AGRONOMY HANDBOOK

Midwest Laboratories℠

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SOIL AND PLANT ANALYSIS RESOURCE HANDBOOK

FOREWORD

Agriculture related analyses are indispensable in supplying accurate, current information for making management decisions regarding soil fertility and plant nutrition.

Maximum benefit can be gained if the samples are taken properly, analyzed reliably, and interpreted correctly.

Increasing world demand for food, feed, and fiber is challenging our present agricultural production systems to satisfy an expanding world population. More food production requires increased acreage devoted to agricultural crops and increased yields.

Loss of agricultural land, high costs of energy and other production inputs, decreasing supply of irrigation water, and increasing governmental regulations have all had a negative impact on the food production capacity of this country.

To meet this challenge, our efforts in agriculture must be focused on greater efficiency of production.

This publication is written to give guidelines for the taking of agriculture related samples and the interpretation of the analytical data. It also presents information for diagnosing specific physical and chemical soil problems and determining corrective treatments.

Included are various tables and illustrations which are of interest to agriculturists.

ACKNOWLEDGEMENTS:

Although most of the information contained in the previous editions of "Soil and Plant Analysis" is still current, much new and updated information is now available.

We have tried to include this in the new updated Agronomy Resource Handbook.

The writing and revisions have been a team effort by the agronomy staff.

Appreciation is expressed to each of the agronomists who has contributed to this publication.

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DISCLAIMER

The statements and recommendations made within the Agronomy Handbook are based on published research data and experience.

No guarantee or warranty is made, expressed or implied, concerning crop performance as a result of using the contents of this handbook.

CHAPTER 1

GENERAL PROPERTIES OF SOIL

SOIL FORMATION

Soil can be described as a complex natural material derived from decomposed rocks and organic materials. It serves as a medium for plant growth by providing nutrients, moisture, and anchorage for plants. The principal components of soil are mineral materials, organic matter, soil moisture, and soil atmosphere. These components will be found in varying amounts in different soils and at different moisture levels.

The development of soils from original rock materials is a long-term process involving both physical and chemical weathering, along with biological activity. The widely variable characteristics of soils are due to differential influences of the soil formation factors:

1. **Parent material** - material from which soils are formed.

2. **Climate** - temperature and moisture.

3. **Living organisms** - microscopic and macroscopic plants and animals.

4. **Topography** - shape and position of land surfaces.

5. **Time** - period during which parent materials have been subjected to soil formation.

Soil Profile

A vertical section through a soil typically presents a layered pattern. This section is called a "profile" and the individual layers are referred to as "horizons." A representative soil has three general horizons, which may or may not be clearly discernible.

Soil profiles vary greatly in depth or thickness, from a fraction of an inch to many feet. Normally, however, a soil profile will extend to a depth of about three to six feet. Other soil characteristics, such as color, texture, structure and chemical nature also exhibit wide variations among the many soil types.

The surface soil (A horizon) is the layer which is most subject to climatic and biological influences.

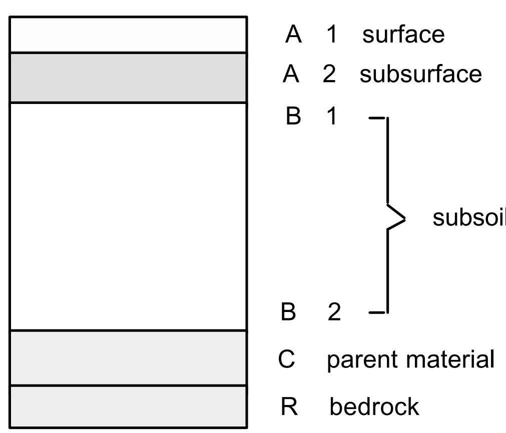


fig. 1. Soil Profile

Most of the organic matter accumulates in this layer, which usually gives it a darker color than the underlying horizons. Commonly, this layer is characterized by a loss of soluble and colloidal materials, which are moved into the lower horizons by infiltrating water, a process called "eluviation."

The subsoil (B horizon) is a layer which commonly accumulates many of the materials leached and transported from the surface soil. This accumulation is called "illuviation." The deposition of such materials as clay particles, iron, aluminum, calcium carbonate, calcium sulfate, and other salts, creates a layer which normally has more compact structure than the surface soil. This often leads to restricted movement of moisture and air within this layer, which produces an important effect upon plant growth.

The parent material (C horizon) is the least affected by physical, chemical, and biological agents. It is very similar in chemical composition to the original material from which the A and B horizons were formed. Parent material which has formed in its original position by weathering of bedrock is termed "sedentary" or "residual," while that which has been moved to a new location by natural forces is called "transported." This latter type is further characterized by the kind of natural forces responsible for its transportation and deposition. When water is the transportation agent, the parent materials are referred to as "alluvial" (stream deposited), "marine" (sea deposited) or "lacustrine" (lake deposited). Wind deposited materials are called "aeolian." Materials transported by glaciers are termed "glacial," and those that are moved by gravity are called "colluvial," a category which is rather unimportant to agricultural soils.

Because of the strong influence of climate on soil profile development, certain general characteristics of soils formed in areas of different climatic patterns can be described. For example, much of the western area has an arid climate, which results in the development of much coarser textured soils (more sand particles) than most of those developed in more humid climates. Also, the soil profiles in many western soils are less developed, since the amount of water percolating through the soils is generally much less than in humid climates. Because of this, many western soils contain more calcium, potash, phosphates, and other nutrient elements than do the more extensively developed eastern soils.

Thus, the soil profile is an important consideration in terms of plant growth. The depth of the soil, its structure, its texture, and its chemical nature determine to a large extent the value of the soil as a medium for plant growth.

SOIL TEXTURE

Soils are composed of particles with an infinite variety of sizes and shapes. On the basis of their size, individual mineral particles are divided into three categories, which are sand, silt, and clay. Such division is very meaningful, not only in terms of a classification system, but also in relation to plant growth.

Many of the important chemical and physical reactions are associated with the surface of the particles. The surface area is enlarged greatly as particle size diminishes, which means that the smallest particles (clay) are the most important with respect to these reactions.

Soil texture is determined by the relative proportions of sand, silt, and clay found in the soil. Twelve basic soil textural classifications are recognized, which are based on the actual percentages of sand, silt, and clay. A textural classification chart for soil material with a diameter of less than 2 mm has been devised by the United States Dept. of Agriculture (fig.) for this purpose.

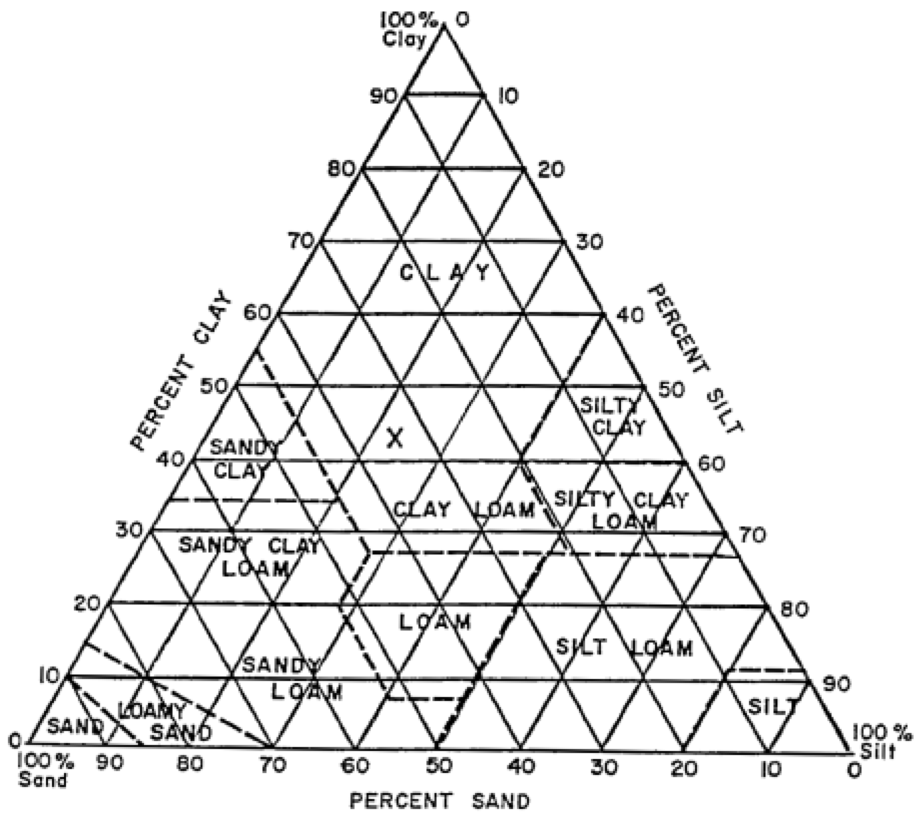


fig. 2. USDA Textural Classification. Triangle for materials less than 2 mm in diameter.

A textural class description of soils can tell a lot about soil-plant interactions, since the physical properties of soils are determined largely by the texture. In mineral soils, the exchange capacity is related closely to the amount and kind of clay in the soil. The water-holding capacity is determined in large measure by the particle size distribution. Fine textured soils (high percentage of silt and clay) hold more water than coarse textured soils (sandy). Finer textured soils often are more compact, have slower movement of water and air, and can be more difficult to manage.

From the standpoint of plant growth, medium textured soils, such as loams, sandy loams, and silt loams, are probably the most ideal. Nevertheless, the relationship between soil textural class and soil productivity cannot be generally applied to all soils, since texture is only one of the many factors that influence crop production.

SOIL STRUCTURE

Except for sand, soil particles normally do not exist singularly in the soil, but rather are arranged into aggregates or groups of particles. The way in which particles are grouped together is termed "soil structure."

There are four primary types of structure, based upon shape and arrangement of the aggregates. Where the particles are arranged around a horizontal plane, the structure is called "plate-like" or "platy." This type of structure can occur in any part of the profile. Puddling or ponding of soils often gives this type of structure on the soil surface.

When particles are arranged around a vertical line, bounded by relatively flat vertical surfaces, the structure is referred to as "prism-like" (prismatic or columnar). Prism-like structure is usually found in subsoils, and is common in arid and semiarid regions. The third type of structure is referred to as "block-like" (angular block or subangular blocky), and is characterized by approximately equal lengths in all three dimensions. This arrangement of aggregates is also most common in subsoils, particularly those in humid regions. The fourth structural arrangement is called "speroidal" (granular or crumb) and includes all rounded aggregates. Granular and crumb structures are characteristic of many surface soils, particularly where the organic matter content is high. Soil management practices can have an important influence on this type of structure.

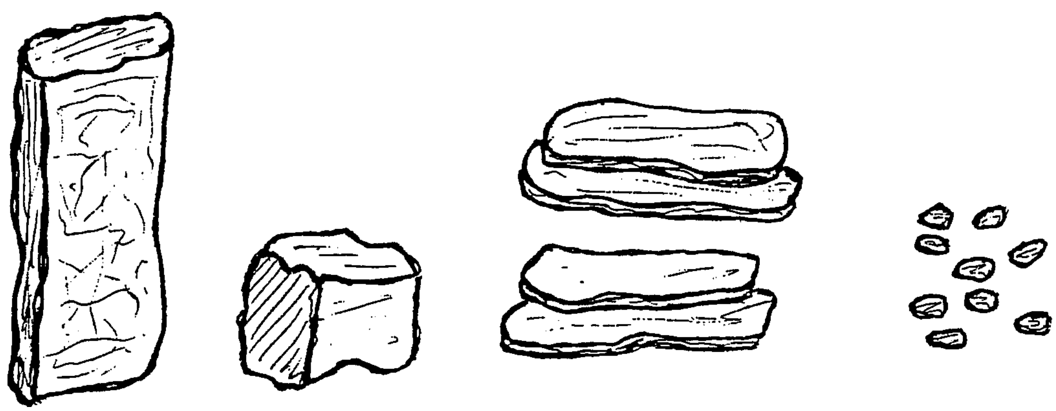


fig. 3. Soil Structure

Soil aggregates are formed by both physical forces and by binding agents--principally products of decomposition of organic matter. The latter types are more stable and resist to a greater degree the destructive forces of water and cultivation. Aggregates formed by physical forces, such as drying, freezing and thawing, and tillage operations, are relatively unstable and subject to quicker decomposition.

Soil structure has an important influence on plant growth, primarily as it affects moisture relationships, aeration, heat transfer and mechanical impedance of root growth.

For example, the importance of good seedbed preparation is related to moisture and heat transfer--both of which are important in seed germination. A fine granular structure is ideal in this respect, as it provides adequate porosity for good infiltration of water and air exchange between the soil and the atmosphere.

This creates an ideal physical medium for plant growth. However, where surface crusting exists, or subsurface claypans or hardpans occur, plant growth is hindered because of restricted porosity, which is the fraction of the bulk volume of the soil not occupied by soil particles. This is the reason that bulk density measurements are important in determining the total porosity of soils.

Bulk density is the mass of soil per unit soil volume, which is usually expressed in grams/cc. Organic matter decreases bulk density due to its low particle density and by causing stable soil aggregates. Compaction and excessive tillage cause high bulk density levels.

Bulk density levels range from 1.0 to 1.3 for clay soils, 1.1 to 1.4 for clay loams and silt loams, and 1.2 to 1.6 for loams, sandy loams, and sands.

SOIL WATER

Not all water in the soil is useful to plants. The total amount of water available to plants depends on the depth of the root system and the water holding capacity throughout that depth.

Soil water can be classified into three kinds:

1. **Hygroscopic Water**

   This part of the water is adsorbed from an atmosphere of water vapor as a result of attractive forces in the surface of the soil particles; it is unavailable to plants.

2. **Capillary Water**

   This water is held in the capillary spaces and as a continuous film around the soil particles. It is the water which forms the soil solution, which contains the soluble products of the soil and is the main nutrient medium for plant roots.

3. **Gravitational Water**

   This water is not held by the soil, but drains under the influence of gravity, and can remove cations and other soluble nutrients that are not adsorbed by the colloidal mass of the soil.

   The maximum water that a soil can hold without losing water due to drainage is called the field capacity level of the soil.

SOIL TEMPERATURE

Soil temperature influences plant growth and microbial activity, and therefore, organic matter decomposition and various nitrogen transformations are dependent on it.

The angle of radiation by the sun on the soil surface affects the intensity of the radiation per unit area.

Soil color, composition and water content, and compaction all have to be taken into consideration with regard to heat absorption.

SOIL MICROORGANISMS

Besides their role in soil-forming processes, soil organisms make an important contribution to plant growth through their effect on the fertility level of the soil. Particularly important in this respect are the microscopic plants (microflora) which function in decomposing organic residues and releasing available nutrients for growing plants.

Some important kinds of microorganisms are bacteria, fungi, actinomycetes and algae. All of these are present in the soil in very large numbers when conditions are favorable. A gram of soil (about one cubic centimeter) may contain as many as 4 billion bacteria, 1 million fungi, 20 million actinomycetes, and 300,000 algae. These microorganisms are important in the decomposition of organic materials, the subsequent release of nutrient elements, and the fixation of nitrogen from the atmosphere.

Soil bacteria are of special interest because of their many varied activities. In addition to the group of bacteria which function in decomposing organic materials (heterotropic bacteria), there is a smaller group (autotropic bacteria), which obtain their energy from the oxidation of mineral materials such as ammonium, sulfur, and iron. This latter group is responsible for the nitrification process (oxidation of ammonium to nitrate nitrogen) in the soil, a process which is vitally important in providing nitrogen for the growth of agricultural crops.

Nitrogen fixing bacteria also play an important role in the growth of higher plants since they are capable of converting atmospheric nitrogen into useful forms in the soil. Nodule bacteria (rhizobia) live in conjunction with roots of leguminous plants, deriving their energy from the carbohydrates of the host plants, and fix nitrogen from the soil atmosphere. Under most conditions free living bacteria (azotobacter and clostridium) also fix atmospheric nitrogen, although to a lesser extent than the rhizobia bacteria.

Because of the important contributions made by the bacteria to the fertility level of the soil, life of higher plants and animals could cease if the functions of the bacteria were to fail.

SOIL MANAGEMENT

The word "manage" is best defined as "to use to the best advantage." When applied to agriculture, it implies using the best available knowledge, techniques, materials, and equipment in crop production.

TILLAGE

Tillage is one of the important management practices used in agriculture. It serves many purposes, including seedbed preparation, weed control, incorporation of crop residues and fertilizer materials, breaking soil crusts and hardpans to improve water penetration and aeration, and shaping the soil for irrigation and erosion control.

Because of the potential damage to soil structure from overworking the soil and for economic and fuel conservation purposes, the modern approach is to use only as much tillage as is required to produce a good crop. The term conservation tillage is applied to this concept.

Conservation tillage is the method of farming which maintains adequate plant cover on the soil surface to conserve soil and water, while reducing energy to till the soil.

The following conservation tillage methods are used:

1. **No-Till**

   Preparation of the seedbed and planting is completed in one operation. Soil disturbance at planting time is limited to the area contacted by the rolling coulter. A minimum of 90% of the previous crop residue is left on the soil surface immediately after planting.

2. **Ridge-Till**

   Preparation of the seedbed and planting is completed in one operation on ridges. Ridges are usually 4-8 inches higher in elevation than the row middles. Ridges are maintained and rebuilt through prior year cultivation. A minimum of 66% of the previous crop residue is left on the soil surface immediately after planting.

3. **Strip-Till (unridged)**

   Preparation of the seedbed and planting are completed in one operation, with tillage limited to a narrow band centered on the growing row. The area between rows, exclusive of tillage bands, is undisturbed. A minimum of 50% of the previous crop residue is left on the soil surface immediately after planting.

4.**Mulch-Till**

Preparation of the seedbed involves loosening and/or mixing the soil and incorporating a portion of the previous crop residue into the soil. Tillage tools include: chisels, wide sweeps, discs, harrow, etc. A minimum of 33% of the previous crop residue is left on the soil surface immediately after planting.

5. **Reduced-Till**

The reduction of conventional tillage trips as a result of vegetative chemical control, combined tillage operations, or multi-function tillage tools. A minimum of 20% of the previous crop residue is left on the soil surface immediately after planting.

This type of tillage is determined by the type of crop, the soil's type, and field conditions. No one set of guiding standards is appropriate for all situations.

SOIL CONSERVATION

Soil conservation is an important management practice, which deserves close attention. It is estimated that annually in the U.S. four billion tons of sediment are lost from the land in runoff waters. That is equivalent to the total loss of topsoil (6-inch depth) from four million acres. Wind erosion is also a problem in certain areas, particularly in arid regions. Management practices such as contouring, reduced tillage, strip planting, cover cropping, terracing, and crop residue management help to eliminate or minimize the loss of soil by water and wind erosion. In addition to these practices, a sound fertilizer program promotes optimal growth of crops, which contributes to soil erosion control by protecting the soil against the impact of falling rain and holding the soil in place with extensive plant root systems.

Proper utilization of crop residues can be a key management practice. Crop residues returned to the soil improve soil productivity through the addition of organic matter and plant nutrients. The organic matter also contributes to an improved physical condition of the soil, which increases water infiltration and storage, and aids aeration. This is vital to crop growth, and it improves tilth. In deciding how to best utilize crop residues, the immediate benefits of burning or removal should be weighed against the longer term benefits of soil improvement brought about by incorporation of residues into the soil.

Special consideration should be given to the environmental aspects of soil management. The environmental implications of erosion are extremely important, since sediment is by far the greatest contributor to water pollution. Management practices which minimize soil erosion losses, therefore, contribute to cleaner water.

The judicious use of fertilizers, which includes using the most suitable analyses and rates of plant nutrients, as well as the proper timing of application and placement in the soil, is also important. Fertilizers are a potential pollution hazard only when improperly used . When used judiciously, they can make a significant contribution to a cleaner, more productive, more enjoyable environment.

ANION ELEMENTS

NITROGEN - PHOSPHORUS - SULFUR

While many forms of nitrogen, phosphorus, and sulfur exist in the soil, it is principally in the form of nitrate, orthophosphate, and sulfate the plants can utilize these negative charged elements. Nitrate nitrogen with one negative charge is readily available for plant feeding, but at the same time, quite subject to leaching. The sulfate form of sulfur with two negative charges is subject to slower leaching. Phosphorus always occurs as, or converts to, phosphate in the soil. The phosphate form of phosphorus, with three negative charges, is relatively resistant to leaching from the soil. Under normal field conditions only small amounts of phosphorus are in the orthophosphate form at any particular time.

It should be pointed out that the processes by which nitrogen, phosphorus, and sulfur are converted into the nitrate, phosphate, and sulfate forms from other chemical forms is accomplished or facilitated by the action of certain types of soil bacteria. For this reason, the amount of organic matter present in a soil to supply food for the bacteria becomes a matter of significant importance.

NITROGEN

Nitrogen is a major constituent of several of the most important substances which occur in plants.

It is of special importance that among the essential elements nitrogen compounds comprise from 40% to 50% of the dry matter of protoplasm, the living substance of plant cells. For this reason nitrogen is required in relatively large amounts in connection with all the growth processes in plants. It follows directly from this, that without an adequate supply of nitrogen appreciable growth cannot take place, and that plants must remain stunted and relatively undeveloped when nitrogen is deficient.

Nitrogen does not exist in the soil in a natural mineral form as do other plant nutrients. It must come from the air, which contains approximately 78% nitrogen. This means, that there are about 35,000 tons of nitrogen over every acre of land. However, in order for crops to utilize this nitrogen, it must be combined with hydrogen or oxygen, which results in the formation of ammonia (NH_3^-) or nitrate (NO_3^-). This process is called nitrogen fixation. Inside the plant these substances are converted into amino acids, which are recombined to form proteins. Any unbalanced condition, either too much or too little, in the supply of nutrients will upset this process.

Many reactions involving nitrogen occur in the soil; most of them are the result of microbial activity.

Two distinct types of bacteria are the symbiotic and the non-symbiotic organisms.

The symbiotic bacteria are those associated with leguminous plants. In return for the supply of food and minerals they get from the plant, these bacteria supply the plant with part of its nitrogen needs, generally not more than 50 to 75% of it.

The non-symbiotic bacteria live independently and without the support of higher plants. There are two different types of non-symbiotic bacteria: the aerobic, which require oxygen, and the anaerobic, which do not need oxygen. These bacteria can supply as much as 50 pounds of nitrogen/acre/year, but generally supply less than 20 pounds.

Nitrogen is also returned to the soil in the form of organic materials, which are derived from former plant and animal life and animal wastes. These materials are largely insoluble in water and are reduced by biological decomposition, oxidation, reduction, and are finally mineralized to nitrate nitrogen for plant use. This recycling of nitrogen from organic matter to soil to growing plants is a part of the nitrogen cycle.

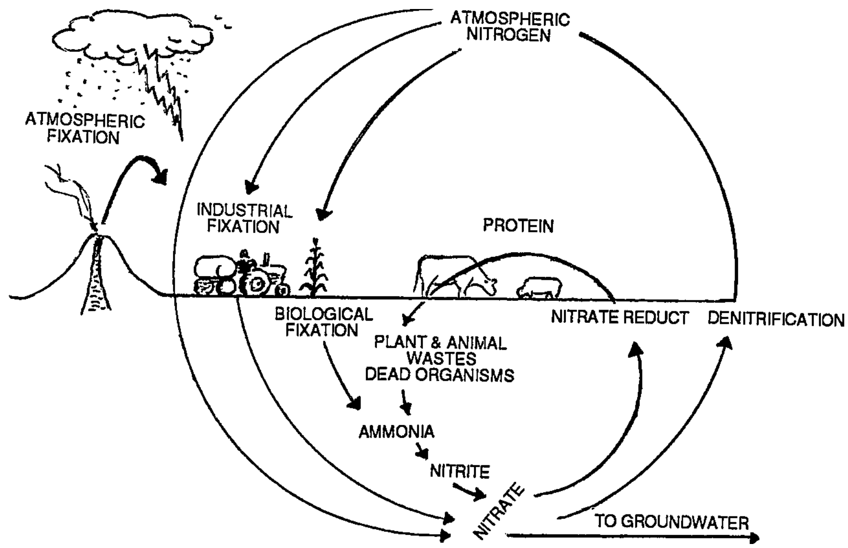


fig. 4. The Nitrogen Cycle

A soil analysis reports organic matter content as a percent of soil weight. Organic matter usually contains about 5 to 6% nitrogen; however, only 2 to 4% of the total nitrogen in this organic fraction in the soil will become available to the plant during the growing season. The actual amount released is very dependent upon climate (temperature and rainfall), soil aeration, pH, type of material undergoing decomposition (different carbon:nitrogen ratio levels), stage of decomposition, and other factors. It is, therefore, quite difficult to calculate the nitrogen release in advance and at best it can be used as an estimated value (ENR). (table 1).

There are considerable advantages in determining available nitrogen (nitrate N and ammoniacal N). If the test is run several times during the life of the crop, it can guide the basic fertilizer application and need for subsequent applications.

Depth of sampling, needed to evaluate the nitrogen availability of a soil, can vary with soil texture, climate, irrigation, and crops to be grown.

In arid regions, when nitrate and ammonia nitrogen of the full soil root profile have been determined by soil tests, this amount should be added to the estimated nitrogen release (ENR) value. This total is then subtracted from the total nitrogen required by the crop for the yield desired, and the difference or net is the approximate amount of nitrogen to be applied. This does not include possible losses due to leaching and/or volatilization. (fig. 5).

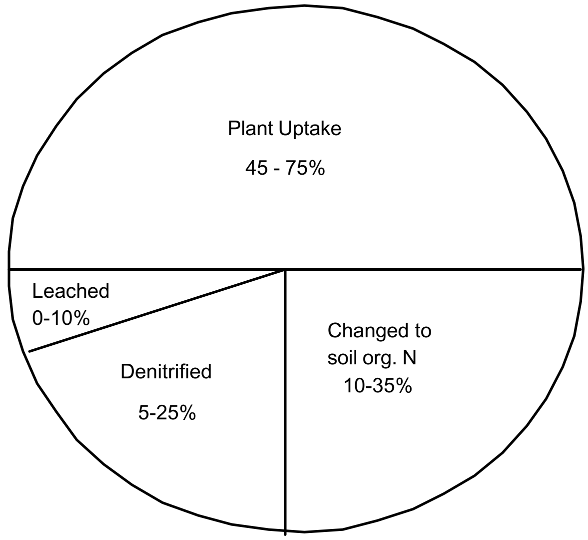


fig. 5. What happens to applied nitrogen?

Factors to be considered when calculating nitrogen needs for a crop should also include the plus or minus effects on the total nitrogen supply of crop residues, manure applications, legumes used as a previous crop, nitrogen sources to be applied, etc.

SAMPLING FOR NITRATE NITROGEN

When soil nitrogen is present in the readily available nitrate form, the amount can be measured and considered in the calculation for total available nitrogen in planning crop fertilization programs.

However, there is no single best approach to obtain and use analysis date of inorganic N for fertilizer recommendations, as the nitrogen availability to crops and its effectiveness in producing yield increases are so closely linked to plant available soil water, precipitation, temperature, soil physical and chemical status, and other environmental conditions.

Depending on the use of the data, it is generally suggested to take one sample from 0-7 inches depth, and another from that depth to 24 inches. If no surface sample is taken, sample depth would be 0-24 inches.

On the average, for each 7 inches of soil depth where nitrate nitrogen is determined, multiply ppm ov available nitrate nitrogen by 2 to obtain pounds per acre (lbs/acre) of available nitrate nitrogen.

table 1.

ORGANIC MATTER PERCENT AND ESTIMATED NITROGEN RELEASE*

Pounds per Acre Nitrogen

% Organic Matter	Clay Loam		Silt Loam		Sandy Loam	
.0 - .3	VL	0 - 30	VL	0 - 45	VL	0 - 55
.4 - .7	VL	31 - 40	VL	46 - 55	L	56 - 65
.8 - 1.2	VL	41 - 50	L	56 - 65	L	66 - 75
1.3 - 1.7	L	51 - 60	L	66 - 75	M	76 - 85
1.8 - 2.2	L	61 - 70	M	76 - 85	M	86 - 95
2.3 - 2.7	M	71 - 80	M	86 - 95	H	96 - 105
2.8 - 3.2	M	81 - 90	M	96 - 105	H	106 - 115
3.3 - 3.7	M	91 - 100	H	106 - 115	VH	116 - 125
3.8 - 4.2	H	101 - 110	H	116 - 125	VH	126 - 135
4.3 - 4.7	H	111 - 120	VH	126 - 135	VH	136 - 145
4.8 - 5.2	H	121 - 130	VH	136 - 145	VH	146 - 155
5.3 - 5.7	VH	131 - 140	VH	146 - 155	VH	156 - 165
5.8 - 6.2	VH	141 - 150	VH	156 - 165	VH	166 - 175
6.3 - 6.7	VH	151 - 160	VH	166 - 175	VH	176 - 185
6.8 - 7.2	VH	161 - 170	VH	176 - 185	VH	186 - 195
7.3 - 7.7	VH	171 - 180	VH	186 - 195	VH	196 - 205
7.8 - 8.2	VH	181 - 190	VH	196 - 205	VH	206 - 215
8.3 - 8.7	VH	191 - 200	VH	206 - 215	VH	216 - 225
8.8 - 9.2	VH	201 - 210	VH	216 - 225	VH	226 - 235
9.3 - 9.8	VH	211 - 220	VH	226 - 235	VH	236 - 245
9.9+	VH	221+		236+		246+

* The estimated lbs/acre of nitrogen released through decomposition or organic matter is dependent upon climatic conditions, soil pH, type of material undergoing decomposition, and other factors. Therefore, the amounts mentioned in this table are strictly estimates.

