NUTRIENT SURVEY OF ARIZONA COTTON WITH REFERENCE TO SOIL TYPE AND WATER QUALITY

by

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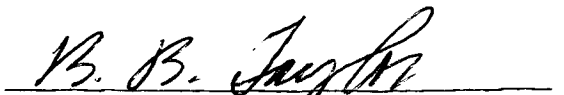

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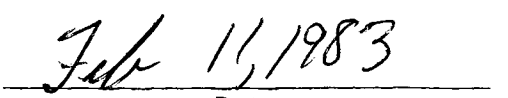

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ABSTRACT

Established cotton fields in 6 counties were sampled during the 1981 growing season. Two composite soil samples were taken from each field and both leaf blade and petiole tissue samples were taken two times during the growing season. Irrigation water samples were also taken. The tissue samples were analyzed for 13 elements, and the soil samples analyzed for 9 element, in addition, PH, EC, CEC and percent saturation values were determined on the soil samples. The level of each plant and soil element was investigated and compared with published critical and/or sufficiency levels. Simple correlation analysis were done between plant data and between plant and soil data. Phosphorus NO_3 and B were low and some samples were low in Zn. Calcium, Mg, K, and Fe levels were adequate and no unusual levels of AL and Ba were found. Some samples contained high levels of Na.

INTRODUCTION

Arizona produces the highest average cotton yields in America as well as the highest cotton yield world wide. Yet, if averaged over five year intervals average yields have not increased since 1955. The state's average appears to have settled at 2 bales per acre.

Although cotton yields appear to have plateaued, farm expenses continue to increase. Arizona's farm expenses rank among the highest in the nation. With today's small margin of profit it is imperative for Arizona farmers to manage at the highest levels of efficiency. Indiscriminate use of fertilizers, pesticides, water and machinery cannot be successful.

Next to water, the most limiting factor for plant dry matter production is low soil fertility. Productive soils must contain 13 minerals of which are essential for plant growth and these nutrients must exist in specific ionic forms. In addition, the concentration of each ion must be within a certain critical range between deficiency and excess. The importance of a nutrient balance in both soil and plant is becoming increasingly more evident. The use of highly purified and concentrated fertilizers coupled with more intensive farming may be depleting our soils of some nutrients previously assumed as naturally sufficient and available for crop utilization. This may especially be true for micronutrients.

The analysis of soil, water and plant tissue should be fundamental in determining the nutritional needs of a crop. Farmers relying

on past experience, trial and error, or the observations of nutrient deficiencies in planning fertility programs may never attain optimal or cost efficient yields. Although tissue testing for micronutrients is widely available, relatively few farmers employ this service regularly. Even fewer request micronutrient analysis. Lack of interest in soil and plant tissue testing is partially due to poor correlations among test results, fertilizer recommendations and crop yields. In turn, a lack of guidelines for interpreting results is a major cause for the poor correlations. Except for a few nutrients, formal guidelines for interpreting cotton tissue and soil test results have not been established in Arizona. Arizona's cotton industry has relied on guidelines established in other areas or developed their own. Attempts to use guidelines developed for other geographical areas or crops has been difficult since plant varieties, soil type, management practices and the length of growing season varies greatly. As an aid to future nutritional studies of cotton, it may be beneficial to know the range of nutrients found in cotton throughout a production region. Since water quality and soil type vary across a given area, quantitative data from these parameters could further aid nutrient research.

The research presented in this paper was a preliminary study to investigate the range of nutrient levels found in upland cotton grown throughout the irrigated regions of Arizona. Since such a survey has never been completed, it could immediately aid cotton growers within the state. In addition, extension and education circles of the university, agricultural industry representatives and International

Mineral and Chemical Corporation (IMC), which supplied the research grant for this study, would also benefit.

The objective of this study was to survey nutrient levels of cotton at early and peak bloom periods throughout Arizona utilizing leaf blade and petiole tissue analysis. In addition, nutrient levels were measured in irrigation waters and in representative soils at approximately one- and two-foot depths.

LITERATURE REVIEW

Cotton (Gossypium hirsutum), L., like all higher plants, requires 16 elements for growth and reproduction. Although some elements are obtained from air and water most are derived from soil solids or agricultural chemicals and minerals which can be processed into fertilizer. All soil nutrients enter the plant in the form of soluble compounds or ions. While the availability of a nutrient is regulated by the charge and structure of the soluble compound or ions, the charge and structure are regulated by other ions in solution and on the soil solids. Ultimately, small fluctuations of moisture, temperature, organic matter, microorganism activity or elemental concentrations in the rhizosphere can alter concentration gradients, solubility products, and ultimately the elements availability to the plant.

In this section essential macronutrients N, P, K, Ca, Mg, and micronutrients Zn, Mn, Fe, Cu, and B will be discussed. The major emphasis will be on Mg. The review will cover the general role of Mg in plants and Mg as a nutrient in cotton tissue and soil. Nitrogen, P, K, and Ca in cotton tissue and soil will also be discussed in general. The micronutrients will be discussed in general. The micronutrients will be discussed briefly, mainly, as they relate to soil and cotton tissue critical levels and/or sufficiency levels. In addition, some nutrient levels utilized by commercial laboratories for recommending fertilizer applications are given.

Magnesium

Role in the Plant

Magnesium has been known to be essential for plant growth for over 100 years. Each chlorophyll molecule contains one atom of Mg, making up 2.7% by weight of the chlorophyll molecule (Gauch, 1972). While about one quarter of the total leaf Mg is found in the chlorophyll, Mg mainly serves as a structural component and is involved as a co-factor in many enzyme transfer reactions. Magnesium is bound to ATP, ADP and other nucleotides and organic acids. Additionally, Mg enhances respiratory enzyme reactions and is vital for the two CO_2 fixing enzymes, ribulose diphosphate carboxylase and phosphoenolpyruvate carboxylase (Rains, 1976; Gauch, 1972). It has also been suggested that Mg is directly involved with protein synthesis binding 30s and 50s ribosomes to form the 70s ribosomes needed during the translation of amino acid bases (Rains, 1976).

Magnesium as a Nutrient in Cotton

Magnesium is absorbed by the roots as an elemental divalent cation. Its mobility in cotton allows distribution from the older to younger leaves. Although Mg levels in plant tissue are affected by soil conditions, Mg levels vary with climatic conditions, plant variety, maturity, management practices, and the level of other nutrients in the plant (Bates, 1971).

Like other oil seed crops, cotton requires high levels of Mg. As the fruit matures, Mg is withdrawn from the leaves and other

vegetative parts for utilization in seed formation. Youngblood (1919) estimated that one bale of seed cotton removes about 43 pounds of Mg per acre. Since lint is mostly cellulose and contains only insignificant amounts of nutrients, the majority of the Mg in seed cotton is in the seed.

Since Mg is mobile in the plant, deficiency symptoms first appear in the older leaves. Garner et al. (1930) described Mg deficiency leaf symptoms as interveinal chlorosis, changing from yellow to purple-red as the season progressed. Cooper (1932) noted difficulty in using leaf color to distinguish Mg deficiency from normal leaf maturation.

Although a Mg tissue level of .2 percent is the accepted critical level for higher plants (Rains, 1976; Salisbury and Ross, 1978), only a few workers have determined Mg critical levels specifically for cotton. Joly (1978), using hydroponic cultures, and sampling the most recently matured tissues determined the petiole critical level for cotton was .25-.30% Mg. Helmy et al. (1960), also sampling the most recently matured tissue, found 85-day-old cotton showed Mg deficiency symptoms when leaf tissue levels were below .28%. He suggested using .32% Mg as a "low level" and .41% Mg as an "intermediate level".

Some investigators have suggested sufficiency levels as opposed to critical levels (Sabbe et al., 1972; Helmy et al., 1960). If a nutrient concentration is below its sufficiency level, then at a later date the plants will be deficient in that nutrient. Sabbe et al. (1972) reported a sufficiency range of .5-.9% Mg for leaf blade tissue up to peak flower bloom. In a study by Helmy et al. (1960), leaf blade

samples were taken at 45 and 85 days after planting. They concluded Mg sufficiency levels ranged between .4-.6% Mg. For the midwest regions a private agricultural consulting and research laboratory, IMC (Sevey, personal communication, 1982) suggest Mg levels greater than .2% in leaf blade and petiole tissue.

Since fertility research on cotton has centered on the plant's response to N, there is a scarcity of information on tissue levels of Mg as well as other essential elements, excluding N. Fertilizer response/yield studies are not included in this review.

As a Soil Nutrient

Although the readily available forms of soil Mg as nitrates, sulfates and chlorides, are exchangeable and water soluble, the actual amount of Mg available to cotton will be determined by the total level of Mg in the soil solution, the percent saturation, clay type and the level of other cations in the soil.

Soil conditions most prone to Mg deficiencies are acidic, highly leached, sandy soils low in organic matter (Embleton, 1966), however, Mg deficiencies may exist on alkaline soils (Bower and Turk, 1946). As a cation, Mg is held to the surface of clay and organic matter particles. Since many agricultural soils in Arizona are sandy loam in texture and most contain below 1% organic matter, some soils in Arizona may be low in Mg. Knezek and Maier (1961) studied Arizona soils with Mg CEC saturation levels ranging from low to high. They noted some response of cotton to Mg fertilization when saturation levels were below 10 to 15%. A recent survey in Arizona (Morse, 1982) showed that 55% of the soils sampled had

Mg saturation levels below 10%. This survey included the primary production soils in the counties of Yuma, Maricopa, Pinal, Pima, and Cochise.

Adams (1975) studied Mg responses of cotton on various soils in Alabama. Using a Mehlick No. 1 soil extractant (double acid, Sabbe, 1980), he found that if extractable Mg was below 15 and 20 ppm Mg on sandy loam or silt loam soils, respectively, a response to Mg fertilization was likely. This extraction technique reportedly removed 80-90 percent of the exchangeable Mg.

Graham et al. (1956) studied Missouri soils for Mg response in general using an ammonium acetate extractant. He concluded soils with less than 10% Mg saturation of the total exchange capacity showed yield responses with Mg fertilization.

Helmy et al. (1960) studied the Mg nutrition of cotton grown in nutrient solutions. Based on results of this study, the critical Mg level for cotton is approximately 12 ppm in the growth media.

For the midwest region IMC (Sevey, personal communication, 1982) uses approximately 50 ppm Mg (Ammonium acetate extracted pH 7.0), as "very low" for interpreting soil analysis in the midwest.

It should be noted that recent nutrient surveys of alfalfa in Arizona indicated many fields may be borderline to deficient in Mg based upon the author's critical values used for interpretation (Smith and Dobrenz, 1980; Morse, 1982).

Potassium

In Cotton Tissue and Soil

A three-bale cotton crop requires approximately 140 pounds of K per acre, of which about 17 pounds would be removed at harvest in the lint and seed (Williams, 1970).

Potassium is absorbed from the soil solution or by contact exchange as a monovalent cation. Although the pattern of uptake closely parallels the growth curve for the first 60 days, about 90% of the total K is taken up during the next 60 days (Williams, 1970). The K concentration then decreases as the plant matures, possibly due to a dilution affect which, in turn, may explain the large variation in published critical levels.

Sabbe and MacKenzie (1973) suggest that since petioles are used for nitrate-nitrogen analysis, there is a lack of research establishing nutrient critical levels for leaf blade tissue. They note that, for K, it is often necessary to refer to petiole critical values to interpret leaf blade analysis.

Bassett and MacKenzie (1978) suggest petiole critical levels from 4 to 2% K depending on the maturity of the plant. In leaf blade tissue on 90-day-old cotton, Page et al. (1963) found .8% K was sufficient for cotton growth. Appling and Giddens (1954) reported 2% K as adequate and .9% K as a deficient level for cotton leaf blade values at early boll set. For the state of North Carolina, Tucker (personal communication, 1982) reports a K critical level for cotton of .6%, and in a survey of cotton in Arkansas, Sabbe et al. (1972) suggest a sufficiency level of K in cotton ranged from .9 to 1.9%.

In the soil, both water soluble and exchangeable K fractions are available to cotton. In addition, slowly available K, often associated with illite clay micas are available to plants. Hoover (1944) showed a soil of predominantly illite clay released three times as much K from the nonexchangeable form than a soil dominated by Kaolinite clays. Buol (1965) pointed out that most soils under cotton cultivation in Arizona contains appreciable amounts of illite clays.

McGeorge (1933) estimated that soils in Arizona contain between 1.4 and 3.0% total K. This represents approximately 5,600 to 120,000 pounds of K per acre foot of soil. Water soluble K fraction ranged between 300 and 1,000 pounds per acre foot and exchangeable K was between 680 and 6,900 pounds per acre foot of soil. These values represent 75 to 250 ppm water soluble K and 170 to 1,700 ppm exchangeable K.

In general most field crops do not respond to K fertilizer when exchangeable K is above 85 ppm (Doll and Lucas, 1973). In California, Reisnauer et al. (1978) reported a response in cotton to K is likely if exchangeable K is below 40 ppm on loam or 60 ppm on clay soils. For the midwest regions a private agricultural consulting and research laboratory, IMC (Sevey, personal communication, 1982), suggest K soil levels below 50 ppm may result in a response to fertilization.

There is no published response of cotton to K fertilizer in Arizona.

Phosphorus

In Cotton Tissue and Soil

Among the major nutrients, P is the least utilized by cotton. A three-bale yield requires approximately 31 pounds of P per acre (Williams, 1970) of which about 50 to 70% would be removed in the lint and seed at harvest (Sabbe and MacKenzie, 1973; Jones and Bardsley, 1968).

Since P is found in relatively high concentrations in the seed, substantial amounts are not required for seedling growth from the soil until a few true leaves have developed (Williams, 1970). Although Olsen and Bledsoe (1942) showed plant uptake is low for the first 90 days, an analysis of their data indicates P is absorbed by cotton in almost a perfect proportion to increases of dry weight (Jones and Bardsley, 1968; Williams, 1970). This indicates P is required throughout the growing season.

Although P critical levels for cotton have been reported for petiole tissue (Bassett and Mackenzie, 1978; Sabbe and Mackenzie, 1973), only sufficiency ranges were found for leaf blade tissue (Chapman, 1966; Sabbe et al., 1972). Sammuels cited in Chapman (1966) reported the low range of P in leaf blade tissue from 45-day-old cotton is .36%. Sabbe et al. (1972) reported a P sufficiency range of .3 to .5% for leaf blade tissue from cotton up to peak bloom.

In the soil, P exists as relatively insoluble compounds as the pH increases or decreases from 6.8. In alkaline conditions the insoluble phosphates consists primarily of Ca and Mg salts. Reisenauer et al.

(1978) and Halvorson cited in Thomas and Peaslee (1973) show that when P is determined by a Olsen $NaHCO_3$ extraction a response is likely if soil P drops below 5 ppm. For soils in Arizona, McGeorge (1940) published guidelines for interpreting P soil analysis. Using a CO_2 extraction, McGeorge recommended that 0 to 5 ppm PO_4 indicates the soil is deficient in available P, while 5 to 10 ppm PO_4 indicates the soil is probably deficient and may give a response in some crops.

Alternatively soil P can be extracted with NH4FHCL (Bray P1 extractant, Sabbe, 1980). In general, extractable P levels by this method are considered low if P is below 8 to 10 ppm (Thomas and Peaslee, 1973; Sevey, personal communication, 1982; Sabbe, 1980).

Calcium

In Cotton Tissue and Soil

Although Youngblood (1919) estimated 23 pounds of Ca are removed with each bale of cotton during harvest, Ca deficiencies in cotton are uncommon (Follett et al., 1981). Sabbe et al. (1972) reported Ca sufficiency ranges for cotton leaf blade tissue of 2.25 to 3.00% for cotton up to peak bloom in Georgia. IMC (Sevey, personal communication, 1982) suggests leaf blade Ca levels of 1.25% as "low" and 2.25% as adequate.

The Ca content of arid soils, like those found in southern Arizona, is likely to be very high because of the low rainfall and limited leaching.

Nitrogen

In Cotton Tissue and the Soil

A summary of California data indicated 60 pounds of N are required per bale of cotton produced (Williams, 1970). Tucker and Tucker (1968) noted more than 100 pounds of N per bale of cotton may be required depending on the plant size in relation to the fruit. Regardless of the total N required, it is estimated that 35 pounds of N per bale is removed in the lint and seed at harvest (Williams, 1970).

Nitrogen is the most widely researched of all essential nutrients. In Arizona, cotton petiole analysis has been developed for measuring NO3-N levels, which may aid as a fertilizer guideline (Gardner and Tucker, 1967).

Recommended NO3-N levels for cotton petioles at specific stages of growth are presented in Table 1.

Since soils in Arizona are characteristically low in organic matter, and the nitrate form of nitrogen is easily leached below the root zone of most plants, Arizona soils are more commonly lower in available N than any other element.

Tucker and Tucker (1968) report the amount of nitrate in the soil is a good indicator of the immediate supplying power of the soil and therefore has been used as a basis for initial fertilizer application. This method is particularly applicable in arid regions where water is supplied by irrigation (Tucker and Tucker, 1968).

However, limited guidelines to interpret soil NO_3 levels are available. Gardner (1963) developed a working curve for NO_3 and cotton yields by fitting soil NO_3 levels and corresponding seed cotton yields

Table 1. Desirable levels of NO_3-N in cotton petiole tissue, at various stages of plant development.*[1]

Stages of Growth	NO_3-N ppm
First square	15,000 to 18,000
First flower	12,000 to 14,000
First boll	6,000 to 8,000
First open boll	4,000

*Gardner and Tucker, 1967

[1]For proper use and interpretation of petiole results, the growth stage of the plants, the current fertilizer program, cropping history, irrigation schedule and soil type must be considered.

from field experiments to the Mitscherlich equation. Computations were based on a maximum yield of approximately 3.5 bales per acre. Since the state's average yield is near two bales per acre, the resulting curve should be applicable for most cotton grown in Arizona. Graphically; the soil NO_3 vs. seed cotton yield plot appears curvealinear. The curve shows a three-bale per acre yield requires more than 55 ppm soil NO_3. Likewise, 2.5, 2 and 1.5 bale yields per acre required soil NO_3 levels greater than 30, 20 and 5 ppm, respectively.

Micronutrients

In Cotton Tissue and Soil

Since Arizona soils are young and formed from well-mixed alluvium, total amounts of micronutrients in the soil should not vary widely from one region to another.

Micronutrient critical and/or sufficiency levels for cotton leaf blade tissue and soils are listed in Tables 2 and 3, respectively. All tissue levels represent an analysis of the most recently matured leaf blade. Soil critical/sufficiency levels represent extraction procedures which were later used on the soil samples collected in this survey.

