NPDES Compliance Inspection Manual

Appendix AE

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Appendix AE –
Management/Soil Science

NUTRIENT MANAGEMENT AND SOIL SCIENCE

Understanding soil science and soil fertility concepts are instrumental in developing, understanding, and implementing nutrient management plans (NMPs) that allow for maximum utilization of the nutrients in the soil while minimizing the runoff of nutrients and pollutants. CAFO inspectors should become aware of the following basic nutrient management and soil science concepts.

Soil Properties

Inspectors should understand the basics of soil properties and how the soil retains nutrients. The nutrients in the soil are a source of information for NMP development and implementation. Important soil priorities are:

- Organic matter is derived from decomposed plant and animal material.
- Bulk density is the mass of dry soil per unit of bulk volume, including the airspace. Soils with a high proportion of pore space to solids have lower bulk densities than those that are more compact and have less pore space. As bulk density increases, pore space is reduced, which inhibits root growth. Fine-textured soils such as silt loams, clays, and clay loams generally have lower bulk densities than sandy soils. Sandy soils typically have less total pore space than finer textured soils.
- Texture is the fineness or coarseness of the mineral particles in the soil and is determined by the relative amounts of different sized mineral particles in the soil.
- Aggregation is the cementing or binding together of several soil particles into a secondary unit.
- Structure describes how soil particles are arranged or grouped together to form structural pieces (building blocks) called peds or aggregates that vary in shape and size. The arrangement of the aggregates determines the soil's structure. Good structure allows favorable movement of air and water and allows and encourages extensive root development.
- Color is an indicator of the soil's composition. Soil colors usually result from various oxidation states of the present minerals. Brighter colors (yellow and red) are an indication of iron oxides and suggest good drainage and aeration. Grayish soils can indicate iron reduction caused by permanently saturated soil. Mottled color soils of various shades of yellow, brown, and gray are indicative of a fluctuating aerobic and anaerobic environment. Very dark browns and black soil colors can be an indication of high levels of organic matter.
- Retention/water-holding capacity is the amount of water retained in a soil that is dependent on the interaction of soil texture, bulk density, and aggregation. The term field capacity defines the amount of water remaining in a soil after downward gravitational flow has stopped, and it is expressed as a percent by weight.
- Soil drainage is defined as the rate and extent of water removal. This includes water movement across the surface and downward through the soil. Topography is a very

important factor in soil drainage. Other factors that affect drainage include the soil layers' texture and soil structure.

