Nutrient Management for Fruit & Vegetable Crop Production

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Nutrient Cycling & Maintaining Soil Fertility

Introduction

Conventional agriculture – ***alternative*** agriculture, ***organic*** agriculture – ***chemical*** agriculture, ***industrial*** agriculture – ***eco***-agriculture: Sharp distinctions are drawn among crop production systems attached to these labels. Differences in practices and philosophy are real, and can be a source of controversy and heated discussion, but there are important underlying similarities among farming systems of all types and labels.

Plants require three factors for growth and reproduction: light, water, and nutrients. The third of these factors, managing crops to provide an optimum nutrient supply, is where some of the major differences among farming systems occurs. These differences frequently are described as ***biological*** vs. ***chemical*** methods of maintaining soil fertility. This distinction is meaningful, but the categories are not mutually exclusive. It is important to understand both biological and chemical processes to effectively and efficiently provide plants with nutrients. Plant nutrients are ***chemical*** elements that are mostly absorbed by plant roots as inorganic chemicals dissolved in water. At the same time, plant nutrients are used by other forms of life and go through many ***biological*** transformations that determine when and how plants take them up. Biological materials like manure are major nutrient sources on many "conventional" farms, as well as organic farms, while inorganic minerals (chemical materials) like rock phosphate and lime are acceptable fertility amendments for certified organic production.

Objectives

The focus of this bulletin is on biology, placing ***nutrient cycling*** at the center of nutrient management, but the biological emphasis is not meant to disregard other factors. The objectives are to examine and illustrate:

1) Biological, chemical, and physical ***processes*** plant nutrients go through as they cycle through the soil
2) How these processes affect ***nutrient availability*** to plants and ***nutrient movement*** from farm fields to surface or groundwater
3) Ways to ***manage crops and soils*** to maximize nutrient availability and minimize nutrient movement to the surrounding environment

Understanding processes helps identify practical options that fit different farming systems. Understanding nutrient cycles helps all types of farmers maintain the fertility of their soils, while at the same time protecting our water resources.

Nutrient Cycling

Essential Plant Nutrients

There are at least 16 essential chemical elements for plant growth. Carbon, hydrogen, and oxygen, obtained in large amounts from air and water, make up the bulk of plant dry matter in the products of photosynthesis, but usually are not included as "nutrient" elements. ***Nitrogen*** (N), ***phosphorus*** (P), ***potassium*** (K), ***calcium*** (Ca), ***magnesium*** (Mg), ***sulfur*** (S), ***iron*** (Fe), ***manganese*** (Mn), ***zinc*** (Zn), ***copper*** (Cu), ***boron*** (B), ***molybdenum*** (Mo), and ***chlorine*** (Cl) are obtained from the soil and required by all plants. Sodium, silicon, and nickel are essential elements for some plant species and, although not required, have positive or ***beneficial*** effects on the growth of other species. Cobalt is essential for nitrogen fixation by legumes. Additional elements, such as selenium and iodine, are not required by plants, but can be important in plant nutrition because they are essential nutrients for humans and other animals that consume plants.

All essential nutrients are equally important for healthy plant growth, but there are large differences in the amounts required. N, P, and K are ***primary macronutrients*** with crop requirements generally in the range of 50 to 150 lbs/acre. Ca, Mg, and S are ***secondary macronutrients***, required in amounts of about 10 to 50 lbs/acre. ***Micronutrient*** requirements (Fe, Mn, Zn, Cu, B, Mo, and Cl) are generally less than 1 lb/acre.

Plant Nutrients & Their Chemical Symbols

Primary macronutrients

***N =** nitrogen**, P =** phosphorus**, K =** potassium*

Secondary macronutrients

Ca = calcium, **Mg** = magnesium, **S** = sulfur

Micronutrients

Fe = iron, **Mn** = manganese, **Zn** = zinc,
Cu = copper, **B** = boron,
Mo = molybdenum, **Cl** = chlorine

(chemical symbols are used throughout this bulletin)

Sources of Plant Nutrients in the Soil

Plants obtain mineral nutrients through root uptake from the soil solution. Sources of these soluble nutrients in soil include:

1) ***Decomposition*** of plant residues, animal remains, and soil microorganisms
2) ***Weathering*** of soil minerals
3) ***Fertilizer*** applications
4) Manures, composts, biosolids (sewage sludge), kelp (seaweed), and other ***organic amendments*** such as food processing byproducts
5) ***N-fixation*** by legumes
6) ***Ground rock*** products including lime, rock phosphate, and greensand
7) Inorganic ***industrial byproducts*** such as wood ash or coal ash
8) ***Atmospheric deposition***, such as N and S from acid rain or N-fixation by lightning discharges
9) Deposition of nutrient-rich ***sediment*** from erosion and flooding

Losses of Plant Nutrients from the Soil

Mineral nutrients also can be lost from the soil system and become unavailable for plant uptake. Nutrient losses are not just costly and wasteful, they can be a source of environmental contamination when they reach lakes, rivers, and groundwater. Nutrient losses occur through:

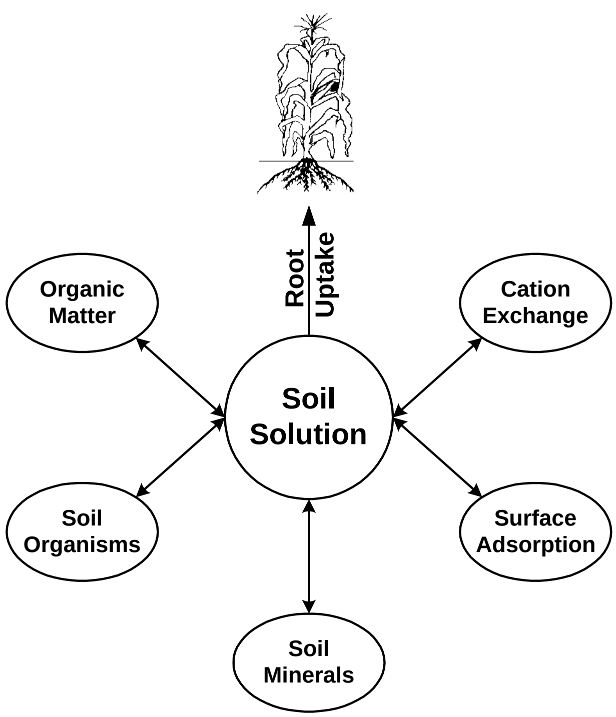
1) ***Runoff* –** loss of dissolved nutrients in water moving across the soil surface

2) ***Erosion*** – loss of nutrients in or attached to soil particles that are removed from fields by wind or water movement
3) ***Leaching*** – loss of dissolved nutrients in water that moves down through the soil to groundwater *or* out of the field through drain lines
4) ***Gaseous losses*** to the atmosphere – primarily losses of different N forms through volatilization and denitrification (see Nitrogen Cycle on page 5)
5) ***Crop removal*** – plant uptake and removal of nutrients from the field in harvested products

Nutrient Pools in the Soil

In addition to the variety of inputs and outputs, plant nutrients exist in many different forms → or ***nutrient pools*** within the soil (Fig. 1). These pools range from soluble, readily available forms to weakly bound forms that are in rapid equilibrium with soluble pools → to strongly bound or precipitated forms that are very insoluble and become available only over long time periods. Nutrients in solution can be taken up immediately by plant roots, but they also move with water and can easily leach below the plant root zone or be lost in runoff from farm fields. ***The "ideal" fertile soil has high nutrient concentrations in the soil solution when crop growth rates are high and a large storage capacity to retain nutrients when crop needs are low or there is no growing crop***.

Fig. 1. **Soil Nutrient Pools**



Exchangeable cations (see text box below) are a shor
nutrient ions in the soil solution. Soil organic matter
is an important supply of N, P, S, B, and trace-me

Cations & Anions

Ions are chemical elements or compounds with an electrical charge. *Cations* have a **positive charge** and *anions* have a **negative charge**. Most plant-available forms of essential plant nutrients are ionic.

relatively soluble types (chlorides and sulfates) to insoluble forms (feldspars, apatite, mica) that release nutrients through weathering reactions with chemical and biochemical agents such as organic acids. Adsorbed anions, like phosphate and iron oxides bound to clay and organic matter surfaces, are held strongly and released very slowly, but can contribute to the long-term supply of plant-available nutrients.