Table 2. Nutrient critical levels for Mn, Zn, Fe, Cu and B in cotton leaf blade tissue.

Copper	5 - 10 ppm	(Tucker, personal communication, 1982; Gastenson, personal communication, 1967; Sparr et al., 1968)
Iron	30 - 40 ppm	(Tucker, personal communication, 1982; Sparr et al., 1968)
Zinc	10 - 11 ppm	(Tucker, personal communication, 1982; Ohki and Ulrich, 1977; Gastenson, personal communication, 1967; Sparr et al., 1968)
Boron	15 - 20 ppm	(Tucker, personal communication, 1982; Sparr et al., 1968; Gastenson, personal communication, 1967)
Manganese	10 - 20 ppm	(Tucker, personal communication, 1982; Ohki and Ulrich, 1977; Hinkle and Brown, 1968; Sparr et al., 1968).

Table 3. Recommended levels for Mn, Cu and B in the soil.*

Manganese	very low	5 - 20 ppm	(Cox and Kamprath, 1972)
Boron	very low	.5 ppm	(Anderson and Boswell, 1968; Reisenauer et al., 1973)
	toxic	5 ppm	(Sabbe, 1980; Reisenauer et al., 1973)
Copper	very low	.5 - .9 ppm	(Sabbe, 1980)

*Extraction method for reported nutrient levels are similar to those used for soil analysis in this survey.

MATERIALS AND METHODS

Field Selection

During the 1981 cotton growing season in Arizona, soil and plant tissue samples were collected from cotton fields in Maricopa, Pima, Pinal, Yuma, Graham and Cochise counties. Fields represented major soil types under production and ranged from heavy to light in texture. Twenty fields were selected from Maricopa county, 24 from Pinal County, 17 from Yuma County, 16 from Cochise County, 13 from Graham County, and 19 from Pima County. The approximate fields locations are shown in Figure 1. A breakdown of soil types represented in each county is shown in Appendix A.

Soil Sampling

Soil survey maps (when available) allowed both soil type and textural classification on a per field basis. A smaller portion of each field was selected as the sampling area. Each sampling area was well-buffered by the selected soil type to ensure uniformity in samples (Figure 2). During the entire testing period, all soil samples were taken from the sample area.

Two composite soil samples representing 0 to 25 cm and 26 to 50 cm depths were taken from each sampling area between June 9 and August 31. Each composite sample consisted of about 15 Oakfield probe cores, randomly selected throughout the sampling area. A tilling spade

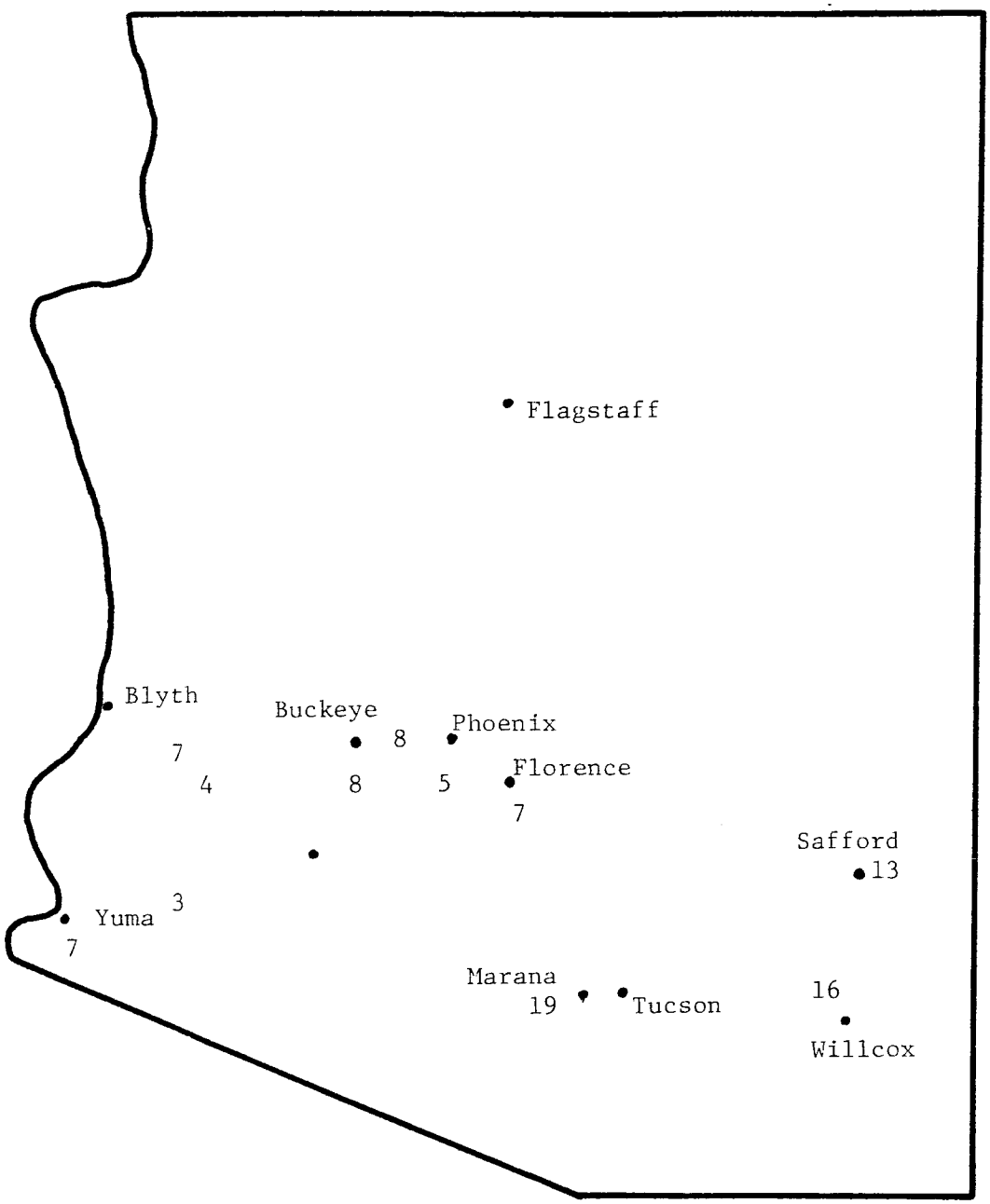

Figure 1. Approximate location and number of cotton fields selected for sampling.

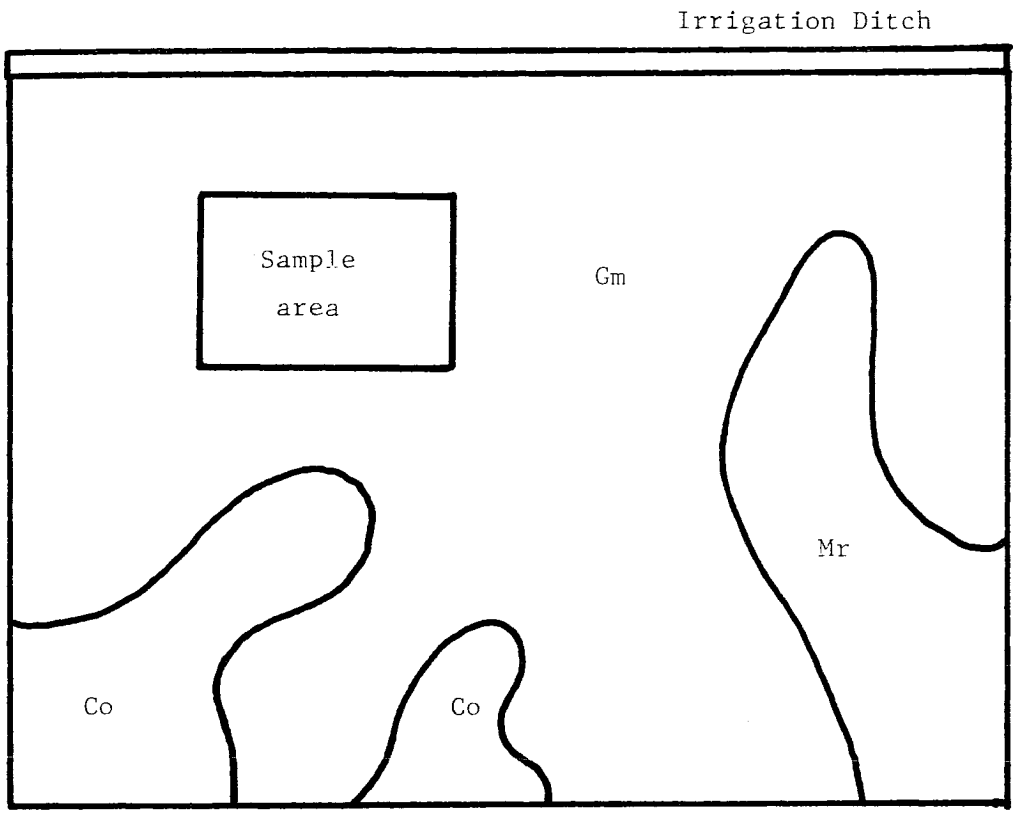

Figure 2. Sample area selection to obtain a uniform soil type.

(White and Collins, 1982) was used for sampling areas containing gravel. The samples were air dried, seived and subsampled for analysis.

Cotton Tissue Sampling

Tissue samples were taken during early bloom and again during the peak blooming period of the growing season. Cotton maturity rates vary across Arizona so sampling dates varied according to development of the cotton plant in each county.

Tissue samples were taken from about 30 separate plants chosen at random within the sampling area. The blade and petiole from the most recently matured leaf was sampled and separated for later analysis.

The tissue samples were oven dried at 70^{o}C and ground in a Wiley mill through a 40 mesh screen.

Soil Analysis

Two professional labs, IMC and Lengyel's Agricultural Consulting Service and Laboratory, performed the analysis. Analysis performed by IMC included 1:1 soil water suspension to determine pH, a 1:5 soil ammonium acetate (pH7) extract, to determine the soluble and exchangeable cations (Ca, Mg, K, Na) from which a cation exchange capacity and percent cation saturation value were calculated. A 1:10 soil-Bray P-1 extract (0.03 NH4F+0.025N HCl), was used for phosphorus determinations. The Mechlich-Bowling (Sabbe, 1980) method was used for copper analysis, 1:4 soil-hydrochloric acid extract was used to determine Zn. A 1:10 soil phosphoric acid extract was used for Mn determinations and B was determined by the hot water extraction method. The cation extracts of Na, K,

Mg, Mn, Zn, and Cu were analyzed by atomic Absorption Spectrophotometry. Boron determinations were measured on a Gilford Spectrophotometer. Phosphorus was determined on a Brinkman probe colorimeter.

The analysis performed by Lengyel's lab includes: saturated soil paste pH determonation, 1:5 soil water CO_2 extraction for the determination of phosphorus, 1:5 soil water extract to determine nitrate (phenoldisulfonic acid method, (Johnson and Ulrich, 1950)), and a 1:5 soil water extract to measure electrical conductivity. Phosphorus was measured on a Bausch and Lomb spectrometer, NO_3 determinations were on a Beckman Zeromatic pH meter and EC was determined on a Beckman conductivity bridge (RC-16B2).

Tissue Analysis

A complete tissue analysis was performed by IMC. The elements included in the analysis were: P, K, Ca, Mg, Mn, Fe, Cu, Zn, B, Na, Al and Ba (total determinations), on the cotton leaf blade samples and NO_3-N (soluble fraction) and Mg (total determination) on the cotton petiole samples. Plant tissue was ashed at 550°C and then dissolved in 3N HNO_3. All elements except Mg and NO_3-N were determined by a JY48P inductively Coupled Plasma Emission Spectrometer (SA, Inc.). For Mg analysis a 2% Lanthium solution was added to the HNO_3 dissolved ash sample. Magnesium was determined on a Perkin-Elmer Model 5000 Atomic Absorption Spectrophotometer. Nitrate-Nitrogen determination was by nitrate ion selective electrode, according to Baker and Smith (1969).

Water Samples

Water samples representing the ground water applied during irrigation were taken from 35% of the sample areas. All samples were taken at the pumping source. New Nalogene 100 ml bottles were rinsed three times with the sample water and filled in a way to exclude air. It should be noted that irrigation waters are often a mixture of waters from various pumps in an area. Therefore, variation in water quality applied to the field is expected. Water samples were analyzed by atomic absorption by Lengyel's lab. The analysis included Ca, Mg, Na, K, CO_3, HCO_3, pH and electrical conductivity. The elemental ions were anzlyed by a Perkin Elmer model 560 Atomic Absorption Spectrometer. Carbonates and Bicarbonates were determined by titration with HCL. The pH and EC on a Beckman Zeromatic pH meter and Beckman model RC-16B 2 conductivity bridge, respectively. The water analysis results are shown in Appendix B.

Statistical Analysis

To identify relationships which could affect an element's concentration in the cotton tissue samples, simple correlations analysis were calculated. 1) Between the chemical constituents in cotton tissue and 2) Between chemical constituents in cotton tissue and chemical constituents in the soil.

Since the sample population was very large, many correlations were highly significant though small in magnitude. Unless noted, only those correlations which resulted in coefficient values greater than .550 are discussed.

In some cases the plant's elements were better correlated to the soil data after subdividing the samples by soil texture. Only the significant correlations in these instances are presented and discussed.

Results of the correlation analysis among each plant element and all soil data from all samples representing a 26 to 50 cm depth are shown in Appendix C.

Multiple regression equations for each element analyzed in the plant tissue are given in Appendix D.

RESULTS AND DISCUSSION

In this section, the level of macronutrients and micronutrients in cotton tissue and soil samples are given and discussed in relation to published critical and/or sufficiency levels. The greatest emphasis will be on Mg. The results of a simple correlation analysis between the soil analysis (soil data), and tissue analysis (plant data) are presented.

Magnesium

In Cotton Tissue

Joly (1978) and Helmy et al. (1960) suggested critical levels for cotton leaf blades or petiole tissue ranged from .25 to .32% Mg. Since all tissue samples contained more than .4% Mg (Figures 3 and 4), both leaf blade and petiole levels appear to contain adequate Mg.

To prevent deficiencies, some investigators suggest using Mg sufficiency levels as opposed to critical levels as guidelines for fertilizer application. Sufficiency levels for 90-day-old cotton, as suggested by Sabbe et al. (1972) and Helmy et al. (1960) are .5 to .9% and .4 to .6% Mg, respectively, for leaf blade tissue. Figure 3 shows 4% and 3% of all leaf blade tissue samples in the first and second sampling periods, respectively, contain between .4 and .5% Mg. These samples, which may be borderline sufficient in Mg according to Sabbe et al. (1972), all represent cotton fields in Graham County (Safford area) except for one field in Pima County (Avra Valley). Two of the four fields

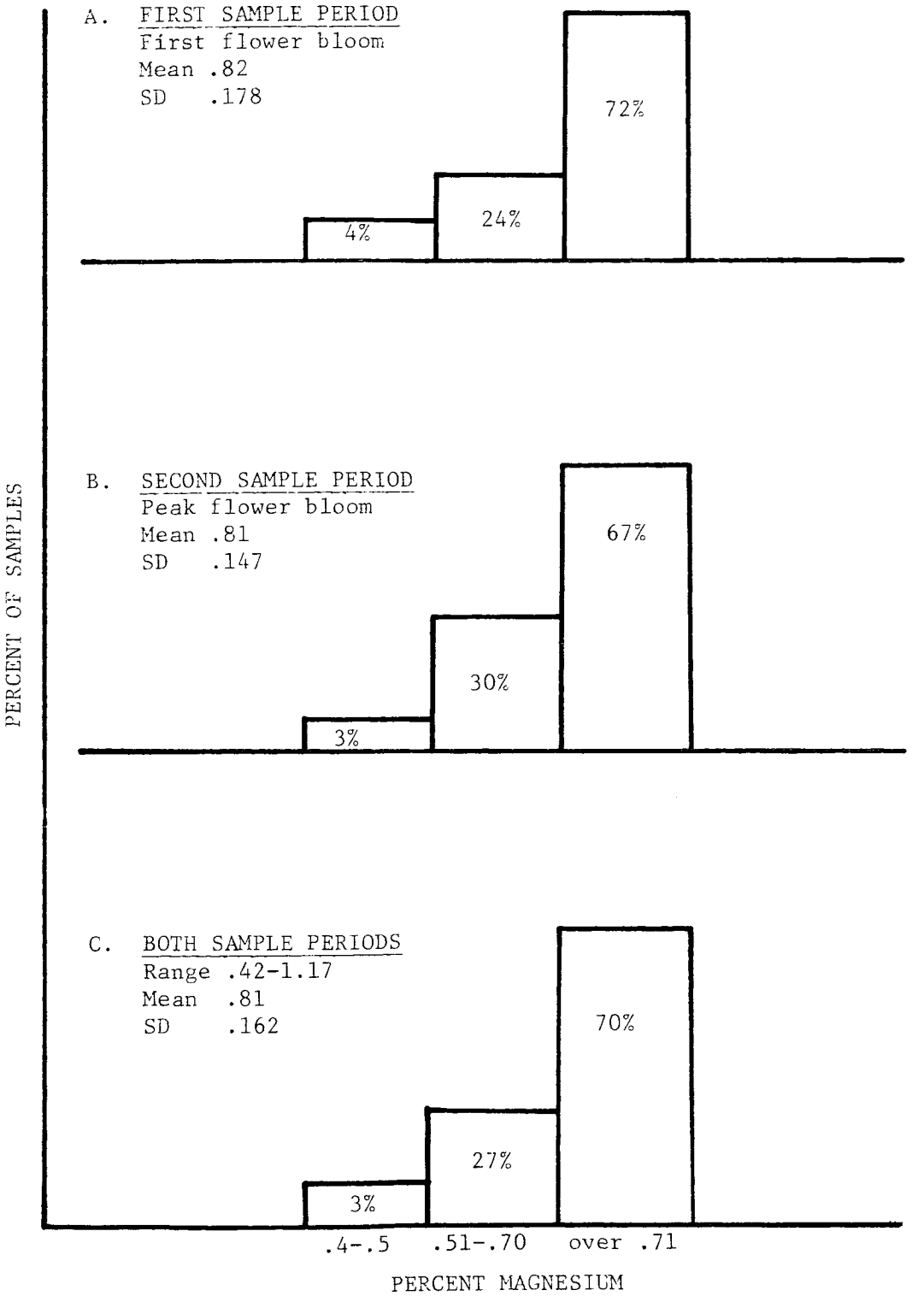

Figure 3. Distribution of Mg in the samples of cotton leaf blade tissue.

