Nutrients in North Carolina Soils and Waters

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Both surface and subsurface drainage waters from all land contain some nutrients. These nutrients are necessary for life in surface waters but can become a problem when they are present in excessive amounts. The nutrients of most concern with regard to water quality are nitrogen and phosphorus in surface water and nitrate nitrogen in ground water.

North Carolina soils were originally low in both nitrogen and phosphorus so these nutrients had to be added to soils to grow a good field crop or lawn. The addition of these nutrients to soils for increased plant growth increases their concentration in the water that drains from the land and increases the nitrate concentration in the shallow groundwater below most fields. This is accepted as scientific fact now, and modern soil textbooks contain a discussion of factors controlling losses of both nitrogen and phosphorus to water from soils. However, this was not the situation in the late 1960s when the first research designed primarily for water quality purposes was conducted in the Soils Department at North Carolina State University (NCSU).

In 1968, Ralph McCracken, who was then Department Head of Soil Science, suggested that research on effects of fertilizer usage on water quality was needed. The director of the newly initiated Water Resources Research, Dr. Howells, and others were making "unfounded" statements that agricultural fertilizers were causing water quality problems. The Tennessee Valley Authority (TVA) and NCSU had paired watersheds in western North Carolina that could be used for a joint research project.

I intended to run the one experiment to show that Dr. Howells was wrong in his statements about fertilizers. However, the research did not fit my preconceived ideas, and it showed that addition of fertilizer nitrogen to grazed bluegrass pastures in the North Carolina mountains did result in a very significant increase in nitrogen in the runoff water. When the experiment was completed and the results ready for publication in a scientific journal, I was shocked to learn that TVA did not want the information published because of the effect it might have on fertilizer sales. It is interesting to note 30 years later that TVA's research program is totally for environmental protection.

During the past 30 years, water quality research in the Soils Department at NCSU has increased from part time for one faculty member to the largest single area of endeavor. We now understand most of the factors controlling losses of nutrients from soils and have developed many best management practices (BMPs) to minimize their losses and maintain the quality of the receiving waters.

Nitrogen

Because nitrogen in fertilizers and animal waste is present in very water-soluble inorganic forms or is converted to these forms when added to soils, the nitrogen moves into the soil with rain or when applied as irrigation from a lagoon. Because of its solubility and tendency to move into the soil with the first rainfall, only small amounts of inorganic nitrogen are usually present in surface runoff water. The inorganic nitrogen in the soil can be utilized by plants, move vertically to ground water, move laterally toward surface waters or be converted to a gas under special conditions. Nitrogen normally does not accumulate in North Carolina surface soils that are sufficiently well drained to for crop production.

The efficiency of utilization of nitrogen fertilizers by grain crops is about 50 percent: that is, a little over half of the fertilizer nitrogen added to crops is ultimately harvested with the crop. Up to 80 percent of the applied nitrogen may be harvested in forage crops used for hay. However, with forage crops that are grazed, the percentage of nitrogen harvested is much lower than that harvested by grain crops.

If fertilizers are added in excess of recommended rates, the utilization efficiency decreases. It should be understood that productive agricultural systems tend to be very leaky with regard to nitrogen even when the best management practices known are utilized. It is sometimes difficult for producers to understand that even if they follow all of the recommendations of the Cooperative Extension Service or the Natural Resources Conservation Service and have a good crop year, there will still be a significant amount of fertilizer nitrogen that can get into the shallow groundwater.

It has also been difficult to convince strong proponents of conservation tillage that this very good BMP for reducing sediment and phosphorus losses has very little effect on reducing nitrogen losses. The only way that conservation tillage reduces nitrogen losses to water is for it to increase yields, which increases the amount of nitrogen harvested with the crop. Research here by Wagger and his students has generally shown no effect of conservation tillage on yields in the coastal plain.

The unharvested nitrogen applied as fertilizer generally moves with the water to the shallow ground water. Thus the nitrate-nitrogen concentration in the shallow groundwater below most agricultural fields fertilized according to agronomic recommendations is 10 to 20 milligrams per liter. The World Health Organization states that 10 milligrams per liter is maximum for drinking water.

When fertilizer applications exceed the recommended rates, nitrogen concentrations in shallow groundwater increase proportionately. Under North Carolina’s climatic conditions, a general guide for estimating the nitrate concentration in shallow groundwater under land receiving fertilizers is that “there will be 1 milligram per liter of nitrate-nitrogen for every two pounds of nitrogen not harvested by the crop.”

North Carolina is fortunate to have soils that have a clay layer at 10-30 feet below a large percentage of the fields in the coastal plain, which is the area receiving the highest applications of nitrogen fertilizer. This clay layer prevents the nitrate in the shallow groundwater from moving into the deeper aquifers where most drinking wells are located.

Most of the nitrate present in the shallow groundwater is transported via lateral flow to streams protected by riparian buffers. We have sampled below many fields where the shallow groundwater contained more than the drinking water standard for nitrate but have never found more than 1-2 milligrams of nitrate nitrogen in water below a significant aquatard (clay layer nearly impermeable to water). This is the reason that North Carolina has some surface water quality problems but few drinking water wells contaminated with nitrate.

