REFERENCE SUFFICIENCY RANGES FOR PLANT ANALYSIS IN THE SOUTHERN REGION OF THE UNITED STATES

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Editor
C. Ray Campbell

For a complete list of regional project members and contributing authors, see the List of Contributing Authors on the following pages.

Abstract

Plant analysis is a chemical evaluation of nutritional status. Concentrations of essential elements found in indicator tissue reflect the nutritional status of plants. Proper interpretation of plant analysis results is critical to effective use of this management tool. Guidelines for interpretation of analytical results have been developed over years based on research, surveys, and experience. Plant analysis continues to evolve as an important management tool as interpretive databases for various crops, stages of growth, and indicator tissue are developed.

Reliability of interpretive guidelines vary with extent of research conducted on various crops. This bulletin provides an overview of available interpretive information for most economically important crops. In some cases, sufficiency ranges are based on surveys and experience, while in other cases, there are significant research studies that can be cited. Interpretations of important ratios of essential elements are reported as available. DRIS interpretation norms are provided for crops as they are reported in the literature.

The overview of sufficiency ranges and other interpretive data identifies voids in the research base and additional work needed to improve plant analysis. This bulletin is designed to be a work in progress. The information provides a starting place from which improved sufficiency ranges can be developed. Revisions will be published as additional information becomes available.

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This bulletin from Regional Project SERA-IEG-6 included researchers from Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, Oklahoma, Puerto Rico, South Carolina, Tennessee, Texas, Virginia, and the Virgin Islands. It is being electronically published with the approval of the Directors of the Southern Agricultural Experiment Stations. Under the procedure of coooperative publications, it becomes in effect, a separate publication for each of the cooperating stations listed.

Reference Sufficiency Ranges for Plant Analysis in the Southern Region of the United States

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Preface

Plant analysis has evolved through years of research and experience to become an integral part of modern crop management. What began as a diagnostic tool to pinpoint nutrient deficiencies in crops exhibiting ymptoms has evolved as a primary tool in nutrient management. Significant economic returns are now realized from using plant analysis to guide efficient use of nutrients in growing healthy crops. As concerns over protecting the environment have gained importance, plant analysis now plays a critical role in guiding safe use of waste products to grow crops while ensuring optimum yields and minimizing risk to the environment. During the next decade, plant analysis will be an integral part of prescription-based, site-specific fertilizer technology.

This bulletin is a reference for information needed to properly interpret plant analysis results in the Southern United States. Students as well as field agronomists should find the bulletin a valued resource. After extensive reviews of pertinent research, sufficiency guidelines are provided for major crops. The brief outline format facilitates a quick review of the research base for interpreting analytical results. Where the research base is limited, guidelines are provided based on surveys and accumulated experience to provide a starting point for further refinement.

Special appreciation is expressed to all who contributed to the development of this bulletin and especially to members of the Southern Extension and Research Activities Group for their leadership and support of this activity. Appreciation is also expressed to Dr. George Kriz, Administrative Advisor, for his leadership and sincere support of the work group. Gratitude is also expressed to the Editorial Committee for their close review of the bulletin.

C. Ray Campbell, Editor

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Foundation for Practical Application of Plant Analysis

C. R. Campbell and C. O. Plank

Modern application of plant analysis has evolved from years of research and experience with individual crops. In most cases, research was not conducted for the sole purpose of identifying critical limits or sufficiency ranges. These values were extrapolated from research in which the primary purpose was to develop response curves for specific fertilizer application and soil test calibration. Equally important in developing this tool has been experience gained in interpreting plant results and observing response to fertilizer treatments. Extensive use of plant analysis in solving problems and managing healthy crops fosters confidence in this important management tool.

Scientific Basis for Plant Analysis

Plant analysis is the chemical evaluation of essential element concentrations in plant tissue. Essential elements include those that are required to complete the life cycle of a plant. The elements carbon (C), oxygen (O), and hydrogen (H) are supplied by the atmosphere and water and generally are not considered limiting. Agronomists place most emphases on essential elements supplied by soil or feeding solutions. Macronutrients — nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S) — are required in greatest quantities. Micronutrients — iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), boron (B), molybdenum (Mo) and chlorine (Cl) — are required in very small quantities. Toxicities of micronutrients are equally important and yield limiting as deficiencies. Plant analysis is also effective in diagnosing toxicities of micronutrients. Cobalt (Co) is also essential for symbiotic N2-fixing bacteria associated with legumes.

The interpretation of plant analysis results is based on the scientific principle that healthy plants contain predictable concentrations of essential elements. A number of researchers have offered schematics showing the relationship between maximum yield and concentrations of essential elements (Ulrich and Hills 1967; Brow 1970; Dow and Roberts 1982). Chapman (1967) added interpretation ranges to these relationships (Fig. 1). Schematics of crop response and nutrient concentrations are based on general scientific principles and do not account for differences due to plant part sampled, tissue age, stage of growth, variety, and other factors.

Campbell has further expanded this relationship to include excess and toxic levels of nutrients along with an interpretation index (Fig. 2). The additional ranges allow agronomists and

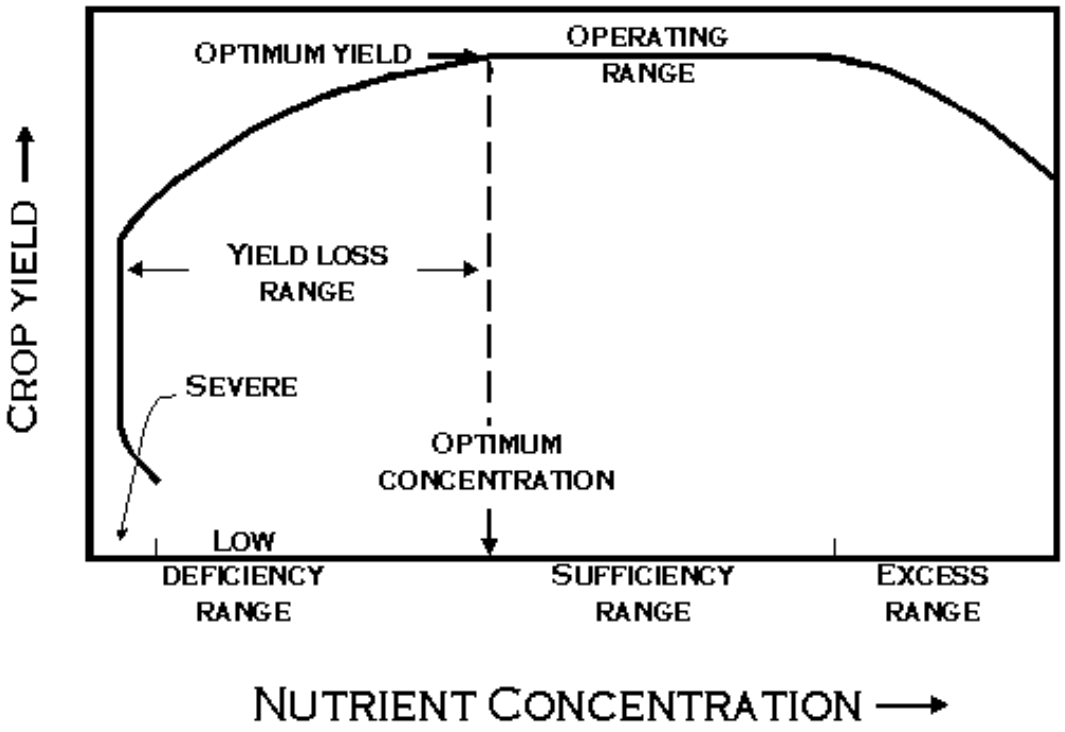

Figure 1. Schematic of yield and nutrient concentration (Chapman 1967).

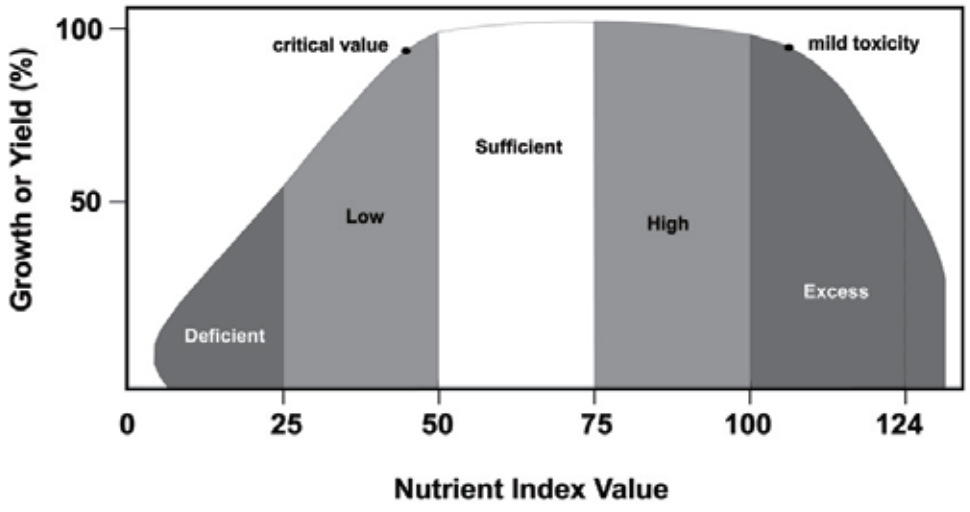

Figure 2. Schematic of yield or growth in response to increasing nutrient concentration and interpretation.

farmers to address excess and toxic levels of elements that may not only influence growth but increase risks to the environment. The interpretation index allows practitioners of plant analysis to become interpreters without extensive training and knowledge of sufficiency ranges for individual elements and crops.

Best indicator samples have been identified for most economically important crops. For crops receiving greater research support, indicator samples have been identified by stage of growth.

Plant analysis is generally associated with evaluation of leaf samples. In recent years, diagnostic tests and criteria have been developed for petioles of indicator leaf samples. These tests have generally served to fine tune the prediction of nitrogen status. Potassium and phosphorus have also been evaluated in petioles of important crops including cotton, grape, and strawberry. Nitrate nitrogen or petiole nitrate levels, as they are commonly referred to, indicate the current status of nitrogen by placing emphases on the mobile form of the element rather than the total that has been assimilated in the plant.

Interpretation Methods Used in Plant Analysis

There are three major methods of interpreting plant analysis results. They include the use of critical values, sufficiency ranges, and ratios. Most advisory services use sufficiency ranges for primary interpretation. Ratios and DRIS analysis are generally used as secondary and supportive evaluations.

- **Critical Values**
  Critical values have been defined as the concentration at which there is a 5–10% yield reduction. The use of critical values for practical interpretation has limited value. It is best suited to diagnose severe deficiencies and has little application in identifying hidden hunger. Symptoms are generally evident when nutrient concentrations decrease below the critical value. Critical values play an important role in establishing lower limits of sufficiency ranges.

- **Sufficiency Ranges**
  Sufficiency range interpretation offers significant advantages over the use of critical values. First, hidden hunger in the transitional zone can be identified since the beginning of the sufficiency range is clearly above the critical value. Sufficiency ranges also have upper limits, which provide some indication of the concentration at which the element may be in excess.

- **Ratios**
  In simplest form, the use of ratios in the interpretation of plant analysis results involves the evaluation of two essential elements together recognizing the effect of one element on the other. The most commonly used ratio is N:S (Nitrogen to Sulfur). The ideal N:S ratio for most crops is 10–15. As the N:S ratio approaches and exceeds 18, sulfur is limiting in relation to nitrogen. In reality, the plant does not assimilate nitrogen well because sulfur is limiting. The N:S ratio can be high when both nitrogen and sulfur concentrations are within the sufficiency ranges for these elements.

Other ratios commonly used to support sufficiency range interpretation include N:K and Fe:Mn. Interpretative data bases for these ratios are available for a limited number of crops. In general, the N:K ratio should be 1.2–2.2. The Fe:Mn ratio should be > 1.

The most complex application of ratios in the interpretation of plant analysis results is DRIS (Diagnostic Recommendation Integrated System). This technique, which was developed by Sumner and others (Beaufils 1973; Walworth and Sumner 1987), places emphasis on the relationship among essential elements rather than absolute concentrations. In short, DRIS ranks the essential elements in their order of limitedness. Theoretically, if the most limiting element is applied then the second element becomes most limiting. DRIS evaluation compares ratios of essential elements in the unknown sample to ratios of these elements in high yielding populations. Modification of DRIS interpretation in recent years to account for the magnitude of limitedness has significantly improved this diagnostic tool. Previously, elements were listed in a descending order of limitedness even when the most limiting element was not a significant problem. Normal ratios of high yielding populations are available for a number of economically important crops.

Sampling Procedures That Enhance Accuracy and Effectiveness

Careful sampling ensures the effectiveness of plant analysis as a diagnostic tool. For major crops, best indicator samples have been identified by stage of growth. For young seedlings, the entire plant is sampled 2.5 cm above the soil level. For larger plants, the most recent fully expanded or mature leaf is the best indicator of nutritional status. As some crops, including corn, approach flowering and fruiting, the best indicator of nutritional status is the leaf adjacent to the uppermost fruit (earleaf). When unfamiliar with sampling protocol for a specific crop, it is generally acceptable to select the most recent mature leaf as the best indicator of nutritional status.

A very small amount of plant material is required for a laboratory test (< 1 gram), but reliable samples must include enough leaves to adequately represent the affected area. For crops with small leaves (azalea), 25–30 leaves are required for a good sample. Larger leaved crops, including corn or tobacco, require significantly fewer leaves for an adequate sample.

- **Problem Solving**
  Diagnostic samples should be taken at the first indication there may be a problem. Generally, the earlier in the life cycle of the plant, the more reliable the sample. Samples taken prior to or at flowering are significantly more reliable than those taken in various stages of maturity. Comparative samples from good and bad plants allow a high degree of accuracy in identifying the most limiting element. Matching soil samples taken from the root zones of plants in each of the sample areas provide more complete information for problem solving.