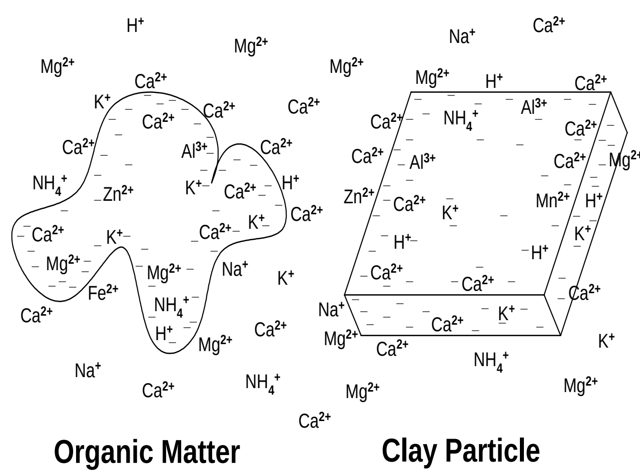
Cation Exchange Capacity (CEC)

Clay particles and organic matter have negatively charged sites that hold positively charged ions on their surfaces (Fig. 2). CEC protects soluble cations from leaching out of the plant root zone. These ions are rapidly exchangeable with other soluble ions, so when root uptake depletes the nutrient supply they replenish plant-available cations in the soil solution. Cation exchange is the major nutrient reservoir of K^+, Ca^{2+}, and Mg^{2+}, is important for holding onto N in the ammonium (NH_4^+) form, and to some extent supplies micronutrient trace metals like Zn^{2+} and Mn^{2+}. Cation exchange helps soils resist changes in pH in addition to retaining plant nutrients.

Organic Matter

Soil organic matter is a very important factor in soil fertility. It is a reservoir of plant nutrients, has a high CEC, buffers soil pH, and chelates micronutrients. Organic matter exists in different forms in soil, ranging from living ***soil organisms*** → to fresh, readily decomposed ***plant residues*** → to ***humus*** that is very stable and resistant to further degradation. Living soil organisms include bacteria, fungi, actinomycetes, nematodes, earthworms, mites, and insects. They make up the ***soil food web***, which carries out biological nutrient cycling. Plant roots are a sometimes forgotten part of the living soil biomass. Readily decomposed or ***active organic matter*** is the form of organic matter through which nutrients are actively recycled. Decomposition produces gums, polysaccharides (sugars), and other compounds that are the "glues" of water-stable soil aggregates necessary for good soil structure. Stable humus contributes to long-term nutrient supply and is the organic matter fraction with high CEC. ***Chelation*** is the ability of soluble organic compounds to form complexes with micronutrient metals that keep them in solution and available for uptake. In ***organic soils*** (peats and mucks), trace metal complexes with organic matter can reduce their availability.

Fig. 2. **Cation Exchange Capacity (CEC)**



The cycling of plant nutrients through soil organic matter supplies a significant portion of a growing crop's nutrient needs. Another aspect of this cyclical process is that organic matter not only contributes to soil fertility, but fertile soils contribute to the production of organic matter. ***One of***

the best ways to add organic matter to the soil is to maintain fertility and grow healthy crops that add large amounts of plant residue.

Nutrient Cycles

Soil fertility can be maintained when nutrients are efficiently recycled through the soil food web and soil-plant-animal system. Nutrient cycling is conveniently illustrated in diagrams that range from very simple (see Fig. 3 – *Basic Plant Nutrient Cycle*) to extremely complex (see Fig. 4 – *Nitrogen Cycle*).

Basic Plant Nutrient Cycle. The basic plant nutrient cycle highlights the central role of soil organic matter. Cycling of many plant nutrients, especially N, P, S, and B, closely follows parts of the ***Carbon Cycle***. Plant residues and manure from animals fed forage, grain, and other plant-derived foods are returned to the soil. This organic matter pool of carbon compounds becomes food for bacteria, fungi, and other decomposers. As organic matter is broken down to simpler compounds, plant nutrients are released in available f... uptake and the cycle ... Plant-available K, Ca, Mg, P, S, and some micronutrients are ... released when soil miner... precipitates dissolve (see Fi...

Fig. 3. **Basic Plant Nutrient Cycle**

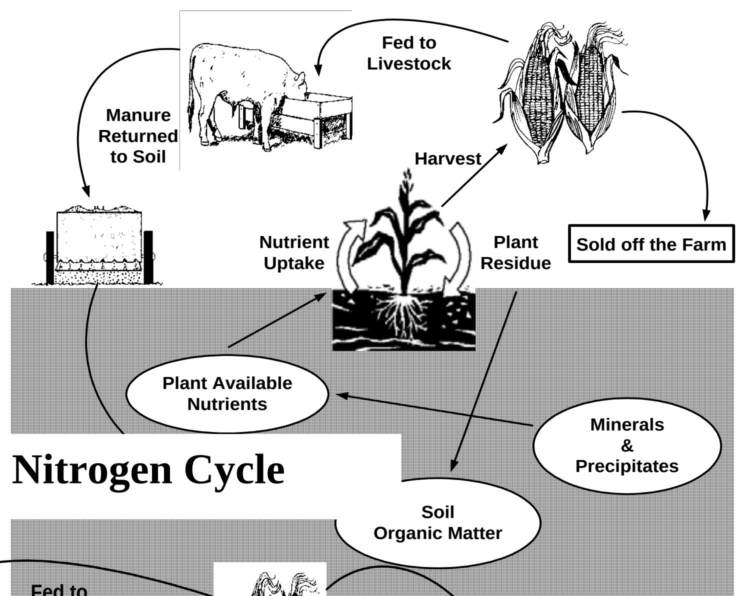
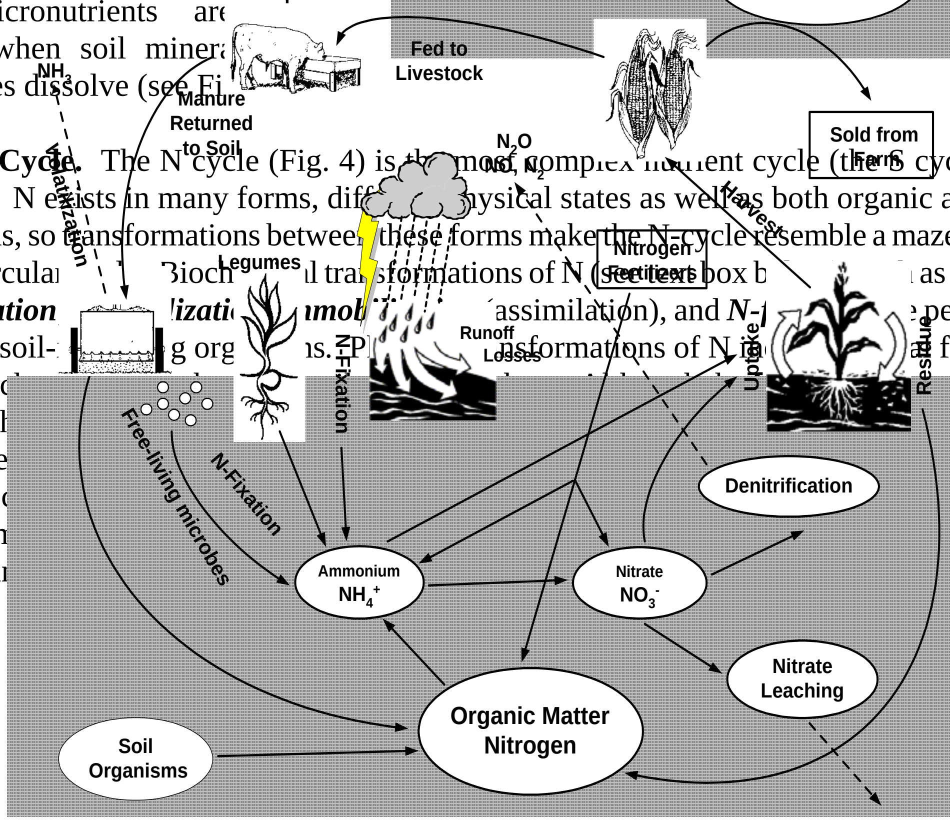


Fig. 4. **Nitrogen Cycle**



Nitrogen Cycle. The N cycle (Fig. 4) is the most complex nutrient cycle (the S cycle is equally complex). N exists in many forms, diff... physical states as well as both organic and inorganic compounds, so transformations between these forms make the N-cycle resemble a maze rather than a simple, circula... Bioch...l transformations of N (see text box b... as ***nitrification***, ***denitrification*** ...***lizati***... ***mob***... assimilation), and ***N-f***... performed by a variety of soil-... g organisms. P... nsformations of N i... forms that are gases, whic... complex, it is probably th... this: 1) N is usually the ... ere is often a very large ... le and one of the most m... nd become a contaminan... ***management***.