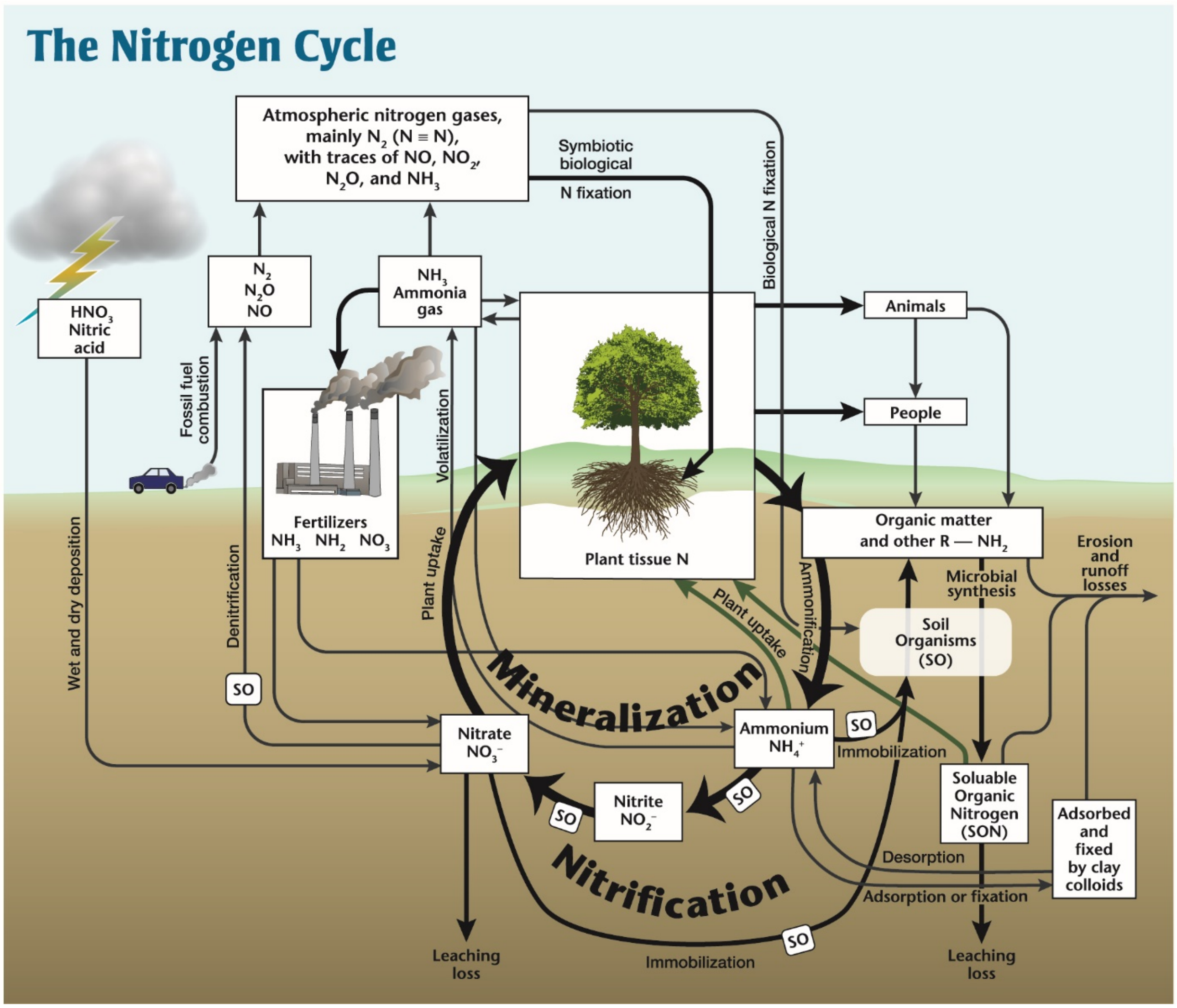
- Cat-ion Exchange Capacity (CEC) is a measure of the soil's ability to retain cat-ions and is indicative of the soil's fertility. Soil materials have a net surface charge, usually negative, that allows them to hold and retain ions (i.e., nutrients) against leaching. The net negative charge of a soil is largely attributed to the clay and organic matter in the soil and will naturally attract positively charged nutrients and repel negatively charged nutrients. Cat-ions, positively charged nutrients (e.g., ammonium ($NH3+$)), remain in the soil while anions, negatively charged nutrients (e.g., nitrate ($NO3-$)), are repelled and easily leached out of the soil.
- Soil Fertility is the ability of a soil to provide nutrients for plant growth.
- Soil pH affects plant nutrient availability because pH greatly influences the solubility of certain elements. Most crops grow best in slightly acidic soils (pH 6.0 to 6.5).

Soil and Plant Availability of Nutrients

Soil is a pathway for nutrients to flow to surface and groundwater and soil is a medium for nutrient transformations. The nutrient transformations affect the amount and form of nitrogen and phosphorus available to the plant. Appropriate manure and fertilizer applications in an NMP will account for many of the transformations. It is important for an inspector to understand the behavior of nitrogen and phosphorus in the soil.

Nitrogen Cycle and Nitrogen Movement in the Soil

Nitrogen is an essential part of amino acids, the building blocks for proteins, making it an important plant nutrient. Nitrogen in the soil exists in both organic (proteins, amino acids, urea, in living organisms and decaying plant and animal tissues) and inorganic forms [ammonium ($NH4+$), nitrite ($NO2-$), nitrate ($NO3-$), and ammonia ($NH3$ (gas)). The majority of nitrogen in the soils is in an organic form which is largely unavailable for plant uptake.



When manure is land applied as an organic compound, only a small fraction of the nitrogen is soluble as ammonium and plant available. However, a larger portion of that nitrogen is mineralized by microbes and is slowly released over many years. Nitrogen mineralization rates of the organic nitrogen present in manure vary depending on various environmental factors such as soil type, the manure source, and climate.

Nitrate is a negatively charged ion that is not adsorbed to the negatively charged soil mineral surfaces. If in excess, the negatively charged nutrient is repelled by the soil surfaces and lost to groundwater through leaching. Factors that contribute to nitrogen leaching or runoff include over-application of nitrogen as fertilizers or manure particularly on sandy or coarse-textured soils; improperly timed applications of nitrogen, poorly designed or nonexistent soil conservation measures; and periods of exceptionally heavy rainfall.

