Site-Specific Nutrient Management

For Nutrient Management Planning To Improve Crop Production, Environmental Quality, and Economic Return

Overview: Chapter 1 of 10

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Chapter 1:
Overview of Soil Fertility, Plant Nutrition, and Nutrient Management

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Introduction

Understanding the principles of soil fertility is vital to efficient nutrient management, crop production, as well as environmental protection. There are 17 chemical elements known to be essential for plant growth, and 14 of these elements come from the soil (Table 1). Each essential plant nutrient is needed in different amounts by the plant, varies in mobility within the plant, and varies in concentration in harvested crop components. It is useful to know the relative amount of each nutrient that is needed by a crop and the relationship to amounts removed with crop harvest.

Table 1. Essential plant elements, source, roles, and relative quantities in plant.

Element	Source	Role in Plant	Concentration
Carbon (C)	Air	Constituent of carbohydrates; necessary for photosynthesis	45%
Oxygen (O)	Air/Water	Constituent of carbohydrates; necessary for respiration	45%
Hydrogen (H)	Water	Maintains osmotic balance; important in many biochemical reactions; constituent of carbohydrates	6%
Nitrogen (N)	Air/Soil	Constituent of amino acids, proteins, chlorophyll, and nucleic acids;	1-5%
Potassium (K)	Soil	Involved with photosynthesis, carbohydrates translocation, protein synthesis	0.5-1%
Phosphorus (P)	Soil	Constituent of proteins, coenzymes, nucleic acids, and metabolic substrates; important in energy transfer	0.1-0.5%
Calcium (Ca)	Soil	Component of cell walls; plays a role in the structure and permeability of cell membranes	0.1-0.4%

Element	Source	Role in Plant	Concentration
Magnesium (Mg)	Soil	Enzyme activator; component of chlorophyll	0.1-0.4%
Sulfur (S)	Soil	Component of certain amino acids and plant proteins	0.1-0.4%
Chlorine (Cl)	Soil	Involved with oxygen production and photosynthesis	0.01-0.1%
Iron (Fe)	Soil	Involved with chlorophyll synthesis and in enzyme electron transfer	50-250ppm
Manganese (Mn)	Soil	Controls several oxidation-reduction systems and photosynthesis	20-200ppm
Boron (B)	Soil	Important in sugar translocation and carbohydrates metabolism	6-60ppm
Zinc (Zn)	Soil	Involved with enzymes that regulate various metabolic activities	25-150ppm
Copper (Cu)	Soil	Catalyst for respiration; component of various enzymes	5-20ppm
Molybdenum (Mo)	Soil	Involved with nitrogen fixation and transforming nitrate to ammonium	0.05-0.2ppm
Nickel (Ni)	Soil	Necessary for proper functioning of urease and seed germination	0.1-1ppm

To be classified as essential, the element needs to meet the following criteria:

1. The plant cannot complete its life cycle (seed to new seed) without it.
2. The element's function cannot be replaced by another element.
3. The element is directly involved in the plant's growth and reproduction.

Non-mineral nutrients

Three elements, carbon (C), hydrogen (H), and oxygen (O), are non-mineral nutrients because they are derived from air and water, rather than from soil. Although they represent approximately 95% of plant biomass, they are generally given little attention in plant nutrition because they are always in sufficient supply. However, other factors such as soil management and the environment can influence the availability and crop growth response.

Mineral nutrients

The 14 mineral nutrients are classified as either macronutrients or micronutrients based on their plant requirements and relative fertilization need. There are six macronutrients: nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S). The macronutrients, N, P, and K, are often classified as 'primary' macronutrients, because deficiencies of N, P, and K are more common than the 'secondary' macronutrients, Ca, Mg, and S. The micronutrients include boron (B), chlorine (Cl), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), nickel (Ni), and zinc (Zn). Most of the macronutrients represent 0.1 - 5%, or 100-5000 parts per million (ppm), of dry plant tissue, whereas the micronutrients generally comprise less than 0.025%, or 250 ppm, of dry plant tissue (Table 1).

