PLANT NUTRIENT MANAGEMENT

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Summary

Plant nutrient management is critical to the sustainability of agricultural production systems. Nitrogen, phosphorus, potassium and sulfur are the four macronutrients required for crop growth. In order to maintain agricultural sustainability, nutrients that are removed from the soil by crops must be replaced. Different crops have different nutrient demands and the proportion of nutrients taken up by the plant may not be the same as that exported. There are several methods of ensuring that soil nutrient replacement occurs. (1) Biological mechanisms—includes symbiotic associations of crops with specialized microorganisms, such as nitrogen fixers or mycorrhiza. (2) Return of nutrients to the soil as organic amendments such as crop residues, livestock manure, and other amendments. (3) Commercially produced inorganic fertilizers are the most widely used method to replace soil nutrients, and the wide variety of fertilizers

available offers the opportunity to replace specific nutrients. Other management techniques that contribute to sustainable agronomic practices are (1) crop rotations, those that incorporate a variety of crop types favoring an integrated nutrient management system by maximizing the potential inputs of all sources of nutrients; (2) precision farming techniques that are capable of making on-farm nutrient management plans and can be more specific by mapping and subsequently fertilizing fields according to nutrient requirements. This maximizes the yield while minimizing the economic and environmental costs of over-fertilization.

1. Introduction

Global demand for a reliable supply of safe, nutritious, and wholesome food for a rapidly expanding world population is greater today than ever before. The population had reached six billion by the end of the twentieth century and continues to grow. Food production has to meet the needs of these people. Research in agronomy, plant science, and soil science has furnished new nutrient management strategies to support and maintain the anticipated world food production increase. Commercial fertilizers, together with high-yielding crop varieties and chemical crop protection, drove the "green revolution" of the 1960s, which dramatically increased global food production. According to the Food and Agriculture Organization of the United Nations (FAO), the global use of nitrogen, phosphorus, and potassium fertilizers in crop production has more than trebled from 1959/60 (27.2 million nutrient metric tonnes) to 1994/95 (123.25 million nutrient metric tonnes).

Nutrient management is a critical component of all soil-plant production systems. The soil with its associated environment, air and water, can be a rich source of the macronutrients nitrogen (N), phosphorus (P), potassium (K), and sulfur (S). However, plants consume these nutrients and to sustain the soil-plant production system they must be replaced. Nutrients may be removed from the field by many mechanisms: by export of product from the farm, by transport of harvested materials to on-farm livestock for feed, by microbial conversion to gases released to the atmosphere, by leaching into the groundwater, and by runoff from fields. Nutrients lost by these processes must be replaced. Several techniques are used to replace soil nutrients. (1) Commonly, commercial fertilizers are applied based on soil testing to replace specifically the lost nutrients in appropriate quantities. (2) Similarly, manure and other organic amendments may be applied with or without additional fertilizers to meet crop demand. (3) Some crops support bacteria that convert (or "fix") nitrogen from the air into plant-available forms. The most common example is the inoculation of legumes with *Rhizobium*, nitrogen-fixing bacteria that live in root nodules. Many farms use crop rotations with "green manures," nitrogen-rich legumes plowed into the soil as a nitrogen source.

A brief overview of the four macronutrients for crop production is used to demonstrate how nutrient management plans can increase soil-crop productivity. The micronutrients (iron, zinc, manganese, copper, boron, chlorine, molybdenum, and sometimes sodium, cobalt, vanadium, nickel, and silicon) are also critical to crop production but they rarely limit crop production. Calcium and magnesium are often deemed macronutrients, but they too seldom limit crop growth to the same extent as nitrogen, phosphorus, potassium, and sulfur. Plants have specific nutrient requirements depending on species, varieties, soil type, and climatic conditions. However, to be available for plant use the nutrients must be in specific chemical forms (plant available forms) that are soluble and are thus present in the soil solution.

