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Utah Fertilizer Guide

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Foreword

The **Utah Fertilizer Guide** is designed to provide practical answers to routine questions related to soil fertility management. The Guide emphasizes laboratory analysis of soil and plant samples as the keystone to optimum fertilizer rates for maximum economic plant yield and quality. The focus of the Guide is on soil fertility problems peculiar to the semi-arid and arid soils of Utah.

The Guide summarizes information used by the Utah State University Soil, Plant and Water Analysis Laboratory (SPWL) for interpreting analytical results of materials submitted by growers, Extension personnel and industrial agriculturists. The Guide can be applied by any laboratory or agency that uses the same standardized analytical procedures used by the SPWL.

The preparation of this Guide employed the skills of scientists with extensive experience in the individual chapters they authored or co-authored. This approach allows benefit to be derived from their expertise in a given subject area for which they accept full responsibility. Their contribution, without which this Guide would not be possible, is deeply appreciated.

The **Utah Fertilizer Guide** has an open-ended format which allows individual chapters to be revised and additional chapters to be written as new information becomes available. Also, individual chapters, which represent specific commodity or fertilizer and soil management issues, may be circulated separately or in selected groups to satisfy specific extension and land manager purposes.

Chapter 1
Diagnosing Plant Nutritional Disorders—An Overview

K. F. Topper and D. W. James

There is a variety of approaches to diagnosing plant nutritional problems. Nutritional disorders relate most frequently to nutrient deficiencies but occasionally elemental toxicities occur. There are four general approaches to soil fertility diagnoses: 1) Soil Testing; 2) Plant Tissue Testing; 3) Plant Nutrient Deficiency Symptoms; and 4) Fertilizer Strip Trials in the Field.

Detailed discussion on soil and plant tissue testing for field, horticultural, ornamental and vegetable crops are given in Chapters 3, 4, 5, 6 and 7 of this **Utah Fertilizer Guide**. Salt problems are discussed in Chapter 9. This chapter describes general concepts of diagnosing plant nutritional disorders.

Diagnostic Soil Testing

Diagnostic soil testing measures the nutrient supplying capability of a soil thereby identifying nutritional deficiencies, toxicities, and salt accumulation problems.

Soil sampling is an integral part of soil testing. Good laboratory procedure cannot compensate for poor field sampling procedure. If the soil sample does not represent the field being diagnosed, then the laboratory result may be meaningless or even misleading. Field sampling procedures are outlined in Chapter 2 of this Guide and this chapter should be included with any combination of other chapters that are selected to satisfy specific crop and soil management needs.

Soil testing is most applicable for field crops although important advantages are provided to other types of cropping systems. Soil testing predicts soil fertilizer requirements before the crop is planted. Soil chemical analyses measure the nutrient supplying capacity of the soil through a standardized chemical extraction procedure. The amount of an element reported from soil analysis is often referred to as the “extractable nutrient.” The amount of nutrient extracted is calibrated by field fertility studies which provide the basis for interpreting the kinds and amounts of fertilizer required at a given soil test level.

Soil fertility studies are conducted on important crops and soil types in a region to obtain a correlation between a particular soil test procedure and the level of fertility associated with maximum yield. Use of different soil extraction procedures can result in different analytical results which may not be related to standardized soil test procedures appropriate for a given region. The **Utah Fertilizer Guide** can be used in interpreting results from any soil testing laboratory if that laboratory uses the same standardized procedures that are employed by the USU Soil, Plant and Water Analysis Laboratory.

There are two basic philosophies followed in the interpretation of diagnostic soil testing. First is the sufficiency approach, alluded to above. Sufficiency means that fertilizer is recommended only when a crop yield response to fertilization is expected as determined by soil test results. Generally the sufficiency approach maximizes economic returns on the fertilizer investment because it lowers the cost per unit of production.

The second approach is one in which fertilizer recommendations are based primarily on crop removal of plant nutrients. The maintenance approach does not adequately take into account the soil's ability to supply nutrients from its mineral and organic fractions. In other words, there is little justification for replacing what a crop has removed if the soil is already highly fertile. Several studies have shown that the maintenance approach does not result in higher yields when compared to the sufficiency approach. The result usually is that lower net economic returns occur as a result of higher fertilizer investments. An example of the lower net returns generally associated with applying fertilizer, when it is not required, is shown in Table 1.1. If unwarranted use of micronutrients were incorporated in this example, further reductions in net returns would be encountered.

Table 1.1. Returns per acre based on a hypothetical soil sample adequate in phosphorus (P) and potassium (K) levels.*

	Fertilizer applied/ac.	Fertilizer cost/ac.	Yield (T/ac.)	Returns	
				gross/ac.	Net/ac.
Sufficiency Approach	0	$0	6	$360	$360
Maintenance Approach	70 lbs P_2O_5 270 lbs K_2O	$41	6	$360	$319

* $NaHCO_3$ soil test level of P = 7 ppm(mg/kg) and K = 130 ppm(mg/kg); alfalfa price of $60/T & fertilizer cost of KCL at $110/T & $Ca(H_2PO_4)$2 at $178/T.

** Maintenance approach assumes these soil test levels are maintained such that P_2O_5 and K_2O recommendations are based on crop removal.

The **Utah Fertilizer Guide** emphasizes the sufficiency concept specifically because it maximizes economic returns. Fertilizer recommendations given by the diagnostic laboratory may require modification by the farmer to reflect individual management practices and site specific conditions. Extension agents may be consulted for help on localizing the fertilizer recommendations.

Portable soil test kits designed for use in the field are of limited value because field calibration information is generally lacking. It is suggested that personal experience and a good record keeping system is more reliable than the portable soil test kit.

Plant Tissue Testing

Plant tissue testing is most applicable to tree fruit crops in routine practice. This is because of the difficulty of sampling the subsoil where most of the active root system of tree crops are located. Thus, in contrast with field crops, the soil test is of limited utility for evaluating the soil fertility needs of trees.

Plant tissue analysis identifies nutritional disorders while the crop is growing. Field trials are used as a basis for correlating the nutrient content of a particular plant part and growth stage to crop responses from fertilization. This is an on-going process which requires modification as new information develops. The relationship between nutrient concentration of a plant part and crop yield has three distinct zones (Figure 1.1). 1) The lowest nutrient concentration range where fertilization will increase yield; 2) a transition zone (critical nutrient range) in which the crop may or may not respond to fertilization; and 3) the

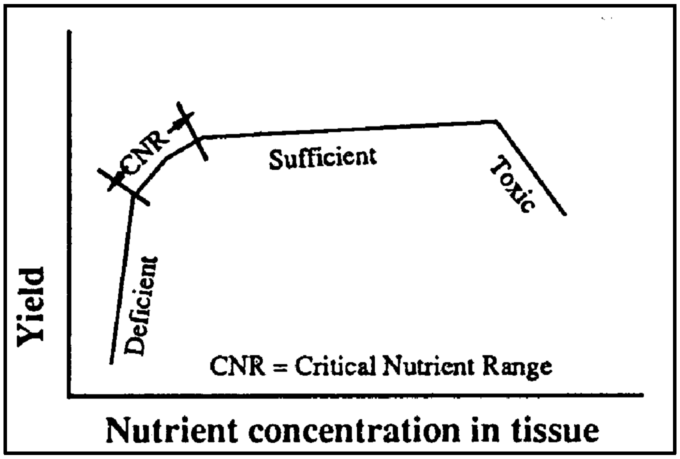

Figure 1.1 Relationship between nutrient concentration in plant tissue and yield (taken from Critical Nutrient Ranges in Northwest Crops. A. I. Bow, WREP 43.

sufficiency zone in which increases in yield with further increases in nutrient concentration does not occur. At the highest nutrient concentration levels a toxic zone may exist in which further increases in nutrient availability result in a decline in plant growth. In terms of fertilizer recommendations, the borderline or critical range is often represented as the level to be achieved or maintained through fertilization. When nutrient concentrations are above this range they should not receive additional fertilization for best economic results. Thus, it is important to know the interpretive procedures used and the basis of fertilizer recommendations as related to plant tissue testing.

Another approach receiving some attention is known as the Diagnoses and Recommendation Integrated System (DRIS). This system ranks nutrients based on plant tissue analyses from high yielding crops in a given area. Nutrient ratios are evaluated as a tool for managing nutritional balances. An extremely large data base is required to calibrate the DRIS for a given crop and locality. Its use is therefore limited in Utah since the necessary background information has not been developed. Most diagnostic laboratories follow the previously described critical range method.

Special care must be taken in sampling plant tissue material for nutritional diagnostics. A specified plant part and growth stage must by collected because the nutrient content of plants change as the crop matures and because the nutrient content differs in different plant parts. Details concerning how to properly collect a plant sample will be discussed in the specific chapter addressing each particular crop.

The use of field portable plant tissue test kits is not recommended because of the lack of adequate correlation information.

Nutrient Deficiency Symptoms

Plant visual appearances can provide an indication as to the nutritional status of the plant. Specific plant nutrient deficiency symptoms will be discussed for each type of crop in succeeding chapters. The appearance of a growth disorder based on visual symptoms does not absolutely mean a nutritional problem exists. The symptom could be a result of insects and/or diseases or any combination of factors which affect plant growth. Thus, it is a good practice to confirm apparent nutrient deficiency symptoms with plant tissue analyses. However, where diseases and insect problems are minimal, deficiency symptoms are characteristic for each nutrient element and may be used in connection with soil and plant tissue testing as a guide to effective soil fertility management.

Fertilizer Strip Test

Sometimes a soil test result is marginal and the situation may call for fertilizer application. On the other hand, the farmer may feel that his management practices and soil conditions are such that routine fertilizer recommendations may be inadequate. The fertilizer strip test is a tool which can provide on-site information. In very general terms, alternating strips of a specific fertilization rate or application method are combined with the normal practice. It is important that only one fertilizer variable be changed when comparing two treatments so that valid yield comparisons can be made. More details are given in Chapter 10 of the Guide.

Conclusions

There are four basic methods of predicting and evaluating fertilizer requirements for crop production. It is recommended that these methods be used in a complementary manner to maximize economic returns. There are large differences in interpretations of the same soil and plant analysis. It is desirable to compare fertilizer recommendations with practical experience.

The **Utah Fertilizer Guide** provides specific details concerning nutritional disorders for the important crops and soil types in the state. It is recommended that the entire Guide be studied and those parts that are applicable be utilized to obtain the highest yield and quality of crops that is economically feasible.

Chapter 2
Soil Sampling

D. W. James and *K. F. Topper*

Chemical analyses of soil samples is a prime source of information on soil fertility. When the soil test procedure is well calibrated with crop nutrient requirements, and where soil samples are properly obtained, the diagnostic soil test result can be a firm foundation on which to base soil fertility management practices.

Other chapters of the **Utah Fertilizer Guide** discuss soil test interpretations. This chapter emphasizes the proper soil sampling technique. A nonrepresentative soil sample is essentially useless, and may even be misleading when seeking the most appropriate soil fertility management for a given soil and crop situation.

Since an appropriate plant sampling technique for tissue analyses depends on crop type, plant sampling is discussed in the respective chapters of the **Utah Fertilizer Guide** which deal with different crops.

The soil sampling techniques described below are based on two contrasting field situations: Fields that are relatively uniform or homogeneous and fields that are relatively nonuniform or heterogeneous.

Soil Sampling Equipment

The basic soil sampling tools include the following:

1. A stainless steel soil sampling tube which has a knife edge cutting end and is slotted for easy extraction of the soil core (Fig. 2.1). This tube is used for sampling the plow layer or surface 10 to 12 inches of soil.
2. Plastic buckets for collecting soil cores during the field sampling operation.
3. Soil sample bags or boxes for use in transporting the soil sample to the diagnostic laboratory.
4. For depth soil sampling below the 0-12 inch layer (when testing for nitrates for example), a hydraulic ram mounted on a pickup truck or tractor is very useful for forcing sampling tubes into the subsoil. If this kind of equipment is not available then a specially built hand-driven soil sampling tube is usually needed.

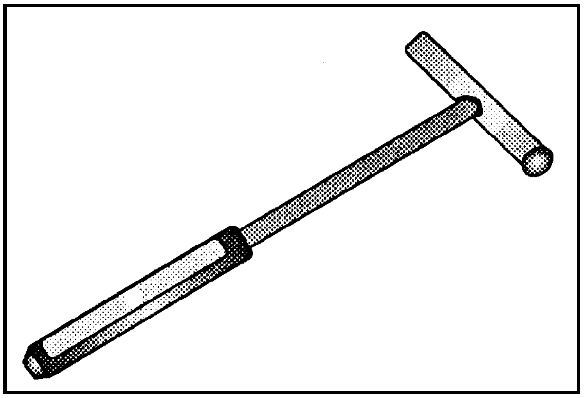

Figure 2.1 Soil sampling probe.

Soil Sampling Depth

Most fertility elements are immobile in soil. In Utah the principal elements of concern in this category include phosphorus (P), potassium (K), and zinc (Zn). The appropriate sampling depth for the immobile elements is the plow layer. Applied fertilizer, whether band or broadcast-applied, will be mixed into the plow layer during the plowing operation. It is recommended therefore, that soil samples be taken uniformly to the 10 to 12 inch depth which will be adequate for all routine plowing depths.

The principal mobile fertility element in soil is nitrate-nitrogen (NO_3-N). Diagnostic tests for this element require that the soil sampling procedure represent most or all of the effective root zone. For corn and wheat, for example, the soil sample should be taken to at least 4 feet or to a limiting layer, whichever occurs first. Limiting layers include water table, caliche or other cemented layers, gravel layers, or bed rock. The depth soil samples should be segregated into two or more depths, including the surface (0-12") layer, and at least one sample representing all lower layers. Each foot depth increment below the surface should be maintained separate. Most of the soil fertility information with respect to nitrogen will come from the subsurface samples. The surface sample alone has very little utility for prescribing nitrogen fertilizer needs.

An effective procedure is to run the routine soil test package (i.e. pH, EC, P, K and NO_3-N) on the surface sample. Then for all subsurface samples analyze only for NO_3-N.

Special caution is needed with nitrate soil sampling and analysis. Changes may take place in soil nitrate composition if the sample is stored in a closed (e.g. plastic) bag and held at room temperature for several days. Soil samples to be tested for nitrate should be air-dried immediately, or frozen, or taken to the diagnostic laboratory immediately after the field sampling is complete.

Components of soil salinity and sodicity are also mobile and depth soil sampling is necessary for these kinds of diagnostic tests as well.

When to Soil Sample

Soil sampling can be done any time. However, there are specific advantages of soil sampling in the fall and spring. Fall fertilization has the advantage of incorporation of applied fertilizer with fall plowing. On the other hand, spring soil testing for nitrates will provide a better evaluation of nitrogen availability for the spring crop establishment period. Residual nitrogen from the previous season depends on the amount of snow-melt/rainfall that has occurred between growing seasons.

How Often to Soil Test

Test the soil before crop establishment and subsequently every three years for perennial crops. For annual crops it would be good practice to sample the soil annually or at least biennially. Farm managers should keep complete soil test records for all farm fields, together with fertilizer application records (kinds and amounts) in order to relate changes in soil test results to cropping and fertilizer practices. This will allow for the development of site specific information which can improve the efficiency of the overall farm soil fertility management program.

Sampling Uniform Fields

A uniform field or field portion will have similar characteristics in respect to slope, aspect, soil depth and texture, cropping history, fertilization history, and uniform irrigation for irrigated fields. A uniform field will have uniform appearing crops in terms of presence or absence of deficiency symptoms, and uniform growth and productivity. Thus, for a large field which includes distinctive differences within its perimeters, there will be as many soil samples as there are distinctively different field portions. Clearly identify field differences before beginning soil sample collection in the field.

Soil sampling of uniform fields involves collection of 20 to 30 soil cores, using the slotted soil sampling tube shown in Figure 2.1. The sample is collected by following a zigzag path, taking care to force the path into corners and along edges of the field. Figure 2.2 illustrates the idea. The soil cores are then crushed and thoroughly mixed before reducing the sample size to the appropriate amount for transfer to the laboratory. This is referred to as a composite soil sample.

Crushing and mixing of the collected soil cores, together with reduction in sample size, must be done properly to assure that the final sample represents the original whole sample.

It is recommended that one composite soil sample not represent more than 20 to 30 acres regardless of apparent field uniformity. This is because non-uniformity is usually difficult to assess over broad areas of landscape. Thus a 50 acre field will be divided for sampling purposes into two or three smaller portions.

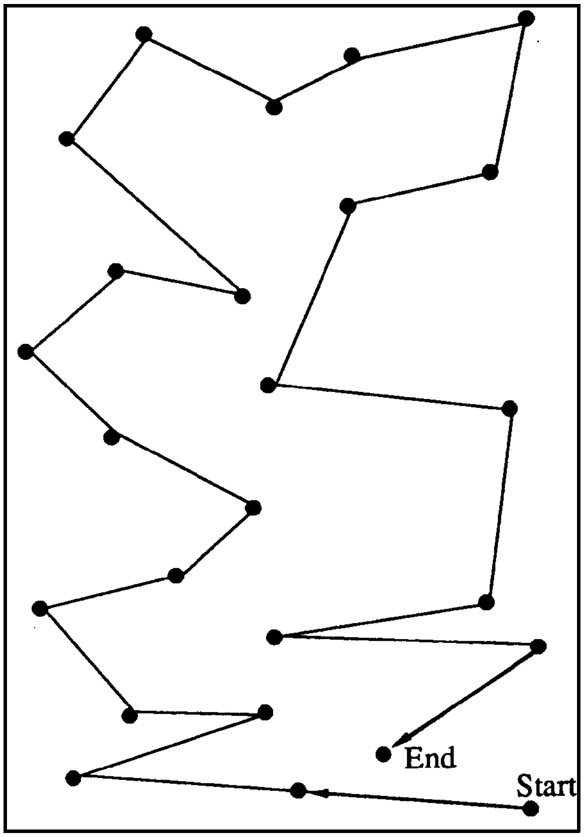

Figure 2.2. General approach used to sample a uniform field. Each dot represents a sampling spot.

Sampling Nonuniform Fields

Extreme field heterogeneity can result from subsoil exposure and also from fertilizer application by any of several injection methods (banded at seeding time, side-dress etc.) without a subsequent plowing or tillage operation which would tend to mix the fertilizer in the plow layer.

Sampling Fields with Exposed Subsoil

Subsoil is typically very low in fertility, especially in regard to phosphorus. Subsoil exposure results from soil erosion and from land leveling. Eroded fields, hill tops, and side gullies are susceptible to subsoil exposure. In Utah this is seen frequently on summer-fallow wheat land. Leveling or smoothing of irrigated lands is a common practice to facilitate uniform water application by furrow or border methods.

On leveled lands the pattern of subsoil exposure usually depends on the original field contours. Soil is cut and moved from high areas and deposited in low areas, resulting in differing degrees of subsoil exposure in the cut areas. An example of field heterogeneity generated by land leveling is given in Figure 2.3. In this example the average soil test P was

12.6 which, standing alone, would not indicate any P fertility deficiency. But, in the actual case, 13.6% of the field was severely P deficient and 35.6% of the field was moderately deficient. This means that 51.8% of the field would have yielded at less than its potential if no P fertilizer was applied based on the average soil test value. On the other hand, if fertilizer was uniformly applied at any rate, 27.6% of the field would not provide a return on the fertilizer P investment, assuming two or three years for amortization.

Sampling of leveled fields is done by marking the field ends and sides at regular intervals, for example every 100 or 200 feet. Five or six soil cores are then collected from a 3-foot diameter circle centered on the intersection of the field grid lines. This type of sample is referred to as a point sample. Point samples are maintained separately and labeled with the field grid numbers in order to map the soil variability and facilitate the application of the appropriate amounts of fertilizer for each soil test category.

A 100 foot-square grid system would result in an average of 4.4 samples per acre while a 200 foot-square grid would result in an average of 1.1 samples per acre. On casual inspection this may seem to be prohibitive. However, intensive soil sampling may be indispensable in restoring cut lands to their original level of productivity within reasonable time limits.

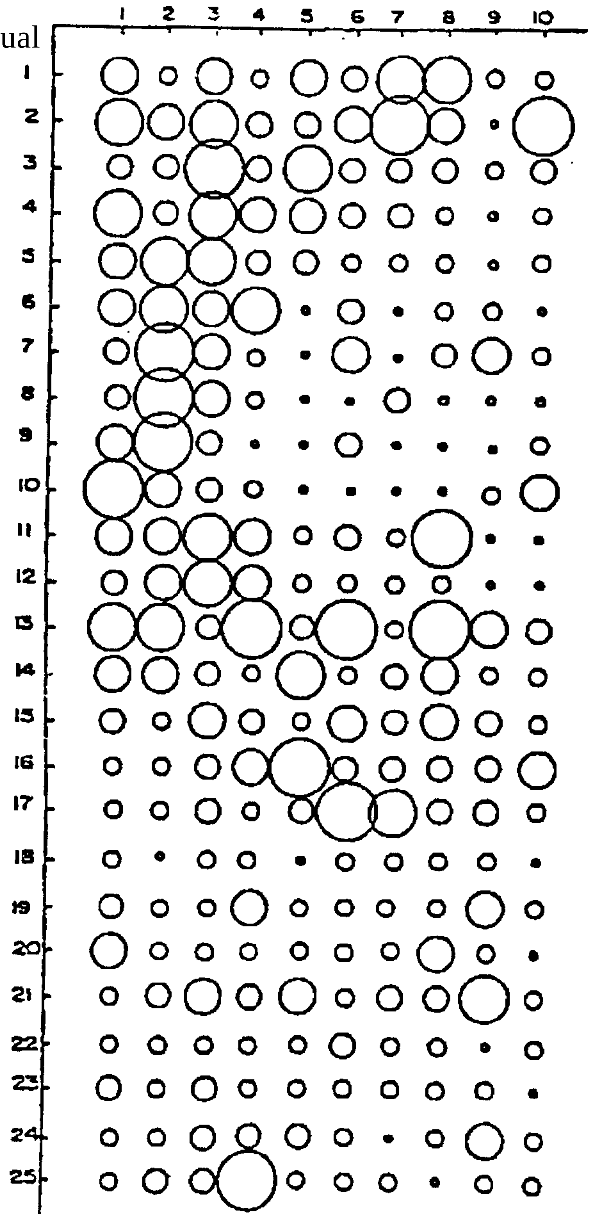

Figure 2.3. Soil test P results obtained from point soil samples taken on a 100 foot square grid on a newly leveled field in Cache County, Utah. Circles from small to large represent the following soil test P ranges: 0-3, 4-7, 8-11, 12-15, 16-19, and 20 respectively.

It is not necessary to apply all the standard soil fertility tests on every sample from an intensively sampled field; usually phosphorus alone will suffice. Further, when large numbers of samples to be treated alike are submitted to the laboratory, lower per sample analytical costs are encountered. Thus, the cost of re-establishing uniform crop growth and yield on leveled fields, expressed in terms of soil analyses, will usually be small compared to the loss of productivity associated with nonuniform soil fertility. Specific details on intensive soil sampling for specific field situations may be obtained from the Soil Plant and Water Analysis Laboratory at Utah State University.

Intensive soil sampling of nonuniform fields need not be repeated once the heterogeneity has been reduced by judicious application of fertilizer. The routine composite soil sample should suffice for future soil fertility diagnostics.

Soil Sampling No-till and Minimum-till Fields

Ordinarily fertilizer is mixed throughout the plow layer at plow time, whether or not the fertilizer was originally applied broadcast or injected (shanked) into the soil. Fertilizer mixing does not occur, however, where no-till or minimum-till is practiced. This is not important to plant use of fertilizer carried over from the previous season, but it does represent a special challenge in regard to obtaining representative soil samples which will accurately assess fertilizer requirements for the current season.

Injection fertilization without subsequent plowing, or other deep tillage operation, results in high soil variability. Narrow fertilizer-enriched bands alternate with wider strips (depending on injector spacing) of soil which has the lower, unfertilized, fertility level. The best soil sampling procedure for these conditions has not been fully developed. It is suggested however, that no-till and minimum-till fields be sampled in a manner similar to that suggested for uniform fields (Figure 2.2) except that the **number of soil cores collected for the composite sample be doubled**. In other words, for otherwise uniform field areas which have been injection fertilized without subsequent plowing, collect at random 40 to 60 soil cores for development of the composite soil sample. It is important that every core be collected at random so as not to bias the soil sample with too much representation in or out of the fertilizer enriched soil band. Also soil core crushing and mixing to form the composite soil sample would obviously be more involved. The suggestions given above for preparing the composite soil sample collected from plowed fields would need to be followed with extra caution.

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Chapter 3
Field Crops

K. F. Topper, T. A. Tindall and *D. W. James*

This Chapter of the **Utah Fertilizer Guide** expands the general discussion of Chapter 1 on methods used for soil fertility diagnoses in field crops. The general approaches are: diagnostic soil testing; plant tissue testing; and plant nutrient deficiency symptoms.

Using these diagnostic procedures, separately or in combination, the farm manager can achieve maximum economic return on his fertilizer investment. Other chapters that would be useful in connection with soil fertility management for field crops include Chapter 2, Soil Sampling; and Chapter 8, Fertilizer Compositions and Reactions in Soil.

The diagnostic tests, their interpretations and associated recommendations included in this chapter, were developed at the Utah Agricultural Experiment Station and in collaboration with research and extension colleagues in other western states. We gratefully acknowledge the inputs of our counter-parts in other states. Some specific information sources are indicated in the tables.

