Section D

What happens when nitrogen is applied to the soil?

Soil nitrogen processes

Nitrogen Cycle: All nitrogen in or added to the soil is subject to the processes of the nitrogen cycle (*Figure D-1*). Some processes are beneficial to plant nutrition while others provide no benefit or are detrimental to plant growth. For example, nitrogen can be converted from forms that are not available to plants, to available forms (and vice versa) by soil bacteria. Nitrogen can be moved by leaching out of the reach of plant roots or can escape into the atmosphere through gaseous loss known as denitrification. Understanding the basic nitrogen cycle provides insight into plant nutrient relationships and can provide the basis of nutrient management decisions on how much and when to apply supplemental nitrogen. The following paragraphs will introduce and provide detail on nitrogen cycle processes as they affect nutrient management.

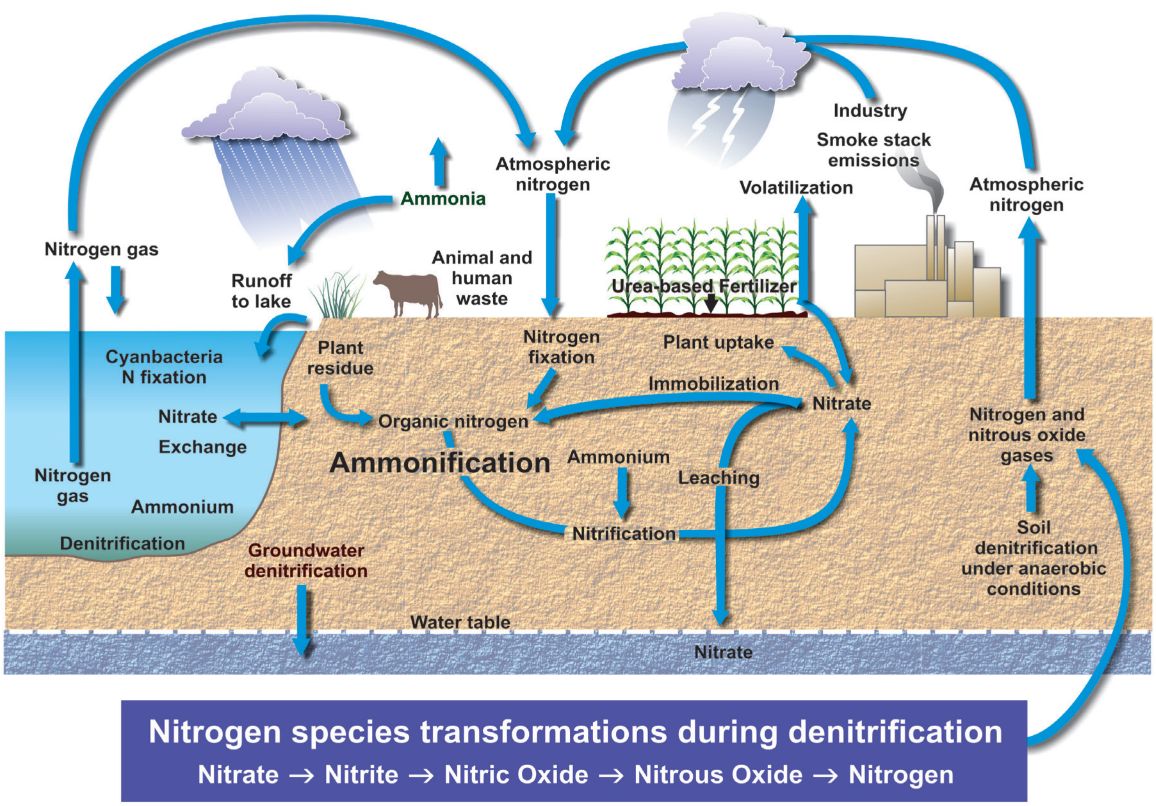

Figure D-1. Generalized nitrogen cycle within water, soil and in the air.