2. Macronutrients for Crop Production

2.1. Nitrogen

Nitrogen is often the most limiting nutrient for crop production. Consequently, most nutrient replacement plans focus on this element. Figure 1 is a schematic representation of nitrogen transformation in the soil. Nitrogen is taken up by plants in one of two forms: NO_3-N (nitrate-N) or NH_4^+-N (ammonium-N). When applied in an organic form, such as occurs in manures, green manures, or organic wastes, the organically bound nitrogen must be mineralized to one of those two mineral forms. This mineralization occurs in two steps: ammonification (transformation of organic nitrogen to ammonium-N) and nitrification (transformation of ammonium-N to nitrate-N). Both steps are aerobic reactions, mediated by many soil microorganisms. High amounts of carbon-rich material added to soil may induce the reverse reaction (immobilization), wherein nitrate is reduced to ammonium and then to organic-N, thus temporarily reducing the amount of nitrogen available to the plant. New nitrogen may enter soil from the atmosphere through fixation of dinitrogen (N_2 gas) by microorganisms. Conversely, soil nitrogen may be released to the air as N_2 by denitrification, a microbial process favored by cool wet conditions. Denitrification not only results in nitrogen loss, but also yields nitrous oxide (N_2O), a gas linked to global warming and the breakdown of beneficial ozone in the upper atmosphere.

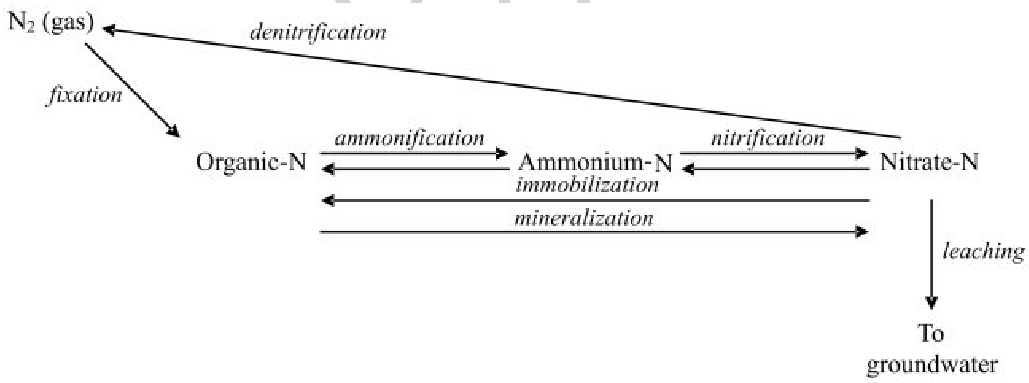

Figure 1. Some potential nitrogen transformations in soil

2.2. Phosphorus

Phosphorus, the second most limiting nutrient to crop production, is needed for the production of many critical biomolecules in the plant, such as DNA and adenosine triphosphate (ATP). Phosphorus is taken up by plants in the form of PO_4^{-3}, which is commonly referred to as orthophosphate. Phosphorus is naturally present in soils partly in a mineral form. In soils of high pH, much of the phosphate may occur as calcium phosphate (e.g. apatite); in soils of low pH, the dominant phosphorus forms are iron and aluminum phosphates (taranakites). Phosphorus may also be “fixed” in soil, chemically bound to soil minerals ("fixed" here is used differently than for nitrogen). Consequently, phosphorus is most available at neutral or near neutral pH values. For plants to take up phosphorus, it must be in an available form in the soil solution. Soil organisms and plant roots produce carbon dioxide (CO_2) and organic acids that help to dissolve mineral phosphorus for plant uptake. Symbiotic relationships between plants and mycorrhizal organisms increase the amount of the bulk soil that can be explored for phosphorus and the plant may benefit from the extra phosphorus that is solubilized by the microbe. Phosphorus does not have a gaseous phase, so its cycle is very different from that of nitrogen. Phosphorus dynamics are best viewed as a chemical equilibrium that may be affected by microorganisms (Figure 2). Dissolved phosphorus is immediately available for plant uptake. Labile phosphorus is highly reactive and very quickly converted to dissolved phosphorus in response to equilibrium shifts. Nonlabile phosphorus is not very reactive and is slowly released only as the other two pools are depleted. As for nitrogen, organically bound phosphorus may be mineralized to orthophosphate ions, or the reverse may occur, when mineral phosphorus is immobilized into organic phosphorus. Again, these reactions are driven by the relative availabilities of carbon and phosphorus in the system. Phosphorus losses from soil are most likely to occur with soil erosion. Water erosion will remove nonlabile phosphorus that is associated with soil particles as well as the dissolved phosphorus that moves in solution.

