WATER-QUALITY PROBLEMS IN THE ECOSYSTEM AS INDUCED BY MASS FLUXES OF PHOSPHORUS AND NITROGEN

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Abstract: Sustainable nitrogen and phosphorus management aims to achieve three goals: 1) the maintenance of soil organic matter to ensure adequate long-term nitrogen supplies in the soil, 2) regulation of soluble forms of nitrogen to ensure that plant needs are met, and 3) the minimization of environmentally damaging losses from the soil-plant system. Abundant growth of plants in terrestrial system is usually considered beneficial, but in aquatic system too much growth may engender water problems. The unwanted growth of algae and aquatic weeds can make water body unsuitable both as a source of drinking water and as habitat for fish. Streams natural water is clear, free of excess growth of algae and other aquatic plants, and is with diverse associate communities of organisms. When phosphorus from farmland is added to a phosphorus-limited stream through runoff water, it stimulates a burst of algal growth referred to as algal bloom. Critical levels of phosphorus in water, above which eutrophication is likely to be triggered, are 0.03 mg/l of dissolved P and 0.1 mg/l of total P. Under these anoxic conditions, growth of many aquatic organisms are severely limited, especially fish. Such eutrophic water often becomes turbid, limiting growth of beneficial submerged aquatic vegetation and benthic organisms, which serve as food for much of the fish community. In extreme cases it leads to massive fish kills.

Keywords: algal bloom, aquatic environment, eutrophication, nutrient

Introduction:

The biogeo-chemistries of nitrogen and phosphorus have much in common. Both are essential nutrients found primarily in organic forms in the soils. Both move in soils and plants mostly in the form of anions. Both undergo oxidation and reduction to form gases and both are responsible for serious environmental problems (Edem et al. 2015a).

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This work explores the economy of these two elements, starting from nitrogen.

Nitrogen in the soil is the most important element for plant development. It is required in large amounts in the soil to avoid a deficiency in plant production and health. Nitrogen is a major part of chlorophyll and the green colour of plants. It is responsible for lush, vigorous growth and the development of a dense plant. Although nitrogen is the most abundant element in our atmosphere (about 78%), plants cannot use it until it is naturally processed in the soil by microbes (Addiscott 2006). Nitrogen is an essential building block of amino and nucleic acids, essential to life on Earth. As part of the symbiotic relationship, plants convert the 'fixed' ammonium ion to nitrogen oxides and amino acids to form proteins and other molecules, (e.g., alkaloids). In return for the 'fixed' nitrogen the plant secretes sugars to the symbiotic bacteria.

Elemental nitrogen in the atmosphere cannot be used directly by either plants or animals, and must be converted to a reduced (or 'fixed') state in order to be useful for higher plants and animals. Precipitation often contains substantial quantities of ammonium and nitrate, thought to result from nitrogen fixation by and other atmospheric electric phenomena (Addiscott 2005). However, because ammonium is preferentially retained by the forest canopy relative to atmospheric nitrate, most fixed nitrogen reaches the soil surface under trees as nitrate. Soil nitrate is preferentially assimilated by tree roots relative to soil ammonium.

Nitrogen occurs in all living organisms, and the nitrogen cycle describes the movement of the element from air into the biosphere and organic compounds, then back into the atmosphere. Synthetically-produced nitrates (NO_3) are key ingredients of industrial fertilizers, and also key pollutants in causing the eutrophication of water systems (Edem et al. 2015b). Nitrogen is a constituent element of amino acids and thus, of proteins and nucleic acids (deoxyribonucleic acid-DNA and Ribonucleic acid-RNA). It resides in the chemical structure of almost all neurotransmitters, and is a defining component of alkaloids, biological molecules produced by many organisms. The human body contains about 3% by weight of nitrogen, a larger fraction than all elements save oxygen, carbon, and hydrogen (Rittmann et al. 1994).

Nitrogen is available to the soil in many forms or applications (Fiencke et al. 2005):

- fixation from the air by soil microbes;
- chemical or inorganic fertilizer;
- manure and sewage sludge;
- compost tea and other liquid (fermented) fertilizers;
- guano and other fish or seaweed concentrates.