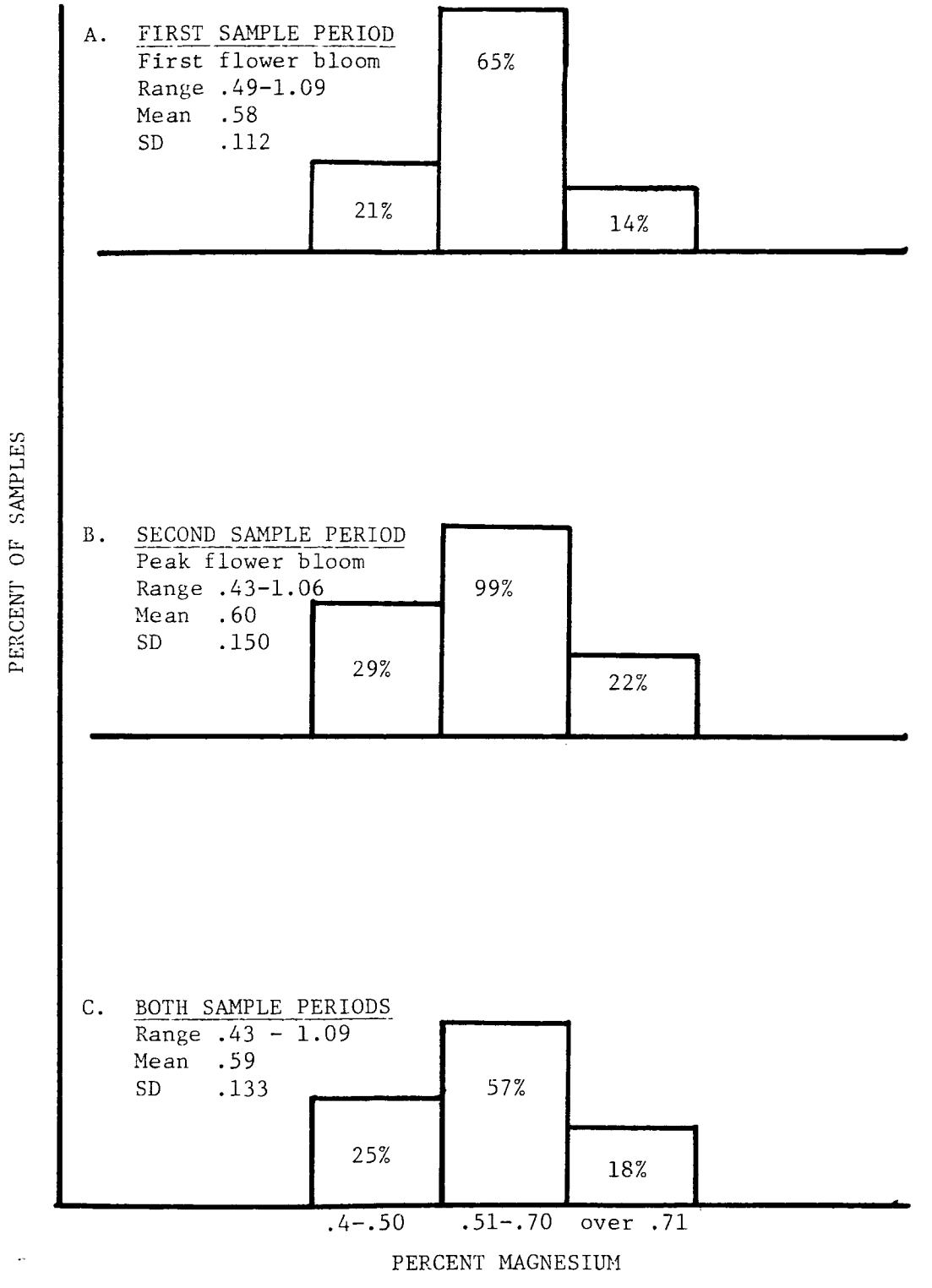

Figure 4. Distribution of Mg in the samples of cotton petiole tissue.

represented in Graham County were below .5% Mg during both the first and second sampling periods, soil types differed in each of the four fields.

In the Soil

The distribution of Mg in the soil samples, along with the range, mean and standard deviation is shown in Figure 5. The extraction procedures used on the soil samples did not differentiate between the exchangeable and water soluble cations (Sabbe, 1980). In addition, some Ca and Mg carbonates were probably solubilized by the ammonium acetate (pH7) extractant. Since these factors could cause an error when calculating cation exchange capacities and percent saturation values, guidelines based on these calculations are not applicable.

Exchangeable, plus water soluble Mg extracted from the soil samples averaged 635 ppm and ranged from 85 to 850 ppm (Figure 5). The range and average values of extractable Mg found in various soil textures and all soil samples combined are listed in Table 4. Values are given in meq/100 g and kg/ha. The range of Mg levels found in the irrigation water samples was 1 to 82 ppm and averaged 22.5 ppm (Table 5).

Adams (1975) and Helmy et al. (1960) reported a response of cotton to Mg fertilization is likely if exchangeable Mg levels are below 20 and 12 ppm Mg, respectively. All samples contained more than 80 ppm Mg. However, both exchangeable and water soluble Mg fractions were extracted.

Alternatively, when the water soluble/exchangeable fraction of Mg in the soil and the Mg in the irrigation water are added, the total represents the amount of Mg available for plant growth. Tables 4 and 5

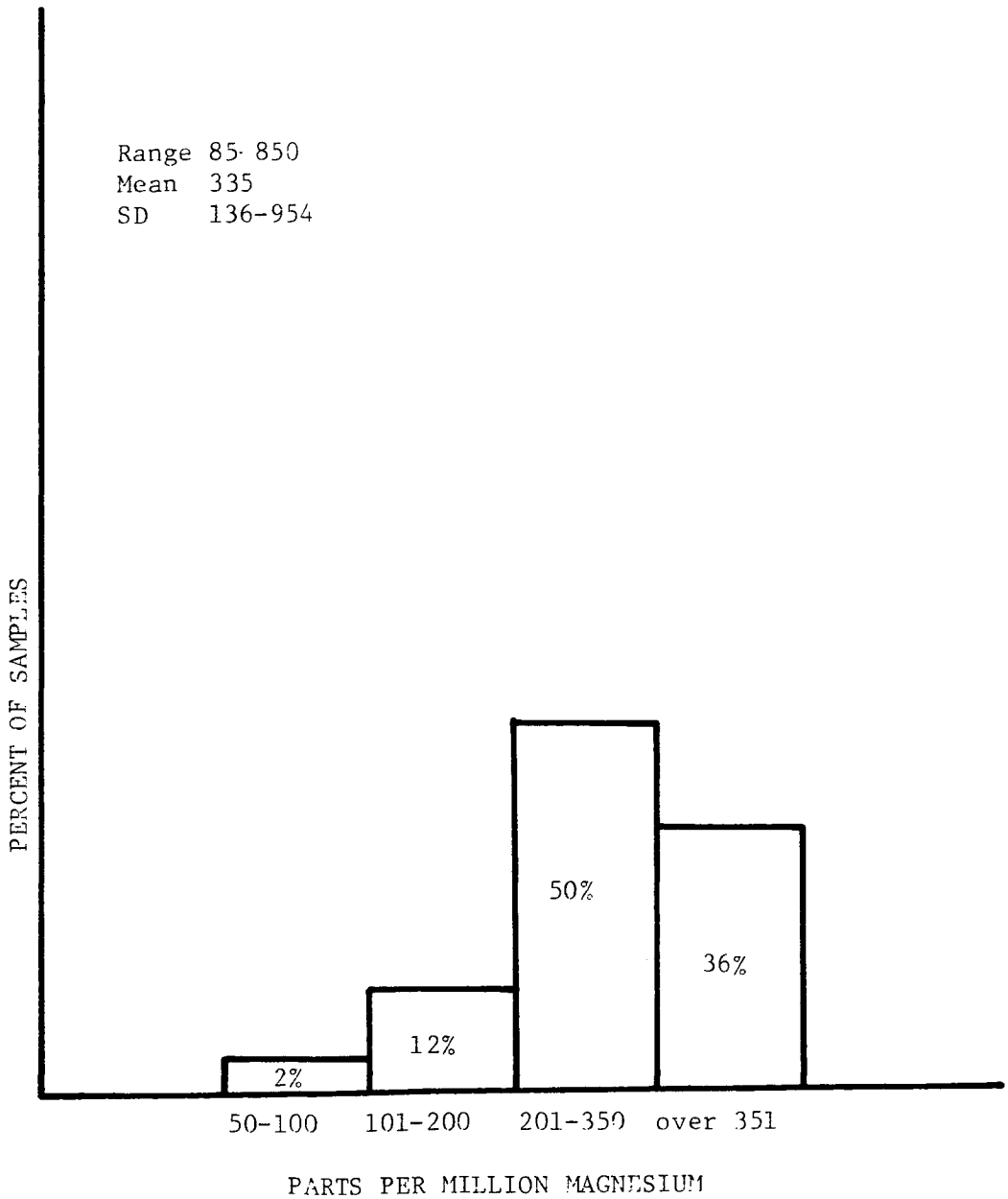

Figure 5. Distribution of Mg in the soil samples (25 cm depth)

Table 4. Exchangeable plus water soluble Mg in soil samples.

Soil	CEC[2]	meq/100 g	kg/ha[1]	No. of fields represented
Clay	18.8	5.074	2,166	10
Clay loam	16.11	3.658	1,561	18
Loam	12.4	2.832	1,209	26
Sandy loam	9.0	2.892	977	27
All soil	14.1	2.977	1,270	109

[1]For the top 25 cm

[2]Calculated

Table 5. High, low and average Mg levels in irrigation water samples.

Water	ppm Mg	kg/ha
High Mg	82.00	249.80
Low Mg	1.00	3.05
Average Mg	22.5	68.54

Based on 104.6 cm of water as the mean consumptive use.

show the total average amount of Mg available in the top 25 cm is 1,338 kg/ha. In addition, the solubility of Mg minerals and available Mg forms from deeper soil depths could be available to the plant. Since three bales of cotton will remove approximately 129 kg Mg/ha, this yield would leave a more than adequate amount of Mg to supply future crops. Furthermore, it is conceivable that irrigation water containing 60 ppm Mg, or more, would replace more Mg than is removed by a 2-bale-per-hectare yield.

Although a few fields in Graham County may be borderline sufficient in Mg and require Mg fertilization at a later date, in general these soil, water and plant sample data indicate an adequate supply of Mg is available for cotton growth and reproduction in the fields represented in this survey.

Correlation Analysis

Leaf Blade Fraction

In the first sample period, leaf Ca and B were correlated to leaf blade Mg with coefficients of $.746^{xx}$ and $.764^{xx}$ respectively (Table 6). No correlations greater than .550 were found in the second sample period, but when all samples were combined, the correlation coefficients for Ca and B with Mg are again greater than .550 (Tables 7 and 8).

Since synergistic relationships between Ca or B and Mg within plants are not mentioned in the literature, these correlations may represent a general increase of nutrients in the plant, as opposed to true cause and affect relationships.

Table 6. Correlation coefficients between leaf tissue elements for the first sample period.

		Petiole		Leaf Blade											
		NO_3-N	Mg	Ba	Al	Na	B	Zn	Cu	Fe	Mn	Mg	Ca	K	P
Leaf Blade	P	.091	-.165*	.533*	.531**	.034	.346**	.377**	.439**	.437**	.406**	.287**	.466**	.424**	
	K	.239*	-.203*	.285**	.523**	.249*	.453**	.386**	.440**	.511**	.405**	.409**	.508**		
	Ca	.100	.066	.464**	.608**	.398**	.798**	.350**	.645**	.608**	.515**	.746**			
	Mg	-.258*	.449**	.205*	.511**	.333**	.764**	.382**	.488**	.544**	.317**				
	Mg	.082	.173*	.543**	.613**	.164*	.464**	.258**	.597**	.534**					
	Fe	-.029	.157*	.386*	.890**	.192*	.627**	.422**	.418**						
	Cu	-.099	.009	.388**	.532**	.217	.537	.370							
	Zn	-.049	.030	.104	.316**	.075	.392								
	B	-.385**	.201*	.389**	.609**	.493									
	Na	-.140	.097	.136	.159*										
	Al	.014	.140	.519**											
	Ba	-.019	-.039												
Petiole	Mg	-.148													
	NO_3-N														

* .05
**.01

Table 7. Correlation coefficients between leaf tissue elements for the second sample period.

		Petiole		Leaf Blade											
		NO_3-N	Mg	Ba	Al	Na	B	Zn	Cu	Fe	Mn	Mg	Ca	K	P
Leaf Blade	P	.122	-.405**	.296**	.024	-.201*	.065	.189*	.141	.141	.173*	-.145	.199*	.177*	
	K	.520**	-.556**	.061	.071	-.126	-.256**	.200*	-.131	.201*	.260**	-.109	.095		
	Ca	.115	.055	.142	.433**	.124	.545**	.298**	.286**	.463**	.280**	.527**			
	Mg	.135	.474**	-.066	.382**	.377**	.443**	.218**	.228**	.366**	-.055				
	Mn	.117	-.071	.449**	-.017	-.172*	-.209**	.168**	.109	.040					
	Fe	.195*	.191*	.009	.928**	.168*	.179*	.195**	.032						
	Cu	.007	.255**	.195*	.046	.087	.255**	.125							
	Zn	.299**	-.142	-.074	.058	.063	.014								
	B	-.257**	.253**	.072	.259**	.291**									
	Na	.085	.302**	-.033	.303**										
	Al	.107	.082	.088											
	Ba	.005	.043												
Petiole	Mg	-.341**													
	NO_3-N														

* .05
**.01

Table 8. Correlation coefficients between leaf tissue elements for the first and second sample periods.

		Petiole		Leaf Blade											
		NO_3-N	Mg	Ba	Al	Na	B	Zn	Cu	Fe	Mn	Mg	Ca	K	P
Leaf Blade	P	.270**	-.277**	.418**	.514**	-.086	.246**	.420**	.348**	.478**	.332**	.121*	.273**	.451**	
	K	.458**	-.352**	.205**	.517**	.105*	.217**	.425**	.239**	.531**	.366**	.211**	.322**		
	Ca	-.049	.064	.309**	.419**	.277**	.682**	.267**	.419**	.426**	.389**	.641**			
	Mg	-.079	.448**	.093	.421**	.351**	.644**	.316**	.352**	.441**	.162**				
	Mn	.150**	.031	.504**	.441**	.026	.207**	.252**	.359**	.394**					
	Fe	.209**	.002	.270**	.914**	.162**	.483**	.476**	.356**						
	Cu	.051	.147**	.292**	.390**	.149**	.397**	.309**							
	Zn	.195**	-.054	.064	.382**	.068	.287**								
	B	-.289**	.213**	.268**	.492**	.419**									
	Na	-.047	.195**	.067	.162**										
	Al	.203*	.030	.361**											
	Ba	.029	.004												
Petiole	Mg	-.247**													
	NO_3-N														

* .05
**.01

Since only small correlation coefficients were seen between leaf blade and soil levels of Mg when all samples were combined (Tables 9 and 10), the samples were subdivided according to soil texture and correlation analysis between leaf blade Mg levels and the soil data was repeated (Table 11).

In the clay soils the calculated K saturation level was correlated to leaf blade Mg levels with coefficients of $-.640^{x}$ and $-.638^{x}$ in the first and second sample periods, respectively. These coefficients suggest antagonism of K on Mg and agree with other reports in cotton (Helmy et al., 1960; Adams, 1975; Maples and Keogh, 1974).

Also in the clay soils there was a $-.865^{xx}$ r value between total soil N and leaf blade Mg levels in the first sampling. This indicated excess Na may lead to lower Mg levels in leaf blade tissue. However, Figure 3 Histogram A shows the Mg levels in plant tissue samples were not low.

In the clay loam soils, leaf blade Mg levels were primarily influenced by soil P (CO_2 extraction) and to a lesser degree by Ca. The correlation coefficients between P and leaf blade Mg for the first and second sample periods were $-.631^{xx}$ and $-.719^{xx}$, respectively. Similar correlations to soil P were noted by Helmy et al. (1960) and Takahashi and Yoshida (1958). Since at a high pH, P normally forms insoluble compounds with Ca as opposed to Mg (Bohn et al., 1979) the relationship between P and Mg may be metabolic as opposed to a precipitation reaction in the soil.

In all soil textures, the Ca saturation levels were antagonistic to leaf blade Mg levels more consistantly than any other factor.

Table 9. Correlation coefficients between elements analyzed in cotton leaf tissue from the first sample period and all soil sample data (25 cm depth).

Soil Data cm depth	Leaf Blade Tissue												Petiole Tissue	
	Mg	Ca	P	K	Mn	Fe	Cu	Zn	B	Na	Al	Ba	NO_3-N	Mg
NO_3	.360**	.409**	.008	.259**	.133	.143	.241**	.260**	.388**	.465	.122	.139	-.184**	.136
P^1	.015	.043	.502**	.235*	-.058	.149	.199*	.198*	.013	-.105	.139	.223**	.113	-.268**
P^2	-.330**	-.227**	.114	-.134	-.106	-.162	-.150	.017	-.224**	-.262**	-.161*	.105	-.109	-.184*
K	-.148	-.061	-.109	.005	.224**	.008	.116	-.034	-.037	.019	.061	.061	.048	-.078
Ca	-.283**	-.076	-.084	.047	.243**	.037	.037	.058	-.109	-.156	.031	.041	.220**	-.168*
Mg	.198*	-.110	.050	.176*	.293**	.225**	.182*	.177*	.147	.088	.226**	-.138	.025	.150
Mn	-.003	-.139	.204*	-.053	-.038	.095	-.058	.082	-.115,	-.238**	.082	.044	-.037	.067
Cu	-.199*	-.330**	-.380**	-.133	-.253**	-.335**	-.155	-.173*	-.251**	-.174*	-.295**	-.259**	-.168*	.100
B	.329**	.277**	.011	.209*	-.062	.060	.131	.028	.330**	.638**	.023	.109	.219**	.082
Na	.089	.122	.267**	.034	.047	-.119	.063	-.074	.149	.314	.089	.084	-.241**	.122
K^3	.081	.015	-.005	.009	-.051	.011	.061	-.097	.059	.236**	-.122	.085	-.122	.040
Ca^3	-.526**	-.228**	-.164*	-.177*	-.046	-.257**	-.210**	.124	-.273**	-.146	-.194*	.058	.230**	-.331**
Mg^3	.490**	.244**	.181*	.183*	.068	.281**	.208**	.170*	.279**	.075	.215**	-.098	-.207*	.351**
CEC^4	-.198*	-.040	.067	-.104	.282**	.221**	.078	.084	-.058	-.151	.081	-.059	.179*	-.110
pH^5	.147	-.078	-.278**	-.102	-.261**	-.105	-.177*	.044	.033	.119	-.144	-.314**	-.132	.139
pH^6	.170*	.007	-.335**	.068	-.061	-.079	-.165*	-.055	.101	.136	-.096	-.066	.094	.251**
EC	.256**	.354**	.085	.291*	.161*	.053	.171*	.120	.319**	.435	.042	-.057	-.171*	.107

[1] CO_2 extract

[2] Bray P-1 extract

[3] Calculated saturation value

[4] Calculated value

[5] 1:1 soil:water extract

[6] Soil-water paste extract

[7] Electrical conductivity

* .05

** .01

Table 10. Correlation coefficients between elements analyzed in the cotton leaf tissue from the second sample period and all soil sample data (25 cm depth).