VL = Very low
L = Low
M = Medium
H = High
VH = Very High

table 2.

ESTIMATED NITROGEN RELEASE BY VARIOUS CROPS AND MANURE (during decomposition)

SOURCE:	CREDIT IN LBS/ACRE*: 1st year	2nd year
Green alfalfa or clover (plowed down)	+ 30 lbs N/Ton	+ 10 lbs N/ton
Mature alfalfa, hay, mulch	+ or - 10 lbs N/Ton	
Grass cover	- 20 lbs N/Ton	
50% Grass, 50% Legume	0 lbs N/Ton	
Corn stover	- 20 lbs N/Ton	
Soybean stubble	+ 1 lb N/bu soybeans harvested	
Straw mulch	- 10 to 20 lbs/N/Ton	
Weeds	-20 lbs N/Ton	
Conservation Tillage		
Where more than 50% crop residue remains on the surface following tillage operation	-30 lbs N/acre for the first two years of conservation tillage	
Manure		
regular	+ 3 to 4 lbs N/Ton	
liquid	+2 to 3 lbs N/Ton	
if manure is analyzed	30 to 40% of total N during the 1st year	

* data are expressed on a dry basis.

Nitrogen release figures mentioned in the above table are averages, as climatic conditions, quality of previous crop, variety grown, and other factors have to be taken into consideration.

During periods of minimum rainfall (no leaching and low crop production), much of the applied nitrogen plus as much as 50% of the amount of nitrogen from normal nitrification may be carried over to the next growing season. However, under conditions of high rainfall and severe leaching, no nitrogen carryover can be expected, and losses of applied nitrogen can occur. Analytical determination of the residual nitrogen is advisable under the above-mentioned conditions.

MANURE AS A NITROGEN SOURCE

Manure is an extremely valuable by-product of all livestock farming systems, and when properly managed, can supply large amounts of readily available essential plant nutrients.

In addition, most solid manures contain a good supply of organic matter and humus. This is of vital importance in the maintenance of a good soil structure. Manure management should include every effort to utilize as much of its value as possible. All manure management systems involve some degree of storage or treatment before land application. During this storage and handling, nitrogen is lost due to volatilization, leaching, and denitrification.

As a general rule, incorporating manure into a cool, moist soil the same day of application provides the highest nitrogen retention rates.

Animal manure actually provides two forms of nitrogen--organically bound nitrogen and inorganic nitrogen. Inorganic nitrogen is the form which is taken by the plant root system and used for growth. The organically bound nitrogen in the soil breaks down over a period of time to form inorganic nitrogen.

The rate of conversion of organic nitrogen to inorganic nitrogen is called the mineralization or decay rate. Therefore, not all of the nitrogen which has been incorporated into the soil can be used by the plants during the first year after manure application. (table 3).

table 3.

MANURE NITROGEN AVAILABILITY FACTORS FOR VARIOUS STORAGE, TREATMENT, APPLICATION, AND INCORPORATION METHODS*

			N Availability Factor **		
Category	**Treatment Method**	**Species**	**1st yr.**	**2nd yr.**	**3rd yr.**
1	Fresh manure; incorporated same day	CATTLE	0.60	0.13	0.08
		POULTRY	0.80	0.06	0.02
		SWINE	0.70	0.10	0.04
2	Fresh manure; incorporated 1-4 days	CATTLE	0.50	0.13	0.08
	Fresh manure; flushed; liquid spread	POULTRY	0.70	0.06	0.02
	Liquid-holding tank; injection	SWINE	0.60	0.10	0.04
3	Fresh manure; incorporated 5 or more days later	CATTLE	0.42	0.13	0.08
		POULTRY	0.60	0.06	0.02
		SWINE	0.50	0.10	0.04
4	Fresh manure; flush; solids separation; liquid spread	CATTLE	0.46	0.10	0.06
	Liquid-holding tank; incorporated 1-4 days	POULTRY	0.63	0.05	0.02
	Solid manure stack; incorporated same day	SWINE	0.55	0.08	0.04
5	Liquid-holding tank; incorporated 5 or more days	CATTLE	0.37	0.10	0.06
	Solid manure stack; incorporated 1-4 days	POULTRY	0.54	0.04	0.01
		SWINE	0.46	0.08	0.03
6	Solid manure stack incorporate 5 or more days	CATTLE	0.27	0.11	0.06
	Earth-holding pond; liquid spread	POULTRY	0.44	0.04	0.01
	Deep litter, poultry	SWINE	0.36	0.08	0.03
7	Open-lot storage solid spread	CATTLE	0.18	0.11	0.06
		POULTRY	0.34	0.04	0.01
		SWINE	0.26	0.08	0.03

* ref. "Using animal manure as fertilizer," Clemson Univ.-Circular 578

** Multiply nitrogen content of manure by N avail. factor to obtain approximate available nitrogen.

The quantity, composition, and value of manure produced, vary according to species, weight, kind and amount of feed, and kind and amount of bedding. About 75% of the nitrogen, 80% of the phosphorus, and 85% of the potassium contained in animal feeds are returned as manure. Manure from well-fed animals is higher in nutrients and worth more than that of poorly fed ones. Also, it is noteworthy that the nutrients in liquid manure are more readily available to plants than the nutrients in the solid excrement.

The following table gives the average composition of manures from various sources.

table 4.

SOURCE	% MOISTURE	NITROGEN			PHOSPHATE			POTASH		
Cattle		%	lb/T	*	%	lb/T	*	%	lb/T	*
Beef/Steer	74	.70	14	63	.55	11	50	.72	14	65
Dairy	79	.56	11	50	.23	5	21	.60	12	54
fresh/bedding	80	.50	10	45	.30	6	27	.55	11	50
liquid	92	.25	5	23	.10	2	9	.24	5	22
Swine										
fresh	75	.50	10	45	.32	6	29	.46	9	41
liquid	97	.09	2	8	.06	1	5	.08	2	7
Horse										
fresh	65	.69	14	62	.24	5	22	.72	14	65
Sheep										
fresh	65	1.40	28	126	.48	10	43	1.20	24	108
Poultry										
fresh	75	1.50	30	135	1.00	20	90	.50	10	45
liquid	98	.50	10	45	.35	7	32	.15	3	14
dry	7	4.50	90	405	3.50	70	315	2.00	40	180

* lbs/1000 gallons. It is assumed that 1 gallon manure weighs 9 lbs.

ref. Mich. State Univ.; Penn. State Univ.; Kansas State Univ.

NITROGEN AND IRRIGATION SYSTEMS

Nitrogen is the plant nutrient most commonly deficient for crop production and the one most often applied through the irrigation system. Nitrogen can be applied in this manner in several forms: ammonium sulfate, ammonium nitrate, calcium nitrate, urea, or a mixture of these compounds. Depending on the source of nitrogen fertilizer, reactions differ with soils and should carefully be considered in selecting the best nitrogen source to apply. The moisture holding capacity and infiltration rate are two important soil properties which should affect the way of application of the irrigation water. The soil should not become saturated, as this could result in nitrogen loss by leaching, denitrification or volatilization.

However, under certain conditions an excess of water is applied to avoid the buildup of salts. Any form of nitrogen applied to soil will eventually become nitrate and will be available for movement with the irrigation water. Once nitrogen fertilizer is in this form of nitrate, it is susceptible to potential losses by leaching or denitrification. The dates and frequency of irrigation are also important factors to consider for the best placement of fertilizer.

Results of good water management together with good nitrogen control can be instrumental in obtaining maximum dollar return.

NITROGEN APPLICATION

The problem of when, how, and what type of nitrogen to apply should also receive attention.

The following considerations have to be kept in mind:

1. Nitrate nitrogen is immediately available to plants and should be used in cases where an immediate source of available nitrogen is needed, especially in low organic matter soils where microbial activity may be limited. Nitrate nitrogen can be very useful for seedings where the soil is subject to low temperatures. However, the nitrate form can leach in low capacity soils and be lost for use by plants.

2. The ammonium form of nitrogen is immobile and will not leach as readily as the nitrate form. A small amount is used by young plants as the ammonium ion, but the majority remains in the soil until it converts into nitrites and on to nitrates which are biological processes.

   Ammonia nitrogen is preferably applied ahead of the growing season.

3. The urea form of nitrogen is readily soluble in water, but in general is not subject to leaching, as it is converted into the ammonium form of nitrogen and as such held in the soil until nitrification takes place.

4. Nitrate nitrogen is not released from the organic matter through mineralization until the soil temperature has reached 50-60°F.

5. Sugar beets, potatoes, and orchard trees need to have adequate nitrogen until the fruits mature.

RECOMMENDATION RATES FOR NITROGEN

Every crop and variety of crop in any area have slightly different nitrogen needs for the most economic response. Every area and each soil type within an area will require different amounts of nitrogen per acre for best response for the same crop. Soil type and management, moisture control, weed control, insect and disease control, plowdown of residues, residual soil fertility, times of application, plus many other factors influence recommendation rates.

As a general guide in determining the total amount of nitrogen required for a given crop, refer to table 21 in the back of the book (page 97).

Rate calculation:

Nitrogen (lb./acre) needed for given crop at a certain yield.
Add 15-30% loss due to leaching.
Add or subtract amounts of N added to or required from the soil by crop residue, manures, etc. (table 2, page 16).
Subtract amount of estimated N release from organic matter, which is given on soil report (or table 1, page 15.)

Nitrogen for Legume Crops

Under conditions of proper balance of soil nutrients, pH, soil structure, soil temperature and moisture control that enhance the proliferation of the desirable azotobacters that can supply up to 70% of the nitrogen required by legumes, applications of additional nitrogen probably are not beneficial. However, under field conditions the above-mentioned conditions are seldom ideal, and therefore, there may be times during the growing period that supplemental nitrogen can be very beneficial. Under improved management, which involves more fully and efficiently integrating of all soil and crop production inputs, such N application should not only be beneficial but also needed to produce high yields.

For example, soybeans planted in cool soils with high or excessive moisture content may benefit from applied nitrate nitrogen during their early growth period. It should be remembered that a yield of 60-bushel soybeans will require 324 pounds N during the growing season. Assuming that good nodulation under good conditions supplies 70% or 227 pounds N of this requirement, an additional 97 pounds N would have to come from the N released by the organic matter or applied sources.

Since most soils of less than 3% organic matter release less than 100 pounds N during the average season, and nodulation in general supplies only 50% of the crops required needs, an additional application of at least 20 pounds N could achieve higher yields.

The same concept should be considered in alfalfa production. Five to six tons of alfalfa per acre require about 250-270 pounds N, which can be achieved during the growing season.

However, ten tons of alfalfa per acre require 500-600 pounds N. Properly inoculated alfalfa fixes large amounts of nitrogen from the atmosphere, but this might might not be enough to sustain today's high yield alfalfa systems.

Therefore, applications of supplemental nitrogen could help young alfalfa seedlings during establishment and before nodule activity occurs. Applying nitrogen to established alfalfa is not generally recommended. Placing N in a band with P and K has often given better results than broadcast applications, especially on coarse-textured soils under irrigated production systems.

When treating pastures and hayland, split applications of nitrogen fertilizer applied to legume/grass mixtures high in legumes will tend to decrease the legume in proportion to the grass more than a single application of nitrogen will, but in nitrogen fertilization it favors grasses at the expense of the legumes. A carefully planned balanced fertilization program with N-P-K as needed, produces the highest yield of forage in terms of quality factors on a per acre basis.

CONCLUSIONS

Of all the plant food nutrients essential to the growth and development of plants, nitrogen plays the supreme role of good and bad. Excess of nitrogen in relation to the balance of other plant food elements can cause many failures such as lodging and low quality grains, forages, fruits, and vegetables, decrease in disease resistance and delays in the maturity of crops.

Deficiency of nitrogen can seriously curtail crop yields, growth, and quality.

The proper level of nitrogen with balanced levels of the other plant food elements, along with good soil conditions, and employment of good management practices, can give excellent results.

PHOSPHORUS

Phosphorus in the soil and determination of its availability to plants is very complex problems. It is hard to predict the effects of phosphorus fertilizers upon crops for all kinds of soils and for different growing seasons. The satisfactory utilization of phosphorus is dependent not only upon phosphate concentration, but upon the concentration of the other plant food elements, as well as soil temperature, moisture, pH, and the soil microorganisms.

All soils have some phosphorus reserves in compounds of different chemical form, such as phosphates of iron, aluminum, calcium, etc.; and though these reserves may be measured in large amounts in the soil, plants may still suffer from phosphorus deficiency. The natural release of phosphorus from these compounds may be severely limited, due to certain physiological and biological conditions of the soil resulting in the continuation of insoluble and unavailable forms of phosphorus. (fig. 6).

Plants adsorb phosphorus primarily in the form of ions of ortho or dihydrogen phosphate (H_2P0_4). The difficulty in supplying enough of this available form of phosphorus is, that the reactions of soils tend to make water soluble phosphates into water insoluble phosphates, thus adding to the phosphorus reserves which are not as available to plants. Acid soils containing excess iron and aluminum, and basic soils containing excess calcium, cause a chemical recombination of acidic available forms or water soluble phosphates into forms less soluble (fig. 6 & 7).

Much of the soluble phosphorus is built into bodies of the soil microorganisms and subsequently becomes part of the soil humus. Therefore, the phosphorus needs of plants is partly dependent upon the amount of phosphorus ions released from the phosphorus reserves by the biochemical processes of the soil. To supply enough phosphorus for plant needs, a reserve of phosphorus in excess of soil biological needs must be maintained, as well as proper soil conditions for maximum biological activity.

Phosphorus does not leach easily from the soil, and research studies indicate that only on well fertilized sandy or organic soils low in phosphorus fixation capacity would phosphorus leaching be of possible significance. Most soils have the capacity to adsorb and hold large quantities of applied phosphate, and therefore, the greatest loss of fertilizer phosphate from the soil would be by erosion of soil particles rather than by leaching of soluble phosphorus.

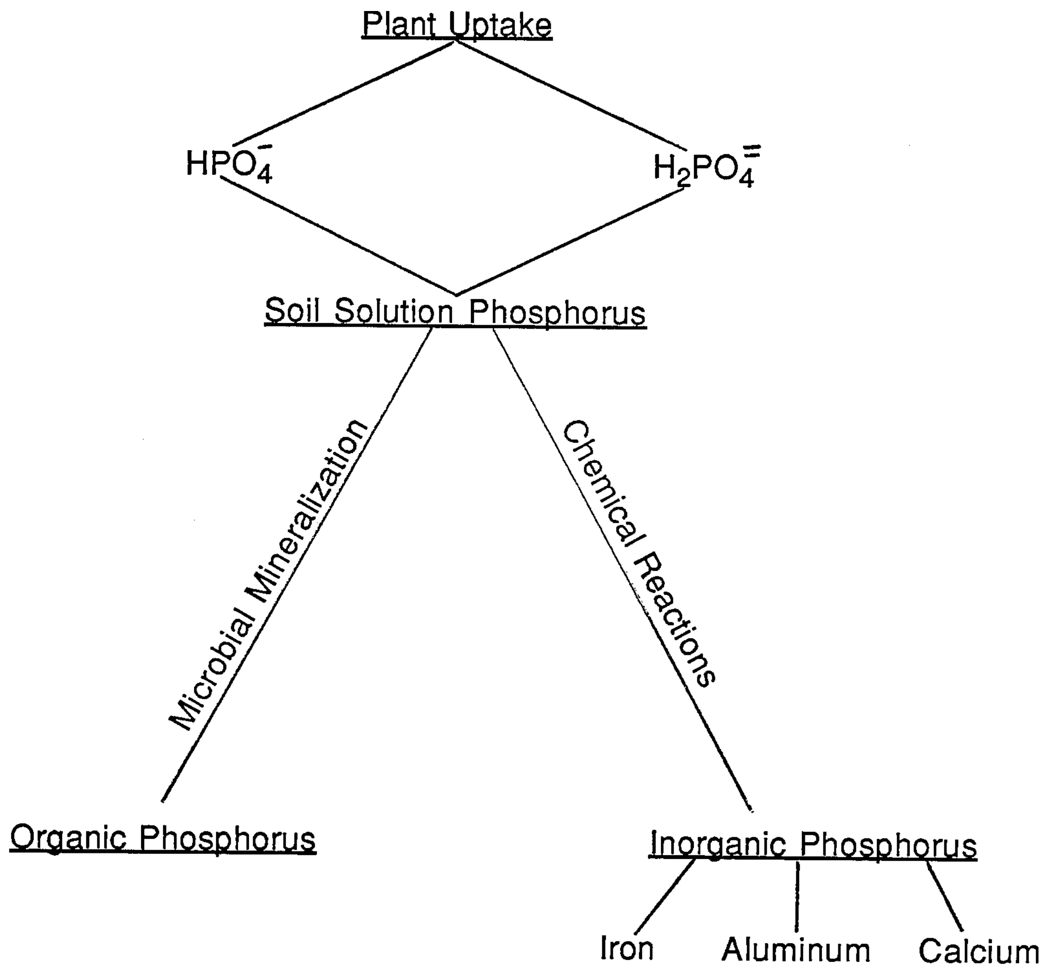


fig. 6. Soil Phosphorus Forms and Plant Uptake

THE HILLS AND VALLEYS OF PHOSPHORUS FIXATION

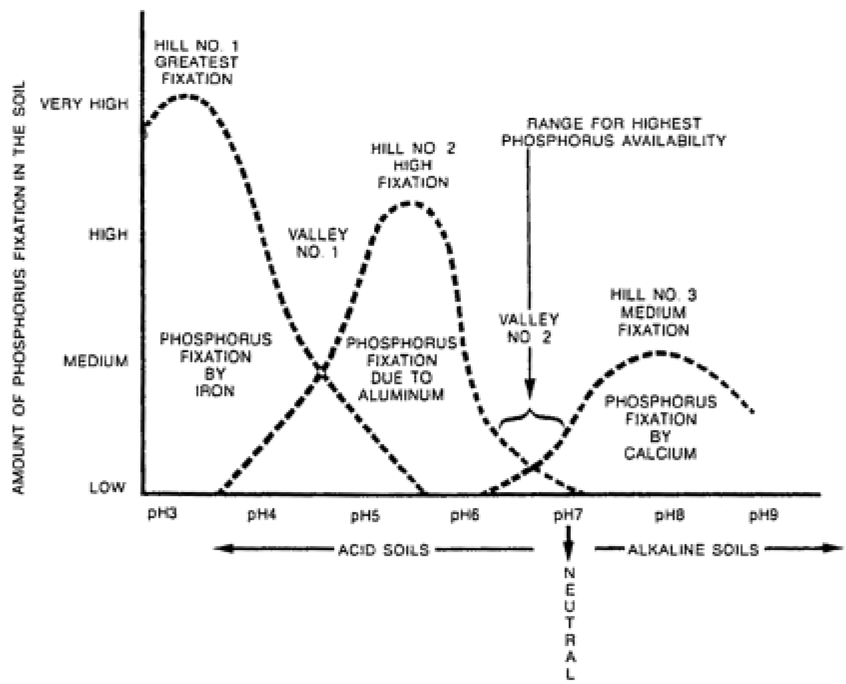


fig. 7. Phosphorus Availability in Relation to pH

SUPPLYING PHOSPHORUS

The addition of phosphorus to the soil may have a three-fold purpose:

1. To furnish an active form of phosphorus, as a starter fertilizer, for immediate stimulation of the seedling plant.

2. To provide a continuing supply of available phosphorus for the crop during the entire growing season.

3. To ensure a good reserve supply of phosphorus in the inorganic or mineral, the organic, and the adsorbed forms.

It is a well-known fact that most crops get only 10% to 30% of their phosphorus requirements from the current year's fertilizer application. The rest comes from the soil. The other part of the phosphorus application becomes part of the soil's reserves for feeding of subsequent crops. It performs the very necessary and desirable function of building up the phosphorus fertility of soils so that phosphorus will be available in later years. It has been found that phosphorus fixed by the soil from fertilizer is not as tightly held as "native" phosphorus and becomes available to plants over a period of time.

Soil fertility levels, pH, soil condition, crop(s) to be grown, and management practices have to be considered when deciding which application method is most appropriate.

1. **Broadcast**

Phosphorus fixation possibility due to much fertilizer/soil contact will especially occur in soils with high pH where calcium phosphate is formed, or under acid conditions which could result in the formation of iron and aluminum phosphates. Although these compounds raise the level of soil fertility and are slowly available to successive crops, the immediate result is a decline in the plant availability of soluble phosphate fertilizers.

2. **Banding**

Banding puts a readily available P source in the root zone. It is superior to broadcasting on cold soils. Banding is also desirable for soils low in available phosphorus due to fertility or fixation.

Soils with high phosphorus test levels require only a maintenance application, which can be made by this method, especially on cold, poorly drained soils, and where short season crops or small grains are to be grown.

Band application can be made at seeding slightly to the side and below the seed, with tillage equipment such as a field cultivator, or surface band application (so-called "strip treatment") before plowing. The last method has given promising results for corn at Purdue University, where this method was developed.

When applied with nitrogen, phosphorus is more readily available to plants than when applied without nitrogen; zinc fertilization can tend to reduce phosphorus availability.

DETERMINING PHOSPHORUS LEVELS IN SOIL

There are several laboratory methodologies by which to determine the availability of phosphorus in soils.

The majority of soils are tested by the Bray P_1 and Bray P_2 methods, the Olsen sodium bicarbonate extraction method, and the Mehlich No. 1 test. Recently Colorado State University developed a soil extract solution (AB-DTPA), which can be used to determine phosphorus and many other elements, which are important for plant growth. New methodologies are continuously developed.

1. **Bray P_1**

This method determines the amount of readily available phosphorus. It is especially applicable in areas where insoluble phosphates may be found.

A level of 20-39 ppm P (124-180 pounds P_2O_5/acre) or more is adequate for most crops, although higher amounts might be needed for certain vegetable crops or high yield goals.

Bray P_1 levels may be categorized as follows:

Rating		Extractable Phosphorus			
		ppm P	lbs/A P_2O_5	Kg/Ha P	Kg/Ha P_2O_5
Very Low	(VL)	0 - 8	0 - 40	0 - 19	0 - 45
Low	(L)	9 - 17	41 - 80	20 - 39	46 - 91
Medium	(M)	18 - 26	81 - 120	40 - 59	92 - 137
High	(H)	27 - 39	121 - 180	60 - 89	138 - 206
Very High	(VH)	40+	181+	90+	207+

2. **Bray P_2**

The Bray P_2, or strong Bray phosphorus test, extracts the water soluble phosphates (ammonium- and mono-calcium phosphates), weak acid soluble phosphates (di-calcium phosphate), and a small amount of the active reserve phosphates (i.e., tri-calcium phosphate). In general, if the phosphorus is determined by this method in an acid soil, 40-60 ppm P (185-275 lbs. P_2O_5/acre) is desired for good crop production.

A level of at least 60 ppm P (275 lbs. P_2O_5/acre) is desired for high yields or high requirement leaf or vegetable crops. The relationship between P_1 and P_2 can help evaluate the phosphorus fixing ability of a soil. A wide ratio (greater than 1:3) may be the result of high pH, free calcium, high clay content, or use of highly insoluble phosphate fertilizer.

Bray P_2 levels can be rated as follows:

Rating		Extractable Phosphorus			
		ppm P	lbs/A P_2O_5	Kg/Ha P	Kg/Ha P_2O_5
Very Low	(VL)	0 - 11	0 - 52	0 - 25	0 - 59
Low	(L)	12 - 25	53 - 119	26 - 57	60 - 132
Medium	(M)	26 - 42	120 - 196	58 - 95	133 - 219
High	(H)	43 - 59	197 - 274	96 - 133	220 - 307
Very High	(VH)	60+	275+	134+	308+

3. **OLSEN SODIUM BICARBONATE EXTRACTION**

This methodology was initially proposed for calcareous soils, particularly those containing more than 2% calcium carbonate; however, it also proves to be valid for neutral to slightly acid soils with an organic matter level of less than three percent.

It is not a reliable index of phosphate availability in strongly acid or high organic matter soils.

At a soil pH of approximately 6.2 or less a bicarbonate reading of 55-65 ppm can be considered adequate for most crops and usually no further crop response can be detected from added phosphorus. As the soil pH increases, the critical value of the extractable phosphorus level will decrease. At the neutral point a phosphorus test reading of 12-15 ppm may be considered as adequate for most field crops with high yield goals. As a result of this change in critical values, the bicarbonate test is difficult to interpret on acid soils, and under these conditions the Bray P_1 (and Bray P_2) tests are advisable in determining the P level in the soil.

The table below gives relative availability ranges and their ratings.

Rating		Extractable Phosphorus			
		ppm P	lbs/A P_2O_5	Kg/Ha P	Kg/Ha P_2O_5
Very Low	(VL)	0 - 3	0 - 14	0 - 7	0 - 16
Low	(L)	4 - 7	15 - 32	8 - 16	17 - 37
Medium	(M)	8 - 13	33 - 60	17 - 29	38 - 66
High	(H)	14 - 22	61 - 101	30 - 49	67 - 112
Very High	(VH)	22+	101+	49+	113+

4. **MEHLICH NO. 1 OR DOUBLE ACID EXTRACTION**

This methodology and the so-called Morgan extraction method are primarily developed for determining phosphorus in low capacity (sandy) soils, which are relatively low in organic matter content and have a pH level of 6.5 or less. These tests are adaptable to Coastal Plain soils of the eastern United States, but are not suitable for alkaline soils.

A general interpretation of the Mehlich test is given in the following table.

Rating		Extractable Phosphorus			
		ppm P	lbs/A P_2O_5	Kg/Ha P	Kg/Ha P_2O_5
Very Low	(VL)	0 - 5	0 - 23	0 - 11	0 - 26
Low	(L)	6 - 15	24 - 69	12 - 34	27 - 77
Medium	(M)	16 - 30	70 - 138	35 - 68	78 - 155
High	(H)	31 - 50	139 - 230	69 - 112	156 - 260
Very High	(VH)	51+	231+	113+	261+

The advantage of this extraction methodology is that the same extraction solution can be used for the determination of the cations and zinc.

GENERAL REMARKS ABOUT PHOSPHORUS TESTS

The increasing occurrence of farm soils with pH changes and adjustments caused by addition of amendments and fertilizers poses some unanswered questions about phosphorus testing and which tests are of the greatest value. However, the use of a specific methodology under certain soil conditions will give results, which can be interpreted and used for giving soil fertility recommendations.

Soil types and pH levels are the main factors which determine which methodology should be applicable. In many cases more than one methodology can give tests results which can be rated for probable response to P fertilization.

In all cases, the test result values give only an estimate of available phosphorus. The test extractions are proportional to the available phosphorus and the results should be considered as indicator numbers.

CORRECTION OF PHOSPHORUS DEFICIENCIES

Phosphorus fertilizer applications depend on many factors such as crop to be grown, yield desired, balance of other nutrients, cultural practices, available moisture, and others which influence soil conditions.

It is virtually impossible to list suggested phosphate applications for all crops, under all soil conditions, for all test values found; so we must consider only the general factors that should enter into the decision as to how, when, where, and what to apply.

For most crops and soil conditions, crop response to fertilizer phosphorus will nearly always be observed for soils testing "low," frequently for soils testing "medium," and usually will not be observed when testing "high." Although under cold and wet conditions a starter fertilizer containing P could assist in initiating the growth of a seedling.

A maintenance application is advisable for most soil-crop conditions.

Under calcareous (or alkaline) conditions, to prevent fast tie-up, banding of the fertilizer near the side of and slightly below the seed is advisable. Weak starter solutions are also of value.

Broadcast application, adequately incorporated, of recommended amounts of readily available phosphorus can be used to supply long-term needs of the crop. This gives long-term response, even though the material may be converted to relatively insoluble forms after application.

Different crops have different needs for phosphorus. Some require large amounts, while others require small amounts. Application rates which would be adequate in some instances of limited yields of a crop are totally inadequate when high yields of that crop are the goal.

table 5.

SUGGESTED AVERAGE PHOSPHORUS RECOMMENDATIONS

CROPS	YIELD per acre	RATINGS VL	L	M	H	VH
		RECOMMENDATIONS LBS/ACRE AS P_20_5				
Alfalfa - seeding	6 T	130	100	65	50	30
Alf./Clover - est.	8 T	130	100	65	50	30
Barley	100 bu	110	70	50	35	25
Beans (dry)	30 bu	105	85	65	40	30
Coastal Bermuda	8 T	150	100	70	25	0
Corn	140 bu	140	105	75	45	25
Cotton	3 bales	150	100	65	35	20
Fruit Trees	all	110	90	65	45	30
Grass - seeding	6 T	105	80	50	30	20
Grass - est.	6 T	150	100	70	40	20
Oats	100 bu	80	65	45	30	25
Oats/Alf. - seeding	6 T	105	85	60	40	30
Onion	400 cwt	325	275	200	125	70
Pasture	6 T	150	100	60	30	0
Peanut	50 cwt	150	100	60	30	0
Peas	3 T	170	130	100	65	30
Potato	400 cwt	260	210	150	100	70
Rice	70 cwt	100	75	50	25	0
Rye	60 bu	80	65	50	25	20
Soybeans	50 bu	105	85	60	40	30
Strawberry	all	180	150	100	60	30
Sugarbeet	25 T	200	160	120	80	50
Tobacco	30 cwt	240	160	120	80	50
Tomato	500 cwt	300	230	160	100	70
Wheat	70 bu	150	100	80	50	30

T = Ton = 2000 lbs. bu = bushel cwt = hundredweight = 100 lbs.