Plant uptake of nutrients

Each nutrient cannot be taken up by plants in its elemental form, but instead is taken up in an 'ionic' or charged form, with the exception of B as boric acid which is uncharged (Table 2). Most fertilizers are made up of combinations of these available nutrient forms, so when the fertilizer dissolves, the nutrients can be immediately available for uptake. Knowing what form of a nutrient the plant absorbs helps us to better focus on what controls the cycling and movement of that nutrient in soil. In addition, understanding nutrient functions and mobility within the plant are useful in diagnosing nutrient deficiencies.

Table 2. Nutrient forms taken up by plants.

Element	Form
Nitrogen (N)	NO_3^- (nitrate), NH_4^+ (ammonium)
Potassium (K)	K^+
Phosphorus (P)	$H_2PO_4^-$, HPO_4^{-2} (phosphate)
Calcium (Ca)	Ca^{+2}
Magnesium (Mg)	Mg^{+2}
Sulfur (S)	SO_4^{-2} (sulfate)
Chlorine (Cl)	Cl^- (chloride)
Iron (Fe)	Fe^{+2} (ferrous), Fe^{+3} (ferric)
Manganese (Mn)	Mn^{+2}
Boron (B)	H_3BO_3 (boric acid), $H_2BO_3^-$ (borate)
Zinc (Zn)	Zn^{+2}
Copper (Cu)	Cu^{+2}
Molybdenum (Mo)	MoO_4^{-2} (molybdate)
Nickel (Ni)	Ni^{+2}

Nutrient uptake by roots is dependent on the activity of the root, ability to absorb nutrients, and the nutrient concentration at the surface of the root. Roots come directly in contact with some nutrients (called ‘root interception’) as they grow; however, this only accounts for a very low percentage of the total amount of nutrients taken up by plants. Therefore, other mechanisms must cause the movement of nutrients to the plant.

Water moves toward and into the root as the plant uses water, or transpires. This process, called ‘mass flow’, accounts for a substantial amount of nutrient movement toward the plant root, especially for the mobile nutrients such as NO_3^-. Specifically, mass flow has been found to account for about 80% of N movement into the root system of a plant, yet only 5% of the more immobile P. It has been found that ‘diffusion’ accounts for the remainder of the nutrient movement.

Diffusion is the process where chemicals move from an area of high concentration to an area of low concentration. By fertilizing near the plant root, the plant is less dependent on exchange processes and diffusion to uptake nutrients, especially P. The nutrients that are most dependent on diffusion to move them toward a plant root are relatively immobile, have relatively low solution concentrations, and yet are needed in large amounts by the plant, such as P and K. The secondary macronutrients (Ca, Mg, S) often do not depend on diffusion because their solution concentrations are fairly high in soil relative to plant requirements.

Nutrient mobility within the plant

All nutrients move relatively easily from the root to the growing portion of the plant. Interestingly, some nutrients can also move from older tissue to newer tissue if there is a deficiency of that nutrient. Knowing which nutrients are ‘mobile’ (i.e., more able to move) is very useful in diagnosing plant nutrient deficiencies because if only the lower leaves are affected, then a mobile nutrient is most likely the cause. Conversely, if only the upper leaves show the deficiency, then the plant is likely deficient in an 'immobile' (i.e., less able to move) nutrient, because that nutrient cannot move from older to newer tissue (leaves). Table 3 lists the six mobile and eight immobile mineral nutrients. Sulfur is one element that lies between mobile and immobile elements depending on the degree of deficiency.

Table 3. Mobile and immobile nutrients in plants.

Mobile nutrients	Immobile nutrients
Nitrogen (N)	Sulfur (S)
Phosphorus (P)	Calcium (Ca)
Potassium (K)	Iron (Fe)

Mobile nutrients	Immobile nutrients
Chloride (Cl)	Zinc (Zn)
Magnesium (Mg)	Manganese (Mn)
Molybdenum (Mo)	Boron (B)
	Copper (Cu)
	Nickel (Ni)

Timing of nutrient uptake

Nutrient uptake does not necessarily match plant growth or the most critical need. For example, when corn growth represents 50% of its total mature biomass, it has accumulated approximately 100% of its mature K, 60% of its N, and 55% of its P (Figure 1). Phosphorus, for example, is critical for early cell division and multiplication when the amount absorbed is very small. Therefore, supplying sufficient K early in a crop's growing season is likely more important than during the middle of the growing season. However, late in the growing season, nutrients accumulate in the grain rather than in the leaves or stalk. Therefore, mid-season nutrient application may increase both quality and grain yield if other plant requirements are met, such as water. For example, N topdressed at tillering has been found to increase both yield and protein of winter wheat, especially at low soil N levels. Therefore, it is important to understand nutrient needs and timing of nutrient uptake for each crop that you're working with.

