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Nitrogen transformation and losses in soil: A cost-effective review study for farmer

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Abstract

Environmental and economic issues have increased the necessity to know better understand the role and fate of nitrogen (N) in crop production systems. Nitrogen is the nutrient most often deficient for crop production in India, and its use can result in substantial economic return for farmers. Losses of nitrogen from the soil and plant system not only reduce soil fertility and plant yield but can also create adverse impacts on the environment. Nitrogen fertilizer useful to crops is partially lost through different mechanisms, including ammonia volatilization, de-nitrification, and leaching. These losses may cause environmental problems like polluting the atmosphere, aquatic systems, and groundwater. However, losses can be reduced a considerable extent by various techniques. Research has been conducted in whole world to minimize nitrogen fertilizer losses. This paper reviews this information on nitrogen fertilizer losses, indicating management practices for minimizing these losses from the soil-water system.

Keywords: Importance of nitrogen, sources, transformation and losses from soil

Introduction

Nitrogen is a colourless, odourless element. Nitrogen is within the soil under our feet, within the water we drink, and in the air we breathe. In fact, nitrogen is that the most abundant element in Earth's atmosphere: approximately 78% of the atmosphere is nitrogen. Nitrogen (N) is a main key factor to maintaining higher yield production and worldwide economic viability of agricultural systems. Crops require nitrogen in relatively large amounts, making it the nutrient most often deficient in crop production. Since nitrogen is one of the foremost active and mobile elements, its management is difficult, especially in irrigated systems where significant losses are often produced by leaching and de-nitrification. Management of nitrogen inputs to accomplish a balance between profitable crop production and minimizing nitrogen loss to the environment should be every producer's goal. The behaviour of nitrogen within the soil system is complex, yet understanding the essential processes can cause to a more efficient nitrogen management program. Nitrogen is changing its chemical form continually and moving from plants through animals, soil, water and therefore the atmosphere. This movement and transformation of nitrogen in the environment is called as the "nitrogen cycle" (Figure-1). Critical processes in the nitrogen cycle affecting manure handling and plant growth include the following: Nitrogen enters the soil from many different sources and leaves the root zone of the soil in many different ways.

The major pathways for nitrogen loss are ammonia (NH₃) volatilization; emissions of nitrous oxide (N₂O), oxides of N (NO and NO₂), and de-nitrogen (N₂) gases; leaching of nitrates (NO₃); and off-site transference due to wind and water erosion of nitrogen tied within the organic matter and convert to the inorganic NO₃ and ammonium (NH₄) compartments. Nitrogen is dynamic and mobile. Its fate and transport in agricultural systems is suffering by management and unpredictable events. Its average worldwide nitrogen use efficiencies (NUEs) reported to be about 50% and whilst low as 33% for cereals.

Farmers usually apply a constant rate of nitrogen to agricultural fields assuming that nitrogen sources, sinks, and mechanisms for loss are constant across fields. It is well documented that variability of soil properties that affect nitrogen sources makes managing nitrogen to maximize NUE difficult. In soil properties contain soil organic matter, residual soil NO₃-N, amount of crop residue returned to the top soil, yield variability (nitrogen sink), and changes in soil chemical and physical properties.

Fields vary from coarse gravelly areas where nitrogen losses are primarily attributed to NO_3 -leaching, to clayey areas where water is ponded and nitrogen losses may be primarily dominated by de-nitrification ($\text{N}_2/\text{N}_2\text{O}$). Management is being established because the predominant factor which will reduce

nitrogen losses in the environment. If we improve management of nitrogen to increase NUE we'll got to roll in the hay within the context of the nitrogen cycle accounting for nitrogen loss mechanisms and how to manage them. This paper will review how we can quantify these N losses.

Fig 1: Nitrogen Cycle Source- Wikipedia

Nitrogen cycle

The nitrogen cycle is a repeating process in which nitrogen moves through both living and non-living things: the atmosphere, soil, water, plants, animals and bacteria move through the different parts of the cycle, in the cycle forms nitrogen must change. In the atmosphere, nitrogen exists as a gas (N_2), but within the soils it exists as nitrous oxide (NO), nitrogen dioxide (NO_2) and when used as a fertilizer, can be found in other forms, such as ammonia gas (NH_3) and ammonium (NH_4) which may be processed even further into a different fertilizer.

The nitrogen cycle there are five stages, and we will now discuss each of them in turn: fixation or volatilization, mineralization, nitrification, immobilization, and de-nitrification. In this image, microbes within the soil turn nitrogen gas (N_2) into what is termed as volatile ammonia (NH_3), therefore the fixation process is named volatilization. Leaching is where certain forms of nitrogen (such as nitrate, or NO_3) becomes dissolved in water and leaks out of the soil, potentially polluting waterways.