Phosphorus fertilizers, now widely used around the world, are derived from rock phosphates (apatites) mined from sedimentary and igneous rock deposits around the world. Rock phosphate is treated with sulfuric acid and often reacted with other chemicals such as ammonia to make fertilizer products that are also sources of nitrogen or other nutrients. Another good source of phosphorus is manure. Most livestock manures are enriched in phosphorus relative to other nutrients: in most cases, a crop that has all of its nitrogen needs met by manure application is likely to have been over-fertilized with phosphorus.

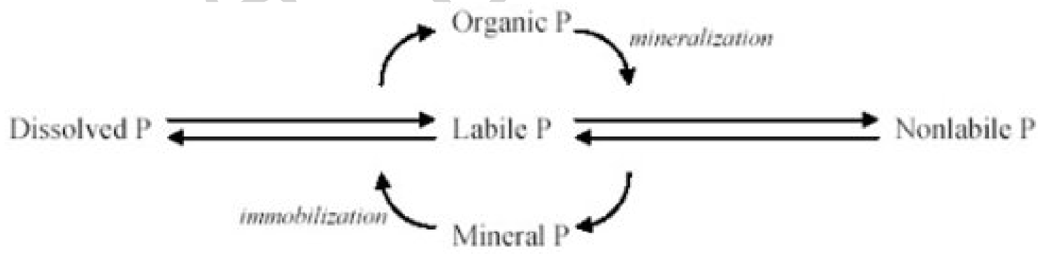

Figure 2. Phosphorus dynamics in soil

2.3. Potassium

Potassium is relatively abundant in most soils around the world because it occurs in many clay minerals. The potassium in these minerals may be released by weathering. The potassium in these soils occurs in four forms: mineral, nonexchangeable (fixed to minerals), exchangeable, and soluble (Figure 3). Because of continued crop uptake, mineral potassium is continually being weathered to maintain the equilibrium concentration of potassium in solution. Plants take up potassium as K^+ ions from solution. Exchangeable potassium is held to negatively charged ion exchange sites on soil minerals and organic matter. The rate at which this potassium is released depends on the concentration of other ions in solution and the rate at which the plants are taking up potassium. Weathering of mineral potassium governs the rate at which plant available potassium is replenished in the soil solution. Consequently, a dynamic equilibrium between these forms is continuous. Under certain conditions, the K^+ ion may be "fixed" by soil minerals, wherein the ion is very tightly bound to clay particles. This nonexchangeable potassium is released only very gradually.

The most common fertilizer source of potassium is "muriate of potash," the chemical name of which is potassium chloride (KCl). Potash is approximately 52% potassium and can be directly applied to soil or blended with other commercial fertilizers to make a multinutrient fertilizer.

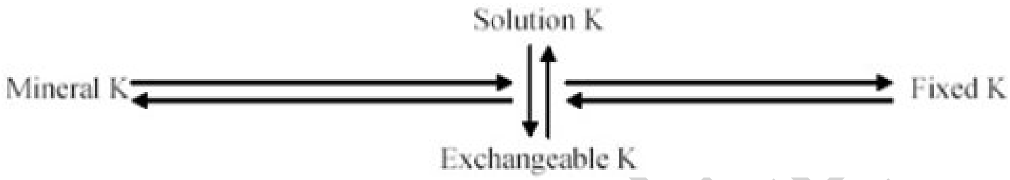

Figure 3. Potassium dynamics in soil

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Biographical Sketches

Vanessa L Bailey completed her B.Sc. in Agriculture (Soil Science) at the University of Manitoba in 1994, and completed her Ph.D. in Soil Science at the University of Alberta in 1999. Since then she has worked on research projects in agricultural, environmental, and global issues. She is currently conducting research on C sequestration at the Pacific Northwest National Laboratory in Richland, Washington.

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