Interpreting Soil Test Results

Diagnostic soil tests are used to estimate the plant availability of nutrient elements in the soil. If the extractable nutrient level is high, then the plant will have an adequate supply of this nutrient. If the extractable nutrient level is low, crop yield will be limited by nutritional deficiency. It is through field calibration or correlation procedures that the relationship between soil tests and plant nutrient deficiency-sufficiency are established. The most important feature of the calibration is the “critical soil test level” or “range.” Below this level, crop yield will be depressed because of nutritional stress and fertilizer application will increase yield. Other plant growth factors, such as soil moisture and pest controls, are assumed to be optimal. When the soil test is at the critical level, fertilizer application will not affect yield but will simply maintain soil fertility above yield limiting levels. Fertilizer recommendations given here are intended to raise soil tests above the critical level and to maintain them at non-limiting levels.

The critical soil test level varies somewhat depending on crop type and other management practices. The crop and soil type are considered in the fertilizer recommendations.

Different soil test methods usually give different results in terms of the absolute numbers obtained in the chemical analysis. Accordingly, the specific procedure used by a diagnostic laboratory must be known in order to interpret that lab’s soil test results. Analytical results from any laboratory that employs the same procedures used by the Utah State University Soil, Plant and Water Analysis Laboratory (SPWL) can be interpreted using the **Utah Fertilizer Guide**. The SPWL list of routine soil testing procedures is available upon request.

Nitrogen

Soil has an inherent ability to supply some of the crop N requirements from the breakdown of soil organic matter by soil bacteria and fungi. Production of leguminous crops (i.e. alfalfa, beans), manure applications, and the previous year's fertilization (methods and amounts) will contribute towards some and possibly all of the current N requirements.

Predicting Nitrogen Requirements

In order to assess soil N fertilizer requirements before the crop is planted, a complete knowledge of past management practices is required, or the soil must be tested for available N. The plant available forms of N include ammonium-N (NH_4-N) and nitrate-N (NO_3-N). NH_4-N readily nitrifies to NO_3-N if soil moisture and temperature are favorable. Therefore, the SPWL tests only for nitrate-N in its diagnostic procedures.

Because of the rapid microbial transformations of N it is essential that soil samples be handled correctly. The sample must be air-dried immediately after sampling, or frozen until delivery to the soils laboratory, or the sample must be delivered to the laboratory within 24 hours of sample collection. It is recommended that the soil sample be placed in a plastic bag or other water-proof container, but that the container not be made air-tight, pending delivery to the soils laboratory.

A major limitation in N soil testing is the special field sampling procedures needed to accurately assess N availability. Details concerning the proper way to collect a soil sample for diagnostic N testing are explained in Chapter 2 of the **Utah Fertilizer Guide**. Soil test interpretations for the major field crops grown in Utah are presented in Table 3.1. If the soil is not sampled throughout the proposed crop rooting depth, it is more accurate to predict the crop N requirement using cropping history and type of crop to be planted, as shown in Table 3.2. General corrections to base N requirements, based on management history and current season cropping plans, are given in Table 3.3.

Table 3.1. Fertilizer N recommendations based on soil test N (STN).[a]

Crops	N Recommendations (lbs/ac)
Field Beans	55 - 3(STN)
Barley/Oats	50 + (yield goal (bu/ac)) - 4(STN)
Corn-Grain	220 - 5(STN)
Corn-Silage	100 + 5 (yield goal (T/ac))- 5(STN)
Onions	120 - 5(STN)
Potatoes	180 + 0.6 (yield goal (cwt/ac) - 300) - 6(STN)
Wheat-Irrigated	50 + (yield goal (bu/ac)) - 4(STN)
Wheat-Dryland	80 - 5(STN)

[a] STN = Sum of NO_3-N (mg/kg) in topsoil and subsoil samples. N recommendation should be expressed in terms of ±10 lb/ac to allow adjustments for specific site conditions.

Table 3.2. Fertilizer rates by crop type and length of growing season (long, medium, short) where soil test N is not measured.*

Crop	Standard Yield Goals Long	Med.	Short	Crop Units	Base N Recom. lbs N/A Long	Med.	Short	Adjustment for different yield goal
Corn Silage	28	22	---	Ton	200	150	---	4 lbs N/T/ac
Corn Grain	160	140	---	Bu	200	170	---	1.6 lbs N/bu/ac
Irr. Wheat	140	100	---	Bu	170	120	---	2.0 lbs N/bu/ac
Barley	110	100	85	Bu	130	110	85	1.6 lbs N/bu/ac
Potatoes	300	250	---	Bu	130	100	---	0.5 lbs N/bu/ac
100% Grass	4	3	2	Ton	150	100	75	------------
Alfalfa	6	5	4	Ton	0	0	0	
Dryland Grain	---	---	---	Bu		40-70**		
Onion	---	---	---			70-90		

*N recommendations should be expressed in terms of ± 10 lbs N/ac to allow adjustment for specific site considerations.

**N requirement is dependent upon available soil moisture.

Table 3.3. Corrections to basal N recommendations of Table 3.2 as related to crop history, crop residue management and soil type.

Situation		Correction (lbs N/ac)		
Alfalfa (pure stand)		-100		
Grain stubble plowed down		+ 50		
Manure applied since last crop		- (T/ac x 5)		
Crop last year was 31-70% legume		- 25		
Crop last year was 71-90% legume		- 50		
		Soil Texture		
Row Crops last year		Sandy	Med.	Fine
N last year	0-99 lbs N/ac	0	0	0
N last year	100-149 lbs N/ac	0	-25	-50
N last year	150-199 lbs N/ac	-25	-50	-75

Soil Moisture Versus N Fertility Management

The reliability of any N fertilizer recommendation depends upon the amount of water supplied to the soil. For irrigated crops, N recommendations are based on the assumption that the water is distributed equally throughout the field and that proper irrigation scheduling is practiced. This means supplying sufficient water to satisfy evapotranspiration without excessive leaching. Excessive irrigation will cause NO_3-N to leach out of the root zone resulting in decreased N availability for crop use. Higher or supplemental rates of N fertilizer may be applied to compensate for leaching losses. The cost of extra fertilization to compensate for poor irrigation control must be balanced against the cost of improved irrigation management. Also, the potential problems concerning nitrate-N contamination of ground water must also be considered. It is expected, within the near future, cost of poor irrigation management will include costs associated with reducing environmental pollution, where it occurs, as nitrates move from farm land to the groundwater.

When plant growth is limited by lack of irrigation water then the N requirements are lower. N requirements for dry-land crops depend on the stored soil water content at the beginning of the season, plus any rainfall that occurs during the growing season. The heavy precipitation period of 1984-86 resulted in significant yield increases in dry-land grain production with concomitant increases in optimum N fertilizer rates, up to 70 lbs N/acre on spring wheat, for example. How-ever, during drier, more normal periods, the amount of N recommended would be 25-50 lbs/ac. Soil moisture availability must be considered in determining the appropriate N recommendations for every crop and field situation.

Phosphorus

Phosphorus (P) may limit crop yields in Utah soils. Although the total amount of P is quite high in soils, the quantity available for plant use may be low. Chapter 8 of the **Utah Fertilizer Guide** describes the soil chemical reactions of fertilizer P in more detail.

The concentration of phosphate-P in the soil solution is low with respect to daily plant removal. Solution P is supplied by mobilization of phosphate from the soil labile pool. The labile pool is that portion of the total nutrient composition that is readily released from soil minerals. Most soil testing methods measure the concentration of P in the soil solution and a portion of the labile pool.

Different extraction procedures for P will yield different soil test results. The suitability of a particular extraction procedure depends upon the soil characteristics of a given region. It is essential, therefore, that the diagnostic procedure utilized for a given soil is the same as the procedure used in soil test calibration for the area.

The $NaHCO_3$ soil test P procedure is widely used in the western U.S. and other semi-arid parts of the world. It is the procedure used at the SPWL, and interpretations of soil test P levels along with fertilizer recommendations provided in Table 3.4 are based on this method. Fertilizer recommendations are intended to maintain adequate P levels for 2 to 3 years. Soil test levels ranging from 0-6 mg/kg (ppm) are low and most crops will readily respond to P fertilization. Crops growing on soil testing 7-10 mg/kg will usually respond to P fertilization. At soil test levels above 10 mg/kg, crops will usually show a “no yield response” to added P fertility. The decision to apply P when the soil test is 10-15 mg/kg range depends upon an individual farmer’s economic situation. Except where indicated otherwise, P fertilization is not recommended when the soil test level is above 15 mg/kg.

Table 3.4. P fertilizer recommendations for field crops in Utah (lbs P_2O_5 per acre) based on soil test phosphorus.

STP[a]	Field Crops	Grass hay and Turf	STP[a]	Potatoes	STP[a]	Dryland Grain
0-3	210	120	0-6	230	0-3	60
4-7	130	65	7-15	160	4-7	45
8-10	100	40	16-20	100	8-9	30
11-15	50	0-40	21-30	0-50	10-12	0-30
>15	0-50	0	>30	0	>12	0

[a] STP = $NaHCO_3$ soil test procedure (mg/kg = ppm).
Fertilizer recommendations may need to be adjusted by ± 10 lbs/ac depending on local conditions.

Potassium

Potassium (K) is an important soil fertility element which has been identified in recent years as being limiting to irrigated crops in Utah. Research at USU has shown that certain conditions predispose soils to be K-deficient. These conditions include use of irrigation waters with low levels of dissolved K, soils that are coarse textured, and intensive crop management.

Soil testing for K can readily identify those soil and crop situations where application of K fertilizer will promote best crop performance. There are several soil test methods which are used in the western U.S. One of the most common methods is the $NaHCO_3$ extraction procedure. Soil test interpretations along with fertilizer recommendations based on this method are provided in Table 3.5. Soils testing less than 100 mg/kg may respond to K fertilization. Application of K fertilizer at soil test levels greater than 100 mg/kg is not justified for most field crops based on current information.

Table 3.5. K fertilizer recommendations for field crops in Utah (lbs K_2O per acre) based on STK.

STK[a]	Field Crops (alfalfa, corn, grain, etc.)	Potatoes
0-40	200	250
40-70	160	210
70-100	120	140
100-150	80	100
>150	0-50	0

[a] STK = $NaHCO_3$ extractable K (mg/kg). Fertilizer K recommendations may need to be changed by plus or minus 20 lbs in each category depending on local conditions.

Iron and Zinc

The soil test extraction procedure used by the SPWL for iron (Fe) and zinc (Zn) is the DTPA soil extractant (Page et al., 1982). DTPA is a chelating agent which forms complexes with Fe, Mn, Zn, and Cu. General interpretations are shown in Table 3.6. Although evidence indicates that soils testing less than 5 mg/kg (ppm) may be deficient in Fe, there have been cases in Utah where this critical level has not accurately predicted Fe deficiencies. Other factors need to be evaluated to make this test reliable.

There are presently no Fe fertilizers that are completely effective in correcting lime-induced iron chlorosis. The one exception may be an Fe chelate known as Sequestrene 138. However, this fertilizer is usually cost prohibitive so it is generally recommended to use a crop variety which is efficient in its uptake of Fe. The USU Extension Publication EC 408 entitled “Control of Iron Chlorosis in Utah” may be referenced for further details.

Zinc (Zn) deficiency in Utah field crops is not common. When it occurs in crops like corn, potatoes, onions, or beans, a crop response may be observed to 5-10 lbs Zn/ac. The critical level for DTPA-extractable Zn is 0.8 mg/kg (ppm) soil.

Table 3.6. Generalized fertility interpretations for DTPA extractable micronutrients (mg/kg (ppm)).

	Zn	Fe	Cu	Mn
Low	0-0.8	0-3.0	0-0.2	0-1.0
Marginal	0.8-1.0	3.1-5.0	----	----
Adequate	>1.0	>5.0	>0.2	>1.0

Sulfur

Annual crop requirements of sulfur (S) range between 20 and 30 lbs S/ac. S deficiencies have not been clearly identified in Utah. The majority of irrigation water in Utah will supply more than 11-22 lbs S/ac/yr.

Plant available S is also released from organic matter and from rainfall. It is unlikely that sulfur deficiencies will occur in Utah irrigated crops.

Prediction of S deficiencies based on soil testing has had limited success. This is because of the numerous S sources, including irrigation water, depositions with dust and rain, and mineralization of organic S in the soil. Plant tissue analysis is helpful in determining S-deficiency. When a soil test is less than 8 mg/kg SO_4-S it is tentatively recommended that a trial application of 10-20 lbs S/ac be applied.

Other Fertilizer Elements

Chapter 3 provides recommendations for fertilizer practices based on observed crop responses to individual fertilizer elements in Utah-grown field crops. Application of nutrients other than those mentioned here are not recommended. It is possible that future research will determine other elemental deficiencies, in which case changes will be made in the **Utah**

Fertilizer Guide. In the meantime, “shotgun” application of nutrients is not recommended since the main effect will usually be an increase in fertilizer costs and lower net economic returns. In fact, application of some nutrients may inhibit plant growth when excessive levels of plant available forms are present in the soil. An example would be application of boron fertilizer in soils already high in plant available boron. Table 3.6 provides soil test interpretations for two nutrients (copper and manganese) which have not been observed to be deficient in Utah soils. They are merely listed as interpretive guidelines.

Plant Tissue Testing

Plant tissue analysis may serve two general purposes:

(1) To determine whether current soil fertility management practices are satisfying crop nutritional needs in relation to the climatic conditions and the irrigation, harvesting, and other crop production management practices.

(2) To help establish the cause of visual growth disorders—whether they are the result of insects, diseases, or plant nutrient deficiencies. Plant nutrient deficiency symptoms, as a diagnostic tool, are discussed in detail in the next section.

The interpretation of plant tissue analyses depends on time of season and plant part sampled. Studies focusing on plant tissue analysis as a diagnostic tool have emphasized economy and ease of plant sampling. In corn for example, the youngest fully developed leaf is taken before tasseling, but after tasseling the flag leaf (leaf opposite and below the ear node) is collected. In alfalfa the upper two-thirds portion of the whole stem (including leaves) is collected at late bud or early bloom. In potato only the petiole (leaflets stripped off) is taken from the youngest fully mature leaf at different growth stages.

In all cases the plant part sampled is collected at random from 25 to 30 plants over the field area represented by the sample. The plant sample is air dried while protecting it from dust and other contamination. The fresh plant sample may be taken directly to the laboratory where it will be dried at 50 to 60°C, then finely ground in preparation for chemical analysis.

Among the agronomic crops, plant or tissue analysis has been most intensely studied in Utah for potatoes and sugarbeets. Lesser amounts of information are available on other crops. Table 3.7 summarizes some critical nutrient ranges for crops grown in the Pacific northwest region. These data are considered to be applicable to Utah conditions. Table 3.7 takes into consideration both plant part and time of season.

Plant Nutrient Deficiency

Symptoms

Visual symptoms of plant nutrient deficiencies are an important diagnostic tool for evaluating the nutritional health of crops in the field. The experienced observer can recognize nutritional disorders because the symptoms are characteristic for each element. Insect and plant disease problems may obscure nutrient deficiencies, but when pests and diseases are minimal the deficiency symptom may be conclusive evidence of plant nutrient disorders.

Soil fertility and plant nutrient deficiencies in Utah field crops have been limited to nitrogen, phosphorus, potassium, iron and zinc. Deficiency symptoms of these elements in selected crops are described in the following paragraphs. Refer to Chapter 4 for similar discussions on fruit crops.

Table 3.7. Critical nutrient ranges in Utah field crops.**

Nutrient	Time or Growth Stage	Plant Part	Adequate***	Reference
Alfalfa				
P	1/10 bloom	top 2/3	0.2-0.3%	O-5
K	1/10 bloom	top 2/3	1.4-1.8%	O-5
Zn	1/10 bloom	top ½	10-14 ppm	W-2,10
S	1/10 bloom	top 2/3	0.19-0.21%	O-5
Barley (spring)				
No$_3$-N	early tilling	crown tissue	6000-8000 ppm	I-11
ZN	heading	leaves of 2nd mode	20-25 ppm	W-36
Beans (field)				
N	1st trifoliate leaf	whole tops	3.4%	I-9
P	1st trifoliate leaf	whole tops	0.2-3%	I-9
K	full bloom	whole tops	2.6-3.2%	W-21
Zn	mid season	youngest mature leaf	20-25 ppm	W-8
Corn (field)				
N	silking	ear leaf	2.4-3.7%	W-1
P	silking	ear leaf	0.23-0.26%	I-9
K	silking	whole leaf opposite and below ear	1.7-2.0%	W-21
Zn	pollination	6th leaf from bottom	15-20 ppm	W-37
Grass (orchard)				
N	12" height	tops	3.5-4.0%	O-1
P	6" height	tops	0.35-0.40%	O-4
K	6" height	tops	1.8-2.2%	O-4
S	early bloom	tops	0.10-0.15%	W-13
Potatoes				
NO$_3$-N	vegetative, tuberization, tuber growth	4th petiole	15,000-25,000 ppm	I-10*
NO$_3$N	maturation	4th petiole	5,000-10,000 ppm	I-10
P	vegetative, tuberization, tuber growth	4th petiole	0.22-0.30%	I-10
K	vegetative, tuberization, tuber growth	4th petiole	7.0-3.0%	I-10
Zn	tuberization	4th petiole	10-20 ppm	I-10
Wheat				
N	boot	top two leaves	2.3-2.7%	O-17,20
N	jointing	total tops	2.5-3.0%	O-17,20
NO3-N	jointing	1st 2" above ground	0.08-0.15%	I-7
P	heading/early boot	total tops	0.15-0.20%	W-13
K	early boot	total tops	1.5-2.0%	W-13
K	heading	total tops	1.25-1.75%	W-13

*Personal Communications with J. Ojalla, Idaho Extension Potato Specialist.

**Information referenced to "Critical Nutrient Ranges in Northwest Crops," WREP 43, Washington State University.

***Adequate refers to the critical nutrient range (ppm = mg/kg; 1% = 10,000 mg/kg).

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Nitrogen: N deficiency in corn, small grains, and milo (sorghum) appears as light green or yellowish color. Older leaves are affected first. As the severity increases the lighter color appears in the younger plant parts. With very severe N deficiency the older leaves die and may fall off the plant. N deficiency has not been observed in legume crops in Utah.

Phosphorus: P deficiency symptoms are less well characterized because changes in plant color or shape do not occur. In general, P-deficient plants are stunted or have reduced growth vigor. Visual detection of P deficiency is aided if a well nourished crop is nearby for comparison. Years ago it was said that purple coloration of plant tissue, especially in corn, was an indication of P deficiency. However, purple color is associated with genetic and environmental factors and has little, if any, relation to P nutrition.

Potassium: K fertilizer responses have been observed in Utah in alfalfa and corn grown on low-K soils. In alfalfa K deficiency appears as small white spots in older leaves. The spots are localized near the leaf margin. As the severity increases the number of spots increases and they develop closer to the midrib of the leaflet. In severe cases a general yellowing of the leaf may be superimposed over the spotting effect.

A second K deficiency symptom in alfalfa may be seen in the same area as the more common spotted symptom described above. The second symptom appears as uniform marginal chlorosis of the leaflet. The boundary between chlorotic and normal leaf cells is sharp and somewhat irregular. As the severity increases the proportion of chlorotic tissue increases, and in the extreme, may occupy more than half of the leaf area. Both K deficiency symptoms may be seen on different plants in the same field.

K deficiency in corn has apparently been marginal because the characteristic symptoms have not been seen in field trials where K fertilizer responses have been measured. It is expected that symptoms will become visible when the stress is more severe. K deficiency in corn is expected to appear as a marginal chlorosis or necrosis beginning first on the older leaves. Where it occurs, the symptom will be most prominent toward the leaf tip.

Iron: Fe deficiency in Utah crops is frequently seen in corn, milo (sorghum), and alfalfa. This deficiency is referred to as lime-induced chlorosis because it occurs in plants growing on calcareous soils. However, all calcareous soils do not react alike in terms of iron deficiency.

Fe deficiency appears as interveinal chlorosis; the veins and adjacent tissue have the normal green color and the interveinal areas are light green to yellow. In severe cases the entire leaf will be chlorotic.

Lime-induced chlorosis is aggravated by too much soil moisture, soil salinity and, in some cases, excessive soil phosphorus.

As previously stated in the **Utah Fertilizer Guide**, there is no effective, economical soil treatment for control of iron deficiency in field crops. The best protection, where this problem is prone to occur, is 1) select iron-efficient cultivars, minimize or avoid excessive soil moisture, and 2) do not load the soil excessively with barnyard and feedlot manures.

Zinc: Zn deficiency in field corn occurs sporadically in Utah. It is associated to some extent with land leveling and subsoil exposure. When it occurs, Zn deficiency may appear early in the season when corn is less than 10 inches high. In mild deficiency situations, the symptom may disappear as the season progresses. As the deficiency becomes more severe the chlorotic strips coalesce toward the leaf base, and in the extreme the lower part of the leaf will appear white and translucent and the plant overall will be stunted. Sometimes the stalk will take on a red or purple coloration. Zn deficiency is easily controlled with the application of Zn-containing fertilizers.

Fertilizer Application Methods

In general, the main concern with fertilizer application is to get the fertilizer **into** the soil and not simply **on** the soil. There are situations, however, when soil incorporation of fertilizer is not feasible, as for example, established alfalfa and pasture. In any case, the most appropriate fertilizer application method will minimize field application cost while maximizing fertilizer use efficiency. Rapid fertilizer application methods are cheaper, but not necessarily the most appropriate because method or placement of fertilizer affects fertilizer use efficiency by the crop.

Fertilizer application methods may be grouped into two main methods, broadcast and banding or injection. Foliar application of fertilizer is another method applicable under specialized conditions. The method of application will be dictated by the form of fertilizer selected, whether gas (anhydrous ammonia), liquid, or dry. Since both the cost per unit of fertilizer element and cost of field application are related to fertilizer form, the decision on which fertilizer to purchase should be based on both the purchase price and application cost.

Broadcast

Broadcast application of fertilizer is recommended for three cropping situations:

(1) Annual cropping, where the fertilizer may be broadcast on the soil surface before plowing or before seed bed preparation, or any other tillage operation which will assure incorporation of the fertilizer into the soil. Broadcast without soil incorporation on open fields is not recommended for nitrogen because of the potential for loss of significant amounts of nitrogen to the air as a result of volatilization of the ammonia. (See Chapter 8 for further discussion on potential losses of nitrogen from improperly applied fertilizer.)

Gaseous volatilization problems do not apply to other elements. But when phosphorus, potassium, zinc, etc. are not mixed into the soil they remain on the surface and thus may be inaccessible to plant roots. These fertilizer elements would not be permanently lost but would be incorporated into the soil in the following season with routine plowing and seed bed preparation activities.

(2) Spring application of nitrogen fertilizer to winter wheat. It is not feasible to put all the needed nitrogen into the soil at seeding time because some soil nitrogen may be lost with rainfall and snowmelt. Supplemental fertilization is necessary in early spring and this is done by broadcasting N fertilizer over the growing crop.

(3) Fertilization of perennial crops such as alfalfa and pasture. Broadcast phosphorus fertilizer to established irrigated alfalfa and pasture lands has proven effective because the plant roots are active near the soil surface when it is moist in these types of crops. When the crop rotation sequence is known well in advance, much of the phosphorus can be supplied at the time of perennial crop establishment. That is, apply sufficient phosphorus to satisfy the expected needs of the crop for 3 to 4 years.

In regard to irrigated grass pastures, annual or semi-annual applications of nitrogen are needed for best crop performance. It is not feasible to supply all of the fertilizer needs when the pasture is established. Thus, periodic broadcast application of nitrogen and other fertilizer elements is recommended for perennial pastures. Urea fertilizer as a source of N should not be applied to established pasture unless it can be moved quickly into the soil by concurrent or subsequent irrigation. This is because urea decomposes rapidly in the thatch and the N is lost as ammonia to the atmosphere.

Dry fertilizers are field broadcast using either a drop or rotary spreader. With the gravity drop spreader the fertilizer passes through openings at the bottom of the hopper. The application rate is determined by adjusting the size of the openings. These spreaders can be very precise and will provide a uniform distribution pattern when properly handled.

Rotary or centrifugal spreaders have an impeller attached directly beneath the hopper that spins as the spreader moves. The fertilizer is distributed in a fan-like pattern behind the spreader. This method is rapid and economical. However, most of the fertilizer drops in the middle one-half of the distribution pattern and special attention must be given to overlap from one pass to another to assure uniform fertilizer application. Fertigation is a variation of broadcast application of fertilizer that is quite popular because the cost of application is low.

Fertigation

Fertigation is the addition of liquid fertilizer into irrigation water, the fertilizer is then distributed on the field with the water. Fertigation is not generally recommended as a method of satisfying all of the fertilization needs, but it is used as a supplemental method in special circumstances.

Fertigation is an option for treating soil fertility deficiencies caused from inadvertent under-fertilization at the beginning of the season. It can also be used beneficially on fall-planted small grains where leaching of fertilizer during the winter makes it uneconomical to apply all the needed fertilizer to the crop in the fall. Fertigation is more common on sandy soils because it is difficult to avoid deep percolation and leaching losses on these types of soils.

The land manager desiring to apply fertilizer via the irrigation system should keep in mind that commercial sprinkle systems do not distribute water uniformly. In general, water application is heaviest near the nozzle, decreasing in a non-linear pattern to zero at the perimeter of the sprinkle circle. This feature is considered in the design of an overhead irrigation system. A certain amount of overlap between adjacent sprinklers is designed into the system to smooth out variations in the amount of water applied per unit area.

The coefficient of uniformity (CU) is used as an index of sprinkle irrigation application uniformity. If water distribution is perfectly uniform the CU is 100 percent. Closer spacing of nozzles improves irrigation water application uniformity but increases system cost. In practice, a compromise is made between system cost and the CU. Typical commercial sprinkle irrigation systems have nozzle spacings of 40 x 50 or 40 x 60 feet. This results in a CU of about 80 percent, which is considered acceptable.