  When symptoms on plants are zonal and the most recent mature leaf appears normal, it is helpful to sample leaves showing symptoms in addition to the most recent mature leaf. Knowledge of the accumulation of elements in certain plant parts also helps in selecting

additional samples that should be taken when problem solving. For example, bud samples provide additional confirmation of boron deficiency. Likewise, older plant leaves are important in diagnosing boron toxicity.

- **Monitoring**
  The evaluation of healthy crops in fine tuning nutrient application requires consistent sampling. Ideally, monitoring samples should be taken the same time of day and from the same area in the field each sampling date. If there is wide variability in the field, it is desirable to take the sample from a relatively small area. Results can then be evaluated for that specific area. All other areas in the field can be compared to the standard sampling area.

  Monitoring samples for intensively managed crops, including vegetables in greenhouses or fields, should be taken no less than every two weeks. Hydroponic crops should be sampled weekly. Less intensive field crops, including corn, should be sampled just prior to sidedressing and at flowering. Additional samples are taken as the need arises.

- **Petiole Sampling**
  Petioles for nitrate nitrogen determination should be removed from the most recent mature leaf or trifoliate. Ideally, petioles should be removed at sampling to avoid further transport of nitrates. Values generally are lower when petioles are removed at the laboratory. Petiole nitrate monitoring requires sampling no less than every two weeks during critical development periods, including flowering and fruit development.

- **Signs of Problems in Sampling**
  Chronic deficiencies or excesses of certain nutrients may indicate a sampling problem. Since calcium accumulates in lower leaves as cell walls develop, consistently low levels of this element when there are no symptoms may indicate the sample is being taken too near the growing point. Likewise, consistently high calcium and low potassium may indicate the sample is being taken too far down from the growing point. Comparative sampling of upper and lower leaves is helpful in identifying the best indicator sample.

- **Sampling Containers and Laboratory Transport**
  Samples should always be shipped to laboratories in a paper container. Plastic containers that promote respiration and decomposition by disease organisms should never be used. Most laboratories provide a proper sample container. Samples should be packed loosely so that drying can begin in transport. Samples can be dried in ovens at 80° C before shipping to save shipping expense but valuable response time is lost.

- **Environmental Conditions**
  Caution should be exercised when sampling crops damaged by disease, insects, drought and other factors. Comparative samples of good and bad plants help to neutralize the effects of some environmental factors. Environmental conditions should always be noted on the sample information form. Many times plant samples help to eliminate nutrition as a causal agent when other factors like disease or insect damage are suspected.

Applications of Plant Analysis

There are a number of important applications of plant analysis in research and production agriculture. Plant analysis is very effective in documenting response to nutrient applications. Leaf concentrations have, therefore, been correlated with yield and soil test values in calibration work. This data base provides the basis for problem solving and monitoring. Crop requirements have been well established using plant analysis. Nutrient uptake patterns, accumulation, and partitioning have been defined for many crops. Fertilizer efficiency, depending on placement and form, have also been effectively studied. Although plant analysis was first used in production agriculture to diagnose potential deficiencies, it now has developed into an important management tool in monitoring the nutritional status of healthy crops.

- **Problem Solving**
  Comparative samples from good and bad areas of production fields are very effective in pinpointing the limiting element(s). Matching soil samples from the root zones of plants in each of these areas provide additional evidence of the problem and help determine the best corrective action. Comparative plant and soil samples from areas responding differently also help to isolate or neutralize the overriding influence of confounding factors including moisture, insects, disease, and other sources of injury.

- **Monitoring**
  In recent years, plant analysis has become an integral part of managing healthy crops to enhance yield and quality while also maximizing efficiency and protecting the environment. As pressure has mounted to dispose of waste products on farm land, plant samples have provided a means for monitoring these sites to ensure maximum crop performance while avoiding excess application. Intensively managed vegetable crops with trickle irrigation and feeding require weekly sampling to guide nutrient management. With interest in precision agriculture and prescription fertilizer application, monitoring will become even more important in the future.

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Reference Sufficiency Ranges

— Field Crops —

Canola

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- **Critical Values**

Critical values at 90% relative yield										
N	P	K	Ca	Mg	S	Mn	Fe	B	Cu	Zn
3.60%	0.37%	2.15%	1.60%	0.10%	0.47%	20 ppm	82 ppm	20 ppm	4 ppm	28 ppm

- **Sampling Procedures**

Sample the uppermost recently mature leaf blades prior to flowering.

- **Sufficiency Ranges**

Macronutrients					
N	P	K	Ca	Mg	S
4.00–6.40%	0.42–0.69%	3.50–5.10%	2.10–3.00%	0.15–0.62%	0.65–0.90%

Micronutrients				
Fe	Mn	Zn	Cu	B
100+ ppm	30–250 ppm	33–49 ppm	5–25 ppm	25–54 ppm

Important Ratios
The calculated N:S ratio should not exceed 16–17 to 1.

- **DRIS Norms**

DRIS norms have not been reported at this time.

- **Remarks**

  The critical values given were calculated from the paper by Haneklaus and Schnug (1991) and based on 90% relative yield. The critical levels were established using the boundary line approach of Walworth and others (1986).

  The lower end of the sufficiency range was calculated at 100% relative yield using the data of Haneklaus and Schnug (1991) and the upper end of the range was established using the data reported by Reuter in Reuter and Robinson (1986).

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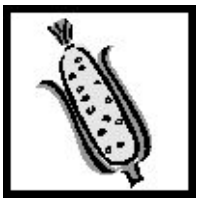

Corn

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- **Critical Values**

At Tasseling

Macronutrients					
N	P	K	Ca	Mg	S
3.0%	0.25%	2.0%	0.4%	0.25%	0.12%

Micronutrients					
Fe	Mn	Zn	Cu	B	Mo
15 ppm	15 ppm	15 ppm	5 ppm	10 ppm	0.1 ppm

- **Sampling Procedures**

Seedling (< 4 inches in height)
Whole plants should be collected by cutting 1 inch above the soil surface. Depending on size, 15 to 20 plants are adequate for a sample.

Early Growth (> 4 inches in height to tasseling)
The most recent mature leaf (MRML) is the best indicator sample. Depending on size, 15 to 20 leaves are adequate for a sample.

Tasseling / Bloom
The earleaf is the best indicator sample. This is the leaf adjacent to the uppermost developing ear. Fifteen to twenty leaves are adequate for a sample.

Maturity
The earleaf is the best indicator sample. This is the leaf adjacent to the uppermost developing ear. Fifteen to twenty leaves are adequate for a sample.

Notes for All Samples
Problem-solving samples can be taken at any time during the growing season. Comparative samples of "good" and "bad" plants or sample areas should be taken according to guidelines at the stage of growth. Monitoring samples should be taken at lay-by and tasseling (bloom). Samples should be shipped to the laboratory in paper containers.

- **Sufficiency Ranges**

Important Ratios
The N:S ratio should be between 10 and 15 at all growth stages for optimum yields. Sulfur is limiting at N:S ratios greater than or equal to 18.

Seedling (< 4 inches in height)

Macronutrients					
N	P	K	Ca	Mg	S
4.0–5.0%	0.4–0.6%	3.0–4.0%	0.3–0.8%	0.2–0.6%	0.18–0.5%

Micronutrients					
Fe	Mn	Zn	Cu	B	Mo
40–250 ppm	25–160 ppm	20–60 ppm	6–20 ppm	5–25 ppm	0.1–2.0 ppm

Early Growth (> 4 inches in height to tasseling)

Macronutrients					
N	P	K	Ca	Mg	S
3.0–4.0%	0.3–0.5%	2.0–3.0%	0.25–0.8%	0.15–0.6%	0.15–0.4%

Micronutrients					
Fe	Mn	Zn	Cu	B	Mo
30–250 ppm	20–150 ppm	20–70 ppm	5–25 ppm	5–25 ppm	0.1–2.0 ppm

Tasseling / Bloom

Macronutrients					
N	P	K	Ca	Mg	S
2.8–4.0%	0.25–0.5%	1.8–3.0%	0.25–0.8%	0.15–0.6%	0.15–0.6%

Micronutrients					
Fe	Mn	Zn	Cu	B	Mo
30–250 ppm	15–150 ppm	20–70 ppm	5–25 ppm	5–25 ppm	0.1–2.0 ppm

Maturity

Macronutrients					
N	P	K	Ca	Mg	S
2.5–3.5%	0.25–0.4%	1.6–2.5%	0.2–0.8%	0.12–0.5%	0.12–0.4%

Micronutrients					
Fe	Mn	Zn	Cu	B	Mo
30–250 ppm	15–150 ppm	16–50 ppm	4–20 ppm	3–20 ppm	0.1–2.0 ppm

- **DRIS Norms**

DRIS norms, based on a high-yielding subpopulation, have been provided by Elwali and others (1985).

Parameter	No.	Mean	SD
N/P ‡	1909	9.035	2.136
N/K	1908	1.463	0.426
P/K	1909	0.169	0.054
Ca/N	1553	0.160	0.057
Ca/P	1554	1.447	0.612
Ca/K	1553	0.237	0.122
Mg/N	1556	0.071	0.029
Mg/P	1557	0.639	0.330
Mg/K	1556	0.104	0.063
Mg/Ca	1554	0.465	0.182
S/N	788	0.084	0.019
S/P	788	0.703	0.225
S/K	787	0.114	0.029
Ca/S	785	1.978	0.893
S/Mg	788	1.195	0.395
Fe/10 N	1297	0.394	0.097
Fe/10 P	1298	3.588	1.177
Fe/10 K	1297	0.568	0.201
10 Ca/Fe	1298	0.410	0.189
10 Mg/Fe	1298	0.190	0.098
Fe/10 S	687	4.868	1.419
Mn/10 N	1459	0.151	0.087
Mn/10 P	1550	1.416	1.063
Mn/10 K	1549	0.218	0.140
Mn/10 Ca	1547	1.048	0.676
Mn/10 Mg	1550	2.485	1.780
10 S/Mn	782	0.648	0.351
Mn/Fe	1293	0.405	0.249

Parameter	No.	Mean	SD
10 N/Zn	1526	11.797	4.459
Zn/10 P	1527	0.883	0.420
Zn/10 K	1526	0.140	0.068
10 Ca/Zn	1524	1.919	1.087
10 Mg/Zn	1527	0.830	0.504
10 S/Zn	760	0.952	0.365
Fe/Zn	1268	4.464	1.837
Mn/Zn	1520	1.716	1.175
Cu/10 N	1401	0.031	0.013
Cu/10 P	1402	0.277	0.140
Cu/10 K	1401	0.045	0.022
10 Ca/Cu	1402	6.022	3.511
10 Mg/Cu	1402	2.768	1.935
Cu/10 S	664	0.375	0.211
Cu/Fe	1236	0.079	0.036
Cu/Mn	1395	0.260	0.174
Cu/Zn	1372	0.356	0.200
B/10 N	402	0.024	0.012
B/10 P	403	0.269	0.135
B/10 K	402	0.043	0.033
B/10 Ca	403	0.153	0.076
B/10 Mg	403	0.335	0.152
10 S/B	112	3.185	1.039
B/Fe	389	0.068	0.036
B/Mn	399	0.173	0.150
B/Zn	410	0.265	0.134
B/Cu	401	0.950	0.620

‡ Nutrient concentrations are expressed in g/kg for N, P, K, Ca, Mg, and S and in mg/kg for Fe, Mn, Zn, Cu, and B. The data presented are number of observations (No.), means, and standard deviations (SD) of DRIS reference parameters in the subpopulation yielding > 10.0 Mg of grain per hectare.

- **Remarks**

  Sufficiency ranges are based on available literature and experience interpreting plant samples.

  DRIS should be used to support sufficiency range interpretation and identify the most limiting element or order of impact on growth.

  Results are less reliable as corn approaches maturity. Comparative “good” and “bad” samples should be used when sampling during various stages of maturity.

- **References**

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Cotton

C. C. Mitchell and W. H. Baker

- **Sufficiency Levels and Critical Values**

  Sufficiency ranges for cotton have often been used based upon observations and ranges of analyses of plant tissue from healthy or normal cotton crops. For this reason, ranges may be broad and too inclusive. Therefore, use of a sufficiency range for cotton and the implied critical concentration (lower end of sufficiency range) of a nutrient for deficiencies or toxicities are not absolute.

- **Sampling Procedures**

  Petiole analysis
  Sample petioles from the most recently matured leaf on the vegetative stem at intervals beginning the week before first bloom and continuing for 7 or 8 weeks after bloom. Samples should be taken at weekly intervals and compared for the results to be meaningful. Interpret petiole analysis for NO3-N, total P, and total K only. Nitrate analysis is the most meaningful and the primary reason for sampling.

  Leaf blade at early bloom
  Sample the uppermost, mature cotton leaf blade on the vegetative stem. Discard the petiole. (Note: some research has included both leaf blade and petiole.] This is usually the 3rd to 5th leaf from the terminal. Sample during the period of one week before to one week after first bloom.

- **Sufficiency Ranges**

  Petioles
  The petioles from the most recently matured leaf on the vegetative stem at intervals beginnin "Arkansas Intepretation" may be more appropriate for loess and other fine-textured soils of the mid-South whereas the "Georgia Interpretation" was developed for the coarser textured soils of the Atlantic and Gulf Coastal Plain.