Table 5 has been designed to give general guidelines for obtaining crop response to phosphate applications. Soil conditions, management, and other factors have not been taken into consideration.

The use of the table is self-explanatory and gives suggested phosphate applications by taking into consideration desired yield of a crop and the soil test rating.

FACTORS AFFECTING PHOSPHORUS AVAILABILITY

AERATION

Oxygen is necessary for plant growth and nutrient absorption; it is needed for processes that increase the phosphorus supply through the mineralization and breakdown of organic matter.

COMPACTION

Compaction reduces the degree of aeration by decreasing the pore sizes in the root zone of the growth media. This in turn restricts root growth and reduces absorption of phosphorus and other nutrients.

MOISTURE

Increasing moisture in the soil increases the availability of phosphorus to plants and the availability of fertilizer phosphorus. However, excessive moisture reduces aeration, root extension and nutrient absorption.

SOIL PARTICLE SIZE

Small soil particles, such as clay, usually tie up more phosphorus than larger soil particles, such as sand.

TEMPERATURE

Temperature may increase or decrease phosphorus availability. In many soils increasing temperature increases the rate of organic matter decomposition, which releases phosphorus to plants. Temperatures excessive for optimum plant growth interfere with active phosphorus absorption. The utilization of phosphorus within the plant is greatly reduced under low temperatures. Each plant has a threshold temperature value below which phosphorus is not absorbed. The problem may be connected with a vitamin deficiency caused by low temperatures.

SOIL pH

Soil pH regulates the form in which soil phosphorus is found. (fig.). Acid soils may contain a large amount of iron, aluminum, and manganese in solution. Alkaline and calcareous soils contain calcium, magnesium, and in some cases sodium. All of these elements combine with phosphorus to form compounds of varying solubilities and degrees of availability to the plant.

OTHER NUTRIENTS

Other nutrients may stimulate root development, thus increase phosphorus uptake. The ammonium form of nitrogen may stimulate the uptake of phosphorus, possibly because of the resulting acidity, as ammonium-N is nitrified to nitrate-N.

ORGANIC MATTER

The presence of organic matter, and especially the influence of microbial activity, increases the amount and availability of phosphorus from this source of the soil.

MICRONUTRIENT DEFICIENCIES

Deficiencies of the micronutrients may prevent crop response to applied phosphorus fertilizers.

SULFUR

Sulfur is rapidly becoming the fourth major plant food nutrient for crop production. It rivals nitrogen in protein synthesis and phosphorus in uptake by crops.

The largest portion of total sulfur in the soil is contained in the soil organic matter (O.M.). Sulfate sulfur becomes available to the plant through bacterial oxidation of organic matter, elemental sulfur, atmospheric sulfur compounds, and other reduced forms of sulfur. (fig.8).

Plants usually absorb sulfur as the sulfate (SO_4^-) ion, which generally is not retained in the soil in any great extent, as the sulfates, being soluble, tend to move with soil water and are readily leached from the soil under conditions of high rainfall or irrigation. This is especially true in low capacity (sandy) soils.

The oxidized forms of sulfur may be reduced under water-logged conditions and enter the atmosphere as H_2S or other sulfur gases.

Immobilization of the SO_4 form occurs as bacteria assimilate nitrogen, sulfur, and other nutrients during the decomposition of animal and crop residues.

Intensification of agriculture, use of improved crop varieties, the use of sulfur-free fertilizers, aerial pollution control, less use of manure, and the introduction of insecticides and fungicides which replace sulfur based dusts, are factors which aggravate the sulfur deficiency problem.

The best method of building sulfur reserves in the soil is by adding available organic materials and maintaining an adequate organic matter content. Where satisfactory organic sulfur reserves cannot be maintained, certain fertilizers or amendments have to be used to supply the crops with their sulfur requirements.

THE SULFUR TEST

Soil tests for sulfur determine the extractable sulfate sulfur. Because of the mobility of sulfate sulfur in the soil, these tests are not as reliable in predicting crop response as phosphorus and potassium tests.

The following soil test levels, expressed as ppm SO_4-S, are given as general guidelines.

Rating		Soil Test Level (SO_4-S ppm)
Very Low	(VL)	0 - 3
Low	(L)	4 - 7
Medium	(M)	8 - 12
High	(H)	13 - 17
Very High	(VH)	18+

Various soil factors, including organic matter level, soil texture, and drainage should be taken into consideration when interpreting sulfur soil test results and predicting crop response.

Under high yield, intensive cropping systems, sulfur requirements are higher. Therefore, soil test values need to be in the high reading range or adequate amounts of sulfur need to be applied to supply crop needs, depending on desired yield goals.

The ratio of nitrogen to sulfur in the plant tissue also is a good reliable indicator of sulfur requirement. Sulfur deficiencies could show up in a build-up of non-protein nitrogen compounds or as nitrates in the plant tissue, as this deficiency reduces the activity of the enzyme nitrate reductase in plants.

On the average grass type crops require a ratio of one part sulfur to every fourteen parts of nitrogen, whereas the legume crops require approximately a ratio of one part of sulfur to every ten parts of nitrogen.

FUNCTIONS OF SULFUR

1. Use as a plant nutrient and to increase efficiency of nitrogen used by plants.
2. To increase protein in grasses and grain.
3. To increase yields.
4. To control nitrate build-up in forage crops.
5. To lower pH of alkaline soils and thus increase the availability of other plant nutrients.
6. To control sodium, calcium, and salt build-up in problem soils.
7. To reclaim alkaline - saline soils.
8. To improve the physical condition of soils.

SULFUR CONTAINING MATERIALS

Several sulfur containing materials can be used to perform the above-mentioned functions.

They are given in the following table 6.

COMPOSITION OF PRINCIPLE SULFUR-CONTAINING MATERIALS

table 6.

MATERIALS	N Nitrogen	P_2O_5 Phosphorus	K_2O Potassium	Mg Magnesium	Ca Calcium	S Sulfur	Fe Iron	Al Aluminum
	PERCENT (%)							
Aluminum Sulfate						14.4		11.4
Amm. Phosphate Sulfate	13 - 16	20 - 39	.2	.1	.3	15.4		
Amm. Polysulfide	20.5					45.0		
Amm. Sulfate	21					23.5		
Amm. Sulfate Nitrate	26					15.1		
Ammoniated Super Phosphate	3 - 6	18 - 20			17.2	12.0		
Amm. Thiosulfate Sol.	12					26.0		
Calcium Polysulfide Sol.					9.0	24.0		
Calcium Sulfate (Gypsum)			.5	.4	22.5	18.6		
Ferric Sulfate						18 - 19	20 - 23	
Ferrous Sufate (Copperas)						11.5	20	
Lime-Sulfur Sol.					6.7	23.8		
Magnesium Sulfate (Epsom Salt)				9.8	2.2	13		
Potassium Magenesium Sulfate			22	11.2		22.7		
Potassium Sulfate			50	1.2	.7	17.6		
Sol. Sulfur (Elemental)						85 - 99		
Sulfuric Acid (100%)						32.7		
Sulfur Dioxide						50		
Superphosphate (normal)		18 - 20	.2	.2	20.4	12 - 14		
Superphosphate (Conc.) - Sulfur		40 - 50	.4	.3	13.6	1.0		

References: The Sulfur Institute
Western Fertilizer Handbook
Fertilizer Technology and Usage

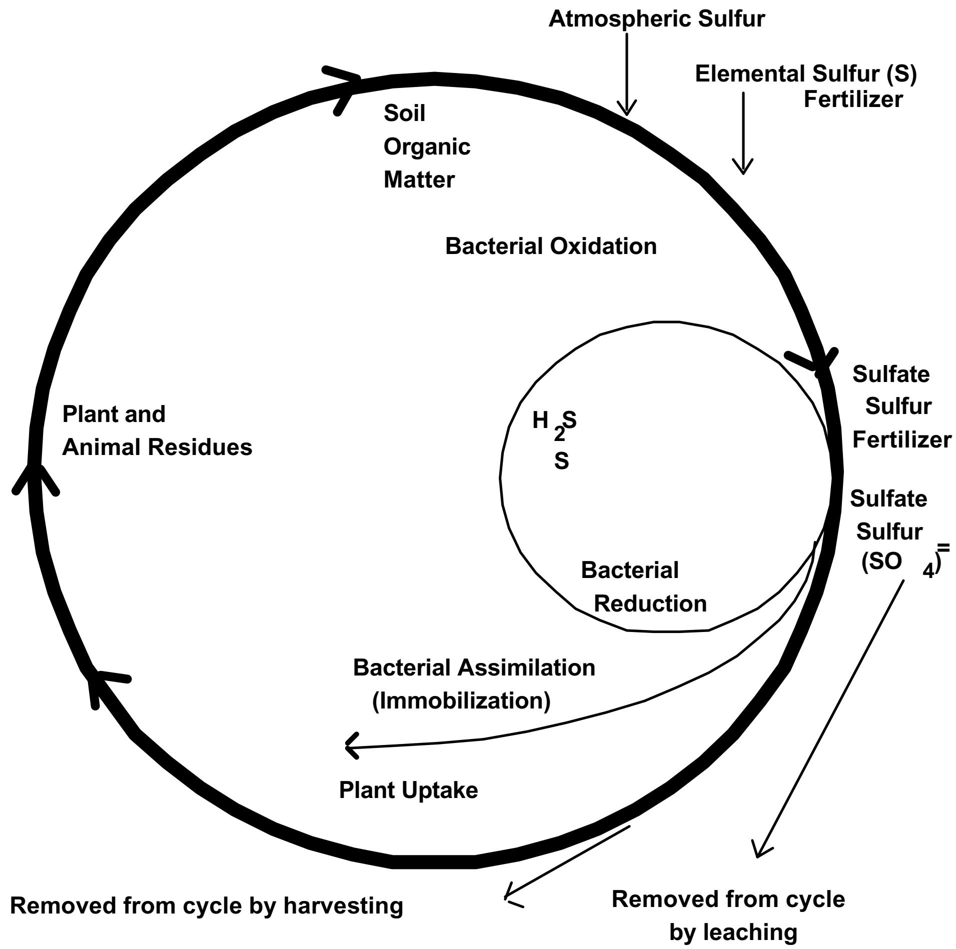


fig. 8. The Sulfur Cycle

ref: The Sulfur Institute

SULFUR RECOMMENDATIONS

Sulfur recommendations which are suggested in the following table are strictly guidelines and should be modified depending on soil conditions and management situations (table 7).

In some soils, the distribution of sulfur in the root profile to a depth of three feet should be considered.

If the soil has relatively high sulfur levels at lower depths , the recommended amounts can be lowered, and only the seedling establishment requirement needs to be considered.

If the available sulfur level at the lower depths is very low, slight increases in the recommended amounts should be made.

table 7.

SULFUR RECOMMENDATIONS
Based on Sulfate Soil Test Ratings

CROPS	YIELD per acre	RATINGS				
		VL	L	M	H	VH
		RECOMMENDATIONS - LBS./ACRE as S*				
Alfalfa - seeding	6 T	30	25	20	10	5
Alf./Clover - est.	8 T	30	25	20	10	5
Barley	100 bu.	20	15	10	5	0
Beans (dry)	30 bu.	20	15	10	5	0
Coastal Bermuda	8 T	30	25	20	10	5
Corn	140 bu.	20	15	10	5	0
Cotton	3 bales	25	20	15	10	5
Fruit Trees	all	15	10	5	0	0
Grass - seeding	6 T	25	20	15	10	5
Grass - est.	6 T	20	15	10	5	0
Oats	100 bu.	20	15	10	5	0
Oats/Alf. - seeding	6 T	30	25	20	10	5
Onion	400 cwt.	25	20	15	10	5
Pasture	6 T	20	15	10	5	0
Peanut	50 cwt.	25	20	15	10	5
Peas	3 T	20	15	10	5	0
Potato	400 cwt.	25	20	15	10	5
Rice	70 cwt.	20	15	10	5	0
Rye	60 bu.	20	15	10	5	0
Soybean	50 bu.	20	15	10	5	0
Strawberry	all	30	25	20	10	5
Sugarbeet	25 T	25	20	15	10	5
Tobacco	30 cwt.	25	20	10	5	0
Tomato	500 cwt.	25	20	10	5	0
Wheat	70 bu.	20	15	10	5	0

T = Ton = 2000 lbs. bu. = bushel cwt. = hundredweight = 100 lbs.

* to convert sulfur (S)/acre recommendation to sulfate (SO_4)/acre a pplication, multiply the sulfur (S) needs by 3.

SULFUR RECOMMENDATIONS

SULFUR USE ON NATURALLY ALKALINE OR OVERLIMED SOILS

Frequently, symptoms of nutrient deficiencies are seen in crops growing on soils which are neutral or alkaline and on soils which have been overlimed excessively. Because of the high pH values, the availability of certain essential nutrients to crops has been reduced considerably.

These nutrient deficiencies may be corrected temporarily by foliar applications, which is a procedure used in general farming practices.

However, in intensive crop production on relatively small acreages, reducing of the soil pH may be more practical and permanent. This is especially true if the pH is not greatly higher than desired.

Any of the acid-forming compounds may be used for this purpose, but the application of elemental sulfur is the practice usually followed to reduce soil pH.

The following chart gives the amount of elemental sulfur needed to reduce the soil pH to about pH 6.5 for a depth of 7 inches.

Soil pH found	Broadcast Application lbs. S/Acre		Band/Furrow Application lbs. S/Acre	
by measurement	Sandy Soils	Clay Soils	Sandy Soils	Clay Soils
7.5	400 - 600	800 - 1000	200 - 250	300 - 500
8.0	1000 - 1500	1500 - 2000	300 - 500	600 - 800
8.5	1500 - 2000	2000 and up	500 - 800	800 and up
9.0	2000 - 3000		800 and up	

ref. Western Fertilized Handbook.

In many calcareous or alkaline soils it is not economically feasible to use the amount of acidifying material required on a broadcast basis to neutralize the total alkalinity of the soil mass. Soil zones favorable for root growth and nutrient uptake can be created by applying acidifying sources of sulfur in bands or furrows (see chart).

The observed benefits of banding such materials have been noted on various crops throughout the areas having such soils.

SULFUR USE FOR RECLAMATION OF ALKALI AND SALINE-ALKALI SOILS

Alkali or sodic soils, including saline-alkali soils, are sodium-saturated in a dispersed or deflocculated condition. In this condition the water cannot or is impaired from entering the soil. In contrast, the calcium-saturated soil is flocculated, which permits good water penetration and movement.

Therefore, to bring about the reclamation of alkali or sodic soils, the excess sodium on the cation exchange complex must be replaced by calcium, which may be supplied by applying gypsum or some other soluble calcium salt directly to the soil. For reclamation of soils to be successful, the displaced sodium must be removed from the root zone by leaching with water of suitable quality, which can be determined by analysis.

Calcium containing amendments react in the soils as follows:

gypsum + sodic soil ------------------------ calcium soil + sodium sulfate

The acid containing materials go through three steps:

sulfur + oxygen + water ---------------------- sulfuric acid
sulfuric acid + lime ---------------------------- gypsum + carbon dioxide + water
gypsum + sodic soil --------------------------- calcium soil + sodium sulfate

The type of material to use will depend on whether or not the soil contains free calcium carbonate. As a general rule, the sulfuric acid is the most rapidly acting material of the ones listed as follows.

Amendment	Tons equal to 1 Ton Sulfur	Amendment	Tons equal to 1 Ton Sulfur
Sulfur	1.00	Iron Sulfate (copperas)	8.69
Lime-Sulfur (24%)	4.17	Aluminum Sulfate	6.94
Sulfuric Acid	3.06	Limestone ($CaCO_3$)	3.13
Gypsum ($CaSO_4.2H_2O$)	5.38	Amm. Thiosulfate	3.85

CATION EXCHANGE CAPACITY

Cation exchange capacity (CEC) is a measure of the capacity of a soil or soil material to hold exchangeable cations.

It can be defined as the amount of negative charges per unit quantity of soil that is neutralized by exchangeable cations.

A cation is an ion carrying a positive charge of electricity, while the soil colloid has a negative charge.

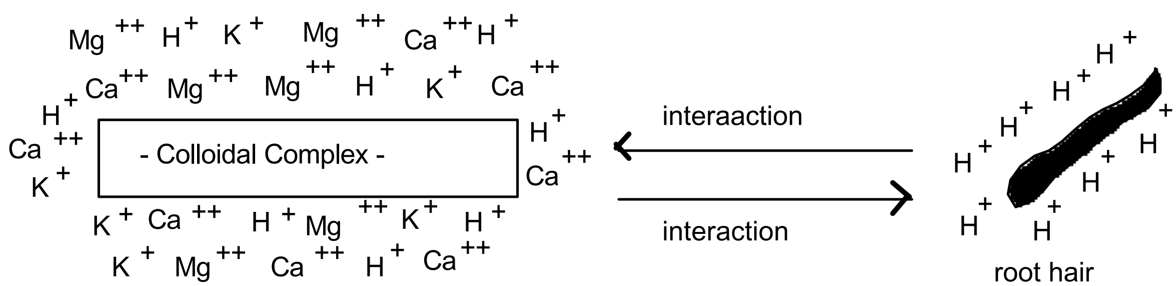


fig. 9 Interactions between soil colloid and plant root hair

The cations of greatest significance with respect to plant growth are calcium (Ca^{++}), magnesium (Mg^{++}), potassium (K^{+}), sodium (Na^{+}), hydrogen (H^{+}), as well as ammonium (NH_4^{+}). The first four are plant nutrients and are involved directly with plant growth. Sodium and ammonium have a pronounced effect upon nutrient and moisture availability. In very acid soils, a large part of the cations are hydrogen and aluminum in various forms.

The kinds, amounts, and combinations of clay minerals and amounts of organic matter and its state of decomposition also contribute to CEC. The cations are not held with equal bonding energies. Organic matter exchange sites only weakly bond cations. Higher exchange capacity clays tend to bond the divalent cations such as Ca^{++} and Mg^{++} with higher energy than K^{+}. These characteristics can affect nutrient availability. Soils with kaolinitic clays have a lower bonding energy and, therefore, for a given soil test level or percent saturation of an element would show relatively greater availability.

If the cation exchange capacity is largely neutralized by calcium, magnesium, potassium, and sodium, it is said to be base saturated. However, if cropping and/or leaching have removed most of the basic cations, the soil is low in base saturation or high in acid saturation. The total amounts of acidic cations relative to the cation exchange capacity is a measure of acid saturation. This is also a measure of lime requirement of a soil.

The exchange capacity generally is expressed in terms of equivalent milligrams of hydrogen per 100 grams of soil, which term is abbreviated to milliequivalents per 100 grams or meq/100 g. By definition it becomes the weight of an element displacing one atomic weight of hydrogen.

An equivalent weight is equal to the atomic weight divided by the valence (number of chemical bonds).

Element	Atomic Weight	Valence	Equivalent Weight
Ca	40.08	2	20.04
Mg	24.31	2	12.16
K	39.10	1	39.10
Na	22.9	1	22.99

In the laboratory the cation exchange capacity is measured in terms of the sum of the concentrations in parts per million (ppm) of the displaced cations, and these values are calculated to meq/100 g in the following manner:

$$\text{meq/100 g} = \frac{\text{ppm of cation}}{\text{equiv. wt. X 10}}$$

Following are the weight figures used for the conversion of cations to milliequivalent values.

200 ppm or 400 lbs. Ca/Acre	=	1 meq Ca/100 grams of soil
120 ppm or 240 lbs. Mg/Acre	=	1 meq Mg/100 grams of soil
390 ppm or 780 lbs. K/Acre	=	1 meq K/100 grams of soil
230 ppm or 460 lbs. Na/acre	=	1 meq Na/100 grams of soil
10 ppm or 20 lbs. H/acre	=	1 meq H/100 grams of soil

Excess salts, free salts, or alkaline compounds not part of the exchange capacity complex, but which appear in the test results, will bias exchange capacity calculations.

DETERMINING THE SOIL NEED FOR CATIONS

Three considerations are involved in determining soil needs for the three major cations.

1. **Cation Exchange Capacity**

Different soils hold by adsorption different total amounts of calcium, magnesium, potassium, sodium, hydrogen, and other cations. This total adsorbed amount, called cation exchange capacity, depends on the kinds and amounts of clay, silt, sand, and organic matter.

2. **Ratio of these Elements**

The cation exchange capacity is for practical purposes a fixed amount in a given soil. However, we can change the ratios among the elements within this total to achieve an adequate "blend" of the important cations for plant growth.

3. **Desired Degree of Saturation**

In most instances it is not necessary nor economically desirable to completely saturate the exchange complex with the exchangeable base elements. An 80-90% saturation of the exchange capacity with a balanced ratio of exchangeable bases will usually be completely adequate for most crops.

RECOMMENDING APPLICATIONS OF CATIONS

POTASSIUM

Soil potassium (K) can be classified into three categories:

1. **Relatively Unavailable Potassium**

This form is locked in insoluble primary minerals that release far too little to help growing crops. It constitutes approximately 90-98% of the total K in soil.

2. **Slowly Available Potassium**

This form is dissolved from primary minerals or potassium fertilizer and attached to the surface of organic matter and clay minerals and between layers of clay minerals where it is only released by weathering. It constitutes 1-10% of the total K in soil.

3. **Readily Available Potassium**

This form is held by organic matter and on the edges of the clay mineral layers. It is also present already dissolved in the soil solution from where it may be taken up by plant roots. It constitutes 0.1-2% of the total K in soil.

Potassium does not leach readily in medium and fine textured soils; however, on sands and organic soils leaching losses can be serious.

Losses of K occur usually through crop removal, leaching, or soil erosion.

To keep adequate amounts of potassium in the soil so the plants can take it up when they need it, one can use various manners of application.

Three factors influence the decision in which manner to apply potassium:

1. The soil's fertility level.

2. Crop to be grown.

3. Tillage system.

Broadcasting is the best way to get on larger amounts while band application at planting is important with lower application rates or cool, wet conditions. Annual maintenance applications--to replace yearly losses from crop removal, fixation, and soil-water movement--can be broadcast and incorporated or placed in bands at planting or both.

With no-till and plenty of crop residues, potassium broadcast on the surface is advisable in humid regions. Plant roots are dense enough near the surface because of the moist condition under the crop residues. Some growers broadcast and chisel in the potassium. Before starting these practices, two things should be done:

1. Build up the K fertility level.

2. Plow every two to three years to prevent potassium accumulation in the soil surface.

The following are some of the principle potassium containing materials which can be used in a fertility program:

MATERIAL	POTASH (% K_20)
Manure (dried, cattle, variable)	1 - 3
Nitrate of Soda-Potash	14
Potassium Chloride (muriate)	60 - 62
Potassium Magnesium Sulfate	22
Potassium Nitrate	44
Potassium Sulfate	50

Recommendations for fertilizer potash are based on crop to be grown, yield goal, geographical location, and soil type.

At very high soil K levels fertilization with a K containing fertilizer might not be recommended; however, many growers prefer to replace the amount of potash removed by the previous crop. The amount of potash recommended on soils with low or very low test levels could be in excess of the amount that will be taken up by the crop. This excess will remain to build up the K level in the soil.

Potash Recommendation - Example

Soil CEC	20 meq/100 g
Soil K level (ppm)	145 ppm (290 lbs./acre)
Crop	Corn
Yield Goal	150 bu./acre

Calculation:

Desired K level for 20 meq soil (see table 8)	195 ppm
Value found (see soil analysis report)	145 ppm
To be applied	50 ppm
Conversion ppm K to lbs./acre K_20 (X 2.4)	120 # K_20
Potash removed by 200 bu. corn (grain)	57 # K_20
Amount of potash to be applied	177 # K_20

If this crop is to be used for silage, an additional 210 # K_20 could be applied to compensate for K_20 removal by the forage part (table 21).

table 8.

BALANCED SATURATION OF POTASSIUM, MAGNESIUM, AND CALCIUM*

The values indicate the desired parts per million (ppm) of the various cations in a a balanced exchange complex of the soil. To convert ppm to lbs./acre, multiply by two.

	POTASSIUM		MAGNESIUM	CALCIUM
C.E.C. meq/100 gram	High 2.5 - 7% base sat.	Normal 2 - 5% base sat.	10 - 15% base sat.	65 - 75% base sat.
50	488	390	600	6500
49	478	382	588	6370
48	468	375	576	6240
47	458	367	564	6110
46	449	359	552	5980
45	439	351	540	5850
44	433	349	528	5720
43	426	347	516	5590
42	419	344	504	5460
41	413	341	492	5330
40	406	338	480	5200
39	401	335	468	5070
38	397	331	456	4940
37	393	327	444	4810
36	388	323	432	4680
35	382	319	420	4550
34	377	314	408	4420
33	371	309	396	4290
32	364	304	384	4160
31	358	298	372	4030
30	351	292	360	3900
29	345	284	348	3770
28	339	274	336	3640
27	332	264	324	3510
26	325	254	312	3380
25	317	244	300	3250
24	309	234	288	3120
23	300	224	275	2990
22	292	215	263	2860
21	282	205	252	2730
20	275	195	240	2600
19	270	192	236	2470
18	267	187	230	2340
17	262	182	225	2210
16	256	176	218	2080
15	248	170	210	1950
14	240	164	202	1820
13	231	158	193	1690
12	220	152	183	1560
11	208	147	172	1430
10	195	141	160	1300
9	187	135	148	1170
8	177	129	135	1040
7	164	123	121	910
6	148	117	106	708
5	130	108	90	650
4	110	85	75	520

* This table should be used strictly as a guide. Excellent yields may be obtained at other than these suggested values.

Some difficulties have been experienced with single heavy applications of muriate of potash, particularly in soils of less than ten (10) cation exchange capacity (CEC), as this could build up the salt concentration and reduce plant growth. Not more than 300 - 600 lbs. of this soluble salt should be added at one time, depending on soil conditions, soil type, and method of application.

Should a heavy application be desirable, or necessary, split applications (two to three applications/year) are advisable. If a single heavy application is to be made, it should be done well ahead of cropping and thoroughly incorporated into the soil.

In areas of low rainfall and high cation exchange capacity soils, it may not be economically feasible to maintain the soil at the "ideal" level of potassium. For these soils a lesser saturation may be decided upon as determined by the prevailing factors. For small grain crops being raised for grain production only, a potassium level of 80 - 90% of the desired level may adequately provide sufficient K to raise a normal yield.

CALCIUM

Total calcium in soils ranges from less than 0.1 to 25%. The calcareous soils in the arid West have the highest levels, while the acid soils in the humid Southeast have the lowest. However, not all of the total calcium in soils is in the form available for crops. Exchangeable calcium generally is considered to be the primary available form.

Applying lime to bring the soil pH into the proper range for optimum plant growth usually supplies sufficient calcium. Limestone broadcast and not incorporated into the soil will probably not likely be revealed by the soil test. Such known additions, if well mixed in the soil, should be credited as part of the soil treatment to be applied.

Calcium is recorded in the soil test report as parts per million (ppm) available calcium.

This nutrient plays an important role in the fertility of soils. Some plants, such as alfalfa, clovers, and certain leafy vegetables require large amounts of calcium. Plants of these types thrive best when the predominant base in the soil is calcium. If other bases, such as magnesium, potassium, or sodium are present in amounts equal to or higher than calcium, nutritional disturbances can occur.

Calcium has many functions. It is associated with the development of protein, assists root development and movement of carbohydrates within the plant, and is needed for the formation of cell walls, seed production, and other processes. If the plant is low in calcium, the growth may be adversely affected.

MAGNESIUM

The total magnesium in soils varies considerably and can range from 0.05% in red-podsolic soils to 1.34% in desert soils.

Magnesium in the soil arises from the decomposition of rocks containing such minerals as olivine, serpentine, dolomite, biotite, and others. It is slowly released from these minerals and is adsorbed by the clay particles or organic exchange materials. A part is lost in the percolation, a part is absorbed by living organisms, and a part is reprecipitated as a secondary mineral.

Magnesium is recorded in the soil analysis report as parts per million (ppm) of available magnesium.

The level of magnesium needed or desired in a given soil for good crop production depends on the crop to be grown, the soil's exchange capacity (CEC), and the levels of calcium and potassium in the soil. High rates of applications of calcite limestone or potassium could result in an induced magnesium deficiency.

As a rule, if the soil test indicates that the ppm of exchangeable potassium to exchangeable magnesium ratio is more than 3 to 1, crops should be watched for magnesium deficiency.

Silty or clay soils with a CEC greater than 10 meq/100g are considered to have adequate magnesium if the saturation of magnesium is maintained at 10 percent. Adequate magnesium levels normally are above 50-70 ppm.

Magnesium deficiencies can be corrected with dolomite limestone on acid soils. On soils which are not acid, magnesium deficiency can be corrected by broadcast or band application of magnesium containing materials; i.e., magnesium sulfate (epsom salt), potash-magnesium sulfate or finely ground magnesium oxide. These materials can also be used in liquid suspension fertilizers. Magnesium sulfate can also be used as a foliar spray when dissolved in water (10 to 20 lbs. $MgSO_4$/30 gallons).