First Sample Period	Leaf Blade Tissue												Petiole Tissue	
Soil Data 25 cm depth	Mg	Ca	P	K	Mn	Fe	Cu	Zn	B	Na	Al	Ba	NO_3-N	%
NO_3	-.028	.028	.003	.169*	.065	.031	-.005	.194*	-.062	.378**	.067	-.007	.337**	.052
P[1]	-.025	.027	.260**	.011	-.058	.047	-.097	-.059	-.071	-.145	-.031	.084	.009	.145
P[2]	-.283**	-.103	.228**	.013	.046	-.009	.028	-.179*	-.114	-.261**	-.034	.240**	-.165*	-.100
K	-.160*	.044	-.063	.245**	.243**	-.165*	.147	.069	.032	-.061	-.124	-.080	.008	-.153
Ca	-.127	.290**	.031	.106	.465**	-.095	.219**	.074	.038	-.222**	-.058	.040	-.010	-.112
Mg	.211**	.187*	.015	-.068	.188*	.175*	.201*	.036	.132	-.023	.220**	-.136	.044	.003
Mn	-.050	-.193*	.004	-.203**	-.058	.108	-.107	.044	.168*	-.287**	.074	.070	-.175*	-.044
Cu	.003	.195*	.107	.192*	-.108	-.193*	.348**	-.173*	.314**	.137	.091	-.090	-.246**	.196*
B	.269**	.008	-.120	.065	-.371**	.097	.003	.090	.201**	.689**	.153	-.230**	.122	.115
Na	.089	.092	.021	.054	-.031	.1062	.213**	-.090	.207**	.481**	.074	-.084	-.070	.112
K[3]	-.063	-.275**	-.078	.181*	-.207**	-.123	.141	.008	.122	.160*	.138	.082	.031	-.059
Ca[3]	-.427**	.089	.060	.074	.285**	.238**	.025	-.134	.085	.242**	-.241**	.190*	-.113	-.151
Mg[3]	.001	.009	-.038	-.147	.239**	.305**	.023	.145	.138	.206**	.316**	-.180*	.108	.197*
CEC[4]	-.070	.290**	.023	.086	.443**	.045	.237**	.058	.063	-.198*	-.002	.156	-.044	-.105
pH[5]	.134	.024	-.262**	-.082	-.280**	.115	-.012	.025	.224**	.241**	.124	-.237**	-.060	.156
pH[6]	.050	.060	-.110	.135	.111	.106	.151	.049	.221**	.258**	.120	.012	.047	.190*
EC	.004	.102	-.091	.064	-.155	.109	-.021	-.039	-.058	.415**	.222**	-.201**	.171*	-.080

[1] CO_2 extract

[2] Bray P-1 extract

[3] Calculated saturation value

[4] Calculated value

[5] 1:1 soil:water extract

[6] Soil-water paste extract

[7] Elextrical conductivity

* .05

** .01

Table 11. Correlation coefficients between leaf blade Mg and soil data (25 cm depth), after subdividing samples by soil texture.

Soil Texture	Sample Period	P[1]	Ca	Mg	Ca[2]	Mg[2]	K[2]	Na	NO_3	SAR[3]
Clay	1						-.640*	-.865**		
	2				-.563*	.618*	-.638*	.637*	.832**	
Clay Loam	1	-.631**			-.572**	.569**				
	2	-.719**								
Loam	1		-.503		-.563*	.489				
	2		-.519*							
Sandy Loam	1		-.573**	.588**	-.609**	.716**		.570**		.598**
	2		-.461		-.695**	.795**		.512*		.549*

[1] CO_2 extraction

[2] Calculated saturation value

[3] Calculated sodium absorption ratio

* .05
**.01

Likewise, there was a more consistant relationship of Mg tissue levels with the Mg saturation levels than the total soil Mg level. These results indicate the amount of Mg in the soil, relative to other cations, is a better indicator of leaf blade tissue Mg levels. Whether or not the Mg saturation levels are better correlated to cotton yield response should be investigated.

Petiole Fraction

The results of a correlation analysis between petiole tissue Mg levels and all other plant elements analyzed are listed in Tables 6, 7 and 8 for the first and second sample periods and both sample periods combined, respectively. Tables 9 and 10 lists the correlation coefficients between petiole Mg levels and all soil data for the first and second sample periods, respectively.

Magnesium levels in the petiole tissue were poorly correlated to all other plant elements and soil data. Likewise, no correlation coefficients greater than .550 were seen between petiole Mg and the soil data after first subdividing the samples by soil texture (Table 12).

The Mg fraction in the leaf blade as opposed to the petiole was better correlated to the soil data, indicating a higher sensitivity to soil conditions. Thus leaf blade tissue for Mg would appear superior to petioles for estimating cotton's response to soil fertilization.

To further identify factors which may influence the levels of Mg in leaf blades or petiole tissue, ratios of various elements found in the leaf tissue were correlated to the leaf blade and petiole tissue

Table 12. Correlation coefficients between petiole Mg and soil data (25 cm depth), after subdividing samples by soil texture.

Soil Texture	Sample Period	K	Mg	Mg^1	Ca	Ca^1	K^1	Na	NO_3
Clay	1								
	2					-.410*			
Clay Loam	1			.453		-.475*			
	2			.478*					
Loam	1		-.402	.474					
	2	-.467					.565**		-.493
Sandy Loam	1								
	2							.539*	

[1]Calculated saturation value
* .05
**.01

[1]CO_2 extraction

levels of Mg. The results are shown in Tables 13 and 14 for the first and second sample periods, respectively.

The ratio of Mg:P was positively correlated to both leaf blade and petiole Mg levels in the first and second sample periods with coefficients greater than .550 (Tables 13 and 14). The Mg:P ratio indicates that higher P levels in the leaf tissue were associated with lower Mg levels in the tissue. Helmy et al. (1960) found P accumulated in Mg-deficient cotton blade tissue. The Mg:P correlations support these findings. Whether the ratio represents antagonism of P on Mg or a build up of P at low Mg levels is not known.

Correlation coefficients of $-.613^{xx}$ and $-.699^{xx}$ were found between leaf blade Mg and the ratio of Ca:B in the first and second samplings, respectively (Tables 13 and 14). Petiole Mg levels were correlated at the first and second sampling periods to the ratio of Mg (petiole tissue):Ca, with coefficients of .649** and .738**, respectively. The latter correlations may suggest antagonism of Ca on Mg, however, more work is needed for verification. Since Ca and B have been found antagonistic of each other (Olsen, 1972), B may be reducing the effect or competition of Ca on Mg. The solubilizing of Mg borates in the soil and precipitation of Carborates may be involved.

Potassium

In Cotton Tissue

The distribution, range, mean and standard deviation of K in cotton leaf blade samples are shown in Figure 6, Histograms A through C.

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Potassium

In Cotton Tissue

The distribution, range, mean and standard deviation of K in cotton leaf blade samples are shown in Figure 6, Histograms A through C.

Table 13. Correlation coefficients between elements in the leaf tissue and ratios of various elements in the leaf tissue for the first sample period.

	Leaf Blade										Petiole[1]	
	Mg	Ca	P	K	Mn	Fe	Cu	Zn	B	Na	NO_3-N	P
P:NO_3-N[1]	.117	.008	-.041	-.269**	-.104	-.051	-.032	-.007	.265**	.036	-.682**	.117
Mg:P	.583**	.199**	-.609**	-.080	-.095	.039	.021	.032	.345**	.296**	-.339**	.557**
Mg[1]:P	.177*	-.226**	-.743**	-.428**	-.145	-.222**	.738**	-.232**	-.037	.083	-.213**	.730**
K-NO_3-N[1]	.168*	.067	-.154	-.186*	-.087	-.034	-.029	-.031	.319**	.134	-.699**	.132
Mg:Ca	.473**	-.221**	-.261**	-.236**	-.263**	-.052	-.154	.054	.056	.011	-.196*	.562**
Mg[1]:Ca	-.182*	-.658**	-.444**	-.596**	-.269**	.399**	.459**	-.258**	-.416**	-.196*	-.024	.619**
Mg:NO_3-N[1]	.184*	.033	-.196*	-.271*	-.128	.063	-.049	-.051	.258**	.101	-.623**	.217**
Mg[1]:NO_3-N[1]	.096	-.059	-.235**	-.329*	-.145	-.118	-.102	-.091	.142	.033	-.544**	.256**
P:Fe	-.512**	-.651**	.166*	-.541*	-.439**	.785**	-.488**	-.368**	-.662**	-.300**	-.146	-.136
K:Zn	-.398**	-.307**	-.311**	.055	.294**	.343**	-.446**	-.679**	-.409**	-.076	.281**	-.248**
Na:Zn	.228**	.237**	-.171*	.099	.070	.039	.047	.113	.395**	.958**	-.172*	.115
Fe:Zn	.407**	.570**	.278**	.320**	.317**	.835**	.327**	-.030	.492**	.173*	.091	.099
Zn:NO_3-N[1]	.473**	.396**	.082	.033	.152	-.302**	.152	.349**	.601**	.218**	-.883**	.155
P:Zn	-.510**	-.399**	.153	-.302**	-.253**	-.356**	-.253**	.614**	-.507**	-.264**	.204*	-.245**
Ca:B	-.613**	-.455**	-.083	-.205*	.347**	-.444**	-.359**	-.342**	-.847**	-.403**	.522**	-.327**
Fe:Mn	-.496**	.438**	.315**	.460**	-.052	.729**	.212**	.361**	.436**	.133	-.034	.012
K:Mn	-.100	-.221**	-.106	.124	-.762**	-.227**	-.385**	.072	-.273**	-.084	.088	-.280**
Fe:Ca	.474**	.432**	.313**	.406**	.303**	.776**	.051	.298**	.460**	.159	.029	.205**
Fe:(Cu+Zn)	.419**	.523**	.298**	.442**	.417**	.854**	.290**	.009	.500**	.179*	.013	.109
P:K	-.141	-.117	.576**	-.439**	.008	.032	.035	.045	.125	-.245**	-.097	-.005

[1]Petiole tissue element * .05 **.01

Table 14. Correlation coefficients between elements in the leaf tissue, and ratios of various elements in the leaf tissue for the second sample period.

	Leaf Blade										Petiole[1]	
	Mg	Ca	P	K	Mn	Fe	Cu	Zn	B	Na	NO_3N	Mg
P:NO_3-N[1]	-.305**	.082	.256**	-.382**	-.202*	-.250**	.044	-.301**	.365**	-.097	-.543**	.019
Mg:P	.653**	.142	-.797**	-.301**	-.184*	.016	.026	-.066	.259**	.313**	-.112	.658**
Mg[1]:P	.397**	-.041	-.761**	.505**	-.194*	-.216**	.060	-.201*	.204*	.215**	-.313**	.844**
K:NO_3-N[1]	-.783**	-.121	.046	-.348**	-.225**	-.284**	.036	-.343**	.363**	-.082	-.569**	.081
Mg:Ca	.483**	-.477**	-.394**	-.202**	-.330**	.103	-.073	-.093	-.145	.227**	.021	.463**
Mg[1]:Ca	.064	-.589**	-.461**	-.487**	-.275**	-.405**	-.009	-.294**	-.174*	.117	-.344**	-.735**
Mg:NO_3-N[1]	-.072	.012	-.041	-.464**	-.254**	-.248**	.151	-.307**	.509**	.006	-.569**	.272**
Mg[1]:NO_3-N[1]	-.092	-.014	-.112	-.491**	-.252**	-.289**	.169*	-.306**	.441**	.019	-.553**	.366**
P:Fe	-.531**	-.358**	.522**	-.088	.009	.667**	.068	-.146	-.184*	-.325**	-.160	-.173
K:Zn	.429**	-.358**	-.127	.241**	-.118	-.227**	-.311**	-.691**	-.162*	-.244**	-.164*	-.200
Na:Zn	.352**	.106	-.277**	-.214**	-.236**	.054	.063	-.180*	.378**	.936**	-.054	.402**
Fe:Zn	.189*	.240**	.070	.043	-.108	.808**	-.119	-.301**	.171*	.067	-.040	.127
Zn:NO_3-N[1]	-.114	-.015	-.081	-.498**	-.021	-.163*	.047	-.057	.269**	-.067	-.950**	.345**
P:Zn	-.465**	.234**	.488**	-.145	-.098	-.218**	-.135	-.568**	-.003	-.274**	-.292**	.223
Ca:B	-.699**	.254**	.095	.387**	.473**	.181*	-.078	.262**	-.660**	-.239**	.385**	-.330**
Fe:Mn	.319**	.196*	.016	.010	-.515**	.733**	-.065	.029	.227**	.182*	.115	-.063
K:Mn	.019	-.302**	-.097	.189*	-.814**	.045	.224**	-.107	-.003	.126	.186*	-.136
Fe:Cu	.219**	.222**	.032	.232**	-.066	.892**	-.304**	.079	-.004	.059	.145	-.292**
Fe:(Cu+Zn)	.201*	.234**	-.004	.107	-.097	.859**	-.196*	-.227**	.121	.009	.019	-.179*
P:K	.0.	.129	.792**	-.457**	-.029	.001	.225**	.042	.231**	-.088	-.198*	-.018

[1]Petiole tissue element * .05 ** .01

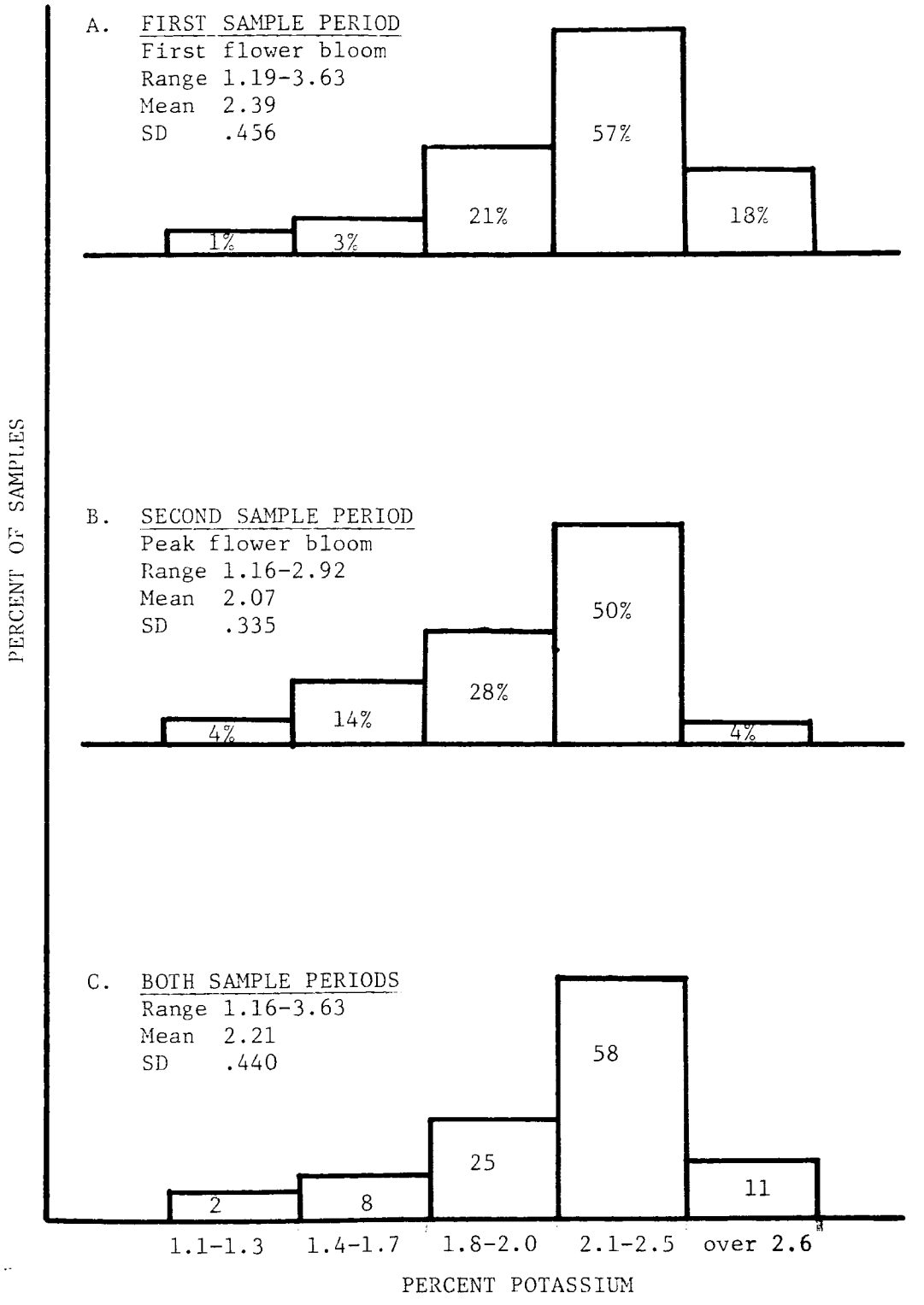

Figure 6. Distribution of K in the samples of cotton leaf blade tissue.

Potassium critical levels for cotton leaf blades have been established at .8 to .9% K (Appling and Giddens, 1954; Page et al., 1963; Ticknell et al., 1960) thus suggesting adequate levels of K were found in leaf blade samples collected during this survey. In addition, for cotton up to 90 days old, a K sufficiency of 2% (Appling and Giddens, 1954) and 1.5% (Ticknell et al., 1960) in leaf blade tissue has been suggested. At the second sampling, 10% and 46% of the leaf blade samples contain less than 1.5% K and 2% K, respectively.

The tissue analysis indicates all leaf blade samples were within established critical K levels. However, some tissue K levels may be borderline indicating that in the near future K fertilization may be required.

In the Soil

Although the K extraction procedure did not differentiate between water soluble and exchangeable K fractions in the soil, the water soluble K would be a very small percent of the total extracted K (McGeorge, 1933; Morse, 1982). The distribution of K in the soil as well as the range, mean and standard deviation is shown in Figure 7.