"Arkansas" Interpretation (Benton and others 1979)

Time of sampling	*Nitrate nitrogen (ppm)*	*Phosphorus (ppm)*
Week of bloom	10,000–35,000	>800
Bloom + 1 week	9,000–30,000	*
Bloom + 2 weeks	7,000–25,000	*
Bloom + 3 weeks	5,000–20,000	*
Bloom + 4 weeks	3,000–13,000	*
Bloom + 5 weeks	2,000–8,000	
Bloom + 6 weeks	1,000–5,000	
Bloom + 7 weeks	0–5,000	
Bloom + 8 weeks	0–5,000	

* A decrease in P concentration of more than 300 ppm from the previous week usually indicates moisture stress

"Georgia" Interpretation (Lutrick and others 1986; Plank, personal communication)

Time of sampling	*Nitrate nitrogen (ppm)*	*Phosphorus (ppm)*
Week before first bloom	7,000–13,000	>800
Week of bloom	4,500–12,500	>800
Bloom + 1 week	3,500–11,000	*
Bloom + 2 weeks	2,500–9,500	*
Bloom + 3 weeks	1,500–7,500	*
Bloom + 4 weeks	1,000–7,000	*
Bloom + 5 weeks	1,000–6,000	*
Bloom + 6 weeks	500–4,000	
Bloom + 7 weeks	500–4,000	
Bloom + 8 weeks	500–4,000	

* A decrease in P concentration of more than 300 ppm from the previous week usually indicates moisture stress

"California" Petiole K Interpretation (Bassett and MacKenzie 1976)

Time of sampling	*% Potassium (K)*
Week of first bloom	4.0–5.5
Bloom + 4 weeks	3.0–4.0
Bloom + 6 weeks	1.5–2.5
Bloom + 8 weeks	1.0–2.0

Youngest, Mature Leaf Blade
The following sufficiency ranges were compiled from several sources (Anderson and others 1971; Hodges and Hadden 1992; Mullins and Burmester 1990, 1992, 1993; Plank 1988; Reeves and Mullins 1993; Sabbe and Mackenzie 1973; Sabbe and others 1972).

Macronutrients (%)						
	N	P	K	Ca	Mg	S
early bloom	3.0–4.5	0.2–0.65	1.5–3.0	2.0–3.5	0.3–0.9	0.25–0.8
late bloom / maturity	3.0–4.5	0.15–0.6	0.75–2.5	2.0–4.0	0.3–0.9	0.3–0.9

Micronutrients (ppm)					
	Fe	Mn	Zn	Cu	B
early bloom	50–250	25–350	20–200	5–25	20–80
late bloom / maturity	50–300	10–400	50–300		15–200

- **References**

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Grain Sorghum

F. R. Cox and L. Unruh

- **Critical Values**

  There are critical values for both deficiency and toxicity that presumably set the levels at which below the former and above the latter there would be a yield depression. There are numerous observations on the critical level for deficiency where the break between that and sufficiency is usually fairly sharp, but very few on toxicity where there is a more gradual transition from adequate to excess. Both of these points are not exact, but vary with environmental conditions, varieties, etc. The critical level for deficiency sets the lower limit of the sufficiency range as will be used in the tables that follow, but it should be remembered that this value may not be exact; it can vary 25% or more with changes in extraneous conditions. In that there is little data for setting the critical level for toxicity, the sufficiency range is usually between the critical level for deficiency and a "high" value, which really has no particular meaning but may be around the maximum concentration ordinarily observed. Any known or estimated critical levels for toxicity will be covered in the "Remarks" section.

- **Sampling Procedures (Jones and others 1971)**

  Seedling Stage (< 4 cm tall)
  Sample whole aboveground portion of plant.

  Vegetative or Prior to Heading
  Sample entire, fully developed leaf below the whorl.

  Flowering or at Heading
  Sample second leaf from the top of the plant. This is the recommended sampling procedure when determining the nutrient status of the treatments, and yield.

  Grain Filling
  Sample second leaf from the top of the plant.

- **Sufficiency Ranges**

Seedling

Macronutrients					
N	P	K	Ca	Mg	S
3.9– %	0.2–0.5%	2.0– %	0.3–0.6%	0.25–0.6%	0.24+ %

Micronutrients				
Fe	Mn	Zn	Cu	B
75–400 ppm	13–200 ppm	12–150 ppm	4–20 ppm	3–30 ppm

Vegetative

Macronutrients					
N	P	K	Ca	Mg	S
3.0–4.0%	0.2–0.4%	2.0– %	0.3–0.6%	0.2–0.5%	

Micronutrients				
Fe	Mn	Zn	Cu	B
75–200 ppm	8–100 ppm	12–100 ppm	2–15 ppm	1–10 ppm

Flowering

Macronutrients					
N	P	K	Ca	Mg	S
2.5–4.0%	0.20–0.35%	1.4– %	0.3–0.6%	0.2–0.5%	

Micronutrients				
Fe	Mn	Zn	Cu	B
65–100 ppm	8–100 ppm	12–100 ppm	2–7 ppm	1–10 ppm

Grain Filling

Macronutrients					
N	P	K	Ca	Mg	S
2.4–4.0%	0.2–0.3%	1.4– %	0.3–0.6%	0.1–0.5%	

Micronutrients				
Fe	Mn	Zn	Cu	B
40–80 ppm	8–100 ppm	12–100 ppm	1–5 ppm	1–6 ppm

- **DRIS Norms**

Chemical analyses for the high-yielding subpopulation of sorghum crops and resulting norms selected for DRIS indices (Arogun 1978) §

Element / Parameter	Mean (g/kg)	CV (%)
N	30.3	17
P	3.4	15
K	13.1	11
Ca	4.4	20
Mg	2.4	24
P/N	0.112	19
N/K	2.355	23
P/K	0.259	21
N/Ca	7.200	30
P/Ca	0.759	31
K/Ca	3.080	24
Mn/N	0.079	26
P/Mg	1.518	45
Mg/K	0.183	26
Mg/Ca	0.553	30

§ Means and coefficients of variation in the subpopulation (135 of 907 crops) yielding >7.1 Mg of grain ha-1.

- **Remarks**

Some recorded toxicity levels at the seedling stage are: Mn >500 ppm, Zn >300 ppm, Na >30 ppm, and Cl >0.2%.

- **References**

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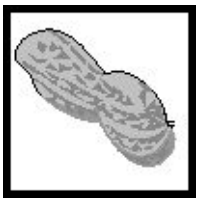

Peanut

C. R. Campbell and C. O. Plank

- **Critical Values**

  None reported.

- **Sampling Procedures**

  All Growth Stages
  Sample whole aboveground portion of plant.

  Problem-solving Samples
  Sample entire, fully developed leaf below the whorl.

  Monitoring Samples
  Sample second leaf from the top of the plant. This is the recommended sampling procedure when determining the nutrient status of the treatments, and yield.

- **Sufficiency Ranges**

All Growth Stages

Macronutrients					
N	P	K	Ca	Mg	S
3.5–4.5 %	0.2–0.5%	1.7–3.0%	0.5–2.0%	0.3–0.8%	0.2–0.35%

Micronutrients					
Fe	Mn	Zn	Cu	B	Mo
50–250 ppm	20–350 ppm	20–60 ppm	5–20 ppm	20–60 ppm	0.1–5.0 ppm

Important Ratios
Ca:Zn ratios less than 45–50 indicate zinc toxicity.

- **DRIS Norms**

  DRIS norms have not been reported for peanut.

- **Remarks**

  Sufficiency ranges are based on available literature and extensive experience interpreting plant samples.

  Zinc toxicity is a significant problem and occurs when zinc concentration approaches 200 ppm. Zinc toxicity is usually associated with low pH and extensive municipal or animal waste application.

- **References**

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Rice

Paul F. Bell and John L. Kovar

- **Critical Values**

  A critical value is defined as the concentration of an essential element at which there is a 5–10% reduction in growth or yield.

- **Sampling Procedures**

  Mid-tillering
  Leaf samples should be taken from the youngest, fully developed leaves. About twenty leaves should be collected. Critical values for sulfur (S) were developed from analysis of whole plant (above-ground) samples.

  Panicle Initiation
  Leaf samples should be taken from the youngest, fully developed leaves. These are the Y-leaves. About twenty leaves should be collected. The panicle should be at least 2 mm in length.

- **Sufficiency Ranges**

Mid-tillering

Macronutrients					
N	P	K	Ca	Mg	S
2.8–3.6%	0.14–0.27%	1.5–2.7%	0.16–0.39%	0.12–0.21%	0.17+ %

Micronutrients				
Fe	Mn	Zn	Cu	B
90–190 ppm	40–740 ppm	20–160 ppm	6–25 ppm	5–25 ppm

Important Ratios
For adequate N and S, the N/S ratio should be < 10, with N > 1.6% and S > 0.15%.

Panicle Initiation

Macronutrients					
N	P	K	Ca	Mg	S
3.0–3.4%	0.18–0.29%	1.5–2.7%	0.19–0.39%	0.15–0.39%	0.15+ %

Micronutrients				
Fe	Mn	Zn	Cu	B
70–190 ppm	40–800 ppm	20–160 ppm	6–25 ppm	6–15 ppm

Important Ratios
For adequate N and S, the N/S ratio should be < 10, with N > 1.6% and S > 0.15%.

- **DRIS Norms**

Nutrient Ratio	Mean	CV (%)
N/P	9.8174	13.2
N/K	1.19847	32.5
N/Ca	6.7736	33.5
N/S	17.2864	53.3
N/Mg	19.7246	18.8
10 N/Cu	6.3309	15.0
P/K	0.12042	23.2
P/Ca	0.71713	28.2
P/Mg	2.12043	17.8
P/S	1.80124	56.4
10 P/Cu	6.811	13.8

Nutrient Ratio	Mean	CV (%)
10 P/Fe	0.6195	80.7
K/Mg	20.0648	21.7
K/S	16.0629	66.5
K/Cu	6.4452	18.7
K/Fe	0.6012	91.7
Ca/S	3.00039	82.8
10 Ca/Fe	0.873	59.2
Mg/S	0.94908	60.5
Mg/Cu	0.3302	20.7
10 Mg/Fe	0.298	85.6
Fe/Mn	0.15069	35.1

- **Remarks**

The information presented in the section is based on the published research cited in the reference list. DRIS norms were developed from a database of eastern Arkansas rice tissue analyses and yields (Counce and Wells 1986). A reliable sufficiency range for S diagnosis was not available. Rice varieties differ in both their requirement for N and leaf N critical values (Brandon and Wells 1986).

In addition to sufficiency ranges, nutrient and other ion toxicities also have been reported. Aluminum (Al) toxicity is likely if whole plant Al is >300 ppm (Tanaka and Yoshida 1970). Research (Baker and others 1976) has shown that rice is sensitive to soil arsenic (As). The critical level in shoots ranges from 20–100 ppm. In roots, the critical level is 1000 ppm.

Paddy rice is more susceptible to As toxicity due to the presence of more readily absorbed arsenite (As III). In some cases, ferrous iron (Fe II) may also pose a toxicity problem. Toxicity is possible in rice if chloride (Cl) reaches >10,000 ppm and nitrate >1600 ppm (Helms 1994). Leaf concentrations of manganese (Mn) in the range 4000–8000 ppm are toxic to rice (Adriano 1986). Molybdenum (Mo) toxicity is very rare, but an approximate value would be >100 ppm for leaves from grass species such as rice (Jones 1991). In Louisiana, sodic injury can occur when leaf Na in pre-boot-stage rice exceeds 2000 ppm. Zinc (Zn) toxicity was reported by Chino (1981) when rice shoots contained 100–300 ppm and rice roots contained 500–1000 ppm.

With respect to deficiencies, rice and other cereal grasses are not sensitive to low Mo. For whole plants at boot stage, 0.09–0.18 ppm are considered sufficient. Deficiency of silicon (Si) may occur when Si is <5% in straw sampled at maturity (Tanaka and Yoshida 1970).

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Small Grain —Barley, Oats, Rye, Wheat

C. O. Plank and S. J. Donohue

- **Critical Values**

The values given here are best estimates based on extensive experience. They apply to all samples and growth stages.

Macronutrients					
N	P	K	Ca	Mg	S
3.0%	0.15%	2.0%	0.15%	0.10%	0.10%

Micronutrients					
Fe	Mn	Zn	Cu	B	Mo
25 ppm	15 ppm	15 ppm	3 ppm	1 ppm	0.05 ppm

- **Sampling Procedures**

Seedling to Tillering
Whole plants should be collected by cutting 1 inch above the soil surface. Samples can be taken by grasping existing growth at a given site and cutting at the recommended level above the soil with a small knife. Dead leaves should be avoided as much as possible. After collecting subsamples from several locations in a field, clippings should be combined for a representative sample.

Jointing to Flag Leaf Emergence
Break the top two to three leaves (growing point) from representative plants in several locations of the field. Combine for a representative sample. Stems should be included.

Flag Leaf to Maturity
Flag leaves from representative plants in the field should be collected randomly. A minimum of 15 to 20 leaves should be collected from a given field or area.

Problem-solving Samples
These samples can be taken at any time during the growing season. Comparative samples from "good" and "bad" areas should be taken according to guidelines at the stage of growth.

Monitoring Samples
These samples should be taken at full tillering (Zadoks 30; Feekes 5) to predict nutritional status and additional nitrogen required to optimize yield. Final monitoring samples should be taken at flag leaf emergence (Zadoks 45; Feekes 10) to evaluate nutrient program.

- **Sufficiency Ranges**

Important Ratios
The N:S ratio should be between 10 and 15 for optimum yields. N:S ratios greater than or equal to 18 indicate that sulfur is limiting in relation to nitrogen.

Seedling to Tillering; Jointing to Flag Leaf Emergence

Macronutrients					
N	P	K	Ca	Mg	S
4.0–5.0%	0.2–0.5%	2.5–5.0%	0.2–1.0%	0.14–1.0%	0.15–0.65%

Micronutrients					
Fe	Mn	Zn	Cu	B	Mo
30–200 ppm	20–150 ppm	18–70 ppm	4.5–15 ppm	1.5–4 ppm	0.1–2.0 ppm

Flag Leaf Maturity

Macronutrients					
N	P	K	Ca	Mg	S
4.0–5.0%	0.2–0.5%	2.0–4.0%	0.2–1.0%	0.14–1.0%	0.15–0.65%

Micronutrients					
Fe	Mn	Zn	Cu	B	Mo
30–200 ppm	20–150 ppm	18–70 ppm	4.5–15 ppm	1.5–4.0 ppm	0.1–2.0 ppm

- **DRIS Norms**

DRIS norms for small grains have not been reported.

- **Remarks**

  Sufficiency ranges are based on available literature and experience interpreting plant samples.

  Results are less reliable as crop approaches maturity. Comparative “good” and “bad” samples should be used when sampling at various stages of maturity.

  Sufficiency ranges can generally be applied for wheat, oats, rye, and barley although most of the research has been done on wheat.