Mineralization: Mineralization is the process by which organic nitrogen (N) is converted to inorganic, or plant available N (*Figure D-2*)**.** Specifically, mineralization is the conversion of organic N to NH_4^+(ammonium). This process is very important for plant growth as organic N is not available for plant use, while NH_4^+ is. Mineralization is composed of two processes: aminization and ammonification. Both aminization and ammonification are carried out primarily by bacteria through the process of organic matter (OM) decomposition. The rate at which the bacteria work depends on soil temperature, soil moisture, and the amount of OM in the soil. As soils warm up in the spring, bacteria become increasingly active and use OM as an energy source. Bacteria decompose proteins in the OM, releasing amino acids, amines, and urea. This step is called aminization. The amino acids, amines, and urea are then further decomposed by bacteria releasing ammonium (NH_4^+) that is available for plant use. This step is called ammonification. Ammonium is relatively unstable and is therefore susceptible to multiple fates in the soil. These include; plant uptake; nitrification (explained below), fixation by clay minerals, and conversion to NH_3 (ammonia), which can be lost to the atmosphere through volatilization.

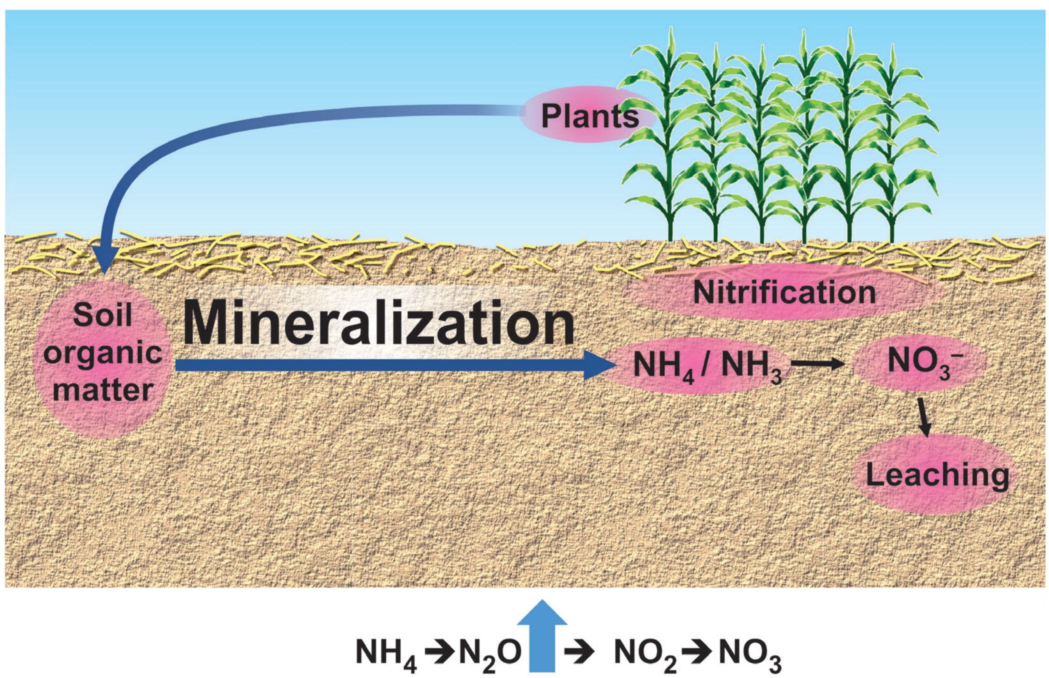

Figure D-2. The conversion of soil organic matter to ammonium and then to nitrate.

Nitrification: Nitrification is the process by which ammonium (NH_4^+) is converted to nitrate (NO_3^-) (*Figure D-3*). Both NH_4^+ and NO_3^- are inorganic forms of N and both are plant available. Both N sources can be used by corn and other agronomic crops, nitrate is preferred. Ammonium will nitrify to nitrate over time (usually less than three weeks during the growing season). As with mineralization, nitrification is carried out by soil bacteria.