There is controversy involved with inorganic or synthetic nitrogen usage (Umoh et al. 2015). Over application of chemical nitrogen leads to soil and soil-water contamination through run-off and leaching. The considerable consumption of fossil fuels in the manufacturing and processing of synthetic nitrogen fertilizers is also cause for concern. In terms of environmental stewardship organic sources of nitrogen is preferred (Abubaker et al. 2013). When synthetic and/or inorganic nitrogen are applied care is taken not to apply them in excess as it could damage microbial activity and potentially up to 70% can be lost through soil leaching and volatilization to the atmosphere as a gas (Edem et al. 2015a).

Nitrogen Sources

The earth's atmosphere consists of 78% nitrogen and is the ultimate source of nitrogen. In most areas of the world, the nitrogen found in soil minerals is negligible. Nitrogen may be added to or lost from soil by a number of processes. In the soil, nitrogen can undergo a number of transformations (e.g., transformed into amino acids) through microbial activity.

Rainfall adds about 18 kg of nitrogen to the soil per hectare per year (Krishna 2014). The nitrogen oxides and ammonium that are washed to earth are formed during electrical storms by internal combustion engines and through oxidation by sunlight. There are scientists who also believe that some of the gaseous products resulting from the transformation of nitrogen fertilizers may cause a depletion of the ozone (O_3) layer around the earth. The extent of this possible damage is yet to be substantiated.

Crop residues decompose in the soil to form soil organic matter. This organic matter contains about 5 percent nitrogen (Guillard and Kopp 2004). A hectare of top soil with 2 percent organic matter would contain up to 7,000 kg of nitrogen. However, this is highly dependent on climate and soil health including the level of soil carbon and microbial activity in the soil. Generally, about 1 to 3 percent of this organic nitrogen is converted per year by microorganisms to a form of nitrogen that plants can use. The critical point is that soil N can be only maximized in a healthy soil environment (i.e. adequate soil carbon and microbial activity levels to facilitate N transformation and its availability to plants). The failure to achieve these soil conditions on farms is the key reason why much of the N fertilizer application is lost to soil leaching and volatilization into the air.

Legumes also fix atmospheric nitrogen through their symbiotic association with Rhizobium bacteria. When plant roots are well-nodulated, the legume plant does not benefit from the addition of nitrogen fertilizer. Perennial legumes, such as alfalfa, can fix about 400 kg of nitrogen per hectare per year (Han et al. 2011).

Manure contains an appreciable amount of nitrogen. Most of this nitrogen is in organic forms: protein and related compounds. Cattle manure contains about 5 to 20 kg of nitrogen per ton. About half of this nitrogen is converted to forms available to plants during the first growing season. Lesser amounts are converted during succeeding seasons. Each ton of applied manure is equal to about 2 to 9 kg of commercial fertilizer nitrogen (Galloway and Cowling 2002). Commercial fertilizer nitrogen comes in three basic forms: gas, liquid and dry. All forms are equally effective when properly applied. Once applied, fertilizer nitrogen is subject to the same transformations as other sources of nitrogen. There is no difference between the ammonium (NH_4^+) or nitrate (NO_3^-) that enters the plant from commercial fertilizer and that produced from natural products such as manure, crop residues or organic fertilizers.