To illustrate the practical implications, at CU = 80%, if 90 percent of the area is to receive at least 1 inch of water, there must be an average of 1.47 inches applied to the overall area. Under these conditions about 10 percent of the area would be under-irrigated, 80 percent would be slightly over-irrigated and 10 percent would be heavily over irrigated.

Extending the concept to fertigation, for each pound of nitrogen per acre that is applied via sprinkle irrigation, there must be an average of 1.47 pounds of nitrogen applied to the whole field. This would mean that 10% of the field would receive less than one pound while 10 percent of the field would receive over 1.94 lbs. If the rate of water application was greater than the soil water intake rate there would be surface accumulation and overland movement of water and dissolved fertilizer, further distorting the uniformity of application. If surface water flow was to result in transport of fertilizer off the field, environmental contamination could result.

It is recommended that sprinkle fertigation be carefully avoided during windy periods because of the effect of wind on sprinkle system application uniformity.

Because of the chemistry of fertilizer materials in water, nitrogen is the element most easily applied via fertigation. (See Chapter 8 for the preferred forms of nitrogen for this purpose.) Phosphorus fertilizers react with water constituents and unless the water is acidified (sulfuric or phosphoric acids) calcium phosphate compounds precipitate in the lines and nozzles. Insertion of acidifying materials creates the potential for excessive maintenance costs on the irrigation system because of corrosion of metal parts.

Fertigation via furrow-applied water is not recommended as a routine practice because of the risk of fertilizer loss in run-off water and because the application uniformity is very low. Loss of fertilizer in runoff water represents not only a direct economic loss to the farmer, but constitutes also an undesirable risk of environmental pollution. Water (and contained fertilizer) loss in furrow run-off water could be controlled by collecting water at the bottom of the field and recycling it back to the headlands by pumping. Whether or not recycling of water in this manner would be economically feasible would depend on the value of water (e.g. dollars per acre-foot) and the cost of installing the collection and redistribution system.

In summary, fertigation is a useful method of supplemental fertilization if it does not degrade the environment and the irrigation system is well managed to keep the applied fertilizer in the root zone to facilitate crop utilization.

Banding or Injection

Band or injection application of fertilizer usually places the material 4 to 6 inches below the soil surface. Banding is done to the side of the seed in row crops at the time of seeding, and side dressing to the side of the row after crop establishment. Banding and side dressing are done with any form of fertilizer—gas, liquid or dry. The main precaution would be to have sufficient distance between the seed or plant roots and banded fertilizer to avoid chemical injury to the plants. The higher the fertilizer rate, the greater would be the risk of salt injury. Four inches between the seed and banded fertilizer is usually sufficient for routine fertilizer rates.

Another variation of band application is placing the fertilizer directly with the seed at planting time. This is sometimes referred to as “starter” fertilizer. Of necessity, the rate of fertilizer must be carefully limited to avoid fertilizer burn or salt injury to the seedlings. No more than about 20 to 25 pounds nitrogen or phosphorus (not both) per acre can be included in the “starter” treatment with safety.

Foliar Application of Fertilizers

In contrast with fruit tree management (see Chapter 4), foliar application of minor elements like zinc and iron has not proven to be effective in overcoming nutrient deficiencies in field crops. The best assurance is to determine the need for minor elements before the crop is established and apply the material by banding or broadcasting with the major fertility elements.

Foliar application of the major fertility elements (N, P, K) is not an effective fertilization procedure because the concentration of nutrients in solution has to be limited to levels that will not cause salt injury to the foliage. This means that no more than about 20 to 25 pounds of nitrogen or phosphorus or potassium (not all) per acre can be applied at one time; where additional amounts are needed additional passes over the field are necessary at intervals no closer than one week apart. Also, leaves and stems are not efficient organs for absorbing nutrient elements. This implies that fertilizer should be applied to the soil so that the roots can have ready access to the needed elements.

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Chapter 4
Fertilization of Fruit Crops

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Proper fertilization of fruit trees is a profitable investment. Fertilizer is relatively cheap compared with the increased yield and quality of fruit that often results. The amount and kinds of fertilizer that are best for a given soil and orchard situation are based on soil type, presence of cover crop; type of fruit, rootstock and age of tree; prior fruitfulness and growth; and expected crop performance for current year.

There are 15 or more essential plant nutrient elements. Nutrient elements that have been observed to be deficient in fruit trees under Utah conditions include nitrogen, phosphorus, iron, manganese, and zinc. The other elements are available in the soil and air in sufficient quantities to usually satisfy fruit crop needs. The challenge is to decide which elements are limiting tree growth and fruit production and how to supply them to the tree in the proper amounts.

Diagnosing soil fertility and plant nutrient needs of fruit trees involves one or more of the following procedures: soil analysis, leaf analysis, and visual symptoms of nutrient deficiency and excess. Soil analysis is appropriate before an orchard is planted. Leaf analysis is the most reliable indicator of fruit tree nutrient levels in orchards. Visual symptoms provide an indication of a problem which can be verified by leaf analysis. Leaf analysis is also used to help differentiate between nutritional disorders and disease symptoms.

Soil Analysis

Soil analysis is desirable in determining if a site is suitable for an orchard. It can prevent a costly mistake. For most soils in the semi-arid and arid regions of the west, a soil analysis for texture and other physical properties, pH, salinity, phosphorus, potassium, and zinc should be evaluated before a decision is made regarding the suitability of land for orchards.

Soil variability can be considerable in a relatively small area. Thus, many soil samples may need to be taken and evaluated separately. Chapter 2 of the **Utah Fertilizer Guide** explains how to collect soil samples.

Soils with an electrical conductivity of 3 dS/m (mmhos/cm) or more are referred to as saline soils when dealing with fruit trees. Salinity reduces root activity and absorption of water and nutrients. Minor element nutritional problems have been associated with saline soil conditions. These include iron, manganese and/or zinc deficiencies. If saline soil conditions exist, then reclamation needs to be undertaken to leach the soluble salts from the soil before fruit trees are planted. If the soil is sodic, characterized by a high sodium adsorption ratio (and sometimes a pH above 8.3), then fruit trees should not be planted unless the soil is reclaimed. Details regarding salt affected soils are provided in Chapter 9 of the **Utah Fertilizer Guide**.

Information regarding soil texture and depth is helpful in establishing the proper irrigation schedule. Porous soils require frequent light irrigations while heavier soils (high clay content) require longer irrigation sets at less frequent intervals. Trees planted in light textured soils (sandy soils) will grow better as will nematode resistant rootstocks.

Fruit trees are deep rooted, thus an ideal soil texture for an orchard is sandy loam. Clay soils are generally not recommended for fruit trees because this type of soil can, under conditions of excess moisture, be depleted of soil oxygen for long periods of time causing the roots to die. Also, low oxygen favors root or collar infection by ***Phytophthora*** disease organisms which readily kills fruit trees. However, pear and apple trees on resistant phytophthora rootstocks have been grown successfully in clay loam soils with proper water management. Stone fruit trees generally do not grow as well in clay loam soils as they do in sandy soils.

Calcareous soils, typical of Utah and other western areas, generally restrict the availability of iron, manganese, and zinc.

If the soil is low in phosphorus, a phosphate fertilizer should be plowed deep into the soil **before** trees are planted. Phosphorous tends to be immobile in soil, and the fertilizer needs to be placed in the area of the root zone.

The soil analysis may indicate an excess of some nutrients. This may occur if the soil has been heavily fertilized with animal manure.

In some cases a high level of one nutrient may hinder the absorption or utilization of another nutrient. For example, high phosphorus levels can reduce the uptake of iron and zinc under some conditions. Iron, zinc, and manganese interact with each other and an imbalance in one of these elements may affect the absorption of the other two elements. Potassium and magnesium can be antagonistic towards each other and reduce absorption. High boron levels are toxic to plants. Growers can aggravate the situation by applying excess amounts.

Increasing the level of the nutrient that is deficient or being suppressed can alleviate a nutritional deficiency. However, care must be taken not to induce the deficiency of another nutrient by increasing the level too much. Nutrient levels can sometimes be decreased by growing a crop for a few years that uses high levels of the nutrient in excess.

A general interpretation of a soil analysis is provided in Table 4.1.

Table 4.1. General guidelines of soil analysis suitable and potential problem soils for orchards.

	Suitable	Potential Problems	Units
pH	6.2-8.3	> 8.3	unitless
Ec_e	0-3	> 3	dS/m
SAR	0-9	> 9	$(mmol_c/L)^{1/2}$
K*	> 100	0-100	mg/kg
P*	15-100	0-14	mg/kg

*$NaHCO_3$ extractable K and P. Specific recommendations are available from the USU Soil, Plant and Water Analysis Laboratory.

Leaf Analysis

The desired foliar nutrient element levels for several fruit species are listed in Table 4.2. Values considered below normal and excessive are also listed. In order to obtain a good evaluation of the tree’s nutrient condition, it is necessary to closely follow the prescribed methods for collecting and handling leaf samples. These methods are presented later in this chapter.

Table 4.2. Nutrient level range in leaves of apple, peach and sour cherry during late July.[1]

	APPLE			PEACH			SOUR CHERRY		
	Deficiency	Normal	Excess	Deficiency	Normal	Excess	Deficiency	Normal	Excess
	(Percent)			(Percent)			(Percent)		
Nitrogen	1.6	2.0-2.2	3.0	2.0	3.0-3.6	4.0	1.7	2.3-2.6	3.5
Phosphorus	.10	.14-.20	.65	.10	.14-.20	.65	.10	.14-.20	.65
Potassium	.90	1.2-3.0	4.0	1.0	1.5-2.8	3.0	.10	1.3-2.8	3.0
Calcium	.50	.8-2.4	3.0	.50	1.0-2.4	3.0	.50	.8-2.4	3.0
Magnesium	.18	.23-.33	2.0	.18	.23-.80	2.0	.18	.25-.80	2.0
	(mg/kg)			(mg/kg)			(mg/mk)		
Mangenese	20	40-200	220	20	35-200	220	20	35-200	220
Iron	40	50-200	220	40	50-200	220	40	50-200	220
Boron	25	30-60	100	25	30-60	100	25	30-60	100
Zinc	15	18-80	200	15	18-80	200	15	18-80	200

[1] Levels were determined after an evaluation of data from Oregon, Pennsylvania, New Jersey and personal information (1% = 10,000 mg/kg; mg/kg = ppm).

Care must be taken when comparing leaf analyses with the levels provided in Table 4.2. For example, slightly lower nitrogen levels are desirable in leaves of red-colored apple varieties. Green-skin apple varieties may benefit from increased size if the leaves are a little higher in nitrogen than is listed. Higher nitrogen levels may also be important in the more precocious and less vigorous varieties.

Environmental conditions influence the assimilation of nutrients by the plant. Thus, soil fertility adjustment on a seasonal basis needs to be correlated with tree growth and vigor. For example, a light crop because of a freeze or alternate season bearing of a previous heavy crop may be reflected in a leaf analysis.

Another important factor in interpreting leaf analyses is to be aware of the irrigation practices being used. Maintaining the soil moisture level too high can reduce the ability of the fruit tree to absorb nutrients. High soil moisture levels, especially in heavier soils, reduces the soil oxygen level making it difficult for the roots to function properly. An adequate soil oxygen supply is especially important in the spring when new roots are being formed and the new flush of canopy growth is beginning. Some nutrients must be absorbed before the new roots become suberized, which occurs about 3 weeks after bloom. Once new roots suberize, some nutrients are no longer absorbed, and the nutrients in the plant must meet the tree’s need for the rest of the growing season. A low magnesium level in fruit trees in most arid regions could indicate a prolonged period of excessively high soil moisture level, unless an excessive amount of potassium is present.

Some deficiency symptoms, such as iron, can be corrected by readjusting irrigation practices. Fruit trees seem to have less problems if the soil moisture is allowed to drop to 50% of the available moisture capacity before another irrigation is applied to help with periodic soil oxygenation.

Chemical analysis of leaf samples is a precise analytical procedure. The main challenge with leaf analysis is in obtaining a representative sample from the field, and processing the sample properly to facilitate a better interpretation of the analytical values. Refer to Form 1 for general guidelines on how to collect fruit tree leaf samples. Interpretation of a leaf analysis takes into account the age, species, variety, environmental conditions and cultural practices such as use of a sod, fertilizer applied, and amount of irrigation used by the grower.

The Utah State University Soil, Plant and Water Analysis Laboratory analyzes leaf samples. Form 2 is the plant analysis information sheet which must be completed for samples submitted to the laboratory. Contact your county agent or extension fruit specialist for more information.

If a grower has leaf analyses done on a regular basis, the values obtained may be correlated with the tree performance, then adjustments in the fertilizer applications can be made more accurately.

Form 3 is used to provide fertilizer recommendations based upon plant samples analyzed by the USU Soil, Plant and Water Analysis Laboratory. The elements listed in Form 3 are those that might be a problem in Utah soils.

Visual Symptoms

Many growers rely on visual nutrient deficiency symptoms in determining what fertilizers to use. If deficiency symptoms are present, there has likely already been a loss in photosynthesis resulting in lower quality and/or quantity of fruit. There will be additional time lapse after fertilization and before the tree can absorb and utilize the fertilizer applied to correct the symptoms. The following discussion describes deficiency symptoms of specific nutrients.

Nitrogen

Nitrogen deficiency is expressed by pale yellowish green leaves; thin short shoot growth; small, poor quality fruit and general lack of tree vigor. More nitrogen is used by fruit trees than any other element. Many growers make an annual application of nitrogen to trees.

Excess nitrogen application may also be a problem. Excess nitrogen results in excessive vegetative growth such as waterspouts in the tree and/or suckers from the base of the tree, fewer flowers, poorly colored fruit that does not store well, and delayed cold hardening in the fall.

Shoot growth in non-spur apple trees should be 12 to 18" and in peach trees 12 to 20" long. A reduction or elimination of nitrogen fertilization for a couple of years may be needed if excess growth occurs.

Phosphorus

Trees lacking phosphorus do not grow properly. The leaves are small and may become purple in color.

Fruit trees do not require much phosphorus. If a soil analysis indicates it is low, mono-ammonium phosphate can be incorporated into the soil surface at the time of orchard establishment. Phosphorus deficiencies often occur where land leveling has removed top soil. Such areas should be sampled, evaluated, and fertilized separately from other areas.

Iron

Visual symptoms of iron deficiency in fruit trees occur as yellowing of leaf tissue between the veins, a condition often referred to as iron chlorosis or lime-induced chlorosis. The veins in the leaves remain green, though in severe cases the entire leaf may become colorless and later turn brown and die along the margin. The deficiency is usually first recognized on young, rapidly growing leaves. Only a portion of the tree may be affected. Young trees having shallow roots are especially susceptible with considerable variation in symptoms occurring among seasons. Trees growing in saline wet soils have more iron deficiency symptoms than if the soil were dry at times. Thus the deficiency occurs more on trees in clay soil which is watered often. Chlorotic trees are more likely to sustain winter injury than healthy trees.

Peach, pear, and apple trees exhibit iron chlorosis symptoms more frequently than do cherry, plum, and apricot trees. Strawberry, raspberry, and grape plants also can be affected by this deficiency.

Manganese

Manganese deficiency in fruit trees appears as the fading of green color from the margin toward the mid-rib of the leaf between the veins. The faded area becomes brownish-yellow in color as the season progresses. The leaves are usually normal in size, although fruit yields are reduced. Symptoms are first evident on older leaves. Manganese deficiency is more common with peaches and apricots than the other tree fruits.

Zinc

Zinc deficiency symptoms appear as very narrow, irregularly-shaped leaves and shortened internodes, which give rise to the name of little leaf or rosette. The symptoms are first observed on young leaves as reduced size and yellow mottling. Affected trees often have leaves only at the tip of their branches in small tufts. Symptoms may occur on only one side or one branch of a tree.

Peach, apple, and cherry trees are affected less frequently than apricot and plum trees.

Orchards fertilized with manure for a number of years or that are planted on old corral sites have been especially susceptible to zinc deficiency.

Calcium

Calcium imbalances, due to over cropping or wet soil conditions, can result in cork spot and bitter pit. This is not as common in Utah as in the east or other parts of the country.

Soil Fertility Control Measures

Nitrogen

Generally annual applications of nitrogen are required for good tree growth and fruit yield. Apply nitrogen according to the amount of annual growth. Apple trees with 10" to 14" of terminal shoot growth and peach trees with 12" to 16" of growth are doing about right. A guide as a starting point is to apply 0.1 pound of nitrogen per inch of trunk diameter. Apply the fertilizer between late November and early March to allow the nitrogen to move into the root zone with rain and snowmelt. The fertilizer should be applied no later than one month before bloom in the spring.

Apply the nitrogen to the soil half way between the drip-line and trunk in a narrow band. For young trees, the width of the fertilizer band may be 1 foot nearer the tree trunk. For mature trees, the band may be 2 to 3 feet wide and 6 to 8 feet away from the tree trunk.

Apply up to 1/8 pound of actual nitrogen per tree for trees 1 to 3 years old. Trees 3 to 8 years old may receive 3/8 pound of nitrogen per tree per year. Large apple and cherry trees may need 1 or more pounds of nitrogen annually. Orchards with a grass cover crop usually need up to 20 percent more to supply the needs of the cover crop.

Barnyard manure is generally an uneconomical source of nitrogen for trees if it has to be transported very far. A ton of cow manure contributes approximately 10 to 12 pounds of actual nitrogen. Commercial nitrogen fertilizer can be purchased for much less than it costs to obtain and spread manure. However, when soil tilth is poor, manure contributes organic matter and improves soil structure.

Foliar sprays of 5 pounds of urea per 100 gallons of water applied at the petal fall stage until the solution begins to drip off the foliage and again 10 days later, provides a source of nitrogen to apple trees that need additional nitrogen in early summer. Urea sprays applied after July 15, however, often reduce fruit color. Peach, pear, and apricot trees do not respond as well as apple trees to urea sprays. The waxy coating (cuticle) on the leaves of these trees does not allow good absorption of urea.

Iron

Excessive irrigation on calcareous soils may induce iron deficiency symptoms. Where this occurs, allow the soil in the root zone to dry between irrigations.

There are chemicals available which are somewhat effective in reducing iron deficiency. Iron chelated compounds, such as Fe 138, Nutra plus Fe, and Sorba spray Fe are examples. Directions for application are on the container.

If chelate materials are used as a foliar spray, they need to be applied early in the summer to peach and apple, before the fruit is one inch in diameter, in order to prevent an objectionable residue on the fruit. Usually more than one foliar application in the growing season is needed to obtain a satisfactory recovery from iron deficiency. Also, where iron deficiency is a chronic problem, there is little if any residual effect of foliar iron applications from one season to another.

Growers with a drip irrigation watering system have also been successful in reducing iron deficiency by placing sulfur-dioxide in the water. This reduces the pH and increases absorption of the iron.

Iron sulfate applied either to the soil or as a spray does not satisfactorily control iron chlorosis in Utah orchards and is, therefore, not recommended.

Chlorotic pear and peach trees respond where iron phosphate or iron citrate crystals (obtained from drug stores or supply houses in 00 size gelatin capsules) are placed in the trunk during the dormant season. Iron sulfate should not be used, since it dissolves too rapidly and is toxic to the tree. Holes 3/8 inches in diameter and 1 inch deep are made in the trunk. The holes are spaced at intervals of 3 inches apart around the trunk, alternating between about 2 inches and 16 inches above the soil surface. A capsule is inserted in each hole, which is then sealed with grafting wax. As the gelatin capsules slowly decompose, the iron compound dissolves and is absorbed by the tree. The capsules can also be placed in large branches. Treatment must be made before leaves appear in early spring. Peach trees have sometimes been weakened and also damaged by disease organisms entering the hole, even when sealed with grafting wax.

An important control measure for iron deficiency control is the selection of iron-efficient varieties, or as is the case for concord grape, the use of an iron-efficient rootstock. Thus, iron deficiency control is obtained by changing the plant type rather than changing the fertility of the soil.

Manganese

Apply up to 2 pounds of manganese sulfate to the soil around the periphery of a mature tree and spade it into the soil to about 4 inches deep. This material is not rapidly inactivated by the soil so a single application should be effective for a few years.

Zinc

Spray with a solution containing the equivalent of 5 pounds of actual zinc (usually in the form of zinc sulfate) per 100 gallons of water on affected apple, pear, and peach trees during their late dormant stage of growth in the spring. Spray to drench the entire tree. This material, at this concentration, should not be applied to trees after the buds start to open. If the trees are not treated during the dormant stage and the deficiency shows up after the leaves are developed, a spray of ZN EDTA or Nutra phos Zn may be used. This should be applied before the fruit reaches 1 inch in diameter. Galvanized nails or glazier points with a heavy zinc coating have also been placed in the trunk of apple trees to correct the deficiency.

Soil and Cover Crop Management

A cover crop returns organic matter to the soil, reduces erosion from rain and wind, allows equipment to be used on wet soil, and reduces soils compaction. A sod also provides a cooler temperature resulting in fewer mites. Soil structure is also improved with a cover crop. A cover crop uses both water and nutrients, which need to be supplied to avoid competition to fruit trees. A sod cover crop requires approximately 50 lbs. of N per acre per year. Periodic soil sampling and analysis of P and K levels are recommended so these nutrients are maintained at adequate levels. High phosphorus levels encourage the growth of clover which is not a good cover crop. Irrigation scheduling should take into consideration cover crop demands.

A perennial grass, such as dwarf red fescue, is recommended as a cover crop. Orchard cover crop mixes containing perennial rye grasses and fescues are widely used since they require minimal mowing. A strip 18 to 24 inches from each side of the trees, free of sod or weeds, should be maintained especially with stone fruits. Grass should be mowed regularly so it does not become higher than 12 inches tall.

Clean cultivation during the summer months has been a common practice for stone fruits such as peaches, cherries, plums, and apricots. However, a cover crop is beneficial to stone fruit plantings if additional nutrients and water are added for the grass. Growers have observed less sunburn in their sour cherry orchards when they have used a cover crop. Apple and pear trees can withstand competition of sod or cover crop for nutrients and water much better than stone fruits.

Form 1.

PROCEDURES FOR COLLECTING FRUIT TREE LEAF SAMPLES AND FORWARDING FOR ANALYSIS

STEP 1 Leaf samples should be collected between approximately July 15 and August 15.

STEP 2 Select five fruit trees of the same variety. A single sample should not represent an area of more than five acres. Mark or map plants sampled for future reference. In diagnosing poor growth areas take a composite sample from affected plants and a separate sample from non-affected plants.

STEP 3 Collect 10-20 leaves per plant at random from around the tree at shoulder height and combine them into one sample. Collect those leaves in the center of the current season's growth (see diagram below).

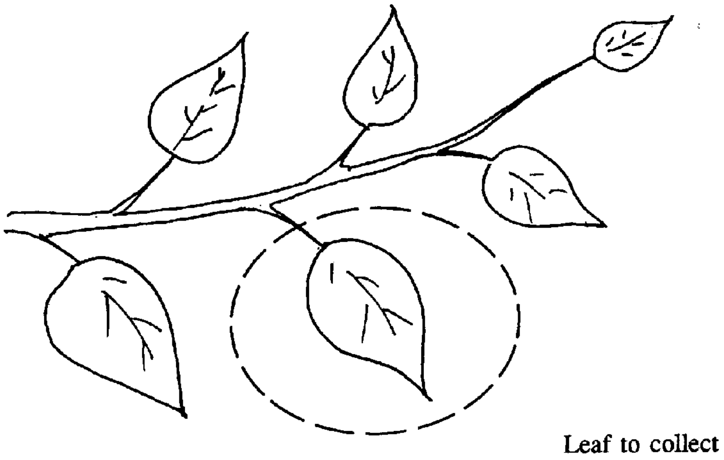
STEP 4 The leaves should be briefly rinsed (less than 30 seconds) in clear, soft water. Allow the leaves to air dry before sending to the lab.

STEP 5 Repeat steps 1-4 for each fruit variety to be tested.

STEP 6 Fill out the Plant Analysis Information Sheet and place it along with the dried leaves (or fresh leaves in a plastic bag, if the leaves are to be washed by the lab) into a No. 4 paper bag. Either package and mail sample(s), or arrange with your county agent for delivery to the lab. Mail to:

SOIL, PLANT & WATER LAB
UTAH STATE UNIVERSITY
LOGAN, UT 84322-4830

Be sure to send a check payable to the USU SOIL TESTING LAB so that analysis can be completed.



Form 2. PLANT ANALYSIS INFORMATION SHEET

SOIL, PLANT & WATER LAB
UTAH STATE UNIVERSITY
LOGAN, UT 84322-4830

LABORATORY CODE ____________________

SAMPLE NO. ____________________
COLLECTION DATE ____________________
SAMPLE COLLECTED BY ____________
FIELD IDENTIFICATION ____________

GROWER'S NAME ____________________
ADDRESS ____________________
____

COUNTY ____________________
PHONE # ____________________
PLANT OR CROP TYPE ____________
VARIETY ____________________
PLANT AGE OR GROWTH STAGE ____________________

* *

FIELD HISTORY (place an X by appropriate response or answer).

