Tillage Effects on Nutrient Loadings of Waterways

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Introduction

Conservation tillage is the fastest growing agricultural practice in the history of U.S. agriculture. Conservation tillage increased from 30 million acres in 1972 to approximately 100 million acres or one-third of total U.S. cropland in 1982 (Myers, 1983). Some agricultural leaders project that 50 to 75 percent of U.S. cropland will be farmed with conservation tillage methods by the year 2010 (Crosson, 1981; OTA, 1982).

The use of conservation tillage is increasing because in most cases it is a cost-effective practice which reduces production costs (labor, equipment, and fuel), increases yields, conserves moisture, and maintains the long-term productivity of soils by reducing soil erosion and increasing the organic matter and nutrient content of soils.

Conservation tillage also is being promoted because it is thought to be one of the best available techniques for controlling nonpoint source water pollution from cropland. This paper discusses the environmental consequences of excessive nutrients in surface waters and the effects of conservation tillage on the transport of commercial nitrogen (N) and phosphorus (P) fertilizers to surface waters. Also discussed are fertilizer application techniques that can be used in conjunction with conservation tillage to minimize nutrient losses in surface runoff.

Environmental Consequences of Nutrients

Nitrogen and phosphorus are essential nutrients for aquatic as well as terrestrial vegetation. If present in sufficient quantities, however, N and P can promote eutrophication or premature aging of lakes and estuaries. Accelerated eutrophication causes excessive algae growth, which creates turbid conditions that may eliminate submerged aquatic vegetation and destroy the habitat and food sources of aquatic animals and waterfowl. When the algae die and decay, they may also reduce dissolved oxygen levels and suffocate fish and shellfish. Blooms of toxic algae can also release toxins to water that affect the health of swimmers, and under extreme circumstances, kill cattle and other animals that drink the water. Taste and odor problems caused by eutrophication can also reduce the quality of water for recreation and increase water treatment costs.

Nutrients are transported from cropland to waterways in soluble and sediment-bound forms in surface runoff and in soluble forms in subsurface flow. Nitrate (NO_3-N) is an extremely soluble form of N and is the only nutrient transported principally in subsurface flow. Subsurface transport mechanisms will not be discussed further in this paper. Principal forms of N and P transported in surface runoff include NO_3-N, ammonium (NH_4-N), organic N, orthophosphate (PO_4-P), organic P, and mineral P. All of these nutrient forms exist in both soluble and sediment-bound phases, but all are associated primarily with sediment except NO_3-N. Orthophosphate is also highly soluble but it tends to bind to organic matter and clays.

Soluble inorganic forms of nutrients such as NO_3-N, NH_4-N, and PO_4-P are the nutrients of primary concern with respect to water quality because they are the only forms of N and P which aquatic plants can assimilate directly. Soluble organic N and P are not immediately available to plants but since they can be rapidly metabolized to soluble inorganic forms by bacteria we must be concerned with their presence.

In addition, an equilibrium exists between sediment-bound and soluble nutrients. Consequently, if we decrease the concentrations of soluble nutrients in water, and sediment-bound nutrients are present, the sediment will release soluble nutrients until a new equilibrium is reached. Thus, it is obvious that all forms of N and P are significant with respect to eutrophication but soluble inorganic nutrients are the most important with respect to eutrophication because they are immediately available to plants.

To prevent eutrophication and nuisance algae growth, it has been suggested that concentrations of PO_4-P, NO_3-N, and total N (Nt) in lakes be limited to 0.025, 0.3, and 1-2 mg/L, respectively (Wetzel, 1983). Recommended limiting concentrations for PO_4-P in streams where they enter lakes are 0.05 mg/L and 0.10 mg/L in streams far upstream of lakes (NCAES, 1982).

Nitrate is the only major nutrient for which a health limit has been set. The maximum permissible concentration of nitrate (NO_3-N) in domestic water supplies is 10 mg/L. Nitrate itself is not toxic but it can be reduced to nitrite (NO_2-N) in the gastrointestinal tracts of infants and react with hemoglobin in the bloodstream to impair oxygen transport. This condition is referred to as methemoglobinemia and is most common in agricultural areas where surface and ground waters have been contaminated with N fertilizer (USEPA, 1976).

Cropland, pasture, and range have been identified as significant sources of N and P polluting the nation's water supplies. Cropland, pasture, and range together contribute nearly 6.8 million tons of N and 2.6 million tons of P to U.S. surface waters each year (Bailey and Wadell, 1979). This represents

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approximately 61 and 46%, respectively, of the total amount of N and P delivered to the nation's waters. To control nutrient losses and to protect water supplies, management practices such as conservation tillage, contouring, terraces, and improved fertilizer and pesticide management are being promoted. These practices are particularly needed in the Southern Region (Southern Plains, Delta States, Southeast, and Appalachia) where nonpoint source pollution is the main water quality problem and where cropland is the principal source of nonpoint source pollution (USEPA, 1984). Conservation tillage has great potential for reducing agricultural nonpoint source pollution in the Southern Region because only 23% of the cropland was in conservation tillage in 1987 (Magleby and Schertz, 1988).

Effects of Conservation Tillage on Nutrient Transport

Conservation tillage is defined as any tillage or planting system which leaves at least 30 percent of the soil surface covered with crop residue after planting. Major types of conservation tillage include no-tillage, ridge-till, strip-till, and mulch-till. Conservation tillage affects nutrient transport in surface runoff by increasing crop residue on the soil surface, decreasing soil erosion and surface runoff, and reducing incorporation of fertilizers.