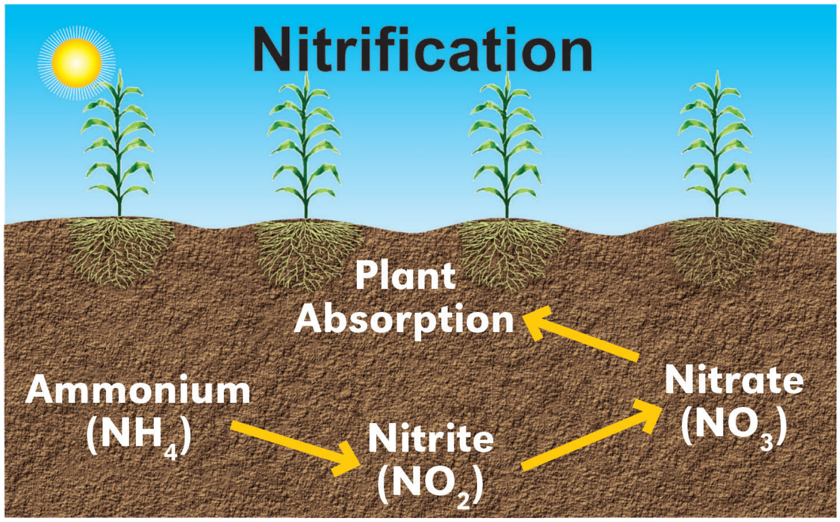

Figure D-3. Detail of the conversion of ammonium to plant available nitrate.

Immobilization: Immobilization is the process by which plant available inorganic forms of N (NH_4^+ and NO_3^-) are converted to plant unavailable organic forms of N (*Figure D-4*). This process is essentially the reverse of mineralization and is driven by soil bacteria and soil carbon and N levels. Immobilization usually occurs when high levels of residue with a high carbon (C) to nitrogen (N) ratio are added to the soil, such as wheat stubble or corn stalks. The carbon residue is an energy source for microbes and they need nitrogen in the soil solution to grow. The N is sequestered in the microbe's body until they die and it is released back to the soil solution. Bacteria can reduce NH_4^+ and NO_3^- levels quite dramatically and can out-compete plants for the N source, thereby immobilizing or tying up the N. In most production situations, N needs to be applied in sufficient quantities early in the season to overcome this effect, or placed below the residue so as not to be near the carbon source. Late season release of immobilized N may have water quality implications.

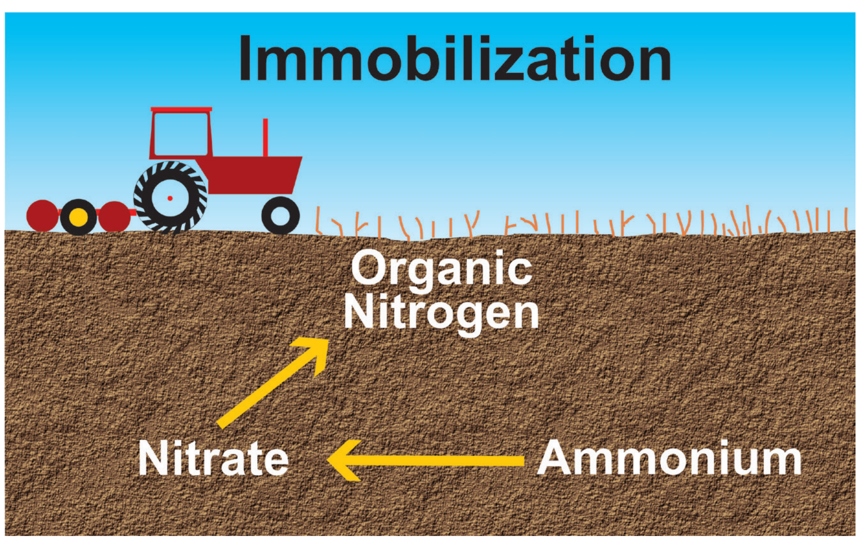

Figure D-4. Immobilization temporarily removes nitrates from the soil solution.