General Vigor of Plants: ____Vigorous ____Moderately Vigorous ____Weak
Irrigation System: ____Flood ____Furrow ____Sprinkler ____Drip
Soil Texture ____Sandy Loam ____Loam ____Clay Loam ____Other (specify)
Soil Depth: ____Shallow ____Deep ____Soil Series: ____________ (name)
Soil Drainage: ____Rapid ____Moderate ____Slow
Cover Crop: ____None ____Sod ____Legume ____Weeds
Last Year's Crop: ____________________________________ (name & vigor)

FERTILIZER USED (Enter Amount in lbs/acre)

	TYPE	THIS SPRING	1 YEAR AGO
NITROGEN			
PHOSPHORUS			
POTASSIUM			
OTHER(S)			
NUTRIENT SPRAYS			

* *

OTHER SPRAYS USED ____________________
WEED CONTROL ____________________

Does this sample represent an average of planting YES/NO; Problem area YES/NO? (circle)
If there is a problem, do you think it is nutritional: Describe: ____________________
____

* *

ANALYSIS REQUESTED
(check appropriate number)

	Price/Sample
Basic leaf tissue Test #1 (N, P, K)	$15.00
Leaf tissue Test #2 (N, P, K, Ca, Mg, Fe, Zn, Mn, Cu, Na, S) . ..	$25.00

*Please enclose a check or money order payable to USU SOIL TESTING LAB to cover analytical costs along with sample description sheet. Chemical analysis cannot be completed until payment is received. Other analysis can be completed upon request. Contact lab for details.

Form 3. FERTILIZER RECOMMENDATIONS
for
Lab Sample No. ______________________

NITROGEN:

____ No fertilizer needed.

____ Continue with current program.

____ Apply ____ pound of actual nitrogen (____ lb. of 21-0-0, ____ lb. of 34-0-0, or ____ lb. of 45-0-0) per inch of trunk diameter measured 1 foot above the ground. Application should be in a narrow band half way between the drip-line and trunk of the tree at least 2 weeks before growth begins in the spring. Split applications may be necessary of sandy soils.

POTASSIUM:

____ No fertilizer needed.

____ Low. Broadcast 100-200 pounds of potassium sulfate per acre or divide this rate by the number of trees per acre and apply in a band to trees as described under NITROGEN.

PHOSPHORUS:

____ No fertilizer needed.

____ Low. Not sufficiently critical to justify correction measures.

____ Deficient. Band ____ pounds of monoammonium phosphate per tree as described above for nitrogen.

IRON:

____ No fertilizer needed.

____ Low. Avoid excess nitrogen, pruning and watering.

____ Deficient. Apply a foliar spray of Nutra phos Fe @ 10 lbs/acre, Sorba spray Fe @ 2 quarts/acre or 1/4 to ½ pound Sequestrene Fe 138 per tree (depending on tree size) to the soil surface under the tree canopy in the spring. Work into the soil since it is light sensitive.

Another alternative is to apply 2 or 3 foliar sprays of Fe 138 at the rate of 2 pounds per 100 gallons. This should be applied to apple and pear trees before fruit reaches 1 inch in diameter.

ZINC:

____ No fertilizer needed.

____ Low. Not sufficiently low to justify correction.

____ Deficient. Apply 5 pounds of actual zinc per 100 gallons of water as a dormant spray. It should be applied before any green tissue appears in the spring and not within 3 days of an oil spray, unless label permits it. Trees should be thoroughly wetted.

MANGANESE:

____ No fertilizer needed.

____ Low. Not sufficiently low to justify correction.

____ Deficient. Apply up to 2 pounds (depending on tree size) manganese sulfate to the soil around the periphery of each tree and spade it into the soil to about 4 inches deep.

Chapter 5
Turfgrass and Ornamental Plants

W. F. Campbell and *W. A. Varga*

Vigorous and resilient turfgrasses and ornamental plants must be provided a well-balanced supply of the essential plant nutrients. Fortunately, Utah soils generally contain an adequate supply of most nutrients. However, nitrogen, and occasionally other nutrients, need to be supplied as chemical fertilizers or animal manure. Essential mineral elements are generally available to plants from three sources: (a) applied chemical fertilizers, (b) the decomposition of organic matter, including animal manures, and (c) weathering of soil minerals.

In Utah, fertilizer requirements vary widely, depending on site specific conditions; thus, general recommendations for turfgrasses and ornamentals are inappropriate. Since turfgrasses and ornamentals are quite different with respect to nutritional diagnoses and management, they will be discussed in separate sections.

Section I: Turfgrass

Application of chemical fertilizers is the accepted practice in turfgrass management and culture. Originally, fertilizer consisted mostly of fresh or partially decomposed animal manures which are still useful but not too widely used because of aesthetic reasons. Composted and dried manures and other organic materials are marketed in Utah, and when properly applied, satisfy soil fertility requirements. Cost should be a major consideration when deciding on use of organic fertilizers in lieu of chemical forms.

Any soil fertility management program should begin with a diagnostic soil test. Results of soil tests should be interpreted in terms of the needs and uses of turfgrass. The recommended soil test for Utah soils includes pH, $NaHCO_3$-extractable phosphorus and potassium, texture and soil salinity.

Soil samples must be characteristic of the field or site and must be gathered when the ground is not frozen. Refer to Chapter 2 for suggestions on different procedures that are recommended for sampling uniform and non-uniform areas.

Generally, soil samples are taken to a depth of 6 inches for turf. Samples from a sodded area should be dried and sieved to remove grass roots and other vegetative material. Annual soil testing may be desirable for the first few years on newly established turfgrasses. On well-established areas, the soil need only be tested every two to three years.

Diagnostic Soil Testing

Nitrate-nitrogen is the nitrogen form most readily available and absorbed by plants. But this form of nitrogen is highly mobile in soil and its concentration at any moment depends strongly on the amount and frequency of irrigation or rainfall.

Most soil nitrogen is tied-up in organic matter and as such is unavailable to plants. The nitrogen becomes available as micro-organisms decompose the organic matter. The rate of nitrate nitrogen released, therefore, is a function of the microbial activity, which is dependent on environmental conditions, principally soil temperature and moisture. The amount and availability of nitrate nitrogen in the soil varies with the weather and is unpredictable. Soil tests for nitrogen are not recommended because interpretation of the results are difficult or impractical, especially in soil samples that represent only the 6-inch surface layer.

Soil test guidelines for phosphate and potassium fertilizer application using the standard sodium bicarbonate soil test procedure are:

When soil test phosphorus is less than 10 mg/kg (ppm), add phosphorus-containing fertilizer. When soil test potassium is less than 100 mg/kg (ppm), add potassium-containing fertilizers. The amounts and methods of fertilizer application are detailed below.

Salt-affected Soil

For a more complete discussion of salt-affected soils, see Chapter 9 which explains the causes, effects and control of soil salinity.

Soil is considered saline for turf if the ECe (electrical conductivity) is above 3 dS/m (mmhos/cm); however, this varies, depending on the specific grass type. Appendix I provides a guideline of salt tolerance for a few turf plants, while Appendix II lists some optimum pH ranges. These appendices are included only to illustrate that different grasses vary in their tolerances to salt-affected soils. Correction of soil salinity requires good drainage and the application of large amounts of good quality irrigation water. If good drainage is not available, or if large amounts of water cannot be supplied, it may not be feasible to initiate a soil reclamation program. If the salt problem is related to high sodium levels, then a different approach must be used, as outlined in Chapter 9. Soil testing laboratory personnel and Extension turf management specialists can help provide specific reclamation details for specific problem situations.

Nutrient Deficiency Symptoms

Turf grass quality is highly subjective because it depends mainly on visual appearance. However, color intensity, as measured by chlorophyll analysis, and density have been used as indicators of turf quality. The quality of turfgrass is often the direct result of fertilization.

Nitrogen is the key nutrient in a turf fertility program because turfgrass plants require more nitrogen than any other essential element. On a dry weight basis, a healthy turfgrass plant is composed of 3 to 5% nitrogen. Nitrogen is the nutrient most likely to be deficient, largely because significant amounts are lost from soil through leaching and volatilization. Since nitrogen is an important component of the chlorophyll molecule, nitrogen-deficient plants turn yellowish-green, a condition known as chlorosis. Thus, poor turf color may indicate a nitrogen deficiency. Density of turfgrass stands also varies with nitrogen availability. Thus, the effects of nitrogen fertilization are readily visible. Shortly after nitrogen-containing fertilizers are applied, plants turn a darker green color and vertical shoot growth increases significantly.

Phosphorus deficiency in turfgrass is generally expressed as slowed growth. In other words, there is no obvious symptom of phosphorus deficiency in turf unless there is a well-nourished sod strip nearby for comparison. Soil testing for phosphorus is the most reliable guide for avoiding deficiencies of this element.

Turfgrass plants supplied with adequate amounts of potassium are better able to tolerate stresses such as cold, heat, drought, and diseases. Potassium-deficient turfgrass leaves are usually mottled, spotted, or curled. Leaves may also appear “scorched” or “burned” along the margins and on the tips. These symptoms first appear in older leaves. Dead areas in the leaves may fall out and leave ragged edges. In Utah, potassium deficiency in turfgrass is experienced mostly on light textured, sandy soils. Soil testing for potassium is a reliable guide to the need for potassium fertilization for turf.

Symptoms of sulfur deficiency normally first appear on new leaves. The symptoms are somewhat similar to those of nitrogen deficiency, which appear first on older leaves. The homeowner can distinguish between nitrogen and sulfur deficiency by applying and watering a readily soluble nitrogen fertilizer into the soil. Turfgrass that is nitrogen deficient will turn a darker green within a week after the nitrogen fertilizer application. Grass that is sulfur deficient will not turn green with the application of nitrogen. In this case, sulfur-containing fertilizer is recommended. The most common ones are potassium sulfate (0-0-50) which contains about 18% sulfur and ammonium sulfate (21-0-0) which contains about 24% sulfur. The application of either of these fertilizers in amounts sufficient to satisfy nitrogen or potassium needs will provide more than enough sulfur to satisfy sulfur requirements. See Chapter 8 for more information on the chemical and physical make-up of commercial and organic fertilizer materials.

Micronutrients, especially iron, may be deficient in Utah. Iron (Fe) deficiency chlorosis is fairly common in turfgrasses under Utah conditions; however, soil testing has had very limited success in diagnosing an Fe deficiency.

Fertilization Practices

Fertilizer application is normally expressed in pounds of nitrogen per 1,000 square feet of turf area. Low maintenance areas may receive none to as little as 1 pound of nitrogen per 1,000 square feet per year. The rate for a high quality bluegrass turf may be as much as 6 to 8 pounds of N per 1,000 square feet per year, but generally 3-4 pounds per year is more than adequate. The fertilizer is usually split two or more times during the year. For example, a 3-pound annual nitrogen application could be applied as 1 pound in early spring, 1 pound in mid-summer, and 1 pound in the early fall.

Homeowners commonly want to know how large an area will a 50-pound bag of fertilizer cover, the rate to apply, how often to apply fertilizer, and the best and least expensive fertilizer to buy. These questions can be answered by the following example: A 50-pound bag of fertilizer with an analysis of 30-10-10 means there exists 30% of elemental nitrogen, 10% of P_2O_5 and 10% of K_2O. (See Chapter 8 for more details on fertilizer chemical and physical make-up.) This fertilizer bag contains 15 pounds of nitrogen (0.30 x 50 lbs), 5 pounds of P_2O_5, and 5 pounds of K_2O (0.10 x 50). If applied at the rate of 1.5 pounds of N per 1,000 square feet [(15/1.5) x 1,000], the 50-pound bag of 30-10-10 will cover 10,000 square feet. Applying this much two to three times per year will provide ample nutrition for vigorous bluegrass turf areas. However, in most instances once phosphorus and potassium fertilization has been completed, there is sufficient for the next several years while nitrogen must be annually applied.

Fertilizer Application Methods

Many lawn-care companies apply fertilizers in a liquid form. Pesticides may be applied at the same time. Liquid application is usually less expensive than granular applications, although sprayers to apply liquids cost much more than spreaders used to apply granular materials. Generally, 3 to 5 gallons of the fertilizer-water mixture are applied per 1,000 square feet to ensure that the fertilizer is washed into the root zone. Urea is soluble in water and is the most widely used fertilizer applied in this manner. Fertigation, or applying nutrients through the irrigation system, is used on some turf areas. The fertilizers are metered into the irrigation lines. Since some liquid fertilizers are acidic, irrigation lines should be flushed thoroughly afterwards to prevent corrosion.

Most fertilizers for turfgrass are dry and in pellets or granules. The dry fertilizers are distributed with either a drop or rotary spreader. In a drop or gravity-type spreader, fertilizers drop through openings at the bottom of the hopper to the ground. Application rate is determined by adjusting the size of the openings. These spreaders are usually precise and provide a relatively uniform distribution pattern when properly handled. The width of these spreaders varies from about 2 feet for home lawns to 12 feet or more for golf course, parks or athletic fields. Operators should avoid over-lapping or skips between application swaths across the turfgrass area to prevent streaking due to the uneven fertilizer distribution. The streak may appear as light green color which reflects nitrogen deficiency where the fertilizer was not applied and burnt or scorched areas where the spreader overlapped too much, causing excess fertilization. The latter problem may be ameliorated by applying excess irrigation water at each watering for a week or two.

Rotary or centrifugal spreaders usually have an impeller attached directly beneath the hopper that spins as the spreader moves. Small hand-carried, hand-cranked versions are also available for home use. Fertilizers drop through the adjustable openings at the bottom of the hopper, fall onto the rotating impeller, and are thrown away from the spreader in a semicircular pattern. It is usually faster to apply fertilizer with a rotary-type spreader because its granular materials are broadcast over a wider area than with the drop-type spreaders. Spreader width varies from about 6 feet to 30 feet. Special care must be exercised with rotary spreaders to assure uniform fertilizer application or light green and scorched turf areas will result. It is recommended that the overall fertilizer application be divided and half be applied with passes in one direction and the remainder be applied with passes in another direction.

Part II: Ornamental Plants

Ornamentals comprise a multitude of plants which serve primarily to enhance the beauty of a landscape. Such plants may be trees, shrubs or perennial and annual flowers. Each may or may not develop favorably in the landscape because of inherent plant type limitations, such as hardiness, exposure, inadequate irrigation, excessive water or poor drainage, disease, insects, plant variety, and, not least of all, soil type and nutrient requirements.

Ornamentals as a group should not be considered as a crop, but rather as a group of non-related plants associated together for aesthetic and not necessarily productive purposes. Each tree, shrub, and annual or perennial flower may or may not respond to blanket fertilizer recommendations. The following discussion will provide some criteria for ornamental plant nutrient needs.

Soil Testing

Diagnostic soil testing should be considered to determine soil pH, available nutrients, and soil salinity, all of which may limit the choice of ornamentals in the planning stage or plant growth and development once the ornamental is planted into the soil. The recommended test for Utah soils includes pH, $NaHCO_3$ extractable phosphorus and potassium, texture, and soil salinity. The soil sample must be representative of the site, which may be a challenge due to the soil disturbance typical of a landscape environment. Details on soil sampling are provided in Chapter 2 of this guide. In addition, it is wise to determine and evaluate the soil type if possible, and to further investigate the soil profile of the particular location to be planted in ornamentals.

When soil is drastically disturbed, such as in the home building process, the natural soil horizons (6" to 24" in depth) may be disturbed or actually removed from the site. This disturbance results in a soil of lower quality for ornamental plant development. In this instance every attempt must be made to provide quality topsoil to a depth of 12" to 24" so that adequate plant root development is possible. Such a procedure is the single most important insurance for successful ornamental plant growth on a disturbed landscape.

One may then select plant materials particularly suited to the soil pH and salinity. Some ornamental plants, pines and junipers for instance, are more tolerant, although not completely resistant to higher salt levels in the topsoil. Tables and charts exist in several gardening books specifically applicable to Western conditions which describe some of the ornamentals' salt tolerances. Appendices I and II provide some guidelines which can be used to determine relative salt tolerance and optimum pH ranges. Interpretation of these tables should be general because site-specific factors affect the plant's growth response to the soil pH and salt content. Refer to Chapter 9 for detailed discussion of salt-affected soils.

Nutrient Deficiency Symptoms

Most topsoil contains adequate amounts of the nutrient elements for ornamental plants deemed suitable for use in Utah landscapes. If a plant exhibits a lack of vigor, yellowing of older leaves (possible nitrogen deficiency), or yellowing of new leaves while leaf venation remains green (iron deficiency) one may apply the appropriate nutrient through fertilization. It is important to recognize the difference between these nutrient deficiency symptoms and other problems, such as a salt burning of the leaves or plant disease problems and insects.

To some extent symptoms of nutrient deficiency may be brought on by poor drainage. Such a problem may occur from mechanical compaction during construction and/or soil profile disruption, or from traffic patterns over the developing root zone of the plant. Poor drainage reduces oxygen levels in the soil which directly limits root development. Also, with time, poor drainage may contribute to the build-up of soluble salts which can limit plant growth.

Fertilizer Application Methods

Prior to fertilizer application, especially if drainage or compaction is a problem, some means of aeration is desirable. Aeration can be accomplished using a 3/4-inch pointed bar and sledge hammer and by driving the bar into the soil to a depth of 12 to 18 inches, spacing aeration points 12 to 18 inches in and around the dripline of the tree or shrub. On large trees, such as the European White Birch, several dozen aeration points may be useful.

In addition, these holes can then be utilized to fertilize trees. Any tree can be fertilized just prior to bud break in late April or May. Trees in poor condition should be fertilized to encourage near optimum conditions for growth and development. General guidelines for fertilizer application rates for trees are provided in Table 5.1.

Shrubs may also require fertilization but often have less need than trees. A broadcast application of ½ pound of ammonium sulfate, or an equivalent amount of a complete fertilizer, applied to 100 square feet of area under shrubs, should provide adequate nutrients for plant development.

If there is concern of rapid leaching of the nitrogen from the soil profile a slow release type fertilizer may be useful. In some shrubbery plantings and in large annual and/or perennial flower plantings such slow-release formulas may be beneficial to plant growth. As noted earlier, the nutrient of primary concern is nitrogen, so routine application of phosphorus and potassium is not required. Soil testing can provide a guideline for the assessment of the plant availability of phosphorus and potassium.

The correction of an iron deficiency is quite difficult in the calcareous soils located in Utah. The best approach is through planting varieties which are not susceptible to iron chlorosis. Table 5.2 lists some ornamentals which are sensitive to lime-induced chlorosis and should therefore be avoided. When a plant exhibits iron chlorosis application of iron in the form of a chelated compound, such as Fe 138, Nutra plus Fe, and others, is most effective. Iron sulfate does not satisfactorily control iron chlorosis. The chelated iron may be sprayed directly on the plant's foliage as directed by the manufacturer. Trees may respond to iron phosphate or iron citrate crystals (obtained from drugstores or supply houses in 00 size gelatin capsules) by placing the crystal directly into the trunk during the dormant season. Details on this procedure are provided in Chapter 4 of the **Utah Fertilizer Guide**.

To summarize, landscape managers should be encouraged to plan strategies for each particular landscape by assessing the soil profile, sampling and testing the soil properly, then selecting plants most adapted to the soil conditions and managing the soil through proper aeration, irrigation and fertilization practices. Annual flowers and other shallow-rooting plants require regular irrigation while most other ornamentals require infrequent, deep irrigation.

Table 5.1. Some suggested rates of fertilizer application for shade trees.

Measure the trunk diameter 3 ft. above the ground. In late April apply 1/10 pound of N for each inch of diameter.

Inches diam.	Ammonium Sulfate	Ammonium Nitrate	N, P, K Fertilizers
1	2 oz.	1 ½ oz.	4 oz.
2	4 oz.	3 oz.	8 oz.
3	6 oz.	4 oz.	12 oz
4-6	2-3 lbs.	1 ½-2 lbs.	4-6 lbs.
7-10	3-4 lbs.	2-3 lbs.	6-8 lbs.

Table 5.2. Trees, shrubs and vines most sensitive to lime-induced iron chlorosis.

Trees	Shrubs and Vines
Silver Maple (Acer saccharinum)	Dwarf Bridalwreath (Spirea sp.)
Red Maple (Acer rubrum)	Junipers (Juniperus sp.)
European White Birch (Betula pendula)	Grapes (Vitus sp.)
Ornamental Pears (Pyrus sp.)	
Washington Hawthorne (Crataegus phaenopyrum)	

Appendix I. Relative Tolerance of Plants to Salinity

(In general, those at the top of each column are considered more tolerant than those at the bottom of the same column.)

EXCELLENT	GOOD	FAIR	POOR
		Ornamental Shrubs	
	Arborvitae	Pyracantha	Rose
	Juniper	Privet	Most ornamental plants
		Turf Plants	
Bermuda grass	Slender wheatgrass	Perennial ryegrass	White Dutch Clover
	Russian Wildrye	Bromegrass	Creeping red fescue
			Kentucky Bluegrass
			Colonial Bentgrass

Adapted from Richards, L. A. (Ed.) 1974. Diagnosis and improvement of saline and alkali soils. USDA, Handbook No. 60.

Appendix II. Table of Optimum pH Ranges

Ornamental Plants	
Alder	5.5-6.5
Allyssum	6.0-8.0
Arborvitae	6.0-8.0
Ash	6.0-8.0
Aster	6.0-8.0
Azelea	5.0-6.0
Barberry	6.0-8.0
Beech	6.0-7.0
Begonia	6.0-8.0
Birch	5.0-6.0
Calendula	6.0-8.0
Carnation	6.0-8.0
Chestnut	5.0-6.5
Chrysanthemum	6.0-8.0
Colorado Spruce	6.0-7.0
Cotoneaster	6.0-8.0
Dahlia	6.0-8.0
Elder	6.0-8.0
Elm	6.0-8.0
Fir	5.0-6.0
Forsythia	6.0-8.0
Gladiolus	6.0-8.0
Hemlock	5.0-6.0
Holly, American	5.0-6.0
Hollyhock	6.0-8.0
Honey Locust	6.0-8.0
Huneysuckle	6.0-8.0
Iris (many species)	6.0-8.0
Juniper, Common	6.0-7.5
Juniper, Creeping	5.0-6.0
Juniper, Mountain	5.0-6.0
Lilac	6.0-8.0
Lily	5.0-6.0
Locust	6.0-8.0
Magnolia	5.0-6.0

Ornamental Plants (Continued)	
Maple	6.0-8.0
Maple, Mountain and Striped	5.0-6.0
Mock Orange	6.0-8.0
Mountain Ash	4.0-5.0
Nasturtium	6.0-8.0
Oak (most species)	6.0-7.0
Oak (Blackjack, Post, Southern Red & Willow)	5.0-6.0
Oak, Scrub	4.0-5.0
Pansy	6.0-8.0
Petunia	6.0-8.0
Pine (many species, but not all)	5.0-6.0
Poplar	6.0-8.0
Privet	6.0-8.0
Purplelead Plum	6.0-8.0
Red Cedar	6.0-7.0
Rhododendron	5.0-6.0
Rose	6.0-8.0
Russian Olive	6.5-8.5
Snapdragon	6.0-7.0
Spirea	6.0-7.5
Tamarix	6.0-8.0
Verbena	6.0-8.0
Viburnum	6.0-8.0
Violet	6.0-8.0
Willow	6.0-8.0
Yucca	6.0-8.0
Zinnia	6.0-8.0

Turf Plants	
Bentgrass	5.5-6.5
Bermudagrass	6.0-7.5
Bluegrass	6.0-7.5
Bromegrass	6.0-7.5
Tall Fescue	6.0-8.0

Adapted from Thran, D. F., W. W. Miller, R. A. Young. Guide to the interpretation of soil and water tests. C-191. Coop Ext. Serv., Univ. Nevada, Reno.

Chapter 6
Greenhouse Culture

L. A. Rupp

The production of floricultural crops in greenhouse environments is one of the most intensive forms of agriculture in existence. As a result of the enhanced growth permitted by greenhouse environments, and the requirements of amended soilless media, large quantities of fertilizer are used. For example, greenhouse grown chrysanthemums can require 4,000 pounds of nitrogen per acre, per year for optimum production. Fertility levels are often so high that precautions must be taken to prevent pollution of ground water by nitrates. Successful management of greenhouse fertility requires strict attention to several factors. Plants must be observed continuously for nutrient related abnormalities. Competent testing of the soil to determine pH, soluble salts, and mineral content is needed to supplement visual observations. Soil testing should be combined with foliar analysis to determine nutrient status of growing tissue. Lastly, corrections made should be minor. Drastic changes in fertility or amendments can cause as much or more damage than the problem that was being corrected.

Soil Testing Methods and Limitations

The soil testing technique used for greenhouse soils at the USU Soil, Plant and Water Analysis Lab is the water saturated soil paste method. General fertility guidelines for this soil test method are provided in Table 6.1.

Table 6.1. General guidelines for greenhouse growth media analyzed by the Standard Media Extract method.

Component	Category				
	Low	Acceptable	Optimum	High	Very High
Soluble Salt, dS/m*	0-.75	.75-2.0	2.0-3.5	3.5-5.0	5.0+
Nitrate-N, mg/L*	0-39	40-99	100-199	200-299	300+
Phosphorus, mg/L	0-2	3-5	6-9	11-18	19+
Potassium, mg/L	0-59	60-149	150-249	250-349	350+
Calcium, mg/L	0-79	80-199	200+		
Magnesium, mg/L	0-29	30-69	70+		

Source: Dahnke, 1980.
*dS/m = mmho/cm; mg/L = ppm.

The validity of soil tests is directly dependent on the sample taken. To correctly sample the soil, the top ½ inch of soil should be removed and a full depth core sample taken. Several samples should be randomly taken from a bed, or from several pots, depending on the growth method.

In addition to determining the nutrient level of a soil, soil testing is valuable in its ability to determine soil pH and soluble salt levels. Since nutrient availability, especially micronutrients, is directly correlated with soil pH, maintaining an optimum pH is critical for the nutrition of most floricultural crops. In a greenhouse context, soluble salts refer to all of the dissolved minerals in the soil. A hazard of using high fertility levels is the potential for inadvertently building up soluble salts in the growing medium to a point where medium salinity adversely affects plant growth. While various species differ in their ability to withstand high levels of salinity, seedlings are usually more sensitive than established plants and suffer more from excess levels of fertility. Salt levels are expressed as a measure of electrical conductivity (EC) of a soil-water mixture and the units are dS/m (equivalent to mmhos/cm, see Chapter 9). Interpretation of the EC varies with the test used (Table 6.2).