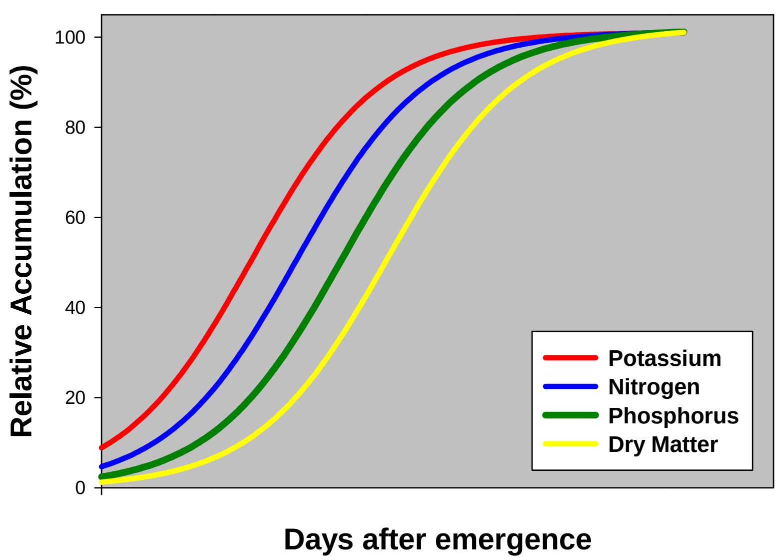

Figure 1. Schematic accumulation patterns of K, N, P, and dry mater in corn.

Nutrient response function

In Figure 2, yield is severely affected when a plant nutrient is deficient, and when the nutrient deficiency is corrected, yield increases rapidly (Zone A) until the critical range of plant nutrient concentration is reached and yield is maximized. Nutrient sufficiency occurs over a wide concentration range, where yield is unaffected (Zone C). Increases in nutrient concentrations (by fertilizer application) above the critical range indicate that the plant is absorbing nutrients above that needed for maximum yield, commonly called *luxury consumption*. Elements absorbed in excessive quantities can reduce plant yield directly through toxicity or indirectly by reducing concentrations of other nutrients below their critical ranges (Zone D). The minimum amount of fertilizer required to maximize crop yield is called the *optimum physical rate* or *agronomic optimum rate* (AOR) and it is located within Zone C. Even though the exact relationship between crop yield and nutrient rate will vary, the general shape of this relationship is relatively consistent for many crops and nutrients.

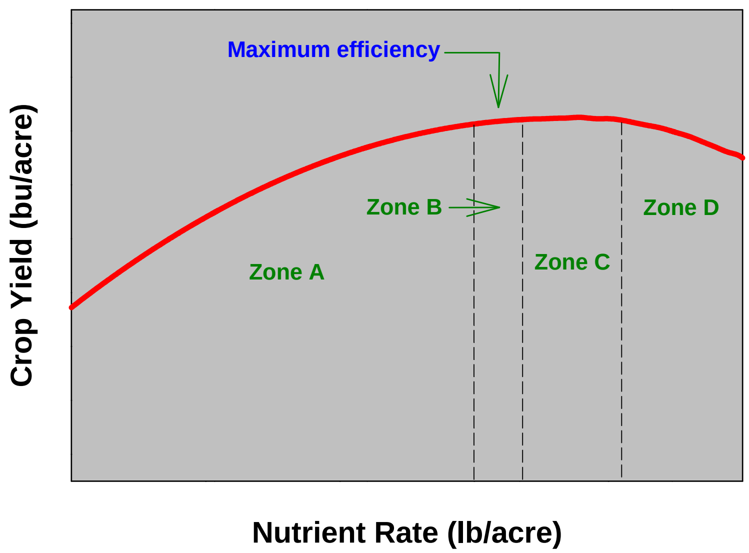

Figure 2. Relationship between crop yield and essential nutrient application rate.