SODIUM

Sodium plays an important role in soil-plant relations, particularly in arid and semiarid regions.

Sodium is generally a prominent constituent of the soil solution in saline soils, and as such adversely affects the growth of many plants.

However, sodium can also give a positive influence on the mineral nutrition of plants, especially on potassium deficient soils. When plants show a response to sodium under such conditions, it is generally considered that sodium can effectively substitute for potassium in one or more of several essential functions normally filled by potassium.

It is also known that this element often enhances the growth of sugar beets in the presence of ample potassium. Table beets show similar responses.

SODIUM'S ASSOCIATION WITH SALT PROBLEMS

The sodium tends to displace the other cations on the exchange complex, to accumulate in the soil solution, and to interfere internally with the plant physiology.

Sodium may exist in the soil either as a free salt or as part of the exchange complex. Free sodium will leach readily, while exchangeable (absorbed) sodium can be removed from the exchange complex by replacing it with another cation.

When the use of gypsum or sulfur containing materials is warranted, fineness of grind, mixing thoroughly in the soil as deep as practical, and use of good quality water are important considerations.

Gypsum or Sulfur Needed to Replace Exchangeable Sodium:

Sodium to be Replaced		Amount to Apply	
meq/100 g	ppm	Gypsum/acre ft.	Sulfur/acre ft.
1	230	1.7 tons	0.32 tons
2	460	3.4	0.64
3	690	5.1	0.96
4	920	6.8	1.28
5	1150	8.5	1.60
6	1380	10.2	1.92
7	1610	11.9	2.24
8	1840	13.6	2.56
9	2070	15.3	2.88
10	2300	17.0	3.20

All soil amendments should be well mixed into the soil and water applied soon afterwards to start reclamation.

The approximate amount of water that must pass through the root zone to reclaim a salt affected soil can be estimated from the following information.

6 inches of water per foot of root zone will remove 50%
12 inches of water per foot of root zone will remove 80%
24 inches of water per foot of root zone will remove 90%

The following general guide to plant effects associated with different ranges of specific conductance measured in a 1:2 soil:water ratio by volume is used to interpret soluble salt analysis data, which are expressed in mmhos/cm at 25°C (= deciSiemen/m). (Also see table 9.)

mmhos/cm at 25° C*	Effects*
less than 0.40	Salinity effects mostly negligible.
0.40 - 0.80	Very slightly saline; but yields of very salt sensitive crops may be restricted.
0.81 - 1.20	Moderately saline. Yields of salt sensitive crops are restricted. Seedlings may be injured. Satisfactory for well-drained greenhouse soils.
1.21 - 1.60	Saline condition. Yields of most crops restricted. Salinity higher than desirable for greenhouse soils.
1.61 - 3.20	Strongly saline. Only salt tolerant crops yield satisfactorily. Bare spots due to germination injury. Greenhouse soils should be leached.
more than 3.20	Very strongly saline. Only a few very salt tolerant crops yield satisfactorily.

* Excess salts can only be removed by leaching with sufficient water of suitable quality. The dissolved salts must be carried below the root zone.

** Saturated paste specific conductance measurements are interpreted as follows:

less than 1.0	mmhos/cm	-	Salinity negligible
1.1 - 2.0	mmhos/cm	-	Very slightly saline
2.1 - 4.0	mmhos/cm	-	Moderately saline
4.1 - 8.0	mmhos/cm	-	Saline condition
8.1 - 16.0	mmhos/cm	-	Strongly saline
more than 16.0	mmhos/cm	-	Very strongly saline

table 9.

RELATIVE SALT TOLERANCE RATINGS* OF SELECTED CROPS

Field Crops	Tolerance Rating	Forage Crops	Tolerance Rating
Barley	T	Alfalfa	MS
Corn	MS	Bentgrass	MS
Cotton	T	Bermuda grass	T
Flax	MS	Brome, smooth	MS
Oats	MT	Clover	MS
Peanuts	MS	Dallis grass	MS
Rice	MS	Fescue	MT
Rye	MT	Kallargrass	T
Safflower	MT	Orchard grass	MS
Sesame	S	Ryegrass	MT
Sorghum	MT	Salt grass, desert	T
Soybean	MT	Sudan grass	MT
Sugar beet	T	Timothy	MS
Sugarcane	MS	Trefoil	MT
Triticale	MT	Vetch	MS
Wheat	MT	Wheatgrass	MT

Vegetable Crops	Tolerance Rating	Fruit/Nut Crops	Tolerance Rating
Artichoke	MT	Almond	S
Asparagus	T	Apple	S
Bean	S	Apricot	S
Beet, red	MT	Avocado	S
Broccoli	MS	Blackberry	S
Cabbage	MS	Cherry, sweet	S
Carrot	S	Date Palm	T
Cauliflower	MS	Fig	MT
Celery	MS	Grape	MS
Cucumber	MS	Grapefruit	S
Kale	MS	Lemon/Lime	S
Kohlrabi	MS	Mango	S
Lettuce	MS	Muskmelon	MS
Onion	S	Olive	MT
Peas	S	Orange	S
Pepper	MS	Papaya	S
Potato	MS	Peach	S
Pumpkin	MS	Pear	S
Radish	MS	Persimmon	S
Spinach	MS	Pineapple	MT
Squash	MS	Plum/Prune	S
Tomato	MS	Pomegranate	MT
		Raspberry	S
		Strawberry	S
		Tangerine	S
		Watermelon	MS

* Rating Interpretation:

		1:2 Soil/Water Ratio	Saturated Paste
S	Sensitive	0.0 - 0.8 mmhos/cm	0.0 - 2.0 mmhos/cm
MS	Moderately sensitive	0.9 - 1.6 mmhos/cm	2.1 - 4.0 mmhos/cm
MT	Moderately tolerant	1.7 - 2.4 mmhos/cm	4.1 - 8.0 mmhos/cm
T	Tolerant	2.5 - 3.2 mmhos/cm	8.1 - 16.0 mmhos/cm

SOIL REACTION (pH)

The soil reaction is important as it affects nutrient availability, solubility of toxic substances like aluminum, the rates of microbial activities and reactions, soil structure and tilth, and pesticide performances.

Soil pH is expressed as a numerical figure and can range from 0 - 14. A value of seven is neutral; a value below 7.0 is acid, and above 7.0 is alkaline.

The pH value reflects the relative number of hydrogen ions (H^+) in the soil solution. The more hydrogen ions present, compared to the hydroxyl ions (OH^-), the more acidic the solution will be and the lower the pH value. A decrease in hydrogen ions and increase in hydroxyl ions will result in more alkaline or basic conditions.

The ratio between hydrogen ions and hydroxyl ions changes tenfold for each unit change in pH. Therefore, a soil with a pH of 5.0 is ten times as acidic as a soil with a pH of 6.0.

Soils are becoming more acid as a result of the removal of the cations calcium, magnesium, potassium, and sodium through leaching or by growing crops. As the cations are removed from the soil particles, they are replaced with acid-forming hydrogen and aluminum.

Most common nitrogen fertilizers also contribute to soil acidity, since their reactions increase the concentration of hydrogen ions in the soil solution.

Many agricultural soils are in the pH range 5.5 - 8.0. The growth of crops on these soils are influenced by the favorable effects of near-neutral reaction on nitrification, symbiotic nitrogen fixation and the availability of plant nutrients.* The optimum pH range for most crops is 6.0 - 7.5 and for leguminous and other alkaline preferring crops 6.5 - 8.0. A desirable pH range for organic soils is 5.0 - 5.5.

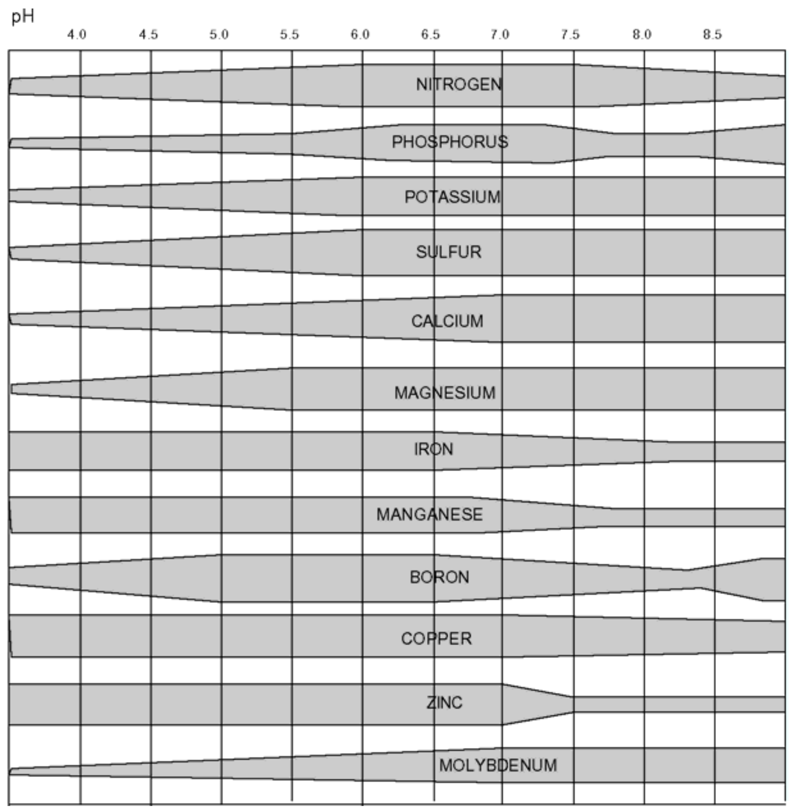
Hydrogen ions in the soil solution are increased when the salts increase. This results in a more acid condition or lower pH. The salts may be a result of fertilizer residues, irrigation water, natural conditions, or microbial decomposition of organic matter.

Infertile, sandy, highly leached soils usually contain very little soluble salts.

* (table 10 and 11).

table 10.

NUTRIENT AVAIABILITY IN RELATION TO pH



Ref.: Illinois Agronomy Handbook 1979-80

table 11.

INFLUENCE OF SOIL pH ON LIME REQUIREMENT AND NUTRIENT AVAILABILITY

pH_w	7.5	7.0	6.5	6.0	5.5	5.0
Lime Requirement	No lime required except for alfalfa and sweet clover.			Lime required except for special acid tolerant crops.		
Phosphate Relation	Phosphates become fixed with calcium		Phosphates are generally soluble.		Phosphates become fixed with iron and aluminum.	
Trace Element Relation	Manganese, iron, copper, zinc, boron are increasingly fixed.		Manganese, iron, copper, zinc, boron, cobalt are increasingly available satisfactory amount.		Manganese, aluminum, iron, copper, zinc, cobalt, and boron are increasingly soluble; manganese and aluminum toxicity may occur.	
Bacteria and Fungi Activity	Bacteria thrive, Fungi languish Nitrogen is freely fixed.		Desirable bacteria and fungi activity. Nitrogen is freely fixed.		Fungi thrive, Bacteria languish, Nitrogen is not freely fixed.	

INTERPRETATION OF pH_w AND pH_s VALUES

The activity of hydrogen ions as measured with the soil in distilled or deionized water is designated by the symbol pH_w.

The soil analysis report uses pH as a symbol for this analysis method of determining the alkalinity or acidity of soils.

The pH_s symbol signifies that it has been measured by using 0.01 molar calcium chloride instead of distilled water. It may be interpreted in terms of degree of soil saturation by cations other than hydrogen. In special cases, where fertilizer or other salts are known to be present, attention to the salt effect on pH is warranted and the use of this method is advisable.

The difference between pH_s and pH_w can range from 0 to 1.1 pH units depending on the soil's own salt content.

pH	Interpretation	
	Rating	Remarks
4.5 and lower	Very strongly acid	Too acid for most crops
4.5 - 5.2	Strongly acid	Too acid for many crops.
5.3 - 6.0	Medium acid	Too acid for some crops.
6.1 - 6.9	Slightly acid	Optimum for most crops.
7.0	Neutral	Optimum for most crops.
7.1 - 7.5	Slightly alkaline	Optimum for most crops.
7.6 - 8.2	Medium alkaline	Too alkaline for some crops.
8.3 - 9.0	Strongly alkaline	Too alkaline for many crops.
9.1 and higher	Very strongly alkaline	Too alkaline for most crops.

pH_s	Interpretation
7.5 and higher	Alkali soil.
7.5	Free lime in the soil.
7.0	Complete saturation by cations other than hydrogen.
6.5 - 7.0	Ideal for leguminous crops; good for most crops.
6.0 - 6.5	Ideal for most crops; satisfactory for alfalfa.
5.5 - 6.0	Satisfactory for many crops.
5.0 - 5.5	Deficient in calcium; liming advisable.
4.5 - 5.0	Very deficient in calcium; unsatisfactory for most crops.

In organic soils the solubility of iron and aluminum are not as great as in mineral soils and the high exchange capacities provide ample amounts of calcium at lower pH levels. Such soil may function satisfactorily for many crops at pH_s values in the range from 5.0 - 5.5.

Desirable pH ranges for various crops are given in table 12.

table 12.

DESIRABLE SOIL pH RANGES

Field Crops and Forages	Range	Vegetables	Range
Alfalfa	6.5-7.5	Asparagus	6.5-7.5
Barley	6.0-7.0	Beans (Field)	6.0-7.5
Clover (Alsike)	6.0-7.5	Beans (Kidney)	6.0-7.5
Clover (Arrowleaf)	5.5-7.0	Beans (Snap)	6.0-7.5
Clover (Crimson)	5.5-7.0	Beets (Sugar)	5.5-6.5
Clover (Red)	6.0-7.0	Brussels Sprouts	6.0-7.5
Clover (Sweet)	6.5-7.5	Cabbage	6.0-7.5
Clover (White)	6.0-7.0	Cantaloupes	6.0-7.0
Coastal Bermuda	5.5-7.0	Carrot	6.0-7.5
Corn	6.0-7.0	Cauliflower	6.0-7.0
Cotton	5.5-7.0	Celery	5.5-7.0
Fescue	6.0-7.5	Collards	5.5-6.5
Grass (Orchard)	6.0-7.0	Corn (Sweet)	5.5-7.5
Grass (Sudan)	5.5-6.5	Cowpeas	5.5-7.0
Lespedeza	6.0-7.0	Cucumbers	5.5-7.0
Millet	5.5-6.5	Eggplant	5.5-6.0
Milo	5.5-7.0	Endive	5.5-7.0
Oats	5.5-7.5	Kale	5.5-7.0
Peanuts	5.5-7.0	Lettuce	6.0-7.0
Rice	5.5-6.5	Mustard	5.5-6.5
Rye	5.5-6.5	Okra	6.0-6.5
Sorghum	5.5-7.0	Onions	5.5-7.0
Soybeans	6.0-7.5	Parsley	5.5-7.0
Sugarcane	5.5-7.0	Parsnips	5.5-7.0
Sunflower	6.0-7.5	Peas	6.0-7.0
Tobacco	5.5-7.5	Peppers	5.5-7.0
Vetch (Hairy)	5.5-7.0	Potatoes (Sweet)	5.5-6.0
Velvet beans	5.5-6.5	Potatoes (White)	5.0-6.0
Wheat	6.0-7.0	Pumpkin	5.5-7.5
		Radishes	6.0-7.0
		Spinach	6.0-7.0
		Squash	6.0-7.5
		Tomatoes	6.0-7.0
		Turnips	5.5-7.0

Fruits and Nuts	
Almond	6.0-7.0
Apples	5.5-7.0
Apricot	6.0-7.0
Blueberries	4.5-6.0
Cherry (Sour)	6.0-7.0
Cherry (Sweet)	6.0-7.5
Citrus	6.0-7.0
Grapes	5.5-7.0
Peach	6.0-7.5
Pear	6.0-7.5
Pecan	6.0-8.0
Plums	6.0-7.0
Strawberries	5.0-6.5
Tung	5.0-6.0
Walnut	6.0-8.0
Watermelon	5.5-6.5

table 12. (continued)

Ornamental Shrubs and Trees

Abelia	6.0-7.0	Hydrangea (blue flower)	4.5-5.5
Althea (Rose of Sharon)	6.0-7.0	Hydrangea (pink flower)	6.0-7.0
Annual Flowers (various)	5.5-6.5	Juniper	5.0-7.5
Ash (Green)	6.0-7.0	Locust	6.0-7.0
Azalea	4.5-5.5	Magnolia (deciduous)	5.0-6.0
Beech	6.0-7.0	Maple (Silver, Sugar, Red)	6.0-7.0
Birch	5.0-6.0	Mimosa	5.5-6.5
Boxwood	6.0-7.0	Mulberry	6.0-7.0
Camellia	4.5-5.5	Oak (Scarlet or Red)	6.0-7.0
Cedar (Red)	5.0-7.0	Oak (White)	5.5-6.5
Cherry (Flowering)	5.0-7.0	Pine	5.0-6.5
Cottonwood	5.5-7.0	Poplar	6.0-7.0
Crab apple (Flowering)	6.0-7.0	Rhododendron	5.0-6.0
Crape myrtle	5.0-6.0	Roses	5.5-7.0
Cypress (Bald)	5.0-6.5	Spirea	6.0-7.0
Dogwood	5.0-6.5	Spruce (Norway)	5.0-6.5
Elm	6.0-7.0	Sweet Gum	6.0-7.0
Gardenia	5.0-6.0	Viburnum	6.0-7.5
Honeysuckle	6.0-7.0	Willow	6.0-7.0
Holly (American)	4.0-6.0	Yew	6.0-7.0
Holly (Japanese)	5.0-6.5		

LIMING OF THE SOIL

While pH is related to soil acidity, it is not a direct measurement of the amount of acidity or the amount of hydrogen ions which must be replaced and neutralized by liming.

A pH reading measures the active acidity, while the buffer pH indicates the potential acidity. The amount of potential acidity for any given soil pH will depend upon the amount and type of clay and the level of organic matter in that soil. Therefore, it is possible to have two soils with the same soil pH but with different buffer pH's. A lower buffer pH represents a larger amount of potential acidity and thus more limestone is needed to increase the soil pH to a given level (table 13).

Due to the great variety of soil typeswith which we work,we use two different methods to determine the buffer.

A. **SMP Buffer Test (pH_{SMP}).**

This buffer solution was developed in Ohio and measures the total soluble and exchangeable hydrogen and aluminum. It is reliable for soils with a greater than 1 Ton/acre lime requirement and it is also well adapted for acid soils with a pH below 5.8 containing less than 10% organic matter and having appreciable amounts of aluminum.

If the soil pH is greater than 6.5, the SMP buffer test is not made, since lime is not needed for most crops.

Crops raised on organic soils usually do not benefit from liming unless the soil pH is lower than 5.3.

B. **Adams-Evans Buffer Test**

This buffer method is primarily an adaptation of the SMP buffer, but it is specifically designed for low organic matter, sandy soils of the coastal plains where amounts of lime are needed in small quantities and the possibility of over-liming exists. The chemistry of the Adams-Evans buffer solution works in the same manner as the SMP buffer solution.

The pH of the Adams-Evans buffer solution is 8.0. When the buffer solution is added to an acid soil, the original pH of the buffer will be lowered. Since it is known how much acid is required to lower the buffer solution pH to any given level, the total acidity of the soil can be determined.

table 13.

AMOUNTS OF LIME REQURIED TO BRING MINERAL AND ORGANIC SOIL TO INDICATED PH ACCORDING TO PH_{SMP} TEST

SAMPLING DEPTH: 9 INCHES APPLICATION RATE: T/ACRE

pH_{SMP}		Mineral Soils			Org. Soils
	7.0	7.0	6.5	6.0	5.2
	Pure $CaCO_3$	Ag-ground Limestone*			
7.0					
6.9					
6.8	1.2	2.0	1.5	1.0	1.0
6.7	2.0	3.0	2.5	2.0	1.5
6.6	2.7	4.0	3.5	3.0	2.0
6.5	3.5	5.0	4.5	3.5	3.0
6.4	4.5	6.0	5.5	4.5	3.5
6.3	5.3	7.5	6.0	5.0	4.0
6.2	6.1	8.5	7.0	6.0	4.5
6.1	6.8	10.0	8.0	7.0	5.0
6.0	7.6	11.0	9.0	7.5	6.0
5.9	8.7	12.0	10.0	8.0	6.5
5.8	9.3	13.0	11.0	9.0	7.0
5.7	10.1	14.5	12.0	10.0	7.5
5.6	10.9	15.5	13.0	10.5	8.0
5.5	11.7	16.5	14.0	11.5	9.0
5.4	12.7	18.0	15.0	12.5	9.5
5.3	13.4	19.0	16.0	13.0	10.0
5.2	14.3	20.0	17.0	14.0	10.5
5.1	15.2	21.5	18.0	14.5	11.0
5.0	16.0	22.5	19.0	15.5	12.0
4.9	16.9	23.5	20.0	16.0	12.5
4.8	17.6	25.0	21.0	17.0	13.0

* Ag-ground lime of 90%+ TNP or $CaCO_3$ equivalent, and fineness of 40% 100 mesh, 50% 60 mesh, 70% 20 mesh, and 95% 8 mesh.

To convert lime recommendations to depth of tillage other than 9 inches, divide above rates by 9 and multiply by the depth of plowing (inches).

Maximum lime recommendation for one season is 5 T/acre.
Retest advisable in two to three years for additional lime needs.

table 14.

CALCIUM AND MAGNESIUM SUPPLYING MATERIALS

Material	%Ca	%Mg	TNP*
Ashes (wood)	23.3	2.2	
Basic Slag (Ca/$MgCO_3$)	29	4	60-90
Bone Meal	23	.4	60-70
Burned Lime (CaO)	60-70		150-175
Calcium Limestone ($CaCO_3$)	32	3	85-100
Chelates (Ca/MgEDTA)	3-5	2-4	
Dolomite Limestone (Ca/$MgCO_3$)	22	11	95-108
Epsom Salt ($MgSO_4.7H_2O$)		10	
Gypsum ($CaSO_4.2H_2O$)	23		
Hydrated Lime ($Ca(OH)_2$)	45-55		120-135
Kieserite ($MgSO_4.H_2O$)		18	
Magnesium Oxide (MgO)		55	
Marl	35	.5	90-100
Natural Organic Complexes	4-12	4-9	
Potassium Magnesium Sulfate ($K_2SO_4.2MgSO_4$)			11

*Total Neutralizing Power

Liming materials and amendments which supply calcium and magnesium are given in table 14. Calcium nitrate and both normal and triple superphosphate also contain significant amounts of calcium (table 20).

Liming is generally done through a broadcast application; however, the economics of many crops grown on high organic soils with a low pH may not justify blanket applications of lime to raise the pH. Banding is advisable under such conditions. The lime must be finely ground and thoroughly mixed with the band layer.

The importance of highly reactive limestone is more evident whenever heavy nitrogen treatments are used. Under such conditions the grower should consider making up his calcium shortage even if it takes less than 2 tons of limestone.

Where calcium is needed for reclamation of soils high in sodium, gypsum (calcium sulfate) generally is used rather than limestone.

FLUID LIME SUSPENSIONS

It appears that fluid lime suspensions are an effective means to raise the pH and make it possible to get a uniform application while it also may have some economic advantage in areas where regular limestone is not available.

These suspensions contain only fine particle sizes--usually 100 to 200 mesh material--suspended in water or liquid fertilizer. Most mixtures being applied contain 50 to 75 percent lime, 0.5 to 5.0 percent attapulgite clay as a suspending agent, and may contain a small quantity of dispersing agent. The remainder of the solution is either water or fertilizer. Most agronomists agree that a phosphorus containing fertilizer should not be used. Lime-nitrogen solutions should be immediately incorporated to prevent nitrogen loss by volatilization.

PELLETIZED LIME

Pellet lime is available as a source of lime which is easier to spread and blend with dry fertilizer ingredients. This product can be spread annually at lower rates for maintenance of proper soil pH values. Pellet lime is ground limestone formulated with a special binder which produces a sized, hard pellet that breaks down when applied to moist soil.

Besides limestone there are other materials which can be used as suspension materials to increase soil pH. Calcium carbonate sludges, flue dust from cement plants, sludges from paper mills, and certain other by-products or waste materials with high calcium and/or magnesium carbonate content. Be sure to test these materials before making a suspension as to their calcium, magnesium, and possibly impurities contents.

There are several advantages and disadvantages with respect to fluid lime which should be considered before making a decision to use it.

Advantages compared to dry material:

1. Reacts faster than coarser materials.
2. Less required for a given pH change, at least initially.
3. Can combine with N, K, S fertilizer solutions and herbicides.
4. No dust problem during application.
5. Uniformity of application may be easier.
6. Flotation equipment can be used.
7. Fast reaction on rented land.
8. May be more economical in areas where no lime is available.
9. Useful for no-till situations where surface soil has become acid.
10. Can be used where annual applications to maintain soil pH are desired.

Disadvantages compared to dry materials:

1. Cost may be greater, especially long-term.
2. Cannot be used with phosphorus fertilizer.
3. Large pH changes not possible with small quantities.
4. Fluid lime containing calcium oxide or hydroxide should not be mixed with N solutions containing free ammonia. If used, lime-nitrogen suspensions should be incorporated immediately after application to prevent volatilization of nitrogen.
5. Caution should be taken when herbicides are used in the lime mixture, as pH increases herbicide activity, which could cause crop injury.

Conclusion

Fluid lime suspensions are an effective method of lime application. The assessment of the feasibility for a given area will be dictated by the cost of the material applied compared to an equal ECC rate of ag-lime, taking into account the application advantage or disadvantage that might be present.

ADJUSTMENTS FOR TYPE OF LIMING MATERIALS

The actual amount of a given liming material required to achieve a desirable effect on soil pH is influenced by its total neutralizing power (TNP) which is also referred to as calcium carbonate equivalent (CCE), and the fineness of grind. The effective calcium carbonate (ECC) rating of a limestone is the product of the CCE (or purity) and the fineness factor.

The latter is the sum of the products of the percentages of limestone on various mesh sizes multiplied by the percentage of effectiveness which that particular particle size is assigned. The more surface area in a given weight of liming material, the faster that material will dissolve and helps to assist in adjusting the soil pH.

Relative efficiency factors have been established for various particle sizes as shown in the following table:

Particle Size	Relative Efficiency Factor
Passing 100 mesh	1.00
60 - 100 mesh	0.78
40 - 60 mesh	0.55
20 - 40 mesh	0.27
8 - 20 mesh	0.13
0 - 8 mesh	0.05

The Total Neutralizing Power (TNP) or Calcium Carbonate Equivalent (CCE) is calculated by using analysis data of the liming material.

The chemical composition of agricultural limestone is expressed in several ways, depending on state lime laws or regulations and locally accepted terminology, the following table should be helpful to convert from one form of expression to another:

Conversion			Factor
Ca	to	CaO	1.40
Ca	to	$CaCO_3$	2.50
CaO	to	$CaCO_3$	1.78
Mg	to	MgO	1.66
Mg	to	$MgCO_3$	3.47
MgO	to	$MgCO_3$	2.09
Mg	to	$CaCO_3$ equiv.	4.12
$MgCO_3$	to	$CaCO_3$ equiv.	1.19

Our recommendations for lime are based on an assumption of 90+% effective calcium carbonate equivalent (ECC).

If the quarry analysis of the lime is different, calculate the desired amount as given in the following example:

Particle Size	% Passing		Rel. Efficiency Factor	Fineness Factor
Passing 100 mesh	60	X	1.00	60.00
60 - 100 mesh	10	X	0.78	7.80
40 - 60 mesh	--	X	0.55	——
20 - 40 mesh	25	X	0.27	6.75
8 - 20 mesh	5	X	0.13	.65
0 - 8 mesh	--	X	0.05	——
			Fineness Factor	75.2

$$\frac{\text{Ton recommended/acre}}{\text{Fineness factor x CCE (=TNP)}} = \text{adjusted T/acre rate}$$

MICRONUTRIENTS

Importance of Micronutrients

Cropland acres are frequently found deficient in one or more of the micronutrients--boron, copper, manganese, iron, zinc and molybdenum. In many situations a deficiency of certain micronutrients is the factor responsible for ineffective utilization of the major and secondary nutrients supplied in fertilizer programs and liming programs. Although only required in small amounts by plants, their deficiency or toxicity can have just as much effect on crop production as any of the major elements.

There are a number of reasons for the growing importance of ensuring adequate levels of micronutrients in the soil.

1. Increased fertilizer rates resulting in increased yields means a higher removal of micronutrients from the soil.

2. Some micronutrients are no longer contained as impurities in high analysis fertilizers and fertilizer materials.

3. Improved crop varieties are capable of producing higher yields per acre and consequently remove more micronutrients from the soil.

4. Land forming or land leveling with the removal of several inches of topsoil many times results in a deficiency of certain micronutrients on the cut areas.

5. High phosphorus levels, either natural or from fertilizer application, have been found in some areas to induce micronutrient deficiencies.

Micronutrient deficiencies have as drastic an effect on crop yields and quality as do the primary and secondary nutrients (N, P, K, Ca, Mg, and S). In addition when they are present in toxic amounts, certain of the micronutrients can also cause large reductions in yield. Conditions of extreme deficiency can result in a complete loss on the affected acreage.

"Deficiency Symptoms" and "Hidden Hunger"

Deficiency symptoms are the visual signs that occur when a plant is experiencing a shortage of one or more of the nutrients. These signs vary according to crop and the element which is deficient. For example, an iron deficiency normally manifests itself through a "chlorosis" or yellowing of a part of the leaf.