Denitrification: Denitrification is the process by which nitrate in the soil is converted to gaseous forms of nitrogen that can escape from the soil into the atmosphere (*Figure D-5*). The process is dependent on soil bacteria and almost all denitrification takes place in saturated or compacted soils that have a limited oxygen supply. When oxygen is not available, certain bacteria are capable of using the oxygen from nitrate as a substitute energy source. As oxygen is removed from nitrate gaseous forms of N are created (NO, N_2O, and N_2). These forms of nitrogen can then escape into the atmosphere. Denitrification occurs where water is ponded for a significant amount of time and is common during flooded conditions.

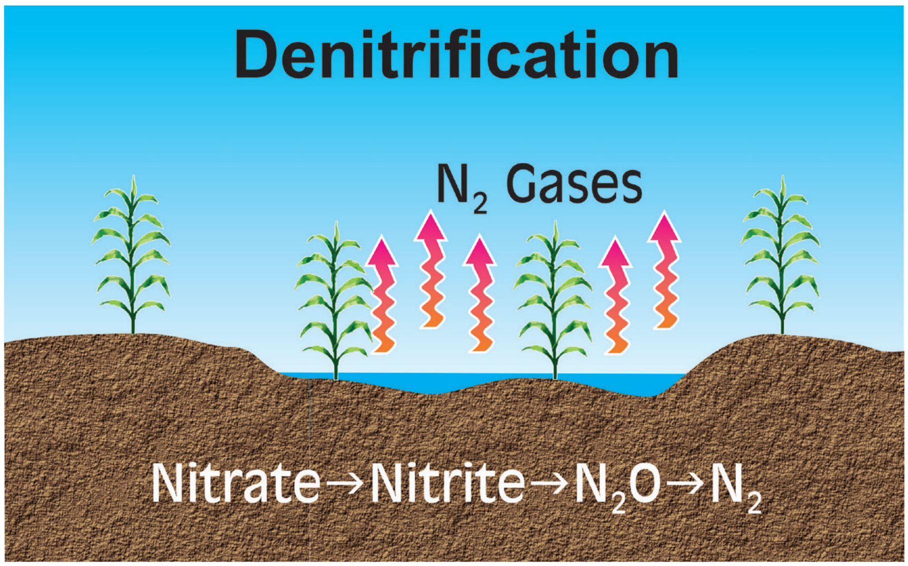

Figure D-5. Denitrification occurs in low-oxygen conditions and removes nitrates from the soil solution.

Volatilization: Volatilization is the process by which ammonia (NH_3) is lost into the atmosphere (*Figure D-6*). Volatilization occurs naturally in soils but losses are usually small. There are two ways nitrogen can volatilize. The first is through the direct loss of ammonia from either fertilizer or animal manures. The second is through the breakdown (hydrolysis) of urea. Both primarily occur when applied fertilizers are placed on the soil surface and not incorporated following application. Fertilizers placed below the soil surface or incorporated by precipitation or sprinkler irrigation of at least 0.5 inches will move urea into the soil and minimize volatilization.