Adequate nutrient supply, from the soil or applied nutrient, is vital to soil fertility and crop production. A limited supply of one of the essential nutrients can limit crop yield, although other factors such as another nutrient, light, heat, or water can also limit yield. The concept that a certain sufficiency level of a nutrient will limit plant growth or yield to a certain level independently of levels of other nutrients or growth factors is known as the 'law of the minimum'. Nitrogen and water are known as closely following this principle. On the other hand, insufficient supply of other nutrients (such as P and K, for example) tend to limit growth or yield to a certain proportion of the potential maximum depending on sufficiency levels of other growth factors. Therefore, how different nutrients behave according to these principles generally influence the degree and type of interactions between nutrients and with other growth factors. Although N is usually the first limiting nutrient for non-legume crops, without adequate supply of other nutrients, N use efficiency (NUE) suffers. For example, increased N uptake and utilization with adequate K means improved NUE and higher yields. Figure 3 shows how corn yield and NUE were increased by fertilizer K application to a deficient soil, resulting in improved economic and environmental benefits.

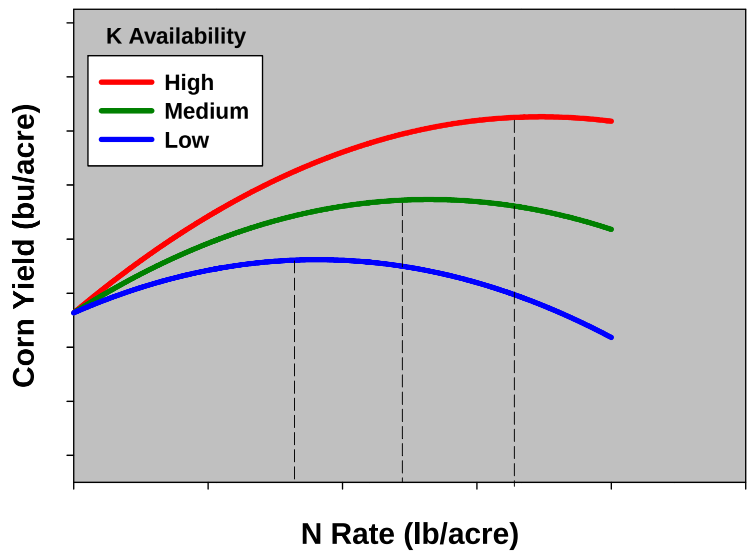

Figure 3. Potassium improves yield response to N fertilizer and N use efficiency.

Nutrient diagnostic methods: correlation, calibration, and interpretation

Nutrient diagnostic methods are tools for determining plant nutrient needs. They can include soil testing, plant analysis, crop sensor readings, etc. The development of a diagnostic method for a given nutrient has historically involved three steps: 1) selecting a soil/plant extractant or methodology to measure any crop characteristic related to plant nutrition, 2) correlation of the value of any of these methods with the amount of nutrient taken up by plants, and 3) calibrating the value in terms of its effect on some desirable crop characteristic, usually yield of marketable product. Fertilizer recommendations are then based on interpretation of calibration data and fertilizer response curve (Figure 2).

No matter how good a chemical method of analysis, a soil/plant test value is meaningless unless it can be related to the nutrient status of the soil and sufficiency for a specific crop in order to apply a corrective soil amendment or fertilizer treatment. A single numerical value reported by a soil test (say 11 ppm for P) has no meaning unless information is gathered to evaluate (1) what tat value means concerning growth and/or yield level in relation to the amount needed to maximize growth or yield, (2) whether crop growth or yield will be greater when the nutrient is added to the soil and how much greater , and (3) the amount of nutrient needed for the crop to attain better growth or yield in different soils and for different crops at different test levels.