Although extracted K levels in the soil samples ranged from 118 to 500+ ppm K, 93% of the samples contained morethan 200 ppm K. Reisenauer et al. (1978) noted a response of cotton to fertilization is not likely if exchangeable K levels are greater than 100 or 80 ppm in clay or loamy soils, respectively. Analysis suggest all soils contained adequate amounts of K.

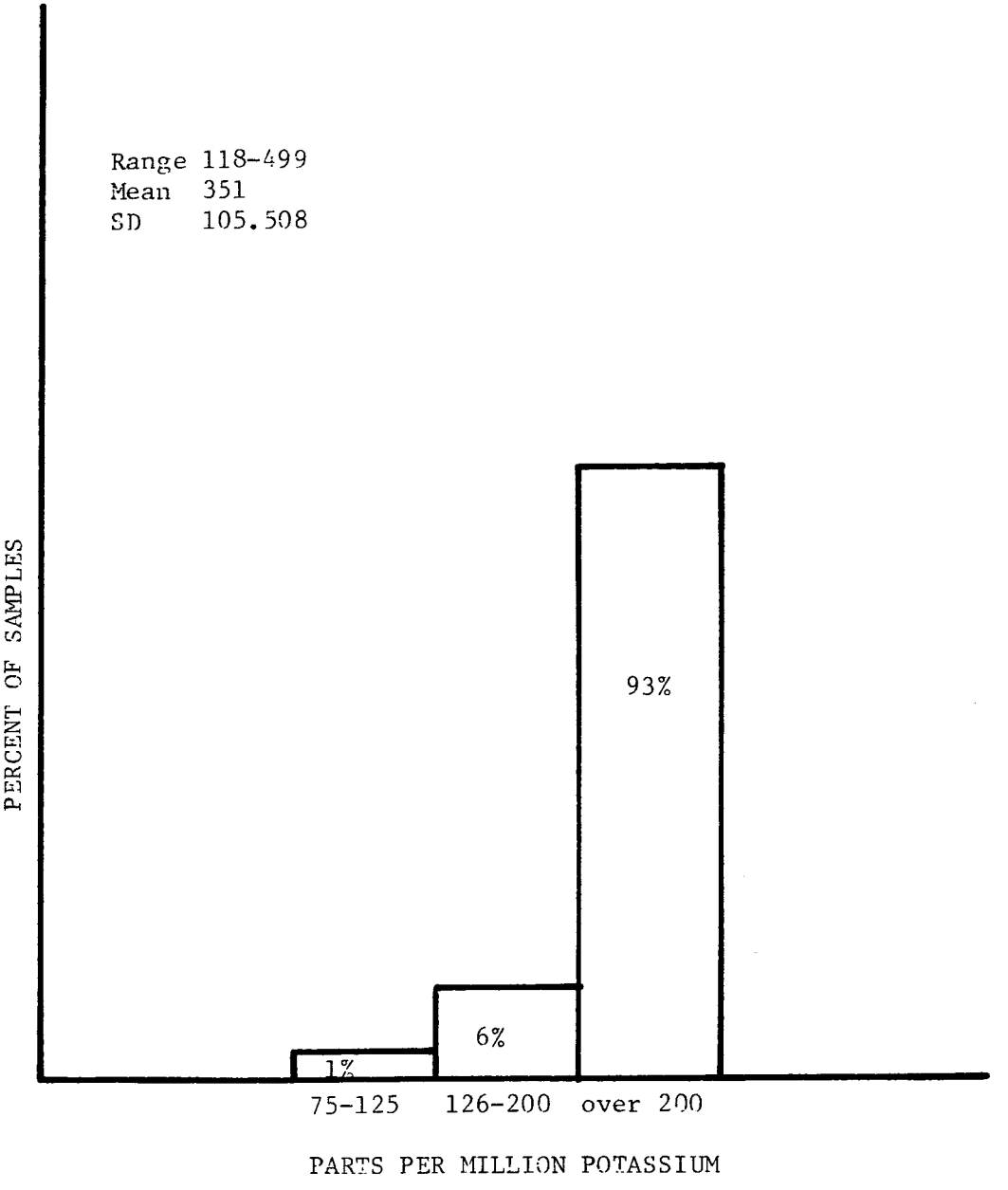

Figure 7. Distribution of K in the soil samples (25 cm depth).

Alternatively, when the average soil extracted K (water soluble plus exchangeable K fractions) and K in the irrigation water are added, (Tables 15 and 16) a total of 1,743 kg/ha represents the amount of K available for plant growth in the top 25 cm. Additionally, the total K available does not include K from depths greater than 25 cm, and the K released from fixed sources. Since about 11 kg/ha is removed in the lint and seed of a two-bale cotton crop (Williams, 1970), soils in the survey are assumed to have more than adequate K.

Correlation Analysis

The results of a simple correlation analysis between leaf blade K levels and all other plant elements analyzed are listed in Tables 6, 7 and 8 for the first and second sample periods and both periods combined, respectively.

All correlation coefficients in Tables 6 and 8 are below .550. In the second sample period, a correlation value of -.556** was found between petiole Mg and leaf blade K (Table 7). This correlation may indicate competition between Mg and K during absorption (Helmy et al., 1960; Maples and Keogh, 1974).

Overall, the magnitude of the correlation values in the first sampling compared to the second sampling may indicate a response from more active growth and nutrient uptake rather than cause and effect relationships.

Although only small correlations were found between leaf blade K levels and soil data when all soil samples were combined (Tables 9 and 10), a few larger correlations are evident when the samples are subdivided by soil texture (Table 17).

Table 15. Exchangable plus water soluble K in soil samples.

Soil	CEC**	meq/100g	kg/ha*	No. of Fields Represented
Clay	19.1	0.913	1.670	10
Clay Loam	17.7	1.026	1.876	18
Loam	13.1	0.941	1.721	26
Sandy Loam	10.2	1.027	1.878	27
All Soil	14.9	.946	1.730	109

*For the top 25 cm
**Calculated

Table 16. High, low and average K levels in irrigation water samples.

Water	ppm	kg/ha
High Mg	13.00	39.60
Low Mg	2.10	6.40
Average Mg	4.48	13.65

Based on 104.6 cm of water as the mean consumptive use.

Table 17. Correlation coefficients between leaf blade K and soil data (25 cm depth), after subdividing samples by soil texture.

Soil Texture	Sample Period	K	K^1	Ca^1	Mg^1	Na	NO_3	SAR^2	B
Clay	1		.620*						
	2					-.773**			
Clay Loam	1				.417*		.487*		
	2							.432*	
Loam	1	.436						.482	
	2	.555**						.428	
Sandy Loam	1			-.513*	.546*			.447	.542**
	2								

[1]Calculated saturation value

[2]Calculated sodium absorption ratio

* .05
**.01

In the clay textured soils, leaf blade K levels were positively correlated to calculated K saturation levels (r=.620*) in the first sample period, and negatively correlated to soil Na levels (r= -.773**) in the second sample period.

These correlation coefficients indicate the percentage of K on the exchange complex was the most important factor determining the K content of the samples in the first period, however, competitive effects of Na may have led to lower levels of K in plant tissue in the second sampling.

The results of a correlation analysis between various plant element ratios and leaf blade tissue K levels are shown in Tables 13 and 14 for the first and second sample period respectively.

The plant nutrient ratio of Mg (petiole tissue):Ca was negatively correlated to the plant K level in the first sample period (Table 13).

The Mg (petiole tissue):Ca ratio indicate higher levels of Mg in the petiole, relative to Ca levels in the blade, were associated with high K levels in leaf blades. Although these correlations suggest Ca can antagonize K levels in the petiole or will accumulate in the leaf blade when K is low in the petiole tissue, the correlation are not understood.

Phosphorus

In Cotton Tissue

The distribution of P in leaf blades in the first and second samplings, and both samplings combined are shown in Figure 8,

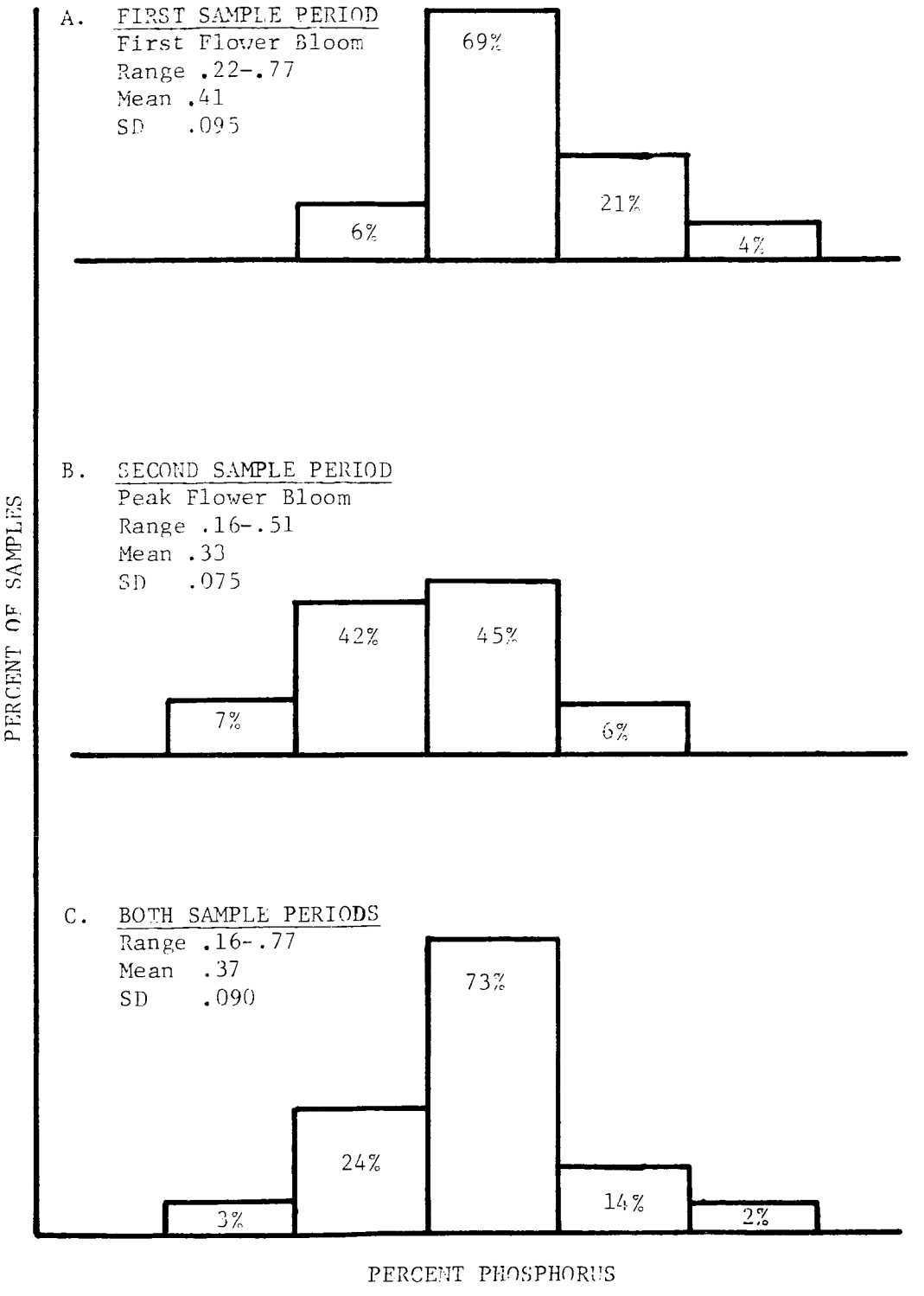

Figure 8. Distribution of P in the samples of cotton leaf blade tissue.

Histograms A through C. The range, mean and standard deviation are also included.

As reported in Chapman (1966), and Sabbe et al. (1972), the P sufficiency range for cotton leaf blade tissue up to peak bloom is .30 to .50% P. Albeit Figure 8 shows 94% of the leaf blade samples contained more than .30% P in the first sampling (Histogram A). In the second sampling 49% of the samples were below .3% P. In addition, 7% of the leaf blades contained less than .2% P (Histogram B) in the second sample period.

Although P is known to decline during the growing season from a dilution effect (Jones and Bardsley, 1968) a large percentage of the leaf blade P levels were below established sufficiency ranges suggesting the need for additional available P.

In the Soil

The distribution of P in the soil samples, along with the range, mean and standard deviation is shown in Figure 9. Reisenauer et al. (1978) reported a response in cotton is likely if soil P levels are below 5 ppm ($NaHCO_3$ extract). McGeorge (1940) reported soils in Arizona are deficient in P if soil levels are below 1.6 ppm P, and that soils are probably deficient in available P if levels are below 3.3 ppm P (CO_2 extract). Mueller (1981) studied both CO_2 and $NaHCO_3$ extraction procedures for soil P. He found the $NaHCO_3$ extract removed 2.44 more P than does a CO_2 extractant.

It is difficult to compare the soil results with such a wide range of recommended soil P levels (1.6 - 3.3 ppm P). If the lower

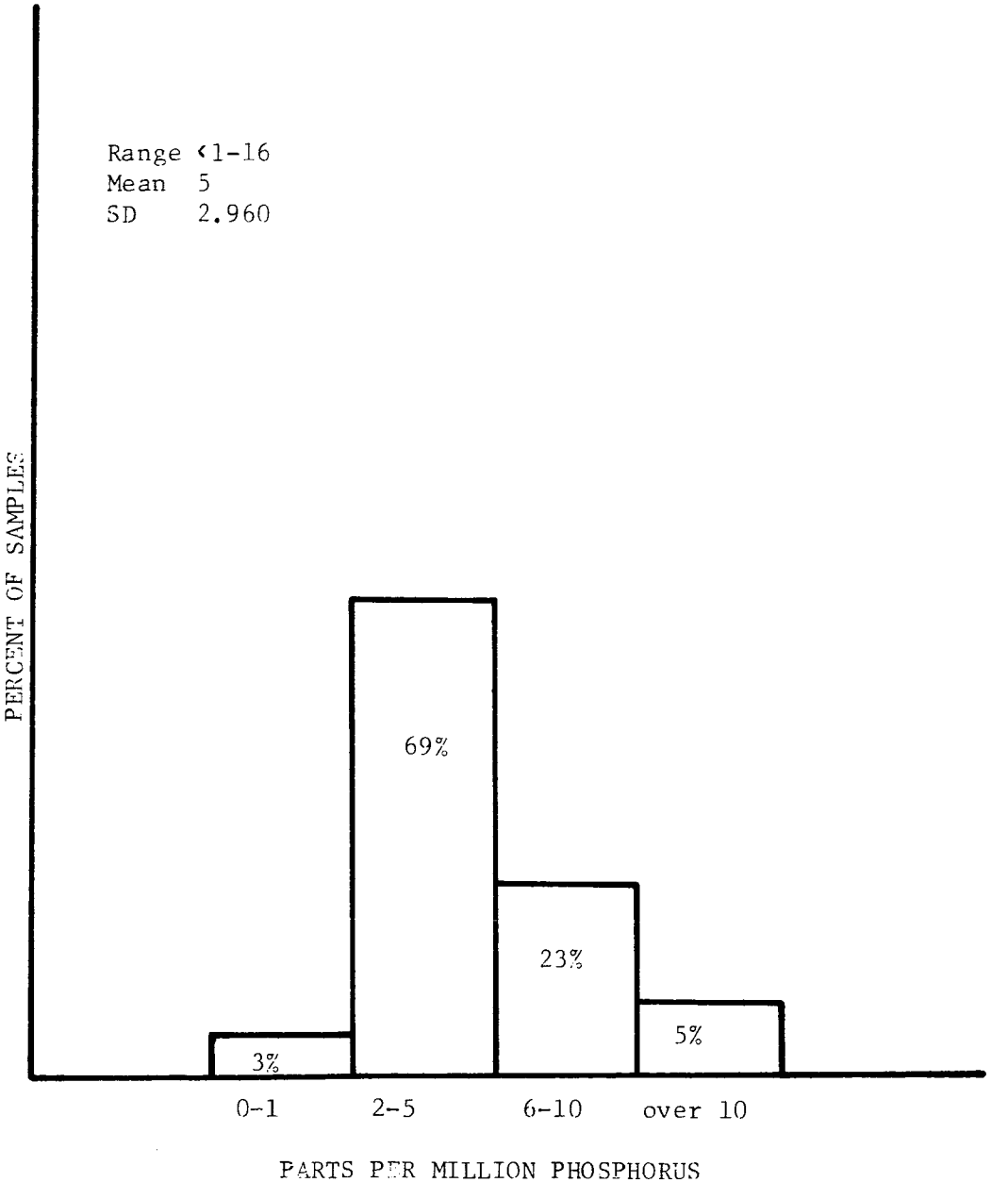

Figure 9. Distribution of P in the soil samples (25 cm depth CO_2 extract).

level of 1.6 ppm P is used to interpret the soil analysis, only 3% of soils may require P fertilization. However, if the upper range of 3.3 ppm P is used to interpret the results, up to 38% of the soils analyzed would be considered low in P. The soil samples containing below 3 ppm were not confined to a particular region or soil type, indicating soil P may be low in many soils across Southern Arizona, regardless of soil type or texture. Both soil and plant tissue results indicate P may be limiting to plant growth in a large percentage of fields sampled in this survey. Since P critical levels for cotton leaf blade or petiole tissue have not been established in Arizona, and guidelines for interpreting soils analysis (McGeorge, 1940) are over 40 years old, further research is urgently needed to establish P fertilization guidelines for cotton in Arizona.

Correlation Analysis

The results of simple correlation analysis between leaf blade P levels and the other plant element levels for the first and second sample periods, and both periods combined are shown in Tables 6, 7 and 8, respectively. The correlation analysis results between leaf blade P levels and all soil, data is shown in Tables 9 and 10 for the first and second sample periods, respectively.

Correlation values of leaf blade P tissue levels with all other plant elements in both first and second sample periods were less than .550.

Although correlation values between leaf blade P levels and soil P levels were greater when soils were extracted with CO_2 ($r = .502$)

as opposed to Bray P-1 (Sabbe, 1980) solution (r = .114, Table 9), the values were less than .550. Table 18 shows the correlation coefficients between soil P and leaf blade P levels in loam and sandy loam soils. These values suggest the CO_2 extract estimates available P levels in coarser textured soils better than fine textured soils, however the correlation coefficients for the CO_2 are small.

The results of a correlation analysis between various plant element ratios and the leaf blade tissue P levels are shown in Tables 13 and 14 for the first and second sample period, respectively.

In the first and second sample periods, the Mg:P ratio in the leaf blade tissue was correlated to leaf blade P levels with correlation coefficients of 0.609** and -.792**, respectively. Likewise, the Mg (petiole tissue):P ratio was correlated to the leaf blade P level with coefficients of .-743** and .761**, respectively. These correlations indicate P accumulates in the leaf blade tissue as Mg levels in the plant decrease. As mentioned earlier, Helmy et al. (1960) reported a similar relationship between Mg and P in cotton. These data suggest Mg is vital to plants for normal P metabolism.

