Water flow beneath the root zone is one way shallow aquifers become recharged (the other is through the bottoms of rivers and lakes). Water that moves through the soil contains dissolved salts and organic matter. For our purposes, the most important dissolved ion is nitrate.

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Nitrate is a naturally occurring, negatively charged ion. It moves through soil because clays are also negatively charged and repel nitrate. Nitrate is of concern because the US EPA has established a 10 ppm nitrate-N limit for public drinking water supplies, and because it is involved in the development of hypoxic areas in near-shore ocean water.

The most well known hypoxic zone for us is the northern Gulf of Mexico. This 'Dead Zone' has affected the ecosystem in an area about 7,000 square miles, and shifted the shrimp fisheries of Louisiana to Texas (Turner and Rabalais, 1994). Much of the nitrate in the Mississippi River apparently comes from agriculture on tile-drained soils in the North Central Region (Antweiler et al., 1996). Research in several states has shown that nitrate losses in tile drainage effluent under corn and soybean are very high – often in the range of 20 to 80 lb N/acre annually. This nitrate is delivered to ditches, which eventually drain into the river system. Denitrification, the conversion of nitrate to N gases, occurs along the way, but significant loading of the Mississippi still occurs.

How do perennial forages fit into systems that protect the Gulf of Mexico? It is very clear that these crops, even a legume like alfalfa, reduce nitrate losses to very low values in tile-drained land. Research in southwestern Minnesota showed that losses from alfalfa or CRP were always less than 5 lb N/acre, compared to losses 6 to 14 times higher under corn or soybean (Randall et al., 1997).

Many of the perennial forages grown in the Upper Midwest have deep root systems. Alfalfa's roots grow about 4 to 8 feet deeper each year the stand persists, if soil conditions allow. Deep root systems help prevent nitrate leaching, because the crop has more time to absorb nitrate from the soil solution before it escapes the root zone. Nitrate removal from the subsoil at depths below those of many annual crops helps prevent N loss from the farm (Blumenthal and Russelle, 1996). High fertilizer N use efficiency also nearly eliminates nitrate losses under vigorous grasses (Vetsch et al., 1999).

The likelihood and seriousness of leaching vary with soil depth and texture, rainfall, irrigation, and snowmelt amounts, crop evapotranspiration, and presence of a susceptible water body (aquifer or surface water). In some situations, nitrate leaching is unlikely to degrade water, because of high denitrification rates (MPCA, 1998). In other situations, the public costs of ground water contamination can be very high. Strategic planting of perennial forages in the wellhead protection area, on shallow or sandy soils, for example, can greatly reduce the probability of significant nitrate leaching (Kelley and Russelle, 2000). Thus, the entire area need not be converted to perennials to achieve water quality goals, but conversion of some land parcels to crop rotations that include perennial forages will provide significant public benefits. The same approach has been used to target highly erodible land for perennial plantings.

Of course, leaching can be prevented only when rainfall or irrigation are not excessive. In more humid regions than the Upper Midwest, nitrate losses from pastures can be very high (Jarvis and Hatch, 1994). Intensive humid-region pasture management has resulted in significant contamination of ground water (Burden, 1982). Higher nitrate losses occur under grazing than mowing at the same fertilizer N rate, because of faster N cycling and greater spatial variability (Garwood and Ryden, 1986). Irrigation often increases the risk of nitrate leaching because it limits the storage capacity of the soil for subsequent rainfall. For nitrate leaching to be important, however, nitrate concentration must be high. Our recent field research on a sandy soil in Minnesota showed that alfalfa, orchardgrass, and bromegrass stands all reduced the nitrate concentration of water flowing through the root zone from 25 to less than a few ppm nitrate-nitrogen (Russelle et al., 2001a). This means that, even when conditions favor nitrate leaching during the growing season, perennial forages help protect ground water aquifers.

Remediation

Perennial forages can also be used to remediate contaminated sites. Legumes, like alfalfa, are particularly useful for nitrate removal, because they are quite flexible in obtaining N. Legumes can absorb both nitrate and ammonium in the root zone and utilize atmospheric N_2 gas that is fixed by rhizobia in root nodules. This flexibility is of great value when it comes to protecting water quality. On an abandoned barnyard in Wisconsin, we planted normal Agate alfalfa and a special type of Agate alfalfa that cannot fix N from the air. Nitrogen availability in the soil was tremendously variable, due to the location of manure piles from bedding and feeding areas. Normal alfalfa has grown quite well and uniformly on the areas where it was planted, yielding 5.2 tons of dry matter per acre in 1999. In contrast, the nonfixing alfalfa yielded 3.7 tons/acre and yield varied widely, depending on soil N supply. At one harvest, yield of the nonfixing alfalfa ranged from 0.3 to 1.9 tons/acre. Average N uptake from the soil and manure by the nonfixing alfalfa was 220 lb/acre in 2000, while total N in the fixing crop (from soil, manure, and atmosphere) was 340 lb/acre.

Alfalfa's high protein yield per acre also makes it a valuable crop for cleaning up sites with too much available N. Most N absorbed by plants is converted to protein. We used alfalfa at the site of a derailment in North Dakota to remove excess nitrate from the soil and ground water (Russelle et al., 2001b). The contaminated ground water was irrigated on the alfalfa and annual crops of corn and wheat. Total N removal in alfalfa was 870 lb/acre over the 3 years, whereas the annual crops removed only 330 lb/acre. In the last year of the cleanup, corn silage produced the same dry matter yield as alfalfa, but removed only one-half as much N, because of corn’s lower protein content.

Perennial legumes have another advantage over grasses in nitrate clean up situations. When nitrate supply is excessive, grasses and other nonlegumes may accumulate high concentrations of nitrate in herbage. Nitrate toxicity can result if livestock consume this forage. In one situation where manure slurry had been applied too generously (75,000 gal/acre), alfalfa and birdsfoot trefoil maintained herbage concentrations less than 3000 ppm nitrate-N, whereas lambsquarter and pigweed contained up to 9700 ppm nitrate-N and Canada thistle contained 13,000 ppm (Russelle et al., unpublished data).

Like all plant species, alfalfa roots produce a good environment for bacteria to grow. Bacterial populations are usually 10 to 100 times more numerous next to the root than in the bulk soil. This bacterial growth is due in part to the organic food sources that roots provide from dead cells and exudates. They also feed on the N and carbon in dead and dying roots, which comprise one-third to one-half of the small diameter roots alfalfa produces each year (Goins and Russelle, 1996). Facultative anaerobic bacteria under perennial forages remove nitrate through denitrification (Schnabel et al., 1996). These bacteria are more active under perennial than annual vegetation because of higher carbon supplies from root exudates, dead microbial bodies, and dead roots. Denitrification rates may be greater in pastures than in mechanically harvested perennial forages (Jarvis and Hatch, 1994).

The road from here

Well managed perennial forages help protect the environment. We are developing new alfalfas that tolerate stresses like salinity and ammonium-N for wastewater or manure applications, that have improved root systems for absorbing N, and that are either more or less capable of nitrate uptake from the soil. We are also evaluating new uses of perennial forages to expand their role in environmental protection, such as the perennial biocurtain concept, which involves narrow strips of perennials planted directly over subsurface drainage tiles to remove excess nitrate. Ecological benefits can be maximized by planting perennial forages in strategically selected fields. Agricultural consultants should be knowledgeable about these benefits and the management approaches needed to optimize them, and farmers who grow perennial forages should be recognized for the environmental benefits they provide to the nation.

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