Table 6.2. Interpretation of soluble-salt levels.

Dilution[1]			Saturated[2] Paste	Interpretation
1:2	1:2	1:5	Extract,	
Soil	Soilless	Soil	Soil and Soilless	
	Units[3]			
0-25	0-?	0-10	0-1	Insufficient nutrition
26-50	?-100	11-25	1-2	Low fertility unless applied with every watering
100		50	3-5	Maximum for planting seedlings or rooted cuttings
51-125	100-175	26-60	2-4	Good for most plants
126-175	176-225	61-80	4-8	Good for established plants
176-200	225-350	81-100	8-16	Danger area
Over 200	Over 350	Over 100	Over 16	Usually injurious

[1] Source: Nelson, dS/m*10^3.

[2] dS/m

The EC of a soil or leachate can be a helpful tool for obtaining an estimate of soil nutrient status. Leachate from pots under constant liquid feeding should have an EC similar to that of the fertilizer solution being added. Higher EC measurements would indicate the presence of too much fertilizer, while a low EC would indicate that insufficient fertilizer is being added to the medium. All irrigation and liquid fertilization should be done to the point that water leaches from the bottom of the pot, to prevent salt buildup. If high soluble salts do occur, they can be corrected by irrigating 2-3 times with tap water to the point of leaching. A waiting period of 3 hours should be observed between irrigations. Caution should be used with this method to avoid damaging the soil structure of soil-based media.

Plant Tissue Testing

Foliar analysis of plant nutrient levels is an important supplement to soil testing. In contrast to a soil test's ability to predict present and future conditions, a foliar analysis reflects present and past conditions through the accumulation of nutrients by the plant. Such additional information can be very valuable in correcting nutritional problems. With greenhouse crops, especially perennial crops such as roses, foliar analysis is not a post-mortem for a crop, but can be an effective management tool for the current crop. Foliar analysis is less beneficial for short-term crops such as bedding plants. The efficacy of foliar analysis is based on the fact that the level of elements in the leaves correlates well with plant growth. This is true for all conditions except when foliar element levels are in the luxury consumption zone (more than adequate but less than toxic concentrations).

Samples for plant analysis are usually taken at 4-6 week intervals. In general the youngest fully expanded leaves are sampled. With roses, the two top 5-leaflet-leaves are sampled just as the calyx splits and color begins to show on the bud. Chrysanthemums are sampled at 5-6 weeks after planting for cut flowers, and 5-6 weeks after pinching for pot plants. Tissue samples of geraniums are taken when leaves are 1 - 1 ½ inches (2 ½ - 4 cm) in diameter.

Optimal levels of foliar nutrients have been determined through extensive research with individual floricultural crops (Tables 6.3-6.6). The concentration of macro elements is expressed as a percentage of tissue dry weight. In general, dry tissue should consist of 2.5-4.5% N, 0.2-0.3% P, 2.5-5.0% K, 0.5-1.5% Ca and 0.35-0.55% Mg. Micronutrients are found in much smaller concentrations and while formerly expressed in parts per million (ppm), they are currently expressed with the equivalent units of milligrams/kilogram (mg/kg), (optimum levels are: 75-125 mg/kg Fe, 50-100 mg/kg Mn, 25-100 mg/kg Zn, 5-15 mg/kg Cu, 25-100 mg/kg B and 0.15-1.0 mg/kg Mo). The optimum concentrations of macro elements varies with specific crops, while micronutrient requirements tend to be similar with most crops. The minimum foliar nutrient levels for specific floricultural crops are found in Table 6.7.

Table 6.3. Suggested elemental foliar tissue levels for lilies.

Element	Foliar levels (dry weight basis)
Nitrogen	3.3 - 4.8%
Phosphorus	0.40 - 0.67%
Potassium	2.5 - 4.5%
Calcium	0.81 - 1.2%
Magnesium	0.20 - 0.52%
Manganese	42 - 174 mg/kg
Iron	70 - 268 mg/kg
Copper	7 - 16 mg/kg
Boron	30 - 280 mg/kg
Zinc	8 - 40 mg/kg

Source: Mastalerz 1977.

Table 6.4. Suggested foliar nutrient levels for poinsettia.

Element	Foliar levels (dry weight basis)
Nitrogen (N)	4.0 - 6.0%
Phosphorus (P)	0.3 - 0.7%
Potassium (K)	1.5 - 3.5%
Calcium (Ca)	0.7 - 2.0%
Magnesium (Mg)	0.4 - 1.0%
Manganese (Mn)	100 - 200 mg/kg
Iron (Fe)	100 - 500 mg/kg
Copper (Cu)	6 - 15 mg/kg
Boron (B)	30 - 100 mg/kg
Zinc (Zn)	25 - 60 mg/kg

Source: Mastalerz 1977.

Table 6.5. Suggested foliar nutrient levels for *Chrysanthemum X Morifolium* Good News.

Element	Tissue level (dry weight basis)	Plant Part Effectively Reflecting Mineral Status
Nitrogen	4.5-6%	Upper leaves
Phosphorus	0.26(?)-1.15%	Upper or lower leaves
Potassium	3.5-10%	Lower leaves
Calcium	0.5-4.6%	Upper leaves
Magnesium	0.14-1.5%	Lower leaves
Sulfur	0.3-0.8%	Upper leaves
Iron		Upper leaves
Manganese	195-260 mg/kg	Upper or lower leaves
Boron	25-200 mg/kg	Upper leaves
Copper	10 mg/kg	Middle leaves or leaves from lower axillary growth
Zinc	7.3 mg/kg	Lower leaves

Source: Kofranek 1980.

Table 6.6. Suggested foliar nutrient levels for roses.

Nitrogen	3.0 - 5.0%
Phosphorus	0.2 - 0.3%
Potassium	1.8 - 3.0%
Calcium	1.0 - 1.5%
Magnesium	0.25 - 0.35%
Zinc	15 - 50 mg/kg
Manganese	30 - 250 mg/kg
Iron	50 - 150 mg/kg
Copper	5 - 15 mg/kg
Boron	30 - 60 mg/kg

Source: Joiner, et al., 1983.

Table 6.7. Minimum critical foliar levels of nutrients for florist crops in general and for a few specific crops.

Nutrient	General Crops	Rose	Carnation	Chrysanthemum	Poinsettia	Geranium	Reiger Begonia
N%	—	3.0	3.0	4.5	3.5	2.4	4.7
P%	0.3	0.2	0.45	0.3	0.2	0.3	0.2
K%	—	1.8	3.0	3.5	1.0	0.6	0.95
Ca%	—	1.0	1.0	1.0	0.5	0.8	0.5
Mg%	0.3	0.25	0.3	0.3	0.2	0.14	0.25
Fe mg/kg	50-60	—	—	—	—	—	
Mn mg/kg	30	—	—	—	—	—	—
Zn mg/kg	20	—	—	—	—	—	—
Cu mg/kg	5	—	—	7	—	—	—
B mg/kg	25	—	—	—	—	—	14

Concentrations above these are sufficient, while those below are associated with deficiency. Macronutrient standards are specific to each crop. Few micronutrient standards have been developed for specific crops. Fortunately micronutrient standards do not vary much among crops. (Source: Nelson, 1985)

Plant Nutrient Deficiency Symptoms

Nutrient deficiency in floricultural crops generally results in many of the same symptoms as are found in agronomic or other crops. However, there are unique problems that may develop as a result of deficiencies.

Nitrogen is a mobile element in plant tissue and as a result deficiencies develop in older leaves first. The primary symptom is chlorosis that begins as a pale green and advances to green-yellow, yellow-green, yellow, and cream colored depending on the extent of the deficiency. The chlorosis is uniform on the leaf and usually results in leaf drop before necrosis occurs. Young leaves may be stunted in size.

Phosphorus is also a mobile nutrient in the plant, with deficiencies developing in lower leaves. The typical symptom is a dull or darker leaf color which may be followed by the expression of red, yellow or blue pigments on the underside of the leaf near the main vein. Under extreme deficiency, necrosis develops near the leaf tip and spreads to the base. Again young leaves may be stunted, as compared to older leaves.

Deficiency of potassium occurs in the older leaves first and may often be distinguished by chlorosis. Affected leaves go from green to necrotic, with the necrosis starting at the leaf tip or upper margin and moving to the base. Alternatively, irregular necrotic spots may occur.

During the process of adjusting soilless media pH to a proper range of 5.2 - 6.5, sufficient calcium is usually added to prevent any deficiency of this element. Calcium may also be commonly supplied through calcium nitrate, dolomite, and superphosphate. Calcium is an immobile nutrient so deficiencies occur in the new leaves, and result in small size and chlorosis. Older leaves may be thick and brittle. Severe deficiency may result in tip death.

Magnesium is mobile in the plant and a lack of it usually results in a distinctive bronze-yellow chlorosis. The chlorosis is generally limited to leaf margins, with the tips and vein area remaining green. Severe problems can result in necrosis. The addition of lime as dolomite is an excellent method for reducing such deficiencies. Sulfur deficiencies are very rare in greenhouses because sulfur is often a carrier component of fertilizers. Symptoms of sulfur deficiency are similar to that of nitrogen, but they occur on newer leaves.

Micronutrient deficiencies are often a problem in greenhouse crops, especially when they are grown in soilless media such as a peat-vermiculite mix. In general, mixes containing a soil component are less susceptible to micronutrient shortages due to the presence of these minerals in the soil. However, the addition of soil to the mix may contribute to deficiencies if soil characteristics such as pH are altered to the point that certain nutrients become unavailable.

Probably the most common micronutrient deficiency is that of iron. It is a nonmobile nutrient in the plant, and the symptoms appear as interveinal chlorosis of the new leaves. The green veins of the leaf are sharply defined, but may give way to a total chlorosis of the leaf under extreme deficiency. Manganese deficiency is very similar to that of iron except that the green vein bands are much broader, and it seldom advances past the green-yellow stage.

Deficiencies of other micronutrients may also occur. Zinc deficiency usually results in small leaf size and ‘rosette’ formation due to shortening of the internodes. Nonuniform stunting of the leaves may also occur. Copper deficiency leads to stunting and small terminal leaves. It can also result in death of the terminal and subsequent ‘witches broom’ formation. A lack of boron in the medium can cause short internodes, thick brittle stems, small stiff leaves and black necrotic spots on the stem. Molybdenum (Mo) deficiency causes ‘strap’ leaf of younger leaves. Leaves also become thick and tough, with irregularly wrinkled margins. A unique symptom of Mo deficiency on poinsettia is a yellowing of young mature leaves that may progress to scorching or burned margins.

Fertilizer Application Methods

A number of techniques are used to fertilize greenhouse crops, including, preplant mixing of either soluble or slow-release fertilizers into the growing medium, constant or weekly feeding through the addition of soluble fertilizers to irrigation water, and top-dressing with a soluble or slow-release fertilizer. Combinations of the above methods may also be used.

Physically mixing P into the soil prior to planting is the most efficient method of distribution. One of the greatest cost components of soluble fertilizers is P in a soluble form. If P can be added to the soil initially before planting, subsequent applications of soluble fertilizers without P would be less expensive. If using a soil-based medium, it is recommended to test the soil before P fertilization to insure against excessive P levels.

A common method currently used consists of preplant incorporation of treble superphosphate (0-45-0) at approximately 1.5 lbs/cubic yard in soil-based media, and 2.25 lbs/cubic yard of soilless media. At normal soil pH levels, P is quite insoluble regardless of the fertilizer formulation used. As a result of this insolubility, it is not readily susceptible to leaching, but will remain in the soil.

Nitrogen and potassium are supplied as soluble fertilizers in the irrigation water. If fertilizer is applied with each irrigation a concentration of 200 mg/L (ppm) N and K should be used. Weekly applications can be used instead of continuous, but the N rates need to be raised to between 250 mg/L (bed-ding plants) and 720 mg/L (chrysanthemums and poinsettias) depending on the plant tolerance. It is preferable to apply low concentrations with greater frequency because there is less chance of burning from high salt concentrations, and it permits a greater uniformity of soil nutrient levels. Constant liquid feeding is also advantageous in that it is tied directly to plant growth rate as a function of irrigation water needed. Liquid fertilizer should be used at the lowest possible rate that still permits optimum growth. This insures a constant, low rate of fertility, but only as the plant needs it. A further advantage is that less fertilizer is released from the greenhouse as a possible pollutant. Stock solutions of soluble fertilizers are usually mixed in concentrations of 100 or 200 times that required for final use. They are then metered into the irrigation system with accurate injection systems to insure appropriate dilution.

Slow release compounds such as Osmocote and MagAmp (7-40-6) may be used alone or in combination with liquid fertilization. These fertilizers are formulated to gradually release nutrients into the soil over an extended time period. The gradual release is accomplished by either limited solubility (MagAmp), diffusion through a plastic coating (Osmocote), breakdown of complex organics (urea formaldehyde), sulfur coatings, or chelate. Plastic encapsulated fertilizers are also formulated to have varying release periods. With Osmocote, 14-14-14 and 19-6-12 grades have a 3-4 month release, 18-6-12 and 13-13-13 have an 8-9 month release, and 17-7-12 has a 12-14 month release. Some pot plants have shown enhanced growth with a fertilization program based on a combination of slow release and soluble fertilizers. Slow release sulfur-coated products are usually unsatisfactory for greenhouse crops because all the nitrogen present is as ammonium or urea, and because its release is based on microbial action. In general, most plants do best with 65-75% of their N supplied in the nitrate form, and 25-35% in the ammonium form. Fertilizers such as ammonium nitrate and ammonium sulfate may be used. However, in sterilized or soilless mixes caution must be used to avoid high levels of ammonia, which can be toxic due to the slow rate of nitrification (conversion of ammonia to nitrate).

Specific Fertilization Requirements

Bedding Plants

Bedding plants respond well to a number of different fertilization programs. Roughly half of all growers use a slow release fertilizer such as Osmocote or MagAmp. Liquid fertilizers may be used alone or in combination with the slow release forms. Straight constant liquid feed programs of 100-150 mg/L N and K, with P incorporated into the mix at 0.5-1.0 kg/cubic meter work well. In such programs trace elements should be added and dolomite limestone incorporated to raise the pH of peat-based mixes, and to provide Ca and Mg. Bedding plants also respond well to a number of complete mixes such as 20-20-20, 20-10-20, 16-8-24, etc., at 100-150 mg/L N. Media pH should be at 5-7 and total soluble salts at 0.4-1.4 dS/m.

Chrysanthemums

As mentioned previously, potted chrysanthemums are heavy feeders which require intensive fertilization. Optimum nutrition is critical during the first half of the growth period. The pH should be maintained at 6.2-6.7 through a balance of acidic peat and more basic soil or dolomitic limestone. Maintaining the pH level near this range insures maximum availability of nutrients in the soil. The high N and K requirement is satisfied with a 200 mg/L constant feed that may be supplemented with a slow release fertilizer. Irrigation should be done to the point of leaching from the pot to prevent harmful salt buildup. During the last third of the growth period the nitrogen level is cut in half, and then eliminated 2 weeks prior to bloom. Fertilization by slow release compounds such as osmocote are more effective as a top-dressing than incorporated. Incorporation permits constant release of fertilizers into the soil as long as it is moist. With surface application, additional fertilizer is added only during irrigation. Recommended slow-release fertilizer programs include Osmocote 14-6-12 or 14-6-12 plus 8-3-10 (6 month formulation). Soluble salt levels as determined by a saturation paste extract should be less than 2.5 dS/m. Foliar nutrient levels should be similar to those shown in Table 6.7.

Poinsettias

Poinsettias require fairly high nitrogen fertilization, but more moderate phosphorus and potassium levels. They are also more prone to nutrient-related problems than are other pot plants. While high levels of nitrogen should be applied, the plants cannot tolerate high salt levels. A constant liquid feed program of 240-260 mg/L N (or weekly to 750 mg/L N as 20-9-17 or 25-5-8), 40-50 mg/L P. Also, application of 130-160 mg/L K and 0.1 mg/L Mo should be sufficient. Another constant liquid feed program for poinsettias includes predrenching the soil with 400 mg/L N before planting, and then continuing for 3 weeks. After 3 weeks, the N rate is reduced to 300 mg/L, and 2 weeks before sale, it is cut to 0-200 mg/L. Phosphorus is held at 26-132 mg/L, potassium at 250-400 mg/L, molybdenum at 0.1-1.5 mg/L and magnesium at 25-50 m/L. Boron should be kept at less than 0.3 mg/L to prevent injury. To further avoid boron problems, pH should be 6-6.5 and extractable calcium at 150 mg/L.

Liquid fertilization programs may also be supplemented with a 3-month schedule Osmocote 14-6-12 at 4-6 kg/cubic meter, or as a top dressing at 1 teaspoon per 6 inch pot. Inversely a ½ dose of slow release fertilizer can be supplemented with 200 mg/L N as a constant liquid feed. Formulations should be high in nitrate-N, especially in soilless mixes, due to the susceptibility of poinsettias to ammonium toxicity as evidenced by yellowing of the margin and then necrosis of lower leaves. While most greenhouse crops never exhibit Mo deficiency, poinsettias are very susceptible to it. Molybdenum deficiency results in marginal yellowing, followed by general yellowing and marginal necrosis of upper mature leaves. Supplemental fertilization with Mo, especially in soilless mixes, and maintaining a pH of 6.5 usually solves the problem.

Because poinsettias are produced for the Christmas season, the amount of available natural light gradually decreases during the production period. Fertilizer levels should be reduced as day length and light intensity decreases. If fertilizers are being applied as a constant liquid feed, the reduction in watering due to reduced light in the fall should automatically reduce the amount of fertilizers used.

Roses

Rose fertilization varies with the season and the extent of top growth being supported. Fertilization is usually discontinued during the cool, low-light months of December and January. It may also be discontinued during hot summer months if growth ceases. The most common recommendation for rose fertilization consists of constant liquid feed of 200 mg/L N, 150 mg/L K, and iron and magnesium as needed. Iron deficiency is especially a problem in Utah when roses are grown in ground beds with alkaline soils. In such cases, chelated iron fertilizers are usually required for proper nutrition. Calcium (if needed) and phosphorus should be incorporated into the soil prior to planting. Optimum soil pH should be approximately 6.5.

Easter Lilies

Easter lilies may be fertilized with a constant liquid feed of 150 as KNO_3 and $Ca(NO_3)_2$ until buds are 1.3 cm long, then $Ca(NO_3)_2$ only is used. Plant nitrogen levels must be maintained at a high concentration during early growth. This may be somewhat difficult due to low transpiration rates when the lilies are small and the late spring weather is cloudy and cool. Adding 1 teaspoon of urea formaldehyde as a top dressing on 6-inch pots in mid-January can correct the problem. One of the major problems with Easter lilies has been their tendency toward scorching of the leaves. Scorch has been shown to be caused by high fluoride (F) levels. Sources of F have usually been identified as superphosphate and perlite. In the western states, locally produced 0-45-0 fertilizer should have little if any F contamination. High concentrations of calcium and nitrate-nitrogen, as well as a high pH, help reduce the problem. Recent studies have shown that perlite may be used as a soil amendment as long as soil pH is maintained at a high enough level (6.6-7.2). Soluble salts should be held to less than 2 dS/m. Fertilization should take place up until 10 days prior to Easter.

Geraniums

Fertilization requirements of geranium are similar to those of other pot plants (Table 6.8) except the optimum pH is 6.0-7.5. Plants can be grown using a constant liquid feed of 15-15-15, 15-7-12 or 15-13-12 at a N concentration of 200-220 mg/L. Basic requirements can also be met with a preplant incorporation of 300-600 g treble superphosphate per cubic meter and either a constant feed of 200 mg/L N and K or a weekly feed of 500 mg/L. Another option is to irrigate with 250-350 mg/L N, as 15-15-15 for three out of every four irrigations. Nitrogen should be at least 50% nitrate, and pH should be held near neutral. Osmocote 14-6-12, 18-4-7, or 18-3-10 may be used at 6.5-8.0 kg/cubic meter for a 21/2-3 month cycle.

Fertilizer recommendations for other minor crops are listed in Table 6.9.

Table 6.8. Suggested medium nutrient levels for constant fertilization of geraniums.

Nutrient	Recommended Level
Nitrogen NO_3-N	50-250 mg/L
Phosphorus	125-450 mg/L
Potassium	0.75-1.5 meq/100 g and 3-7.5% CEC
Calcium	8-13 meq/100 g and 52-85% CEC
Magnesium	1.2-3.5 meq/100 g and 7.5-21% CEC
pH	6.0-7.5

Source: White, 1971.

Table 6.9. Nutritional programs for some flowering plants.

Species	Suggested Nutrition
African violet (Saintpaulia ionatha)	Constant Feed 75 mg/L N-P-K 75-100 mg/L N-P-K 450-210-360 mg/L N-P-K Slow Release 2.7 kg 14-6-12 Osmocote m^3
Begonia-Elatior (Begonia semperflorens)	Constant Feed 50-100 mg/L N-P-K 100-150 mg/L N and P; 50-125 K
Calceolaria (Multiflora nana)	Constant Feed 150 mg/L N-P-K
Cineraria (Senecio cineraria)	Constant Feed 100 mg/L N and K 150 mg/L N-P-K
Cyclamen (Cyclamen pesicum)	Constant Feed 150-200 mg/L N-P-K 100-5-125 ppm N-P-K (young plants) 150-200 ppm N, 50 ppm P, 175-250 ppm K (large plants)
Gloxinia (Sinningia speciosa)	Constant Feed 450-210-360 mg/L N-P-K 100 mg/L N-P-K
Hydrangea (Hydrangea macrophylla)	Constant Feed 100-200 mg/L N from a 25-10-10 ratio
Kalanchoe (Kalanchoe blossfeldiana)	Constant Feed 200-300 mg/L N, 50-200 P mg/L, 150-250 mg/L K Slow Release 8-16 kg 14-6-12 Osmocote m^3

Source: Joiner, et al., 1983.

Greenhouse Tomatoes

Tomato nutrition in greenhouses is largely dependent on the growing medium used, use of manure or mulch, and cropping plans. When grown in soil, soil samples should be taken before a new crop is planted and 2-3 times during the season. It is often preferable to apply phosphorus and potassium on a preplant basis. These minerals can be applied as 25-45 lbs 0-20-20 (before fall planting) or 15-25 lbs 0-20-20 (before spring planting) per 1000 square feet of bed. Similar fertility levels may be obtained by adding 10-15 lbs of treble super-phosphate or 25-30 lbs superphosphate and 20-25 lbs potassium sulfate per 1000 square feet. Nitrogen can be applied as a side dressing of ammonium nitrate, sodium nitrate, calcium nitrate, or potassium nitrate as needed. Medium pH should be maintained at 6-7.

If fertilizers are to be applied in liquid form, tomatoes should be started with 1:5:2 (N:P:K) at 100-175 mg/L N, followed by 1:2:1 after a few weeks. During maximum growth, a 1:1:1 formulation is recommended until full height is obtained. At that time growth is maintained by alternating applications of ammonium nitrate and potassium nitrate. The grower must be very careful to avoid excessive applications of N, especially during winter months. Plant nutrient status can be monitored by regular foliar tissue sampling. The youngest fully expanded leaf (5th or 6th leaf from the top) is collected and the petiole used for macronutrient analysis, while the blade is used for micronutrient analysis. Concentrations of elements should fall in the following range: NO_3-N, 1.2-1.5%; PO_4-P, 0.6-0.8%; K, 5-8%; Ca, 2-3%; Mg, 0.4-1.0%; Fe, 40-100 mg/kg; Zn, 25-35 mg/kg; Cu, 4-6 mg/kg; Mn 25-30 mg/kg; Mo, 1-3 mg/kg; B, 20-60 mg/kg. Nutrient solutions for tomato plants should be similar to that described in Table 6.10. Nitrogen concentration will vary with local conditions and the stage of the crop.

Table 6.10. Various concentrations of nutrient elements in the Steiner solution.

Major Nutrient	mg/L
Nitrogen (N)	166-175
Phosphorus (P)	48
Potassium (K)	280-300
Calcium (Ca)	180
Magnesium (MG)	48-50
Sulfur (S)	100+

Micronutrient	mg/L
Iron (Fe)	2.5-4.0
Manganese (Mn)	0.5-1.0
Boron (B)	0.5-1.0
Zinc (Zn)	0.1-0.5
Copper (Cu)	0.1-0.5
Molybdenum (Mo)	0.1

Source: Greenhouse Vegetable Guide, Texas Ag. Ext. Service.

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Chapter 7
Vegetable Crops

Alvin R. Hamson

Most vegetable crops require fertile soils for high yields. Commercial vegetable growers are inclined to apply fertilizer liberally to vegetable crops because of the high costs of seed, insecticides, herbicides, labor and machinery in producing vegetables. This rationale is based on the premise that high yields of quality vegetables are obtained when all inputs of production are near the maximum. For this reason they are reluctant to risk loss in yield or quality because of inadequate fertilization. However, over-fertilization generally results in lower economic returns and, in some situations, can cause a decline in crop yields as well as increase the potential of groundwater contamination. Thus, the basis of any fertilization program for vegetable crops should utilize soil testing to insure optimum soil fertility levels.