- **References**

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Soybean

W. E. Sabbe, G. M. Lessman and P. F. Bell

- **Critical Values**

  Presently, critical values for the R2 stage are 0.30% P, 1.50% K, 17 ppm Mn and 21 ppm Zn. These values are included in a manuscript submitted for publication (personal communication P. Bell).

- **Sampling Procedures**

  Early Growth and Flowering
  The most recently mature leaf blades are collected for subsequent analysis.

- **Sufficiency Ranges**

Early Growth

Macronutrients					
N	P	K	Ca	Mg	S
3.5–5.5%	0.30–0.60%	1.7–2.5%	1.1–2.2%	0.03–0.60%	

Flowering

Macronutrients					
N	P	K	Ca	Mg	S
3.25–5.0%	0.30–0.60%	1.5–2.25%	0.8–1.4%	0.25–0.70%	0.25–0.60%

Micronutrients				
Fe	Mn	Zn	Cu	B
25–300 ppm	17–100 ppm	21–80 ppm	4–30 ppm	20–60 ppm

- **DRIS Norms**

  DRIS norms and indices are currently under study.

- **Remarks**

  The sufficiency ranges and critical levels were the result of the chosen references. With three exceptions (Anderson and others; Dombeck and Sabbe; Sabbe and others unpublished data), all references were research based with most being fertilizer amendment studies. No data on sufficiency ranges for seedling data are presented as that aspect is not well researched.

- **References**

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Sugarcane

G. J. Gascho

- **Critical Values**

Critical values in the literature vary with plant part sampled, plant age, variety and with the time of the day sampled. For the top-visible dewlap leaf during the "Grand Growth" period, the following critical levels have been published (Evans 1956; Gascho and Elwali 1978).

Macronutrients					
N	P	K	Ca	Mg	S
1.80%	0.19%	0.90%	0.20%	0.12%	

Micronutrients				
Fe	Mn	Zn	Cu	B
5 ppm	25 ppm	15 ppm	3 ppm	4 ppm

- **Sampling Procedures**

Several systems have evolved in tissue sampling of sugarcane. Much is sampled just prior to the "Grand Growth" period. However, that period is often difficult to determine as the harvest varies from 9 months to up to 4 years from planting or ratooning. Therefore, various sampling practices are conducted in different areas.

A common practice is to use the leaf-blade lamina (midrib removed). The leaf selected is often the third (3) from the top of the plant. Some agronomists identify this leaf-blade by finding the uppermost leaf which has a distinct collar on the stalk termed "top-visible dewlap leaf."

A system of "crop logging" developed in Hawaii (Clements 1980) utilizes the leaf sheaths from the 3rd to the 6th leaves from the top of the plant for P, K, Ca and Mg and the lamina of the leaf blades from the same leaves for N. Another sampling procedure utilizes stalk internodes number 8 to 10 from the base of the stalk (Hawaiian Sugar Planters Association).

Care must be exercised to standardize the time of day that samples are collected. Thein and Gascho (1980) found that concentrations of N, P, Ca and Mg in leaf samples decreased significantly during the day (Table 1). Early morning sampling is preferred (Clements 1980).

Table 1. Mean tissue nutrient concentrations in sugarcane TVD leaf blade laminas as a function of time of day § †

Time of Day	Plant Tissue Nutrients				
	%N	%P	%K	%Ca	%Mg
8 a.m.	2.03	0.24	1.41	0.28	0.20
11 a.m.	1.97	0.25	1.40	0.27	0.19
2 p.m.	1.88	0.23	1.38	0.26	0.18
5 p.m.	1.80	0.22	1.40	0.25	0.18
Significance ‡	**	**	NS	**	**

§ Source: Thein and Gascho (1980).
† TVD = top visible dewlap.
‡ The 1% level of significance of linear regression is indicated by **. NS = not significant.

- **Sufficiency Ranges**

Top Visible Dewlap (approx. 3rd leaf blade lamina)

Macronutrients					
N	P	K	Ca	Mg	S
2.00–2.60%	0.22–0.30%	1.00–1.60%	0.20–0.45%	0.15–0.32%	

Micronutrients				
Fe	Mn	Zn	Cu	B
50–105 ppm	12–100 ppm	16–32 ppm	4–8 ppm	10–50 ppm

Hawaiian Systems

Macronutrients			
	N	P	K
Crop logging, leaf blades 3–6, lamina	1.85%		
Crop logging, leaf sheaths 3–6		0.08%	2.25%
HSPA, internodes 8–10	0.24–0.35%	0.03–0.04%	0.7–1.0%

- **DRIS Norms**

DRIS norms have been developed in several areas. The crop has been shown to respond well to “in crop” corrections made following DRIS analysis. The norms developed in Florida on muck soils are quite similar to those developed in South Africa on mineral soils (Table 2).

Table 2. Sugarcane TVD leaf blade lamina norms from Florida and South Africa § †

Nutrient Ratio	Florida	South Africa
N/P	8.706	8.197
N/K	1.526	1.511
K/P	5.633	5.464
Ca/N	0.151	0.128
Ca/P	1.314	1.146
Ca/K	0.222	0.205
Ca/Mg	1.373	1.158
Mn/N	0.113	0.116
Mn/P	0.984	0.962
Mn/K	0.163	0.186

§ Data from Beaufils and Sumner (1976) and Elwali and Gascho (1983).
† TVD = top visible dewlap.

- **Remarks**

The critical values and sufficiency ranges presented in this paper are not absolute for all sugarcane. They are heavily based on the author's studies on the muck soils in Everglades Agricultural Area of South Florida and on the top-visible-dewlap leaf blade lamina collected in the early morning. Muck soils enhance N uptake. As a result, N concentrations in varieties grown in Florida are generally higher than those produced on mineral soils in other areas.

- **References**

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Tobacco, Burley

C. R. Campbell

- **Critical Values**

  Limited published information:

Magnesium (Mg)	0.2% (whole plant)
Molybdenum (Mo)	0.38% (whole plant), 0.42% (cured leaves)

- **Sampling Procedures**

  The most recent mature or fully expanded leaf (MRML) is the best indicator of nutritional status. This is the first leaf back from the growing point that is fully developed. Cell division is complete, but cell expansion will continue. The MRML is generally the 4th or 5th leaf back from the bud.

  A total of 6 to 10 leaves are required for analysis, depending on size. As leaves become larger, the lamina from one side of the midrib can be removed from several leaves for a representative sample. In either case, midribs should be removed before grinding.

  Diagnostic samples should be taken at first signs of a problem. Comparative samples from "good" and "bad" plants should be taken along with matching soil samples from the root zones. If symptoms are zonal on the plant, it is helpful to take the MRML sample and a separate sample of leaves showing the symptoms.

  To monitor nutritional status, samples should be taken at lay-by and/or flowering.

  After topping, the 2nd or 3rd leaf from the top of the stalk is the best indicator sample of nutritional status.

  Samples are shipped to the laboratory in paper containers.

- **Sufficiency Ranges**

Most recent mature leaf

Macronutrients (%)						
Growth Stage	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)
Seedling	4.0–6.0	0.2–0.5	3.0–4.0	0.6–1.5	0.2–0.6	0.15–0.6
Early growth	4.0–5.0	0.2–0.5	2.5–3.5	0.75–1.5	0.2–0.6	0.15–0.6
Flowering	3.5–4.5	0.2–0.5	2.5–3.5	0.75–1.5	0.2–0.6	0.15–0.6
Maturity	3.0–4.0	0.2–0.5	2.5–3.5	0.75–1.5	0.2–0.6	0.15–0.6

Micronutrients (ppm)						
Growth Stage	Fe	Mn	Zn	Cu	B	Mo
All	50–300	20–250	20–60	5–10	18–75	0.2–1.0

Excessive or Toxic Nutrient Levels
Manganese toxicity can occur at approximately 1000 ppm but is temperature dependent. Toxicity occurs most often at low temperatures and is generally associated with low pH.

Important Ratios
The N:S ratio should be less than 18 at all growth stages.

- **DRIS Norms**

DRIS norms for cured burley have been developed by Evanylo and others (1988).

- **Remarks**

Sufficiency ranges were established based on available references and experience interpreting analytical results.

- **References**

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Tobacco, Flue-cured

C. R. Campbell

- **Critical Values**

  Limited published information:

Boron (B)	15–16 (bud leaves)
Manganese (Mn)	18–25 (most recent mature leaves)
Magnesium (Mg)	0.2% (most recent mature leaves)

- **Sampling Procedures**

  The most recent mature or fully expanded leaf (MRML) is the best indicator of nutritional status. This is the first leaf back from the growing point that is fully developed. Cell division is complete, but cell expansion continues until maturity. The MRML is generally the 4th or 5th leaf back from the bud.

  To evaluate nitrogen status and gain information on ripeness for harvest, samples should be taken from the upper, middle or lower stalk positions.

  Depending on size, a total of 6 to 10 leaves are required for analysis. Laboratory work can be completed on only one leaf, but it must be representative of the area sampled. As leaves become larger, lamina from one side of the midrib can be removed from several leaves for a representative sample. Midribs should always be removed before grinding.

  Diagnostic samples should be taken at first signs of a problem. Comparative samples from "good" and "bad" plants should be taken along with soil from the root zones.

  To monitor nutritional status and fine tune fertilizer programs, samples should be taken at lay-by and topping. As the plant approaches maturity, samples of lower, middle, and upper stalk positions can be taken to further evaluate nitrogen status and assess ripeness for harvest.

  Samples are shipped to the laboratory in paper containers.

- **Sufficiency Ranges**

		Macronutrients (%)					
Growth Stage	Tissue	N	P	K	Ca	Mg	S
Seedling	MRML	4.0–6.0	0.2–0.5	3.0–4.0	0.6–1.5	0.2–0.6	0.15–0.6
Early growth	MRML	4.0–5.0	0.2–0.5	2.5–3.5	0.75–1.5	0.2–0.6	0.15–0.6
Flowering	MRML	3.5–4.5	0.2–0.5	2.5–3.5	0.75–1.5	0.2–0.6	0.15–0.6
Maturity	MRML	2.25–3.0	0.17–0.5	1.6–3.0	0.75–1.5	0.2–0.6	0.15–0.6
Harvest	Upper leaf	2.0–2.25	0.14–0.3	1.5–2.5	0.75–1.5	0.2–0.6	0.15–0.4
Harvest	Middle leaf	1.6–2.0	0.13–0.3	1.5–2.5	1.0–2.0	0.2–0.6	0.15–0.4
Harvest	Lower leaf	1.3–1.75	0.12–0.3	1.3–2.5	1.0–2.5	0.18–0.75	0.15–0.4

		Micronutrients (ppm)				
Growth Stage	Tissue	Fe	Mn	Zn	Cu	B
Seedling	MRML	50–300	20–250	20–60	5–10	18–75
Early growth	MRML	50–300	20–250	20–60	5–10	18–75
Flowering	MRML	50–300	20–250	20–60	5–10	18–75
Maturity	MRML	50–300	20–250	20–60	5–10	18–75
Harvest	Upper leaf	40–200	20–350	18–60	5–10	18–30
Harvest	Middle leaf	40–200	20–350	18–60	4–10	18–30
Harvest	Lower leaf	40–200	18–350	18–60	3–10	15–30

Excessive or Toxic Nutrient Levels
Manganese toxicity can occur as concentration approaches 1000 ppm and is usually associated with low pH.

Important Ratios
The N:S ratio should be less than 18 at all growth stages.

- **DRIS Norms**

  DRIS norms have not been reported for cured flue-cured tobacco.

- **Remarks**

  Sufficiency ranges were established based on available references, research, crop monitoring, and experience interpreting analytical results.

- **References**

  Mills HA, Jones JB Jr. 1996. Plant analysis handbook II: a practical sampling, preparation, analysis, and interpretation guide. Athens (GA): Micro-Macro Publishing.

  Miner GS, Tucker MR. 1990. Plant analysis as an aid in fertilizing tobacco. In: Westerman RL, editor. Soil testing and plant analysis. 3rd ed. Madison (WI): Soil Science Society of America, Inc [SSSA]. p 645–57. (SSSA book series; 3).

Reference Sufficiency Ranges

— Forage and Hay Crops —

Alfalfa

C. O. Plank

- **Critical Values**

  None established.

- **Sampling Procedures**

  Sample the top 4 to 6 inches of the plant prior to or at 1/10 bloom stage.

- **Sufficiency Ranges**

Macronutrients					
N	P	K	Ca	Mg	S
3.00–5.00%	0.25–0.70%	2.00–3.50%	0.80–3.00%	0.25–1.00%	0.25–0.50%

Micronutrients				
Fe	Mn	Zn	Cu	B
30–250 ppm	25–100 ppm	20–70 ppm	4–30 ppm	20–80 ppm

Important Ratios
Maintain the N:S ratio between 10:1 and 15:1 for ruminant nutrition.

- **DRIS Norms**

  DRIS norms from populations yielding 3.5 megagrams (metric tons) per hectare per cutting are given below (Walworth and others 1986). These norms were developed from alfalfa grown in Georgia using the harvested aerial portion of the plants at approximately 1/10th bloom.

Expression	*Norms §*	*CV (%)*
(N/DM) × 100	2.952	7.2
N/P	12.450	19.1
N/K	1.499	18.2
N/Ca	2.534	11.6

Expression	*Norms §*	*CV (%)*
(Ca/DM) × 100	1.186	13.1
Mg/Ca	0.1365	23.1
Zn/Ca	18.27	24.7
Cu/Ca	7.097	19.3

§ Concentrations of N, P, K, Ca and Mg are expressed in dekagrams per kilogram and those of Zn, Cu and B in milligrams per kilogram.