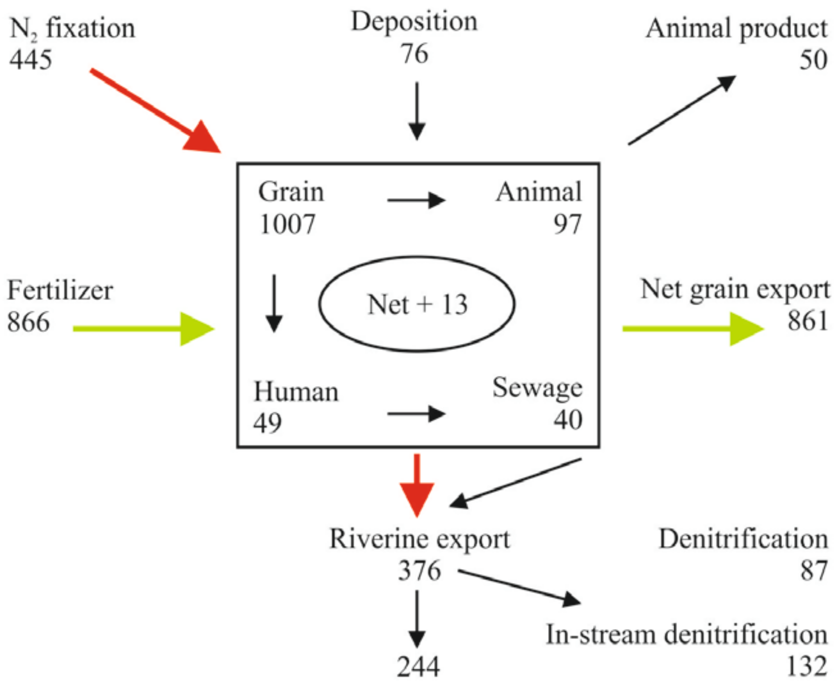
Nitrogen for the soil

Nitrogen (N) in the form of synthetic nitrogen fertilizer is the traditional form of delivery to the farm or pond soil. Nitrogen (N) in a liquid fertilizer that has undergone fermentation will produce a result similar to the transformation of N in the soil (under microbial activity and in the presence of carbon and hydrogen) where it becomes bound into compounds such as amino acids (as in Fig. 1, N in an amino acid along with O_2, C and H). Amino acids in soils are part of the humic acid fraction. This is why it helps to add humic acid as an ingredient to the liquid formulation. Also, it pays to have good carbon levels in the soil to increase humic acid production and availability of N in these compound or complex forms. This is why N (as a single element) does not act alone in a healthy soil (Addiscott 2005).

The question is: do you want nitrogen (N) delivered as a chemical or as food? Also, do you want to maximize N delivery from the atmosphere through microbial activity in the soil (this way it is free)? Microbial activity (diversity and abundance) in the soil can be sustained in the absence of chemicals and compaction and where beneficial microbes are incorporated into the soil along with trace minerals and other nutrients (nutrient cycling) (Eickhout et al. 2006).

There is over 5000 tons of N in the atmosphere above 1 hectare of land and available for use by soil microbes. Most (about 70%) nitrogen supplied in a chemical form to a soil can be lost through the soil hydrology and into the air where soil conditions are poor. Therefore, it is best to deliver N in a complex form or as compounds (amino acids). This is what happens or is produced in a fermentation/digestion of N and other nutrients. For example, magnesium in the fermentation will link with N to form magnesium nitrate (Galloway and Cowling 2002). Also, N in high levels can be antagonistic to (suppress) copper and potassium and possibly also molybdenum. Copper availability in a soil is critical to plant, animal and human health (David and Gentry 2000).

Figure no. 1 Diagram illustrating the principles of N deposition, transformation and lost by denitrification from the soil and from waters (Source: David and Gentry 2000)



Nitrogen that has been transformed or complexed into amino acids, in a fermentation may be the best form to deliver N to the soil as this should make the N more useful as a soil and plant conditioner, with little or no loss of N (i.e. available for immediate use by plants).

The appropriate/economic level of free N needed to apply to a soil is probably about 3% of the formulation (liquid or granule), and it should be provided in a form that is immediately available for metabolism as an amino acid/protein. The fermentation of the following ingredients yield better results: Nitrogen sulphate, high N plant materials (pre-fermented to extract nitrogen in a complex form), urine (because it is ready to complex), humic and fulvic acid, fish and seaweed concentrates and sea minerals to obtain the minerals that N needs to become complex with so as to form amino acids and other compounds for the soil and microbes (Neff et al. 2013).