Fertility Status in Utah Soils

The purpose of a fertilizer program on vegetables in Utah is to add nutrients which may not be adequately supplied by the soil or irrigation water. Nitrogen, phosphorus, potassium, iron, and zinc may be deficient in soils in Utah or when present, they may exist in forms not available to plants. Potassium occurs in sufficient amounts in most Utah soils and in many irrigation waters to satisfy the needs of vegetable crops. However, deficiencies of potassium may be expected on very light, well-drained sandy or gravelly soils which are irrigated by waters low in potassium salts. Potassium deficiencies can be identified through soil testing. It is not common to detect deficiencies of iron, or zinc in vegetable crops in our soils. Potential zinc deficiencies can be identified through soil testing.

Most vegetable crops require nitrogen fertilizer for optimum yields. When they lack nitrogen, crops grow slowly and have a light green color which results in low yields and poor quality.

Utah soils may be deficient in phosphorus (P) and can be identified through soil testing. Annual applications of phosphorus without consideration of the soil P level can lead to excessively high amounts which can cause micronutrient availability problems. The symptoms of phosphate deficiency may include dark green color, with purpling on the underside of the leaves of some of the crops. Plants are stunted and yields are noticeably reduced. Yields are often reduced before deficiency symptoms appear.

Timing of Fertilization

Fertilizer nutrients are absorbed by actively growing roots of vegetable crops in moist soil. Nitrogen placed on the surface will leach down to the roots if irrigation and/or rainfall is adequate, but it should be incorporated into the soil. Phosphorus and potassium do not move extensively and should be placed deeply enough to be in moist soil during all of the growing season. All of the phosphorus and potassium and about one-half of the nitrogen should be applied shortly before or near to the time of planting with the remainder of the nitrogen applied as side dressings during the early part of the growing period. This is particularly true on coarse textured soils.

Fertilizer Application Methods

Band application of at least part of the fertilizer near the seed or plant row is generally desirable. Band applications of fertilizer are particularly effective in obtaining maximum response from relatively minimal quantities of fertilizer.

Fertilizer banded for snap beans, sweet corn and cucurbits should be placed 3 inches deeper than the seed and 3 to 4 inches to the side of the row. For transplanted vegetables, such as tomatoes, peppers, eggplant, cabbage, cauliflower, and broccoli, the fertilizer should be placed 4 to 6 inches deep in bands, 4 inches to the side of the row. Repeated side dressings of nitrogen are made by drilling the fertilizer in a shallow furrow 6 inches to a foot to the side of the row one or more times as the nitrogen is needed. The first side dressing with nitrogen is made after vegetables such as tomatoes, peppers, eggplant, snap beans, watermelons, and muskmelons have begun to set fruit or pods. This minimizes the effect of excess nitrogen in reducing the fruit or pod set.

Beware of banding too close to the row with rates above 80 to 100 pounds of nitrogen and potassium combined, since salt injury to the seed or seedlings can occur. Vegetables, such as snap beans and sweet corn, along with the cucurbits, which include watermelons, muskmelons, cucumbers, and squash, are as a group very sensitive to salt damage which will occur by high rates of nitrogen or potassium fertilizers. For this reason care should be taken to reduce the quantity of nitrogen or potassium salts when the fertilizer is banded at the time of seeding or when it is applied as a starter fertilizer in nutrient solution. This caution does not preclude the need of adequate fertilization with nitrogen. For instance watermelons generally respond best to most of the fertilizer applied early in the growing season whereas muskmelons and cucumbers require repeated applications of nitrogen as a side dressing if production is to be maintained throughout the growing period.

Fertilizer Recommendations for Commercial Production

Farm practices vary so much from farm to farm that no specific recommendations on fertilizer applications can be given that will be optimum for all farms. General nitrogen fertilizer recommendations are given in Table 7.1 with the higher rates of nutrients suggested for soils of relatively low fertility, for previously uncropped land that is being developed, or for land which has recently been leveled which exposes infertile subsoil. Excessive rates of nitrogen fertilizer tend to increase vegetative growth but reduce the set of fruit or pods of tomatoes, peppers, eggplant, snap beans, watermelons, and muskmelons.

Nitrogen (N) fertilizer application rates for most vegetable crops are based on individual crop requirements, previous cropping history, previous fertilization history, and irrigation management practices. If high rates of N were applied the previous year on fine textured soils or if a leguminous crop (e.g. beans, peas, alfalfa) was grown the previous year, then the lower rates of N should be applied. Soil testing for available nitrogen (NO_3N) has limited utility, so it is generally more accurate to determine N fertilization rates based on specific field management practices.

Determination of whether to apply phosphorus, potassium or zinc can be assessed through soil testing if the soil samples are collected properly. Refer to Chapter 2 of the **Utah Fertilizer Guide** for details concerning proper sampling procedures. Soil test interpretations with general fertilizer rates are provided in Table 7.2. These nutrients should not be applied without knowledge of the soil's fertility status due to economic consequences and potential problems associated with excessively high levels of plant available phosphorus.

Table 7.1. Nitrogen fertilizer recommendations for selected vegetable crops.

Crop	N (lbs/ac)
Asparagus	50- 80
Snap beans	50-200
Table beets	75-100
Cabbage, cauliflower, broccoli, Brussels sprouts	50-150
Carrots, parsnips	50-100
Celery	100-150
Muskmelons, watermelons, cucumbers, pumpkins, squash	50- 75
Peppers, eggplant	50-150
Tomatoes	50-100
Lettuce	50-100
Onions	100-250
Peas	50- 75
Sweet corn	100-150
Spinach	50-100
Turnips, radishes	50- 75

Table 7.2. Generalized fertilizer recommendations for vegetable crops in Utah based on soil test analyses.

Interpretative Categories	P*	lbs P_2O_5/ac	K*	lbs K_2O/ac	Zn**	lbs Zn/ac
Very low	0-3	160	0-40	200	0-0.5	1010
Low	4-7	80	40-20	160	0.5-0.8	5
Borderline	8-10	50	70-100	100	0.8-1.0	0-5
Adequate	>15	0	>100	0	>	0

*$NaHCO_3$ Soil test extraction expressed in mg/kg (ppm).

**DTPA extractable expressed in mg/kg.

Home Garden Fertilization

Because of the relatively small size of most home gardens, it is easy to maintain a high level of soil fertility. Home garden fertilizer recommendations in the Utah Extension Circular 313, “Growing Vegetables, Recommended Varieties for Utah,” indicate that three pounds of a 10-20-0 fertilizer or equivalent should be applied for each 100 square feet of garden soil. This fertilizer should be broadcast and worked in so that it will remain in moist soil throughout the growing season. This recommendation for the home garden if expanded to an acre basis, would be equivalent to 1300 pounds of 10-20-0 fertilizer per acre or 130 pounds of nitrogen and 260 pounds of P_2O_5 per acre. By consulting Table 7.1, which indicates commercial fertilizer recommendations for vegetable crops, you will note that the home garden fertilizer rate is relatively high. This could lead to environmental concerns if a drinking water source received cumulative amounts of fertilizer from a large number of home gardens.

Also, care should be taken to not apply too much fertilizer on the home garden because excess nitrogen stimulates vegetative growth at the expense of fruitfulness and excess phosphorus reduces the availability of such minor elements as iron, manganese, and zinc. The detrimental effects of excessive phosphorus can be avoided by testing the soil every three years. Soil test interpretations are provided in Table 7.3.

The three pounds of 10-20-0 fertilizer or equivalent per 100 square feet is equivalent to 6 cups per 100 square feet. If the fertilizer is banded in a band 3 to 4 inches deep, 3 inches to the side of the row, the fertilizer rate may be reduced by half or 1 cup per 10 feet of row. If the fertilizer is placed for transplants 4 inches to the side of the transplant and 4 to 6 inches deep, each transplant should receive 2 tablespoons of the mixed fertilizer per plant.

Well-rotted manure is of value in supplying fertilizer nutrients and in improving the structure and tilth of garden soils. If one to two bushels of manure are applied to each 100 square feet, generally additional fertilization is unnecessary. Many gardeners tend to apply excessive amounts of organic materials and fertilizers. Besides problems associated with excessive levels of phosphorus, the salt levels can be raised to detrimental levels which can be readily monitored through soil testing.

Table 7.3. Generalized soil test interpretations for gardens in Utah.

	P*	K*
Low	0-18	0-125
Medium	19-30	125-150
High	31-60	>150
Excessive	>60	---

[*] $NaHCO_3$ Soil test extraction expressed in mg/kg (ppm).

[**] DTPA extractable expressed in mg/kg.

Chapter 8
Fertilizer Composition and Reactions in Soils

D. W. James

This chapter of the **Utah Fertilizer Guide** discusses the kinds of fertilizers that are used in managing soil fertility. Both commercial fertilizers and animal manures are included. Some discussion is also provided on the factors that influence the efficiency of fertilizer usage by plants. The purpose of this part of the discussion is to give some explanation of why some fertilizers are more effective than others under some conditions.

The diagnoses of the kinds and quantities of fertilizer needed for a given soil and crop situation is discussed in detail in other chapters of this manual. (Pertinent chapters are: 2, Soil Sampling; 3, Field Crops; 4, Fertilization of Fruit Crops; 5, Turfgrass and Ornamental Plants; and 7, Vegetable Crops.)

Commercial Fertilizers

The Fertilizer Guarantee

The market offers a wide array of commercial fertilizer guarantees which includes one, two or all three of the major fertilizer elements. If secondary and minor fertilizer elements are provided, these are also described on the label. Since fertilizers can be custom blended to satisfy any specific need, there is a large variety of fertilizer compositions that can be purchased.

Commercial fertilizer must contain the minimum elemental composition shown on the label. Fertilizer labeling is regulated by statutes of the State of Utah, and the State Department of Agriculture (located in Salt Lake City) monitors the market and enforces fertilizer labeling regulations.

The fertilizer guarantee consists of three sequential numbers which indicate, respectively, the percentages of total N, water-soluble plus citrate-soluble P_2O_5 and water-soluble K_2O in the fertilizer material. Thus, a label showing 6-12-8 guarantees that the fertilizer contains at least 6% of N, 12% P_2O_5 equivalent, and 8% K_2O equivalent.

As indicated, N is guaranteed simply as percent of the element. For P and K the guarantee is expressed as the percent of the oxide equivalents, i.e. P_2O_5 and K_2O. The expression “oxide equivalent” is a source of confusion because neither phosphorus pentoxide nor potassium oxide exists in fertilizers, nor in soil or plant materials. Use of the oxide expression for fertilizer guarantees is a carry-over from the early chemists who expressed all chemical compositions in terms of the oxides. State and federal fertilizer regulations were written in terms of P and K oxides. If these laws could be changed it would greatly simplify fertilizer and soil fertility jargon.

Table 8.1 shows the chemical composition of commonly available simple and compound N, P and K fertilizers. A simple fertilizer is one that contains only one element, either N, P or K as in 34-0-0, 0-45-0 and 0-0-60. A compound fertilizer is one that contains more than one fertility element (usually N and P) in a chemically combined form. For example, 18-46-0 (solid prills) or 10-34-0 (liquid) are made by adding NH_3 (gas) to the appropriate phosphoric acid. The basic fertilizer materials of Table 8.1 may be mixed in any combination of provide different elemental ratios. Some mixes frequently seen on the market are 16-20-0, 12-24-0 and 16-16-16. As suggested above, the basic fertilizer materials can be custom mixed to satisfy any specific need.

Table 8.1. Simple and compound fertilizer materials.

Material	Formula	Elemental Composition[1]	Label Guarantee	Physical Composition
Ammonium nitrate	NH_4NO_3	34.5% N	34-0-0 (33.5 to 34.5)[3]	solid
Ammonium sulfate	$(NH_4)_2SO_4$	21% N	21-0-0	solid
Anhydrous ammonia	NH_3	82% N	82-0-0	gas
Aqua ammonia	NH_3 in water solution	20-24% N	20-0-0 (20 to 24)[3]	liquid
Urea	$(NH_2)_2CO$	46% N	46-0-0	solid
Uran or Solution-32	NH_4NO_3 & $(NH_2)_2CO$ in water solution	32% N	32-0-0	liquid
Treble superphosphate (concentrated superphosphate)	$Ca(H_2PO_4)_2$[2]	19.7% P	0-45-0 (0-52-0)[1,2]	solid
Mono-ammonium phosphate	$NH_4H_2PO_4$	11% N, 24% P	11-55-0[4,5]	solid
Di-ammonium phosphate	$(NH_4)HPO_4$	18% N, 20% P	18-46-0 (18-52-0)[3,4,5]	solid
Superphosphoric acid			0-76-0	liquid
Ammoniated superphosphoric acid	NH_3 in H_3PO_4 plus $H_4P_2O_7$ and higher condensates in water solution	10% N, 14.8% P	10-34-0[4]	liquid
Potassium chloride	KCl	50% K	0-0-60[6]	solid
Potassium sulfate	K_2SO_4	41.7%	0-0-50[6]	solid

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[1] The nitrogen percent corresponds directly to label guarantee for N%. P and K percentages are in terms of the elements. To change listed percent P to percent P_2O_5 equivalent multiply by 2.29. To change percent K to percent K_2O equivalent multiply by 1.20.

[2] This is the mono-calcium phosphate monohydrate form of phosphorus, which is referred to as water-soluble phosphate. This fertilizer usually contains a small amount of di-calcium phosphate dihydrate, $CaHPO_4 \cdot 2H_2O$ which is referred to as citric acid-soluble phosphate. Both forms of phosphate are included in the label guarantee percent of plant-available phosphorus in the fertilizer.

[3] Numbers in parenthesis indicate alternative guarantees that occur on the market. Specific guarantees depend on the process used in manufacture.

[4] Label guarantee is expressed as the percentage of phosphoric acid anhydride or P_2O_5 equivalent. To change to the element percentage multiply by 0.437.

[5] Both the mono- and di-ammonium phosphates contain varying amounts of both mono- and di- forms. Therefore the guarantee may vary somewhat from those shown.

[6] Label guarantee is expressed as potassium oxide or K_2O equivalent. To change to element percentage multiply by 0.8.

Mixed fertilizers take two forms. First the fertilizers are mixed while still in liquid form during the manufacturing process. The mix is then dried and formed into prills or pellets that are uniform in composition and color. The mix may be marketed in liquid form, e.g. Uran or 32% solution N (Table 8.1). The second procedure is to mix the dry primary materials, in which case the individual fertilizer materials can be distinguished as prills or crystals of varying color.

Sometimes mixed fertilizers that have a uniform guarantee (for example 16-16-16) are promoted because they are “balanced.” It is true that the guarantee is uniform but the actual composition is not. Thus, 16-16-16 becomes 16-6.9-13.1 when converted to the elemental basis. (See footnotes to Table 8.1 for conversion factors used in changing elements to oxides and vice versa.) A more appropriate definition of a balanced fertilizer is one that meets the specific needs of a given crop-soil situation. This concept suggests that there would be a unique balanced fertilizer for every crop and soil situation, an idea which has obvious practical limitations.

Mixed fertilizers can include secondary and minor fertility elements. Sulfur (S) is the secondary fertilizer element of main concern in Utah. Minor fertilizer elements of interest in Utah include zinc (Zn), iron (Fe), and manganese (Mn). The label guarantee for these elements is always stated in terms of percent of the element and not their oxide equivalents.

Fertilizer Physical Characteristics

As shown in Table 8.1, fertilizers occur as gases, liquids and solids. The physical makeup of fertilizers dictates the kind of equipment and method of application. NH_3 (anhydrous ammonia) requires high pressure storage tanks and application equipment. Some liquid forms (e.g. 10-34-0) are highly acidic and require corrosion-resistant storage tanks and application equipment. Both gas and liquid fertilizers are applied by injection into the soil (4-6 inches deep). The solid forms are applied broadcast to the soil surface or by side dress or banding parallel to crop rows.

Different forms of fertilizer have different advantages, including that of purchase price. The cost of purchase and of application, that is the total cost of fertilization, should be considered in fertilizer selection.

Personnel Hazards

Special caution must be exercised while handling anhydrous ammonia (NH_3 gas) fertilizer. This material is very toxic and can be lethal to man and animals if exposed to large concentrations in the air. No special precautions are needed with other forms of N, nor for P and K fertilizers. The minor element fertilizers (mainly Zn and Mn) can be toxic if ingested and routine precaution should be exercised in avoiding exposure of these materials to children.

Fertilizer Reaction Products in Soils

Nitrogen

Table 8.1 shows that, with the exception of ammonium nitrate (34-0-0) where half of the N is in the nitrate form, all commercial fertilizer-N is in the ammonium ion form, NH_4^+, or in a form that readily converts to ammonium when applied to soil. For example, NH_3 (gas) reacts with the soil moisture to form NH_4^+ (the ammonium ion). Urea-N, $(NH_2)_2CO$, is hydrolyzed to NH_4^+ by the soil-borne enzyme <u>urease</u>. The <u>urease</u> reaction may be summarized by $(NH_2)_2CO + H_2O$ =====> $(NH_4)_2CO_3$. The latter breaks down readily into ammonia gas, carbon dioxide and water. Given good soil moisture and temperature conditions this enzymatic reaction will be essentially complete within 48 hours after soil application of urea. Therefore, with the exception of half of the N in NH_4NO_3, commercial N fertilizers behave essentially as NH_4-N sources regardless of the fertilizer's overall chemical makeup.

The Ammonium ion (NH_4^+) reacts with the soil cation exchange complex and is immobilized. This means that NH_4-N does not move freely about the soil in solution form.

Ammonium-N may be lost to the atmosphere as ammonia gas (NH_3) if the fertilizer is simply broadcast to the soil surface without soil mixing or incorporation (e.g. plowing). The reaction in general form is NH_4OH ====> NH_3 (gas) + H_2O. The tendency for gaseous loss of NH_4-N increases as the soil pH increases above about 6.5, and when the soil surface is moist. The risk of loss of ammonium via ammonia gas is related to the form of fertilizer and decreases in the following order:

$(NH_2)CO$, urea

$(NH_4)_2SO_4$, ammonium sulfate

$NH_4H_2PO_4$, mono ammonium phosphate

NH_4NO_3, ammonium nitrate

Gaseous loss of fertilizer N can be minimized or eliminated if the fertilizer is applied broadcast-plowdown, or banded or side dressed to a depth of 4 to 6 inches. In other words, the fertilizer should be put <u>into</u> the soil and not merely <u>on</u> the soil.

When it is not convenient to incorporate the fertilizer into the soil a compromise must be made between the cost of the extra fertilizer (needed to overcome the loss in efficiency) and the cost of alternative methods of fertilizer management. There are situations, of course, when there is no choice except to broadcast the fertilizer as in the case of an established pasture. With the exception of urea, there is a low risk of gaseous evolution of ammonia from a turf or pasture because the fertilizer has less direct contact with the soil surface. Nitrification of the ammonium-N apparently takes place in the thatch and the nitrate moves into the root zone for plant uptake.

Ammonium-N (NH^+_4) is transformed to nitrate-N (NO^-_3) by soil bacteria in a process referred to as nitrification. The overall process may be illustrated by the reaction:

$$2NH_4^+ + 4O_2 \text{ =====> } 2NO_3^- + 4H^+ + 2H_2O$$

(The nitrification reaction shows that acidity (H^+) is generated by the process. In calcareous soils this acidity is automatically neutralized and there is no effect on soil pH. In poorly buffered soils such as non-calcareous light textured materials, however, soil pH tends to decrease over time with the repeated application of acidifying substances. Under these conditions it may eventually be necessary to apply lime to avoid problems common to acid soils.)

Conditions which favor plant growth, i.e. good moisture and temperature, favor nitrification. Nitrification of the NH_4-N will be 80 to 90 percent complete within 3 to 4 weeks after application in the spring. Accordingly, fertilizer-N, regardless of original composition, behaves like NO_3-N for most of the growing season.

Nitrate-N is completely soluble and moves freely with soil water. If deep percolation occurs as a result of excessive rain or irrigation, then some nitrate will be lost by leaching. If soil water moves upward near the soil surface and evaporates, some NO_3-N will be isolated above the roots in the dry surface soil. This usually occurs to some extent in all furrow-irrigated fields. A late summer rain storm, following a period of no or little precipitation, will flush the nitrates at the soil surface back into the root zone and have the same apparent effect as a fresh fertilizer application.

Nitrate-N may also be lost from the soil when oxygen availability from the air is limited as a result of poor soil structure or with water saturation. The net effect, referred to as denitrification, is loss of nitrate-N in the form of inert gases, such as nitrous oxide (NO) and nitrogen gas (N_2), which return to the atmosphere.

There is risk of ground water pollution from leaching of nitrate-N out of the rootzone. Environmental control agencies are monitoring this situation in Utah and regulations may be forthcoming which will restrict the use of N fertilizer under some conditions. Currently, no clear-cut evidence is available in this state which links farm soil fertility management with nitrate contamination of surface or ground waters.

Because of the interactions between soil water and nitrogen it is impossible to specify the best level of N fertilization unless soil moisture management practices (irrigation method, rate and frequency and/or the climatic regime) are well defined. For example, excess irrigation water results in loss of some soil nitrogen and fertilizer rates must be increased to compensate for the lowered fertilizer efficiency. When too little water is available (droughty conditions), plant demand for nitrogen will be decreased.

Nitrification inhibitors (materials that delay the transformation of ammonium to nitrate) can be mixed with fertilizer materials before soil application. If firm control of soil moisture is not feasible (e.g., irrigation of coarse textured soils) then a nitrification inhibitor might be employed. Since the behavior of nitrification inhibitors is not fully predictable, it is not possible to give a specific recommendation on the use of these materials. It is expected that future research will provide better guidelines on the use of nitrification inhibitors.

Phosphorus

Fertilizer-P exists in two forms, as shown in Table 8.1, depending on the manufacturing process. The most common form, orthophosphate, is represented by the mono-calcium phosphate monohydrate ($Ca(H_2PO_4){\bullet}H_2O$) or MCPM, and di-calcium phosphate dihydrate ($CaHPO_4{\bullet}2H_2O$) or DCPD. The other form is pyrophosphate ($H_4P_2O_7$). Super-phosphoric acid contains both ortho-P and pyro-P. When applied to soil pyro-P is hydrolyzed to ortho-P as follows: $H_4P_2O_7 + H_2O \Longrightarrow 2\ H_3PO_4$. Accordingly, pyro-P behaves like ortho-P soon after field application.

MCPM and DCPD are constituents of treble superphosphate although the DCPD is a minor part. MCPM is classified as water- soluble and DCPD is classified as citrate-soluble. Both kinds of phosphorus are included in the label guarantee.

When treble superphosphate (0-45-0) is used the MCPM quickly transforms to DCPD when the soil pH is above 6.5, as is the case for most Utah soils. The reaction is a two-step process as follows:

$Ca(H_2PO_4)_2{\bullet}H_2O{+}H_2O{\Longrightarrow}CaHPO_4{\bullet}2H_2O{+}H_3PO_4.$
$H_3PO_4{+}Ca(soil){+}2H_2O \Longrightarrow CaHPO_4{\bullet}2H_2O$

As indicated, the phosphoric acid formed by the rearrangement of P in the MCPM is quickly neutralized by calcium compounds in the soil and the net overall effect is the enrichment of soil in respect to its DCPD content. DCPD is also the immediate reaction product of the ammoniated phosphates and of the pyrophosphates after hydrolysis. DCPD is quite immobile in soil. To illustrate, the fertilizer-P enriched soil zone around the fertilizer pellet is limited to a volume about twice the diameter of the pellet. Where fertilizer is applied by banding or side dress, the fertilizer enriched zone will extend away from the band about a half inch. Plowing or other soil tillage operations, following fertilizer application, will tend to mix the P-enriched soil in the tillage layer.

When properly applied, i.e. placed into the soil, P fertilizers having various label guarantees behave alike in regard to satisfying the P needs of plants. The decision as to which P fertilizer to purchase should be based on the cost per pound of the element. In this connection, the ammoniated phosphates (e.g. 11-55-0) are usually quite economical. If both N and P are needed in a fertilization program one of the ammoniated phosphates would be the fertilizer of choice. Fertilizer-N needs, above that provided by the selected N-P combination, would be supplied by mixing any appropriate simple N fertilizer with the ammoniated phosphate.

There is also concern about P contamination of the environment from farm soil fertility management practices. As indicated, P is not mobile in soil so any loss of P from farm lands would be by soil erosion and sedimentation in rivers and lakes. To date, some evidence indicates that high-P concentrations are occurring in the upper parts of some watersheds and this P is evidently of natural origin. No other data are available which indicate that on-farm soil fertility management per se is affecting quality of waters in the environment (James and Jurinak 1986).

Potassium

As shown in Table 8-1, primary K fertilizers include the K salts of chloride (0-0-60) and sulfate (0-0-50). When added to soil these fertilizers dissolve readily increasing the concentration of potassium ion (K^+) in the soil solution. The K in solution reacts with the soil cation exchange complex, increasing the amount of exchangeable K. Some of this K may move into interior cation exchange sites in the clays and become only slowly available for plant uptake. This process has been referred to as K-fixation, a useful expression if it does not convey the idea of irreversible loss of this K for plant uptake. The tendency for fertilizer-K to become slowly available in the soil depends on the kind and amount of clay present.

In the exchangeable form, K is essentially immobile except in very coarse textured soils. Therefore leaching loss of fertilizer-K is rarely significant.

Both potassium chloride (0-0-60) and potassium sulfate (0-0-50) are equally effective in meeting the K needs of plants.

Potassium is a significant constituent of some Utah irrigation waters, especially where the waters contain irrigation return-flow or saline spring flows. However, many original diversion waters in Utah are very low in dissolved K and where these waters are used some soils may become depleted of this element.