Deficiency symptoms appear only after the plant is critically short in a nutrient. By the time these symptoms appear, the crop has already suffered some loss in yield potential.

"Hidden hunger" is a term used to describe a lack of a nutrient which will affect the final yield. It occurs when the nutrient supply falls below the critical level and becomes increasingly worse until finally, deficiency symptoms appear. This is why it is important to monitor the supply of micronutrients through soil and plant analysis to reduce the incidence of "hidden hunger."

Plant Food Balance

Maximum results are obtained from the addition of micronutrients only when the major and secondary nutrients are present in adequate amounts and in a balance required by the crop.

An imbalance of micronutrients often results in as much loss in yield as when the other nutrients are not in balance.

Importance of Applying Micronutrients Early

A high percent of the micronutrient requirements are taken up during the first one third of the growing period. Therefore, it is important to apply these micronutrients before or at planting to get maximum utilization.

If they are applied later, the crop may experience hidden hunger, and yield and quality will be affected.

OCCURRENCE IN SOILS

Total Amounts

The total amount of micronutrients present in the soil varies with the element, but the total amount in the soil is many times greater than that which is present in the available form. Most micronutrient deficiencies occur not due to a lack of the nutrient in the soil, but because adequate amounts are not available to the crop.

Soils vary in their total micronutrient content because of the difference in the minerals from which they are derived. Following are the relative total amounts of micronutrients present in the plow layer of one particular soil.

Element	% in Soil	Amount (ppm)
Iron (Fe)	3.5	35,000
Manganese (Mn)	0.05	500
Boron (B)	0.002	20
Zinc (Zn)	0.001	10
Copper (Cu)	0.0005	5
Molybdenum (Mo)	0.0001	1

Available Amounts

As mentioned before, concern should not be for the total amount of micronutrients in the soil but for the amount that is available. Listed below are some ranges of the amounts of available micronutrients that are commonly found in soils.

	ppm		
Boron	0.1	to	5
Copper	0.1	to	4
Iron	2	to	150
Manganese	1	to	100
Molybdenum	0.05	to	0.5
Zinc	1	to	20

FACTORS AFFECTING AVAILABILITY

Conditions Conducive to Deficiency

There are a number of conditions which are conducive to micronutrient deficiencies:

1. Removal of large amounts by high yielding crops.
2. Leaching from sandy soils.
3. Naturally high pH soils.
4. Overlimed soils resulting in a high pH.
5. Land leveling.
6. Additions of high rates of phosphorus.
7. Soil compaction.
8. Cool, wet growing conditions.
9. Tie-up by the soil.
10. Use of sensitive crop varieties.

Table 10 on page 54 shows the relative availability of major and micronutrients at various pH ranges. With the exception of molybdenum, the availability of micronutrients is greatest in the very slightly to medium acid range. Soil pH is a key factor in regulating nutrient availability.

MICRONUTRIENTS AND THEIR AVAILABILITY TO CROPS

Although soil pH is probably one of the most important factors governing the availability of micronutrients, there are also other soil conditions that can affect their availability.

In the following section availability of each of the micronutrients is discussed individually.

Boron availability decreases on fine-textured, heavy clay and high pH soils. Fine-textured soils with a high pH or which have just been heavily limed may have a limited amount of boron available for plant growth. Boron will leach from the soil; it will be the greatest in light-textured, acid, sandy soils which are low in organic matter.

Copper becomes less available as the pH increases. However, in soils with high organic matter, the availability of copper may be more closely associated with the organic matter content than with the pH. Soils high in organic matter; i.e., peaty, muck soils, maintain a tight hold on copper and availability is decreased. Crops frequently respond to copper applications on soils high in organic matter.

However, Canadian studies have shown that in organic soils threre is an interdependency between copper and manganese, as both elements are held similarly in complex form by the soil organic matter. Heavy copper application might result in manganese deficiency, while the addition of manganese can "release" copper from being complexed, thus causing more copper absorption by the plant roots.

Iron availability decreases as the pH increases. Iron chlorosis often develops on field crops and ornamentals as a result of high pH. High levels of phosphorus in conjunction with iron will form insoluble iron-phosphate compounds and may induce iron deficiency. Iron is not easily leached from the soil under normal conditions. However, poorly drained soils or soils containing excess water with poor aeration which restricts root growth, may cause unfavorable conditions for iron uptake.

Manganese availability decreases as the soil pH increases. Soil pH appears to be the most important factor governing the availability of manganese. In acid soils manganese becomes soluble and is available to plants. If the soil becomes very acid, pH 4.5, toxicity may occur. As the pH increases, solubility and availability decreases. At pH 6.3 and above manganese may not be readily available to plants.

In peats or muck soils manganese may be held in unavailable organic complexes. Manganese deficiency in these soils may be further aggravated by high pH. Susceptible crops sometimes express severe manganese deficiency symptoms under these soil conditions.

Manganese deficiencies are frequently observed in poorly drained soils. Soils developed under poor drainage conditions are likely to contain less total manganese than those developed under good drainage. Poor drainage also limits root growth and uptake of manganese.

Molybdenum deficiencies are usually associated with acid sandy soils. Soil pH is the most influential factor affecting availability. Unlike other micronutrients, the availability of molybdenum increases as the soil pH approaches neutrality (pH 7.0) or goes higher. Most deficiencies can be corrected by liming.

Zinc availability decreases as soil pH increases. At pH 5.0 the availability of zinc is low and the availability decreases as the pH increases to 9.0 where the zinc becomes unavailable to plants. Zinc deficiencies may also be found on acid sandy soils low in total zinc, soils high in phosphorus, some organic soils and on soils where subsoils have been exposed by landleveling practices. In some areas, zinc deficiencies are also prevalent with cool, wet weather during the spring.

Crop and Varietal Response

Table 15 illustrates the difference in response to the application of the different micronutrients. Some crops may show a high degree of response to one element and a low response to others.

Different varieties of a given crop differ in their ability to extract micronutrients from the soil. For example, one corn hybrid may not exhibit any zinc deficiencies on a given soil, while another hybrid may show severe zinc deficiency symptoms.

In the case of iron, soybean varieties vary considerably in their iron requirement and their ability to take up iron from the soil. One variety may make lush green growth, while another variety on the same soil will appear completely yellow because of iron chlorosis.

Care should be taken to select those varieties that are not as sensitive to a given micronutrient on those soils where a deficiency is apt to exist.

table 15.

CROP RESPONSE TO MICRONUTRIENTS

Crops vary in their response to application of a given micronutrient. The following ratings are offered as guides to such response when the level of one or more of these nutrients is low or deficient in the soil.

Crop	Micronutrient Response					
	Mn	B	Cu	Zn	Mo	Fe
Alfalfa	medium	high	high	low	medium	medium
Barley	medium	low	medium	medium	low	high
Beans (dry)	high	low	low	high	medium	high
Clover	medium	medium	medium	low	medium	
Corn	medium	low	medium	high	low	medium
Grass (Forage)	medium	low	low	low	low	high
Oats	high	low	high	low	low	medium
Potatoes	high	low	low	medium	low	
Rye	low	low	low	low	low	
Sorghum	high	low	medium	high	low	high
Soybeans	high	low	low	medium	medium	high
Sudangrass	high	low	high	medium	low	high
Sugar beets	medium	high	medium	medium	medium	high
Wheat	high	low	high	low	low	low
Asparagus	low	low	low	low	low	medium
Blueberries	low	low	medium			
Broccoli	medium	medium	medium		high	high
Cabbage	medium	medium	medium		medium	medium
Carrots	medium	medium	medium	low	low	
Cauliflower	medium	high	medium		high	high
Celery	medium	high	medium		low	
Cucumbers	medium	low	medium			
Lettuce	high	medium	high		high	
Onions	high	low	high	high	high	
Parsnips	medium	medium	medium			
Peas	high	low	low	low	medium	
Peppermint	medium	low	low	low	low	low
Radishes	high	medium	medium		medium	
Spearmint	medium	low	low	low	low	
Spinach	high	medium	high		high	high
Sweet corn	medium	low	medium	high	low	medium
Table beets	high	high	high	medium	high	high
Tomatoes	medium	medium	medium	medium	medium	high
Turnips	medium	high	medium		medium	

FUNCTIONS OF MICRONUTRIENTS IN CROP GROWTH

Boron is needed in protein synthesis and is associated with increased cellular activity that promotes maturity with increased set of flowers, fruit, yield and quality. It also affects nitrogen and carbohydrate metabolism and water relations in the plant.

Copper plays an important role in plant growth as an enzyme activator and as a part of certain enzymes which function in plant restoration. It is very important in the plant's reproductive stage of growth and plays an indirect role in chlorophyll production.

Iron is essential for the formation of chlorophyll and for photosynthesis. Iron is the activating element in several enzyme systems. It is also important in respiration and other oxidation systems of plants and is a vital part of the oxygen-carrying system.

Manganese plays a role in many of the vital processes in a growing plant. It usually functions with enzyme systems of the plant involved in breakdown of carbohydrates, nitrogen metabolism and many other plant processes.

Molybdenum is needed for the symbiotic fixation of nitrogen by legumes. It is vital for the reduction of nitrates and in the synthesis of protein by all plants.

Zinc is essential for the transformation of carbohydrates and regulation of the consumption of sugar in the plant. It forms part of the enzyme systems which regulate plant growth.

DETERMINING DEFICIENCIES

VISUAL SYMPTOMS

An obvious way to determine whether a micronutrient deficiency exists is to keep a look out for deficiency symptoms. However, before these symptoms appear, reduction in potential yield and in some cases a reduction in crop quality, will usually have occurred. Deficiency symptoms for various crops are indicated on pages 87 through 92 (table 20).

COMPLETE SOIL ANALYSIS

A representative soil sample can give a good indication as to whether a micronutrient deficiency may occur. Measuring micronutrients in the soil is made more difficult by the small quantities of elements being dealt with, usually in the parts per million range but sometimes in parts per billion. Because of this, sampling and analysis should be done with the utmost care and precision. (See section on Soil Sampling Techniques.)

Micronutrient soil test ratings are shown in Table 16 . Because of the many factors affecting the availability of micronutrients and the levels needed by plants, the ratings given are general. As mentioned previously, the balance of the major elements and the pH can have a great effect on minor element utilization. To better interpret the test results, the major element test should accompany the minor element analysis. The ratings apply only to our test reports.

Micronutrient recommendations are affected by crop, yield goal, soil pH, and other soil conditions and cultural practices. The recommendations shown in Table 16 are general and may not necessarily apply to individual situations where more crop production inputs are known.

COMPLETE PLANT ANALYSIS

In addition to soil analysis, a complete plant analysis will assist in isolating areas where micronutrient deficiencies may exist. Be sure to collect the correct plant part at the proper stage of growth to obtain realistic analytical results. See the "Sampling Guide for Plant Tissue Analysis" for sampling instruction. Refer to the index for critical values of various crops.

TEST STRIPS OR PLOTS

Test strips in fields where a micronutrient deficiency is suspected is an excellent way to verify a deficiency. Foliar applications or soil applications can be made on rather small areas to determine which of these elements or combination of elements may be needed. Suggested rates and sources are given in tables 16 and 17 .

table 16.

SUGGESTED RATES AND SOURCE OF SECONDARY AND MICRONUTRIENTS FOR FOLIAR APPLICATION*

MINERAL	SOIL TEST PPM	SOIL TEST PPM	APPLICATION RATE*	
	Hot Water Extraction	D.T.P.A. Extraction	High Response Crops	Low Response Crops
BORON	0 - .3 VL		1.5 - 2.0 lbs	.5 - 1.0 lbs
	.4 - .5 L		1.0 - 2.0 lbs	0 - .5 lbs
	.6 - 1.2 M		.5 - 1.0 lbs	0
	1.3 - 2.0 H		0 - 1.0 lbs	0
	2.0+ VH		0	0
	.1 N HCl Extraction			
COPPER	0 - .3 VL	0 - .3 VL	2.0 - 5.0 lbs	1.0 - 3.0 lbs
	.4 - .8 L	.3 - .8 L	1.0 - 4.0 lbs	.5 - 2.0 lbs
	.9 - 1.5 M	.9 - 1.2 M	.5 - 3.0 lbs	0 - 1.0 lbs
	1.6 - 3.0 H	1.3 - 2.5 H	0 - 1.0 lbs	0
	3.0 + VH	2.5+ VH	0	0
IRON	0 - 3 VL	0 - 5 VL	1.0 - 2.0 lbs	1.0 - 2.0 lbs
	4 - 11 L	6 - 10 L	0 - 1.0 lbs	0 - 3.0 lbs
	12 - 24 M	11 - 16 M	0	0
	25 - 50 H	17 - 25 H		
	50+ VH	25+ VH		
MANGANESE	0 - 5 VL	0 - 4 VL	5.0 - 10.0 lbs	2.0 - 6.0 lbs
	6 - 14 L	5 - 8 L	3.0 - 8.0 lbs	1.0 - 4.0 lbs
	15 - 29 M	9 - 12 M	2.0 - 4.0 lbs	0 - 2.0 lbs
	30 - 49 H	13 - 30 H	0 - 3.0 lbs	0 - 1.0 lbs
	50+ VH	30+ VH	0	0
ZINC	0 - .9 VL	0 - .5 VL	5.0 - 8.0 lbs	3.0 - 5.0 lbs
	1.0 - 2.9 L	.5 - 1.0 L	3.0 - 5.0 lbs	2.0 - 3.0 lbs
	3.0 - 4.9 M	1.1 - 3.0 M	2.0 - 3.0 lbs	1.0 - 2.0 lbs
	5.0 - 7.9 H	3.1 - 6.0 H	1.0 - 2.0 lbs	0
	7.9+ VH	6.0+ VH	0	0
	Ammonium Acid Oxalate 1N			
MOLYBDENUM	0 - .05 VL		3.0 - 4.0 oz	
	.06 - .10 L		2.0 - 3.0 oz	
	.11 - .20 M		1.0 - 2.0 oz	
	.21 - .40 H		0	
	.40+ VH		0	

*All recommendations, except iron, manganese, and molybdenum, are on a broadcast basis. For banded application, divide the listed values by two or three.

table 17.

SUGGESTED RATES AND SOURCES OF SECONDARY AND MICRONUTRIENTS FOR FOLIAR APPLICATION*

Element	Lbs. Element per acre	Suggested Sources
Calcium (Ca)	1 - 2	Calcium chloride or calcium nitrate.
Magnesium (Mg)	1 - 2	Magnesium sulfate (epsom salt).
Manganese (Mn)	1 - 2	Soluble manganese sulfate or finely ground manganese oxide.
Copper (Cu)	0.5 - 1.0	Basic copper sulfate or copper oxide.
Zinc (Zn)	0.3 - 1.0	Zinc sulfate.
Boron (B)	0.1 - 0.5	Soluble borate.
Molybdenum (Mo)	0.06	Sodium molybdate (2 ounces)
Iron (Fe)	1 - 2	Ferrous sulfate.

* Use a minimum of 30 gallons of water per acre.

Ref: "Foliar Applied Plant Nutrition" Book

table 18.

MICRONUTRIENT SOURCE

Material	Composition	
Boron	***% Boron***	
Borax	11	
Boric Acid	17	
Fertilizer Borate-46	14	
Fertilizer Borate-65	21	
Solubor	20	
Zinc	***% Zinc***	
Zinc Sulfate	23-36	typically 35%
Zinc Oxide	50-80	
Zinc Chloride (liquid)	28	
Organic Zinc Complexes	5-12	
Zinc Chelates	9-14	
Zinc Carbonate	52-56	
Zinc Oxysulfate	18-36	
Zinc Ammonium Sulfate	16	
Zinc Nitrate	5.5	
Manganese	***% Manganese***	
Manganese Sulfate	25-28	
Manganese Oxisulfate	28	
Manganous Oxide	41-68	
Manganese Carbonate	31	
Manganese Chloride (liquid)	17	
Organic Manganese Complexes	5-12	
Manganese Chelate	5-12	
Iron	***% Iron***	
Ferrous Sulfate	19-21	
Ferric Sulfate	23-28	
Iron Chelates	5-15	
Iron Chloride (liquid)	12	
Organic Iron Complexes	5-12	
Ferrous Ammonium Phosphate	29	
Ferrous Ammonium Sulfate	14	
Copper	***% Copper***	
Copper Sulfate	13-53	typically 25%
Cupric Oxide	75	
Cuprous Oxide	89	
Copper Chloride (liquid)	17	
Copper Chelates	9-13	
Organic Copper Complexes	5-7	
Copper Ammonium Phosphate	32	
Molybdenum	***% Molybdenum***	
Ammonium Molybdate	54	
Sodium Molybdate	39	
Molybdenum Trioxide	66	
Molybdenum Sulfide	60	

table 20.

COMPOSITION OF PRINCIPLE FERTILIZER MATERIALS

	N NITROGEN	P_2O_5 PHOSPHORUS	K_2O POTASSIUM	Mg MAGNESIUM	Ca CALCIUM	S SULFUR	CALCIUM CARBONATE equivalent Lbs. Per Ton
Ammonia, Anhydrous	82						-2,960
Ammonia, Aqua	16 - 25						-720 to -1080
Ammoniated Super Phosphate	3 - 6	18 - 20			17.2	12.0	-140
Ammonia Nitrate	33.5						-1180
Ammonium Phosphate Sulfate	13 - 16	20 - 39	0.2	0.1	0.3	15.4	-1520 to -2260
Ammonium Poly-Phosphate	10 - 21	33 - 52					1000 - 1800
Ammonium Sulfate	21					23.5	-2200
Ammonium Sulfate Nitrate	26					15.1	-1700
Ammonium Thio-Sulfate	12					26	-2000
Calcium Nitrate	15			1.5	19.4	.02	+400
Calcium Sulfate (Gypsum)			0.5	0.4	22.5	16.8	0
Diammonium Phosphate	16 - 21	48 - 53					-1250 to -1550
Limestone, Calcite			0.3	3.4	31.7	0.1	+1880
Limestone, Dolomite				11.4	21.5	0.3	+1960
Lime-sulfur Solution					6.7	23.8	- -
Magnesium Oxide				60			0
Magnesium Sulfate				11	2.2	14	0
Manure (dried, cattle variable)	1 - 3	0.5 - 1.5	1 - 3	.5 - 1	1 - 3	.2 - .4	+300
Monoammonium Phosphate	11	48	0.2	0.3	1.1	2.2	-1300
Nitrate of Soda-potash	15		14				+550
Nitric Phosphates	14 - 22	10 - 22		0.1	8 - 10	.2 - 3.6	-300 to -500
Nitrogen Solutions	21 - 49						-750 to -1760
Phosphoric Acid		52 - 54					-2200
Potassium Chloride (Muriate)			60 - 62	0.1	0.1		0
Potassium Nitrate	14		44	0.4	0.6	0.2	-460
Potassium Sulfate			50	1.2	0.7	17.6	0
Rock Phosphate		30 - 36		0.2	33.2	0.3	+200
Sewage Sludge (Activated)	5 - 6	2.9	0.6	0.7	1.3	0.5	-200
Sewage Sludge (Digested)	2	1.4	0.8	0.5	2.1	0.1	-100
Sodium Nitrate	16		0.2	0.05	0.1	0.07	+580
Sulfate of Potash Magnesia			22	11.2		22.7	0
Sulfur						30 - 99.6	-1900 to -6320
Superphosphate, normal		18 - 20	0.2	0.2	20.4	11.9	0
Superphoshate, concentrated		42 - 50	0.4	0.3	13.6	1.4	0
Superphosphoric Acid		76 - 83					-3200
Urea	46						-1680
Urea Form	38						-1360
Wood Ashes		1.8	5.5	2.2	23.3	0.4	+

TIMING AND APPLICATION METHODS FOR SOIL FERTILITY MATERIALS

Fertilizer efficiency may be expressed in terms of availability and utilization of the fertilizer by crops, as measured by yield.

This efficiency may not be high unless proper timing and placement of the fertilizer makes it remain in the soil and available for plant uptake when needed by the crop.

BROADCAST APPLICATION

Liming

The application of lime or other pH correcting material is usually broadcast well in advance of planting so there is sufficient time for the material to react with the soil solution before the crops are planted.

Nitrogen

Timing is of great importance with the application of nitrogen, as there is a potential loss through leaching, denitrification, and volatilization.

Materials like urea should not be surface applied without incorporation, except by banding of UAN solutions (dribbling), which reduces volatilization. Under alkaline conditions and high humidity loss of ammonia can occur within a relatively short time.

Phosphorus and Potassium

The immobile nature of these elements, except in sandy soils, has resulted in fall application of them, although there is the possibility of fixation under certain soil conditions. This, of course, reduces the immediate efficiency of broadcasting.

However, broadcast/plowdown applications have several advantages:

1. High rates can be applied without injury to the plant.

2. Nutrient distribution throughout the root zone encourages deeper rooting, while placement causes root concentration around a band.

3. Deeper rooting permits more root-soil contact providing a larger reservoir of moisture and nutrients.

4. Broadcasting is an economical way to apply certain nutrients on established pastures and meadows.

5. Broadcasting can insure full-feed fertility to help the crop take full advantage of favorable conditions throughout the growing season.

Many times row and broadcast applications are teamed for best effect; especially under low fertility conditions.

Factors that must be considered in assessing potential nutrient loss include soil type, climatic conditions, nutrient mobility, and method, source, rate, timing of application, and cultural practices such as tillage and irrigation.

ROW AND BAND APPLICATION

Row applications concentrate nutrients for rapid growth and insure nutrient availability when the root emerges; this is an efficient method to supply nutrients for plants with limited root systems.

However, too much fertilizer too close to the seed can decrease germination and injure root hairs due to the existence of a temporary region of high salt concentration near the seed.

This is the reason that a row application of fertilizer containing potash should be placed approximately 2 inches to the side and 2 inches below the seed.

The maximum safe amount of starter fertilizer that can be placed in bands depends on the crop to be grown, distance of the band from the seed, the kind of fertilizer, the row width, type of soil, and soil moisture. Generally, greater amounts can be tolerated as distance from the seed increases, soluble salts in the fertilizer are reduced, soil moisture is increased, and the soil is of a medium (silt loam) to heavy (clay) texture.

Zone placement sometimes is better than banding or broadcast/plowdown. An example of this method is the so-called strip application, which involves the application of fertilizer bands on the soil surface, which are then incorporated (see fig. 10).

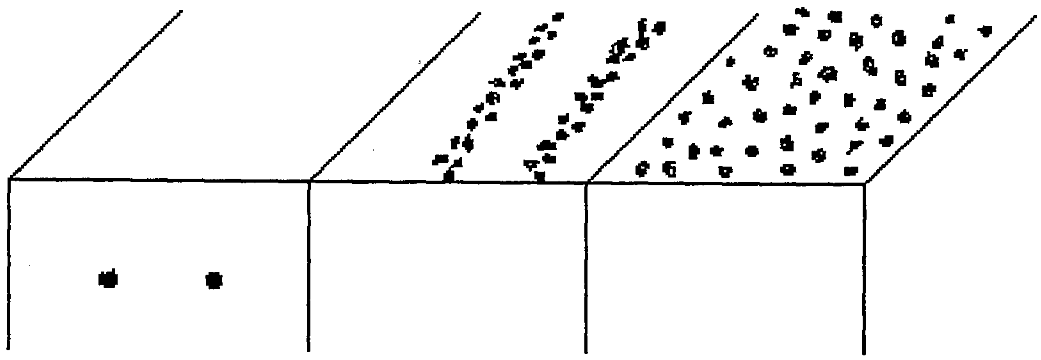
Research at Purdue University by Dr. S. A. Barber, who developed this method, indicates that phosphate and also potash fertilizer mixed with only part of the soil (10-30 percent could be profitable, especially when maintenance applications are made.

Concentrated fertilizer solutions are frequently the most economic buy and usually these are liquids. Application by injection is in many cases the best method, as it places relatively insoluble materials into the root zone and prevents or minimizes loss by volatilization of nitrogen.

An advantage of injection is also that it gives minimum surface disturbance which is advantageous in dryland under decreased tillage conditions.

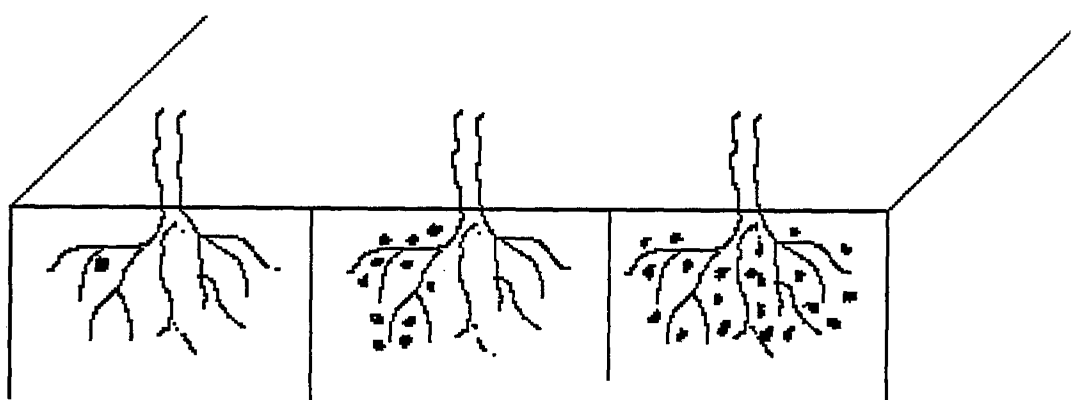
In the application of fertilizers for crop production the local soil and environmental conditions influence the method of application which is used.

THREE METHODS OF FERTILIZER APPLICATION



Band near Row | Strip | Broadcast

The strip and broadcast methods of fertilizer application are made on the surface before incorporation. The areas shown are for two rows.



Band near Row
Applied at planting | Strip
Applied on Surface
Plowed Under | Broadcast
Applied on Surface
Plowed Under

fig. 10.

Ref. "A Program for Increasing the Efficiency of Fertilizers"
by Dr. Stanley A. Barber. Purdue University.
SOLUTIONS - March/April, 1974 issue. p 24-25

GLOSSARY OF FERTILIZER PLACEMENT METHODS

Band - term used loosely to refer to any method in which fertilizer is applied in narrow strips. This term is also referred to as row application.

Broadcast - uniform application across the entire soil surface.

Deep - ill defined method of localized application at least 4 inches below the soil surface, usually injected with a knife or following subsoiler.

Dribble - surface application of fertilizer, usually in fluid form, in narrow band.

Dual - simultaneous knifed application of N and P or other fertilizer; typically involves anhydrous ammonia or N solution injected with fluid fertilizer at the same point of application.

Knifed - injected below the surface behind a knife to cut through the soil and make an opening for the application.

Plowdown - broadcast fertilizer incorported by plowing.

Pop-Up - placement of fertilizer directly with the seed; same as "seed placed."

Row - placement of fertilizer in bands on one or both sides of the row; typically applied 2 inches to the side and 2 inches below the seed of row crops; sometimes used synonymously with band application.

Starter - band, row, or seed-placed application at time of planting.

Strip - placement of fluid or dry fertilizer directly with the seed; same as pop-up for row crops or in the row for small grains.

Ref.: Developed by Emmett Schulte, Univ. of Wisconsin.

SOIL SAMPLING

Chemical analysis of soils or soil testing, is a means to determine the nutrient supplying power of the soil.

The sample should be a true representation of the area sampled, as the laboratory results will reflect only the nutrient status of the sample which is received.

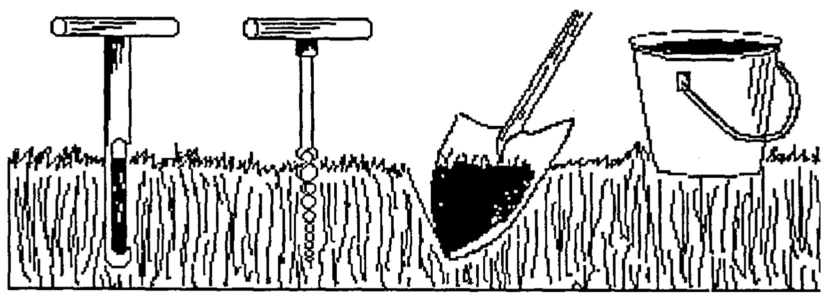
To obtain such a sample, the following items should be taken into consideration.

SAMPLING TOOLS

Several different tools, such as an auger, soil sampling tube, or spade may be used. Sample tubes or augers should be either of stainless steel or be chrome plated.

If using a pail to collect the soil, it should be plastic to avoid contamination from trace elements (i.e., zinc).

fig. 11



SAMPLE PREPARATION

Mix the various cores or slices together in a clean plastic container and take subsamples to be put into the sample bag.

A subsample should be 1 to 1 1/2 cups of soil, which is taken from a well-mixed composite from 10 to 20 random locations in the field. It is advisable to air-dry extremely wet samples before they are bagged.

Identify the sample bags with name, sample number, and field number which correspond with identification on sample information sheet.

SAMPLE AREA

Area to be sampled generally should not be more than forty acres. Smaller acreages may be samples when the soil is not uniform throughout the field.

Soils that differ in soil type, appearance, crop growth or past treatment should be sampled separately provided the area can be treated in that manner (fig. 12). Avoid small areas that are dead furrows, end rows, and which are poorly drained. Stay away from barns, roads, lanes and fence rows.