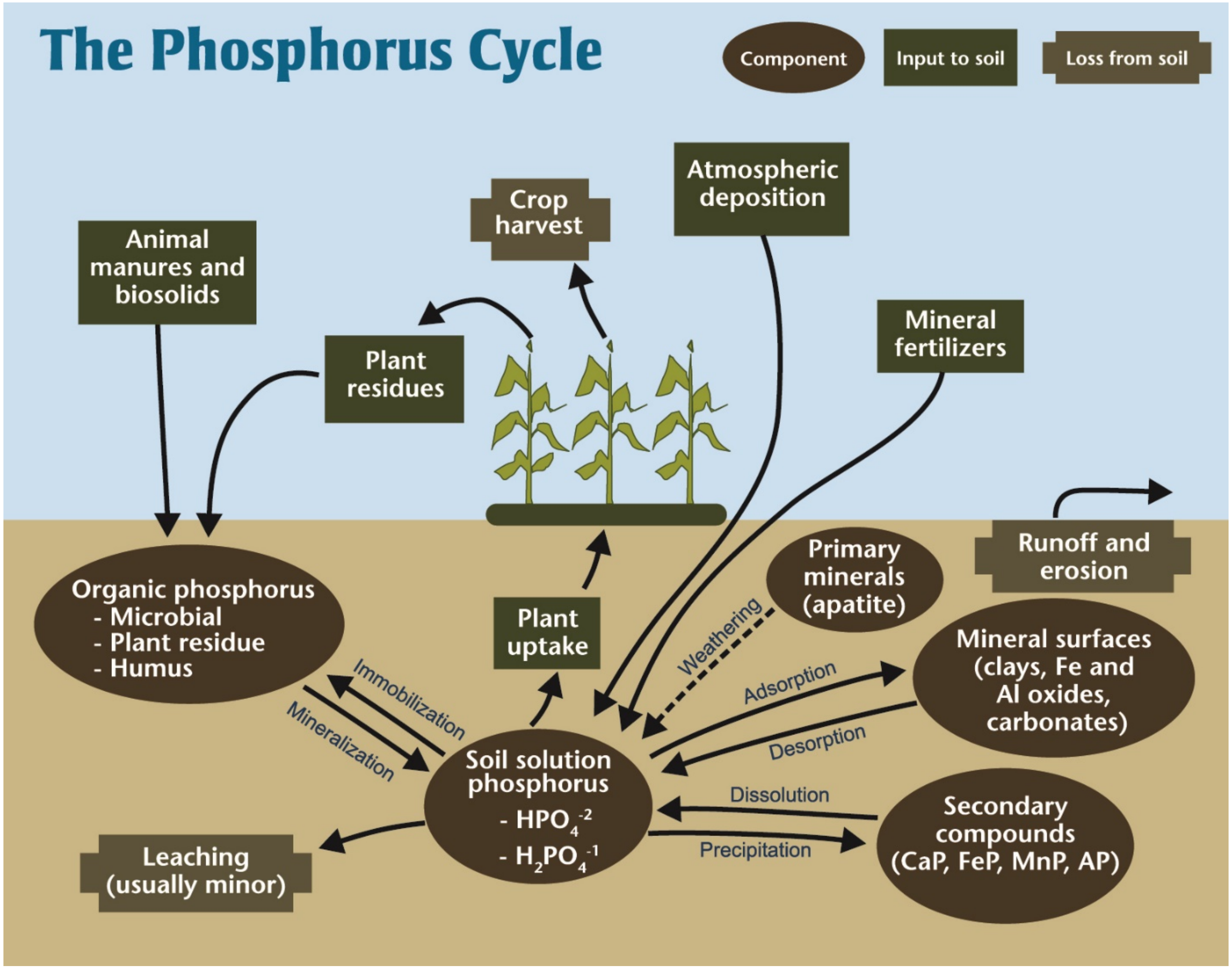
Nitrogen and Legume Credits

The largest amount of nitrogen is found in the atmosphere as an inert gas (N_2). Plants are not able to absorb gaseous nitrogen. Nitrogen becomes plant available when specialized bacteria fix nitrogen gas. Leguminous plants, such as alfalfa and soybeans, have a symbiotic relationship with nitrogen-fixing bacteria, where the bacteria supply sufficient nitrogen to the plant and the plant supplies carbohydrates to the bacteria. Because of that relationship, a legume crop is able to supply its own nitrogen need and enrich the soil with nitrogen for crops that follow in the rotation and therefore is considered a nitrogen credit.