Surface residues associated with conservation tillage reduce soil erosion and transport of sediment-bound nutrients in several ways. First and foremost, crop residue protects the soil from impacting raindrops. If the raindrops do not hit the soil surface directly, soil particles are not separated from the soil mass and erosion is greatly reduced. Baker and Laflen (1983) reported that erosion was approximately halved with every 9 to 16 percent increase in percent residue cover. This means that conservation tillage should reduce erosion by 75 to 90 percent (depending on the amount of surface residue) compared to conventional tillage. Reductions in nutrients transported by sediment are expected to be similar.

Conservation tillage systems also increase infiltration and reduce average annual runoff volumes by about 25 percent compared to conventional tillage (Baker and Johnson, 1983). The reduction in runoff would he expected to reduce the transport of soluble and sediment-hound nutrients. Unfortunately, concentrations of both soluble and insoluble forms of N and P in surface runoff generally increase with conservation tillage and usually offset the reduction in runoff volume. As a consequence of increased infiltration, leaching of soluble nutrients such as N03-N may lead to groundwater contamination.

The most significant factor affecting nutrient transport with conservation tillage involves the placement, timing, and rates of fertilizer applications. The primary goals of conservation tillage are to minimize the disturbance of surface residues and to avoid incorporation of crop residues. From an agronomic and water quality viewpoint, however, we would like to incorporate fertilizers so that they are close to plant roots and away from the soil surface where they are subject to loss via surface runoff and erosion. Unfortunately, these two goals are in conflict because current fertilizer incorporation practices also incorporate residue.

When fertilizers are broadcast and not incorporated, they concentrate near the soil surface where they are most susceptible to surface loss. In contrast, fertilizers are distributed more or less uniformly throughout the plow layer with conventional tillage. In a 5-year study comparing conventional tillage and no-till corn-soybean rotations, Erbach (1982) found that concentrations of P in the upper 2 inches of the soil profile were 67 percent higher with no-till. Similar results are expected with N except that increased infiltration with conservation tillage will tend to leach NO3-N down into the soil profile.

Concentration of nutrients near the soil surface with conservation tillage has two consequence. First, since the surface soil has higher nutrient levels, the concentration of nutrients in eroded sediment will also he higher. For example, in the corn-soybean rotation study discussed above, sediment associated P loss would decrease with no-till only if the 67 percent increase in soil P concentrations were offset by a 67 percent reduction in soil loss.

The second consequence of reduced incorporation of fertilizers is that concentrations of soluble nutrients in surface runoff are significantly higher with conservation tillage than with conventional tillage because soluble nutrient concentrations in runoff are directly proportional to nutrient levels at the soil surface (Baker and Laflen, 1982). Thus, doubling nutrient concentrations in the soil surface will approximately double soluble nutrient concentrations in runoff. As with sediment-hound nutrients, losses of soluble nutrients with conservation tillage will not decrease relative to conventional tillage unless the increased concentrations are offset by larger reductions in runoff volume.

Surface residues have also been identified as a source of soluble nutrients in surface runoff (Barisas et al., 1978; Smith et al., 1974). These researchers concluded that leaching of soluble nutrients from crop residues was a major cause of higher soluble nutrient losses with no-till.

Fertilizer Management Practices for Conservation Tillage

As discussed above, conservation tillage is unlikely to achieve significant reductions in nutrient delivery to waterways unless nutrient levels in surface soils can he reduced. Surface application of fertilizers is the most popular but most inappropriate method of conservation tillage fertilization. New fertilizer application methods are needed which will incorporate fertilizer into the soil with minimal disturbance of surface residue. Shallow tillage with knives or disks may be acceptable to apply nutrients with corn residue hut a single disking for ammonia application with soybean residue may reduce surface cover excessively (Baker and Laflen, 1983).

A study of hand incorporation P fertilizer found that there were no significant differences in soluble P concentrations in runoff from conventional, no-till, and conservation tillage plots (Mueller et al., 1982). Soluble P losses were found to be reduced in proportion to the runoff volume reductions achieved by the different tillage systems. These results support the hypothesis that subsurface application of fertilizers can reduce the concentrations of nutrients in surface runoff and consequently reduce total nutrient losses relative to conventional tillage. Similar results would be expected for insoluble P and both soluble and insoluble N losses.

Morrison (1986) gives an excellent review of machinery for improved fertilizer application with conservation tillage. Slot injectors for liquid and dry fertilizers are described which greatly increase fertilizer use efficiency and minimize losses in surface runoff. Coulter/nozzle, v-wheel and sweep, and high-pressure nozzle slot injectors are described (Morrison, 1986) along with a spoked-wheel point injector developed by Baker et al. (1985). The effectiveness of alternative fertilizer application knife types are also discussed. Fertilizer injection via injectors on paraplow blades is also a promising technique.

If subsurface application equipment is not available, Morrison (1986) recommended dribble banding of liquid and solid fertilizers as the best available surface fertilizer application practice. Dribble banding of liquid fertilizer should also reduce loss of nutrients in surface runoff because the liquid fertilizer will flow further down into the soil than when it is distributed uniformly over the soil surface.

Summary and Conclusions

Conservation tillage is a promising alternative for agricultural nonpoint source pollution control. Conservation tillage reduces soil erosion by 75 to 90 percent and surface runoff volumes by approximately 25 percent compared to conventional tillage. Since most nutrients in surface runoff are associated with sediment, conservation tillage usually results in a net decrease in nutrient losses.

Currently, most fertilizers are surface broadcast to land in conservation tillage. Surface broadcasting of fertilizers causes nutrients to concentrate at the soil surface where they are most susceptible to loss in surface runoff. This increases concentrations of soluble and sediment associated nutrients in runoff and can result in higher losses of some nutrients than with conventional tillage. To minimize this problem, fertilizer application methods must be developed that apply fertilizers below the soil surface while minimizing disturbance of surface residue.

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