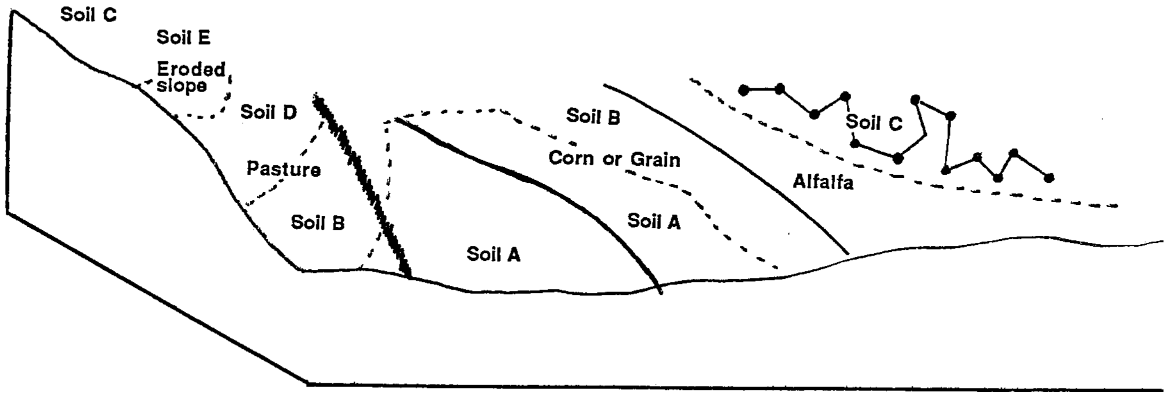


fig. 12

SAMPLING DEPTH

The required depth of sampling is influenced by many factors which are discussed in the section. (fig. 13).

1. Tillage Method

a. Conventional............................plow down
b. Reduced Tillage.......................3/4 of tillage depth
   if nutritional problems.........0-4" and 4-8"
c. Continuous Ridging.................0-6" in ridge) comb.
   0-4" in valley)
d. No Till.......................................0-8"
   to check pH.......................0-2"
e. Deep Placement.......................plow depth and below
f. Band Placement.......................plow depth

2. Crop

In general, samples are taken at depth where the main root system exists.

a. Established lawns and turfs

Sample depth of 3-4 inches, which is the actual rooting depth. The sample should not include roots and accumulated organic material from the surface.

b. Orchards

The greatest root activity occurs at a epthj of 8-12 inches. The sampling depth in orchard soils, therefore, should be up to 12 to 14 inches, taken at the edge of the dripline. Take one core sample from each 15 to 16 trees selected at random in the orchard. Mix the cores to obtain a composite sample which should be from an area no larger than 20 acres.

c. Flower Beds

One sample per 100 sq. ft. consisting of a composite of three cores taken up to 6-inches depth.

d. Vegetable Garden

Sample up to 6-inch depth at various locationsand prepare a composite sample.

e. Shrubs and Small Trees

Take samples at the edge of the limbspread to a depth of 8 to 10 inches.

3. Herbicide Residue Sampling

The depth of the soil sample depends on the herbicide in question and the soil. Most herbicides do not move much in fine textured soil, although there are exceptions (Amiben, Banvel, 2,4-D and Tordon). All herbicides have more movement in coarse textured soils. Correct sampling depth is normally the incorporation depth (commonly 3 - 4 inches).

4. Sampling for Nematodes

During the summer months is the best time to sample for most nematodes, as the crop growth can indicate the presense of nematodes by having stunted appearance. Take the samples, one per each 5 acres, to a depth of 8 inches in the row from 20-25 locations. Mix the samples as soon as possible and put a composite sample of one to two pints into a soil bag. Do not let the soil dry out or get hot. The best method for nematode identification sampling is by taking root tips and feeder root samples. Remember that nematodes can be present in large numbers without any visual symptoms showing on the plant roots.

5. Sampling for Nitrate and Ammonia Nitrogen and Soluble Salts

Rapid changes in nitrate and ammonia levels can occur when after taking a soil sample, the sample is stored moist and warm. It is advisable to dry the sample at 40° - 50°C (100° - 110°F) to ship, unless under refrigeration.

Because nitrate nitrogen leaches easily, deeper sampling is required to effectively determine the total available nitrogen in the soil. Sample to a 2-3 foot depth with samples taken at 7-inch to 1-foot increments to form possible composite samples. Sampling for soluble salts should be in accordance with instructions for nitrate sampling. Soil should be air-dried before shipping or storage for any length of time.

6. Subsoil Sampling

Subsurface or subsoil sampling is frequently of value, and samples can be collected to explain unexpected crop growth patterns resulting from either chemical or physical characteristics of subsoil layers.

Such sampling is also of importance in areas where deep-rooted crops are grown, which obtain the majority of their nutrient requirements at such depths.

To estimate the available soil nitrogen for crop use, the determination of nitrate-nitrogen levels in the soil profile is made.

Separate samples from plow depth and subsurface can be taken if sodium or salinity problems are anticipated.

TIMING OF TAKING SOIL SAMPLES

Generally, soil tests should be taken on all fields at least once every 2 to 4 years, but soils on which vegetables or other high cash crops are grown may need to be tested annually.

It really does not make much diference whether one is sampling cotton, corn, wheat, or soybean fields, the ideal time to sample is right after harvest. At that time of the year the fields are generally very accessible and good representative soil samples are easy to obtain. More time is also available for the evaluation of the soil test data and setting up a good soil fertilization program.

Due to the variation in nutrient availability that may be associated with time of sampling, it is suggested that any given area be sampled about the same time each year.

However, samples taken for diagnostic purposes (fertilization response, poor crop growth, evaluation of soil conditions) are best obtained while the problem areas are delineated by crop or other visual differences.

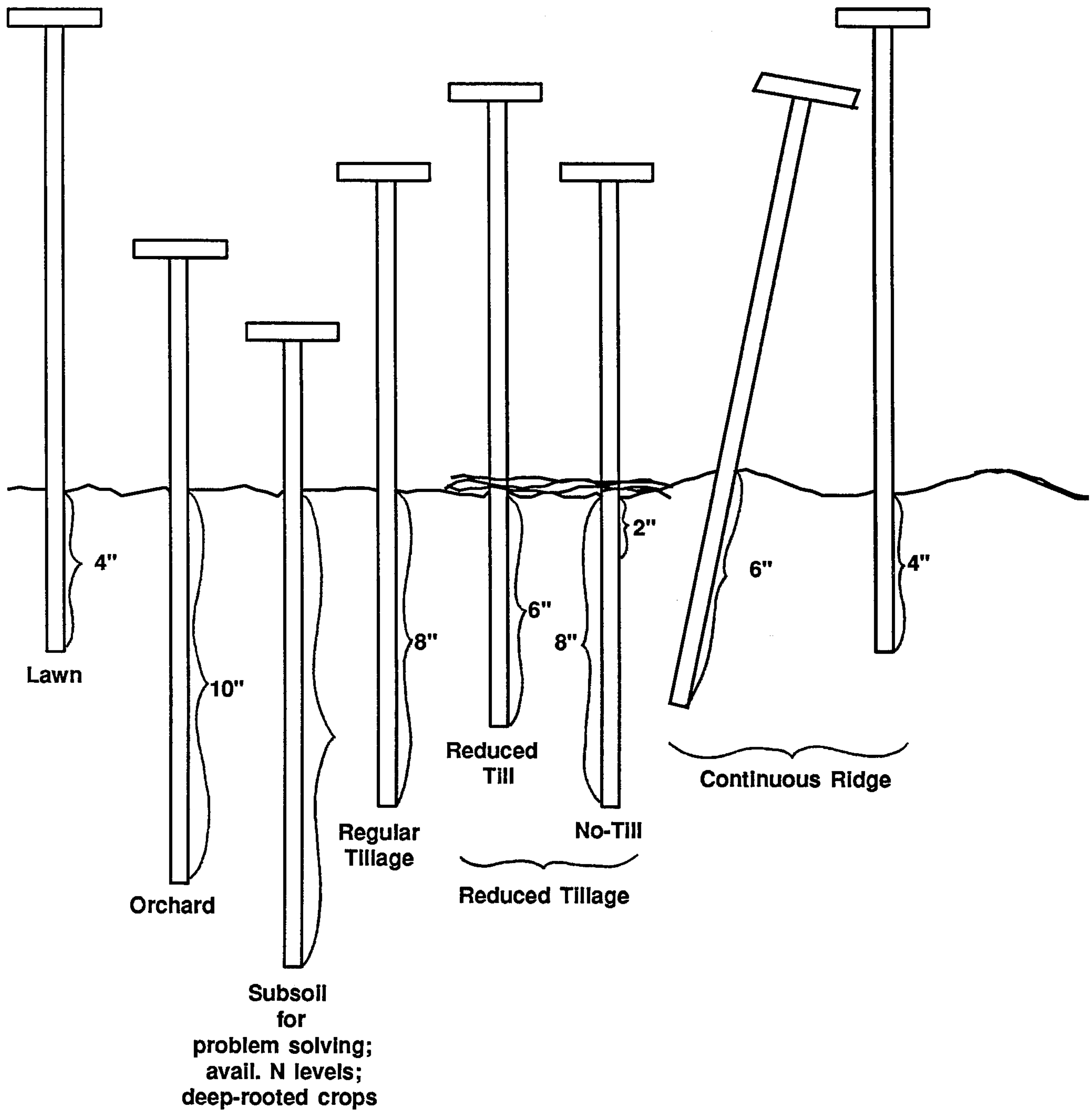


fig. 13 **Sampling Under Special Tillage Conditions**

FACTORS CAUSING IRREGULARITIES IN SOIL ANALYSIS

1. Varied depth of sampling.
2. Combining unlike soil areas into one composite sample.
3. Combining like soil areas with different past liming, fertilizer, or cropping histories into one composite sample.
4. Combining an insufficient number of subsamples into composite from extremely varied or land-leveled fields.
5. Attempting to use single composite sample for too large an acreage.
6. Varying amounts of organic matter or undecomposed organic matter in sample.
7. Soft rocks in sample.
8. Fertilizer or liming materials improperly applied or not thoroughly mixed in soil.
    A. Material still on top of soil.
    B. Coarse materials not dissolved or not extract soluble.
    C. Row fertilizer applications not constituting a proper proportion of sample.
9. Sheet erosion of materla applied.
10. Leaching of certain elements due to materials used, rates of application or excessive water.
11. Drought--too dry for fertilizers to dissolve and become part of the soil system.
12. Necessary soil microbes not present for proper release or conversion of fertilizers to available forms.
13. Forced drying of soil sample at high heat.
14. Soils that have been sampled, dried , or processed in contaminated containers.
15. Improper packaging of samples, allowing contaminants to become part of teh sample.
16. Mixing sample identity.

table 20.

CROP DEFICIENCY SYMPTOMS

BORON

Alfalfa	Top leaves turn yellow or white. Plants become stunted and have a rosetted appearance.
Apples	Apples become discolored. Pitting, cracking, and corking occurs.
Apricots	Twigs die back; fruit fails to set.
Beets (Red)	Scattered brown or black corky spots appear, usually at the surface or near growth rings.
Beets (Sugar)	Leaves turn yellow with cracking of midrib. Crowns rot and internal tissue has a brown discoloration.
Broccoli	Flower buds turn brown. Stems have water-soaked areas which later turn into eliptical cracks.
Cabbage	Stem may break down internally and show discolored water spot or cavities. Leaves may become thick and brittle and have mottled edges.
Carrots	Leaflet margins turn yellow, then reddish and finally brown as tissue dies. Roots may be small with deep, wide splits.
Cauliflower	Leaves become brittle and roll downward. Leaves may consist entirely of enlarged, corky midribs. Curd turns brown.
Celery	Stalk tissue becomes cracked, curls outward, and eventually becomes dark brown in color.
Citrus	Leaves turn yellowish bronze, become thick and brittle, and curl downward. Fruit may be hard or misshapened and have thickened rind.
Corn	New leaves show elongated transparent stripes which later become white. Barren stalks and short, bent cobs are typical.
Cotton	Boll becomes internally discolored at the base. Excessive shedding of squares and young bolls occurs. Squares and bolls rupture at base.
Grapes	Shoot tips die back and leaves become chlorotic. Vines may set no fruit. Clusters appear to dry up at bloom time.

table 20. (continued)

Lettuce	Growth is retarded and young leaves are malformed. Dark spots may appear on margins and coalesce into a complete marginal scorch.
Peanuts	Nuts have a dark, hollow area in the center.
Pears	Blossom blast and dieback of the growing tips occur. Fruit will be pitted, cracked, with internal cork.
Plums	Leaves and fruit drop early. Leaves are small, narrow, long, and strap-shaped with irregular margins. Shoot tips die back.
Radishes	Leaves become pale and chlorotic and petioles brittle. Roots may have rough surface and lose color intensity. Cracks are common.
Small Grain	Plants turn pale green. Heads either fail to emerge or are poorly developed and sterile.
Spinach	Plants are stunted and leaves are pale green. Plants may appear flattened instead of having normal, upright growth.
Strawberries	Plants die back. Fruit may appear pale and crack.
Tobacco	Leaves pucker and buds become deformed.
Tomatoes	Internodes become shortened. Leaves may show chlorosis or turn orange-yellow near dead growth points. Fruit fails to set.
Turnips	Root skin may become roughened. Dark brown, water-soaked areas appear in the center of the root.

ZINC

Alfalfa	Plants become stunted and may show dieback.
Beets (Sugar)	Recently matured leaves are light green. Small pits develop between veins in upper leaf surfaces.
Citrus	New leaves are small. Affected leaves have irregular creamish-yellow mottled areas.
Corn	Leaves may show light striping to overall whitening of leaf tissue between leaf edge and midrib. Plants are stunted with shortened internodes.

table 20. (continued)

Cotton	Internodes become shortened and plants have a bush appearance. Leaves become thick and brittle and may show bronzing and chlorosis.
Flax	Plants have a rosetted appearance. Grayish-brown spots appear on young leaves. Upon drying, spots may change color to brown or white.
Fruit Trees (Apple, Apricot, Cherry, Peach, Plum)	Young leaves become chlorotic and crinkled and characteristic rosettes are formed. Internodes become shortened at tips of shoots.
Potatoes	Veins become rigid and upper internodes shortened. Leaf roll and bronzing may occur.
Small Grain	Tips and margins of older leaves become grayish in color. Other leaf tissue is gray to bronze-green.
Soybeans	Leaves are small with yellowing and bronzing between veins.
Tomatoes	Leaves are small with some curling.
	MANGANESE
Alfalfa	Older leaves are yellow. New leaves are yellow with green veins.
Apples	Leaves are yellow with green veins which usually occurs in a V-shaped pattern. Young leaves may remain green.
Beets (Red)	Leaves turn yellow with veins remaining green. Growth is erect. Margins are curled upward and red and purple tinting may appear.
Beets (Sugar)	New leaves turn yellow. Bronzing of upper leaf surface. Necrotic spots develop along veins.
Cabbage	Leaves are small and yellow. Yellow mottling may be seen between veins.
Celery	Leaflets are yellow with green veins starting at margins. Leaflets elsewhere are olive green.
Cherry	Leaves are yellow with green veins starting at margins to over the entire leaf.

table 20. (continued)

Corn	Leaves show yellow and green striping. Stalks are thin.
Cotton	Young leaves are yellow with green veins. Tissue may become yellowish to reddish gray between veins.
Cucumber	Leaves become yellowish white while veins remain green. Blossom buds often turn yellow. Stems are small and weak.
Flax	Leaves become pale and chlorotic. Necrosis may develop.
Peas	Leaves may show slight chlorosis. Flat surfaces of the seed may have a brown cavity in the center.
Potatoes	Leaves are small, rolled forward, and somewhat chlorotic. Dark brown spots along veins may appear on younger leaves.
Small Grain	General yellowing of plants and stunting. Leaves may show gray-brown necrotic spots and streaks.
Soybeans	Leaves are yellow with green veins. Leaves may turn completely yellow and show necrotic spots.
Sugar Cane	Leaves become striped. Necrotic areas appear in interveinal areas which later coalesce making stripes of dead, dry tissue.
Tobacco	Foliage has a pale appearance. Upper leaves become mottled.
Tomatoes	Leaves near shoot tips are small, rolled forward, and somewhat chlorotic. Small, dark brown spots may appear on leaves.

IRON

The universal symptoms of iron deficiency in green plants is chlorosis. The green color disappears between the veins first and as the deficiency becomes more severe, the small veins, then the large ones, lose their green color. At the early chlorosis stage, there is a sharp distinction between green veins and the light green (or yellow) tissue between the veins.

COPPER

Alfalfa	Leaflets fold backward along petioles and then wither and die. No yellowing occurs.
Apples	Terminal leaves develop necrotic spots and brown areas, wither and die.

table 20. (continued)

Apricots	Terminal growth dieback. Terminals show rosette formation and multiple bud growth.
Avocado	Older leaves have a dull appearance. Shoot tips have multiple bud formation. New leaves abort and dry up.
Beans (Dry)	Leaf edges turn yellow, wither, turn gray and eventually die. Leaves curl and twist and fail to unroll properly.
Clover (Red)	Leaves become light green, wither, and die. Growth is poor.
Corn	Leaves turn yellow with withering and graying of leaf tips. Leaves turn backward and tips of newly emerged leaves die.
Currant	Leaves are pale green and mottled. Growing tips die back.
Eggplant	Leaves are pale green and mottled. Growing tips die back.
Flax	Top leaves turn yellow with rosetting.
Grapefruit	Leaves show a "bowing up" of the midrib. Large dark green leaves develop on long, soft, angular shoots.
Lemon	Twigs show multiple bud development producing a dense, somewhat bushy growth on trees.
Lettuce	Leaves become chlorotic, bleached, and cupped.
Oats	Leaves roll at the tips and become chlorotic. Yellow-gray spots may appear which turn yellow-white.
Olive	Growing tips die. Auxilliary buds below the dead part are often stimulated and produce a bushy growth.
Onion	Scales are thin and pale yellow. Bulbs lack firmness and leaves are chlorotic.
Peach	Malformed leaves develop at the shoot tips and turn yellow between the veins giving the appearance of a green network on whitish-green background.
Pear	Terminal shoots wither and die. Recurrent dieback and renewal of growth may cause a bushy "witches broom" appearance.

table 20. (continued)

Peas	Terminal stem tips become wilted. Flowers abort and no pods are forming.
Pepper	Leaves are dark-bluish green. Plants become stunted and fail to produce flowers.
Plum	Terminal buds die and leaves turn a yellowish color. Eruptions and gumming of the bark may occur.
Potatoes	Growth is retarded with a bluish-green color. Leaves lose turgor and may remain permanently wilted. Terminal buds drop when flowers are developing.
Small Grain	Plants show withering and graying of leaf tips. Leaves turn backward and tips of newly emerged leaves die.
Tomatoes	Plants become stunted with a bluish-green color. Leaves curl and flowers do not form. Chlorosis develops and leaves and stems lack firmness.
	MOLYBDENUM
Legumes	Plants lack vigor and are light green in color. Symptoms are similar to those of nitrogen deficiency.
Non-Legumes	Plants show symptoms of excess nitrate. The leaves are yellowish in color, especially in spots where the nitrate accumulates, such as between the veins and along the leaf margins. The leaf may curl or cup upwards or become distorted, often developing into little more than the midrib with a narrow wavy green stripe along either side.

PLANT ANALYSIS

REASONS FOR USING PLANT ANALYSIS

For growth, development and production plants require a continuous, well-adjusted supply of essential mineral nutrients. If any of these nutrients are in limited supply, crop performance decreases and ultimately results in nutritional disorders. Shortages of mineral nutrients manifest themselves in terms of reduced crop yields and/or poor quality of the crop.

Soil testing generally precedes plant testing for routine fertilizer advisory purposes; however, plant analysis in combination with soil testing is an excellent way to develop a strong fertility program for crop production. As soil analysis indicates the relative availability of nutrients in the soil for crop use, plant analysis provides an indication of which nutrients have been or are absorbed by the plants.

Leaves are considered as the focus of physiological activities and changes in mineral nutrition appear to reflect in the concentrations of leaf nutrients.

Motivation for the determination of nutrient concentration in leaves for diagnostic purposes arises from the assumption, that a significant relationship exists between nutrient supply and levels of elements, and that increases or decreases in concentrations relate to higher or lower yields, respectively.

POSSIBLE CAUSES FOR PLANT NUTRIENT LEVELS ABOVE OR BELOW THE SUFFICIENCY LEVEL

Above Sufficiency Level	Below Sufficiency Level
NITROGEN (N)	
(1) Excessive nitrogen fertilization	(1) Inadequate nitrogen fertilization
(2) High rate of nitrification at the time	(2) Low nitrification rate or perhaps denitrification
(3) Shortage of other element(s)	(3) Low soil phosphorus level
SULFUR (S)	
(1) Excessive available soil sulfate level from natural or applied sources.	(1) Low available soil sulfate level
	(2) Excessive available nitrogen on low organic matter soils
	(3) Inadequate sulfate fertilization or excessive leaching of sulfates

PHOSPHORUS (P)

(1) High soil phosphorus level or excessive application of phosphate fertilizers

(1) Low soil phosphorus level or inadequate phosphorus fertilization
(2) Wet soils
(3) Low soil pH (<5.5) or high soil pH (>7.2).

POTASSIUM (K)

(1) High soil potassium level or excessive application of potassium fertilizers

(1) Low soil potassium level or inadequate potassium fertilization for crop needs
(2) Excessive nitrogen application

MAGNESIUM (Mg)

(1) Diseased or dead tissue
(2) Old plant tissue

(1) Low soil magnesium level (can be due to low soil pH, continuous use of hi-calcium lime on low magnesium soils, or naturally calcareous soils low in magnesium)
(2) High soil potassium levels or application of potassium fertilizers
(3) High soil nitrogen availability

CALCIUM (Ca)

(1) Diseases or dead tissue
(2) Old plant tissue

(1) Low soil calcium level (can be due to low soil pH or highly leached low exchange capacity soils)
(2) High soil potassium levels or heavy application of potassium fertilizers
(3) High soil nitrogen availability

IRON (Fe)

(1) Reduced soil conditions from very wet or flooded soils
(2) Zinc deficiency
(3) Soil or dust contamination

(1) High soil pH
(2) Excessive zinc, phosphate, copper, or manganese availability

MANGANESE (Mn)

(1) High nitrogen or phosphorus applications on acid, low organic soils
(2) Low soil pH
(3) Soil or dust contamination
(4) Contamination from certain fungicide sprays

(1) Low natural soil manganese content
(2) Low availability due to high soil pH (7.0 or above), high organic soils, high soil moisture, and very low organic matter content

(1) Excessive or improper boron fertilization (2) Soil pH lowered from neutral or above to acid	(1) Low soil availability (can be caused by high soil pH or highly leached sandy soils, or low organic matter soils)

COPPER (Cu)

(1) High soil copper content (may be caused by previous year's pesticide sprays or dusts now contained in soil)	(1) Low soil availability (associated with high soil pH, high organic matter content, high concentrations of iron and manganese, and highly leached soils)

ZINC (Zn)

(1) Naturally high soil zinc levels (2) Contamination from brass or galvanized equipment	(1) Low soil zinc content (2) Low soil availability (due to leached soils, high soil pH, high available phosphorus, cut areas with low organic matter content, and certain muck soils)

MOLYBDENUM (Mo)

(1) High soil pH (2) Potassium deficiency in some cases	(1) Low soil pH (5.5). (2) High phosphate levels

SODIUM (Na)

(1) High sodium content in soils	(1) Seldom, if ever, deficient except possibly for sugar beets or spinach

ALUMINUM (Al)

(1) Low soil pH (2) Reduced conditions associated with wet or flooded soils (3) Soil or dust contamination	(1) Cannot be deficient. Not an essential element

SOURCES OF VARIATION

During the early vegetation period, the rate of nutrient uptake is high and this consequently leads to high nutrient contents in the plant tissues. Thus, physiological age is an important factor of variability and young, metabolically active leaves generally contain higher amounts of nutrient elements.

Different parts or tissues of the plants also contain and accumulate varying amonts of elements and this, of course, is important with regard to the choice of the plant part to be sampled and analyzed. This part is called the "index part."

Other major sources of variability in nutrient concentrations are plant species, cultivars or varieties, morphological position on the plants, internutrient effects as well as seasonal variation, time of sampling, time of day, weather conditions, and climate. Often neglected sources of variation include handling of samples, cleaning methods, drying and grinding procedures, and analytical methodology.

A meaningful interpretation of plant analysis data depends upon the care taken in all of the above-mentioned items.

DRIS

A concept that has been developed by Sumner and others is that of using ratios of nutrients to diagnose nutrient deficiencies.

This nutrient ratio approach reduces the importance of the plant growth factor. However, maximum yield or optimum growth is used to calibrate the **D**iagnosis and **R**ecommendation **I**ntegrated **S**ystem (DRIS).

For the nutrient ratio approach to be useful, many nutrient ratios must be used simultaneously. The effects of age of the tissue, position of the leaf sampled, and variety are minimized with this concept. In addition, the DRIS approach establishes a relative order of nutrient requirement of the crop.

We have DRIS program reporting available for alfalfa, corn, potatoes, soybeans, and wheat. New programs are in the development stage, and further information about the status can be obtained from our field representatives or agronomists.

Plant analysis is of value if it is used as a diagnostic tool; however, the limitations must be kept in mind when making interpretations. Plant analysis is a very good tool when used in conjunction with soil testing. Plant analysis alone can only provide information on plant food utilization and nutrient content of plants, (tables 21, 26 and not 30), not soil requirements.

table 21.

PLANT FOOD UTILIZATION

FIELD CROPS

CROP	YIELD	NUTRIENTS (lbs/acre) Nitrogen N	Phosphate P_2O_5	Potash K_2O	Magnesium Mg	Calcium Ca	Sulfur S
Alfalfa	10 T	600	120	600	53	280	51
Corn	200 bu. grain	150	87	57	18	4	15
	stover	116	27	209	47	38	18
Cotton	1500 lbs. lint	105	40	45	12	9	7
	stalks, etc.	95	30	85	24	70	25
Grasses (forage)							
Birdsfoot trefoil	4 T	192	84	272	32	170	30
Bromegrass	5 T	220	66	310	10	40	20
Clover-Grass	6 T	300	90	360	30	170	30
Lespedeza	3 T	150	50	150	25	60	20
Orchard Grass	6 T	300	100	375	25	50	35
Fescue (tall)	5 T	200	80	230	20	45	22
Timothy	5 T	185	67	310	18	40	20
Grasses (turf)							
Bentgrass	2.5 T	260	66	146	13	35	10
Bermudagrass	4.0 T	225	40	160	20	40	15
Bluegrass	3.0 T	200	55	180	20	60	25
Peanut	5000 lbs. nuts	175	33	41	7	12	13
	Vines	125	25	174	24	90	15
Small Grains							
Barley	100 bu. grain	110	40	35	8	11	10
	straw	40	15	115	9	13	10
Oats	100 bu. grain	80	25	20	5	4	8
	straw	35	15	125	15	11	11

table 21. (continued)

PLANT FOOD UTILIZATION

CROP	YIELD	NUTRIENTS (lbs/acre)					
		Nitrogen N	Phosphate P_2O_5	Potash K_2O	Magnesium Mg	Calcium Ca	Sulfur S
Rice	7000 lbs. grain	98	42	23	8	6	5
	straw	52	18	132	9	18	10
Wheat	100 bu. grain	160	60	40	15	5	8
	straw	50	12	140	13	21	16
Sorghum (milo)	180 bu. grain	135	70	40	15	13	20
	stover	145	50	250	30	55	18
Soybeans	60 bu. grain	250	50	86	17	12	12
	stover	80	20	60	10	90	14
Sugar beets	30 T roots	125	20	200	25	35	10
	tops	130	30	325	50	55	35
Sugarcane	100 T stalks	160	95	345	35	50	50
	trash	200	65	275	60	60	35
Tobacco (flue-cured)	3000 lbs. leaves	85	25	155	20	72	14
	stalks, etc.	45	15	100	10	43	8
(burley)	4000 lbs. leaves	145	25	148	27	85	22
	stalks, etc.	135	21	172	18	55	12
FRUITS							
Apple	500 bu.	88	38	160	20	50	20
	250 cwt.	100	46	180	24	53	21
Grape	12 T	102	36	156	18	36	26
Orange	30 T (600 cwt)	290	60	350	42	250	30
Peach	600 bu. (288 cwt)	96	40	120	24	90	21

table 21. (continued)

PLANT FOOD UTILIZATION

VEGETABLES

CROP	YIELD	NUTRIENTS (lbs/acre)					
		Nitrogen N	Phosphate P_2O_5	Potash K_2O	Magnesium Mg	Calcium Ca	Sulfur S
Cabbage	35 T	270	75	247	36	84	65
Cantaloupe	175 cwt.	65	20	115	12	30	10
Celery	75 T	380	165	750	60	195	105
Cucumber	20 T	180	58	340	50	160	32
Lettuce	20 T	120	40	200	14	56	16
Onion	30 T	180	80	160	18	46	55
Potato	25 T (500 cwt.)	265	100	500	45	70	24
Spinach	6 T	60	18	36	6	15	5
Sweet Potato	15 T (300 cwt.)	155	70	310	25	18	24
Tomato	30 T	200	60	340	35	66	42
Turnip	5 T (bunched)	64	14	70	5	27	9
TROPICAL CROPS							
Banana	1200 plants	400	400	1500	156		
Cocoa	900 lbs. beans	416	108	733	119		
	(inc. husks, etc.)						
Coconut	12,100 nuts +	96	31	206	13		8
	2700 lbs. copra						
	and fronds						
Oil Palm	220 cwt.	172	74	268	55		
Pineapple	357 cwt.	153	125	596	64		14

Ref. The Potash and Phosphate Institute; The Ferilizer Institute; California Fertility Assoc.