Nutrient Balance & Nutrient Budgets

Nutrient cycling is not 100% efficient. There are always some losses or "leaks" from the cycles, even for natural ecosystems. In farming systems, where products are bought and sold, the balance between nutrient inputs and outputs is easily shifted in one direction or the other. When the balance between inputs and outputs is quantified, a ***nutrient budget*** can be calculated. Nutrient budgets can be determined at different scales, from single fields → to whole farms → to landscapes and even broader regional areas. Strictly speaking, a cycle is a circular, closed-loop pattern, so the nutrient cycles diagrammed in Figs. 3 and 4 are not true cycles. There are cycles within them, but they include other components and describe a larger picture where there is movement or ***flows of nutrients*** into and out of smaller systems such as farm fields. Nutrient balances or budgets look at these nutrient flows between different systems.

Whole-Farm Nutrient Budgets

Different types of farms have different patterns of nutrient flow. They vary in patterns of internal movement within the farm as well as in the amounts of external transfers both on-to- and off-of- the farm. ***Cash crop*** and ***concentrated livestock*** farms represent two extremes in nutrient-flow patterns, with ***mixed crop and livestock*** farms in an intermediate position. Looking at these three farm types outlines the consequences and challenges faced by a range of different farm types in maintaining soil fertility, using plant nutrients efficiently, and eliminating uncontrolled nutrient flows off farms and into the surrounding environment.

Cash Crops. Cash grain and vegetable farms that do not have livestock frequently export large amounts of plant nutrients in off-farm sales. A 500-cwt/acre potato crop, for example, removes about 215 lbs of N, 30 lbs of P, and 240 lbs of K in the harvested tubers. A 150-bushel/acre corn

A Present-Day Flow of Phosphorus

phosphate rock mined in Florida → → → processed into phosphate fertilizers & transported to the Corn Belt → → → fertilizer applied to corn & soybean fields → → → harvested grain processed into animal feeds → → → feed shipped to the Delmarva Peninsula & fed to chickens → → → litter applied to nearby cropland → → → excess P contributes to nutrient loading & impaired water quality in Chesapeake Bay

The Delmarva (Delaware, Maryland, Virginia) Peninsula is a major poultry production area that supplies consumers throughout the country. Concentrated production makes it difficult to recycle the P in litter, however, because the industry produces several times the amount of P required to meet crop needs on surrounding cropland. Among the strategies explored by the poultry industry to reduce P movement into Chesapeake Bay are: 1) a program to pelletize excess litter into a fertilizer product that can be efficiently transported to a larger region, 2) managing feed rations to supply only enough P to meet the dietary needs of poultry, 3) adding the enzyme phytase to poultry feed to make the P in feed more available nutritionally and reduce the amount that must be fed, and 4) adding aluminum sulfate to litter to chemically immobilize P before landspreading crop contains about 135 lbs of N, 25 lbs of P, and 35 lbs of K in the grain. When corn stover or small grain straw is sold in addition to grain, nutrient losses from the farm are larger, especially for K. To maintain high yields, these nutrients must be replaced. Biologically-fixed N from soybeans or other legumes in the rotation supplies some N, but large N inputs from forage legumes are not usually part of systems without livestock to consume the forage. When high quality hay is grown as a cash crop, nutrient exports off the farm are even greater than for grain or vegetables. There are some deep, naturally fertile soils with high organic matter and mineral reserves that can be "mined" and meet many crop nutrient needs for some time, but large amounts of off-farm fertilizer inputs are required in most soils for cash-crop systems to maintain nutrient sufficiency and crop yields. In this age of globalization, international grain sales have become an important market for U.S. farmers. One consequence of global trade is the associated, worldwide transfer of plant nutrients.

Mixed Crop & Livestock. Farms with both crops and livestock have the potential to recycle a large portion of the nutrients used by crops back to the soil, because about 75% or more of the NPK consumed in animal feed is excreted in manure or urine. Efficient recycling depends upon storage, handling, and application methods that minimize losses, and an effective nutrient management plan that applies manure to fields in amounts matching crop needs with the nutrient content of the manure. Within a farm, manure applications can be a method of transferring nutrients between fields. Depending upon the balance between crop and livestock enterprises, whole-farm nutrient budgets on mixed farms include different amounts of nutrient losses in milk, meat, or eggs, and different levels of nutrient inputs from purchased feed and fertilizer.

Concentrated Livestock. Concentrated animal-feeding operations import large amounts of plant nutrients in purchased grain, forage, and bedding. They are generally net nutrient importers, because purchased inputs exceed nutrient losses from milk, meat, or egg sales. These excess nutrients accumulate in animal wastes that often create storage or disposal problems. High-density livestock operations frequently have an inadequate land base to efficiently use all the manure they generate, so there is the potential for increased risk of water contamination. As livestock operations have become larger, they have also tended to concentrate regionally, resulting in increased geographic separation between feed-grain producers and consumers. Manures are bulky products that are difficult and costly to apply and transport long distances. In some locations it currently is not economical to recycle the nutrients in animal waste, so long-term storage rather than re-use has become the solution to the waste problem. The net result is increasing transfer of nutrients from one part of the country to another and increased dependence on purchased fertilizer inputs in grain production areas (see text boxes on phosphorus flows).

Maintaining Soil Fertility

Management Practices to Maximize Nutrient Cycling & Nutrient-Use Efficiency. Nutrient management can be defined as "efficient use of all nutrient sources" and the primary challenges in sustaining soil fertility are to:

1) Reduce nutrient **losses**
2) Maintain or increase nutrient **storage capacity**
3) Promote **recycling** of plant nutrients
4) Apply additional nutrients in **appropriate amounts**

In addition, cultural practices that support the development of ***healthy, vigorous root systems*** result in efficient uptake and use of available nutrients. Many cultural practices help accomplish these goals, including establishing diverse ***crop rotations***, reducing ***tillage***, managing and maintaining

Phosphorus Flows and the Minnesota River

Phosphorus enrichment of surface waters is a major issue in some parts of Minnesota. In fresh water systems, P is usually the limiting nutrient for growth of algae and aquatic plants, so their growth is stimulated when P in runoff or eroded soil enters lakes and rivers. ***Algal blooms*** lead to accelerated eutrophication of surface waters and degradation of water quality. In extreme cases, depleted levels of dissolved oxygen in the water cause death of fish and other aquatic life.

Water quality concerns led to a recent Minnesota law restricting P fertilizer application on home lawns and other turfgrass areas. In the agricultural landscape, similar concerns are expressed about the ***role of agriculture in P enrichment of the Minnesota River***. P loading into the Minnesota River comes from a variety of sources, including stream bank erosion, water treatment plants, and industrial activity. The extent of the contribution from agriculture is difficult to measure, but P in runoff from farm fields and P attached to eroded soil are certainly potential pathways of P delivery to the river and its tributaries.

Phosphorus flows into Minnesota are not as dramatic as those described for the poultry production areas of the Delmarva Peninsula, but there are similarities and some common pathways. Phosphate rock mined in Florida or other distant locations is processed into phosphate fertilizers that are transported to Minnesota and applied to crop fields. Some of the grain harvested from these fields becomes part of animal feeds that are shipped to places like the Delmarva Peninsula, and additional harvested products are transported for other uses, so some of the imported P flows back out of the state in exported agricultural products. However, some of the imported P accumulates in various forms and locations, and is a potential source of nutrient loading and impaired water quality in the Minnesota River if not properly managed.

Accumulation of P in manure and increasing levels of P in the soil are two ways the flow of P into the state can build up and threaten the Minnesota River or other surface water bodies if not managed efficiently. Concentrated livestock production is not as widespread as it is in the Delmarva Peninsula, but in localized areas the amount of P in manure exceeds the amount of P required to meet crop needs on surrounding cropland. Manure is a valuable resource, but fields with a long history of heavy manure application can exceed the capacity of the soil to efficiently recycle the amount of P in continual manure additions. Buildup of soil P can also occur when P fertilizer is applied at rates exceeding crop P requirements.