Leaf blade P levels were positively correlated to the ratio of P:K in the leaf blade with correlation coefficients of .576** and .792** in the first and second sample periods, respectively. The correlations suggest increases in tissue K are associated with decreased tissue P levels. Since no work indicating antagonism between P and K in cotton was found, further investigation is needed to explain the suggested P and K interaction.

Table 18. Correlation coefficients between leaf blade P and soil data (25 cm depth), after subdividing samples by soil texture.

Soil Texture	Sample Period	P^1	P^2	NO_3	Na	PH^3
Clay	1			.709*		
	2					
Clay Loam	1				-.668**	
	2	.477*				
Loam Soils	1		.723**			-.589**
	2		.464			-.706**
Sandy Loam	1		.529*			
	2	.505	.541*			

[1] Bray P-1 acid extraction

[2] CO_2 extraction

[3] 1:1 soil:water

Nitrogen

In Cotton Tissue

The distribution of NO_3-N in the petiole tissue samples from the first and second sample periods and both periods combined is shown in Figure 10, Histograms A through C. The range, mean and standard deviation are also included.

As noted in the literature review, sufficiency ranges for interpreting NO_3-N levels from cotton petiole analysis are established in Arizona. The recommended NO_3-N ranges for cotton at the first flower and peak flower bloom periods are 12,000 to 14,000 ppm and 6,000 to 8,000 ppm, respectively.

Figure 10 shows that at the first sampling period, 56% of the petiole tissue samples contained below 10,000 ppm NO_3-N while 29% of the samples contained less than 6,000 ppm NO_3-N.

At the second sampling period, 66% of the petiole tissue samples contained less than 6,000 ppm NO_3-N and 37% of the samples contained below 2,000 ppm NO_3-N.

The petiole analysis indicates NO_3-N may be a limiting factor to cotton growth. According to fertility guidelines established in Arizona, a yield response to NO_3-N fertilizer could be expected in over 50% of the fields sampled in this survey.

In the Soil

The distribution of NO_3 in the soil samples, along with the range, mean, and standard deviation is shown in Figure 11. This figure represents 75% of the fields sampled in the survey. To interpret the soil

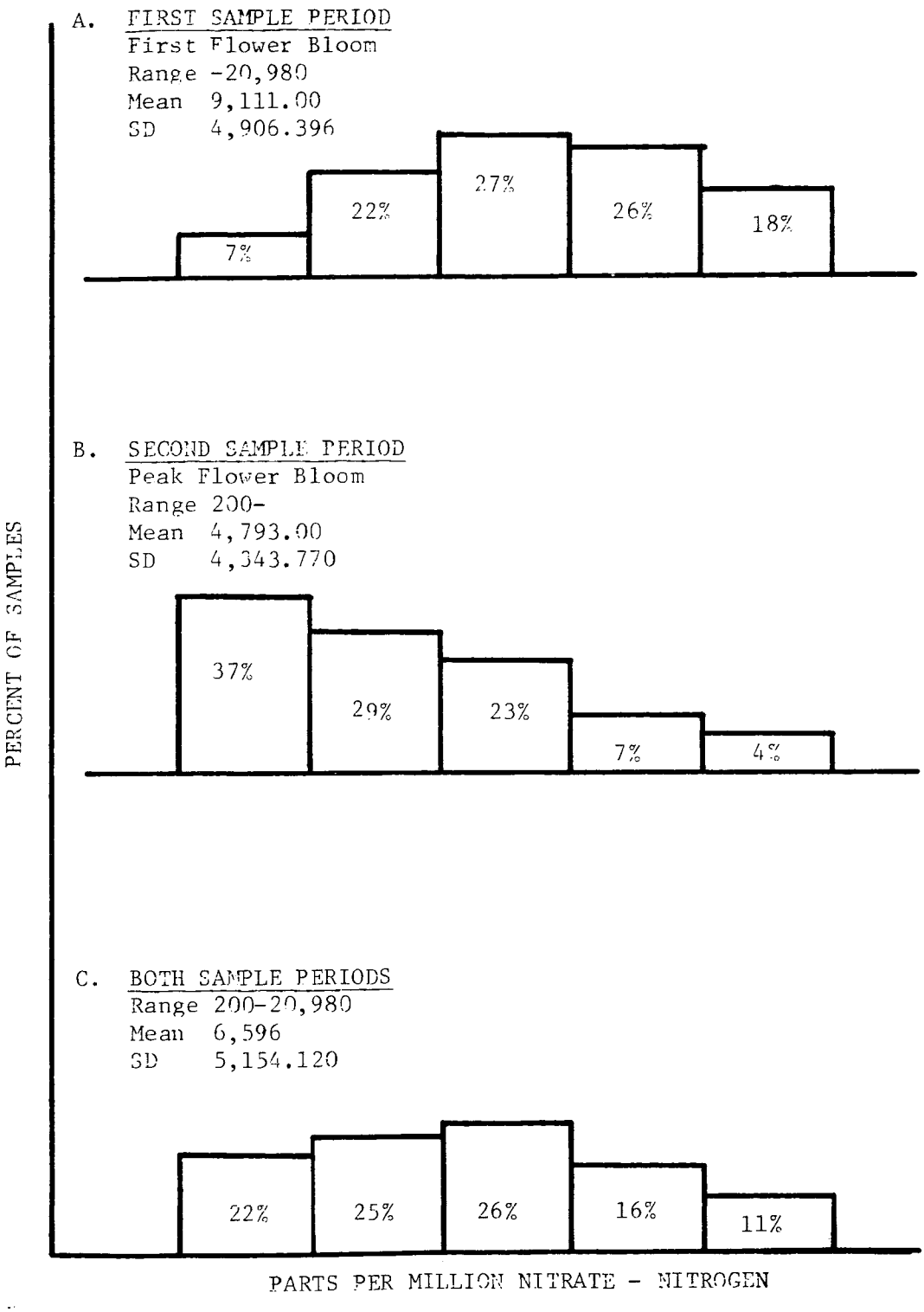

Figure 10. Distribution of NO_3 in the samples of cotton petiole tissue.

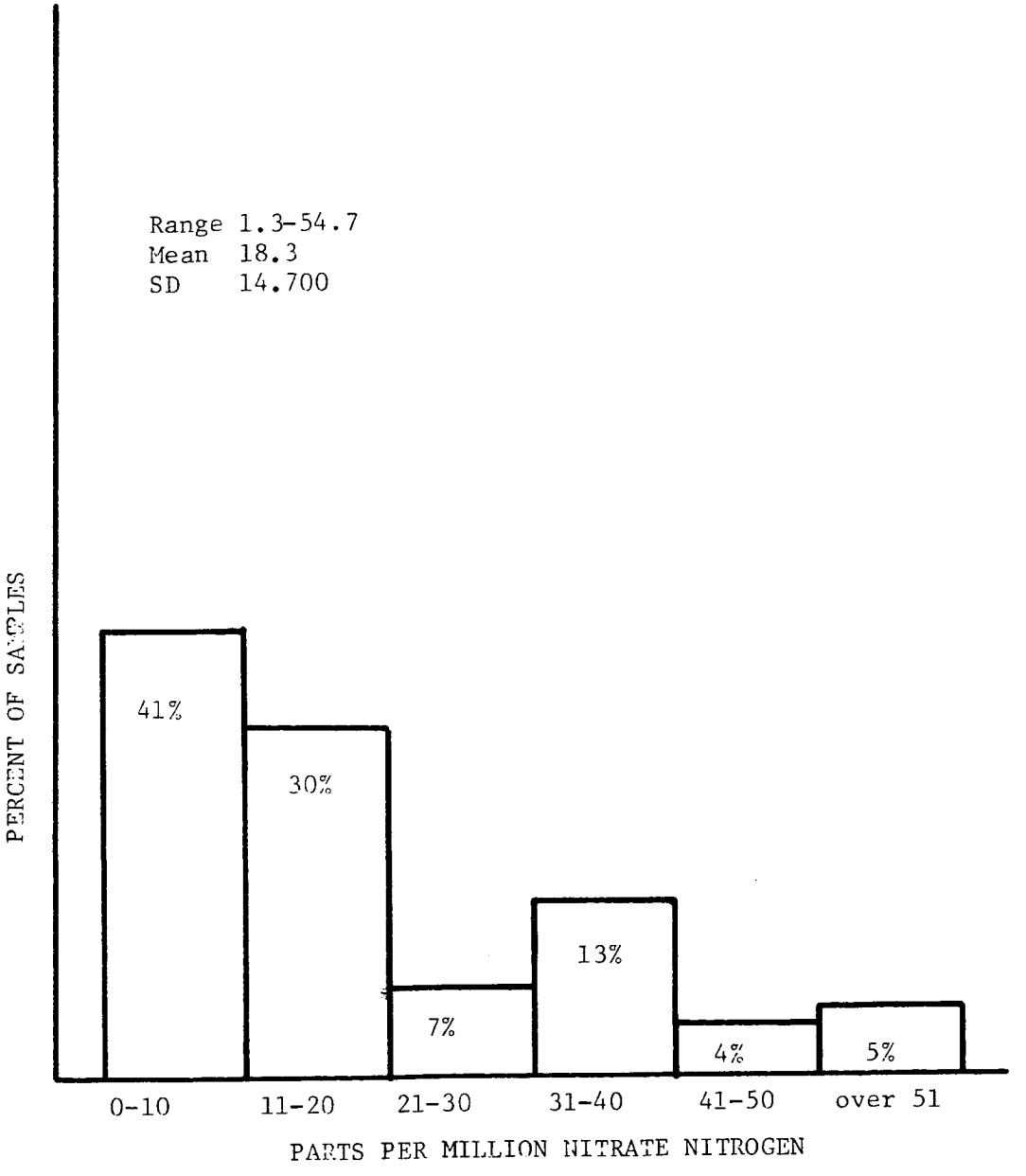

Figure 11. Distribution of NO_3 in the soil samples (25 cm depth).

analysis, NO_3 soil data were compared to the fertility guideline yield curve presented by Gardner (1963). His curve suggested a three-bale-per-acre cotton yield requires more than 55 ppm NO_3 in the soil. Likewise, 2.5, 2 and 1.5 bale yields per acre required soil NO_3 levels greater than 30, 20, and 5 ppm, respectively.

Figure 11 shows that 5% of the soils analyzed contained more than 51 ppm NO_3, 17% contained between 31 to 50 ppm NO_3, 37% contained between 11 and 30 ppm NO_3-N and 41% of the soils contained less than 10 ppm NO_3. These data indicate more than 50% of the soils analyzed were insufficient in NO_3 so far as needed to produce a two-bale-per-acre yield.

Overall, both the soil and petiole tissue analysis indicate nitrogen may be limiting cotton yields in many fields sampled in this survey.

Correlation Analysis

The results of simple correlation analysis between petiole NO_3-N levels and the other plant element levels for the first and second sample periods, and both periods combined are shown in Tables 6, 7 and 8, respectively. Tables 9 and 10 show the correlation coefficients between petiole NO_3-N and all soil data for the first and second sample periods, respectively.

Neither tissue sampling nor soil data showed correlation coefficients equal to the .550 level used as a basis of discussion in this paper.

The samples were subdivided according to soil texture, and the correlation analysis between petiole NO_3-N levels and the soil data was repeated (Table 19).

In the clay textured soils in the second sample period, petiole NO_3-N levels were negatively correlated to total Na and the SAR values with correlation coefficients -.713* and -.679*, respectively. Data suggest that Na affected NO_3-N concentration in the cotton tissue.

Petiole NO_3-N levels were also correlated to soil NO_3 levels during the second sampling period in the clay loam and sandy loam texture soils, with coefficients of .657* and .513*, respectively. In addition, positive correlations greater than .550 are seen between petiole NO_3-N levels and the pH and total K values in the clay loam soils, respectively. These relationships are not understood.

The results of a correlation analysis between various element ratios in the leaf blade tissue and petiole tissue NO_3-N levels are shown in Tables 13 and 14 for the first and second sample periods, respectively. Among the 20 nutrient ratios analyzed, P:NO_3-N, K:NO_3-N, Mg:NO_3-N and Zn:NO_3-N were negatively correlated to petiole NO_3-N levels. These values indicate K, P, Mg and Zn accumulate in leaf blade tissue as NO_3-N levels in the petiole tissue decline.

The correlation values of -.883** and -.950** for the first and second periods, respectively between the Zn:NO_3-N ratio and petiole NO_3-N levels was greater than other ratios.

Although further investigation is needed, these ratios may indicate that during the growing season readily available source of Zn, P, K and Mg may increase the maturation rate of the plant by increasing

Table 19. Correlation coefficients between petiole NO_3-N and soil data (25 cm depth), after subdividing samples by soil texture.

Soil Texture	Sample Period	K	Ca	Zn	NO_3	pH[1]	SAR[2]	Na
Clay	1					.898**		
	2						-.713*	-.679*
Clay Loam	1							
	2				.657*			
Loam	1		.476*					
	2	.696**		.479*		.487*		
Sandy Loam	1		.424					
	2		.473		.513*		.598**	

[1]Soil water paste determination

[2]Calculated sodium absorption ratio

*.05
**.01

the element:NO_3-N ratio of which was correlated with lower petiole NO_3-N levels. In support, Hinkle and Brown (1968) show Zn deficiency delays the maturity of cotton.

Calcium

In Cotton Tissue

The distribution of Ca in leaf blade tissue samples from the first and second samplings and both sample period combined is shown in Figure 12, Histograms A through C. The range, mean and standard deviation are also included.

Although Ca critical levels for cotton leaf blade tissue are not readily found in the literature, Sabbe et al. (1972) suggests a Ca sufficiency range for leaf blade tissue of 2.25 to 3.00%. The range and mean levels of Ca in all leaf blade tissue samples was 2.4 to 6.8% Ca and 4.4% Ca, respectively.

In the Soil

The distribution of Ca found in the soil samples is not presented. Since the pH level of most agronomic soils in Arizona are greater than 7.0, the extraction procedure (NH40AC, 1N, pH 7.0) may have solubilized some calcium carbonates. The range and mean level of Ca extracted was 2.4 to 19.9 meq/100 g soil and 11.24 meq/100 g soil, respectively.

Correlation Analysis

The results of a simple correlation analysis between leaf blade tissue levels of Ca and the other plant tissue elements analyzed are

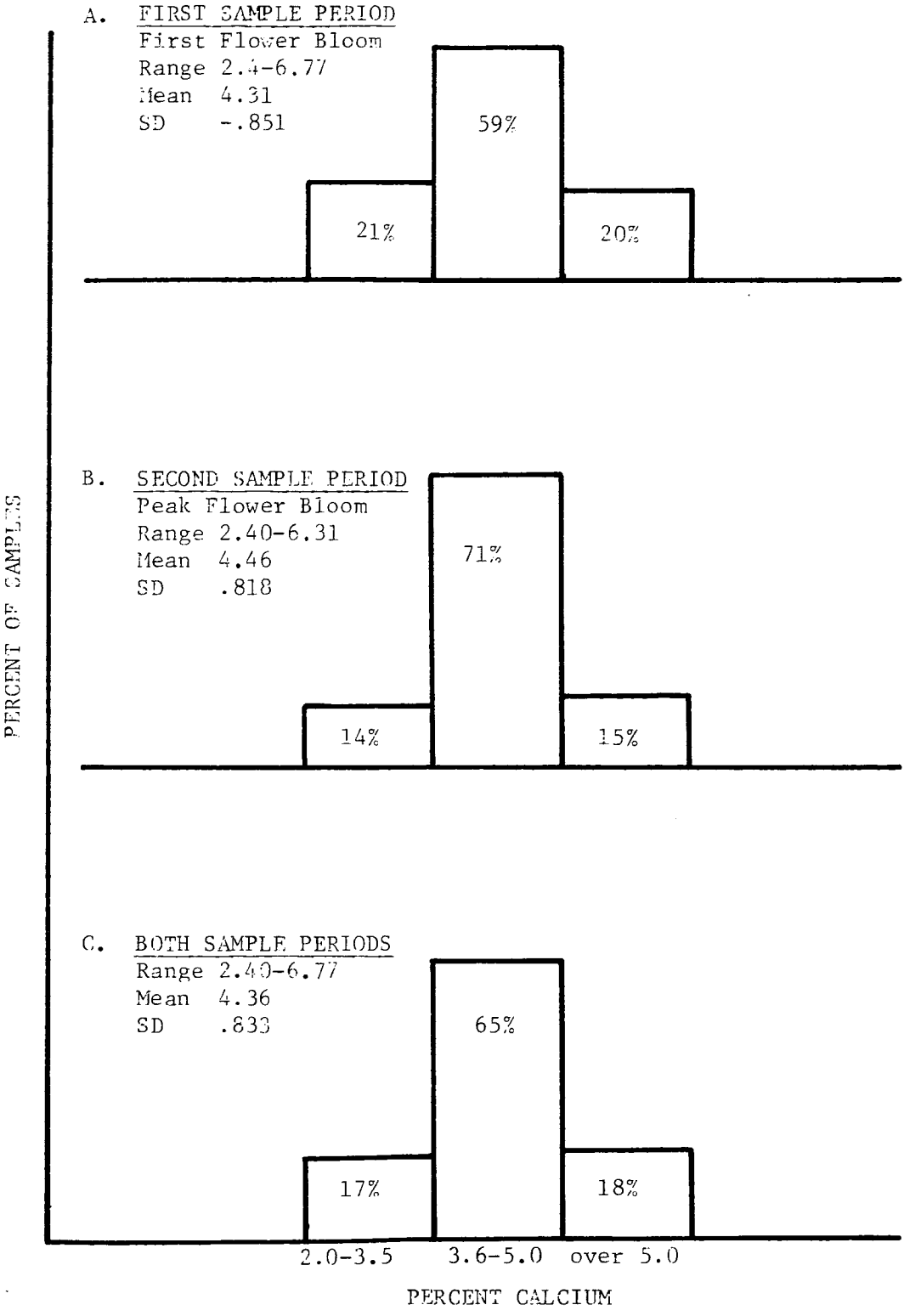

Figure 12. Distribution of Ca in the samples of cotton leaf blade tissue.

listed in Tables 6, 7 and 8 for the first and second sample periods and both periods combined, respectively. In addition, leaf blade Ca levels were correlated to all soil data. These results are listed in Tables 9 and 10 for the first and second sample periods, respectively.

Correlation values in the second sample period of leaf blade Ca levels were less than the .550 level used as a basis for discussion in this paper (Table 7).