A combination of correlation and calibration research is necessary to gather information needed to answer these questions. Correlation is a relationship between the amount of nutrient extracted from soil by a laboratory test and nutrient uptake by plants and/or crop yield in the greenhouse or field. If such a relationship cannot be established, the analytical procedure has little or no usefulness. Sometimes the relationship can be established for only one nutrient and one crop, and on a particular group of soils. This is a limitation that the producer must know and recognize, and the soil test should only be used for those specific conditions. For example, useful correlations have been established between the Bray-1 P test and percent of maximum yield for different crops in many states. These correlations help determine when soil test P is adequate for maximum yields—when no response from additional fertilizer is expected. Different crops such as wheat, corn, and soybean vary in their response to the amount of P in the soil (Figure 4). Yields of both corn and soybean change rapidly with small differences in soil test P. Winter wheat requires higher levels of soil P to attain maximum yields. Because of crop differences, soil test correlation research must be conducted with a large number of crops.

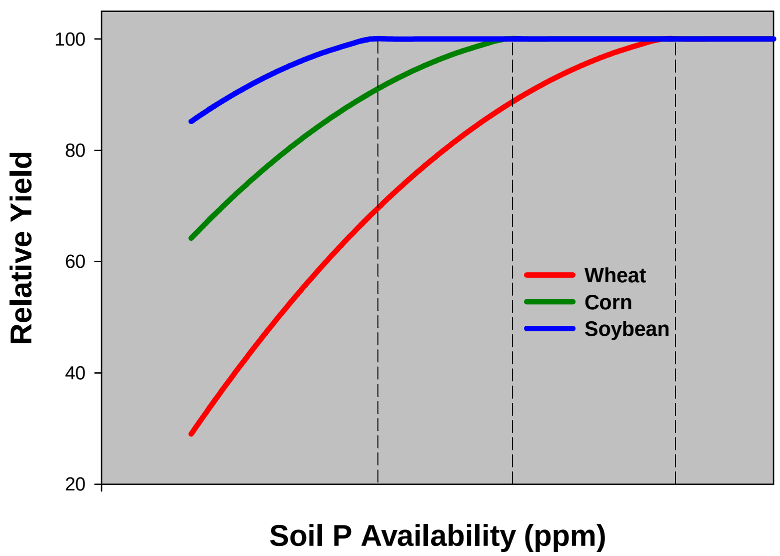

Figure 4. Different crop responses from different soil Bray-1 P levels.

Calibration establishes the relationship between a given soil/plant test value and the yield response from an addition of the fertilizer nutrient to the soil. Figure 5 represents a general example of this relationship. From crop yield responses, one can determine the amount of fertilizer needed over a range of test levels for many soils where a given crop is grown.

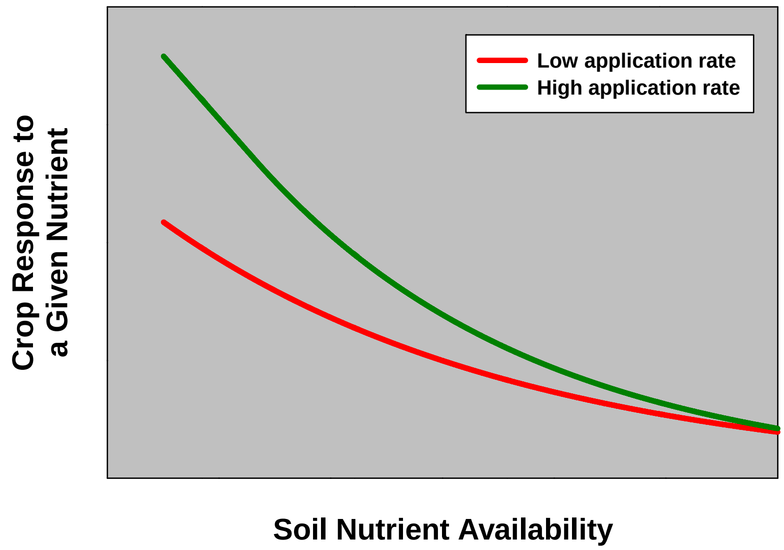

Figure 5. Crop yield response to a low and high rate of a given nutrient as related to the original soil nutrient level.

After field correlation-calibration experiments have been conducted, soil test levels of a given nutrient can be placed into categories related to the magnitude and probability of yield response. These categories give quick insight to fertilizer decisions. Their general meaning is given in Table 4 in terms of the probability of a yield increase due to fertilizer application. This explanation illustrates much of the basic science behind using correlation-calibration to develop fertilizer recommendations, especially for nutrients considered immobile in the soil (such as P and K).

