PLANT NUTRIENT SUFFICIENCY LEVELS AND CRITICAL VALUES FOR COTTON IN THE SOUTHEASTERN U.S.

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Abstract

The Southern Extension and Research Activity on Soil Testing and Plant Analysis (SERA-6 committee) is preparing a publication entitled, *Sufficiency Ranges for Plant Analysis in the Southern Region of the U.S*. A review of the published research which supports current plant analysis interpretation in this region for cotton is presented along with recommendations for use. Guidelines for cotton leaf sampling and interpretation are highly subjective. However, for consistency across the region, the authors recommend sampling the uppermost, mature, leaf blade on the vegetative stem during the period of one week before to one week after first bloom. Concentrations of some nutrients in leaf blades change so little during the season that the accepted concentrations at early bloom may also be used for late bloom and maturity for trouble shooting only. Sufficiency ranges are presented for primary, secondary, and some micronutrients. Petioles from the same plant position should be monitored weekly for nitrate-N, total K and total P only. Nitrate-N in petioles must be considered along with environmental, physiological, and other nutrient stress factors. However, in general, cotton producers in Mississippi and Tennessee westward into eastern Texas and Oklahoma should consider guidelines similar to those currently in use in Arkansas. Cotton producers on irrigated Coastal Plain soils from Alabama and Florida into Virginia should consider guidelines similar to those currently in use in Georgia.

Sufficiency Levels and Critical Values

Sufficiency levels are the minimum nutrient levels at various growth stages which will produce a maximum yield without additional nutrient applications. A critical concentration is the concentration of a nutrient below which plants experience nutrient deficiency and yield reductions (Sabbe et al., 1973). A sufficiency range implies that the lower limit of the sufficiency range is the critical concentration, and the upper limit is critical for toxic effects of the nutrient. This may or may not be true. Sufficiency ranges 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 not all inclusive. Therefore, use of a sufficiency range for cotton and the implied critical concentration of a nutrient for deficiencies or toxicities are not absolute.

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Plant Parts to Sample

Research

Recommendations for analysis of the cotton plant by public laboratories in the Southern U.S. involve sampling either the (1) petiole from the uppermost, mature leaf on the vegetative stem at intervals during the growing season or (2) the blade from this leaf just prior to or at early bloom (usually the 4th or 5th leaf from the terminal). However, strong research-based arguments can be presented to defend or reject either approach in favor of sampling other plant parts such as whole plants, old petioles, old leaves, top leaves, bottom leaves, top petioles , bottom petioles, or leaf blades plus petioles (Hsu, 1979; Kerby and Adams, 1985; Sabbe et al., 1973). Good cases can also be made for taking samples just prior to bloom, at mid-bloom, or at maturity. Some of these arguments depend upon the particular plant nutrient of interest and the degree of plant development. Kerby and Adams (1985) make a good argument for mature leaves, especially when sampling for K. However, the uppermost, mature leaf blade or its associated petiole has become generally accepted because of the ease of identifying and sampling these plant parts during the growing season.

The *most recently mature leaf blades on the vegetative stem (usually at early bloom)* generally have been used by public laboratories not actively promoting a petiole analysis program. According to Sabbe and MacKenzie (1973), the greatest use of leaf blade analysis has been to ". . . judge the efficiency of a fertilizer practice." Leaves are presumed to be accumulators of nutrients and tend to be less affected by climate and seasonal changes than petioles. This allows the producer to sample his crop in a more relaxed manner than would be possible with petioles. However, efforts to develop a suitable sampling technique for assessing the nutrient status of the cotton plant for even a single nutrient has been difficult (Kerby and Adams, 1985). Controversy also exists as to whether one should sample the youngest, mature leaf or older leaves. Hsu (1979) in Mississippi found wide variation in the minimum K concentrations of plant tissue at the same location and from location to location in the same year. Minimum K concentrations in *old leaves* which Hsu recommended for sampling for maximum yield ranged from 0.6% to 2.43%. When data from all location-years were pooled, the yield response was not significantly correlated with plant tissue K concentration. Limited research in Nigeria reported a high correlation between K concentration in the youngest, mature leaves and cotton lint yield (Lombin and Mustafa, 1981). However, Kerby and Adams (1985) concluded that ". . . selection of the youngest, mature leaf as the sample tissue is not consistent with earlier work in the USA." Therefore, information from leaf blade analysis is often inconclusive and must be interpreted with extreme caution. Otherwise, growers and crop advisors may be lead into false expectations of leaf blade analyses.

Petiole analysis from the uppermost mature leaves (3-4 from terminal) for NO_3-N, P, and K at intervals during the growing season has become an accepted practice in many cotton-producing states. Petiole analyses have not been used for other nutrients.

Recommendations

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 must be taken at no less than weekly intervals and compared for the results to be meaningful. Interpret petiole analysis for NO_3-N, total P, and total K only. The 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.