Phosphorus

It has been historically stated by soil scientists that phosphorus does not leach except in very sandy or organic soils because of the chemical interactions between phosphorus and clay minerals. Thus, phosphorus applied to the soil as fertilizer tends to stay in the topsoil and not be lost to either surface or subsurface drainage waters. Large applications of phosphorus to soils tend to accumulate in the topsoil.

The large majority of nonpoint-source phosphorus lost to surface waters is attached to eroded soil particles. However, even small amounts of soluble phosphorus lost in runoff can contribute to problems in the receiving waters. Data collected over the past two decades show that the higher the concentration of phosphorus in the topsoil, the larger the amount of phosphorus lost via surface runoff. Until recently, we have not been concerned with phosphorus losses through leaching and lateral flows.

In recent years, the concentration of farm animals in large production units has caused large amounts of animal waste to be at one location. This has resulted in land applications of animal waste near the maximum rate governed by the limiting nutrient. Historically nitrogen has been the limiting nutrient so animal waste has been applied to the land using the maximum rate of nitrogen allowable. Applications of both swine and poultry wastes have resulted in more phosphorus being applied than is needed for agronomic purposes.

The high concentrations of phosphorus present in soils that have received animal waste applications for many years have resulted in widespread environmental concern because the limiting nutrient for eutrophication in most fresh water is phosphorus. There is concern not only that more phosphorus will be lost via surface runoff but also that it will move through subsurface drainage systems to surface waters. This problem has really been of concern in the Delaware–Maryland eastern shore area where the soils are very sandy and there are very high concentrations of poultry. These two states and several others are in the process of making regulations for application of animal waste based upon phosphorus as the limiting nutrient.

Recent research by Ham, a graduate student in the Soil Science department at NCSU, has shown that some sandy soils that have received animal waste for many years have significant increases of phosphorus to a depth of 4–5 feet. We have no indication that this phosphorus is moving laterally to streams, but there are questions as to how much phosphorus can be added to soils before this kind of movement becomes significant. As of this date, North Carolina soil scientists have not determined a recommended level of soil phosphorus on which waste applications should be based.

Value of Riparian or Planted Vegetative Buffers

A prominent feature of most North Carolina landscapes is the forested area present as narrow bands on either side of small streams. These forested areas (riparian buffers) are usually present because they were either too wet or too steep to conveniently clear for agricultural crops or urban development.

Riparian areas are extremely important for water quality protection in North Carolina. Nitrogen from nonpoint sources most often enters streams through subsurface flow of nitrate from agricultural fields. When the subsurface flow passes below a wooded riparian area, greater than 90 percent of the nitrate is frequently removed from the water before it enters streams.

In North Carolina, data show that drainage water from agricultural fields containing 10–20 milligrams per liter of nitrate nitrogen contains less than 1 milligram per liter when it enters the stream because of nitrate removal by riparian buffers. The removal is largely the result of a process called denitrification that occurs in wet soils containing organic matter—just the kind of conditions one finds next to streams. Denitrification converts the nitrate, which can contaminate surface and ground water, to a harmless dinitrogen gas that already makes up 80 percent of the air.

Since we do not know how to grow crops with sufficiently high yields to feed our population without loss of nitrate to groundwater, it is important that we take measures to prevent this nitrate from reaching surface waters where it may cause eutrophication problems. One of the best methods of preventing the nitrate from reaching streams is riparian buffers. Scientists and water quality regulators are currently searching for reasonable buffer requirements in North Carolina to achieve water quality goals. It is clear that buffers are a reasonable choice in many locations, but many questions about ideal width, location, etc. are unanswerable at this time.

Riparian buffers are also very effective in controlling sediment and pollutants associated with the sediment. Removals of greater than 90 percent are common. However, it is important that flow into the buffer approach not be in a channel because little sediment is removed from water flowing in a channel through the buffer. Riparian buffers are not as effective for phosphorus removal from surface runoff as they are for sediment, but average phosphorus removals of 50 percent can be expected from well-maintained buffers.

It is my opinion that riparian buffers are the single most important factor controlling nonpoint source pollution in North Carolina. If most of the drainage water from agricultural fields in the piedmont and middle and upper coastal plain did not flow through riparian buffers, the water quality in our streams would be much lower.

Controlled Drainage

In the Tidewater area of North Carolina, controlled drainage replaces natural riparian buffers as the management practice that can best be utilized to minimize nitrogen and phosphorus losses from agricultural fields to surface waters. This practice can reduce nitrogen losses to water by 50 percent. On approximately 300,000 acres of North Carolina cropland, controlled drainage is used as an approved BMP.

Use of controlled drainage as a BMP is reducing the entry of nitrogen into North Carolina surface waters by about 3,000,000 pounds annually. The practice is well liked by farmers because it increases corn and soybean yields by about 10 percent. Thus farmers can use the practice to improve the quality of water leaving their farm while increasing their profits.

In areas where controlled drainage has been recommended and been accepted by the agricultural community, the slope of the land is less than 0.5 percent. It is probable that controlled drainage can be used to improve quality of agricultural drainage water in areas where the land slopes are larger. However, the cost of using controlled drainage in these areas would be greater per unit area of land, and yield benefits to the farmer would be less or nonexistent. These circumstances do not rule out the possibility that controlled drainage might still be a BMP of choice in some areas where it has not been routinely recommended.