* The figures mentioned in this table may vary with yield goal, soil type, balance of nutrient levels in the soil, seasonable conditions, moisture levels, and crop variety.

** Legumes normally obtain 50 to 65% of their nitrogen requirements from the air.

CROP MONITORING AND PETIOLE ANALYSIS

Crop monitoring is a method to prevent or correct nutrient imbalance during the growing season.

We have developed crop monitoring programs for corn, grain sorghum, wheat, rice and cotton. Table 22 shows suggested sampling procedures for these crops.

table 22.

CROP MONITORING*
SAMPLING PROCEDURES**

CROP	STAGE OF GROWTH	PLANT PART TO SAMPLE	NO. OF PLANTS TO SAMPLE
CORN	8-leaf stage	whole above ground portion of plant	25-30
	just prior to tasseling	leaf below and opposite from ear	15-20
	immediately after silking	leaf below and opposite from ear	15-20
COTTON ***	1 week prior to 1st bloom	petiole of lst fully expanded leaf from top of plant	25-35
	repeat weekly for 8 to 9 weeks	petiole of lst fully expanded leaf from top of plant	25-35
GRAIN SORGHUM	8-leaf stage	whole above ground portion of plant	25-30
	right before heading	2nd leaf from top of plant	15-20
	during mid-bloom	2nd leaf from top of plant	15-20
RICE	mid-tillering	most recently matured leaf from top of plant	one pint of plant material
	panicle initiation	most recently matured leaf from top of plant	one pint of plant material
	panicle differentiation (just prior to boot)	most recently matured leaf from top of plant	one pint of plant material
WHEAT	mid-tillering	whole above ground portion of plant	one pint of plant material
	next 3-4 sampling times will depend on lab. data of first sampling	whole above ground portion of plant	one pint of plant material

*Soil analysis should be made prior to crop monitoring program being started.
Soil and plant analysis parameters to be tested or suggested in Crop Monitoring brochure.
Special information sheets are available upon request.

** Samples taken at different stages of growth should be collected from the same areas.

*** Soil Samples to be taken at depths of 0-6", 6-18", (and 18-30"). Mix samples taken at identical depths from 12-15 locations per field

A soil analysis should precede a good crop monitoring program to assess the fertility needs and to correct nutrient status of the soil before planting is initiated.

Many times a complete tissue analysis can detect a nutrient deficiency before symptoms appear in the plant. Diagnosis of "hidden hunger" often gives the grower the opportunity to correct the problem during that season; however, once nutrient deficiency symptoms appear, it is usually too late to avoid some loss. Crop monitoring could prevent this from occurring.

table 23.

RELATIONSHIP BETWEEN NUTRIENT CONCENTRATION IN PLANT TISSUE AND CROP BEHAVIOR

Acute deficiency	Visual symptoms and direct effect of fertilization and leaf application.	Limit of visual symptoms.
Latent deficiency	No visual symptoms, but better yield and quality by fertilization. "Hidden Hunger"	Limit of yield response.
Optimal nutrient status	Good growth and generally good quality	
Luxury consumption	Good growth, but internal element accumulation and possible interaction.	Starting level of toxicity.
Excess or toxicity	Yield decrease, possibly with visual symptoms.	

Ref.: Finck, A.Z. Pflanzenernahrung u. Bodenkunde. 119:197-208 (1968)
FAO Soils Bulletin 38/1 (1980) P. 25 - Soil and Plant Testing and Analysis.

Nitrogen is the nutrient most often monitored due to its variable nature. This element can be checked in the leaf joint or leaf stem (petiole) of the plant.

Petiole analysis to identify nitrogen, phosphorus, and potassium levels is often performed during the growth of vegetables and some other crops (table 24).

Specific information about crop monitoring programs can be obtained from our agronomists.

table 24.

CROP MONITORING
Sampling Procedures for Vegetables

Crop	Time of Sampling	Plant Part	Nutrient	Nutrient Level Deficient	Nutrient Level Sufficient
Asparagus	Midgrowth of fern	4" tip section of new fern branch.	NO_3-N ppm	100	500
			PO_4-P ppm	800	1600
			K %	1	3
Bean, bush snap	Midgrowth	Petiole of 4th leaf from tip.	NO_3-N ppm	2000	4000
			PO_4-P ppm	1000	3000
			K %	3	5
Bean, bush snap	Early bloom	Petiole of 4th leaf from tip.	NO_3-N ppm	1000	2000
			PO_4-P ppm	800	2000
			K %	2	4
Broccoli	Midgrowth	Midrib of young mature leaf	NO_3-N ppm	7000	10000
			PO_4-P ppm	2500	5000
			K %	3	5
Broccoli	Ist Buds	Midrib of young mature leaf	NO_3-N ppm	5000	9000
			PO_4-P ppm	2000	4000
			K %	2	4
Brussels Sprouts	Midgrowth	Midrib of young mature leaf	NO_3-N ppm	5000	9000
			PO_4-P ppm	2000	3500
			K %	3	5
Brussels Sprouts	Late growth	Midrib of young mature leaf	NO_3-N ppm	2000	4000
			PO_4-P ppm	1000	3000
			K %	2	4
Cabbage	At heading	Midrib of wrapper leaf	NO_3-N ppm	5000	9000
			PO_4-P ppm	2500	3500

table 24. (continued)

Crop	Time of Sampling	Plant Part	Nutrient	Nutrient Level Deficient	Sufficient
			K %	2	4
Cantaloupe	Early growth	Petiole of 6th leaf from growing tip	NO_3-N ppm	8000	12000
			PO_4-P ppm	2000	4000
			K %	4	6
Cantaloupe	Early fruit	Petiole of 6th leaf from growing tip	NO_3-N ppm	5000	9000
			PO_4-P ppm	1500	2500
			K %	3	5
Cantaloupe	1st mature fruit	Petiole of 6th leaf from growing tip.	NO_3-N ppm	2000	4000
			PO_4-P ppm	1000	2000
			K %	2	4
Carrot	Midgrowth	Petiole of young mature leaf	NO_3-N ppm	5000	10000
			PO_4-P ppm	2000	4000
			K %	4	6
Cauliflower	Buttoning	Midrib of young mature leaf	NO_3-N ppm	5000	9000
			PO_4-P ppm	2500	3500
			K %	2	4
Celery	Midgrowth	Petiole of newest fully elongated leaf	NO_3-N ppm	5000	9000
			PO_4-P ppm	2000	4000
			K %	4	7
Celery	Near maturity	Petiole of newest fully elongated leaf	NO_3-N ppm	4000	6000
			PO_4-P ppm	2000	4000
			K %	3	5
Cucumber pickling	Early fruit set	Petiole of 6th leaf from tip	NO_3-N ppm	5000	9000
			PO_4-P ppm	1500	2500
			K %	3	5
Kiwi	Midgrowth	Petiole of young mature leaf	NO_3-N ppm	2000	9000
			PO_4-P ppm	1000	2500
			K %	2	4

table 24. (continued)

Crop	Time of Sampling	Plant Part	Nutrient	Nutrient Level Deficient	Sufficient
Lettuce	At heading	Midrib of wrapper leaf	NO_3-N ppm	4000	8000
			PO_4-P ppm	2000	4000
			K %	2	4
Pepper, chli	Early growth	Petiole of young mature leaf	NO_3-N ppm	5000	7000
			PO_4-P ppm	2000	3000
			K %	4	6
Pepper chili	Early fruit set	Petiole of young mature leaf	NO_3-N ppm	1000	2000
			PO_4-P ppm	1500	2500
			K %	3	5
Pepper, sweet	Early growth	Petiole of young mature leaf	NO_3-N ppm	8000	12000
			PO_4-P ppm	2000	4000
			K %	3	5
Pepper, sweet	Early fruit set	Petiole of young mature leaf	NO_3-N ppm	3000	5000
			PO_4-P ppm	1500	2500
			K %	3	5
Potatoes	Early season	Petiole of 4th leaf from growing tip.	NO_3-N ppm	8000	12000
			PO_4-P ppm	1200	2000
			K %	9	11
Potatoes	Midseason	Petiole of 4th leaf from growing tip	NO_3-N ppm	6000	9000
			PO_4-P ppm	800	1600
			K %	7	9
Potatoes	Late season	Petiole of 4th leaf from growing tip	NO_3-N ppm	3000	5000
			PO_4-P ppm	500	1000
			K %	4	6

table 24. (continued)

Crop	Time of Sampling	Plant Part	Nutrient	Nutrient Level Deficient	Nutrient Level Sufficient
			K %	4	6
Spinach	Midgrowth	Petiole of young mature leaf	NO_3-N ppm	4000	8000
			PO_4-P ppm	2000	4000
			K %	2	4
Sugarbeets	Midgrowth	Petiole of latest mature leaf	NO_3-N ppm	1000	2000
			PO_4-P ppm	750	1200
			K %	1	3
Sweet Corn	Tasseling	Midrib of lst leaf above primary ear.	NO_3-N ppm	500	1500
			PO_4-P ppm	500	1000
			K %	2	4
Sweet Potatoes	Midgrowth	Petiole of the 6th leaf from growing tip	NO_3-N ppm	1500	3500
			PO_4-P ppm	1000	2000
			K %	3	5
Tomatoes, canning	Early bloom	Petiole of 4th leaf from growing tip	NO_3-N ppm	8000	12000
			PO_4-P ppm	2000	3000
			K %	3	6
Tomatoes, canning	Fruit 1" dia.	Petiole of 4th leaf from growing tip	NO_3-N ppm	6000	10000
			PO_4-P ppm	2000	3000
			K %	2	4
Tomatoes, canning	First color	Petiole of 4th leaf from growing tip	NO_3-N ppm	2000	4000
			PO_4-P ppm	2000	3000
			K %	1	3
Watermelon	Early fruit	Petiole of 6th leaf from growing tip	NO_3-N ppm	5000	9000
			PO_4-P ppm	1500	2500
			K %	3	5

California data.
NO_3-N and PO_4-P obtained by using 2% acetic acid solution.
Total K obtained by digestion.
Ref. Soil Testing and Plant Analysis - SSSA 1973. P.369/70

SAMPLING

Selective sampling, of course, is the first important step and it is necessary to standardize plant/leaf/petiole sampling techniques as perfectly as possible. Plant tissue sampling procedures are given in the following table 25.

It is important that these instructions are carefully followed, as the interpretation of the analysis data is based on the time of sampling and plant part which was sampled for analysis.

When nutrient disorders are suspected, sampling may be done at the time at which they are observed, AND it may be advisable to collect samples at the same time from healthy plants, which are growing in the same area. Soil sample analysis data from poor and good areas will greatly enhance the ultimate reliability of the interpretation and recommended treatments.

Samples should NOT be taken from plants, which are damaged by disease, insects, or chemical applications, unless it is the objective of a study. Dead plants or plant materials also should not be included in the sample. Do not ship leaf samples in sealed plastic bags.

HANDLING AND PACKAGING

If possible, fresh tissue should be air-dried before packaging and shipment to prevent decomposition during transit.

Where samples are large, as during the later stages of growth of corn, it is advisable to stack the leaves and cut tip and base off the leaves, leaving the middle 10-12 inch portions of the leaves for mailing and analysis. This can greatly reduce the shipping volume and costs.

The mailing of soil or dust-covered samples should be avoided. Such samples can be cleaned with a damp cloth or paper towel. Do NOT place root portions or soil and plant parts together into the same mailer.

Include a sample information sheet, which gives the name and address of the sender and grower, party to be billed, party which should receive the analytical data and interpretation, plant species and plant part sampled, stage of growth, visual symptoms when sampled, analysis desired, and any other information which is of importance.

Select the best and fastest method of sending the package.

table 25.

PLANT TISSUE SAMPLING PROCEDURES

CROP	STAGE OF GROWTH	PLANT PART	NO. OF PLANTS
FIELD CROPS			
Alfalfa	At bud or 1/10 bloom	Upper 1/3 of plant.	30-40
Clover	Prior to bloom	Upper 1/3 of plant.	30-40
Corn	Seedling stage	All of above ground portion.	20-30
	Prior to tasseling	First fully developed leaf below whorl.	15-20
	From tasseling to silking	Leaf opposite and below ear.	15-20
Cotton	At full bloom	Youngest fully matured leaf.	40-50
Grasses	At stage of best quality	Leaves from upper 1/3 of the plant.	30-40
Mint	At midgrowth	Young fully developed leaf.	30-40
Peanut	Before or at bloom stage	Young fully developed leaf.	40-50
Small Grain (Barley, oats rice, wheat, rye)	Pior to heading	Four uppermost leaves.	40-50
Sorghum (milo)	Before or at heading	Second leaf from top of plant.	20-30
Soybeans	Prior to or at initial bloom, before pod set	Fully developed leaves at top of plant.	20-30
Sugarbeets	At midgrowth	Fully expanded leaf midway between inside and outside of the whorl. Separate petiole from the blade.	30-40
VEGETABLES			
Asparagus	At maturity	Fern from 18-30 inches up.	30-40
Beans (snap, lima)	Prior to or at initial bloom, before pod set	Fully developed leaves at top of plant.	20-30
Brussels Sprouts	At midgrowth	Young mature leaf.	20-30
Celery	At midgrowth	Young mature leaf.	20-30
Cucumber	Before fruit set	Mature leaf near growing tip of plant.	20-30
Head Crops (Cabbage, cauliflower, etc.	Before heading	Young mature leaf from center of whorl.	10-20
Leaf Crops (Collards, endive, kale, lettuce, etc.)	At midgrowth	Recently matured leaf.	30-50

table 25. (continued)

Melons (musk-, water- cantaloupe, pumpkin, etc.)	Prior to initial fruit set	Mature leaf near growing tip of plant.	20-30
Peas	Before flowering	Leaves from 3rd to 5th nodes from the top.	40-60
Pepper (Chili, sweet)	At midgrowth	Young mature leaf.	40-50
Potato	Prior to or during early bloom	Third to sixth leaf plus petiole from growing tip	20-30
Root Crops (Beet, carrot, onion, radish, turnip, etc.)	At midgrowth before root enlargement	Center mature leaves	20-30
Tomato	Before or during early bloom stage	Third or fourth leaf from the growing tip.	20-30
FRUIT AND NUT TREES			
(Almond, apple, apricot, cherry, fig, olive, peach, pear, plum, prune)	Five to eight weeks after full bloom	4 to 8 leaves from spurs or near base of current season's growth	20-30
Citrus (Grapefruit, lemon-lime, orange, etc.)	At midgrowth	Recently matured leaves from non-fruiting terminals	30-40
Pecans	Six to eight weeks after bloom	Middle leaflet pairs from terminal shoots	30-40
Walnuts	Six to eight weeks after bloom	Middle leaflet pairs from terminal shoots	30-40
VINES			
Grapes	End of bloom period	Petioles or leaves adjacent to fruit clusters	80-100
Kiwi	At midgrowth	First to third leaves beyond fruit on fruiting canes or mid-cane leaves on non-bearing vines. Use leaf blades.	50-60
FRUITS			
Blueberries	At midgrowth	Youngest mature leaves	50-60
Raspberries	At midgrowth	Youngest mature leaves on laterals or "primo" canes	30-40
Strawberries	At midgrowth	Leaf blades without petioles from youngest mature leaves	40-50

table 25. (continued)

TROPICAL CROPS			
Banana	At maturity	One third section on either side of midrib of leaf	5-10
Cacao	At midgrowth	Most recently matured leaf	10-20
Cocos Palm	Four years old	Fourth leaf	2-5
	Five to seven years old	Ninth leaf	2-5
	More than seven years old	Fourteenth leaf	2-5
Coffee (Coffea Arabica)	At midgrowth	Third and fourth leaf pair from apical bud	10-20
Oil Palm	At maturity	Central leaflets of frond 17.	5-10
	Young	Central leaflets of frond 9. Remove midribs from leaflets	10-15
Pineapples	At midgrowth	Middle third section of white basal portion of last matured leaf	10-20
Rubber Palm	At maturity	Most recently matured leaf	2-5
Sugarcane	Up to four months old	Third or fourth fully developed leaf from top of plant	20-30
Tea	At maturity	Most recently matured leaf	30-40
Tobacco	Before bloom	Uppermost fully developed leaf	10-15
ORNAMENTALS AND FLOWERS			
Azalea Begonia Bougainvillea Geranium Hydrangea and others*	At midgrowth	Recently matured leaves from around plants	10-20
Deciduous Trees Deciduous Shrubs and Vines, Broadleaf Evergreens	At maturity	Most recent expanded leaves from around plants	5-10
Narrowleaf Evergreens	At maturity	Terminal cuttings 2-3 inches in length	40-50

table 25. (continued)

Carnations	Newly planted	Fourth or fifth leaf pairs from base of plant	20-30
	Established	Fifth or sixth leaf pairs from base of plant	20-30
Chrysanthemums	Before or during early flowering	Top leaves on flowering stem	20-30
Poinsettias	Before or during early flowering	Most recently matured fully expanded leaf	15-20
Roses	During flowering	Upper leaves on the flowering stem	25-30
Rubber Trees	At midgrowth	Latest matured leaf	2-5

* information about many other floracultural plants is available on request.

PLANT ANALYSIS INTERPRETATION

As previously discussed, plant analysis can be used as a guide for the fertilization of crops; to evaluate the fertilization programs; to monitor crop nutrient balance or imbalance; as a general diagnostic tool with or without soil analysis; and the diagnosis of abnormal growth.

To make the results of analyses useful, proper interpretation guidelines have to be established, which can be based on comparing the nutrient concentrations observed to standard values (see table 26) and classifying the levels found as deficient, low, adequate, high, or excessive with respect to each nutrient; or by employing a system based on the use of nutrient concentration ratios (i.e., DRIS).

Consideration should be given to the following items when interpreting plant analysis data:

1. The time of sampling as related to the stage of growth and character of growth should be known and considered. The nutrient content of a particular plant part can change considerably through the life cycle of most plants.

2. Environmental factors, like moisture (deficiency or excessive), temperature (high or low), and light (period and intensity), can develop unusual nutrient element contents and ratios.

3. Crop variety also can have a significant influence on nutrient levels within the same crop. To obtain a reliable interpretation of the analysis data, it might be necessary to compare nutrient contents of a healthy crop with a crop which has a poor appearance.

4. The uptake by roots and the mobility of plant food elements between plant parts in association with the rate of plant growth will affect the concentration of these elements in plant tissue. This is the reason that the time of sampling and plant part sampled are important information which should be included when plant samples are to be analyzed and data interpretation is needed.

5. Information about the application of fertilizers or limestone to soils can significantly alter the concentration of more than one element in the plant tissues. This may lead to deficiencies or toxicities of certain elements, and an incorrect interpretation of the analysis data.

table 26.

PLANT ANALYSIS GUIDE
NUTRIENT SUFFICIENCY RANGES*

FIELD CROPS

CROP		N	S	P	K	Mg	Ca	Na	B	Zn	Mn	Fe	Cu	Al	Mo
		PERCENT (%)							PARTS PER MILLION (p.p.m.)						
Alfalfa/Clover	From	3.00	0.25	0.25	2.50	0.30	1.00	0.01	25	25	30	50	8	40	1.0
	To	4.50	0.35	0.45	3.80	0.80	2.50	0.04	80	70	100	250	20	300	2.5
Canola	From	2.70	0.49	0.34	2.58	0.40	1.19	0.10	15	25	60	100	4	90	
	To	3.20	0.55	0.40	3.20	0.50	1.40	0.30	20	45	110	200	12	150	
Corn (at tasseling)	From	2.80	0.20	0.25	1.80	0.20	0.30	0.01	6	25	30	50	6	20	
	To	3.50	0.50	0.40	3.00	0.50	0.70	0.03	20	50	100	250	20	300	
Cotton	From	3.50	0.18	0.25	1.30	0.25	1.25	0.05	20	20	25	50	8	50	
	To	4.75	0.60	0.50	2.90	0.75	3.50	0.15	80	50	200	250	20	125	
Flax	From	3.80	0.38	0.35	2.80	0.40	1.20	0.03	15	30	70	85	7	80	
	To	4.40	0.45	0.40	3.50	0.40	1.40	0.03	20	35	120	175	12	150	
Grasses (forage)	From	2.00	0.20	0.30	2.00	0.20	0.40	0.02	10	25	30	50	5	25	
	To	3.00	0.50	0.60	4.00	0.40	0.80	0.15	20	60	200	300	20	250	
Mint	From	2.80	0.24	0.25	2.40	0.24	1.00	0.01	10	30	35	51	6	20	
	To	4.20	0.36	0.37	3.60	0.36	1.80	0.05	30	50	80	350	20	300	
Peanut	From	2.50	0.20	0.25	1.75	0.30	1.50	0.02	20	20	50	50	8	50	
	To	4.50	0.60	0.60	3.00	0.75	2.50	0.06	50	50	200	200	20	200	
Small Grains	From	2.20	0.20	0.30	1.80	0.20	0.25	0.01	8	20	30	35	6	20	
	To	3.50	0.30	0.50	3.00	0.40	0.45	0.03	20	50	60	120	15	300	
Sorghum (milo)	From	2.50	0.20	0.30	1.70	0.20	0.30	0.01	6	25	30	50	6	20	
	To	3.50	0.50	0.50	3.00	0.50	0.60	0.03	20	50	100	250	20	300	
Soybeans	From	4.00	0.25	0.25	1.75	0.25	0.50	0.01	25	25	35	50	8	50	
	To	5.50	0.60	0.50	3.00	0.60	2.00	0.03	60	50	100	150	20	200	
Sugar beets	From	3.00	0.30	0.30	3.50	0.50	0.60	0.01	30	30	40	80	10	50	
	To	4.50	0.90	0.70	6.00	1.20	1.30	0.05	60	60	100	200	20	200	
Sugarcane	From	2.00	0.15	0.20	1.00	0.10	0.20	0.01	5	15	15	40	5	20	
	To	3.00	0.50	0.35	2.20	0.45	0.60	0.10	40	100	200	200	50	200	
Sunflowers	From	3.40	0.25	0.26	2.50	0.37	1.10	0.01	25	20	50	60	6	50	
	To	4.00	0.35	0.35	3.20	0.90	1.50	0.02	40	35	100	200	10	100	
Tobacco	From	3.00	0.25	0.25	2.50	0.40	2.20	0.01	20	30	50	100	9	20	
	To	5.00	0.80	0.60	5.00	0.80	4.00	0.10	40	50	200	250	30	200	
Wheat (High Yield)	From	4.00	0.20	0.24	2.00	0.20	0.28	0.01	6	22	32	36	6	20	
	To	5.00	0.30	0.36	3.00	0.30	0.42	0.03	10	34	48	54	10	300	

table 26. (continued)

PLANT ANALYSIS GUIDE
NUTRIENT SUFFICIENCY RANGES*

VEGETABLES (Field Crops)

CROP		N	S	P	K	Mg	Ca	Na	B	Zn	Mn	Fe	Cu	Al	Mo
		PERCENT (%)							PARTS PER MILLION (p.p.m.)						
Asparagus	From	2.40	0.25	0.30	1.50	0.15	0.40	0.01	25	20	10	50	10	20	
	To	3.80	0.50	0.75	2.40	0.50	1.00	0.10	75	60	180	300	50	200	
Beans	From	3.60	0.25	0.30	2.00	0.35	1.00	0.01	25	35	50	50	8	20	
	To	6.00	0.70	0.70	4.00	1.00	3.00	0.05	70	60	100	200	30	250	
Brussels Sprouts	From	2.50	0.20	0.25	2.50	0.25	3.00	0.01	70	40	200	125	10	20	
	To	5.00	0.50	0.50	3.50	0.40	5.00	0.10	100	80	500	200	25	150	
Celery	From	3.00	0.60	0.40	4.00	0.30	1.50	0.01	25	30	50	60	8	20	
	To	4.80	1.20	0.80	6.00	0.50	4.00	0.25	50	80	150	200	20	300	
Cucumbers	From	3.50	0.30	0.30	2.50	0.60	1.25	0.01	25	30	50	50	10	20	
	To	5.50	1.00	0.70	6.00	1.50	5.00	0.20	80	70	200	200	25	200	
Head Crops	From	2.50	0.30	0.40	3.50	0.30	1.50	0.01	25	25	50	50	5	20	
	To	4.50	1.50	1.00	5.00	0.50	2.50	0.10	50	45	100	200	10	200	
Leaf Crops	From	3.50	0.30	0.40	3.50	0.30	1.25	0.01	25	30	25	60	6	50	
	To	6.00	0.75	1.00	8.00	1.00	2.50	0.20	50	50	40	200	20	150	
Melons	From	2.00	0.30	0.20	2.50	0.50	2.00	0.01	25	20	50	60	5	20	
	To	6.00	1.00	0.80	5.00	1.00	3.50	0.20	75	80	100	120	20	150	
Peas	From	4.50	0.20	0.30	1.80	0.35	1.10	0.01	15	40	40	50	10	10	
	To	6.00	0.60	0.60	2.50	0.80	1.80	0.20	45	80	70	150	30	80	
Peppers	From	3.00	0.30	0.40	4.00	0.50	0.75	0.01	30	30	60	100	15	50	
	To	6.00	0.60	0.80	6.50	1.00	2.50	0.50	75	60	200	250	50	200	
Potatoes	From	4.00	0.25	0.30	3.50	0.50	0.70	0.01	25	30	60	100	10	50	
	To	6.00	0.50	0.70	6.50	1.10	2.00	0.15	60	70	200	200	25	250	
Root Crops	From	3.50	0.30	0.25	3.00	0.25	1.50	0.01	20	25	50	75	5	20	
	To	6.00	0.75	0.80	7.00	1.00	4.00	0.20	80	60	200	250	20	300	
Tomatoes	From	3.00	0.50	0.30	2.50	0.50	2.00	0.01	40	35	100	100	8	20	
	To	6.00	0.90	0.80	5.00	1.00	6.00	0.10	60	50	200	200	20	200	

table 26. (continued)

FRUIT AND NUT TREES

PLANT ANALYSIS GUIDE
NUTRIENT SUFFICIENCY RANGES*

CROP		N	S	P	K	Mg	Ca	Na	B	Zn	Mn	Fe	Cu	Al	Mo
		PERCENT (%)							PARTS PER MILLION (p.p.m.)						
Almond	M	2.20	0.20	0.10	1.50	0.30	2.25	0.01	30	20	30	100	6		
	H	2.70	0.30	0.40	3.00	0.40	4.00	0.10	65	40	80	200	20		
Apple	M	1.75	0.15	0.15	1.20	0.20	1.00	0.01	25	15	30	100	6		
	H	2.75	0.30	0.40	2.00	0.35	1.60	0.15	50	60	100	200	25		
Apricot	M	2.00	0.15	0.20	2.50	0.60	3.00	0.01	25	20	35	100	6		
	H	3.00	0.30	0.40	3.50	0.90	4.50	0.10	50	60	100	200	30		
Avocado	M	1.60	0.20	0.10	1.00	0.30	1.00	0.01	50	30	30	50	5		
	H	2.20	0.60	0.25	2.00	0.80	3.00	0.15	100	50	80	150	15		
Cherry	M	2.00	0.15	0.25	2.00	0.50	2.00	0.01	25	25	50	50	10		
	H	3.00	0.25	0.40	3.00	0.90	3.00	0.10	40	40	70	100	20		
Citrus	M	2.40	0.20	0.15	1.00	0.25	3.50	0.01	30	25	30	60	10		
	H	3.00	0.40	0.30	2.00	0.70	5.50	0.10	60	70	100	150	20		
Fig	M	1.50	0.20	0.10	1.00	0.25	3.25	0.01	25	15	20	50	6		
	H	2.50	0.50	0.50	2.50	0.50	5.00	0.10	50	50	70	200	20		
Mango	M	1.00	0.15	0.10	0.80	0.15	1.50	0.01	25	20	50	50	8		
	H	2.00	0.35	0.35	1.50	0.50	5.00	0.10	50	50	100	200	20		
Olive	M	1.50	0.20	0.10	0.75	0.25	2.00	0.01	20	15	50	45	5		
	H	2.20	0.35	0.20	1.50	0.50	2.50	0.10	35	20	100	100	20		
Peach	M	3.50	0.15	0.20	2.00	0.35	1.50	0.01	25	20	35	100	6		
	H	4.50	0.40	0.50	3.50	0.60	2.50	0.10	50	50	80	250	20		
Pear	M	2.00	0.15	0.15	1.25	0.25	1.30	0.01	25	25	30	60	10		
	H	3.00	0.40	0.50	2.25	0.50	2.00	0.15	70	50	100	150	25		
Pecan	M	2.00	0.10	0.15	1.00	0.25	1.00	0.01	35	35	75	75	15		
	H	3.00	0.25	0.35	2.00	0.50	2.00	0.10	65	60	130	150	25		

table 26. (continued)

PLANT ANALYSIS GUIDE
NUTRIENT SUFFICIENCY RANGES*

FRUIT AND NUT TREES

CROP		N	S	P	K	Mg	Ca	Na	B	Zn	Mn	Fe	Cu	Al	Mo
		PERCENT (%)							PARTS PER MILLION (p.p.m.)						
Plum/Prune	From	2.25	0.15	0.15	1.60	0.35	1.50	0.01	25	20	40	100	6		
	To	3.00	0.30	0.50	2.80	0.75	3.00	0.10	50	60	100	200	25		
Walnut/Filbert	From	2.20	0.20	0.15	1.20	0.25	0.60	0.01	35	20	20	75	6		
	To	3.00	0.50	0.60	3.00	1.00	2.50	0.10	150	60	60	150	15		
FOREST TREES (ave. values)	From	1.30	0.15	0.15	0.50	0.15	0.50	0.01	15	20	25	50	5	50	
	To	3.00	0.30	0.40	2.50	0.40	2.00	0.10	50	80	100	200	25	100	
Evergreens	From	2.00	0.15	0.20	1.50	0.20	0.50	0.01	30	30	30	50	6	5	
	To	3.50	0.40	0.60	3.50	1.00	2.50	0.20	50	75	200	200	40	200	

*Sampling procedures are given in table 25.