Secondary and Minor Fertilizer Elements

There are 12 essential plant nutrient elements that are classified as secondary and minor fertilizer elements. These include calcium, magnesium, sulfur, iron, copper, zinc, cobalt, manganese, molybdenum, vanadium, boron and sodium. Elements in this group of interest in Utah, because of observed or possible crop deficiencies, includes sulfur (S), iron (Fe), zinc (Zn) and manganese (Mn).

Sulfur:

Table 8.1 shows that S is a major constituent of two simple fertilizer materials, ammonium sulfate (21-0-0) and potassium sulfate (0-0-50). The 21-0-0 fertilizer contains about 24% S and the 0-0-50 fertilizer contains about 20% S. When these fertilizers are used to satisfy N or K needs, more than enough S is automatically included to offset any possible S deficiency. Accordingly, when S deficiency occurs one of these primary fertilizers would serve a dual purpose. Where no S deficiency exists, application of 21-0-0 or 0-0-50 would have no effect on soil fertility and plant nutrition beyond their N and K values. Other materials such as elemental S (100% S) and gypsum ($CaSO_4 \cdot 2H_2O$, 18.6% S) also function well as S fertilizers.

In areas where S deficiencies occur fertilizer-S rates of 10 to 20 lbs S/acre eliminate the deficiency. In addition, these rates provide for residual S effects into the second and third years following application.

All but a small fraction of Utah irrigation waters contain sulfur (SO_4) in appreciable quantities. Accordingly, S deficiency in Utah irrigated crops would be expected to be only a remote probability.

Zinc:

The principal inorganic fertilizer form of Zn is zinc sulfate ($ZnSO_4$). This contains about 24% Zn depending on how much water of crystallization is included in the salt. Zn is also available in chelate or organic form. Chelates are complex organic materials of both natural (e.g., tree bark derivatives) and synthetic origin. EDTA and EDDHA are two synthetic chelates that have been on the market for several years. The chelate forms are relatively expensive but some claim that chelate-Zn satisfies deficiencies at lower rates than does $ZnSO_4$. In any event, an application of 10 lbs Zn/acre in whatever form has a significant residual effect for 3 to 4 years following application.

When added to alkaline soils fertilizer-Zn reverts to zinc carbonate or zinc oxide which are relatively insoluble. As such, zinc is immobile in soil.

Iron:

Ferrous sulfate ($FeSO_4$, 20-24% Fe) in solid form and also dissolved in water has been applied directly to soil and to crop foliage. When $FeSO_4$ is applied to soil the reduced iron form (Fe^{2+}) ion is rapidly converted to the oxidized iron form (Fe^{3+}) which precipitates as $Fe(OH)_3$ or Fe_2O_3, both of which are very insoluble and quite unavailable for plant uptake. There is no practical way to alter these reactions in well drained arable soils, which explains the limited success observed with Fe fertilizers. Other chapters of the **Utah Fertilizer Guide** explain the use of chelate-Fe as a foliage application on crops affected by lime-induced chlorosis.

Manganese:

Manganese sulfate (20-24% Mn depending on the amount of water of crystallization) is applied in solution form to both soil and crop foliage. Chelated Mn also serves well for this purpose.

When manganese sulfate is applied to soil the manganese is converted to insoluble chemical forms and is mobile in the soil.

Acid-based Fertilizers

The fluid fertilizer industry in recent years has been marketing “acid-based” fertilizers. These include 10-34-0 or ammoniated super-phosphoric acid. They also include fluid forms such as 32-0-0 to which sulfuric acid (H_2SO_4) has been added. The latter kind of product has lower N-P-K percentages because of the dilution effect of the acid. It also has an appreciable level of guaranteed sulfur. The fluid mix has a low pH and is corrosive and caustic.

Acid-based fertilizers are promoted as having special benefits in basic or calcareous soils, allegedly because they make both major and minor fertility elements more available in the soil.

Research efforts specifically aimed at the question of soil acidification and plant nutrient availability have not as yet substantiated the acid-based fertilizer promotional claims. This applies both to nutrients contained in the fertilizer itself and to indigenous soil fertility elements such as iron and zinc.

It is emphasized again, that fertilizer selection should be based on the combined cost of purchase and field application. In this framework acid-based fertilizers probably would not be competitive because of the higher costs of fluid fertilizers in general and also the corrosion-resistant equipment needed to handle these types of materials.

Animal Manures

Animal manures represent a significant resource when an animal enterprise is part of the farm operation. Since manures are typically low in soil fertility element composition, application rates sufficient to meet fertility needs involves transport of large amounts of material. This represents a major disadvantage in using manure fertilizers when they have to be moved long distances.

Table 8.2 shows the fertility values of typical manures. The values shown are only approximate since N, P and K composition of manures is highly variable. Table 8.2 shows that the type of animal affects the fertility values. In addition, animal diet (grass fed versus grain fed) and whether or not urine is included with the feces have an impact. Fresh material is high in water content. Stored manure is susceptible to weathering and loss of N values. Where bedding materials such as straw and sawdust are used, the raw manures can be diluted to some extent in fertility elements. It is necessary to have a laboratory analysis to accurately estimate the fertility value of a given manure.

Table 8.2. Composition of various farm animal manures. (Adapted from Meek et al. 1975.)

Animal	N	P	K
	percent dry weight		
Pig	2.0	0.6	1.5
Chicken	4.3	1.6	1.6
Beef cattle	3.5	1.0	2.3
Dairy cattle	2.7	0.5	2.4
Sheep	4.0	0.6	2.9

If soils have poor structure, manure helps in good structure development, water infiltration and root penetration. In such cases manuring may have measurable values beyond the simple fertility effects. If soil structure is not a problem then the added organic matter has little effect beyond the N-P-K values.

Manure-borne N and P are mostly in the organic form and as such are not immediately available for plant uptake. These elements only become available as the manure is decomposed in soil. Manure decomposition proceeds quite rapidly if moisture and temperature are favorable. Thus, the rate of release of organic N and P from the decomposing manure would be highest in late spring and summer. This delayed release may be a disadvantage if the soil is initially low in either N or P.

Farms with large animal enterprises (beef, dairy, turkey) need to deal with manure accumulation as a waste disposal problem. When manure is disposed of repeatedly on the same soil, organic matter and phosphorus may accumulate to excessive levels, sometimes leading to other plant nutrition problems such as zinc and iron deficiency. A survey of dairy farm pasture and alfalfa fields in Davis and Weber counties showed that soil test phosphorus was mostly in the range of 50-80 (10-15 is adequate to meet all crop phosphorus needs). Six fields were soil sampled in the vicinity of Utah’s well established turkey producing area (Moroni). These six fields had an average soil test phosphorus of 117 with a range of 45 to 183.

Cattle manure may contain appreciable amounts of salt (where salt is mixed with feed). Therefore, fields receiving excessive amounts of manure may need to be specifically managed to lower the salt content of the soil (see Chapter 9 on saline and sodic soil reclamation).

Field disposal sites should be rotated over a period of several years to avoid problems associated with large and continuous applications of manure.

General Discussion

One purpose of this chapter, with the presentation of overall fertilizer reactions in soils, was to emphasize that within certain narrow limits, various forms of the respective fertilizer elements behave alike in terms of satisfying plant nutrient requirements. On some occasions; however, fertilizer sales promotional efforts attempt to give a different impression. Sometimes extraordinary or even phenomenal qualities are ascribed to a given brand name and in this context the alleged qualities and benefits differ only in a small degree from the “Soil Amendments and Plant Additives of Unproven Utility” discussed in Chapter 10 of the **Utah Fertilizer Guide**. The following statements, taken from fertilizer literature distributed by one company, illustrate the issues involved.

(**Brand Name**) fertilizers...also improve the tilth of the soil and aid water penetration. Sulfuric acid (is added) which can help reduce compaction, clod formation, runoff, crusting, etc. Its effects are immediate; not dependent on slow biological breakdown.

What are the advantages (then list)
Less phosphorus tie-up
Less nitrogen loss by leaching, and less volatilization.
Less tie-up of micronutrients.
More favorable pH for plant yields.
More nutrient availability.
Changes “tied-up” nutrients to available form.
Increases nutrient mobility in the soil.
Increases nutrient uptake.

(Brand Name) is more cost efficient than other fertilizers.
Produces healthy vigorous plants with better disease and stress resistance.
Increases better root development.
Increases protein in wheat, alfalfa.
High yields, more realized profits.
Immediate reaction in the soil—you do not have to wait months or years...
Conditions the irrigation water by lowering the pH.
Cleans the hard water deposits from irrigation equipment—prolonging life.
Loosens tight soils.
Minimizes compaction and clodding.
Increases water penetration and aeration of the soil.
Effective (disease) control.

It is obvious from the fertilizer composition that there was nothing unique in the basic constituents of (Brand Name) fertilizers. The sales promotions were simply trying to give those products extra sales appeal.

The bottom line, as emphasized repeatedly herein, is that the choice of which fertilizer to select for a given soil and crop situation should be based first on diagnosed needs and secondly on cost per unit of the element(s). This includes the sum of purchase and application costs, and also convenience. Farm managers will increase their profit per unit of production by reducing their cost per unit of input. It is entirely possible that (Brand Name) is offered at a lower price. But the experienced buyer would reject (Brand Name) in favor of another brand that would accomplish the same purposes at a savings to his production costs.

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Chapter 9
Irrigation Water Quality and Salt-Affected Soils

J. J. Jurinak and *K. Topper*

Source of Salinity in Soils and Waters

The primary source of salt in soil and waters is the constant geochemical weathering of the constituent minerals of rocks which form the upper surface of the earth's crust.

The intensity and extent of mineral weathering is strongly influenced by climatic conditions. The presence of water is critical to geochemical weathering for it serves as both a reactant in mineral transformation and the medium which transports dissolved weathering products (salts) from the region.

Salt-affected soils are commonly associated with climatic conditions where evapotranspiration greatly exceeds the rainfall over much of the year, that is, arid and semi-arid landscapes. This lack of moisture not only limits the intensity of chemical weathering but the products of weathering which does occur are constrained to a restricted area.

Because water is a vector for salt, salinization of the soil occurs in areas where water drains, that is, low lands and depressions. Salinization is also enhanced when restricted internal drainage promotes a high water table and the coupling of capillary rise and surface evaporation moves salt into the surface soil.

Irrigation Water Quality

Water quality refers to the properties of a water supply that will influence its suitability for some specific use, i.e., how well does the water meet the needs of the user. Quality of water is defined by physical, chemical and biological parameters. Irrigation water quality guidelines emphasize the chemical composition of the water although at times physical characteristics, e.g., the sediment load, may be considered important. The actual suitability of a given water for irrigation depends on the specific condition under which the water is used. These conditions include the salt tolerance of the crop grown, soil properties, irrigation management practices, and the skill and knowledge of the water user. Because of the complexity of defining water quality, any scheme for determining the suitability of water for irrigation must be considered as only a guideline which must be used in conjunction with specific site conditions.

Both the total amount and the type of salt is considered in determining the quality of irrigation water. Ions that occur in macro amounts as Na (sodium), Ca (calcium), Mg (magnesium), K (potassium), HCO_3 (bicarbonate), SO_4 (sulfate), Cl (chloride), and CO_3 (carbonate) determine the chemical status of irrigation water. Boron (B) because of its phytotoxicity and ubiquity is also analyzed. If industrial or municipal drainage water is used for irrigation the analyses of heavy metals and organic compounds is recommended.

The total salinity of water is measured by the electrical conductivity, EC_w. The units of EC_w are decisiemens/meter (dS/m) which replaces the former units of EC_w in mmhos/cm. The units of dS/m are equivalent in value to mmhos/cm. The total dissolved solids, TDS, is reported in mg/L which replaces the units of ppm (parts per million). The units in reporting chemical analyses of soils and waters are given in Table 9.1.

Table 9.1. Chemical constituents of salt-affected soils and irrigation waters and the relation between old and new chemical units.

Parameter	Symbol	Units Old	Units New	Conversion of Old into New Multiply by
WATER				
Electrical Conductivity	EC_w	umho/cm	dS/m	10^{-3}
Sodium Adsorption Ratio	SAR	$(mmol/L)^{½}$	$(mmol/L)^{½}$	1
Calcium	Ca^{2+}	meq/L	$mmol_c/L$	1
Magnesium	Mg^{2+}	meq/L	$mmol_c/L$	1
Sodium	Na^+	meq/L	$mmol_c/L$	1
Potassium	K^+	meq/L	$mmol_c/L$	1
Chloride	Cl^-	meq/L	$mmol_c/L$	1
Sulfate	SO_4^{2-}	meq/L	$mmol_c/L$	1
Carbonate	CO_3^{2-}	meq/L	$mmol_c/L$	1
Bicarbonate	HCO_3^-	meq/L	$mmol_c/L$	1
Nitrate Nitrogen	NO_3-N	ppm	mg/L	1
Boron	B	ppm	mg/L	1
SOIL				
Electrical Conductivity	EC_e	mmho/cm	dS/m	1
Exchangeable Sodium %	ESP	%	%	1
Sodium Adsorption Ratio	SAR	$(mmol/L)^{½}$	$(mmol/L)^{½}$	1
Exchangeable Cations	Ca^{2+}	meq/100 gm	$cmol_c/kg$	1
	Mg^{2+}	meq/100 gm	$cmol_c/kg$	1
	Na^+	meq/100 gm	$cmol_c/kg$	1
	K^+	meq/100 gm	$cmol_c/kg$	1

Criteria for Irrigation Water Quality

The criteria commonly used to judge the suitability of a water for irrigation are salinity, sodicity and toxicity.

Salinity: The salt effect is related to the lowering of the osmotic potential of the water which limits the availability of water to plants. It is a function of the total salt concentration.

Sodicity: The sodic (sodium) hazard is mainly associated with the detrimental effects of excessive exchangeable sodium on the physical properties of the soil. The result is the deterioration of the water and air conducting properties of the soil. Of particular importance is the affect of sodium on water infiltration.

Toxicity: This relates to specific ion effects which alter the metabolic processes of the plant independent of the osmotic potential of the soil solution.

The Salinity Hazard

A salinity problem exists when salt accumulates in the root zone of crops to the extent that a loss of yield occurs. Yield reduction results when the salt concentration in the soil solution lowers the osmotic potential to a level that crops cannot extract adequate water to maintain growth. Salinity may become a limiting factor for the growth of salt sensitive crops as beans or strawberry when EC_w = 0.7 to 1.0 dS/m whereas, salt tolerant crops as sugar beets and barley may show no adverse effects when EC_w = 3.0 to 5.0 dS/m.

The control of salt accumulation in the root zone requires that additional water be applied in excess of plant needs. This process is called leaching. Leaching serves to move a portion of the accumulated salt below the root zone and into the drainage network. The fraction of applied water passing through the root zone at the field level is called the leaching fraction (LF) which is defined as:

$$LF = \frac{\text{depth of water entering the root zone}}{\text{depth of water leaving the root zone}} \qquad (1)$$

Salt accumulation in the root zone will be less with a high leaching fraction (LF = 0.3) than with a lower leaching fraction (LF = 0.1). The salinity of the drainage water (EC_{dw}) percolating below the root zone can be roughly estimated by

$$EC_{dw} = EC_w / LF \qquad (2)$$

The control of salinity by leaching involves large amounts of water, thus it requires a system capable of removing water from the site. Adequate drainage is critical to prevent a rising water table which would aggravate the salinity problem.

The time when leaching is done is not critical provided the salt tolerance of the crop is not exceeded for extended periods. Leaching can be done at each irrigation, alternate irrigations, or seasonally depending on the threshold salinity of the crop (Ayers and Westcot 1985).

Sodic Hazard

The principal affect of excessive sodium in applied irrigation water is to increase the amount of adsorbed sodium in the soil. A sodic problem is normally associated with the reduction of water infiltration which results in the root zone not being supplied with adequate moisture for plant growth.

The infiltration problem results from the low structural stability induced by adsorbed sodium which is manifested in the dispersion of soil aggregates. The dispersed particles eventually clog the water transmitting pores and produces a cement-like soil crust upon drying.

The sodic hazard is associated with the sodium adsorption ratio (SAR) of the irrigation water. The SAR is defined (U.S. Salinity laboratory Staff 1954):

$$SAR = [Na] / [Ca + Mg]^{1/2} \qquad (3)$$

where Na, Ca, and Mg represent the total concentration (mmol/L) of these ions in the irrigation water. The above equation does not take into account the possibility of $CaCO_3$ precipitation in the soil which can serve as a sink for the Ca ion, thus affecting the Na to Ca ratio.

The adjusted SAR (SAR_{adj}) was developed to correct the water composition for possible $CaCO_3$ precipitation in the soil. For the surface infiltration situation, assuming the LF = 1.0, the SAR_{adj} is (Suarez 1981):

$$SAR_{adj} = [Na] / [Mg + Ca_x(P_{CO_2})^{1/3}]^{1/2} \tag{4}$$

where Na and Mg are the concentrations of the respective ions in the water (mmol/L), P_{CO_2} is the partial pressure (atm) of CO_2 in the surface soil and Ca_x is the equilibrium Ca ion concentration (mmol/L) which is a function of the ionic strength (salinity) and the HCO_3 / Ca mole ratio of the water. Tables of Ca_x values have been published which cover a wide range of water composition (Ayer and Westcot 1985; Suarez 1981). The SAR_{adj} is used in place of the SAR to better evaluate the potential of an infiltration problem.

Analyses of 250 irrigation waters from throughout the world indicate that, for most waters, the simple SAR calculation (equation 3) is within ± 10-15 percent of the SAR_{adj} value (Ayers and Westcot 1985). For field work the use of the uncorrected SAR can be used in place of the SAR_{adj} with acceptable error.

The sodic hazard is not only a function of the SAR but also the salinity of the irrigation water. The greater the salinity of the water, the greater the SAR or SAR_{adj} values which can be tolerated before infiltration becomes a problem (Shainberg and Letey 1984). This is explained by the beneficial affect of salinity on the flocculation of soil particles which counteracts the affect of adsorbed sodium. This effect is shown in the salinity and sodicity water quality guidelines which are given in Table 9.2.

Table 9.2. Guidelines for interpretations of water quality for irrigation.

Potential Irrigation Problem		Units	Degree of Restriction on Use		
			None	Slight to Moderate	Severe
Salinity (affects crop water availability)					
EC_w		dS/m	<0.7	0.7 - 3.0	>3.0
TDS		mg/L	<450	450 - 2000	>2000
Infiltration (affects infiltration rate of water into the soil; evaluate using EC_w and SAR together)					
SAR	= 0 - 3 and EC_w	=	>0.7	0.7 - 0.2	<0.2
	= 3 - 6	=	>1.2	1.2 - 0.3	<0.3
	= 12 - 20	=	>1.9	1.9 - 0.5	<0.5
	= 20 - 40	=	>5.0	5.0 - 2.9	<2.9

Toxicity

Toxicity problems are considered independent of salinity effects and refer to nutritional imbalance within a plant or to toxicity symptoms which are attributed to a specific element in the irrigation water. Perennial woody-type plants tend to be most susceptible to toxicity problems. The usual toxic ions in irrigation water are B and Cl.

Boron, although an essential plant element, is phytotoxic if present in amounts appreciably greater than needed. Boron toxicity can affect nearly all crops, but, as with salinity, there is a wide range of tolerance among crops. Plants that are sensitive to B, such as peach, plum and grape, can show toxicity symptoms when the concentration in the irrigation water is 0.5 to 0.75 mg B/L. Whereas, tolerant crops such as tomato, alfalfa, sorghum and sugar beet can tolerate 4.0 to 6.0 mg B/L in the irrigation water. Because field crops in Utah have not shown response to B fertilization and because of its toxicity potential, the application of B is not recommended.

Chloride is also an essential plant element and a common anion in irrigation water. The tolerance of crops to chloride is not as well documented as it is for salinity. Leaf burn from chloride accumulation in Cl sensitive plants such as grapes, raspberries, strawberries, and plums is possible with the prolonged use of water containing 5-6 $\mathrm{mmol_c}$ Cl/L. Sprinkler irrigation tends to aggravate the problem. Because Cl ion does not react with the soil and moves readily with the soil water, leaching can be used to prevent or correct a chloride problem. In this case, toxicity and salinity control are implemented by the same management practice.

Salt Affected Soils

Salt-affected soils are usually divided into two major categories, i.e., saline and sodic soils. A category of saline-sodic soils is often included. The classification of salt-affected soils is based on the chemical composition of the saturation extract (the extract from a dry soil sample saturated with distilled water).

The principal criteria are (1) the electrical conductivity of the saturation extract (EC_e in dS/m at 25ºC) and (2) the SAR (see equation 3) of the extract whose value is, for all practical purposes, equal to the exchangeable sodium percentage (ESP) of the soil. The ESP is defined: ESP = NaX. 100 / CEC where NaX is the amount of adsorbed Na^+ and CEC is the cation exchange capacity. The units of NaX and CEC are $\mathrm{cmol_c}$/kg which is equivalent to meq/100 g. Because the response of soils to salinity and sodicity varies greatly, the values given in Table 9.3 represent averages and should serve only as rough guidelines in classifying salt-affected soils.

Table 9.3 Guidelines for the classification of salt-affected soils.

Criteria*	Normal	Saline	Sodic	Saline-Sodic
EC, dS/m	<4	>4	<4	>4
SAR, $(mmol/L)^{1/2}$	<10	<10	>10-13	>10-13

*Based on saturation extract analysis.

Reclamation of Saline Soils

In principle, the reclamation of a saline soil is simple; add sufficient water to leach the excess salt out of the root zone. Usually leaching is done to reduce the soil solution salinity in the upper 40-60 cm to some average EC value which will result in acceptable yields. Table 9.4 shows relative salt tolerance of some representative crops in terms of the average EC_e in the root zone which will produce a 25 percent yield decrement.

An important consideration in any reclamation project is the presence of adequate drainage, natural or man-made. All soil reclamation requires large volumes of water to leach salt. This water must be removed to prevent a raising water table which serves to aggravate the problem.

The amount of leaching required to remove salt from soil can be estimated by a simple empirical equation (equation 6) developed from field leaching data obtained from various parts of the world (Hoffman 1980):

$$(C/C_o)\ (D_l/D_s) = k \qquad (6)$$

where C is the salt concentration remaining in the soil, C_o is the initial salt concentration in the soil, D_l is the depth of leaching water applied and D_s is the depth of soil to be leached. The initial salt concentration in the soil is given by the EC_e which is measured at the appropriate time. The variable C can be viewed as the desired EC_e (which is based primarily on the salt tolerance of the crop). Using this equation, the depth of leaching water (D_l) can be calculated.

The empirical coefficient k varies with soil type and method of water application. Under a continuous ponding situation, k = 0.3 for fine textured soils, k = 0.1 for coarse textured soils, and k = 0.45 for organic soils. The data indicate that roughly 70 percent of the salt in a medium textured soil can be removed with a depth of water applied equal to the depth of soil reclaimed.

The leaching efficiency is usually improved when the leaching water is applied at a rate below the saturated hydraulic conductivity, i.e., by intermittent ponding or sprinkling. The greater the degree of unsaturated soil moisture the more efficient is a volume of water in leaching salt from the soil. The field data presented by Hoffman (1980) indicate that the unsaturated leaching curve is not sensitive to soil texture and salt release is described by equation 6 with k = 0.1. About one third less water is used with intermittent ponding to remove a comparable amount of salt (from medium and fine textured soils, however, considerable more time is required).

Table 9.4. Relative salt tolerance of typical Utah crops where EC_e represents the average root zone salinity for 25% yield loss (from Ayers and Westcot 1985).

Forage Crops	**EC_e**	**Vegetables**	**EC_e**
Tall wheat grass	13	Beets	6.8
Crested wheat grass	10	Tomato	5.0
Orchard grass	5.5	Sheet corn	3.8
Alfalfa	5.4	Potato	3.8
Clover, red	3.6	Carrot	2.8
Field Crops		Bean	2.3
Barley	13	**Fruit Crops**	
Sugarbeet	11	Grape	4.1
Wheat	9.5	Peach	2.9
Sorghum	8.4	Plum	2.9
Corn	3.8	Apricot	2.6
		Raspberry	2.6

Reclamation of Sodic Soils

The reclamation of sodic soils is more difficult than reclaiming saline soils. Several processes must operate simultaneously to successfully reclaim a sodic soil: (1) exchangeable Na is replaced by Ca^{2+}, (2) the soil permeability must be maintained, and (3) the Na salts are leached from the soil.

An important factor in reclaiming a sodic soil is the maintenance of the soil hydraulic conductivity. This is achieved by keeping the salinity of the soil solution (leaching water) high enough to counter the soil dispersion caused by exchangeable sodium. In general, the higher the soil salinity the higher the ESP at which adequate permeability exists. During sodic soil reclamation, the Na/Ca exchange is usually accomplished under a high salinity regime and then the salt is leached from the soil.

Sodic Soil Reclamation: Amendments

An amendment is usually added to supply the necessary Ca to replace exchangeable Na. Gypsum ($CaSO_4 \bullet 2H_2O$), because of its low cost and availability, is the most common amendment used. The moderate solubility of gypsum can sustain the release of electrolytes over extended periods thus aiding in the maintenance of relatively long term soil permeability. The exchange reaction of gypsum in a sodic soil can be written:

$$2NaX + CaSO_4 = CaX_2 + 2Na^+ + SO_4^{2-}$$

where X is one mole of negative charge (mol_c) on the clay particle and the soluble salt Na_2SO_4 is leached from the soil.

The calculation of the amount of gypsum required to reclaim a sodic soil, the gypsum requirement (GR), is based on the fact that 1 $mmol_c$ of Ca^{2+} will replace 1 $mmol_c$ of NaX (adsorbed Na^+ ion). Assuming that a soil has a bulk density of about 1.5 g/cm^3, then an acre foot = 4.0×10^6 lbs or a ha-30 cm = 4.5×10^6 kg.