Efficient use of fertilizer and manure P requires sound nutrient management planning to reduce the potential for environmental problems. This includes soil testing to determine the need for P, manure analysis, proper storage and handling of manure, and fertilizer and manure application methods that reduce the potential for movement of P from farm fields. In addition, soil management practices that limit surface runoff and reduce soil erosion help protect water quality, as well as sustaining long-term soil productivity.

crop residue, growing ***cover crops***, handling ***manure*** as a valuable nutrient source, ***composting*** and using all available wastes or byproducts, ***liming*** to maintain soil pH, applying supplemental ***fertilizers***, and routine ***soil testing***. These beneficial management practices have multiple effects on nutrient cycling and soil fertility, which make it important to integrate their use and examine their effects on the complete soil-crop system, rather than just a single component of that system. There are many good ways to farm, so different solutions or combinations of practices are appropriate for different systems to reach similar goals.

Crop Rotations

The term ***rotation effect*** was coined to describe the observation that yields for a crop grown in rotation with other crops are usually 5 to 15% greater than for continuous monoculture of that same crop. The reason for increased yields is not always clear, and in most cases it is probably not due to a single cause, but growing a variety of crops in sequence has many positive effects on soil fertility. In a diverse rotation, deep-rooted crops alternate with shallower, fibrous-rooted species to bring up nutrients from deeper in the soil. This captures nutrients that might otherwise be lost from the system. Differences in plant rooting patterns, including root density and root branching at different soil depths, also results in more efficient extraction of nutrients from all soil layers when a series of different crops is grown.

Including sod-forming crops in rotation with row crops decreases soil and nutrient losses from runoff and erosion, and increases soil organic matter. Growing legumes to fix atmospheric N reduces the need for purchased fertilizer and increases the supply of N stored in organic matter for future crops. Biologically fixed N is used most efficiently in rotations where legumes are followed by crops with high N requirements. Rotating crops also increases soil biodiversity and nutrient cycling capacity by supplying different residue types and food sources, reduces the buildup and carryover of soil-borne disease organisms and insect pests (breaks disease and pest cycles), and can help create favorable growing conditions for healthy, well-developed crop root systems.

Soil & Water Conservation Practices

Soil erosion removes topsoil, which is the richest layer of soil in both organic matter and nutrient value. Implementing soil and water conservation measures that restrict runoff and erosion minimizes nutrient losses and sustains soil productivity. Tillage practices and crop residue cover, along with soil topography, structure, and drainage, are major factors in soil erosion. Surface residue limits erosion by reducing detachment of soil particles by wind or raindrop impact and restricting water movement across the soil. Tillage practices manage the amount of crop residue left on the soil surface. Reduced tillage or no-till maximizes residue coverage. Water moves rapidly and is more erosive on steep slopes, so reducing tillage, maintaining surface residue, growing sod crops, and planting on the contour or in contour strips are recommended conservation practices. Using diverse rotations and growing cover crops also can reduce erosion.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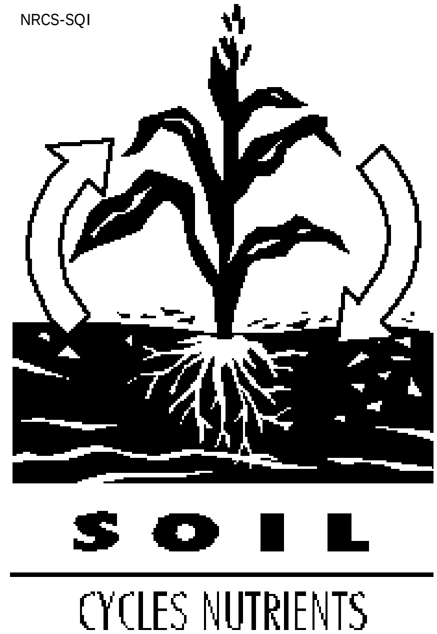
Soils with stable aggregates are less erodible than those with poor structure, and organic matter (including the activity of living soil organisms and fine roots) helps bind soil particles together into aggregates. Tillage breaks down soil aggregates and also increases soil aeration, which accelerates organic matter decomposition. Well-drained soils with rapid water infiltration are less subject to erosion, because water moves rapidly into and through them and does not build up to the point where it moves across the surface. Drainage improvements on poorly drained soils reduce runoff, erosion, and soil compaction. Improving drainage also decreases N losses from denitrification, which can be substantial on waterlogged soils, by increasing aeration. Improving aeration in the plant-root zone also promotes healthy root growth. A negative consequence of improved drainage is loss of nitrate-N and other nutrients through tile outlets to surface waters. Especially important are flushes of residual N after late winter/early spring rains.



Cover Crops and Green Manures

Growing cover crops and green manure crops can be viewed as a type of crop rotation, where adding a non-revenue generating crop between annual cash crops extends the growing season. Many of the benefits, therefore, are the same as those achieved with crop rotation.

The terms cover crop and green manure are frequently used synonymously. They perform many similar functions and many of the same plant species are used as both cover crops and green manure crops. The main difference between the two is that the primary purpose of growing a cover crop is to protect the soil surface from raindrop impact, runoff, and erosion and the primary purpose of a green manure is as a soil-building crop to produce organic material for incorporation into the soil. Winter grains like cereal rye planted after potatoes are cover crops that are designed to hold soil in place until the next main crop is planted in the spring, but they also add organic matter to the soil when they are turned under. Rapidly growing summer annuals like buckwheat and sorghum-sudangrass are planted between short-season vegetable crops as green manures to add organic matter to the soil, but they also protect the soil from erosion between spring and fall vegetables.

Growing legume cover crops adds biologically fixed N. The additional plant diversity with cover crops stimulates a greater variety of soil microorganisms, enhances carbon and nutrient cycling, and promotes root health. The soil surface is covered for a longer period of time during the year, so nutrient losses from runoff and erosion are reduced. This longer period of plant growth substantially increases the amount of plant biomass produced, which in turn increases organic matter additions to the soil. The extended growth period obtained with cover crops also extends the duration of root activity and the ability of root-exuded compounds to release insoluble soil nutrients.

"Soil must grow its own organic matter"

A winter cover crop that makes good fall growth traps excess soluble nutrients not used by the previous crop, prevents them from leaching, and stores them for release during the next growing season. Complementary cover crop mixtures produce root exudates with varying composition and effects, and have different zones of nutrient uptake, because they differ in amount, depth, and patterns of root branching. Deep-rooting cover crops, like sorghum-sudangrass hybrids and sweet clover, can break up some types of compacted soil layers and improve rooting depth for the next crop. Cereal rye, sorghum-sudangrass, and *brassicas* (mustards), such as oilseed radish and forage turnip, all suppress some nematode species and may be useful cover crops in fields with moderate infestation levels. Cover crops also can suppress weeds, which otherwise would compete with crops for nutrients.

Cover crop benefits are probably greatest as soil-building crops preceding high-value perennial fruits and in rotations with low-residue, short-season crops such as annual vegetables. It is often easier find places to grow cover crops in vegetable rotations than in agronomic rotations, and there may be opportunities to grow both summer and fall cover crops in vegetable systems. Many vegetables have relatively shallow, sparse root systems, but are well fertilized because of their value. Both summer and fall cover crops absorb residual nutrients, in addition to increasing the time and amount of surface cover.

Disadvantages of growing cover crops are:

1) Large amounts of residue can make planting difficult and reduce crop stands
2) In wet springs, planting may be delayed if wet soil conditions delay killing the cover crop
3) Soil warms more slowly in the spring under cover crops than for tilled soil and lower soil temperatures can slow seed germination, reduce early-season growth, delay maturity, and reduce crop yields
4) Spring cover crop growth uses water, which can adversely affect the following cash crop in a dry year (in wet years, cover crop water use may be beneficial on poorly drained soils)
5) Some cover crops attract and/or harbor pests that can damage succeeding crops
6) There are expenses and management time required to grow cover crops

Cover crops have many benefits, but when you grow them you need to commit time to their selection and management to fully realize their benefits and avoid potential problems. Select cover crops with characteristics that will meet your objectives and fit your rotations, and then manage them with the same attention and skill you give any other crop.

Manure Management

Returning manure to crop fields recycles a large portion of the plant nutrients removed in harvested crops. On farms where livestock are fed large amou to crop fields is a substantial source of nutrient inpu as nutrients can be lost from the soil, nutrient loss application are both economically wasteful and

Nutrient Management is the efficient use of all nutrient sources. A **Nutrient Management Plan** that takes all nutrient sources into account is not just environmentally sound – it is good business.

nutrients readily leach from manure, especially when it is unprotected from rainfall during storage. N is readily lost through volatilization of ammonia, both during storage and when manure is not incorporated soon after field application. Nutrient losses from manure also occur when it is applied at rates exceeding crop nutrient requirements.