DIAGNOSIS OF FIELD PROBLEMS

If fields are checked regularly, there is often time to correct problems if action can be taken immediately. The cause could be obvious; however, a guideline could be very helpful in making a diagnosis.

The objective is to use all resources to identify and correct any conditions restricting the plant's potential for producing seed, fruit, fiber, and/or forage.

Visual Plant Symptoms

Check each part of the plant thoroughly and record unusual growth, color, deficiency symptoms, delayed maturity, quality of crop, mechanical damage, and injury by insects. Also examine the root system for injury or specific growth patterns.

Soil Conditions

Soil analysis measures only the chemical factors, which influence plant health. However, the physical make-up of the soil affects water holding capacity, water penetration, aeration, and root growth. When the soil's physical characteristics are such that plant roots cannot supply plants with sufficient water and nutrients, or plants suffer from lack of oxygen, the soil has a physical problem.

Such problems could be caused by compaction layering or stratification of different soil textures or hardpans (natural or man-made).

Crop rotation, reduced tillage practices, change in irrigation practices or drainage methods and deep tillage can provide a better environment for root development.

Field History

Obtain information about the previous crop grown in the field, weed, insect/disease problems, fertilization and liming programs, soil and plant analysis data, and yield potential of the soil type. Also, know the crop variety, tillage method, and pesticide and herbicide used.

Weather Observations

Rainfall and temperature have a great influence on nutrient uptake and they can be indirect contributors to fertility problems.

Soil and Plant Analysis

The most effective use of these analyses consists of comparing soil and plant analysis data from good and bad areas.

If the sampling has been done in time, measures can be employed to correct the problem. (See suggestions given under Nutrient Corrective Measures, p 119.)

NUTRIENT CORRECTIVE MEASURES

NITROGEN

Additional amounts may be supplied to the crop with sidedress or topdress applications or in irrigation water. Apply at a rate of 30 to 50 pounds per acre.

PHOSPHORUS

In season surface application on row crops is not normally recommended. However, for severe deficiency, incorporate 30 to 40 pounds per acre of phosphate (P_2O_5) as early in the season as possible.

POTASSIUM

In season application of potassium on row crops may not be effective, except on sandy soil where leaching can occur. For severe deficiency, incorporate 30 to 50 pounds per acre of potash (K_2O) during early growth.

MAGNESIUM

Magnesium may be foliar-applied at a rate of 1 to 2 pounds per acre. If a chelated material is used, check manufacturer's specifications. Repeat applications may be necessary.

CALCIUM

Calcium can also be applied by a foliar method at a rate of 1 to 2 pounds per acre. If a chelated material is used, check manufacturer's specifications. Repeat applications may be necessary.

SULFUR

Sulfur may be applied in the sulfate form to the crop with sidedress or topdress applications or in irrigation water.

Apply at a rate of 10 to 20 pounds per acre. For foliar application use 1 to 2 pounds per acre.

BORON

Apply foliar or as a dust at a rate of .2 to .5 pounds per acre.

ZINC

May be applied foliar at a rate of .5 to 1 pound per acre. If a chelated material is used, follow manufacturer's specifications. Repeated applications may be necessary.

MANGANESE

May be applied foliar at a rate of 1 to 2 pounds per acre. If a chelated material is used, follow manufacturer's specifications. Repeated applications may be necessary.

IRON

When foliar-applied, a rate of 1 to 2 pounds per acre is suggested. If a chelated material is used, follow manufacturer's specifications. Repeated applications may be necessary.

COPPER

Foliar applications can be made at a rate of .5 to 1 pound per acre. Manufacturer's specifications should be followed when a chelated material is used. Repeated applications may be necessary.

table 27.

CONCENTRATION, FUNCTION AND PRIMARY SOURCE OF ESSENTIAL PLANT ELEMENTS

ELEMENT	APPROX. CONC. IN PLANTS	MAIN FUNCTION IN PLANTS	PRIMARY SOURCES
Carbon	45%	Part of all organic compounds.	Carbon dioxide in air.
Hydrogen	6%	Forms main structural components.	Water.
Oxygen	43%	Forms main structural components.	Water, Air.
Nitrogen	1 - 6%	Component of proteins, chlorophyll, nucleic acids.	Soil organic matter, fixation of atm. nitrogen (legumes).
Phosphorus	0.05 - 1%	Energy transfer; metabolism, nucleic acids, nucleoproteins.	Soil organic matter, soil minerals.
Potassium	0.3 - 6%	Protein snythesis; translocation of carbohydrates; enzyme activation.	Soil minerals.
Calcium	0.1 - 3%	Structural component of cell walls; cell elongation; affects cell permeability.	Soil minerals. Limestone.
Magnesium	0.05 - 1%	Component of chlorophyll; enzyme activator; metabolism; cell division.	Soil minerals. Dolomite limestone.
Sulfur	0.05 - 1.5%	Constituent of proteins; involved with respiration and nodule formation.	Soil organic matter. Rainwater.
Iron	10 - 1000 ppm	Chlorophyll synthesis; oxidation reduction reactions; enzyme activator.	Soil minerals.
Manganese	5 - 500 ppm	Oxidation-reduction reactions; nitrate reduction; enzyme activator.	Soil minerals.
Copper	2 - 50 ppm	Enzyme activator; nitrate reduction; respiration.	Soil minerals. Soil organic matter.
Zinc	5 - 100 ppm	Enzyme activator; regulates pH of cell sap.	Soil minerals. Soil organic matter.
Boron	2 - 75 ppm	Cell maturation and differentiation; translocation of carbohydrates.	Soil organic matter. Tourmaline.
Molybdenum	0.01 - 10 ppm	Nitrate reduction; fixation of atmospheric nitrogen by legumes.	Soil organic matter. Soil minerals.
Chlorine	0.05 - 3 ppm	Photochemical reactions.	Rainwater.

Ref: Plant Analysis - A Diagnostic Tool. University of Wisconsin. Bul. A2289.

table 28.

APPROXIMATE POUNDS OF PLANT FOOD NUTRIENT REMOVAL

CROP	UNIT	N	P_2O_5	K_2O	Mg	Ca	S
GRAINS							
Barley	Bu.	1.10	0.40	0.35	0.07	0.04	0.08
Canola	Bu.	3.00	1.31	2.37	0.25	0.25	0.20
Corn	Bu.	0.80	0.40	0.29	0.06	0.03	0.07
Flax	Bu.	2.70	1.10	0.30	0.18	0.25	0.20
Oats	Bu.	0.75	0.25	0.20	0.04	0.03	0.07
Rice	Bu.	0.65	0.28	0.17	0.05	0.04	0.04
Rye	Bu.	1.20	0.35	0.35	0.08	0.07	0.21
Sorghum (Milo)	Bu.	0.85	0.40	0.25	0.08	0.07	0.09
Soybeans	Bu.	4.10	0.85	1.45	0.23	0.22	0.20
Sunflowers	Cwt.	3.60	1.70	1.10	0.28	0.30	0.33
Wheat	Bu.	1.20	0.55	0.35	0.14	0.06	0.10
FORAGES (DRY BASIS)							
Alfalfa	Ton	56.0	15.0	60.0	5.0	28.0	5.0
Bluegrass	Ton	35.0	12.0	35.0	4.0	8.0	4.0
Brome Grass	Ton	40.0	12.0	44.0	4.0	8.5	3.4
Coastal Bermuda	Ton	50.0	12.0	40.0	4.5	7.5	6.0
Corn Silage (wet)	Ton	8.3	3.5	8.0	1.0	1.2	0.9
Cowpeas	Ton	62.0	12.0	42.0	7.5	27.0	6.5
Fescue	Ton	40.0	16.0	48.0	4.8	9.0	4.4
Lespedeza	Ton	48.0	15.0	45.0	7.0	20.0	6.0
Orchard Grass	Ton	45.0	14.0	55.0	4.4	8.0	5.5
Red Clover	Ton	56.0	12.5	45.0	6.0	24.0	5.0
Sorghum/Sudan	Ton	40.0	15.0	55.0	6.0	9.0	4.5
Sweet Clover	Ton	44.0	11.0	44.0	4.8	29.0	8.2
Timothy	Ton	36.0	13.5	54.0	3.5	8.0	3.5
Vetch	Ton	55.0	15.0	45.0	5.0	24.0	5.0
FRUITS & VEGETABLES							
Apples	100 Bu.	17.5	7.5	32.0	4.0	10.0	4.0
Beans, Dry	Bu.	2.5	0.8	0.9	0.1	0.08	0.17
Cabbages	Ton	6.5	2.4	8.0	1.0	2.4	2.2
Cantaloupes	Ton	6.8	2.3	11.5	1.2	3.5	1.1
Celery	Ton	5.2	2.2	10.0	0.8	2.6	1.4
Cucumbers	Ton	9.0	3.0	15.0	2.0	8.0	1.6
Grapes	Ton	5.5	2.0	10.0	0.4	1.0	1.1
Lettuce	Ton	7.0	2.3	10.0	0.7	2.8	0.8
Onions	Ton	6.0	2.7	5.3	0.6	1.6	2.4
Oranges	Ton	9.0	2.0	9.0	1.4	7.0	1.0
Peaches	100 Bu.	16.0	6.4	20.0	4.0	15.0	3.5
Pears	100 Bu.	15.0	6.0	24.0	3.5	12.0	3.0
Potatoes	Cwt.	0.33	0.15	0.53	0.025	0.025	0.016
Spinach	Ton	10.0	3.0	6.0	1.0	2.4	0.8
Sweet Potatoes	100 Bu.	25.0	10.0	50.0	5.0	3.0	4.0
Tomatoes	Ton	3.8	1.45	7.0	0.5	0.6	0.7
Turnips (roots)	Ton	4.5	2.0	8.0	0.6	1.2	0.85
Turnips (tops)	Ton	8.3	0.8	6.0	0.4	4.2	1.0
OTHER CROPS							
Cotton (S&L)	Bales	40.0	20.0	16.0	4.0	3.0	4.5
Peanuts	1000 lbs.	35.0	6.0	8.0	1.2	2.5	2.5
Sugar Beets	Ton	4.10	0.6	7.0	0.4	1.2	0.4
Sugarcane	Ton	1.6	0.9	3.5	0.3	0.5	0.45
Tobacco (flue)	Cwt.	2.80	0.50	5.2	0.9	2.9	0.7
Tobacco (burley)	Cwt.	4.30	0.44	4.7	1.0	2.6	0.9

table 29.

NUTRIENT REMOVAL

CORN - 180 BU./ACRE

Nutrient	Time Period				
	25 days	**50 days**	**75 days**	**100 days**	**125 days**
Nitrogen (N)	19 lbs.	103 lbs.	175 lbs.	226 lbs.	240 lbs.
Phosphate (P_2O_5)	4 lbs.	31 lbs.	67 lbs.	92 lbs.	100 lbs.
Potash (K_2O)	22 lbs.	126 lbs.	198 lbs.	234 lbs.	240 lbs.

SORGHUM - 135 BU./ACRE

	20 days	**40 days**	**60 days**	**85 days**	**95 days**
Nitrogen (N)	9 lbs.	70 lbs.	130 lbs.	175 lbs.	185 lbs.
Phosphate (P_2O_5)	2 lbs.	20 lbs.	48 lbs.	69 lbs.	80 lbs.
Potash (K_2O)	18 lbs.	121 lbs.	206 lbs.	245 lbs.	258 lbs.

SOYBEANS - 50 BU./ACRE

	40 days	**80 days**	**100 days**	**120 days**	**140 days**
Nitrogen (N)	7.6 lbs.	125 lbs.	134 lbs.	196 lbs.	257 lbs.
Phosphate (P_2O_5)	1.1 lb.	21 lbs.	24 lbs.	36 lbs.	48 lbs.
Potash (K_2O)	6.1 lbs.	105 lbs.	112 lbs.	150 lbs.	187 lbs.
Calcium (Ca)	2.4 lbs.	31 lbs.	38 lbs.	49 lbs.	49 lbs.
Magnesium (Mg)	0.6 lb.	10 lbs.	11 lbs.	16 lbs.	19 lbs.

ALFALFA - 8 TONS/ACRE

	1st cut 2.35 T	**2nd cut 2.10 T**	**3rd cut 2.03 T**	**4th cut 1.52 T**	TOTAL **8 Tons**
Nitrogen (N)	136 lbs.	111 lbs.	93 lbs.	75 lbs.	415 lbs.
Phosphate (P_2O_5)	31 lbs.	24 lbs	22 lbs.	17 lbs.	94 lbs.
Potash (K_2O)	124 lbs.	107 lbs.	98 lbs.	72 lbs.	401 lbs.
Calcium (Ca)	50 lbs.	41 lbs.	36 lbs.	24 lbs.	151 lbs.
Magnesium (Mg)	13 lbs.	9 lbs.	7 lbs.	7 lbs.	36 lbs.
Sulfur (S)	6 lbs.	8 lbs.	7 lbs.	5 lbs.	26 lbs.

table 30.

PLANT TISSUE ANALYSIS GUIDE

FLOWERS AND ORNAMENTALS

CROP	PLANT PART SAMPLED		N	S	P	K	Mg	Ca	Na	B	Zn	Mn	Fe	Cu	Al	Mo
			PERCENT (%)							PARTS PER MILLION (p.p.m.)						
Azalea	most recently	L	1.50	.20	.25	1.00	.25	.60	0.00	25	20	50	60	6	0	
	matured leaf	H	3.00	.50	.50	2.00	.75	1.50	0.20	50	200	700	200	100	250	
Begonia	most recently	L	4.00	.30	.30	2.50	.30	1.00	0.00	20	25	50	50	8	0	
	matured leaf	H	6.00	.75	.75	6.00	.75	2.50	0.20	75	200	200	200	100	250	
Bougainvillea	most recently	L	2.50	.20	.25	3.00	.25	1.00	0.00	25	8	50	50	8	0	
	matured leaf	H	4.50	.45	.75	5.50	.75	2.50	0.20	75	200	200	300	200	250	
Croton	most recently	L	1.50	.20	.25	1.25	.30	1.00	0.00	25	20	50	50	10	0	
	matured leaf	H	3.00	.40	.50	3.00	1.00	2.50	0.20	75	200	200	200	250	250	
Geranium	most recently	L	3.50	.25	.40	2.50	.20	.80	0.00	30	18	40	100	8	0	
	matured leaf	H	4.80	.75	.75	4.30	.50	1.20	0.20	250	200	200	250	100	250	
Hydrangea	most recently	L	3.00	.20	.25	2.20	.22	.60	0.00	20	20	50	50	6	0	
	matured leaf	H	5.50	.75	.75	5.00	.50	1.80	0.20	50	200	300	300	50	250	
Poinsettia	most recently	L	4.00	.25	.30	1.50	.25	.70	0.00	30	25	45	100	2	0	
	matured leaf	H	6.00	.75	.75	3.50	1.00	2.00	0.40	250	100	300	300	100	250	
Rose	most recently	L	3.00	.25	.25	1.50	.25	1.00	0.00	30	18	30	60	8	0	
	matured leaf	H	5.00	.75	.50	3.00	.50	2.00	0.20	60	100	200	200	100	250	
Rubber Tree	most recently	L	1.30	.15	.10	.60	.20	.30	0.00	20	15	20	30	8	0	
	matured leaf	H	2.25	.50	.50	2.10	.50	1.20	0.20	50	200	200	200	100	250	
Chrysanthemum	most recently	L	4.00	.25	.25	4.00	.25	1.00	0.00	25	20	50	50	6	0	
	matured leaf	H	6.00	.75	1.00	6.00	1.00	2.00	0.20	75	250	250	250	200	250	
Carnation	most recently	L	3.20	.25	.25	2.80	.25	1.00	0.00	30	25	50	50	8	0	
	matured leaf	H	5.20	.80	.80	6.00	.75	2.00	0.20	100	200	200	200	100	250	
Ornamentals (woody)	most recently	L	2.00	.15	.20	1.50	.30	.50	0.00	30	30	30	50	6	0	
	matured leaf	H	4.50	.40	.60	3.50	1.00	2.50	0.20	50	75	200	200	40	250	
Ornamentals (ave. CA data)	most recently	L	2.00	.20	.20	1.50	.20	.50	0.00	20	25	50	50	5	1	
	matured leaf	H	2.50	.30	.40	2.00	.30	1.00	0.20	50	50	100	100	15	3	

table 30. (continued)

PLANT ANALYSIS GUIDE
NUTRIENT CONCENTRATION RANGES

VINES

CROP		N	S	P	K	Mg	Ca	Na	B	Zn	Mn	Fe	Cu	Al	Mo
		PERCENT (%)							PARTS PER MILLION (p.p.m.)						
Grape (leaf)	M	1.50	.15	.25	1.50	.25	.80	.01	30	25	40	40	10		
	H	3.50	.35	.60	2.50	.80	3.00	.10	50	40	100	100	30		
Grape (petiole)	M	.80	.08	.20	1.50	.30	1.00	.01	25	25	35	15	10		
	H	1.50	.12	.30	2.50	.80	3.00	.05	40	50	100	75	30		
Kiwi	M	2.00	.15	.13	1.40	.20	2.00	.01	30	12	---	---	---		
	H	2.50	.25	.30	2.00	.50	5.00	.15	90	30	---	---	---		
FRUITS															
Blueberry	M	1.75	.12	.15	.30	.12	.35	.01	15	10	30	60	6		
	H	2.20	.20	.40	.65	.30	.80	.05	50	20	100	100	20		
Raspberry	M	2.75	.15	.25	1.50	.30	.60	.01	30	25	50	50	5		
	H	4.00	.25	.60	3.00	1.00	2.50	.05	80	80	150	200	50		
Cranberry	M	1.00	.10	.14	.50	.20	.30	.01	10	15	10	40	6		
	H	1.50	.20	.25	1.00	.30	.60	.05	20	30	200	80	10		
Strawberry	M	2.25	.15	.25	1.75	.25	.60	.01	20	25	50	80	6		
	H	3.00	.30	.50	2.50	.50	1.50	.05	50	50	100	200	20		

table 30. (continued)

PLANT ANALYSIS GUIDE
NUTRIENT CONCENTRATION RANGES

TROPICAL CROPS

CROP		N	S	P	K	Mg	Ca	Na	B	Zn	Mn	Fe	Cu	Al	Mo
		P E R C E N T (%)							PARTS PER MILLION (p.p.m.)						
Banana	M	2.00	.15	.15	2.50	.25	1.50	.01	20	25	75	50	5	5	
	H	4.50	.50	.40	4.00	.80	3.00	.10	50	50	200	200	30	200	
Cocoa	M	2.50	.20	.20	2.00	.40	.40	.01	35	25			10		
	H	4.00	.40	.40	3.50	.60	.80	.10	50	50			20		
Cocos Palm	M	1.80	.15	.15	.75	.35	.60	.01							
	H	2.50	.30	.25	1.25	.60	1.00	.10							
Coffee	M	2.50	.20	.15	2.00	.25	1.00	.01	25	25	50	85	10	5	
	H	3.50	.50	.35	3.00	.50	2.50	.10	75	50	100	200	20	200	
Oil Palm	M	2.50	.20	.15	1.20	.25	.60	.01	10	20	80	50	5	5	
	H	3.50	.50	.30	2.50	.50	1.50	.10	30	50	200	100	20	200	
Pineapple	M	1.50	.20	.20	3.00	.25	.30	.01	20	20	35	75	8	5	
	H	2.50	.40	.40	4.50	.40	1.00	.10	60	50	100	200	25	200	
Rubber Palm	M	3.00	.20	.25	1.50	.25	.50	.01							
	H	4.00	.40	.40	2.50	.40	1.00	.10							
Tea	M	4.00	.20	.40	2.00	.30	.35	.01							
	H	5.00	.40	.80	3.00	.40	.75	.10							

* Sampling procedures are given in table 5.

table 31.

BUSHEL WEIGHTS OF COMMON COMMODITIES

Commodity	lbs.	Commodity	lbs.
GRAINS		FRUITS & VEGETABLES	
Barley	48	Apples	47
Corn (ear)	70	Beans (dried)	60
Corn (shelled)	56	Beets	60
Oats	32	Cabbage	52
Rice	45	Carrots	50
Rye	56	Cucumbers	48
Sorghum	50	Onions	57
Soybeans	60	Peaches	48
Wheat	60	Peanuts	22 to 30
		Pears	58
GRASSES		Peas (dried)	60
		Peppers	25
Bermuda grass	40	Potatoes	60
Bluegrass	14	Potatoes (sweet)	50
Brome grass	14	Tomatoes	56
Fescue	24	Turnips	55
Orchardgrass	14		
Redtop (unhulled)	14	MISCELLANEOUS	
Rye grass	24		
Sudan grass	40	Alfalfa	60
Timothy	45	Bran	20
		Buckwheat	52
CLOVERS		Cornmeal	48
		Cottonseed	32
Alsike	60	Cottonseed meal	48
Crimson	60	Flaxseed	56
Ladino	60	Hempseed	44
Mammoth	60	Rape (dwarf)	50
Red	60	Vetch (hairy)	60
Sweet	60		
White Dutch	60		

table 32.

CONVERSION FACTORS

Nutrient	Column 1	Column 2	To convert column 1 into column 2 multiply by
Nitrogen	N	NO_3	4.4266
	NO_3	N	0.22591
	N	KNO_3	7.22
	KNO_3	N	0.13855
	KNO_3	NO_3	0.61331
	NO_3	KNO_3	1.63
Phosphorus	P	P_2O_5	2.2951
	P_2O_5	P	0.43646
Potassium	K	K_2O	1.2046
	K_2O	K	0.83013
Sodium	Na	Na_2O	1.3479
	Na_2O	Na	0.74191
Magnesium	Mg	MgO	1.6579
	MgO	Mg	0.60317
	Mg	$MgCO_3$	3.4675
	$MgCO_3$	Mg	0.28839
Calcium	Ca	CaO	1.3992
	CaO	Ca	0.71469
	Ca	$CaCO_3$	2.4973
	$CaCO_3$	Ca	0.40044
Sulfur	S	SO_4	3.00
	SO_4	S	0.3333
Boron	B	B_2O_3	3.2181
	B_2O_3	B	0.31074
Zinc	Zn	ZnO	1.2447
	ZnO	Zn	0.80339
Manganese	Mn	MnO	1.2913
	MnO	Mn	0.77443
Iron	Fe	Fe_2O_3	1.4298
	Fe_2O_3	Fe	0.69940
Copper	Cu	CuO	1.2517
	CuO	Cu	0.79892
Molybdenum	Mo	MoO_3	1.5003
	MoO_3	Mo	0.66655

table 33.

CONVERSION FACTORS FOR ENGLISH AND METRIC UNITS

LENGTH

UNITS	km	in.	ft.	yd.	mi.
kilometer	1	39.37	3280.8	1093.6	0.6214
inch	2.5×10^{-5}	1	0.0833	.0277	1.6×10^{-5}
feet	3.0×10^{-4}	12	1	.3333	1.9×10^{-4}
yard	9.1×10^{-4}	36	3	1	5.7×10^{-4}
mile	1.6093	63.36	5280	1760	1

WEIGHT

UNITS	kg	q	Mt.	lb.	t.	Lt
kilogram	1	.01	.001	2.2046	1.1×10^{-3}	9.8×10^{-4}
quintal	100	1.00	.100	220.46	0.1102	0.0984
metric ton	1000	10	1	2204.6	1.1023	0.9842
pound	.4536	.0045	4.5×10^{-4}	1	0.0005	4.4×10^{-4}
short ton	907.18	9.0718	.9072	2000	1	0.8928
long ton	1016.0	10.160	1.0160	2240	1.12	1

AREA

UNITS	ha	sq. ft.	acre	sq. mi.
hectare	1	1.1×10^{6}	2.4711	.0039
sq. foot	9.3×10^{-6}	1	2.3×10^{-5}	3.6×10^{-8}
acre	.4047	43,560	1	.0016
sq. mile	259	2.8×10^{7}	640	1

table 33. (continued)

CONVERSION FACTORS FOR ENGLISH AND METRIC UNITS

YIELD OR RATE

UNITS	kg/ha	quintal or mct/ha	MT/ha	L/ha
lb./acre	1.12	0.0112	0.0011	--------
cwt./acre	112	1.12	0.112	--------
ton/acre	2244	22.44	2.244	--------
bu./acre (60 lbs.)	67.25	0.67	0.067	--------
bu./acre (56 lbs.)	62.72	0.63	0.063	--------
bu./acre (48 lbs.)	53.80	0.54	0.054	--------
bu./acre (32 lbs.)	35.87	0.36	0.036	--------
bale/acre (500 lbs.)	560	5.60	0.560	--------
gallon/acre	--------	--------	--------	9.354
quart/acre	--------	--------	--------	2.339

mct/ha = 100 kg/ha
MT/ha = metric ton (1000 kg)/ha
L/ha = liter/ha

GLOSSARY OF SOIL SCIENCE TERMS

Absorption Movement of ions and water into the plant root.

Acid Soil Soil with a pH less than 7.0

Adsorption The process by which atoms, molecules, or ions are taken up and retained on the surfaces of solids by chemical or physical binding.

Aerate To allow or promote exchange of soil gases with atmospheric gases.

Aerobic Growing only in the presence of molecular oxygen, as aerobic organisms.

Aggregate A unit of soil structure formed by natural processes as opposed to artificial processes, and generally greater than 10 mm in diameter.

Alkali Soil Any soil with a pH greater than 7.0.

Ammonification The biochemical process whereby ammoniacal nitrogen is released from nitrogen containing organic compounds.

Anaerobic Growing in the absence of molecular oxygen, as anaerobic bacteria.

Anion Acid-forming elements, which are negatively charged.

Available Nutrients Nutrient ions or compounds in forms which plants can absorb and utilize in growth.

Base Saturation Percentage The extent to which the adsorption complex of a soil is saturated with alkali or aklaline earth cations, expressed as a percentage of the cation exchange capacity.

Bulk Density The mass of dry soil per unit bulk volume. In general, expressed in grams per cubic centimeter.

Cation Exchange Capacity The sum of exchangeable cations that a soil, soil constitutent, or other material can adsorb. The value is expressed in milliequivalents per 100 grams of soil.

Denitrification Reduction of nitrate or nitrite to gaseous forms of N by microbial activity or chemical reductants producing molecular N or oxides of N.

Electrical Conductivity The measure of salt concentrations in a soil, water, or other solid or liquid material. It is expressed in mmhos/cm or deciSiemen's/m.

Equivalent The weight in grams of an ion or compound that combines with or replaces 1 gram of hydrogen. The atomic weight or formula weight divided by the valence of the element or compound.

Exchangeable	An ion which can replace or be replaced by another ion or ions having the same total electrical charge, generally an adsorbed cation.
Fertigation	Application of plant nutrients in irrigation water to accomplish fertilization.
Fertilizer Requirement	The quantity of certain plant nutrient elements needed, in addition to the amount supplied by the soil, to increase plant growth to a designated level.
Gypsum Requirement	The quantity of gypsum or its equivalent required to reduce the exchangeable sodium content of a given amount of soil to an acceptable level.
Humus	The relatively resistant, usually dark brown to black, fraction of soil o.m., peats, or composts, which is formed during the biological decomposition of organic residues. It contains many times the major fraction or the organic matter in the soil.
Ion	Atom, group of atoms, which is electrically charged as the result of the loss of electrons (cations) or the gain of electrons (anions).
Lime Requirement	The amount of liming material required to change the soil to a specified state with respect to pH or soluble Al content.
Milliequivalent	One thousandth part of an equivalent.
Nitrification	Biological oxidation of ammonium to nitrite and nitrate, or a biological induced increase in the oxidation state of nitrogen.
Nutrient Balance	A ratio among concentrations of nutrients essential for plant growth which permits maximum growth rate and yield.
Organic Matter	The residue remaining in soil from plant and animal life processes, especially after initial decomposition. It is expressed in percent of soil weight.
pH	The negative logarithm of the hydrogen ion activity of a soil. The measurement of the degree of acidity or alkalinity of a soil.
Saline Soil	A nonsodic soil containing sufficient soluble salts to cause a negative affect to the growth of most crop plants.
Sodic Soil	A nonsaline soil containing sufficient exchangeable sodium to adversely affect crop production and soil structure under most conditions of soil and plant type.

Soil Salinity The amount of soluble salts in a soil. Measurement is expressed in mmhos/cm or deciSiemen/m.

Valence The number of atoms of hydrogen which one atom of element will combine with or displace.