Since most of the nitrogen in soils is unavailable to plants, manure is typically applied to crops to provide the important nutrients that the plant needs. However, if legume crops are planned in a rotation, legume crops supply nitrogen rather than using nitrogen from the soil. Once the nitrogen recommendation for a crop is known, the manure application rates can be determined by subtracting from the total nitrogen recommendation the amount that will be available to the crop from all other sources. These sources of nitrogen already in the field are referred to a nitrogen credits. Two common credits of plant available nitrogen (PAN) are organic nitrogen from prior manure applications that mineralizes to available nitrogen compounds over the course of the planning period and nitrogen supplied from legume crops.

Phosphorus Cycle and Phosphorus Movement in the Soil

Sources of soil phosphorus include decomposing organic matter, humus, and weathered rock. Plant available forms of phosphorus include hydrogen phosphate (HPO_4^{-2}) and dihydrogen phosphate ($H_2PO_4^{-}$). Unlike nitrogen, gaseous forms of phosphorus seldom exist and are often not considered in the phosphorus cycle.



When phosphate ions are added to a soil, they are quickly (within hours) removed from solution to form phosphorus containing compounds with very low solubility. Phosphate most commonly forms compounds with either calcium or iron and aluminum (sometimes manganese). Initially, some ions are retained on the exchange complex, which makes them moderately plant available but with time, they undergo sequential reactions that continually decrease their solubility. These reactions result in phosphorus permanently bonding to the calcium or aluminum/iron/manganese ions, becoming buried from additional precipitation reactions. Those reactions can also capture phosphorus within the calcium or iron/aluminum/manganese particles. That is called phosphorus fixation and it is not easily reversible.

Additions of fertilizers and manures typically allow for only 10 to 15 percent of added phosphorus to be taken up by plants because of that fixation capacity. During the early and mid ‐20th century, farmers applied phosphorus in quantities far in excess of the plants' nutritional needs and manure has historically been applied at rates to meet plant nitrogen requirements, which can supply 2 to 4 times the phosphorus requirement. What was not removed in the harvest accumulates in the soil in an insoluble, unavailable form.

If not taken up by plants, phosphorus can be lost with surface runoff as dissolved phosphorus (if not incorporated into a soil) or it can be lost with soil particles through erosion or leaching.

Infiltration, Percolation, Leaching, Runoff and Erosion and its Effects on Water Quality

A primary principle of soil water management is to encourage water movement into, rather than off the soil. The more water runs off the surface, the less infiltrates into the soil. The movement of water impacts the movement of nitrogen and phosphorus in the soil. As water enters a soil (infiltration) and moves down through the soil profile (percolation) it carries dissolved nutrients with it (leaching). Dissolved nutrients can also be carried through runoff over the soil. Leaching losses occur when the amount of rainfall or irrigation water entering a soil exceeds the soil's ability to store the excess rainfall or irrigation. The amount and rate of nutrient losses are influenced by the amount of rainfall or irrigation, the topography of the landscape, the amount of evaporation, the soil type, and the crop cover.

The goal for the application of nutrients is to make them available to crops. As described above, as nitrogen (nitrate) percolates through the soil, it can contaminate ground and surface waters. Nitrate can be toxic because it reduces the capacity for blood to carry oxygen. That can be lethal to human infants and can alter normal body functioning in adults. Surface runoff waters from heavily fertilized lands can contain levels of nitrate toxic to livestock. While phosphorus is not toxic, it can degrade water quality if lost from a soil system in significant quantities. Excessive growth of algae and other aquatic species takes place in water overly enriched with nitrogen and phosphorus. This eutrophication process depletes the water of its oxygen, thus harming aquatic life in the affected waterbody.

Maintaining good soil structure is critical to reducing runoff. Excess water that cannot infiltrate the soil accumulates on the surface and flows downgrade displacing surface soil particles along the way (erosion). Soil erosion damages productive soils and can increase nutrient transport to streams and lakes. Soil properties have an effect on nutrient leaching losses. The physical properties of sand, silt, and clay, and the relative proportions of each have direct bearing on nutrient retention. Coarse soils (soils with a high percentage of sand) generally permit greater nutrient loss than do finer textured soils (soils with higher percentage of silt and clay). Organic matter content and type and amount of clay have significant influence on retention and nutrient storage and exchange. Climatic factors and the amount of rain or irrigation water, along with best management practices, have an effect on the amount of infiltration and leaching that occurs in the soil.

Many best management practices are available to encourage residue management and to minimize negative consequences of soil tillage. Excessive tillage destroys the surface and should be avoided. Tillage across the slope, leaving small ridges, encourages water infiltration. Terraces can also help control the erosive potential of water movement and increase infiltration into the soil.

For a more detailed discussion of these concepts, see Appendix A. "Basic Soil Science and Soil Fertility" of the *CAFO Permit Writer's Manual*.