Analyze manure for its nutrient content and adjust application rates according to crop needs, soil tests, and frequency of manure applications. Avoid applying manure at rates that exceed crop requirements for any nutrient, but especially for N and P on fields that receive manure on a regular basis. This often means that rates should be based on P requirements rather than N requirements. Following heavy manure applications with crops that have high nutrient requirements (especially for N and P) reduces losses and increases nutrient-use efficiency. In addition to nutrient value, manure adds organic matter to the soil, which can improve soil structure and increase CEC. Refer to *Using Manure and Compost as Nutrient Sources for Vegetable Crops* for further information on nutrient content, nutrient availability, and calculation of application rates for efficient use of manure as a source of plant nutrients for vegetable crop production ***(need to make a link to this)***.

Compost & other Soil Amendments

In addition to manure, ***organic amendments*** such as biosolids, food processing wastes, animal byproducts, yard wastes, seaweed, and many types of composted materials are nutrient sources for farm fields. Biosolids contain most of the essential plant nutrients, and are much "cleaner" than they were twenty years ago, but regulations for farm application must be followed to prevent the possibility of excessive trace metal accumulation. Biosolids are also not an acceptable nutrient source for certified organic production.

Composting is a decomposition process similar to the natural organic matter breakdown that occurs in soil. Proper composting conserves volatile and soluble N, and other mobile nutrients in waste products, by incorporating them into organic forms where they are more stable and less readily lost. Composting reduces the bulk of organic wastes and makes transportation and field application of many waste products more feasible. On-farm composting of manure and other farm wastes also facilitates their handling. Most organic materials can be composted, nearly all organic materials contain plant-nutrient elements, and ***recycling all suitable wastes or byproducts through soil-crop systems*** by either composting or direct field application should be encouraged. These practices build up soil organic matter and provide a long-term, slow-release nutrient source. Some composts also have disease-suppressive properties that improve root growth and health.

Inorganic byproducts also can be recycled through the soil and supply plant nutrients. Available materials vary by region, but wood ash, rock dust from quarries, gypsum from scrubbers in power plants burning high-sulfur coal, and waste lime from water treatment plants are among the waste products that are beneficially re-used. When considering the agricultural use of any byproduct, a thorough chemical analysis and review of possible regulations should be done to avoid soil contamination problems. Even seemingly benign byproducts should be analyzed and field-tested on a trial basis before using them on a large acreage.

Table 1. Percentage of the Total Soil Volume Occupied by Plant Roots (in the surface 8-inches of soil)	
Crop	**Root Volume (%)**
Kentucky Bluegrass	2.8
Winter Rye	0.9
Oat	0.6
Soybean	0.4 - 0.9
Corn	0.4

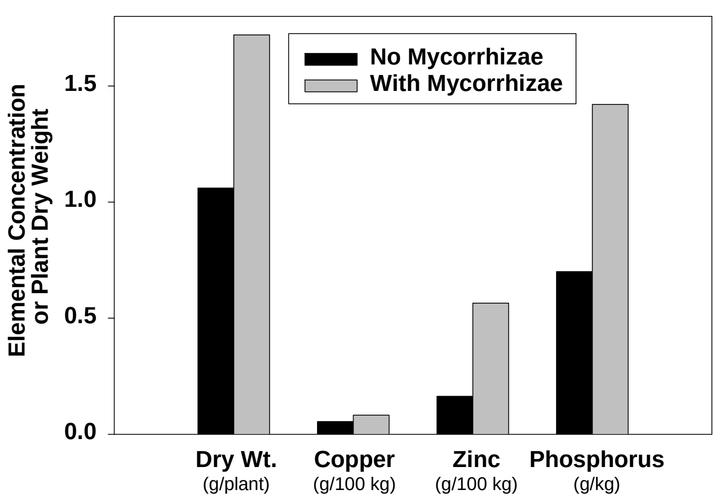
Adapted from S. Barber, *Soil Nutrient Bioavailability,* 1984.

Healthy, Vigorous Root Systems

Vigorous root systems tap nutrient supplies from a larger volume of soil, so management practices that stimulate healthy root growth can also increase nutrient uptake. Uptake efficiency by extensive, well-distributed root systems results from increases in the amount of root surface area in contact with the soil. The extent of root-soil contact is limited by the fact that ***roots occupy only about 1 to 3% or less of total soil volume***, even for fibrous-rooted plants in the surface layer of soil where root density is greatest (Table 1). For immobile nutrients like P, root growth to the nutrient is especially important for uptake, because in most soils ***P moves only about 1/10 of an inch over the entire growing season***.

Root-soil contact is determined by root length (both vertical & horizontal), root branching, and root hairs. Root hairs are located just behind the root tip and have a relatively short life span of a few days to a few weeks. Actively growing feeder roots are necessary to continually renew these important locations for nutrient uptake. Symbiotic associations between soil fungi and plant roots also increase nutrient absorbing capacity (Fig. 5). These fungi, called ***mycorrhizae*** ("fungus roots"), function as an extension of plant root systems. Mycorrhizae obtain food from plant roots and in return increase the nutrient absorbing surface for the plant through their extensive network of fungal strands (hyphae). Mycorrhizae are particularly important for P uptake in low P soils. They can increase Zn and Cu uptake and also provide some protection against root disease.

Fig. 5. Effect of Mycorrhizae on Growth and Cu, Zn, and P Content of 40-Day Old Soybean Plants



Adapted from S. Barber, *Soil Nutrient Bioavailability*, 1984 (from data of Lambert et al., 1979, Soil Sci. Soc. Am. J. 43:976-980).

Root activity also has direct effects on nutrient availability in the soil. Insoluble nutrients are released and maintained in solution by the action of organic acids, chelates, and other compounds produced by roots. Nutrients are also released because the soil immediately adjacent to roots, the ***rhizosphere***, often has a lower pH than the bulk soil around it as a consequence of nutrient uptake. The rhizosphere stimulates microbial activity and microbes also release compounds like organic acids, enzymes, and chelates that solubilize nutrients.

A number of soil factors and management practices affect root growth, distribution, and health. Compacted soil layers restrict root penetration, low pH in the subsoil can restrict rooting depth, water saturation and poor aeration inhibit root growth, and roots will not grow into dry zones in the soil. Alleviating these conditions through some of the management practices described in this bulletin can increase nutrient uptake. Cultural practices that promote soil biodiversity help maintain healthy root systems, because an active and diverse microbial population competes with root pathogens and can reduce root disease.

Phosphorus Cycling: the Critical Importance of Soil P Transformations

Soil P is chemically and physically very reactive, so P transformations in the soil (see Fig. 1) are a critical part of the P Cycle and control P availability to plants. The necessity for *dynamic nutrient cycling processes* in soil is clearly illustrated by comparing crop requirements for P with typical P concentrations in the soil solution. A 150-bushel/acre corn crop has about 40 pounds of P in the grain and stover, so the ***crop requirement is 40 pounds of P/acre*** (ignoring the P requirement of roots). P solubility is very low and the soil solution concentration commonly ranges from less than 0.01 to 1 part per million (ppm). An "average" value for a fertilized agricultural soil is about ***0.05 ppm of dissolved, available P***. Soil with a 25% water-holding capacity holds nearly 250,000 gallons of water in the upper 3-feet of one acre when it is at field capacity. However, because P solubility is so low, the soil solution in this soil will contain only ***1/10 of a pound of plant-available, dissolved P/acre***. This means that soil-P nutrient pools, both inorganic and organic, must be able to ***replenish available P in the soil solution 400 times during the growing season*** to meet crop needs. Roots occupy only a small part of the soil volume and P moves only a short distance

Soil Acidity & Liming

Soil pH has strong effects on the availability of most nutrients. This is because pH affects both the chemical forms and solubility of nutrient elements. Trace metals such as Fe, Zn, and Mn are more available at lower pH than most nutrients, while Mo and Mg are more available at higher pH than many other nutrients. The ideal soil pH for many crops is slightly acid, between about 5.8 and 7.0, because in that range there is well-balanced availability for all nutrients. This pH range also promotes an active and diverse soil microbial population and is a healthy range for earthworms and other soil organisms. Alkaline soil conditions reduce Fe availability, resulting in Fe chlorosis ("lime-induced chlorosis") on crops like soybeans when soil pH is above 7.2.