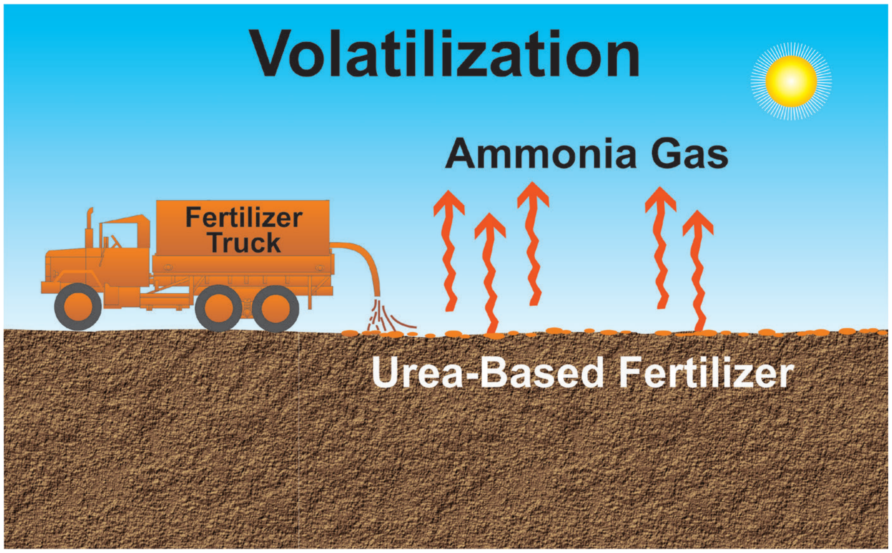

Figure D-6. Volatilization occurs when manures or ammonia containing fertilizers are on the soil surface.

Fixation: Nitrogen gas (N_2) in the atmosphere is converted into plant available forms through the process of fixation (*Figure D-7*). Nitrogen gas is converted into nitrate through two processes. First it occurs through lightning (combustion) and precipitation; and secondly it occurs naturally through symbiotic fixation involving bacteria in association with legumes such as soybean. Non-symbiotic fixation is also possible, involving free-living soil organisms. Industrial fixation (Haber-Bosch process), is the process by which atmospheric N_2 and hydrogen from natural gas are reacted under pressure to produce ammonia that is the basis for all other N fertilizers.

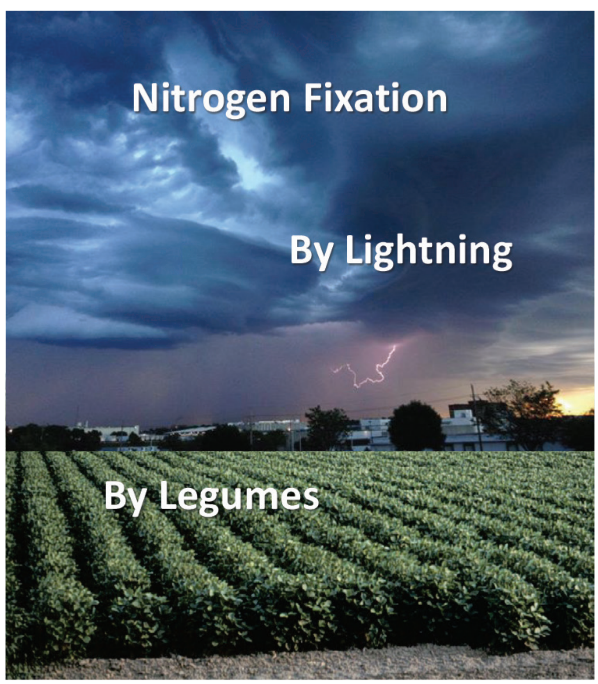

Figure D-7. Examples of ways in which nitrogen can be converted from nitrogen gas into nitrate via the fixation process.

Nitrate Leaching: Nitrogen Leaching is the passage of nitrogen through the soil profile and downward beyond where crop roots can access the nitrogen (*Figure D-8*). When making the decision on when and how to apply N fertilizers, consider the **4Rs** of nutrient management; **R**ight time of application, **R**ight fertilizer type, **R**ight placement, and **R**ight application rate. Research has shown that fall applications of N fertilizer are less efficient than applications during the growing season. Corn uses N more efficiently when applied as close as possible to when the plant needs it. As stated previously N is a very mobile nutrient that is easily lost from the soil through leaching and denitrification. Significant quantities of N applied in the fall can be lost during the off-season.