Table 4. Probability of a crop yield increase due to nutrient fertilizer application.

Nutrient Index Level	Meaning of Index Level for Crops
Very low	Applying the nutrient will be beneficial over 80% of the time.
Low	Applying the nutrient will be beneficial 65% of the time.
Optimum	Applying the nutrient has about 5% chance of being beneficial in growth or yield.
High	Applying the nutrient will be beneficial less than <1% of the time.

Nutrient Management

Nutrient management involves managing all crop fertility inputs and other production practices to achieve efficient crop growth and water quality protection. Nutrient management plans for site-specific situations should minimize undesired environmental effects while optimizing whole-farm profits and production. The term "nutrient management" is most often associated with animal manure management, but applies to all crop fertility inputs whether manure, organic by-products, amendments, or commercial fertilizers.

What is Nutrient Management Planning?

Nutrient management planning principles are basic, and like sound fundamentals necessary for any good business management. They involve:

- Knowing what you have
- Knowing what you need
- Managing properly
- Documenting practices and outcomes

Nutrient management plans must be site-specific, tailored to the soils, landscapes, and management objectives of the farm. In effect, nutrient management planning is much like developing a cash-flow analysis, but using nutrients instead of dollars, although dollars and environmental impacts also should be considered.

Steps in Nutrient Management Planning

1. Obtain accurate soil information for each field or management unit. This could be use of existing NRCS soil maps or require a new farm soil map. Soil samples should be obtained and analyzed according to recognized soil fertility sampling and analytical procedures.
2. Estimate crop yield potential based on soil productivity and intended management. It is impossible to foretell growing seasons, but average yields over last four to six years should provide a reasonable estimate. It is important to be realistic.
3. Calculate plant nutrient applications required. Nutrient recommendations and harvest removal information for common crops are available from the NRCS, local Extension offices, and University soil fertility publications and web sites. It is important to distinguish between nutrient recommendations for specific situations, crop uptake or use by the growing crop, and crop removal which is the physical removal of nutrients from the field with harvesting.
4. Determine the plant-available nutrients in any livestock manure or other by-product amendments that are available for application.
5. Estimate any applicable residual nutrient contributions from fertilizer or manures applied in previous seasons.
6. Determine need for purchase of off-farm nutrients, such as fertilizer or manure.
7. If necessary, use an applicable environmental risk assessment tool, for example the Phosphorus Index (PI), to determine the potential for offsite movement of nutrients on a field-by-field basis. The PI, for example, incorporates several site specific soil conditions and conservation practices; soil test phosphorus level, soil permeability, field slope, manure and fertilizer applications, distance to surface water, and other factors are used to determine the probability of phosphorus movement in the landscape.
8. Apply animal manures and commercial fertilizers to supply nutrients when needed using practices that ensure high use efficiency, such as right source, rate, timing, and placement.
9. Keep records of nutrient sources, application dates, rates, and methods.

Nutrient Management Planning Summary

- Know the soils and fields of your farm
- Be realistic about crop production goals
- Determine nutrient levels and application needs
- Determine all farm-level nutrient resources available
- Assess environmental risks from nutrient applications
- Apply nutrients using sound nutrient management and cropping practices
- Keep field records

Summary

Managing crop nutrients goes beyond soil fertility basics and decisions for single nutrients or application needs for single fields. Nutrient management should encompass the entire production enterprise, which can be comprised of crops and livestock, and should include recognition of all nutrient inputs and outputs from the farming enterprise. Flows of nutrients to, within, and from the enterprise should be identified to provide best management in regard to economic and environmental concerns. Such flows can include fertilizer purchases, manure production, manure purchases, crop harvest and sales, and crop harvest and feeding on farm. While nutrient balance is not a necessity, avoiding nutrient deficiency or excesses helps provide greatest economic return. Coupled with soil management practices, enterprise nutrient management also helps provide longevity of soil productivity and environmental stewardship; both of which are important for future generations use of land and water. With the continual changing of production practices and increasing needs from crop production (such as biomass for feed, bedding, and energy), continual monitoring and adaption is needed to maintain nutrient management stewardship.