In the first sample period (Table 6), leaf blade tissue Ca was positively correlated to the leaf blade and petiole Mg levels with coefficients of .746** and .066, respectively. The large variation indicates a general increase of Ca and Mg in the leaf blade tissue as opposed to a cause and effect relationship.

Leaf blade tissue levels of Ca and B were correlated in the first and second sampling periods with correlation coefficients of .798** and .545** respectively. Leaf blade Ca levels were also correlated to leaf blade levels of K, Fe, Cu and Al in the first sample period with correlation coefficients larger than .550. These correlations do not necessarily represent cause and effect relationships.

As reviewed by Olsen (1972), Ca and B antagonism has been identified with many crops, including cotton. In addition, oxides and hycroxyloxides of Fe and Al are major sites of B absorption in soil (Ellis and Knezek, 1972). The correlation coefficients between leaf blade tissue levels of Ca and B, K, Fe, Cu and Al could be an indication of increased nutrient levels in response to more favorable growing conditions.

Although correlation coefficients were less than .550 between Ca in leaf blade tissue and all soil data in general (Tables 9 and 10), the correlation values increased when the samples were subdivided according to soil texture (Table 20).

Negative correlation coefficients -.695** and -.732** between Ca in the leaf blade tissue and the total soil and calculated saturation soil K levels, respectively in the clay texture soils indicate K may adversely affect tissue Ca levels. The correlation values indicate the percent exchangeable K strongly affected leaf blade Ca levels in the first sample period while the total soil K level influenced tissue Ca levels in the second sample period. Also since leaf blade Ca levels were negatively correlated to the total Na level and the SAR in the clay textured soils, Na may have affected leaf blade tissue Ca levels in the first sample period. In addition, positive correlations appeared with the soil's SAR value in the clay loam and sandy loam soils. Although these correlations suggest higher soil Ca concentrations resulted in lower leaf blade Ca levels.

The results of a correlation analysis between various plant element ratios and leaf blade tissue Ca levels are shown in Tables 13 and 14 for the first and second sample periods, respectively.

The P:Fe ratio was negatively correlated to Ca in the leaf blade tissue with a coefficient of -.651** during the first sample period (Table 13). The correlation may indicate an indirect synergistic relation between Ca and Fe in so far as Fe's negative affect on P in plants (Gauch, 1972; Olsen, 1972). The relationship is not understood.

Table 20. Correlation coefficients between leaf blade Ca and soil data (25 cm depth), after subdividing samples by soil texture.

Soil Texture	Sample Period	K	K[1]	Ca	Ca[1]	Mg[1]	Mg	Na	SAR[2]
Clay	1		-.732**					-.806**	-.479*
	2	-.695**		-.844**					
Clay Loam	1				-.551**	.600**			
	2								
Loam	1							.503*	.503*
	2			.554**					
Sandy Loam	1			-.444*	-.431*	.554**		.576**	.593**
	2								

[1]Calculated saturation value

[2]Calculated sodium absorption ratio

*.05
**.01

Leaf blade Ca levels were negatively correlated to Mg (petiole tissue): Ca with correlation coefficients of -.658** and -.589** in the first and second sample periods, respectively. The coefficients indicate an antagonistic affect of Mg on Ca and may reflect competition for absorption by the root.

Aluminum

Aluminum is not an essential plant nutrient and therefore a recommended Al range for cotton leaf blade tissue is not available. Since Al solubility in soils is low; at pH levels greater than 7.0, toxicity is not a problem in the alkaline soils of Southern Arizona.

Barium

Although Ba is neither an essential plant nutrient or toxic soil element, some investigators suggest Ba can replace Ca and stimulate plant growth (Bollard and Butler, 1966). Chapman (1966) listed intermediate Ba levels for cotton ranging from 35-110 ppm. The cotton leaf blade samples contained from 4 to 87 ppm Ba. A review by Gauch (1972) shows the amount of Ba absorbed by plants is roughly dependent on the exchangeable Ba in the soil. Although Ba levels found in the cotton leaf blade tissue samples appear outside the range reported by Chapman (1966), detrimental effects from low Ba in plants has not been shown. The correlation coefficients given in Tables 6, 7 and 8 do not indicate any adverse affects of Ba on the other elements in cotton tissue samples.

Boron

In Cotton Tissue

The distribution of B in the leaf blade tissue samples from the first and second sampling periods and both periods combined is shown in Figure 13, Histograms A through C. The range, mean and standard deviation for each period is also included.

All leaf blade samples contained adequate amounts of B when compared to the published critical levels of 20 ppm (Tucker, personal communication, 1982; Sparr et al., 1968; Castenson, personal communication, 1967). Boron toxicity in cotton has been observed at tissue levels greater than 200 ppm (Sparr et al., 1968). In the first and second sample periods, 9% and 3% of the leaf blade samples, respectively, contained more than 200 ppm. The maximum level of B in all tissue samples was 254 ppm. High leaf blade B levels were not consistent within soil type or sampling areas.

In the Soil

Figure 14 shows the distribution of B in the soil samples along with the range, mean and standard deviation.

For cotton production, .5 ppm B is recommended as a soil critical level (Anderson and Boswell, 1968; Reisenauer et al., 1973) and 5 ppm B as a soil toxicity level (Sabbe, 1980; Reisenauer et al., 1973). Using these concentrations for interpretation, Figure 14 shows 40% of the soils contain .3 to .5 ppm B and 28% of the soils contained 0 to .25 ppm B. Boron toxicity was not a problem in these soils since the maximum B concentration was 1.8 ppm.

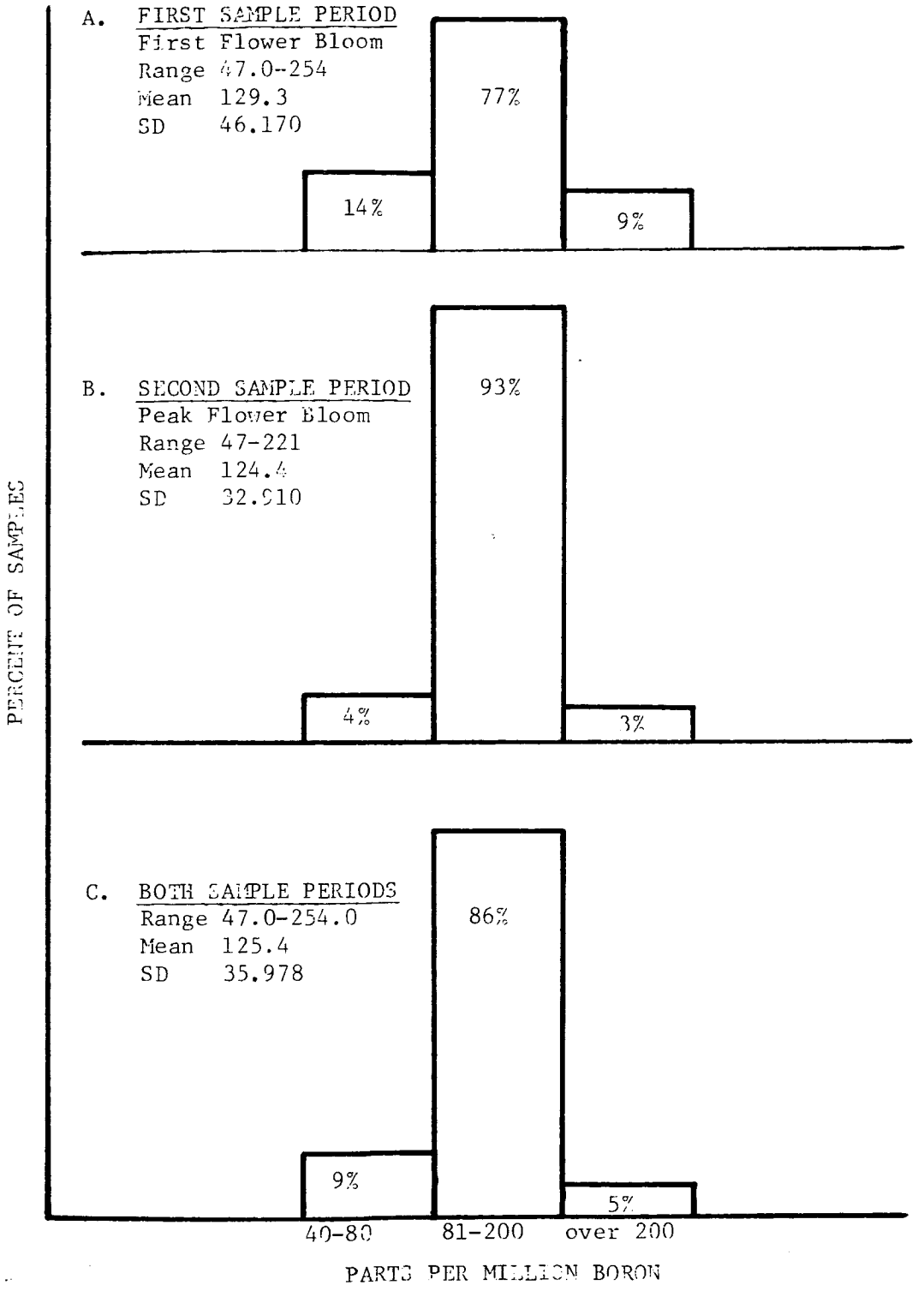

Figure 13. Distribution of B in the samples of cotton leaf blade tissue.

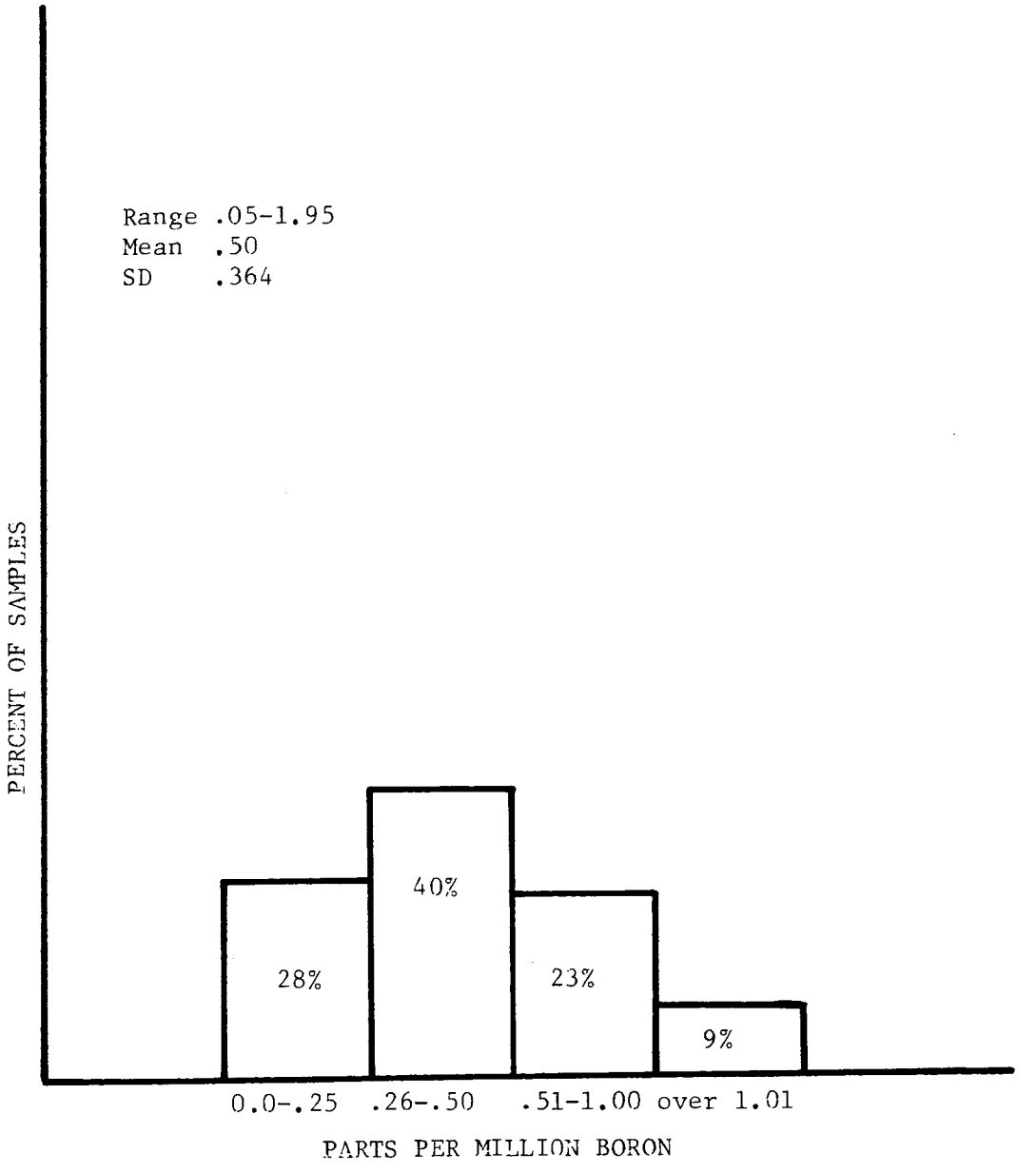

Figure 14. Distribution of B in the soil samples (25 cm depth).

These soil analysis indicates B fertilization may be beneficial in a large portion of the soils sampled. However, the leaf blade tissue samples appeared to contain adequate levels of B. This would indicate the soil extracted B was not well correlated with B absorption in the cotton plant.

Correlation Analysis

The results of a simple correlation analysis between leaf blade tissue B levels and the other plant elements for the first and second sample periods and both periods combined are shown in Tables 6, 7 and 8 respectively. Tables 9 and 10 lists the correlation coefficients between leaf blade B levels and all soil data for the first and second sample periods, respectively.

In the first and second sample periods, leaf blade tissue levels of Ca and B were correlated with coefficients of .798** and .545**, respectively (Tables 6 and 7). Since excessive Ca is known to adversely affect B availability through unfavorable Ca:Ba ratios (Olsen, 1972), the correlations between Ca and B probably reflect a general storage of nutrients in the leaf blade tissue. In the first sampling period, leaf blade B levels were also correlated to tissue levels of Mg, Fe and Al with correlation coefficient of .764**, .627** and .609**, respectively. These correlations do not necessarily represent cause and effect relationships. They could merely indicate increased nutrient levels as a whole in response to more favorable conditions.

Since leaf blade B levels were poorly correlated to the soil data the samples were subdivided by soil texture and the correlation analysis was repeated (Table 21).

Table 21. Correlation coefficients between leaf blade B and soil data (25 cm depth), after subdividing samples by soil texture.

Soil Texture	Sample Period	SAR[6]	pH[1]	pH[2]	Ca	Mn	B	K[2]	Ca[3]	Mg[3]	NO_3	P[4]	P[5]
Clay	1	-.784*				.602*							
	2		-.825**	-.748*			.723*					.874**	.789*
Clay Loam	1				-.475*				-.468*	-.488*	.614*		
	2					.637**							
Loam	1	.521*					.725**	.528			.570**		
	2												
Sandy Loam	1	.548*			-.481				-.465	-.567**			
	2	.594**								.487			

[1] 1:1 soil:water extract

[2] Soil:water paste extract

[3] Calculated saturation value

[4] Bray P-1 extract

[5] CO_2 extract

[6] Calculated sodium absorption ratio

* .05

**.01

In clay textured soils, leaf blade B was negatively correlated to total Na and the SAR value (Table 21) during the first sample period with correlation coefficients of -.786* and -.784*, respectively. It appears that Na affects B tissue levels by reducing the availability of soil B to the plant, since negative correlations between Na and B were not evident in the leaf blade tissue. At the second sampling period in the clay texture soils, leaf blade B was negatively correlated to soil pH and positively correlated to soil P levels. These coefficients indicate higher B tissue levels were associated with lower soil pH values. Since greater B availability in soil is commonly associated with decreasing soil pH (Hinkle and Brown, 1968; Traynor, 1980) the correlations coefficient may be reflecting a true relationship.

Soil B levels were correlated to leaf blade B levels in the clay and loam soils at the second sample period with correlation coefficients of .723* and .725*, respectively.

The results of a correlation analysis between various plant element ratios and the leaf blade tissue levels of B are shown in Tables 13 and 14 for the first and second sample periods respectively.

Leaf blade B levels were correlated to the element ratios of P:Fe, Zn:NO_3-N and Ca:B. The Ca:B correlation coefficients of -.847** and -.660** in the first and second sample periods, respectively, indicate higher tissue levels of Ca were associated with lower tissue levels of B. As mentioned earlier, Ca antagonizes absorption of B in cotton and other plants (Olsen, 1972). The Ca:B correlation coefficients may be reflecting the antagonism of Ca on B.

The ratios of P:Fe and $Zn:NO_3$-N were also correlated to B in the leaf blade tissue in the first sampling period with coefficients of -.662** and -.601**, respectively. These correlations indicate higher tissue levels of P or N relative to Fe and Zn, respectively, were associated with lower leaf blade tissue levels of B. This implies that conditions favoring Fe or Zn absorption also favored B absorption. Although Fe-Borate complexes in the form of oxides and hydroxyoxides are common in high pH soils (Ellis and Knezek, 1972), and the environmental conditions favoring Fe availability would also favor B availability, information regarding a Zn-Borate complexes in the soil was not found. More work is needed to explain the P:Fe and $Zn:NO_3$-N relationship with B.

Copper

In Cotton Tissue

The distribution of Cu found in the leaf blade tissue samples from the first and second sample periods and both periods combined is shown in Figure 15, Histograms A through C.