Expression	*Norms §*	*CV (%)*	*Expression*	*Norms §*	*CV (%)*
Mg/N	0.0550	22.6	B/Ca	34.06	20.7
N/Zn	0.1504	24.5	K/Zn	0.1026	27.0
N/Cu	0.4583	26.1	Cu/K	3.431	15.5
B/N	15.09	19.6	B/K	23.13	33.7
(P/DM) × 100	0.2435	15.5	(Mg/DM) × 100	0.1609	19.2
P/K	0.1240	23.8	Zn/Mg	132.60	31.5
P/Ca	0.2163	23.8	Cu/Mg	43.96	28.0
Mg/P	0.6722	21.3	B/Mg	279.50	23.7
Zn/P	90.45	55.6	(Zn/DM) × 106	21.44	49.8
Cu/P	28.68	27.8	Cu/Zn	0.3462	29.0
B/P	185.40	26.2	Zn/B	0.4967	47.4
(K/DM) × 100	2.034	19.1	(Cu/DM) × 106	6.886	26.6
K/Ca	1.938	19.3	B/Cu	7.048	37.7
Mg/K	0.0831	31.9	(B/DM) × 106	44.18	17.9

§ Concentrations of N, P, K, Ca and Mg are expressed in dekagrams per kilogram and those of Zn, Cu and B in milligrams per kilogram.

- **Remarks**

  DRIS norms developed for some crops may vary somewhat from one geographical region to another. This is illustrated by the work of Walworth and others (1986) who showed that norms developed for alfalfa in the Midwest (Erickson and others 1982) differed significantly from those developed in Georgia. Soils in the two regions differ appreciably and are believed to account for the wide differences in Mg and B norms between the regions. Consequently, when such factors are known, they should be taken into account when selecting both DRIS norms and sufficiency ranges for interpretative purposes.

- **References**

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Coastal Bermuda

C. O. Plank and C. R. Campbell

- **Critical Values**

  See remarks.

- **Sampling Procedures**

  Sample the upper half of the plant prior to seed head formation.

- **Sufficiency Ranges**

Macronutrients					
N	P	K	Ca	Mg	S
2.00–2.60%	0.20–0.40%	1.50–2.30%	0.25–0.50%	0.10–0.25%	0.15–0.25%

Micronutrients				
Fe	Mn	Zn	Cu	B
50–200 ppm	20–300 ppm	15–70 ppm	4–20 ppm	5–15 ppm

Important Ratios
N:S = 12 to 16:1 for medium- to high-intensity forage production.

- **DRIS Norms**

  DRIS norms are given in Kelling and Matocha (1990) and Tarpley and others (1985). Tarpley's data are as follows.

Nutrient Ratio	*Mean*	*CV (%)*
N/P	10.11	11.92
N/S	11.85	16.59
N/Ca	7.61	11.60
N/Mg	14.94	14.75
K/N	0.71	17.74
P/K	0.14	21.87
S/P	0.87	17.57
P/Ca	0.76	9.65

Nutrient Ratio	*Mean*	*CV (%)*
P/Mg	1.48	11.37
S/K	0.12	21.82
K/Ca	5.37	17.54
K/Mg	10.70	25.10
Ca/Mg	1.97	11.92
S/Ca	0.65	15.02
S/Mg	1.29	18.78

- **Remarks**

  The lower limit of the sufficiency ranges reported above are similar to some reported critical values (~90% relative yield). Using 90% relative yield as the lower limit of the sufficiency range for Coastal bermuda is most practical for interpreting plant analysis data. This is due to the rather flat slope of the response curves for most fertilizer elements. Thus, setting the lower limit of the sufficiency range at 100% relative yield would not be economically or environmentally sound. This is particularly true with nitrogen, phosphorus and potassium.

- **References**

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Tall Fescue

G. M. Lessman and W. O. Thom

- **Critical Values**

N	P	K
2.5%	0.2%	2.2%

- **Sampling Procedures**

Samples should be collected every five to six weeks during growing season before flowering. Collect above ground portion of 20 plants.

- **Sufficiency Ranges**

Actively Growing Plants		
Macronutrients		
N	P	K
2.8–3.8%	0.26–0.40%	2.5–3.5%

- **DRIS Norms**

No DRIS norms have been established.

- **Remarks**

Forage grasses that contain less than 0.2% Mg are inadequate for grazing and may cause grass tetany. Fescue containing less than 0.2% Mg will still produce high dry matter yields.

- **References**

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Orchardgrass and Smooth Bromegrass

S. J. Donohue and H. J. Savoy, Jr.

- **Critical Values**

  None established.

- **Sampling Procedures**

  Samples should be collected five weeks after cutting (or five weeks after growth begins in the spring) and before plants flower. Collect above-ground portion of 20 plants.

- **Sufficiency Ranges**

Macronutrients					
N	P	K	Ca	Mg	S
2.50–3.50%	0.25–0.35%	2.50–3.50%	0.30–0.50%	0.15–0.30%	0.20–0.30%

Micronutrients				
Fe	Mn	Zn	Cu	B
50–250 ppm	50–200 ppm	20–50 ppm	3–10 ppm	5–20 ppm

Important Ratios
Maintain the N:S ratio between 10:1 and 15:1 for ruminant nutrition.

- **DRIS Norms**

  No DRIS norms have been established.

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Reference Sufficiency Ranges

— Vegetable Crops —

Bell Pepper

E. A. Hanlon and G. J. Hochmuth

- **Critical Values**

  None established.

- **Sampling Procedures**

  The most recent mature leaf should be sampled. Considerable work in bell pepper has shown that nutrient concentration changes rapidly with stage of growth. For possible correction of nutrient deficiencies, leaves may be sampled just prior to blossoming or at first blossom opening. For next season planning of fertilization needs, additional samples from the most recently mature leaves at early fruit set and early harvest may be useful. Concentrations above the sufficient range for nutrients that are immobile in the soil are indicative of high soil fertility. Fertilization with these nutrients in subsequent seasons should be reduced or eliminated.

- **Sufficiency Ranges**

Prior to Blossoming

Macronutrients					
N	P	K	Ca	Mg	S
4.0–5.0 %	0.3–0.5%	5.0–6.0 %	0.9–1.5%	0.35–0.60%	0.3–0.6%

Micronutrients				
Fe	Mn	Zn	Cu	B
20–150 ppm	30–100 ppm	25–80 ppm	5–10 ppm	20–50 ppm

First Blossom Opening

Macronutrients					
N	P	K	Ca	Mg	S
3.0–5.0%	0.3–0.5%	2.5–5.0%	0.9–1.5%	0.3–0.5%	0.3–0.6%

Micronutrients				
Fe	Mn	Zn	Cu	B
30–150 ppm	30–100 ppm	25–80 ppm	5–10 ppm	20–50 ppm

Early Fruit Set

Macronutrients					
N	P	K	Ca	Mg	S
2.9–4.0%	0.25–0.40%	2.5–4.0 %	1.0–1.5%	0.3–0.4%	0.3–0.4%

Micronutrients				
Fe	Mn	Zn	Cu	B
30–150 ppm	30–100 ppm	25–80 ppm	5–10 ppm	20–50 ppm

Early Harvest

Macronutrients					
N	P	K	Ca	Mg	S
2.5–3.0%	0.2–0.4%	2.0–3.0 %	1.0–1.5%	0.3–0.4%	0.3–0.4%

Micronutrients				
Fe	Mn	Zn	Cu	B
30–150 ppm	30–100 ppm	25–80 ppm	5–10 ppm	20–50 ppm

- **DRIS Norms**

  DRIS norms have not been established for bell pepper.

- **Remarks**

  Tabular data agree with the experimental evidence reported in articles listed in the References section. However, some values are lower than those reported by Jones et. al. (1991). The differences can be attributed to the fact that these values are based upon measurements within experiments, compared to mean values observed with time in the analytical laboratory.

- **References**

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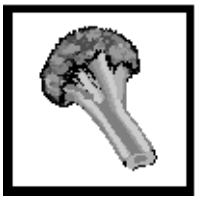

Broccoli

E. A. Hanlon and G. J. Hochmuth

- **Critical Values**

  None established.

- **Sampling Procedures**

  The most recently mature leaves should be sampled at heading. Concentrations above the sufficient range for nutrients that are immobile in the soil are indicative of high soil fertility. Fertilization with these nutrients in subsequent seasons should be reduced or eliminated.

- **Sufficiency Ranges**

Macronutrients					
N	P	K	Ca	Mg	S
3.0–4.5 %	0.3–0.5%	1.5–4.0 %	1.2–2.5%	0.23–0.40%	0.2%

Micronutrients				
Fe	Mn	Zn	Cu	B
40–300 ppm	25–150 ppm	45–90 ppm	5–10 ppm	30–50 ppm

- **DRIS Norms**

  DRIS norms have not been established for broccoli.

- **Remarks**

  Tabular data agree with the experimental evidence reported in articles listed in the References section. However, some values are lower than those reported by Jones and others (1991). The differences can be attributed to the fact that these values are based upon measurements within experiments, compared to mean values observed with time in the analytical laboratory.

- **References**

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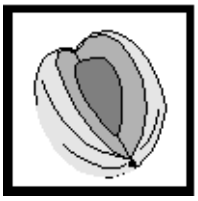

Cantaloupe

R. M. Lippert

- **Critical Values**

  None established.

- **Sampling Procedures**

  1. When vines are 12 inches long, sample the most recently mature leaves closest to the growing tip.
  2. At flower or initial fruit set, sample the most recently mature leaves closest to the growing tip. Sample 12–20 leaves, including the petiole.

- **Sufficiency Ranges**

12-inch Vines

Macronutrients					
N	P	K	Ca	Mg	S
4.0–5.0 %	0.4–0.7%	5.0–7.0 %	3.0–5.0%	0.35–0.45%	>0.2%

Micronutrients				
Fe	Mn	Zn	Cu	B
40–100 ppm	20–100 ppm	20–60 ppm	5–10 ppm	20–80 ppm

At Flower Start or Initial Fruit Set

Macronutrients					
N	P	K	Ca	Mg	S
3.0–4.5%	0.25–0.40%	1.8–4.0%	1.8–5.0%	0.3–1.5%	>0.2%

Micronutrients				
Fe	Mn	Zn	Cu	B
30–200 ppm	20–100 ppm	20–60 ppm	5–20 ppm	20–80 ppm

- **DRIS Norms**

  None established.

- **Remarks**

  A soil test before planting provides a good assessment of nutrient availability. Since canteloupes are commonly grown on acidic, sandy soils in the Southeast, a tissue test will help monitor the availability of leachable nutrients such as nitrogen and sulfur and assess the level of calcium to avoid blossom-end rot.

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Carrot

E. A. Hanlon and G. J. Hochmuth

- **Critical Values**

  None established.

- **Sampling Procedures**

  The most recently mature leaf should be sampled about 60 days after planting. For next season planning of fertilization needs, an additional sample from most recently matured leaves at harvest may be useful. Concentrations above the sufficient range for nutrients that are immobile in the soil are indicative of high soil fertility. Fertilization with these nutrients in subsequent seasons should be reduced or eliminated.

- **Sufficiency Ranges**

60 Days after Seeding

Macronutrients					
N	P	K	Ca	Mg	S
1.8–2.5 %	0.2–0.4%	2.0–4.0 %	2.0–3.5%	0.2–0.5%	

Micronutrients				
Fe	Mn	Zn	Cu	B
30–60 ppm	30–60 ppm	20–60 ppm	4–10 ppm	20–40 ppm

Harvest

Macronutrients					
N	P	K	Ca	Mg	S
1.5–2.5%	0.18–0.40%	1.4–4.0%	1.0–1.5%	0.4–0.5%	

Micronutrients				
Fe	Mn	Zn	Cu	B
20–30 ppm	30–60 ppm	20–60 ppm	4–10 ppm	20–40 ppm

- **DRIS Norms**

  DRIS norms have not been established for carrot.

- **Remarks**

  The literature contains few references, but tabular data agree with the experimental evidence reported in articles listed in the References section. However, some values are lower than those reported by Jones and others (1991). The differences can be attributed to the fact that these values are based upon measurements within experiments, compared to mean values observed with time in the analytical laboratory.

- **References**

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Cauliflower

E. A. Hanlon and G. J. Hochmuth

- **Critical Values**

  None established.

- **Sampling Procedures**

  The most recently mature leaf should be sampled at buttoning to determine if nutrition is adequate for the growing season. For next season planning of fertilization needs, an additional sample from most recently matured leaves at heading may be useful. Concentrations above the sufficiency range for nutrients that are immobile in the soil are indicative of high soil fertility. Fertilization with these nutrients in the subsequent season should be reduced or eliminated.

- **Sufficiency Ranges**

Buttoning

Macronutrients					
N	P	K	Ca	Mg	S
3.0–5.0 %	0.4–0.7%	2.0–4.0 %	0.8–2.0%	0.25–0.60%	0.6–1.0%

Micronutrients				
Fe	Mn	Zn	Cu	B
30–60 ppm	30–80 ppm	30–50 ppm	5–10 ppm	30–50 ppm

Heading

Macronutrients					
N	P	K	Ca	Mg	S
2.2–4.0%	0.3–0.7%	1.50–3.0%	1.0–2.0%	0.25–0.60%	

Micronutrients				
Fe	Mn	Zn	Cu	B
30–60 ppm	50–80 ppm	30–50 ppm	3–5 ppm	30–50 ppm

- **DRIS Norms**

  DRIS norms have not been established for cauliflower.

- **Remarks**

  The literature contains few references, but tabular data agree with the experimental evidence reported in articles listed in the References section.

- **References**

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Celery

E. A. Hanlon and G. J. Hochmuth

- **Critical Values**

  None established.

- **Sampling Procedures**

  The outer petiole should be sampled about 6 weeks after transplanting. For next season planning of fertilization needs, an additional sample from the outer petiole at maturity may be useful. Concentrations above the sufficient range for nutrients that are immobile in the soil are indicative of high soil fertility. Fertilization with these nutrients in subsequent seasons should be reduced or eliminated.

- **Sufficiency Ranges**

Six Weeks after Transplanting

Macronutrients					
N	P	K	Ca	Mg	S
1.5–1.7 %	0.3–0.6%	6.0–8.0 %	1.3–2.0%	0.3–0.6%	

Micronutrients				
Fe	Mn	Zn	Cu	B
20–30 ppm	5–10 ppm	20–40 ppm	4–6 ppm	15–25 ppm

Maturity

Macronutrients					
N	P	K	Ca	Mg	S
1.5–1.7%	0.3–0.6%	5.0–7.0%	1.3–2.0%	0.3–0.6%	

Micronutrients				
Fe	Mn	Zn	Cu	B
20–30 ppm	5–10 ppm	20–40 ppm	3–5 ppm	15–25 ppm

- **DRIS Norms**

  DRIS norms have not been established for celery.