Over 90% of the nitrogen N in the surface layer of most soils occurs in organic forms (humic acids), with most of the remainder being present as NH_4^- which is held within the lattice structures of clay minerals (often not available due to poor microbial activity). The surface layer of most cultivated soils contains between 0.06 and 0.3% N. Peat soils have high N contents to 3.5% due to the presence of high carbon levels. Plant remains and other debris contribute nitrogen N in the form of amino acids.

Nitrogen transformations

Nitrogen exists in a number of chemical forms and undergoes chemical and biological reactions.

Organic nitrogen to ammonium nitrogen (mineralization)

Organic nitrogen comprises over 95 percent of the nitrogen found in soil. This form of nitrogen cannot be used by plants but is gradually transformed by soil microorganisms to ammonium (NH_4^+).

Ammonium is not leached to a great extent. Since NH_4^+ is a positively charged ion (cation), it is attracted to and held by the negatively charged soil clay. Ammonium is available to plants and phytoplankton.

Ammonium nitrogen to nitrate nitrogen (nitrification)

In warm, well-drained soil, ammonium transforms rapidly to nitrate (NO_3^-). Nitrate is the principle form of nitrogen used by plants. However, it leaches easily, since it is a negatively charged ion (anion) and is not attracted to soil clay. The nitrate form of nitrogen is a major concern in pollution to water bodies.

Nitrate or ammonium nitrogen to organic nitrogen (immobilization)

Soil microorganisms use nitrate and ammonium nitrogen when decomposing plant residues. These forms are temporarily "tied-up" (incorporated into microbial tissue) in this process. This can be a major concern if crop residues are high in carbon relative to nitrogen. Examples are wheat straw, corn stalks and sawdust. The addition of 9 to 30 kg of nitrogen per tonne of these organic residues is needed to prevent this transformation. Once the residues are decomposed, the microbial population begins to die back.

Nitrate nitrogen to gaseous nitrogen (denitrification)

When soil does not have sufficient air, microorganisms use the oxygen from NO_3^- in place of that in the air and rapidly convert NO_3^- to nitrogen oxide and nitrogen gases (N_2). These gases escape into the atmosphere and are not available to plants. This transformation can occur within two or three days in poorly aerated soil and can result in large loses of nitrate-type fertilizers.

Ammonium nitrogen to ammonia gas (ammonia volatilization)

Soils that have a high pH (pH greater than 7.5) can lose large amounts of NH_4^+ by conversion to NH_3 gas. To minimize these losses, incorporate solid ammonium-type fertilizers, urea and anhydrous ammonia below the surface of a moist soil.

Proteins, nucleic acids, and other organic chemicals contain nitrogen, so nitrogen is a very important atom in biological organisms. While nitrogen makes up 78% of Earth's atmosphere, most organisms cannot use nitrogen gas (N_2). N_2 enters the trophic system through a process called nitrogen fixation. Bacteria found on the roots of some plants can fix N_2 to organic molecules, making proteins. Again, animals get their nitrogen by eating plants. But after this point, the nitrogen cycle gets far more complicated than the carbon cycle.

Animals release nitrogen in their urine. Fish releases NH_3, but NH_3 when concentrated, is poisonous to living organisms. So organisms must dilute NH_3 with a lot of water. Living in water, fish have no problem with this requirement, but terrestrial animals do have problems (Galloway and Cowling 2002). They convert NH_3 into urine, or another chemical that is not as poisonous as NH_3. The process of releases NH_3 is called ammonification. Because NH_3 is poisonous, most of the NH_3 which is released is poisonous. But soil bacteria have the ability to assimilate NH_3 into proteins. These bacteria effectively use up the NH_3, and make proteins from it. This process is called assimilation.

Some soil bacteria do not convert NH_3 into proteins, but they make nitrate NO_3^- instead. This process is called nitrification. Some plants can use NO_3^-, consuming nitrate and making proteins. Some soil bacteria, however, take NO_3^-, and convert it into N_2, returning nitrogen gas back into the atmosphere. This last process is called denitrification, because it breaks nitrate apart (Prasad and Power 1995).