Interpretation of Analyses

Petiole Analysis

Interpretation of petiole analysis is primarily directed toward NO_3-N with total P concentration as an index of environmental or physiological stress. Total K has received some attention in petiole analysis programs because of the importance of this nutrient in cotton production.

Interpretation used in the central U.S. cotton belt (excluding arid regions of Texas and Oklahoma and the western cotton growing areas) is based primarily on research in Arkansas (Maples et al., 1977; Sabbe et al., 1972) which has been confirmed by Louisiana research (Phillips et al., 1987). These values are similar to those used in California (Bassett and MacKenzie, 1976). Those used in the southeastern U.S. Coastal Plain soils were based on research in Georgia and Northwest Florida (Lutrick et al., 1986); unauthored extension report in 1977 entitled, "Summary of Nitrate Monitoring on Cotton in Georgia by the Extension Service"). Two separate ranges for NO_3-N in petioles are used. The "Arkansas" interpretation (Benton et al., 1979; Miley et al., 1988; Miley and Maples, 1988) generally allows higher concentrations of NO_3-N during the season than the "Georgia" interpretation (C.O.Plank, personal communication). There are some minor differences in the sufficient NO_3-N range as interpreted for northern and southern Arkansas which aren't included in Table 1.

Care should be used when interpreting petiole NO_3-N results to take into consideration environmental and physiological stress and other potential nutrient deficiencies and supplemental fertilization. Factors such as stage of growth, boll load, nodes to white bloom, irrigation and rainfall events, supplemental fertilization, insect damage, heat units, cloud cover, etc. can all affect petiole NO_3-N. Many of these are included in computer programs which help to properly interpret and make recommendations based on petiole NO_3-N and P analyses (Benton et al., 1979; C.O. Plank, personal communication).

As a general guideline, cotton producers in Mississippi and Tennessee westward into eastern Texas and Oklahoma should consider using the "Arkansas" interpretation. This may also include cotton grown in the Limestone Valley soils of northern Alabama, although Touchton et al. (Touchton et al., 1981) concluded that ". . . cotton growers of Alabama are not likely to benefit from a cotton-petiole-nitrate monitoring service because of the erratic behavior of nitrate levels during the period that is essential to identifying a deficiency of N." Cotton producers on irrigated Coastal Plain soils from Alabama and Florida into Virginia should consider using the "Georgia" interpretation.

Youngest, Mature, Leaf Blade at Early Bloom

States that offer cotton leaf blade analysis services through public soil and plant analysis programs in the southern region of the U.S. tend to use similar sufficiency ranges. The ranges in use in extension programs were from cotton surveys conducted in Arkansas (Sabbe et al., 1972) and in Georgia (Anderson et al., 1971) and compiled by Sabbe and MacKenzie (1973). These are presented in Table 2 with some modifications based upon more recent surveys or research (see section IV).

Youngest, Mature Leaf Blade during late bloom (maturity)

Growers may have a need to diagnose visual problems which seem to be more prevalent during late bloom and maturity. This is certainly true for N, K, Mg, and possibly B deficiencies. However, no widespread sufficiency ranges have been adopted for nutrients during this stage of cotton growth. Values reported in Table 2 are based on leaf samples taken at maturity in a cotton survey in Georgia by Hodges and Hadden (1992), unpublished data from an Alabama survey with N and S by C. C. Mitchell, and research by Mullins and Burmester (1990, 1992, 1993). Concentrations in leaf blades of some nutrients change so little during the season that the accepted concentrations at early bloom were used for late bloom and maturity.

Interpreting Each Nutrient

Nitrogen

Most research has clearly pointed toward petiole nitrate as the most sensitive index of plant nitrogen status (Bassett and MacKenzie, 1976; Joham, 1951; Lutrick et al., 1986; Maples et al., 1977; Tucker and Tucker, 1968). However, as work in California and Arizona has shown, the sufficiency ranges do not indicate critical levels which are absolute. It is, however, a desirable range (Tucker and Tucker, 1968). Nitrate levels below or above the desired range do not indicate a deficiency or excess as such, but may give an indication of incipient problems. Nitrate concentrations can be extremely erratic under non-irrigated conditions in humid regions (Touchton et al., 1981). Growers using petiole nitrate analysis to monitor their N fertilization program must pay close attention to soil moisture conditions, plant maturity, boll load, insect pressure, temperature, and any other physiological or environmental condition that could directly affect petiole nitrate. Samples taken at regular intervals along with monitoring P in the petioles can help with petiole nitrate interpretation.

Total N in leaf blades does not seem to change very much during the growing season (Mullins and Burmester, 1990; C.C. Mitchell, unpublished data).