- **Remarks**

  The tabular data agree with the experimental evidence reported in articles listed in the References section. However, some values are lower than those reported by Jones and others (1991). The differences can be attributed to the fact that these values are based upon measurements within experiments, compared to mean values observed with time in the analytical laboratory.

- **References**

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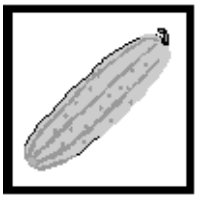

Cucumber

C. R. Campbell

- **Critical Values**

  None established.

- **Sampling Procedures**

  The most recent mature or fully expanded leaf is the best indicator sample for all growth stages. This is generally the 4th or 5th leaf from a growing point.

  A sample containing 15 to 20 leaves generally represents a uniform field well.

  Problem sampling is done any time during the growing season. Comparative "good" and "bad" samples help to pinpoint problems.

  Samples to monitor nutrient levels are taken at two-week intervals beginning two weeks prior to bloom and continuing throughout fruiting.

  Samples are shipped to the laboratory in paper containers.

Sufficiency Ranges

Most Recent Mature Leaf — All Growth Stages

Macronutrients					
N	P	K	Ca	Mg	S
4.0–5.0%	0.3–1.0%	3.0–4.0 %	1.2–2.0%	0.25–1.00%	0.20–0.75%

Micronutrients				
Fe	Mn	Zn	Cu	B
50–300 ppm	25–250 ppm	20–200 ppm	5–60 ppm	25–85 ppm

Important Ratios
The N:S ratio should be less than 18.
The N:K ratio should be 1.2 to 1.8.

- **DRIS Norms**

  DRIS norms have not been reported for cucumber.

- **Remarks**

  Sufficiency ranges were developed from available references and experience reviewing analytical results.

- **References**

Mills HA, Jones JB Jr. 1996. Plant analysis handbook II: a practical sampling, preparation, analysis, and interpretation guide. Athens (GA): Micro-Macro Publishing.

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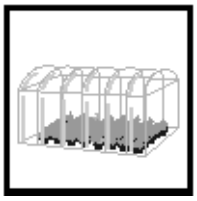


Cucumber, Greenhouse

C. R. Campbell

- **Critical Values**

  None established.

- **Sampling Procedures**

  The most recent mature or fully expanded leaf is the best indicator sample for all growth stages. This is generally the 3rd or 4th leaf from the growing point.

  Eight to ten leaves are required for a good sample.

  Sampling should commence at the first sign of a problem, but no less than two weeks before first flowering for monitoring. Samples should be taken at weekly intervals.

  Samples are shipped to the laboratory in paper containers.

Sufficiency Ranges

Most Recent Mature, or Fully Expanded, Leaf — All Growth Stages

Macronutrients					
N	P	K	Ca	Mg	S
4.5–6.0%	0.3–0.7%	3.5–4.5 %	1.2–1.5%	0.45–0.75%	0.2–0.7%

Micronutrients					
Fe	Mn	Zn	Cu	B	Mo
50–300 ppm	20–300 ppm	20–70 ppm	5–35 ppm	25–85 ppm	0.1–1.0 ppm

Important Ratios
The N:K ratio should be 1.2 to 1.8.

- **DRIS Norms**

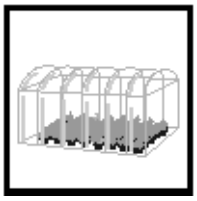
  DRIS norms have not been reported for greenhouse cucumber.

- **Remarks**

  Sufficiency ranges were developed from available references and experience reviewing analytical results.

- **References**

  Mills HA, Jones JB Jr. 1996. Plant analysis handbook II: a practical sampling, preparation, analysis, and interpretation guide. Athens (GA): Micro-Macro Publishing.



Lettuce, Greenhouse

C. R. Campbell

- **Critical Values**

  None established.

- **Sampling Procedures**

  The most recent mature or fully expanded leaf is the best indicator sample for all growth stages. This is generally the 3rd or 4th leaf from the growing point.

  Depending on size, 8 to 10 leaves are adequate for a sample.

  Problem samples can be taken at any time during the growing season. Monitoring samples should be taken at no less than two-week intervals as soon as plants are large enough.

  Samples are shipped to the laboratory in paper containers.

Sufficiency Ranges

Most Recent Mature Leaf — All Growth Stages

Macronutrients					
N	P	K	Ca	Mg	S
4.5–6.5%	0.3–0.8%	6.0–10.0 %	1.0–2.0%	0.35–0.75%	0.2–0.6%

Micronutrients					
Fe	Mn	Zn	Cu	B	Mo
50–200 ppm	20–200 ppm	20–75 ppm	5–15 ppm	25–80 ppm	0.2–1.0 ppm

- **DRIS Norms**

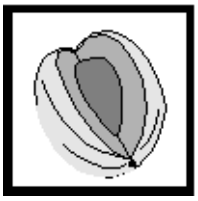
  DRIS norms have not been reported for greenhouse lettuce.

- **Remarks**

  Sufficiency ranges were developed from available references and experience reviewing analytical results.

- **References**

Mills HA, Jones JB Jr. 1996. Plant analysis handbook II: a practical sampling, preparation, analysis, and interpretation guide. Athens (GA): Micro-Macro Publishing.



Muskmelon

E. A. Hanlon and G. J. Hochmuth

- **Critical Values**

  None established.

- **Sampling Procedures**

  The most recently matured leaf should be sampled when the vines are about 12 inches long. Concentrations during harvest can best be judged by sampling the most recently matured leaf at early fruit set. It is doubtful if addition of fertilizer at or immediately after early fruit set will influence crop yield, however. Concentrations above the sufficient range for nutrients that are immobile in the soil are indicative of high soil fertility. Fertilization with these nutrients in subsequent seasons should be reduced or eliminated.

- **Sufficiency Ranges**

12-inch Vines

Macronutrients					
N	P	K	Ca	Mg	S
4.0–5.0 %	0.4–0.7%	5.0–7.0 %	3.0–5.0%	0.35–0.45%	0.2+ %

Micronutrients				
Fe	Mn	Zn	Cu	B
40–100 ppm	20–100 ppm	20–60 ppm	5–10 ppm	20–80 ppm

Early Fruit Set

Macronutrients					
N	P	K	Ca	Mg	S
3.5–4.5%	0.25–0.40%	1.8–4.0%	1.8–4.0%	0.3–0.4%	0.2+ %

Micronutrients				
Fe	Mn	Zn	Cu	B
40–100 ppm	20–100 ppm	20–50 ppm	5–10 ppm	20–80 ppm

- **DRIS Norms**

  DRIS norms have not been established for muskmelon.

- **Remarks**

  Tabular data agree with the experimental evidence reported in articles listed in the References section. However, some values are lower than those reported by Jones and others (1991). The differences can be attributed to the fact that these values are based upon measurements within experiments, compared to mean values observed with time in the analytical laboratory.

- **References**

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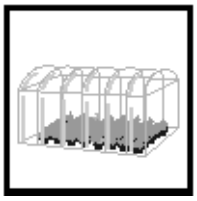


Spinach, Greenhouse

C. R. Campbell

- **Critical Values**

  None established.

- **Sampling Procedures**

  The most recent mature or fully expanded leaf is the best indicator sample for all growth stages. This is generally the 3rd or 4th leaf from the growing point.

  Depending on size, 8 to 10 leaves are adequate for a sample.

  Problem samples can be taken at any time during the growing season. Monitoring samples should be taken at two-week intervals as soon as the plants are large enough.

  Samples are shipped to the laboratory in paper containers.

Sufficiency Ranges

Most Recent Mature Leaf — All Growth Stages

Macronutrients					
N	P	K	Ca	Mg	S
4.0–6.0%	0.3–0.5%	3.0–8.0 %	1.0–1.5%	0.4–1.0%	0.2–0.8%

Micronutrients					
Fe	Mn	Zn	Cu	B	Mo
50–200 ppm	25–200 ppm	20–75 ppm	5–15 ppm	25–60 ppm	0.2–1.0 ppm

- **DRIS Norms**

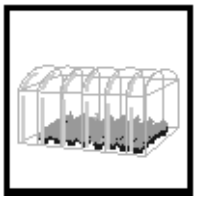
  DRIS norms have not been reported for greenhouse spinach.

- **Remarks**

  Sufficiency ranges were developed from available references and experience reviewing analytical results.

- **References**

Mills HA, Jones JB Jr. 1996. Plant analysis handbook II: a practical sampling, preparation, analysis, and interpretation guide. Athens (GA): Micro-Macro Publishing.



Tomato, Greenhouse

C. R. Campbell

- **Critical Values**

  None established.

- **Sampling Procedures**

  The most recent mature or fully expanded leaf is the best indicator sample for all growth stages. This is generally the 3rd or 4th leaf from the growing point.

  Eight to ten leaves are required for a good sample. After drying, the midribs should be removed and discarded.

  Sampling should commence at the first sign of a problem but no less than two weeks before flowering for monitoring. Samples should be taken at weekly intervals.

  Samples are shipped to the laboratory in paper containers.

Sufficiency Ranges

Most Recent Mature Leaf — All Growth Stages

Macronutrients					
N	P	K	Ca	Mg	S
3.5–5.0%	0.30–0.65%	3.5–4.5 %	1.0–3.0%	0.35–1.0%	0.2–1.0%

Micronutrients					
Fe	Mn	Zn	Cu	B	Mo
50–300 ppm	25–200 ppm	18–80 ppm	5–35 ppm	30–75 ppm	0.1–1.0 ppm

Excessive or Toxic Nutrient Levels
Boron becomes toxic at approximately 200 ppm and can cause distortion and burn of the growing point. In severe cases, boron tops the plant by injuring the growing point. In such cases, yield is decreased.
Excess nitrogen is characterized by lengthened internodes and “bullish” growth in the top of the plant. In severe cases, fruit set is adversely affected. The N:K ratio appears to be more important than nitrogen concentration in limiting the effects of high nitrogen. A N:K ratio of 1.2 to 1.8 is desirable.

- **DRIS Norms**

  DRIS norms have not been reported for greenhouse tomato.

- **Remarks**

  Sufficiency ranges were developed from available references and experience reviewing analytical results.

- **References**

  Plank CO. 1989. Plant analysis handbook for Georgia. Athens (GA): University of Georgia Cooperative Extension Service. 64 p.

Tomato, Trellis

C. R. Campbell

- **Critical Values**

  None established.

- **Sampling Procedures**

  The most recent mature or fully expanded leaf is the best indicator sample for all growth stages. This is generally the 3rd or 4th leaf from the growing point.

  A sample containing eight to ten leaves is generally adequate. Midribs are removed after drying.

  Problem sampling is done any time during the growing season. Comparative good and bad samples help to pinpoint problems.

  Sampling to monitor nutrient levels should commence at least two weeks prior to first bloom and should continue at two-week intervals throughout the fruiting season.

  Samples are shipped to the laboratory in paper containers.

Sufficiency Ranges

Most Recent Mature Leaf — All Growth Stages

Macronutrients					
N	P	K	Ca	Mg	S
3.5–5.0%	0.3–0.7%	3.0–4.5 %	1.0–2.0%	0.3–0.8%	0.2–0.8%

Micronutrients				
Fe	Mn	Zn	Cu	B
45–300 ppm	30–300 ppm	18–75 ppm	5–30 ppm	30–75 ppm

Excessive or Toxic Nutrient Levels
Boron becomes toxic at approximately 200 ppm and can cause distortion and burn of the growing point. In severe cases, plants may be topped by the damage followed by decreased yields.
Excess nitrogen is characterized by lengthened internodes and “bullish” growth in the top of the plant. In severe cases, fruit set may be affected. The N:K ratio appears to be more important than nitrogen concentration alone in determining vulnerability to fruit loss related to excess nitrogen. N:K ratios of 1.2 to 1.8 are ideal.

- **DRIS Norms**

  DRIS norms have not been reported for trellis tomato.

- **Remarks**

  Sufficiency ranges were developed from available references and experience reviewing analytical results.

- **References**

  Mills HA, Jones JB Jr. 1996. Plant analysis handbook II: a practical sampling, preparation, analysis, and interpretation guide. Athens (GA): Micro-Macro Publishing.

  Plank CO. 1989. Plant analysis handbook for Georgia. Athens (GA): University of Georgia Cooperative Extension Service. 64 p.

Vidalia Onion

C. O. Plank

- **Critical Values**

  None established.

- **Sampling Procedures**

  Sample the most recently mature leaves prior to root or bulb enlargement. Avoid dusty or soil-covered leaves and plants whenever possible. Under normal conditions, rainfall is frequent enough to keep leaf surfaces fairly free of dust and soil particles. However, when leaves are dusty, brush or wipe with a damp cloth to remove the contaminants. If this is not effective or if leaves are covered with spray materials, wash in a mild detergent solution (0.30%) and rinse in running water. Do not prolong the washing procedures.

Sufficiency Ranges

Macronutrients					
N	P	K	Ca	Mg	S
3.10–4.27%	0.26–0.48%	1.98–4.22 %	0.90–1.84%	0.16–0.32%	0.15–0.57%

Micronutrients				
Fe	Mn	Zn	Cu	B
undetermined	51–149 ppm	16–45 ppm	5–28 ppm	6–15 ppm

Important Ratios
Maintain the N:S ratio between 5:1 and 15:1.

- **DRIS Norms**

  DRIS foliar norms for onions from populations yielding > 45 megagrams (metric tons) per hectare (n=173) (Caldwell 1991).