Examination of phosphorus losses from farmland and aquaculture ponds

Agricultural management that involves disturbing the soil surface with tillage generally increases the amount of P carried away on eroded sediment. On the other hand, fertilizer or manure that is left unincorporated on the surface of cropland usually leads to increase losses of P dissolved in the runoff water. Lemunyon and Daniel (2002) examined the field-specific parameters needed to estimate P losses from agricultural systems. They described calculation methods for estimating the required parameters and discussed how these assessments can be used to minimize P losses through management. These methods were used in a qualitative P indexing approach where source and transport factors influencing runoff are assigned index values to arrive at a relative assessment of P loss risk. In contrast, semi-quantitative modeling approaches to P index development, like those of Wisconsin, Iowa, Minnesota, and North Carolina, use algorithms designed to estimate actual P runoff losses (Chantigny et al. 2008).

Some studies have monitored P levels in lakes and identified the major mechanisms responsible for transporting P to the water body (NRCS 2005). A northern Wisconsin study at White Clay Lake in the early 1980s monitored the levels of nutrient and sediment delivery (total sediment, total nitrogen, total P, water volumes) to the lake for three years before implementation of new conservation techniques and practices in the watershed. The lake was monitored for another three years after practice implementation with no significant changes due to the new managements noted (Persson et al. 1983). However, since the suggested management practice changes were voluntary, not all of the high priority areas for P loss in the watershed received improved practices. Variations in climate and potential transport of nutrient-enriched sediments may have played a role in masking any conservation improvements. Two decades later, Clear Lake in north central Iowa was also monitored for total P for two years and land management practices and soil nutrient levels in the watershed were assessed (Klatt et al. 2003). They determined storm flow runoff was the greatest contributor of P to the lake. They also found that as soil test P levels in the watershed increased, the lake water total P concentration increased as well.

Birr and Mulla (2001), conducted a regional study on 60 watersheds in Minnesota using average watershed runoff values, agricultural land distances from streams and drainage ditches, county-averaged Bray P soil tests, fertilizer and manure application rates, and total P measurements in streams and lakes in the watersheds. They determined that the modified version of Lemunyon and Gilbert's (1993) original P Index was a useful tool to identify areas with P loss potential using available state and national information.

A study by Cornish et al. (2002) monitored soluble P levels in runoff from a 140 ha dairy farm and from a 4 ha representative sub-catchment within the farm for two years in Australia. The mean soluble P concentrations for nine runoff events were not significantly different at the two scales of measurement. Nine rain simulations on 1 m^2 plots within the 4 ha paddocks were conducted, and the average soluble P concentration was similar to that found in the natural runoff. They concluded that runoff P concentration does depend on scale, but the effects are minimal. The upper portions of the catchment produced lower soluble P concentrations due to lower soil test P. The authors hypothesized that events of longer duration may include the lower soluble P concentrations from these upper catchment areas.

Also, the catchment included 30% native vegetation which would have lowered the P concentrations as well. The main form of P lost was soluble P because of low soil erosion losses. Quinton et al. (2001) investigated rainfall event size effects on removal of P. They determined that dissolved P concentrations [filtered runoff analyzed by inductively coupled plasma (ICP)] usually increased with increasing peak discharge (runoff volume) and that P concentrations usually decreased with increasing event duration. Thus, highest runoff P concentrations would be expected with high volume, short duration events and lowest concentrations would be found with low volume, long duration events. This finding supports the conclusion from Cornish et al. (2002) that longer duration runoff events had lower P concentrations.

Le Bissonnais et al. (1998) measured runoff, crusting, and erosion in 1m^2, 20 m^2 and 500 m^2 plot sizes and in a small catchment in France for two years. In the fall, the fields were seeded with winter wheat. In the spring, some areas were seeded with rye grass/clover blend at the end of April or left un-seeded. They measured much lower sediment 1 m^2 plot than in the 20 m^2 plots, probably due to the shorter concentrations in the 1m flow length and limited runoff velocity to move sediment. They did not find much difference in runoff sediment concentrations of 20 m^2.