Sources of Nitrogen for plant

The atmosphere

Atmospheric nitrogen is the major source for nitrogen in the nitrogen cycle (air is 79 percent N_2 gas). Although unavailable to most plants, leguminous plants can use large amounts of nitrogen via biological nitrogen fixation. In this process, nodule-forming *Rhizobium* bacteria inhabit the roots of leguminous plants and, through a symbiotic relationship, convert atmospheric nitrogen to a form the plant can use.

Legumes can fix substantial amounts of nitrogen into usable nitrogen. For example an alfalfa crop, has the potential to fix huge amount of nitrogen per acre per year. Any legume crop that's left after harvest, including roots and nodules, can supply nitrogen to the soil system when the material is decomposed. Several non-symbiotic organisms fix nitrogen, but nitrogen additions from these organisms are quite low (one to five pounds per acre per year). In addition, precipitation adds small amounts of nitrogen to the soil.

Commercial fertilizer

Commercial nitrogen fertilizers also are derived from the atmospheric nitrogen pool. The major step is to combine nitrogen (N_2) with hydrogen (H_2) to form ammonia (NH_3). The anhydrous ammonia is used as a starting point in the manufacture of other nitrogen fertilizers. Anhydrous ammonia or other nitrogen products derived from NH_3 can then supplement other nitrogen sources for crop nutrition.

Organic Nitrogen Sources

Nitrogen also can become available for plant use from organic nitrogen sources. Before these organic sources are available to plants, they need to be converted inorganic forms. Nitrogen is available to plants as either ammonium (NH_4^+) or nitrate (NO_3^-).

Manures

Animal manures and other organic wastes are often important sources of nitrogen for plant growth. The amount of nitrogen supplied by manure will vary with the kind of livestock,

handling, rate applied and method of application. Because the nitrogen form and content of manures widely varies, a manure analysis is suggested to enhance nitrogen management.

Crop residues

Crop residues from non-leguminous plants also contain nitrogen, but in relatively small amounts compared to legumes. Nitrogen exists in crop residues in complex organic forms and therefore the residue must decay a process which will take several years before nitrogen becomes available for plant use.

Soil organic matter

Soil organic matter is another major source of nitrogen used by crops. Organic matter is primarily composed of rather stable material called humus that has collected over a extended period of time. Easily decomposed portions of organic material disappear relatively quickly, complex residues more resistant to decay. The portion of organic matter decomposes at a rather slow rate and releases about 20 pounds of nitrogen per acre per year.

Cause and effect of nitrogen change

Organic nitrogen that's present in soil organic matter, crop residues and manure is converted to inorganic nitrogen through the mineralization process. In this process, bacteria digest organic material and release NH_4^+ . Formation of NH_4^+ increases as microbial activity increases. Bacterial growth is directly associated with temperature and water content of soil. The NH_4^+ is supplied from fertilizer is the same as the NH_4^+ supplied from organic matter in soil. Ammonium nitrogen has properties of practical importance for soil management. Plants can absorb nitrogen maximum in the form of NH_4^+ because ammonium has a positive charge, it's attracted or held by negatively charged soil and soil organic matter. This means that NH_4^+ doesn't move downward in soils. Nitrogen in NO_3^- form is mobile and light in weight, so they are not attached with soil clay collide and move downward through water.

Nitrogen transformations

Plants absorb most of the N in the NH_4^+ and NO_3^- forms. Nitrate is the dominant source as its concentration is higher than NH_4^+ and it is free to move to the roots. Potatoes, sugarbeet, pine apple, prefer both the forms; tomatoes, celery, bush beans, prefer NO_3^- rice and blue berries prefer NH_4^+ . NO_3^- uptake is usually high and is favoured by low pH conditions. NH_4^+ is less subjected to losses by leaching and de-nitrification. NH_4^+ uptake are best at neutral pH values. When the plants are supplied with NH_4^+ , it leads to acidity in the soil. Nitrogen, present or added to the soil, is subject to many changes, or transformations. These dictate the availability of nitrogen to plants and influence the potential movement of NO_3^- to water supplies.

Mineralization

Nitrogen mineralization is simply the conversion of organic nitrogen to mineral form (NH_4^+ , NO_3^- , and NO_2^-). When organic residues having a C: N ratio wider than 30 are added to the soil, immobilisation of nitrogen takes place.

Aminisation

Heterotrophic soil microbes, mostly, bacteria like *Pseudomonas* and *Bacillus* are believed to dominate in the breakdown of proteins in neutral and alkaline soils. Under acidic conditions fungi prevail. In this step hydrolytic

decomposition of proteins and release of amines and amino acids takes place.