Phosphorus

Phosphorus, like N, is probably best monitored through the use of petiole samples taken at regular intervals, although the relationship between actual petiole concentration and the P status of the cotton plant is weak. Changes in P concentration of petioles is accepted as an indicator of environmental or physiological stress which can influence NO_3-N interpretation. A drop of more than 400 mg P/kg in the petiole from one week to the next may suggest stress unrelated to either N or P nutrition (Benton et al., 1979).

Jones and Bardsley (1968) reported, *"A search for a critical level of phosphate in cotton leaves or petioles indicates that there is a scarcity of data which will allow a tissue test to be evaluated in quantitative terms."* Research and surveys have added to data on petiole and leaf blade P concentrations, but total P in cotton tissue is not well correlated with P fertilization (Fuller et al., 1963; Jones and Bardsley, 1968; Peacock, 1960). Many public laboratories in the Southern Region have used 0.30% P in leaves as the lower end of the sufficiency range. However, based on numerous surveys throughout the region and research indicating lower P concentrations in healthy, productive cotton, a value of 0.20% P for the lower limit of the sufficiency range is given in Table 2 for leaf blades (Mullins and Burmester, 1990).

Potassium

Potassium concentration in leaves decreases as both the leaf and the cotton plant mature. Most laboratories currently use a value of 1.5% for the minimum concentration in the youngest, mature leaf at early bloom (Plank, 1988). The K sufficiency range reported by Sabbe et al. (1972) from the Arkansas survey taken about August 1 was actually 0.90-1.95%, but this was much later than early bloom. The K sufficiency range from the Georgia survey (Anderson et al., 1971) was 2.00-3.00% when sampled in June and July. Perhaps the 1.5% critical value adopted by many laboratories was a compromise. Kamprath and Welch (1968) reviewed literature that suggested 0.8% to 1.2% K was an adequate level in recently matured leaves sampled at the initiation of flowering. In a survey of 290 Alabama cotton fields, Mitchell et al. (1992) found 61% of the youngest, mature leaf blades at or shortly after early bloom were below 1.5% K although rarely did they find evidence of K deficiency. They suggested a need to adjust this sufficiency range. Hodges and Hadden (1992) sampled the uppermost, mature leaf+petiole in 144 Georgia cotton fields at "maturity". They found only 11% of the leaves in mature cotton were below 0.74% K; low leaf K was associated with low soil K levels. Even though the two surveys were taken at different maturity dates for cotton, they do point out that using 1.5% K as the lower end of the sufficiency range may result in diagnostic errors. A valid argument can be made for adjusting the lower end of the sufficiency range at early bloom from 1.5% K to 1.2% K or lower.

On the other hand, Mullins and Burmester (1990) found K concentrations below 1.5% only during late bloom and maturity. Reeves and Mullins (1993) reported yield increases from K applications when leaf K was 1.30 to 1.37% at early bloom. Therefore, based on levels currently used and the research by Reeves and Mullins (1993), we recommend continued use of 1.5% K as a practical lower limit for the sufficiency range at early bloom.

Magnesium

Sufficiency ranges used for Mg in leaf blades are based on ranges in survey samples and not extensive research with known Mg-deficient plants. Lancaster (1958) reported a close relationship between the percentage of Mg in the cation exchange complex of Blackland soils in Mississippi and the Mg content of cotton leaves. Mullins and Burmester (1992) showed little change in Mg concentration of cotton leaves during growth and maturity.

Calcium

Calcium concentration increases as plant tissue ages. It also increases when the plant is under stress. Because most cotton is grown in well limed soils or soils already high in Ca, low leaf Ca should rarely be encountered. It may however, be an indication of other problems such as very acid soil or excessive K fertilization on a weakly buffered (sandy) soil.

Sulfur

Experience by the authors suggest that very low leaf blade S concentration at early bloom is a good indicator of sulfur deficiency. Sulfur deficiencies can easily be separated from N deficiencies with a leaf blade analysis. Sulfur concentrations below 0.15% when other nutrient concentrations are within the sufficiency range are likely S deficient. Nitrogen:sulfur ratios are another good indicator of S deficiency. If the N:S ratio is above 20:1, sulfur may be limiting. If the N:S ratio is above 30:1, a S deficiency exists and classic symptoms are usually seen in the field. In recent surveys, 92% of Alabama fields during early bloom

(Mitchell et al., 1992) and 100% of Georgia fields at maturity (Hodges and Hadden, 1992) had S concentrations above 0.25%. Therefore, 0.25% S seems to be an appropriate lower end of the sufficiency range. Sulfur concentration in the youngest, mature leaf blade, like N concentration, does not change very much as the season progresses.