Residual N is the N remaining in the soil at the end of a cropping season. This is the leftover N that was not used by the crop during the growing season. The amount of residual N is related to nitrogen fertilizer management practices, irrigation management practices, crop yield (plant N uptake), and environmental conditions such as precipitation and temperature that affect mineralization. The majority of residual N is dissolved in water held in the pore space between the soil particles. Nitrate is very mobile and when the water moves in the soil, the N moves as well (*Figure D-8*).

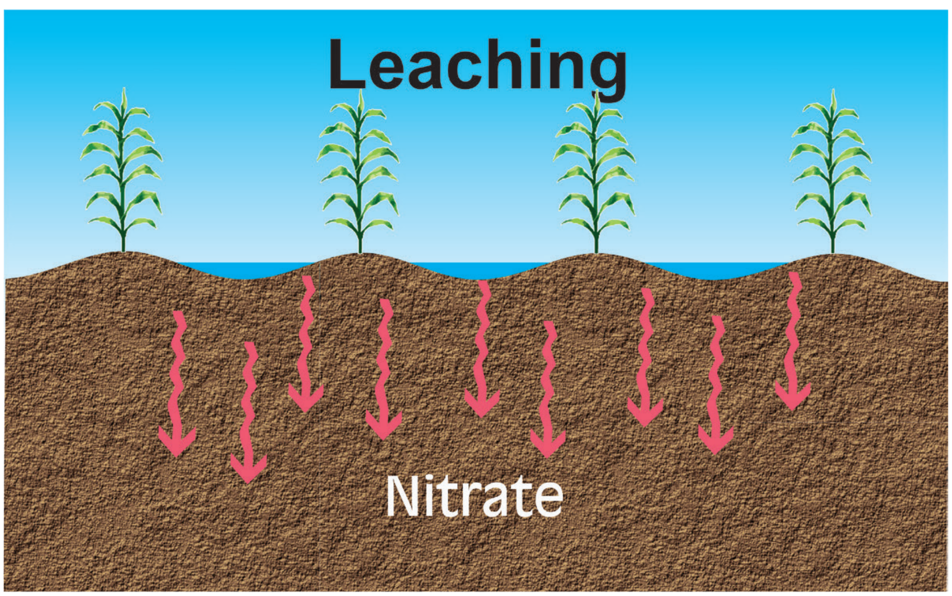

Figure D-8. **Depiction of nitrate-nitrogen being leached due to excessive water application via irrigation or precipitation.**

In the fall, if the distribution of residual N looks like the graph shown in *Figure D-9A*, there either was a crop failure due to insufficient water or storm damage, or the N application rate was too high for the grain yield level. The relatively high concentration of N in the surface 24 inches of soil leaves a lot of N in a high-leaching potential. If excess precipitation is recorded, the nitrate will move deeper in the soil during the offseason.