GR = 1.72 tons/acre-ft for each $mmol_c$ of NaX exchanged, or

GR = 3.85 metric tons/ha-30 cm for each $mmol_c$ of NaX exchanged.

The equation to calculate the amount of NaX to be exchanged is:

$(CEC)(ESP_i - ESP_f)/100$ = NaX to be exchanged, or for field calculations assuming SAR = ESP

$(CEC)(SAR_i - SAR_f)/100$ = NaX to be exchanged,

where the subscripts I and f are the initial and final ESP or SAR values, respectively. Recall units of both CEC and NaX are $cmol_c/kg$ which is equivalent to the units, meq/100 g.

An example using the above equations is given: A sodic soil to be reclaimed has a CEC = 20 $cmol_c/kg$ and the saturation extract has a $SAR_i = 25$. If it is desired to reduce sodic level in the upper 2 feet of soil to $SAR_f = 5$, the amount of gypsum required is:

$$GR = [(25 - 5)/100]\ 20 \times 1.72 \times 2 = 13.8 \text{ tons of gypsum/acre.}$$

To account for inefficiencies in ion exchange, etc., the GR is multiplied by 1.25. Thus field application is 1.25 GR. For the above example: (1.25)(13.8) = 17.25 tons of gypsum applied per acre.

Although relatively expensive, $CaCl_2 \cdot 2H_2O$ is an effective amendment for reclamation. Its solubility results in a high electrolyte concentration which maintains a high water infiltration rate. This feature makes it a more efficient amendment than gypsum in soils of high ESP. The high solubility of $CaCl_2 \cdot 2H_2O$ also allows it to be leached rapidly from the soil, thus the soil may seal after treatment despite the reduced ESP because of the low electrolyte concentration in the soil solution, particularly in non-calcareous soils. Studies suggest that for high sodic soils a mixture of gypsum and calcium chloride may be more effective than gypsum alone (Prather et al. 1978).

Acids (H_2SO_4 or HCl) and acid forming amendments (S) are often added to reclaim calcareous sodic soils (i.e. sodium affected soils high in $CaCO_3$). The H_2SO_4 interacts with soil $CaCO_3$ to form gypsum and HCL reacts to form calcium chloride. Sulfur requires an initial phase of microbiological oxidation to produce H_2SO_4. The availability of acid waste products from mining and industrial activities is increasing and their use as soil amendments may provide a safe and economical means of disposal.

Table 9.5 shows the relative amounts of various amendments required to replace a given amount of exchangeable Na. On a weight basis elemental sulfur is the most efficient amendment.

Table 9.5. Relative reaction speed of various sodic soil amendments compared against one ton of gypsum in calcium supplying power.

Amendment	Equivalent Amounts (lbs)	Speed
Gypsum (95%)	2000	rapid
Sulfuric acid (93%)	1100	rapid
Sulfur dioxide	670	moderate
Sulfur (100%)	335	slow
Aluminum sulfate	2200	rapid
Calcium chloride 1	300	rapid
Organic wastes/residues	Variable	slow

Adapted from J. Vomocil, 1982.

Reclamation: Saline-Sodic Soil

Reclaiming a saline-sodic soil combines with reclamation principles of both saline and sodic soils. In general, the high salinity is maintained while adding an Ca-supplying amendment to replace exchangeable Na with Ca. After reaching the desired reduced ESP level, the salinity is removed by leaching. If the soil contains gypsum, the addition of water only will often suffice to effect both sodic and salinity reclamation in a single operation.

Soil Testing and Sampling

The above discussion indicates the importance of soil sampling and soil chemical analyses in the management and reclamation of salt-affected soils. Chemical data obtained from soil samples analyzed in a reputable soil testing laboratory are essential to the evaluation of the extent and nature of salt problems.

Although detailed description on the procedures used in soil sampling are provided in Chapter 2 of the **Utah Fertilizer Guide**, the sampling for identification of potential salt-affects requires additional consideration. Spatial variability, both horizontally and vertically, can be significant in salinity related problems. Thus, the sampling intensity must be increased relative to normal soil fertility sampling.

If only a general characterization of a uniform field from a single composite soil sample is desired, a minimum of two soil cores per acre taken to a depth of 12 inches would be adequate. A highly variable field would require the greater sampling intensity provided by the grid point sampling technique. To assess the salinity status in detail, the soil should be sampled in 6-inch increments to a depth of several feet or until a restrictive layer is encountered. Each 6-inch increment sample is analyzed separately to evaluate the vertical salinity profile. For maximum information the SAR and EC_e of the saturation extract should be determined.

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Chapter 10
Soil Amendments and Plant Additives of Unknown or Unproven Utility

D. W. James

Fertilizers and other agricultural chemicals are regulated by state and federal statutes that govern product definitions and compositions. Statutes require that fertilizer labels attached to all commercial products show the guaranteed minimum percentage composition of the individual fertilizer elements. These guidelines are discussed in detail in Chapter 8 of the **Utah Fertilizer Guide**. Because of the governmental regulatory activities, fertilizer labels which guarantee element compositions are generally accurate.

Despite the efforts of regulatory agencies, agriculturists are confronted continually by products for soil and/or crop application which have questionable validity. These materials usually do not survive on the market because farm managers learn from experience, and usually some expense, that promotional claims are not substantiated in practice.

The Utah Agricultural Experiment Station and USU Extension Service recommend that farm managers maintain a healthy skepticism toward new products or practices of unknown or unproven utility. This recognizes the possibility that innovative ideas may indeed result in positive benefits to the farm manager. Experience has shown, however, that highly optimistic claims on unproven materials provide benefits only to the manufacturers and sellers. This chapter of the **Utah Fertilizer Guide** describes materials and practices of questionable value and to suggest how land managers can protect themselves from unprofitable expenditures on soil amendments and plant additives.

Typical Claims for “Miracle” Products

Some materials are sold as soil amendments to improve soil physical conditions such as tilth, structure, water infiltration rate, water holding capacity, and rooting depth. It is not uncommon for the same material to be sold with the promise of making sandy soils less open to water flow and clayey soils more porous. Such claims are made without considering the soil’s natural humus content or other physical properties.

Other soil amendments are offered with the promise of improving soil fertility characteristics, such as reducing or eliminating the need for fertilizer elements, making native soil elements more available to plants, providing “balanced” soil fertility, or inoculating soil with “proper” or “improved” strains of bacteria, enzymes or hormones.

Plant additives, for foliar application, are promoted on the basis of assuring “balanced” plant nutrition, and/or “needed” enzymes, vitamins, or growth hormones.

Frequently promotions for soil and plant additives include numerous testimonials in support of alleged benefits which are usually expressed in terms of large economic returns from small investments. Sometimes it is claimed that state and federal research agencies are investigating the material, without disclosing who is doing the work or what results have been obtained from valid scientific tests.

Origin of Questionable Materials

Soil amendments and plant additives of questionable validity have a variety of origins. Following are some examples that have been observed in recent years.

1. Synthetic or natural organic materials sold as soil conditioners including plastic-like materials, and wood industry by-products.

2. Cultured or fermented substances that are alleged to provide a desirable or balanced supply of plant hormones, vitamins, minerals, chelates, etc. These include various raw materials such as sea weed, yeasts, bacterial or fungal cultures, and processed or by-product materials from the milk and other food processing industries.

3. Raw or processed geologic materials, rocks, minerals, and ores. Examples are low grade gypsum, minerals such as alunite, raw rock phosphate, leonardite, lignite and other coal-like materials, "humic acids," and slags. Sometimes processed rock or mineral matter has been mixed with ordinary fertilizers and promoted as a soil amendment which makes native fertility elements "more available" for plant uptake.

4. "Shotgun" treatments of legitimate plant nutrient and fertilizer elements containing several of the following: sulfur, calcium, magnesium, iron, copper, zinc, cobalt, manganese, molybdenum, and boron.

5. Soil acidifying materials intended to lower the pH of basic or calcareous soils with the intention of making native or applied fertility elements more efficient in meeting plant nutritional requirements.

Validating Promotional Claims for Unknown Materials and Unsubstantiated Practices

Land managers are encouraged to test promising new ideas in soil fertility management. However, the recommended "try it and see" approach toward unproven soil and plant additives is offered with the simple precaution that "If it sounds too good to be true, it probably is." Following are some suggestions for evaluating new ideas regarding soil and plant additives. The intent is to assure that no truly promising opportunity is lost while at the same time protecting the user against unjustified costs involved with evaluating non-effective or illegitimate materials and practices.

1. Do not make a significant investment in soil amendments or plant additives before obtaining definitive proof that some benefits can possibly result from the purchase and application thereof. To establish good faith on the part of the promoters, it would be well justified to ask them to cover material costs and some of the other costs involved in field pilot trials on the material or practices in question.

2. Measure crop yield performances with and without the additive or amendment. Such a comparison should be planned carefully, assuring that:

(a) The test material be applied in four or five strips across the full length of the field. The treated strips should be alternated with untreated strips of the same size. The strips should be wide enough to allow for easy segregation and measurement of crop yield from each field strip, both treated and untreated.

(b) The soil fertility and cropping history should be uniform in the field to be used for the trial.

(c) The field has a uniform crop stand and it has been uniformly fertilized in the previous and current season. If the field is irrigated the frequency and amount of irrigation should be uniform during the test period.

(d) Collect yield data from each strip. If feasible, it would be desirable to take yield subsamples within the treated and untreated strips to obtain an estimate of field variability. It would be beneficial also to include some type of crop quality test such as protein and fiber content of hays and silages, protein content of grains, etc.

If a consistent yield and/or quality difference occurs between treated and untreated field areas, contact the Extension Service or the Agricultural Experiment Station. These agencies would be interested in conducting formal research work on the material or practice. The objective would be to determine if the benefits are reproducible and if such benefits could be explained in terms of material composition and identifiable causes and effects on soils and plants.

The Soil, Plant and Water Analyses Laboratory (SPWL) will assist farm managers and others in designing, implementing, and evaluating such field trials. If beneficial results from material applications and practices are real then the SPWL would incorporate the new ideas into its recommendation system.

Glossary
Diagnostic Soil Testing Soil Fertility and Plant Nutrition Environment

D. W. James

Amendment: Any product or material applied to soil to modify acidity, alkalinity, soil physical conditions, or fertility.

Available Plant Nutrients in Soil: (a) Nutrient forms in soil which are readily accessible for plant uptake, or nutrient forms which will become readily accessible during the growing season or other specified time period.
(b) Labile plant nutrients in soil.

Calcareous: A contraction of calcium carbonate. Calcareous soils generally have a highly buffered pH in the range 7.2 to 8.3. The pH is not proportional to the amount of calcium carbonate present. Calcium carbonate may be inherited from soil parent materials (e.g., dolomite or calcite rock), or it may be formed in place by soil forming processes. Characteristically soils in arid and semiarid regions are calcareous in part or all of the profile.

Chelate: Greek for “claw”; natural and synthetic organic substances that have the ability to complex nutrient elements protecting them from precipitation in less soluble, inorganic forms. Chelates are used especially for zinc, iron, manganese and copper. EDTA and DTPA are frequently used synthetic chelating agents. Natural chelating substances are derived from tree bark. Some plant roots exude chelating agents and so expedite nutrient element availability.

Denitrification: The transformation of nitrate-nitrogen to gaseous forms of nitrogen such as di-nitrogen (N_2) and nitrous oxide (NO). Denitrified nitrogen returns to the atmosphere and is lost to soil fertility. Denitrification occurs when oxygen is depleted in the soil, usually because of excess water or soil saturation.

Electrical conductivity: (a) A measure of total dissolved salts in the soil saturation paste extract (ECe) or in irrigation water (EC).
(b) Expressed as dS/m (desi Siemens per meter) at 25° C. This was formerly expressed as mmohs/cm (milli mohs per centimeter). The numerical value does not change with the change in EC unit.

Eutrophy, eutrophication: (a) Lake and river waters with high levels of dissolved nutrients, especially phosphates and nitrates.
(b) Waters characterized by large amounts of algae and other water plants; “algal blooms”; occurs most often in shallow, warm waters.
(c) Waters depleted in oxygen because of the presence of large amounts of readily degradable organic residues (biological oxygen demand).

Extractable Plant Nutrients in Soil: Plant nutrients that are removed from a soil sample by a specified soil test procedure. Different soil extraction procedures may give widely different nutrient extraction levels.

Fertile, fertility: (a) In the broad sense “fertile,” as defined by Webster, is synonymous with “fruitful” or “prolific.” In this context a soil may be well supplied with available plant nutrients and yet be unproductive (infertile) if other growth factors are limiting. For example, desert soils are generally considered to be fertile when irrigated. Thus, soil water availability is a factor of soil fertility. Also, selecting the proper cultivar for a given soil situation may be the difference between success and failure in a crop production enterprise. Accordingly, cultivar, or more specifically plant genetic potential may be an important factor of soil fertility and productivity.

(b) In the more narrow or usual sense soil fertility refers to the plant availability of the essential nutrient elements.

Fixed nutrient elements, fixation in soil: A commonly used term used that has several contrasting meanings.

(a) Symbiotic nitrogen fixation: the conversion of atmospheric di-nitrogen to plant-usable forms. A process performed by rhizobia bacteria located in root nodules in symbiotic association with plants. The most outstanding nitrogen-fixer is alfalfa. Some non-legume nitrogen fixation also occurs but the amount is relatively insignificant in production agriculture.

(b) Phosphorus fixation: In soils below pH 6.0 phosphorus forms insoluble compounds with iron and aluminum “fixing” phosphorus in forms not available for plant uptake. In soils with pH 6.0 and above some phosphorus may become adsorbed to clays as the PO_4 ion, some of which may be readily available and some only slowly available for plant uptake. Generally calcium dominates the chemistry of phosphorus in neutral to alkaline or calcareous soils. Fertilizer phosphorus rapidly changes to dicalcium phosphate, $CaHPO_4$ (DCP) in these soils, in which form the phosphorus is immobile and quite insoluble but nevertheless readily available for plant uptake. As DCP builds up in soil with continued fertilization the phosphorus tends to move into more complex calcium compounds such as octa-calcium phosphate and hydroxyapatite. In the short term complex phosphates are not available for plant uptake and as such this phosphorus is fixed.

(c) Potassium fixation: Potassium entering soil (fertilization or irrigation water) becomes adsorbed on the soil’s cation exchange complex and is essentially immobilized, except in very coarse textured soils. Exchangeable potassium is readily available for plant uptake.

Potassium from fertilizer or irrigation water taken into the interlayer positions of certain clay and silt size minerals (e.g. illite, muscovite). This potassium is trapped when the interlayers collapse, as upon drying. Fixed potassium may release slowly over time to exchangeable forms and as such become readily available for plant uptake.

(d) Ammonium fixation: The same process as potassium fixation since potassium and ammonium have the same ionic radius. Fixed ammonium may also be slowly released to exchangeable form. Fixed ammonium may originate as fertilizer ammonium or from organic matter decomposition.

Gypsum Requirement (GR): (a) The amount of gypsum, or gypsum equivalent as elemental sulfur or sulfuric acid, needed to reclaim sodic soils (land drainage and leaching with excess water are essential in connection with the GR for sodic soil reclamation).

(b) The calibrated sodic soil-GR test. The GR depends on soil cation exchange capacity, exchangeable sodium percentage, and the soil depth to be ameliorated (e.g. 12-18 inches).

Leaching of nutrients: The transport of soluble nutrient elements out of the plant root zone by percolating water. If water application (snow-melt/rain and irrigation) does not exceed the soil moisture storage capacity leaching will not occur.

Lime-induced chlorosis, lime-induced iron deficiency: The tendency for some plants to become iron deficient when grown on calcareous soils. The characteristic visual symptom is yellow leaves with green veins, or interveinal chlorosis. While lime in the soil is the predisposing factor, all limey or calcareous soils do not cause iron deficiency in plants. Factors that operate singly or in combination, contributing to plant iron deficiency on calcareous soils, include: bicarbonate in soil solution or irrigation water; soil salinity; excessive soil water; reduced soil aeration; high levels of available phosphates and nitrates; excessive zinc, manganese and copper; certain types of organic matter additions to soils; plant virus diseases; roots damaged by cultivation or plant parasites such as nematodes.

Lime, free lime: A common term for calcium carbonate.

Lime Requirement (LR): (a) The amount of pure ground agricultural limestone (calcium carbonate) needed to increase the pH of an acid soil to a desired level at a specified depth (e.g. 12 inches).

(b) A calibrated soil LR test. The LR depends on soil pH and exchangeable soil acidity.

Mineralization, nitrogen: Change of organic nitrogen compounds to ammonium-nitrogen through organic matter (plant and animal residues) decomposition.

Mnemonic: A memory assist device. Two mnemonics summarize the essential plant nutrient elements.

(a) CHOPKNS CaFe Mg: Say “Chuck Hopkins cafe (is) mighty good.”

(b) CuZn CoMn MoV BSiCl Na: Say “Cousin, come ‘n move (your) bicycle na(ow).”

Mobile Plant Nutrients in Soil: (a) Nitrate-nitrogen, sulfate-sulfur, and Cl.

(b) Nutrients that are completely soluble in the soil solution and are subject to transport by moving water. When there is no water movement the mobile nutrients do not move.

Nitrification: (a) The transformation of ammonium-nitrogen to nitrate-nitrogen by nitrifying bacteria. This process occurs most rapidly under conditions that favor plant growth, i.e. good soil moisture and good soil temperature.

(b) The two-step process wherein the bacterium Nitrosomonas oxidizes ammonium-nitrogen to nitrite followed by the bacterium Nitrobacter oxidizing nitrite to nitrate. Nitrite-nitrogen rarely accumulates in soil to any significant extent.

Non-mobile Plant Nutrients in Soil: (a) Ammonium-nitrogen and all other nutrients that are not included with the mobile elements.

(b) Nutrients that enter into different chemical and physico-chemical reactions in soil which render them only slightly soluble in the soil solution. The non-mobile nutrients are not susceptible to mass transport by moving water.

Nutrient-use efficiency: Usually expressed as a ratio of dry matter produced per unit of nutrient taken up by plants.

Plant Nutrients, Essential: (a) Chemical elements that are required by plants for growth and reproduction.

(b) Major nutrient elements: N, P, K.

(c) Secondary nutrient elements: Ca, Mg, S.

(d) Minor or micro nutrient elements: Cu, Zn, Co, Mn, Mo, V, B, Si, Cl, Na.

Plant Nutrient Sufficiency Concept: (a) Fertilizer recommendations based on expected crop yield responses as predicted by diagnostic soil tests or plant tissue analysis. Generally the sufficiency approach gives least cost of fertilizer per unit of crop production.

(b) Percent Sufficiency: The RY% associated with a given soil test level.

Relative Yield (RY), Percentage Yield: RY is the observed crop yield at any given soil fertility level divided by the yield that would be expected for a given crop type and variety where there is no plant nutrient deficiency stress or other growth limiting factor. Percentage yield is RY X 100.

Saline soil: (a) Soil with excess soluble salts. (b) Soil with ECe greater than 2.0 dS/m.

Saline-sodic soil: Soil with ECe greater than 2.0 dS/m and ESP greater than 15.

Sodium adsorption ratio, SAR: (a) Ratio of sodium to calcium plus magnesium in the soil solution or irrigation water.

(b) $(Na)/(Ca + Mg)^{1/2}$.

(c) Used for predicting exchangeable sodium percentage from the soil solution or irrigation water composition.

Sodic soil: (a) Soil with excess exchangeable sodium. (b) Soil with exchangeable sodium percentage (ESP) greater than 15.

Soil Test Calibration: (a) The process of establishing the association between crop yield and/or nutrient element composition and specific soil test levels from a correlated soil test procedure.

(b) Fixing the linkage between a correlated soil test and crop yield and plant nutrient composition.

(c) Establishing a reference system or basis for interpreting soil test results in terms of soil fertility and fertilizer requirements.

Soil Test Category: An interval of soil test index values that expresses relative plant nutrient availability in the soil. Soil tests are categorized commonly as low, medium, and high. The low soil test category would be associated with a high probability of crop response to fertilization.

Soil Test Correlation: (a) The process of establishing a significant statistical correlation or association between plant nutrient uptake and/or plant yield and the amount of plant nutrient extracted from soil by a given soil testing procedure.

(b) Establishing the reliability or confidence limits of a soil test procedure as a predictor of plant nutrient availability in soil.

Soil Test Critical Level: (a) The minimum concentration of extractable nutrient, as obtained by a specific soil test procedure, above which crop yield increase would normally not occur at either higher soil test levels or with added fertilizer.

(b) The optimum nutrient level in soil.

(c) The soil test level associated with lowest fertilizer cost per unit of crop production.

Soil Test Index: (a) The soil test value, expressed in parts per million (ppm) or milligrams per kilogram (mg/kg). The index sometimes is converted to pounds per acre (lbs/acre) but frequently this conversion is based on an arbitrary value for soil bulk density. Expressing the soil test index as lbs/acre does not affect the soil test interpretation.

(b) A relative measure of available plant nutrients in soil which is established by soil test correlation and calibration.

Soil Test Interpretation: Converting a soil test index into the kind and amount of fertilizer supplement needed to minimize or eliminate the risk of nutrient element deficiency in a crop. Soil test interpretation is based on the calibrated soil test and takes into consideration crop type and variety, climate, soil moisture regime, length of growing season, etc.

Soil Sample Core: An individual soil sample obtained with a soil sampling tube. The core is typically one inch in diameter. The depth of the soil core should extend through the plow layer—10 to 12 inches.

Soil Sampling: The process of collecting a small portion of soil from a field or land area for the purpose of making diagnostic tests on one or more soil fertility or soil chemistry parameters. Various sampling procedures are used, depending on the objective. Random and non-random soil sampling for the immobile nutrients and depth soil sampling for the mobile nutrients represent contrasting soil management objectives.

Random or Composite Soil Sample: (a) Twenty to 30 individual soil cores taken from the field or area in such a way as to represent the entire field or area. The soil cores are thoroughly mixed or composited (excess soil discarded).

(b) Soil sampling to estimate the **average** overall field condition for the parameter(s) being diagnosed.

(c) Soil sampling procedure recommended for generally uniform fields or field areas.

Non-random or Point Soil Sample: (a) Five or six soil cores taken from a circle less than three feet in diameter, the circle representing a point on the landscape. Usually point soil samples will be collected on a regular pattern (e.g. square grid).

(b) Soil sampling for mapping soil test index contours or isolines for highly heterogeneous fields or areas.

Modified Random Soil Sample: A procedure adapted to soil variability which is generated by band-applied or soil-injected non-mobile fertilizer elements (where the bands are not further mixed by tillage or plowing operations). Band-fertilized fields are generally uniform along lines parallel to the direction of the bands but are non-uniform along lines perpendicular to the bands. The modified random soil sample consists of three or more soil cores grouped at specific distances (one or more inches) on lines oriented perpendicular to the fertilizer bands. The exact location of the fertilizer band may or may not be known. The distance between the fertilizer bands should be known as this affects the spacing of the linear group of soil cores. The procedure is repeated at more or less random intervals in the field or sampling area. All soil core groups thus collected are mixed into one composite sample for the field or area.

Sampling for Mobile Nutrients: Soil cores are collected at one-foot depth increments to the third or fourth foot, or to a limiting layer whichever occurs first. Either the random or modified-random procedure is employed depending on whether the field is sprinkle or furrow irrigated. The cores are composited for each foot depth increment across the field or area. The soil test index for the mobile nutrients is the sum of extractable nutrients from all depth increments sampled.

Yield Goal: (a) Highest feasible crop yield based on climate, soil moisture regime, length of growing season, etc.

(b) Crop yield obtained in the absence of growth limiting factors such as weeds, plant diseases, insects, and in the presence of adequate soil fertility and moisture.

(c) Usually RY ≈ 1.0.

Yield Response Curve: (a) A line obtained by plotting yield levels against soil test levels <u>or</u> rates of applied nutrient. The standard curve, or expected yield curve, is curvilinear but the observed curve may be linear with positive, zero, or negative slope depending on the range of soil test levels or fertilizer rates being compared, and how these ranges or rates relate to the indigenous soil fertility levels.

(b) (1) **Standard response curve**: At low soil fertility levels of a single nutrient element crop yield will be low, e.g. 0.1 to 0.2 RY. As soil fertility increases with respect to the nutrient in question, the yield increases rapidly, with the rate of increase decreasing until yield approaches RY = 1.0.

(b) (2) The law of diminishing returns.

Volatile nitrogen compounds:

(a) Ammonia gas

(1) may be lost to the atmosphere as a result of improperly applied anhydrous ammonia (82-0-0) or aqua ammonia (20-0-0).

(2) may be lost to the atmosphere when ammonium-containing fertilizers (e.g. 21-0-0, 11-52-0), or fertilizers that quickly form ammonium compounds upon field application (46-0-0, 32-0-0) are applied to the soil or crop surface with no soil incorporation.

(3) may be lost to the atmosphere from NH_3 formed during organic matter decomposition under conditions of limited aeration, e.g. manure bunkers, anaerobic lagoon sewage systems, poorly aerated compost pile.

(b) formation of di-nitrogen (N_2) or nitrous oxide (NO) as a result of denitrification of nitrate-nitrogen in soils where aeration is restricted, e.g. water-logged soils.

Water pollution: (a) Ground water: Mostly relates to excess nitrate-nitrogen. USEPA defines excess nitrate as 10 mg/l (ppm) or more of nitrate-nitrogen. At this level nitrate in water is toxic to human and mammalian fetuses and newborn. The level of toxicity for juvenile and adult humans and mammals has not been established.

(b) Surface water: Nitrate-nitrogen higher than 10 mg/L; phosphate-phosphorus higher than 0.05 mg/L.

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