Impacts of phosphorus and nitrogen fluxes on water quality

Phosphorus (P) is an essential nutrient for crop or phytoplankton growth. Neither plants nor animals can live without it. It is an essential component of the organic compound adenosine triphosphate (ATP) (Brady and Weil 2013), which is the energy currency that drives most biochemical processes. Often, total P levels in soil do not reflect plant available P. Phosphorus needs to be added to the soil for proper crop or phytoplankton growth if soil or pond available P levels are not sufficient. Phosphorus fertilizer and manure have been applied to crop fields, sometimes in excess of crop removal, and average soil test P levels have increased with time (Bundy and Sturgul 2001; Peters 2005; PPI 1998). This is especially true in Wisconsin where dairy and other livestock farms produce abundant amounts of manure. The P built up in some soils has led to a serious nonpoint source pollution issue (Carpenter et al. 1998). Phosphorus is lost in agricultural runoff attached to sediment or in the dissolved form. Since P is the limiting nutrient in most freshwater systems, excess P from runoff can cause increased growth of fresh water plants and algae (Correll 1998). Some cyanobacteria may create toxins that can be harmful to the health of humans and livestock if that water is used for drinking (Sharpley et al. 1994).

Once this vegetative and algal growth dies, the decay process depletes oxygen levels, which in turn can harm aquatic life. Since P has been identified as a major contributor to water quality degradation in freshwater streams and lakes (USEPA 2000a, 2000b), approaches to contend with this issue have developed. The P Index concept was brought forward in the early 1990s. This idea sought to include both P source and transport mechanisms in assessing P loss to surface water (Lemunyon and Gilbert 1993). Phosphorus indices can be effective tools because they identify factors contributing to P losses and offer management options for reducing P runoff to surface water (Mallarino et al. 2002). Animal wastes from industrial–style farms often contain elevated levels of P because of excessive phosphorus in animal feeds. The resulting manure allows rainwater to dissolve large amounts of soluble P in both inorganic and organic forms (Sharpley and Moyer 2000). Such manure is commonly over-applied with respect to the phosphorus needs of crops, especially on fields convenient to livestock facilities. These practices have resulted in dramatic increases in the P content of the surface soils. Runoff and erosion from such P - saturated soils are likely to be responsible for serious downstream eutrophication problem.

In contrast to positively charged ammonium ions, negatively charged nitrate ions are not adsorbed by the negatively charged collides that dominate most soils. Therefore, nitrate ions move downward freely with drainage water and are readily leached from the soil. The loss of nitrogen in this manner is of concern for three basic reasons: the loss of this valuable nutrient is a waste that impoverishes the ecosystem, leaching of nitrate anions stimulates the acidification of the soils and the co-leaching of such cations as Ca^{++}, Mg^{++} and K^{+} and the movement of nitrate to groundwater causes several serious water-quality problems downstream (Masciandaro and Ceccanti 1999).

Water quality impacts caused by nitrogen are mainly associated with the movement of nitrate with drainage waters to the ground water. The nitrate may contaminate drinking water causing health hazards for people as well as livestock. The nitrate may also eventually flow underground to surface waters, such as stream, lake, and estuaries. The key factor for health hazard is concentration on nitrate in the drinking water and the level of exposure over periods. Even more widespread are the damages to water quality and to the health of aquatic ecosystems, especially those with salty or blackish water. The total N load may be comprised partly of organic and ammonium forms of N transferred from the land in the surface runoff or on eroded soil material, but N leached through the soil profile as nitrate is often the main contributor. The quality on nitrate lost in drainage water depends on the volume of leaching through the soil and the concentration of nitrate in that drainage water. However, the volume of water is influenced by rate of precipitation, irrigation and evaporation as well as soil texture and structure. Sandy soils in humid regions of Nigeria are highly susceptible to leaching. The concentration of nitrate in leaching water is largely dependent on the size of the soil nitrate pool during the periods of leaching. The nitrate present, in turn, reflects the balance between removal of nitrogen from this pool by plant uptake and the input of nitrogen into the nitrate pool by mineralization, fertilization and atmospheric deposition.