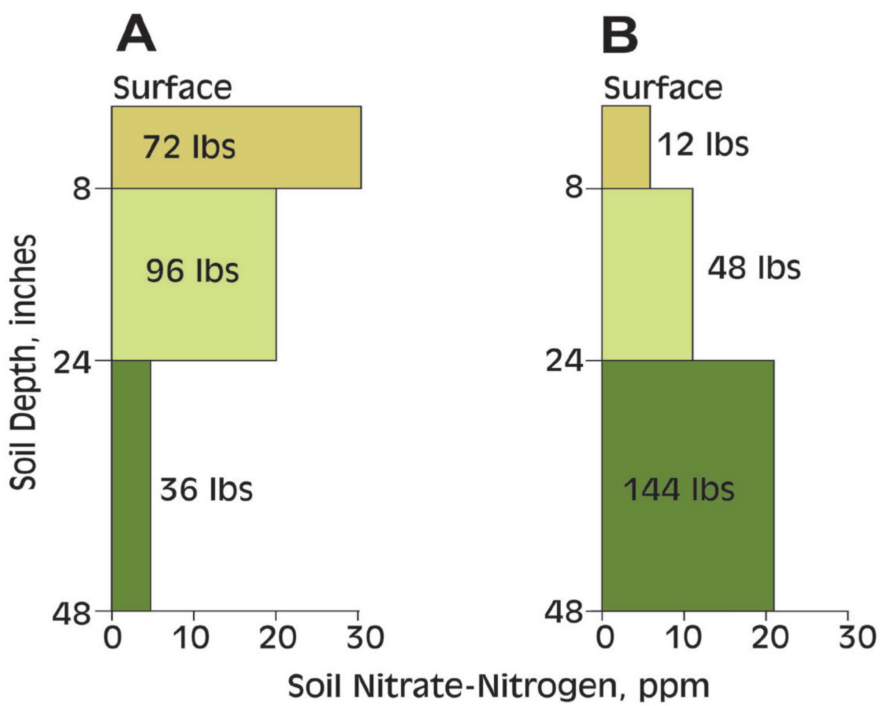

Figure D-9. **Summary of two sets of soil samples: A) taken from soil that was sprinkler irrigated; and B) taken from soil that was irrigated by a furrow irrigation system.**

The distribution of residual N in the soil profile at harvest depends greatly on the method of irrigation (furrow, drip, or sprinkler) and the care taken to manage the water correctly during the growing season. Under furrow irrigation, it is likely that N will be moved deeper in the profile during the growing season because the depth of water applied with each irrigation is typically more than is required to refill the root zone. So the scenario depicted in *Figure D-9B* may represent the position of soil N at the end of the season. With a furrow system that is well-designed, well-maintained, and well-managed, there is a chance that the N will remain in the crop root zone and accessible to crop roots.

Well-managed sprinkler irrigation systems should result in zero deep percolation so that most of the N applied remains in the crop root zone. Under sub-surface drip irrigation, the dynamics of N movement changes depending on the N application method. Surface applied N can create high N levels near the soil surface because N movement will be controlled by amount of precipitation and the soil's water holding capacity. If N is injected into the sub-surface drip system it is possible to move N much deeper into the profile as the nitrate will move with the water.

The way water is applied affects how both water and nitrate move down through the soil. When the application rate is less than the soil intake rate (such as from a gentle rain or a well-managed sprinkler system), water tends to move downward in a relatively uniform manner. For example, *Figure D-10* shows a band of nitrate that has formed from a previous application of anhydrous ammonia. A wetting front is moving down under precipitation. When the wetting front reaches the band, the nitrate tends to spread mainly downward (*Figure D-11*).

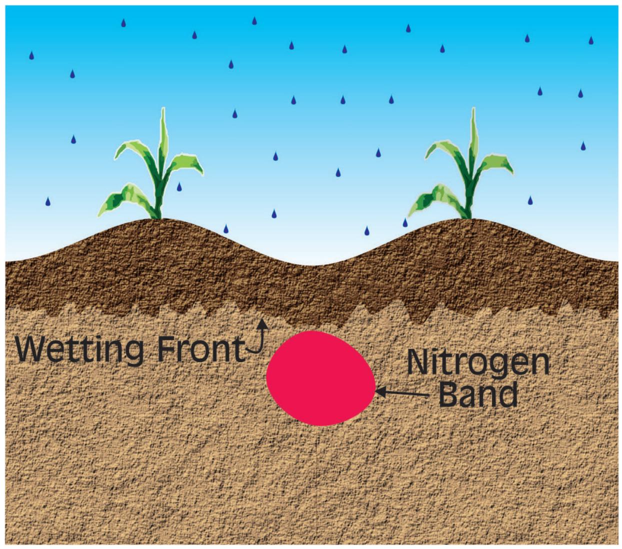

Figure D-10. Depiction of a nitrate band resulting from application of liquid urea ammonium nitrate or anhydrous ammonia using a knife applicator.