Some crops grow better at distinctly lower or higher soil pH than 5.8 to 7.0, usually because of specific nutrient requirements. Blueberries grow best around pH 4.5 to 4.8 and often are Fe deficient when the pH is above 5.2. Most other crops suffer from Al or Mn toxicity when soil pH is that low. Legumes do best at higher pH than most other crops, due to the high requirement for Mo by Nfixing bacteria. Potatoes are often grown at a pH of 5.4 or less, but to reduce the incidence of potato scab rather than for fertility reasons.

The target pH range for crops grown on organic soils is about 1 to 1.5 units lower than it is on mineral soils. Liming is generally not beneficial unless soil pH is 5.4 or less and lime recommendations for organic soils are only designed to raise pH to 5.5. Mn deficiency can occur on vegetable crops like onions when soil pH is 5.8 or higher on organic soils. Plant roots can tolerate lower soil pH on muck or peat soils than they can on mineral soils, because amounts of potentially toxic metals like Al and Mn are lower and they are also bound by the high organic matter levels. However, formation of similar Cu-organic matter complexes can cause Cu deficiency in sensitive crops like carrots on organic soils.

Limestone is the most commonly used material to increase soil pH. Liming also supplies Ca and dolomitic lime supplies Mg as well. Liming ***rates*** depend upon the buffering capacity of a soil, in addition to the measured pH. Buffering capacity, or ability to maintain pH within a given range, is related to CEC and increases as clay and/or organic matter content of the soil increases. The lime requirement for raising soil pH a given amount is much larger for fine-textured, high organic matter soils than for sandy, low organic matter soils. Liming ***frequency*** also depends on soil buffering capacity. Because soil pH changes more slowly on well-buffered, high CEC soils, their larger lime requirements are applied at more widely spaced intervals than on poorly-buffered, low CEC soils, where more rapid changes in pH require smaller, but more frequent, lime applications.

Regular lime applications are required on many soils to maintain soil pH in the desired range, because soil acidification is an ongoing process. Major causes of acidity are ***leaching*** and ***plant uptake*** of basic cations (Ca and Mg), production of ***organic acids*** from organic matter decomposition, and application of acidifying ***N fertilizers***. Ammonium/ammonia N sources, including products like urea that break down to release ammonia, generate acidity when they are converted to nitrate or taken up directly by plant roots.

Ca:Mg Ratios

Some nutrient management philosophies stress exchangeable cation ratios, especially the importance of a large ratio of Ca to Mg. If Ca:Mg is less than 6 or 7:1, application of high-Ca limestone or gypsum (Ca-sulfate) is recommended. Soil Ca certainly can be low, and balance between nutrient cations is important, but from a fertility standpoint, the ***actual amount of exhangeable Ca or Mg*** in soil, rather than the ratio between them, is the most critical factor. In Minnesota, 300 ppm Ca and 100 ppm Mg are adequate soil test levels. There is very little research evidence supporting the existence of an ideal Ca:Mg ratio, while a number of studies show that as long as adequate amounts of both Ca and Mg are present, and Ca:Mg is at least 1:1, crops yield equally well over a wide range of ratios. In fact, a soil could have the “ideal” ratio of Ca:Mg, but actually be deficient in both nutrients. Ca is usually adequate if soil pH is maintained in the proper range. Lime should generally be purchased on the basis of cost per unit of total neutralizing power (TNP). When Mg is low and the ratio of Mg:K is less than 2:1, dolomitic (Ca + Mg) limestone is preferred over high-Ca liming materials.

Reducing soil pH is often necessary for acid-requiring crops like blueberries. Elemental S is the most economical and commonly used material to lower soil pH. Al-sulfate and Fe-sulfate effectively reduce pH, and act more rapidly than elemental S, but they are more expensive and much higher rates are required for equivalent pH changes. Al-sulfate should be avoided, especially on low organic matter soils, because of the potential for Al toxicity to plant roots. Fertilizing with ammonium sulfate, the most acidifying N fertilizer, helps maintain soil pH after it is lowered to the desired range. Do not use ammonium sulfate for large pH changes, because that will result in excessive N applications. Unprocessed elemental S can be applied to reduce soil pH in organic crop production, but not Al, Fe, or ammonium sulfates.

Fertilizer Applications

Many materials can be applied to soil as sources of plant nutrients, but the term "fertilizer" is often used to refer to relatively soluble nutrient sources with a high analysis or concentration. Commercially available fertilizers supply essential elements in a variety of chemical forms, but many are relatively simple inorganic salts. Advantages of commercial fertilizers are their high water ***solubility***, immediate ***availability*** to plants, high ***concentration*** and low ***price*** per unit of nutrient, and the ***uniformity*** and accuracy with which specific amounts of available nutrients can be applied. Because they are relatively homogeneous compounds of fixed and known composition, it is fairly easy to calculate precise application rates and attain relatively consistent performance. This is in contrast to organic nutrient sources, which are a much greater challenge to manage, because of their variable composition, variable nutrient availability, and patterns of nutrient release that are greatly affected by temperature, moisture, and other conditions that alter biological activity.

Don't Forget About Magnesium

Concern about maintaining high soil Ca levels, relative to Mg, should not lead to the misconception that Mg is something to be avoided. ***Mg is an essential plant nutrient***. Among other functions, it is the central atom in the chlorophyll molecule and required for photosynthesis. Forages grown on low Mg soils can cause grass tetany, a serious nutritional deficiency of Mg in cattle. When Ca applications are excessive, other exchangeable cations like Mg (and K) are displaced and can be lost through drain lines or by deep leaching. It is important to maintain adequate amounts, and balance between, all essential cations.

Dolomitic limestone is an important source of Mg, but we sometimes forget that it still contains more Ca than Mg. Dolomites range from 6 to 12% Mg and 20 to 30% Ca (on a weight basis). Expressed on a cation equivalency basis, ***dolomite that is 12% Mg and 21% Ca has a Ca:Mg ratio of a little more than 1:1***. Many factors affect the balance between Ca and Mg in the soil (more Ca is removed by crops, Mg is more easily lost through water movement), but it is important to recognize that commonly available dolomitic limestone in the Midwest (10 to 12% Mg) cannot by itself reduce the Ca:Mg ratio in soil to less than 1:1.

Situations where calcitic lime is preferred over dolomitic lime certainly can occur, but evaluate that need carefully before you pay a significantly higher price for calcite that has to be transported a long distance to your farm.

What About Ca Amendments, Ca:Mg Ratios, and Soil Structure?

Applying gypsum, high-Ca lime, or other Ca amendments is sometimes recommended to add Ca, increase Ca:Mg ratios, and improve soil structure. Ca ions with multiple positive charges help build good soil structure by acting as “bridges” that bind negatively charged clay particles together. These “flocculated” clays are basic building blocks in the formation of stable soil aggregates. The cation sodium (Na), with a single charge, does not promote aggregation and has adverse effects on soil structure (see below). Mg ions are similar to Ca with two positive charges, but some believe that too much Mg relative to Ca forms “tight” soils due to differences in size between Ca and Mg. However, within the ranges of these the two ions commonly found in soil, there is no clear evidence for a Ca:Mg ratio effect on soil structure.

Do some of our fine-textured soils have weak structure and poor drainage because they lack Ca? ***Soil structure is affected by many factors*** (e.g. clay, humus, roots, microorganisms, earthworms, tillage), so it is difficult to clearly separate and evaluate the contribution of Ca. It is clear that Ca is important and high Ca levels are commonly associated with soils that have good structure. What is not always clear are the specific soil conditions where a benefit from Ca can be consistently expected.

Soil conditions where Ca amendments have improved structure include:

1) **Soils with high amounts of exchangeable Na**, where Na ions with a single positive charge tend to disperse clay particles rather than flocculate them. This leads to plugging of soil pores with clay particles, restricted water movement, and surface crusting. Adding gypsum can replace Na with Ca and improve structure, but Na dominated soils occur in arid climates and in higher rainfall areas leaching prevents Na accumulation. Claims that gypsum (Ca) is a universal soil conditioner that loosens tight soils may arise from an erroneous extrapolation of the benefits in arid, irrigated areas to soils with poor structure in all regions.

2) **Soils where organic matter is low, easily dispersed clays dominate, and soil aggregates are weak** and readily broken down by physical forces like tillage and raindrop impact. In these situations, gypsum can promote clay binding, improve structure at the soil surface, and reduce crusting. The gypsum effect is often short-lived, however, and long-term improvements in soil structure require additional changes in soil management such as addition of organic matter and reduced tillage.