Conclusions:

Nitrogen in the air is the ultimate source of all soil nitrogen. This can be achieved with adequate soil carbon levels and a diverse and abundant microbial activity. Nitrogen may enter the soil through rainfall, plant residues, nitrogen fixation by microbes (soil organisms), animal manures and commercial fertilizers. There is ultimately no difference between the nitrogen that enters the plant from commercial fertilizers and that from organic products. Nitrogen may be lost from the soil by plant removal, volatilization, leaching or erosion. Leaching of nitrate (NO_3^-) is a pollution hazard; control nitrogen losses with proper soil management practices. This will occur in sandy soils (low clay levels), low soil carbon (2%), low microbial activity, low soil moisture, compaction and in the presence of chemical residues. Nitrogen is only maximized in the soil by plants when the soil carbon levels are adequate (e.g. above 2%) and microbial activity is diverse and abundant. Nitrogen delivered to the soil as a compound or in a complex form (e.g. amino acids) in a liquid formulation (i.e. fermented) may be the best form to deliver nitrogen to the soil, rather than as N and in an organic form which cannot be used by plants until it is gradually transformed by soil microorganisms to ammonium (NH_4^+). Soil microorganisms use nitrate (NO_3^-) and ammonium (NH_4^+) nitrogen when decomposing plant residues. These forms are temporarily "tied-up" (incorporated into microbial tissue) in this process. However, the soil carbon to nitrogen ratio needs to be balanced.

On eroded farmlands, ground water and stream watersheds with intense agricultural land use are commonly much higher in phosphate and nitrate than those draining forested watersheds. Heavy nitrogen and phosphorus fertilization of crops especially vegetable and grains are major sources of excessive nitrate and phosphate pollutants because the crops usually take up only a portion of the phosphorus and nitrogen applied. These excess nutrient losses induce water quality and stimulate explosive growth of algae, which sink to the bottom when they die. In decomposing this dead tissue, microorganisms deplete the oxygen dissolved in the water to levels unable to sustain aquatic life. Fish, shrimps and other aquatic species either migrate out of the zone or die. Therefore, major efforts are required to educate farmers and others to improve their N and P use efficiency and reduce the transformation of these valuable nutrients into pollutants.

Rezumat:

PROBLEMELE CALITĂȚII APEI ÎN ECOSISTEMELE ACVATICE PROVOCATE DE FLUXURILE DE FOSFOR ȘI AZOT

Managementul durabil al azotului și fosforului vizează atingerea a trei obiective: 1) menținerea materiei organice din sol pentru a se asigura aprovizionarea adecvată pe termen lung a azotului; 2) reglarea formelor solubile de azot pentru a se asigura că nevoile plantelor sunt satisfăcute și 3) minimizarea efectelor dăunătoare mediului din sistemul sol-plantă. Creșterea abundentă a plantelor în sistemul terestru este de obicei considerată benefică, dar pentru sistemele acvatice creșterea excesivă poate cauza probleme privind calitatea apei. Creșterea nedorită a algelor și a buruienilor acvatice poate face ca apa să nu fie potrivită atât ca sursă de apă potabilă, cât și ca habitat pentru pești. Cursurile naturale de apă sunt curate, lipsite de o creștere excesivă a algelor sau a altor plante acvatice, aflându-se în asociere cu diverse comunități de organisme. Când fosforul provenit de pe terenurile agricole se adaugă peste nivelul admisibil prin intermediul apelor de scurgere, acesta stimulează o dezvoltare necontrolată a algelor numită înflorirea algelor. Nivelul critic al fosforului în apă, peste care se declanșează fenomenul de eutrofizare, este de 0,03 mg/l pentru fosforul dizolvat și 0,1 mg/l pentru fosforul total. Sub aceste condiții de hipoxie, dezvoltarea a numeroase organisme acvatice este limitată, în special la pești. O astfel de apă eutrofică devine deseori tulbure, limitând dezvoltarea vegetației acvatice submerse și a organismelor bentonice, care servesc ca hrană pentru multe populații de pești. În situațiile extreme acest fenomen conduce la moartea masivă a peștilor.

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