Ammonification

The amines and amino acids so released are further utilized by still other groups of heterotrophs with the release of ammoniacal compounds. The step is termed as ammonification.

Nitrification

Nitrification is a biological process in which NH_4^+ released by the process of ammonification to nitrate is known as nitrification. This process is carried out by nitrifying bacteria referred to as nitrifiers. It is a two-step process in which NH_4^+ is first converted to nitrite (NO_2^-) and then to nitrate (NO_3^-). It rapidly proceeds in warm, moist, well-aerated soils, and slows at soil temperatures below 50 degrees Fahrenheit. Nitrate is a negatively charged ion not to attracted soil particles or soil organic matter like NH_4^+ . Nitrate is water-soluble and moves below the crop rooting zone under certain conditions.

De-nitrification

In de-nitrification, bacteria convert NO_3^- to N_2 gases that are lost to the atmosphere. Denitrifying bacteria use NO_3^- rather than oxygen in the metabolic processes. The process takes place in waterlogged soil and with ample organic matter to deliver energy for bacteria. For these reasons, de-nitrification is normally limited to topsoil. De-nitrification can quickly proceed when soils are warm and become saturated.

Immobilization

Immobilization is a process in which of soil nitrogen can temporarily reduce the amount of plant-available nitrogen. Bacteria that decompose high-carbon, low- nitrogen residues, like corn stalks or small grain straw, need more nitrogen to decompose the material than is present in the residue. Immobilization occurs when the growing microbes use NO_3^- or NH_4^+ present in the soil to build proteins. The aggressively growing bacteria that immobilize some soil nitrogen also break down soil organic matter to release available nitrogen during the growing season. Therefore total gain of nitrogen during the cropping season because the additional nitrogen in the residue will be the net gain after immobilization-mineralization processes.

Nitrogen loss from the soil system

When developing N programs and evaluating environmental effects, consider nitrogen's mobility factor in the soil. Sandy soils may lose N through leaching, while heavy, poorly drained soils may lose N through de-nitrification.

Leaching

Unlike the previously described biological transformations, loss of nitrate by leaching is a continuous process. In the leaching loss soluble NO_3^- because it moves with soil water, generally excess water, below the root zone. Nitrate that moves below the root zone has the potential to enter groundwater or surface water through tile drainage systems. Coarse-textured soils have a lower water-holding capacity and, therefore, more potential to lose nitrate from leaching compared to fine-textured soils. Nitrate are often leached from any soil if rainfall or irrigation moves water through the root zone.

De-nitrification

De-nitrification is the process in which major loss mechanism of NO_3^- when soils are saturated with water for long times. Nitrogen in the form of NH_4^+ is not subject to this loss. Management alternatives are available if de-nitrification losses are a potential problem.

Volatilization

Significant losses from some surface-applied nitrogen sources can happen through the process of volatilization. In this process, nitrogen is lost in the form of ammonia (NH_3) gas. Manure and fertilizer which contain urea can cause nitrogen to be lost this way. Ammonia is an intermediary form during the process that transforms urea to NH_4^+ . Incorporating these N sources will virtually eliminate volatilization losses.

Nitrogen loss from volatilization is greater when:

- Soil pH is higher than 7.3.
- Air temperature is high.
- The soil surface is moist.
- There's a lot of residue on the soil.

(Volatilization process on alkaline soil)

Crop Removal

Substantial amounts of nitrogen are lost from the soil system through crop removal. A 250-bushel-per-acre corn crop, for instance, removes approximately 175 pounds of nitrogen with the grain. Crop removal accounts for a majority of the N that leaves the soil system.

Soil Erosion & run off

Nitrogen is often lost from agricultural lands through erosion and runoff. Losses through these events normally do not account for a large portion of the soil nitrogen budget, but should be considered for surface water quality issues. Incorporating or injecting manure and fertilizer can help protect against nitrogen loss through erosion or runoff. Where soils are highly erodible, conservation tillage may reduce erosion and runoff of soil, resulting in less surface loss of nitrogen.

Key points for crop producers

Considering the various transformations and reactions of nitrogen in soils, there are some major points to keep in mind:

- Although you can add either organic or inorganic N forms to soil, plants only take up inorganic N (that is, NO_3^- and NH_4^+).
- One form isn't more important than the other and all nitrogen sources can be converted to NO_3^- . Commercial

N fertilizers, legumes, manures and crop residues are all initial sources of NO_3^- and NH_4^+ .

- Once it's in the plant or water supply, it's impossible to identify the initial source.
- Nitrate is always present in the soil solution and will move with the soil water.
- Inhibiting the conversion of NH_4^+ to NO_3^- can result in less nitrogen loss and more plant uptake. While it's not possible to totally prevent the movement of some NO_3^- to water supplies, sound management practices can keep losses within acceptable limits.

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