Expression	*Mean §*	*CV (%)*
N	3.68	16
P	0.37	29
K	3.10	36
S	0.36	57
Ca	1.37	34
Mg	0.24	33
Mn	100.14	49
Zn	30.21	48
Cu	16.74	70
B	10.62	43
P/N	1.10	39
K/N	0.85	39
Ca/N	0.39	37
Mg/N	0.07	41
S/N	0.10	54
Mn/N	28.66	53
Zn/N	7.82	45
Cu/N	4.83	73
B/N	2.83	40
K/P	9.34	50
Ca/P	4.23	53
Mg/P	0.69	40
S/P	1.03	50
Mn/P	312.28	70
Zn/P	88.00	52
Cu/P	51.05	86
B/K	30.12	40
Ca/K	0.54	78

Expression	*Mean §*	*CV (%)*
Mg/K	0.09	69
S/K	0.12	47
Mn/K	35.75	60
Zn/K	10.60	50
Cu/K	6.62	114
B/K	3.78	53
Mg/Ca	0.196	42
S/Ca	0.31	85
Mn/Ca	76.86	48
Zn/Ca	25.00	70
Cu/Ca	12.53	62
B/Ca	8.93	67
S/Mg	1.74	78
Mn/Mg	492.91	79
Zn/Mg	151.28	72
Cu/Mg	77.18	72
B/Mg	49.56	58
Mn/S	331.70	55
Zn/S	95.95	52
Cu/S	59.33	89
B/S	32.00	42
Zn/Mn	0.34	52
Cu/Mn	0.18	63
B/Mn	0.12	51
Cu/Zn	0.66	83
B/Zn	0.38	41
B/Cu	0.84	67

§ Concentrations of N, P, K, Ca and Mg are expressed in dekagrams per kilogram and those of Zn, Cu and B in milligrams per kilogram.

- **Remarks**

  The sufficiency ranges were developed from the data of Caldwell (1991) by taking the mean plus or minus one standard deviation. Onion yields were in excess of 20 tons per acre. The ranges for N, P, K, Ca and Mg agree very closely with those reported by Pankov (1984) and, with but few exceptions, are not too dissimilar from those reported by Plank (1989) and Hochmuth and others (1991). These ranges have been checked against numerous normal- and abnormal-appearing farmer samples that were analyzed at the University of Georgia Soil Testing and Plant Analysis Laboratory and are improvements over previously used ranges (Plank 1989).

- **References**

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Watermelon

R. M. Lippert

- **Critical Values**

  None established.

- **Sampling Procedures**

  At flower start or initial fruit set, sample the most recently mature leaves closest to the growing tip. Sample 12–20 leaves, including the petiole.

  Sufficiency Ranges

Macronutrients					
N	P	K	Ca	Mg	S
2.5–4.0%	0.25–0.7%	2.25–3.5 %	1.1–2.5%	0.25–0.50%	0.2–0.4%

Micronutrients				
Fe	Mn	Zn	Cu	B
30–200 ppm	20–200 ppm	20–50 ppm	4–10 ppm	20–40 ppm

- **DRIS Norms**

  DRIS norms have not been established for watermelon.

- **Remarks**

  A soil test before planting provides a good assessment of nutrient availability. Since watermelons are commonly grown on acidic, sandy soils in the Southeast, a tissue test will help monitor the availability of leachable nutrients such as nitrogen and sulfur and assess the level of calcium to avoid blossom-end rot.

- **References**

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Reference Sufficiency Ranges

— Turf & Lawn Grasses —

Bentgrass

C. R. Campbell and C. O. Plank

- **Critical Values**

  None established.

- **Sampling Procedures**

  A representative sample of clippings from a freshly mowed green is the best indicator of nutritional status. A double handful of clippings is an adequate sample. In as much as possible, the sample should be taken when clippings are free of foreign matter, including sand, pine straw, etc.

  Samples containing significant amounts of foreign matter should be processed by the following procedure.

  1. *Sand*
     To remove sand and heavy foreign matter, pour the sample into a 1000-mL beaker containing distilled water. The bentgrass and lighter materials float to the surface. Stir and remove quickly to avoid leaching water-soluble nutrients. Blot dry and place in dryer.

  2. *Light-weight foreign matter*
     After the sample is dry, sieve the sample on a 1-mm screen (No. 18 U.S. Testing Sieve). The bentgrass falls through the screen while other light-weight particles are retained for removal.

  For problem samples, a matching sample from a "good" green should be taken for comparison.

  Monitoring to fine tune fertility programs and/or maintain records of environmental stewardship is done by sampling greens monthly. Sampling should follow the same management sequence monthly to improve usefulness of the data over time.

  Samples are loosely packed and shipped to the laboratory in paper containers.

- **Sufficiency Ranges**

Clippings from Recently Mowed Green

Macronutrients					
N	P	K	Ca	Mg	S
4.0–5.0%	0.3–0.6%	2.2–3.5%	0.25–0.75%	0.2–0.4%	0.2–0.1%

Micronutrients				
Fe	Mn	Zn	Cu	B
50–300 ppm	25–300 ppm	20–70 ppm	5–15 ppm	3–20 ppm

Important Ratios
The N:S ratio should be 10 to 15. Ratios over 18 indicate a sulfur deficiency. The N:K ratio should be 1.2 to 2.2.

- **DRIS Norms**

DRIS norms have not been reported for bentgrass.

- **Remarks**

Sufficiency ranges are based on available literature and experience reviewing analytical results.

- **References**

Mills HA, Jones JB Jr. 1996. Plant analysis handbook II: a practical sampling, preparation, analysis, and interpretation guide. Athens (GA): Micro-Macro Publishing.

Bermudagrass — 'Tifgreen' & 'Tifton-328'

C. R. Campbell and C. O. Plank

- **Critical Values**

  None established.

- **Sampling Procedures**

  Collect representative samples of clippings after routine mowing. A double handful is an adequate sample size.

  Problem-solving samples can be taken at any time there is adequate growth. Comparative samples from "good" and "bad" areas should be taken to isolate difference between these areas.

  Monitoring samples should be taken monthly to evaluate fertility programs and identify changes needed to improve growth and quality of sod for the intended purpose.

  Samples should be shipped to the laboratory in loosely filled paper containers.

- **Sufficiency Ranges**

Fresh Clippings

Macronutrients					
N	P	K	Ca	Mg	S
3.0–4.0%	0.2–0.4%	1.8–2.25%	0.25–0.5%	0.15–0.3%	0.15–0.65%

Micronutrients					
Fe	Mn	Zn	Cu	B	Mo
50–250 ppm	20–300 ppm	15–70 ppm	5–20 ppm	5–60 ppm	0.1–2.0 ppm

Important Ratios
The N:S ratio should be 10–15 for best growth and quality. Sulfur is deficient when the ratio is greater than or equal to 18.

- **DRIS Norms**

  DRIS norms have not been reported for bermudagrass.

- **Remarks**

  Sufficiency ranges are based on available literature and experience reviewing analytical results.

- **References**

  Mills HA, Jones JB Jr. 1996. Plant analysis handbook II: a practical sampling, preparation, analysis, and interpretation guide. Athens (GA): Micro-Macro Publishing.

  Plank CO. 1989. Plant analysis handbook for Georgia. Athens (GA): University of Georgia Cooperative Extension Service. p 21–8.

Reference Sufficiency Ranges

— Fruit & Nut Crops —

Apple

C. O. Plank

- **Critical Values**

None established.

- **Sampling Procedures**

Sample 50–100 healthy, mid-terminal leaves on current season's growth in mid-season (8 to 10 weeks after full bloom).

- **Sufficiency Ranges**

Macronutrients					
N §	P	K	Ca	Mg	S
1.80–2.10%	0.15–0.50%	1.25–1.80%	1.00–2.00%	0.20–0.50%	NA

§ These values apply to 'Golden Delicious'. For all other varieties, the values are 1.90–2.30%.

Micronutrients				
Fe	Mn	Zn	Cu	B
50–400 ppm	25–200 ppm	20–50 ppm	5–20 ppm	25–60 ppm

- **DRIS Norms**

DRIS norms have not been established for apple.

- **Remarks**

Plant analysis is an excellent means of determining the nutritional status and fertilizer needs of apple. As with many fruit crops, low nutrient levels and/or nutrient imbalances in apple are often manifested in the fruit before deficiency symptoms show on the leaves. Examples are

bitter pit due to inadequate Ca and internal corking due to low B. Therefore, it is important to maintain the nutrient level within the sufficiency range to prevent abnormal growth, fruit color, texture, or shelf life.

In order to make a successful diagnosis, the sample submitted to the laboratory must represent the overall growing conditions and be properly taken. Always follow the sampling instructions provided by the laboratory performing the analysis. In addition, there are several other growth factors that can also influence the nutrient status of the trees. Apple is a poor accumulator of Ca, and many producers routinely apply foliar Ca sprays. If the leaf samples are not properly washed off or if the application of foliar sprays is not noted on the information sheet accompanying the sample, the analytical results for Ca can be easily misinterpreted. Therefore, to aid the diagnostician in evaluating the plant analysis data, it is essential that all available information on cultural and climatic conditions, as well as the symptomology, be known. Most laboratories provide plant analysis kits containing history sheets for recording this information.

- **References**

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Plank CO. 1989. Plant analysis handbook for Georgia. Athens (GA): University of Georgia Cooperative Extension Service. 64 p.

Shear CB, Faust M. 1980. Nutritional ranges in deciduous tree fruits and nuts. Hort Rev 2:142–64.

Blueberry, Rabbiteye

C. O. Plank and M. R. Tucker

- **Critical Values**

  None established.

- **Sampling Procedures**

  Take mature leaves from mid-portion of current season's growth (lateral shoots, position 4, 5, and 6), during the first two weeks after harvest.

- **Sufficiency Ranges**

Two Weeks after Harvest

Macronutrients					
N	P	K	Ca	Mg	S
1.20–1.70%	0.08–0.20%	0.35–0.60%	0.25–0.70%	0.14–0.20%	0.11–0.25%

Micronutrients				
Fe	Mn	Zn	Cu	B
25–70 ppm	25–100 ppm	10–25 ppm	2–10 ppm	12–35 ppm

- **DRIS Norms**

  DRIS norms have not been reported for blueberry.

- **Remarks**

  The sufficiency range data given above are a result of a review of the literature, and several years plant analysis survey data compiled at the University of Georgia Soil Testing and Plant Analysis Laboratory.

- **References**

Austin ME, Gaines TP. 1984. An observation of nutrient levels in old, unfertilized rabbiteye blueberry plants. HortScience 19(3):417–8.

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Grape, Muscadine

C. O. Plank and C. R. Campbell

- **Critical Values**

  None established.

- **Sampling Procedures**

  Sample the most recent mature leaves adjacent to fruit clusters taken in mid to late summer, but before final swelling of the fruit.

- **Sufficiency Ranges**

Macronutrients					
N	P	K	Ca	Mg	S
1.65–2.15%	0.12–0.18%	0.80–1.20%	0.70–1.10%	0.15–0.25%	0.15–0.60%

Micronutrients				
Fe	Mn	Zn	Cu	B
60–120 ppm	60–150 ppm	18–35 ppm	5–10 ppm	15–25 ppm

- **DRIS Norms**

  DRIS norms have not been established for muscadine grape.

- **Remarks**

  The sufficiency range data were taken from portions of the data cited in the references and supplemented with survey data from samples analyzed at the University of Georgia Soil Testing and Plant Analysis Laboratory.

- **References**

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Peach

R. M. Lippert and C. R. Campbell

- **Critical Values**

  None established.

- **Sampling Procedures**

  At mid-season, sample mature leaves from the mid-portion or near the base of the current season's terminal growth from at least 50 trees.

- **Sufficiency Ranges**

Macronutrients					
N	P	K	Ca	Mg	S
2.75–3.50%	0.12–0.30%	1.30–3.20%	1.50–2.50%	0.25–0.50%	0.12–0.40%

Micronutrients				
Fe	Mn	Zn	Cu	B
> 60 ppm	> 20 ppm	20–50 ppm	5–20 ppm	20–80 ppm

- **DRIS Norms**

  DRIS norms have not been established for peach.

- **Remarks**

  Among the macro and micronutrients, the two required in greatest quantity for good peach production are nitrogen and potassium. In sandy soils, sulfur may likely be deficient. A low level of calcium or a high level of zinc in the leaves is often an indication of "peach decline." Deficiencies in manganese, iron, boron, and copper are less prevalent in the Southeast. Leaf content of iron, manganese, and zinc normally fluctuates greatly.

- **References**

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Pear

C. O. Plank and R. M. Lippert

- **Critical Values**

  None established.

- **Sampling Procedures**

  Sample 50–100 healthy, mid-terminal leaves on current season's growth in mid-season.

- **Sufficiency Ranges**

Macronutrients					
N	P	K	Ca	Mg	S
1.80–2.50%	0.12–0.30%	1.00–2.00%	1.00–2.00%	0.25–0.50%	0.10–0.30%

Micronutrients				
Fe	Mn	Zn	Cu	B
30–150 ppm	20–200 ppm	20–50 ppm	5–20 ppm	20–60 ppm

- **DRIS Norms**

  DRIS norms have not been established for pear.

- **Remarks**

  Plant analysis is an excellent means of determining the nutritional status and fertilizer needs of pear. As with many fruit crops, low nutrient levels and/or nutrient imbalances in pear are often manifested in the fruit before deficiency symptoms show on the leaves. Therefore, it is important to maintain the nutrient level within the sufficiency range to prevent abnormal growth, fruit color, texture, or shelf life.

In order to make a successful diagnosis the sample submitted to the laboratory must represent the overall growing conditions and be properly taken. Always follow the sampling instructions provided by the laboratory performing the analysis. In addition, there are several other growth factors that can also influence the nutrient status of the trees. Therefore, to aid the diagnostician in evaluating the plant analysis data, it is essential that all available information on cultural and climatic conditions as well as the symptomology be known. Most laboratories provide plant analysis kits containing history sheets for recording this information.

- **References**

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Pecan

C. O. Plank and C. C. Mitchell

- **Critical Values**

  None established.