3) **Soils with low amounts of Ca in the subsoil.** Gypsum is more soluble than lime, so incorporation of gypsum is a better (although still not rapid) way of moving Ca into high clay subsoils and improving root growth. Often these low Ca subsoils are very acid and better root growth results from displacement of toxic Al by Ca rather than better soil structure. Extremely acid subsoils are rare in the agricultural regions of Minnesota.

Ca amendments can improve soil structure, but their usefulness probably has to be evaluated on a case-by-case basis. This may mean testing their effectiveness on strips in a field before making a large investment to treat the entire area. On a practical basis, it is important to remember that the formation of stable soil aggregates requires organic matter, and the presence and activity of a variety of soil organisms, not just Ca binding of clay particles. In addition, maintaining good soil structure requires soil management that avoids mechanical compaction, avoids physical destruction of soil aggregates by excessive tillage, and uses crop residue management to reduce surface crusting. ***Good soil structure results from the interaction of many physical, chemical,***

The solubility of commercial fertilizers can sometimes be a problem, because soluble nutrients may move out of farm fields when applied in excess or when large rains occur soon after fertilizer application. Soluble nutrients can be lost by leaching on well-drained soils and through tile outlets or
in runoff on poorly drained soils. Denitrification can cause large losses of nitrate-N from water-saturated soils in wet springs.

Increasing soil CEC by increasing organic matter reduces the movement and loss of some nutrients, although not nitrate-N (an anion). Management practices that synchronize nutrient availability with crop demand and uptake also minimize losses. Both application ***timing*** and the ***amount*** of fertilizer applied are important. Splitting fertilizer application into several small applications, rather than a single, large one, is especially important to limit N leaching on sandy, well-drained soils. Split N applications can also reduce N losses in runoff or from denitrification on poorly drained soils. Excess nutrient applications can be eliminated or at least significantly reduced by soil testing on a regular basis, setting realistic yield goals and fertilizing accordingly, accounting for all nutrient sources such as legumes, manure, and other amendments, and using plant analysis as a monitoring tool for the fertilizer program.

Organic agriculture's approach to fertilization is to ***feed the soil and let the soil feed the plant***. Manure, compost, kelp, and other organic fertilizers that supply multiple nutrients are emphasized, but inorganic materials are also important. Inorganic fertilizers for organic crop production must be from natural rock deposits and cannot be chemically processed. They are relatively insoluble with slow release of plant nutrients. Ground minerals like rock phosphate (P), especially *colloidal* or *soft* rock phosphate, greensand (K, P), gypsum (Ca, S), and limestone (Ca, Mg, pH) are commonly applied. Even less soluble products like basalt and granite dust (K, Mg, Ca, trace-metal micronutrients) are also used.

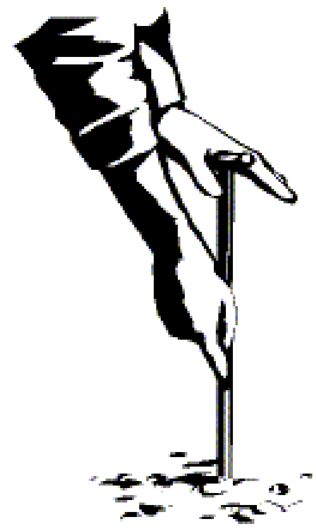
Nutrient release from minerals with low solubility depends upon accelerated weathering reactions, which are stimulated by an active population of soil microbes. Living microorganisms themselves are also a major nutrient storage pool, so organic cultural practices to maintain soil fertility are designed to enhance soil biological activity. Ideally, this microbial population functions both as a "sponge" that soaks up excess nutrients and a nutrient source that releases nutrients when the population turns over, in addition to its role in promoting release of nutrients from minerals and decomposing organic matter. The phrase "feed the soil" refers to the importance of meeting the nutrient needs of these soil organisms and their subsequent roles in meeting the nutrient needs of plants.

Soil Testing

The first step in maintaining soil fertility is to know current nutrient levels. This is accomplished by soil testing, which is an important soil management tool and effective basis for nutrient and lime recommendations. The goal of soil testing is no longer simply to find out whether the soil contains adequate plant nutrients for


NRCS-SQI

optimum growth. It also is a tool for determining whether nutrient levels are excessive and prone to move off-site. ***Soil fertility today is a social issue as well as a crop production concern***.


NRCS-SQI

Soil test each field every 1-3 years, depending upon crop rotation, field history, and the value of the crop. Testing every 3-5 years is probably sufficient for agronomic crop fields with a stable rotation, long-term record of soil tests, and no recent manure or compost applications (only commercial fertilizer since the last soil test). Choose a reliable, experienced laboratory that makes recommendations suitable for the soil types and growing conditions in your location. Laboratories using procedures described in *Recommended Chemical Soil Test Procedures for the North Central Region*, NCR Publication 221, are preferred, because fertilizer recommendations based on University research trials in this region are calibrated using those procedures.

Soil sampling. Collecting a representative soil sample is often the weakest link in a soil-testing program. Each field sampled should be divided into uniform areas having the same soil texture and color, cropping history, and fertilizer, manure, and lime applications. Standard soil sampling depths are 6 to 8 inches for annual crops and 10 to 12 inches for perennial crops. Collect a 0- to 2-foot sample for a soil nitrate test. About 15 to 20 subsamples, one core per subsample, should be collected in a random, zig-zag pattern across the field or sampling area. If you are tempted to save time or money and collect fewer cores to represent more acres, remember that ***any soil test can only be as accurate as the sample you submit***. A single soil sample should never represent more than 20 acres on a level, uniform field or 5 acres on hilly, rolling ground.

Site-specific soil sampling methods for use with the modern technological tools of precision farming, such as yield maps and variable-rate lime and fertilizer application equipment, are continually being developed and refined. Two approaches are currently used: 1**)** ***zone sampling***, where fields are divided into management zones by soil type, topography, soil color, and similar criteria, and 2) ***grid sampling***, where fields are systematically divided into uniform-sized grids (the most common size is 2.5 acres).

Types of soil tests. Standard soil testing in Minnesota focuses on soil organic matter, the macronutrients P and K, soil pH, and the lime requirement if pH is below the desired range. A number of other soil tests are available, but their value is very localized. Their use in different regions of the state depends upon soil types, crops grown, the likelihood of a specific deficiency, and availability of research to usefully interpret soil test results and make reliable recommendations for fertilizer use. Soil tests for Ca, Mg, Mn, Cu, Zn, and soluble salts are useful on some soils and for some cropping systems, but are not usually necessary on a routine basis.

Fertilizer recommendations are commonly based on either ***sufficiency level*** or ***buildup and maintenance*** philosophies. The main difference between the two approaches is that ideal soil nutrient levels, and therefore typical fertilizer rates, are higher for buildup and maintenance (***feeding the soil***) than the more conservative sufficiency level approach (***feeding the plant***).

Fertilizer recommendations for N are not routinely based on soil tests for N. Organic N is the largest pool of N in the soil, but testing for organic N is a poor measure of available N because the rate of organic matter breakdown and N release is variable and unpredictable. It is a biological process that varies with temperature, moisture, aeration, the type of organic compounds being decomposed, and the relative abundance of different types of soil organisms.

> **"Water, Water Everywhere and Not a Drop to Drink"**
>
> Plant roots grow through soil containing about ***1,000 pounds of N per acre for every 1% organic matter*** the soil contains. Plant leaves are bathed in air that is about 78% N, so there are about ***70 million pounds of N in the column of air above every acre*** of land. Despite this abundance of N in both the soil and atmosphere, N is commonly the most limiting nutrient for crop production.

In Minnesota the type of crop grown and the "average" requirement for N by that crop at a specific, anticipated yield level is one of the two primary criteria determining N fertilizer recommendations. The other major factor is soil organic matter content, but organic matter measurements are used to estimate an "average" release of N from organic matter during the growing season. These average requirements are determined by research over many years and weather patterns, and across the different soil types of the region. Additional adjustments to the crop N requirement are made for preceding legume crops, manure applications, other N sources, and in some situations a soil test for nitrate-N.