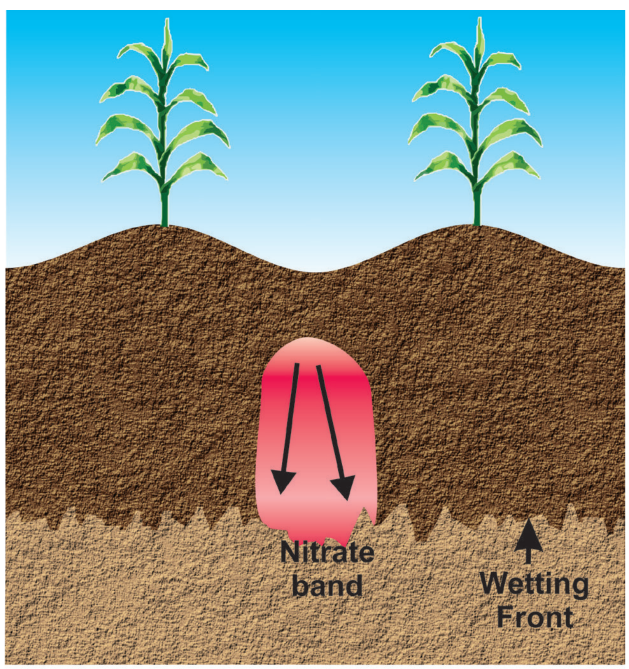

Figure D-11. Depiction of the downward vertical movement from a concentrated band of nitrogen application following excessive precipitation or sprinkler irrigation.

Under furrow irrigation, only part of the surface is completely saturated. This allows the water to flow through the largest pores. There is a faster and more uneven wetting of the soil profile. Also, the depth of water applied with each irrigation event is greater than under sprinkler irrigation. Under these conditions, a nitrate band will tend to spread further, both vertically and horizontally (*Figure D-12*). Excess irrigation will move the nitrate even deeper.

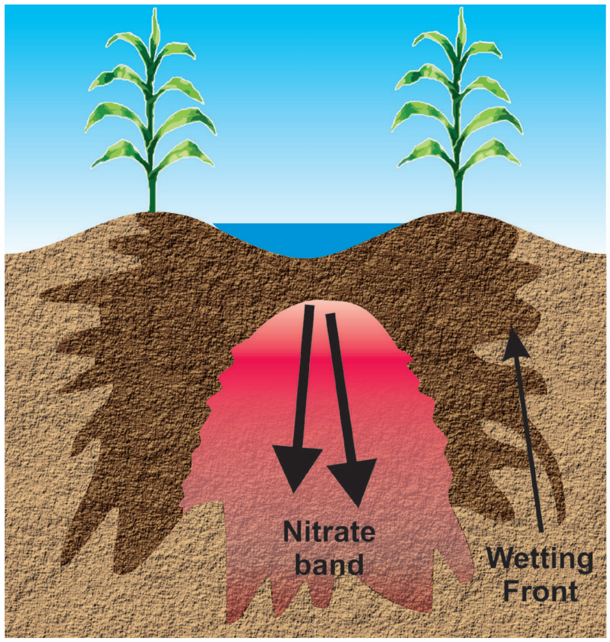

Figure D-12. Impact of furrow irrigation on a concentrated band of nitrogen applied below the soil surface.

Surface runoff

Whenever water runs off the land after rain or irrigation, the water carries sediment. Ammonium may be attached to the sediment and nitrate may be in solution in the runoff water. This physical process is another form of nitrogen loss from the field. Any practices that reduce runoff may reduce nitrogen losses. Incorporating any nitrogen resources that are applied to the field will reduce nitrogen losses by runoff, but may increase sediment losses because of reduced residue cover. Management practices that reduce sediment transfer or soil erosion such as no-till will also greatly decrease the potential for nitrogen movement through runoff.

More Extension Publications (available at ianrpubs.unl.edu)

EC91-735, The impact of nitrogen and irrigation management and vadose zone conditions on groundwater contamination by nitrate-nitrogen (archived publication)

G1338, Managing Furrow Irrigation Systems

G91-1043, Water runoff control practices for sprinkler irrigation systems (archived publication)