- **Sampling Procedures**

  Sample the middle pair of leaflets from the mid-portion of terminal growth 56 to 84 days after catkin fall. The sampling time will vary among states, but in Georgia and Alabama the preferred sampling time is from July 7 to August 7. Under normal conditions, rainfall is frequent enough to keep leaf surfaces fairly free from dust and soil particles. If the leaflets are contaminated with residues from foliar sprays, they should be washed in a mild detergent solution (0.30%) and rinsed in a water bath or running water. Do not prolong the washing procedure or allow the plant material to "stand" in either the washing or rinsing solutions.

- **Sufficiency Ranges**

56–84 Days after Catkin Fall

Macronutrients					
N	P	K	Ca	Mg	S
2.50–3.30% §	0.12–0.30%	0.75–2.50%	0.70–1.75%	0.30–0.60%	0.20–0.50%

§ If irrigated, the optimum range is 2.80–3.00%. For the 'Desirable' variety, the sufficiency range is 2.30–3.00%.

Micronutrients				
Fe	Mn	Zn	Cu	B
50–300 ppm	100–800 ppm	50–100 ppm	6–30 ppm	15–50 ppm

- **DRIS Norms**

  Preliminary DRIS norms for pecans are given by Beverly and Worley (1992), as follows.

Nutrient Ratio	*Mean*	*CV (%)*
N §	27.2	9.4
P	1.4	18.1
K	10.2	20.9
Ca	14.5	33.4
Mg	3.82	29.9
Fe	89.4	40.9
N/P	19.8	18.2
N/K	2.74	20.9
N/Ca	2.44	130.0
N/Mg	7.74	36.7
N/Fe	0.349	36.4
N/Mn	1.107	47.4
N/Zn	0.306	76.5
N/Cu	3.13	41.0
N/Mo	4.56	28.0
N/B	0.746	40.2
N/Al	0.0257	138.0
P/K	0.143	25.4
P/Ca	0.123	117.0
P/Mg	0.414	46.5
P/Fe	0.0175	32.0
P/Mn	0.00535	41.3
P/Zn	0.0164	76.4
P/Cu	0.163	38.9
P/Mo	0.301	25.6
P/B	0.0412	40.0
P/Al	0.00143	154.0
K/Ca	0.948	151.0
K/Mg	2.97	46.3
K/Fe	0.134	35.9
K/Mn	0.0409	50.7
K/Zn	0.121	77.3
K/Cu	1.23	41.7
K/Mo	1.86	32.4
K/B	0.319	53.6
K/Al	0.0104	137.0
Ca/Mg	4.13	42.0
Ca/Fe	0.193	54.2
Ca/Mn	0.0583	58.5

Nutrient Ratio	*Mean*	*CV (%)*
Mn	324	54.5
Zn	126	60.0
Cu	9.69	32.4
Mo	6.3	28.1
B	40.1	34.7
Al	380	34.3
Ca/Zn	0.168	75.4
Ca/Cu	1.62	47.8
Ca/Mo	2.27	29.2
Ca/B	0.325	41.6
Ca/Al	0.0109	135.0
Mg/Fe	0.0518	45.2
Mg/Mn	0.0158	58.3
Mg/Zn	0.0438	71.9
Mg/Cu	0.470	49.4
Mg/Mo	0.565	42.9
Mg/B	0.111	45.0
Mg/Al	0.00389	155.0
Fe/Mn	0.354	46.0
Fe/Zn	1.04	91.7
Fe/Cu	9.98	42.9
Fe/Mo	18.6	45.8
Fe/B	2.77	46.5
Fe/Al	0.0958	149.0
Mn/Zn	3.23	83.6
Mn/Cu	35.4	56.6
Mn/Mo	70.0	45.3
Mn/B	10.2	65.0
Mn/Al	0.328	171.0
Zn/Cu	14.8	57.6
Zn/Mo	21.5	54.7
Zn/B	3.69	66.5
Zn/Al	0.125	183.0
Cu/Mo	1.70	41.1
Cu/B	0.276	43.8
Cu/Al	1.00954	148.0
Mo/B	0.183	71.5
Mo/Al	0.00586	159.0
B/Al	0.0384	170.0

§ N, P, K, Ca and Mg expressed in g/kg (parts per thousand); other elements in mg/kg (ppm).

- **Remarks**

  The sufficiency ranges given above were taken from Plank (1989). The ranges have been developed over the past 25–30 years utilizing research data from various sources, surveys, and plant analysis summaries.

- **References**

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Strawberry — Annual Hill Culture

C. R. Campbell and G. S. Miner

- **Critical Values**

  None established.

- **Sampling Procedures**

  The most recent mature trifoliate and petiole are the best indicator samples. Concentrations of essential elements are determined on the trifoliate. Nitrate nitrogen is determined on the petioles.

  Fifteen trifoliates and petioles are required for a representative sample.

  Samples are collected during fall growth as needed to solve problems and monitor crop development. Intensive biweekly sampling is initiated when spring growth begins and continued throughout flowering and harvest (approximately March 1–May 30) in North Carolina. Petioles are removed from trifoliates at the sampling site.

  Samples are shipped to the laboratory in paper containers.

- **Sufficiency Ranges**

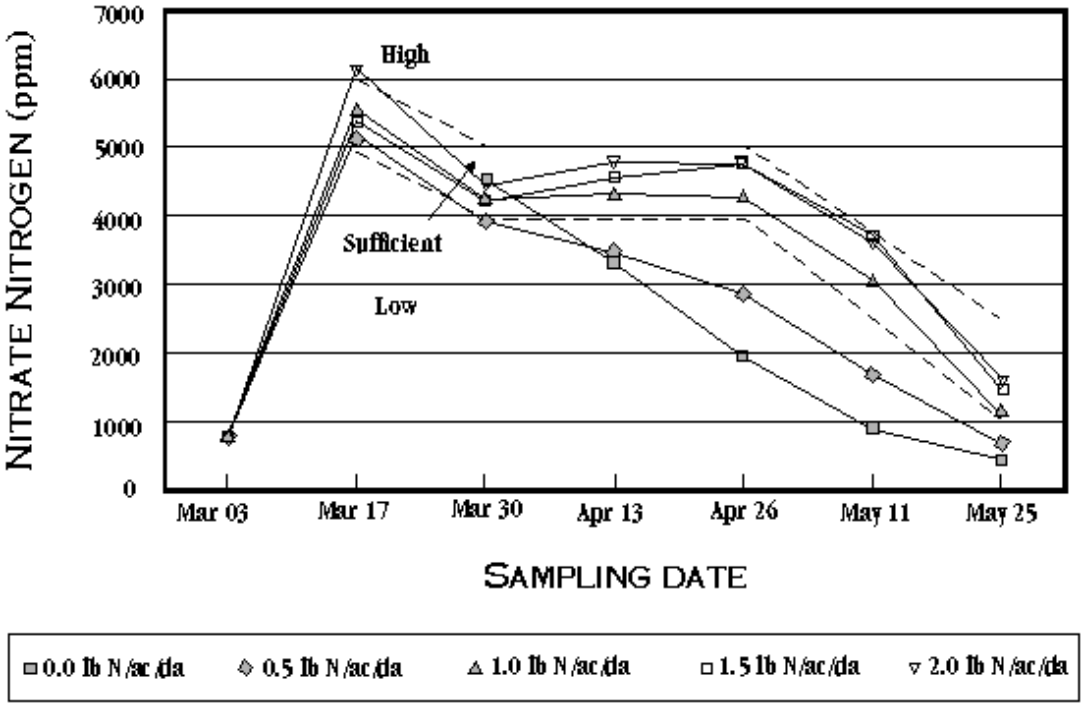
Most Recent Mature Trifoliate — All Growth Stages

Macronutrients					
N	P	K	Ca	Mg	S
3.0–4.0%	0.2–0.4%	1.1–2.5%	0.5–1.5%	0.25–0.45%	0.15–0.40%

Micronutrients				
Fe	Mn	Zn	Cu	B
50–300 ppm	30–300 ppm	15–60 ppm	3–15 ppm	25–50 ppm

Excessive or Toxic Nutrient Levels
Boron becomes toxic as concentrations approach 200 ppm B. Excess boron results in a marginal leaf burn beginning first on lower leaves and progressing up the plant. Severe cases result in >10% yield loss.

Petioles from Most Recent Mature Trifoliate — Spring Growth



- **DRIS Norms**

  DRIS norms have not been reported for strawberry.

- **Remarks**

  Sufficiency ranges were adopted from California studies and modified for North Carolina conditions based on numerous field studies.

  Petiole nitrate nitrogen values well above the sufficient zone during fruiting result in soft fruit.

- **References**

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Reference Sufficiency Ranges

— Ornamentals & Flowers —

Ornamental Cabbage

C. R. Campbell

- **Critical Values**

  None established.

- **Sampling Procedures**

  The most recent mature leaf is the best indicator.

  Ten to 15 leaves are required for a representative sample.

  Samples are collected during vegetative growth as soon as plants are large enough.

  Samples are shipped to the laboratory in paper containers.

- **Sufficiency Ranges**

Vegetative Growth — Most Recent Mature Leaf

Macronutrients					
N	P	K	Ca	Mg	S
3.5–4.5%	0.2–0.6%	3.0–4.0%	0.5–1.0%	0.2–0.4%	0.2–1.0%

Micronutrients					
Fe	Mn	Zn	Cu	B	Mo
50–300 ppm	20–250 ppm	20–75 ppm	3–10 ppm	20–40 ppm	0.1–2.0 ppm

Important Ratios
The N:S ratio should be between 10 and 15. Ratios above 18 are considered high and indicate a need for sulfur.

- **DRIS Norms**

  DRIS norms for ornamental cabbage have not been reported.

- **Remarks**

  Sufficiency ranges were developed based on experience and published ranges for similar crops.

- **References**

  Mills HA, Jones JB Jr. 1996. Plant analysis handbook II: a practical sampling, preparation, analysis, and interpretation guide. Athens (GA): MacroMicro Publishing, Inc.

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Poinsettia

C. R. Campbell

- **Critical Values**

Levels at which deficiency symptoms are evident and growth and development are affected.										
N	P	K	Ca	Mg	S	Fe	Mn	Cu	B	Mo
3.50%	0.15%	1.00%	0.50%	0.20%	0.05%	30 ppm	15 ppm	1 ppm	15 ppm	0.5 ppm

- **Sampling Procedures**

The most recent fully expanded or mature leaf is the best indicator of nutritional status. This is the first fully expanded leaf below the growing point.

Sampling is initiated as soon as plants are large enough that leaf removal will not limit further development.

Sampling is discontinued when bracts near full development.

Depending on size, approximately 10–15 leaves are required per sample.

- **Sufficiency Ranges**

All Growth Stages

Macronutrients					
N	P	K	Ca	Mg	S
4.0–6.0%	0.3–0.6%	1.5–3.5%	1.00–1.75%	0.3–1.0%	0.1–0.3%

Micronutrients					
Fe	Mn	Zn	Cu	B	Mo
50–300 ppm	20–250 ppm	20–60 ppm	2–10 ppm	25–75 ppm	1–5 ppm

Important Ratios
The N:S ratio should not exceed 18.

Excessive or Toxic Nutrient Levels							
N	P	K	Cl	F	Li	Mn	B
7.3%	0.9%	4.0%	3.0%	5 ppm	20 ppm	1000 ppm	200 ppm
Boron toxicity is common where irrigation water contains 0.5 ppm B or higher. Excess boron causes a marginal leaf burn that begins on older leaves. Toxicity symptoms progress up the plant with time. Leaf margins contain very high concentrations of boron.							
Lithium toxicity is associated with some water supplies and vermiculite deposits containing high concentrations of this element. Symptoms include marginal burn on older leaves. Leaf margins contain very high concentrations of lithium.							

- **DRIS Norms**

  DRIS norms for poinsettia have not been reported.

- **Remarks**

  Critical values were taken from the work of Ecke and others (1990) and modified based on experience. Sufficiency ranges and toxicity values were taken from work of Ecke and others (1990) and modified based on experience.

- **References**

Ecke P Jr, Matkin OA, Hartley DE. 1990. The poinsettia manual. Encinitas (CA): Paul Ecke Poinsettias. p 121.

Reference Sufficiency Ranges

— Tree Crops —

Fraser Fir

C. R. Campbell and L. E. Hinesley

- **Critical Values**

  None reported.

- **Sampling Procedures**

  Needles from most recent mature foliage in the upper half of the tree are the best indicator sample. Do not sample needles from the leader or top whorl.

  For monitoring, the preferred sampling time is in the fall after dormancy.

  Comparative samples from "good" and "bad" trees can be taken for diagnosing problems at any growth stage. The best indicator sample is needles from the current year's growth.

  Samples should contain 15–20 laterals from ten or more trees representing the field.

- **Sufficiency Ranges**

Current Year's Growth after Dormancy

Macronutrients					
N	P	K	Ca	Mg	S
1.5–2.0%	0.2–0.6%	0.6–0.8%	0.45–0.60%	0.10–0.20%	0.08–0.20%

Micronutrients				
Fe	Mn	Zn	Cu	B
40–300 ppm	30–300 ppm	18–75 ppm	5–10 ppm	18–30 ppm

Important Ratios
The Fe:Mn ratio should be greater than or equal to 1.

- **DRIS Norms**

  DRIS norms have been published by Beverly (1991), Hockman and others (1989), and Kopp and Burger (1990).

Expression	*Mean*	*CV (%)*
N	2.28%	3.53
P	0.23%	11.61
K	0.88%	6.45
Ca	0.38%	16.59
Mg	0.10%	10.59
P/N	0.10	14.47
N/K	2.61	7.23
Ca/N	0.17	15.40

Expression	*Mean*	*CV (%)*
Mg/N	0.04	10.92
P/K	0.26	11.62
Ca/P	1.71	20.06
Mg/P	0.43	12.62
Ca/K	0.44	18.19
Mg/K	0.11	12.00
Mg/Ca	0.25	10.70

- **Remarks**

  Sufficiency ranges are based on available research and modified based on experience interpreting plant analysis results.

  DRIS norms are based on work of Beverly (1991), Hockman and others (1989), and Kopp and Burger (1990).

  Nutrient concentrations vary with maturity of foliage. With the exception of copper, concentrations of most elements increase between mid-summer and late fall.

- **References**

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