Soil nitrate testing. The majority of the N taken up by most crops is in the nitrate form and testing for soil nitrate is used to adjust N fertilizer recommendations in regions with low rainfall and limited leaching. Under these conditions, residual soil nitrate from a previous crop can accumulate in the soil profile and be available for root uptake by the following crop. Soil testing for nitrate-N is strongly recommended for the western part of Minnesota to improve the accuracy of N fertilizer recommendations. Collect soil samples to a depth of 2 feet, either in the fall or in the early spring before planting. The measured amount of nitrate-N is used to adjust N recommendations and prevent excessive N fertilizer applications.

In more humid areas, soil nitrate testing has not been considered an accurate measure of nitrate availability during the growing season, because it is easily lost before crops are planted or established by denitrification, leaching, or through tile lines. However, recent research has led to development of a recommended procedure for measuring residual nitrate-N in south central, southeast, and east central Minnesota. In contrast to recommendations for western Minnesota, samples for nitrate testing ***should not be collected in the fall*** for these parts of the state with higher rainfall. Sample to a depth of 2 feet, but only in the spring before planting, at planting, or soon after planting. At the present time, recommendations for adjusting N rates in these regions have only been developed for corn. The importance of N management for both crop production and water quality protection may stimulate additional research to extend its use to other crops, but currently it should only be used for monitoring purposes on crops other than corn. Nitrate testing is not recommended on sandy soils.

Conventional Soil Testing and Organic Agriculture

Conventional soil tests use chemical solutions to extract nutrient elements from soil. These ***chemical extractants*** include acid, alkaline, or concentrated salt solutions, and various complexing agents and buffers. Questions are sometimes raised about the validity of such “chemical” methods for evaluating soil fertility in “non-chemical” organic farming systems. An alternative advocated by some is that a simple water extraction is more natural and better suited for organic agriculture.

These are reasonable questions, but the goals of soil testing and the role of nutrient cycling in soil fertility supports the idea that conventional soil testing methods are as useful to organic farming as they are to conventional agriculture. ***Solutions to fertility problems will differ, but conventional soil testing is reasonably accurate for assessing the fertility needs of soils in both conventional and organic systems***.

The goal of analyzing soil samples is to find out whether the soil contains adequate, but not excessive, plant nutrients for optimum growth and crop production. Roots absorb nutrients from soil water, so ***mixing soil with water removes soluble nutrients and analyzing this solution tells you the supply of nutrients immediately available for plant uptake***. This method works well in situations like frequently fertilized greenhouse crops, which are grown in artificial media with low nutrient-holding capacity, but gives only part of the picture for field-grown crops. Simple water extractions don’t provide sufficient information to analyze the nutrient status of field soils, because what you really want to know are the total amounts of nutrients that will be available to a crop throughout the full growing season. In addition to what is immediately available, you need a ***measure of the capacity of the soil to replenish the supply of nutrients in the soil solution*** as roots absorb them (e.g. see “Soil P Transformations”).

The native soil solution is not pure water. It is a chemically reactive solution that solubilizes nutrients and plays an active role in nutrient cycling, so extractants that mimic this activity are the most “natural” and useful. Organic farming depends upon building a biologically active soil as a basis for fertility, which means creating a corresponding soil solution that is chemically and biochemically active. If anything, it is probably even more important in an organic farming system, than a conventional system, to measure the slowly available supply of soil nutrients.

The ideal chemical extractant removes all nutrient forms capable of cycling into the soluble, readily available nutrient pool during the next growing season. No extractant is that complete or selective, but useful chemical procedures remove an ***extractable fraction*** of one or more soil nutrients that is well ***correlated*** with nutrient uptake by plants. The extracted amount is a useable ***index of nutrient availability***. Soils with low soil-test values are very likely to respond to nutrient additions, while high-testing soils are very unlikely to benefit. Specific ***fertilizer recommendations*** are based on ***calibration*** research that determines the amount of fertilizer a crop will respond to at any given soil test level.

Development of chemical extractants specifically designed for organic systems probably could improve their accuracy. For example, conventional soil tests may underestimate P availability in soils with large amounts of organic P, and depending on the method, may be low or high for soils where large applications of rock phosphate have been made. However, more ***correlation and calibration research on organic crops, measuring responses to organically certified nutrient sources***, could be a more productive approach than developing completely different extractants. Results of conventional soil tests are definitely useful to organic agriculture, but there are opportunities to improve the way they are applied.

Plant Analysis

Plant analysis is a nutrient management tool most effectively used in conjunction with a regular soil-testing program. The crop integrates effects of soil fertility and other growth factors, and balanced plant nutrition is the ultimate goal of crop nutrient management, so it makes sense to directly analyze plants. Just as in soil testing, proper sampling is critical. ***Nutrient sufficiency levels are based on analyzing specific plant parts, sampled at a specific growth stage***. Recently matured, fully expanded leaves, or petioles (leaf stalks) from recently matured leaves, are the most frequently used plant tissues.

A shortcoming of plant analysis is that when a nutrient deficiency is diagnosed, it may be too late in the season to correct the problem for the current crop. However, plant analysis is a requirement for sound nutrient management of perennial fruit crops, can be cost effective on a routine basis for high-value vegetables, and is a useful validation tool for the fertility program of all crops. Plant analysis is the only way to confirm a crop nutrient deficiency and is often a better diagnostic tool than a soil test for micronutrients.

Soil tests in conjunction with plant analysis are necessary because: 1) when a nutrient deficiency is diagnosed by plant analysis, there usually are no standardized recommendations for the amount of that nutrient you need to apply to overcome the deficiency, and 2) when a nutrient deficiency is diagnosed, the cause is not necessarily inadequate nutrient supply in the soil.

Several plant tests are specifically designed to refine N management. ***Chlorophyll meters*** are hand-held instruments used in the field to measure the "greenness" or chlorophyll content of plant leaves. They give an indirect measure of leaf N, because most N in leaves is contained in chlorophyll. Another approach, used for intensively grown, drip-irrigated vegetables, is on-farm analysis of sap squeezed from fresh petioles. Both nitrate-N and K can be monitored with ***petiole-sap testing*** and results used to determine ***fertigation*** rates for these nutrients through the irrigation system.

Keeping detailed records of plant analysis, soil tests, lime and fertilizer applications, crop yields and quality, and changes that occur over time are key elements of a nutrient management program. This information permits producers to monitor crop responses on their own farms to different soil test levels and standard fertilizer recommendations. They can use the accumulated results to adjust these "average" recommendations to the unique conditions of their farms and cropping systems.

Summary

Goals of effective nutrient management are to provide adequate plant nutrients for optimum growth and high-quality harvested products, while at the same time restricting nutrient movement out of the plant-root zone and into the off-farm environment. ***Biological processes*** control nutrient cycling and influence many other aspects of soil fertility. Knowledge of these processes helps farmers make informed management decisions about their crop and livestock systems. How these decisions affect soil biology, especially microbial activity, root growth, and organic matter, are key factors in efficient nutrient management. Managing soil organic matter and biological nutrient flows is complex, because crop residues, manures, composts, and other organic nutrient sources are variable in composition, release nutrients in different ways, and their nutrient cycling is strongly affected by environmental conditions.

Chemical and physical processes in soil largely control mineral solubility, cation exchange, solution pH, and binding to soil particle surfaces. Knowledge of soil chemistry makes it possible to formulate fertilizers that supply readily available plant nutrients. Management of inorganic nutrient sources is simpler than organic nutrient sources, because of their known and uniform composition and the predictability of their chemical reactions, but they are also more easily lost from farm fields. Chemical and biological processes and their effects on plant nutrients cannot be clearly separated, because inorganic nutrients are quickly incorporated into biological cycles and biological processes release nutrients from organic matter in plant-available, inorganic forms.

Use chemical fertilizers only after accounting for all organic nutrient sources to avoid overloading the system and losing soluble nutrients. For many farming systems, inorganic fertilizer will still be the largest nutrient input, but even then it is useful to think of chemical fertilizers as supplementary nutrients. When used to supplement biological nutrient sources, inorganic fertilizers can help make more efficient use of other available plant-growth resources, such as water and sunlight, by eliminating nutrient supply as the limiting factor in crop growth and yield. Chemical processes should be managed so they work together with biological processes for a productive agriculture and healthy environment.

"Both chemical and organic systems are essential. Both chemical and organic materials have an important role in nourishing plant life. Neither is capable of doing a sustained job without an ecologically balanced soil system."

Charles Walters

This bulletin was originally published by the Ohio State University Piketon Research & Extension Center (SWR-2, 1999). It has been updated and adapted to fit Minnesota conditions and University of Minnesota recommendations.