Zinc

A cotton yield response to zinc fertilization has not been reported in the southeastern U.S. Therefore, defining a lower limit to the sufficiency range for cotton grown in this region is not possible. Hinkle and Brown (1968) reviewed research in California where Zn deficiencies have occurred and reported that ". . . 10 ppm zinc in the cotton leaf blade of the most recently matured leaf may approximate the critical level." They also found this value used in Russia for Zn deficient cotton. Surveys in Alabama and Georgia reported 12% and 37%, respectively, of cotton leaf blades below the 20 mg/kg value reported in Table 2. This points out the problems of attempting to use sufficiency levels alone without more information. Obviously, since there have been no reported yield increases to Zn fertilization by cotton in Alabama or Georgia, plants were not likely Zn deficient.

Manganese

Cotton is not likely to be grown on the poorly-drained, Coastal Plain soils where Mn deficiencies are likely to develop. However, leaf Mn concentrations below 20 mg Mn/kg should be of concern if soil pH is above 6.5 and the soil is typical of those where Mn deficiency is likely such as the coastal flatwoods and Spodosols of the Atlantic Coastal Plain.. Manganese toxicities are more common on acid, unlimed soils. If the Mg level in the leaf tissue is less than 0.30% and the Mn level greater than 350 mg/kg, soil acidity may be the major concern (Plank, 1988). A simple soil pH test will confirm the diagnosis of Mn toxicity.

Boron

Hinkle and Brown (1968) reviewed research that reported a critical B concentration in "immature cotton leaves" of 15 ppm. The Georgia survey by Hodges and Hadden (1992) found only 3% of the cotton leaves below 20 mg/kg given in Table 2. The range found in 114 cotton fields at maturity was 18-269 mg B/kg. However, convenient, rapid, laboratory analytical techniques of digesting leaf material and analyzing the digested sample using inductively coupled argon plasma spectroscopy, may introduce inadvertent B contamination from laboratory glassware. Laboratories reporting results and consultants using the B results need to be aware of this potential problem which can easily be overlooked when interpreting results.

Iron, Copper, and other micronutrients

Plant leaf analysis for these micronutrients is not likely to help diagnose problems and will not be of much benefit to the grower. Deficiencies of these on soils of the Southeastern Cotton Belt are highly unlikely. Ranges reported for Fe and Cu are those from surveys and represent "typical" ranges rather than a true sufficiency range. Data from Mullins and Burmester (1993) indicate the large error associated with micronutrient analysis but supports the typical ranges in Table 2.

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Table 1. Sufficiency ranges for interpreting NO_3-N and P in cotton petioles

Time of sampling	Nitrate-N Minimum	-	Maximum	P
	----------mg/kg----------			
"Arkansas" Interpretation[1]				
Wk of bloom	10,000	-	35,000	>800
Bloom+1 wk	9,000	-	30,000	*
Bloom+ 2 wk	7,000	-	25,000	*
Bloom+3 wk	5,000	-	20,000	*
Bloom+4 wk	3,000	-	13,000	*
Bloom+5 wk	2,000	-	8,000	
Bloom+6 wk	1,000	-	5,000	
Bloom+7 wk	0	-	5,000	
Bloom+8 wk	0	-	5,000	
"Georgia" Interpretation[2]				
Wk before 1st bloom	7,000	-	13,000	>800
Wk of bloom	4,500	-	12,500	>800
Bloom+1 wk	3,500	-	11,000	*
Bloom+ 2 wk	2,500	-	9,500	*
Bloom+3 wk	1,500	-	7,500	*
Bloom+4 wk	1,000	-	7,000	*
Bloom+5 wk	1,000	-	6,000	*
Bloom+6 wk	500	-	4,000	
Bloom+7 wk	500	-	4,000	
Bloom+8 wk	500	-	4,000	
"California" Petiole K Interpretation[3]				
	-----% K-----			
Wk of 1st bloom	4.0	-	5.5	
Bloom+4 wk	3.0	-	4.0	
Bloom+6 wk	1.5	-	2.5	
Bloom+8 wk	1.0	-	2.0	

[1] Benton et al., 1979
[2] Lutrick et al., 1986; C.O. Plank, personal communication
[3] Bassett and MacKenzie, 1976
* A decrease in P concentration >300 mg P/kg from the previous week usually indicates moisture stress.

Table 2. Recommended sufficiency ranges for the youngest, mature, cotton leaf blades on vegetative stems sampled at early bloom and late bloom/maturity.

Nutrient	Early bloom			Late bloom/ maturity		
	----------%----------					
N	3.00	-	4.50	3.00	-	4.50
P	0.20	-	0.65	0.15	-	0.60
K	1.50	-	3.00	0.75	-	2.50
Ca	2.00	-	3.50	2.00	-	4.00
Mg	0.30	-	0.90	0.30	-	0.90
S	0.25	-	0.80	0.30	-	0.90
	----------mg/kg----------					
Cu	5	-	25	---		
Zn	20	-	200	50	-	300
Fe	50	-	250	50	-	300
Mn	25	-	350	10	-	400
B	20	-	80	15	-	200