The critical level for Cu in leaf blade tissue range from 5 to 10 ppm (Castenson, personal communication, 1967; Sparr et al., 1968; Tucker, personal communication, 1982). The wide range in critical levels makes it difficult to interpret the cotton tissue results. If 5 ppm Cu is used as the critical value, only 1% of the samples in both sampling periods would be regarded as deficient in Cu. If a critical level of 10 ppm is used for interpretation, 48% and 71%, respectively of the leaf blade samples in the first and second sample periods

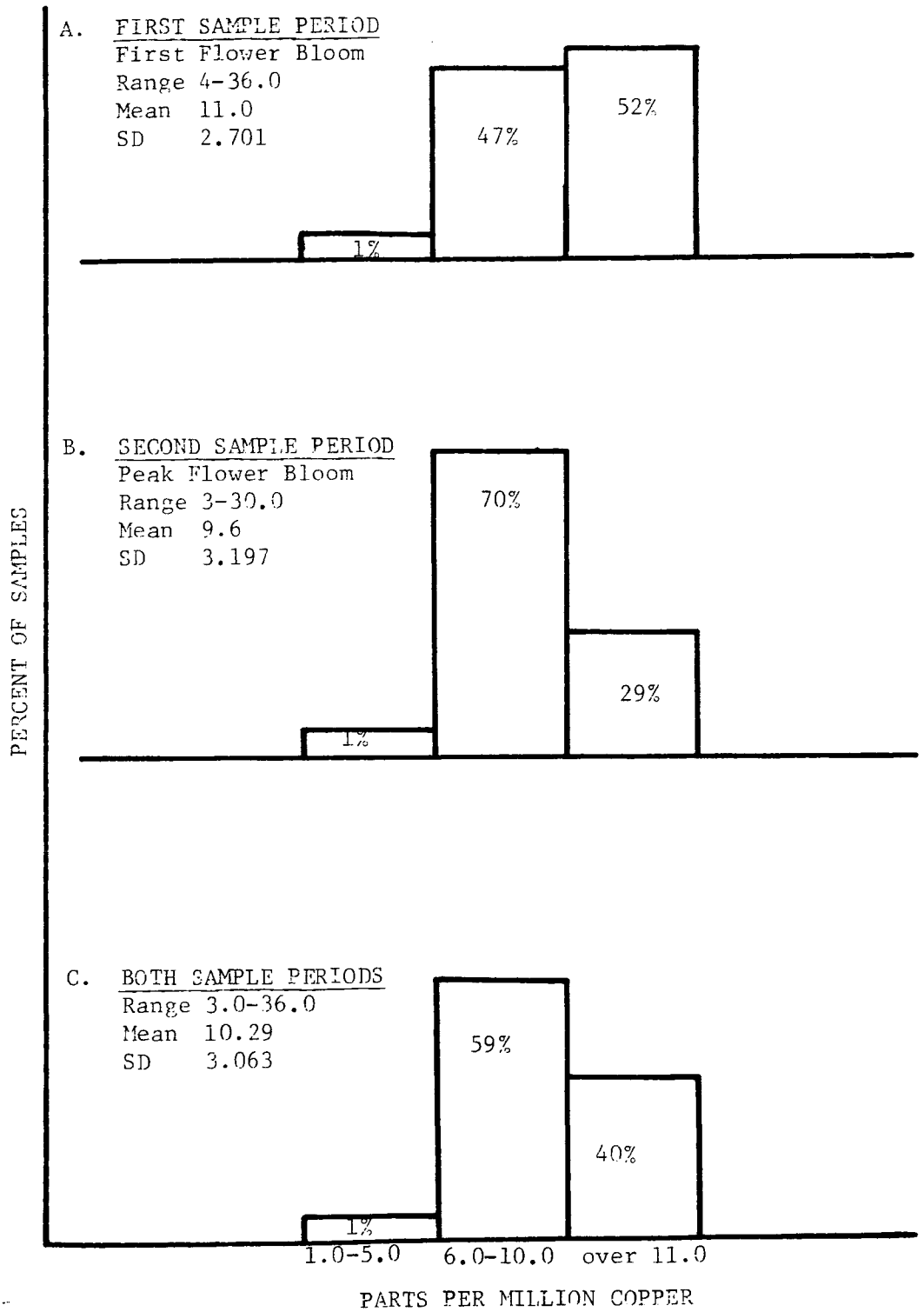

Figure 15. Distribution of Cu in the samples of cotton leaf blade tissue.

would be deficient. If 7 ppm Cu is used as the critical level, 7% and 22% of the tissue samples in the first and second sampling periods, respectively, would be considered deficient in Cu.

Although a yield response to Cu fertilizer of cotton in Arizona has not been published, the leaf blade tissue analysis indicate Cu may be limiting growth depending upon the critical value used to interpret tissue results.

In the Soil

The distribution of Cu in the soil samples along with the range, mean and standard deviation is shown in Figure 16. Copper critical levels for soils under cotton production were not found in the literature. For soils in general, Sabbe (1980) noted Cu levels of .5 to .9 ppm as low. Using these guidelines to interpret the soil analysis, 94% of the soils contained adequate Cu, while 4% may be low in Cu.

Since Tables 9 and 10 show no correlation existed between the leaf blade and soil levels of Cu, immediate emphasis should be placed on developing Cu critical levels for leaf blade tissue.

Correlation Analysis

The results of a simple correlation analysis between leaf blade tissue levels of Cu and other plant tissue elements are listed in Tables 6, 7 and 8 for the first and second sample periods and both periods combined, respectively.

In the second sampling period, there were no correlation coefficients greater than the .550 level.

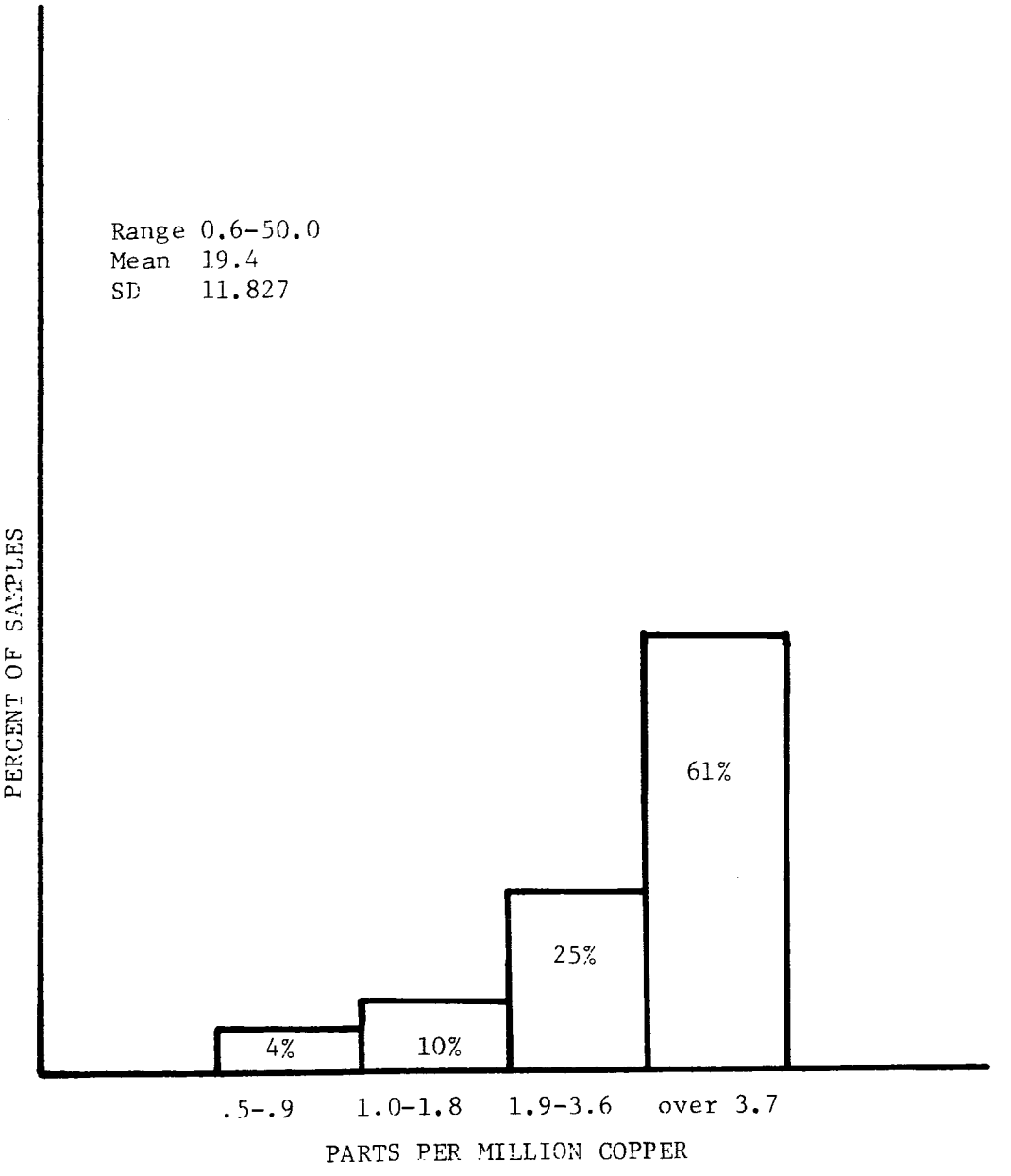

Figure 16. Distribution of Cu in soil samples (25 cm depth).

In the first sample period, leaf blade levels of Ca and Mn were correlated to Cu with coefficients of .645** and .597**, respectively. Since correlation coefficients between Ca and Cu during the second sample period were small, the correlations in the first sample period probably represent nutrient uptake in response to more favorable growing conditions as opposed to cause and effect relationships.

Although correlation were less than .550 between Cu in the leaf blade tissue and all soil data (Tables 9 and 10), correlation coefficients greater than .550 were found when the samples were subdivided according to soil texture (Table 22). For the clay texture soils, the data in Table 22 show correlation coefficients of -.663*, -.668* and -.706* with soil P and B levels and the SAR values in the first sampling period, respectively. In the second sample period, in clay texture soils, Mg, Mn, N, P, B and the calculated CEC saturation levels of Ca and Mg were all negatively correlated with coefficients greater than .550, indicating an antagonistic relationship between these soil factors and the leaf blade levels of Cu.

In clay loam soils, NO_3 and P were correlated with coefficients of .651* and -.669*, respectively during the first and second sampling periods. While in the sandy loam soils, leaf blade Cu levels were correlated to the calculated Ca and Mg saturation levels at the first sampling period with correlation coefficients of -.609* and .716**, respectively.

No correlation coefficients greater than .550 were found in the loam textured soils.

Table 22. Correlation coefficients between leaf blade Cu and soil data (25 cm depth), after subdividing samples by soil texture.

Soil Texture	Sample Period	P[1]	P[2]	Mg	Mn	Mg[3]	Ca[3]	NO_3	pH	pH[5]	SAR[6]	B
Clay	1								.608*		-.706	-.668
	2	-.634*	-.663*	-.597*	-.579*	-.633*	.650*	-.717*		.619*		-.555
Clay Loam	1							.651*				
	2	-.669*										
Loam	1	.425								-.489		
	2								-.481			
Sandy Loam	1					.716**	-.609*	.458				
	2											

[1] CO_2 extraction

[2] Bray P-1 acid extraction

[3] Calculated saturation value

[4] 1:1 soil:water extraction

[5] Paste soil-water determination

[6] Calculated sodium absorption ratio

* .05

** .01

Overall, many of the soil factors appeared to influence Cu in the leaf blade tissue both positively and negatively depending upon the soil texture.

Tables 13 and 14 show correlation coefficients values between Cu in the leaf blade tissue and for various plant element ratios were less than .550.

Iron

In Cotton Tissue

The distribution of Fe in the leaf blade tissue samples from the first and second sampling periods and both periods combined is shown in Figure 17, Histograms A through C. The range, mean and standard deviation for each period is also included.

At North Carolina State, Tucker (personal communication, 1982) reported Fe critical levels for cotton leaf blade tissue of 30 ppm. Castenson (personal communication, 1967) suggested that deficiency occurs when leaf blade Fe levels fall below 79 ppm, while Sabbe et al. (1972) reports a Fe sufficiency range for leaf blades of 50 to 250 ppm. The Fe concentrations in the cotton tissue samples ranged from 54 to 825 ppm.

Figure 17 shows that 4% and 19% of the leaf blade samples in the first and second sample periods, respectively contained 50 to 79 ppm Fe. All other tissue samples contained more than 80 ppm Fe. The leaf blade tissue samples from the second sample period containing 50 to 79 ppm Fe represented 48% of all fields sampled in the Willcox-Kansas

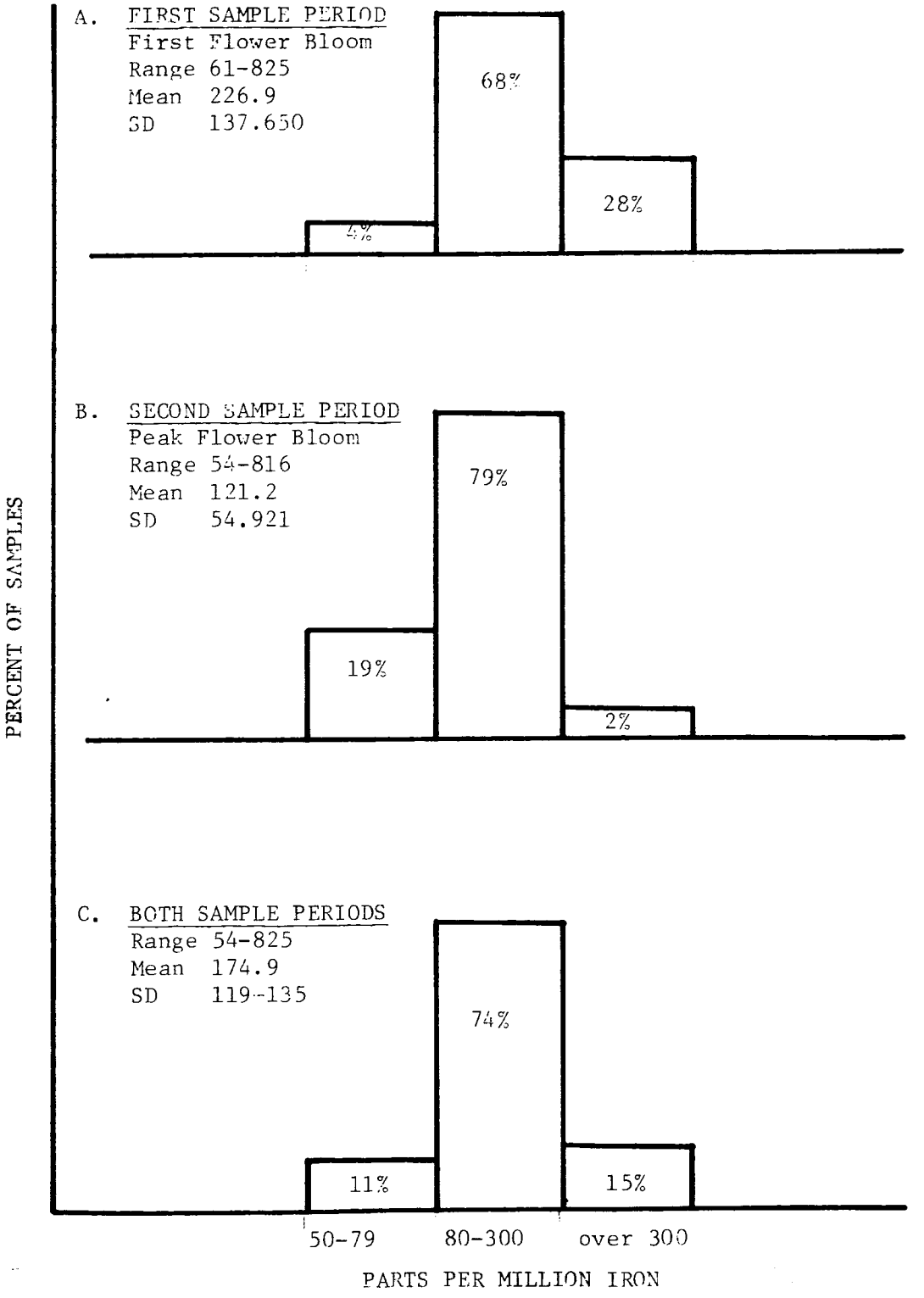

Figure 17. Distribution of Fe in the samples of cotton leaf blade tissue.

Settlement - Safford area and 36% of all fields sampled in the Avra Valley-Marana farming areas.

Though all tissue samples were adequate in Fe according to Sabbe et al. (1972), these data indicate Fe may be limiting to cotton in the farming regions mentioned above if the tissue level recommended by Castenson (personal communication, 1967) are used for interpretation.

In the Soil

The soil samples were not analyzed for Fe.

Correlation Analysis

Leaf blade Fe levels in the first sample period were positively correlated to tissue levels of Al, B and Ca (Table 6). In the second sample period only leaf blade levels of Al and Fe were correlated, having an r value of .928** (Table 7).

Further work is needed to determine if the correlation coefficients represent true relationships. Our data suggest a synergistic relation between Ca and Fe while Olsen (1972), site Ca can antagonize Fe absorption in plants. The correlation coefficients between B and Fe may be reflecting the solubilizing of Fe-borate complexes in the soil.

The r value between Fe and Al in the second sample period is large. This coefficient may represent a true relation, however, since the leaf blade tissue was not washed prior to analysis dust contamination may also be an explanation (Sevey, personal communication, 1982).

Although correlation values between soil data and leaf blade Fe were less than .550 (Tables 9 and 10), when the samples were subdivided

by soil texture correlation coefficients greater than .550 were found (Table 23).

In the first sample period leaf blade Fe was correlated to Mn in the clay soils and Zn in the loam soil with correlation coefficients of .832** and .612*, respectively. These positive correlations with Mn and Zn could be synergistic relationships or due to similarities in soil properties such as decreased solubility in alkaline soils.

At the second sample period in the clay texture soils leaf blade Fe was negatively correlated to the total soil levels of K and Ca with coefficient of -.613* and -.682*, and to the saturation levels of Ca and Mg with coefficients of -.666* and -.679*, respectively. In many soils Fe deficiency is directly attributed to high levels of Ca (Castenson, personal communication, 1967), however the Ca correlation coefficients could also indicate a pH effect, since high soil Ca levels are associated with high pH. Since there is no mention of an antagonistic relationship between Fe and Mg or K in the literature, more information is needed to determine if these correlation coefficients represent true relationships.

Leaf blade Fe levels were positively correlated to the element ratios of P:Fe, Fe:Zn, Fe:Mn, Fe:Cu and Fe:(Cu + Zn) at both sampling dates (Tables 13 and 14).

The correlation coefficients indicate higher leaf blade levels of Fe are associated with lower leaf blade levels of Zn, Mn and Cu. Since Zn, Mn, and Cu can compete with Fe for chelated sites in the soil and possibly in the plant, the correlations may represent true antagonistic relationships.

Table 23. Correlation coefficients between leaf blade Fe and soil data (25 cm depth), after subdividing samples by soil texture.

Soil Texture	Sample Period	K	Ca	Mn	Ca[1]	Mg[1]	Cu	Zn
Clay	1			.832**				
	2	-.613*	-.682*	.669*	-.666*	-.679*		
Clay Loam	1							
	2						-.508*	
Loam	1	.443						.612*
	2							
Sandy Loam	1				-.471	.511		
	2							

[1]Calculated saturation value

* .05
**.01

Tentative optimal levels for the ratios of Fe:Cu, Fe:Mn and Fe:(Cu + Zn) in plant tissue are published for crops other than cotton (Appendix E).

The mean levels of Fe:Cu, Fe:Mn and Fe: (Cu + Zn) from the cotton leaf blade samples in this survey are shown in Appendix F. Since both soybeans and cotton are dicots, C-3 plants, and have similar root systems, the average ratio values for cotton tissue samples are better compared to those values recommended for soybeans than for the other crops listed in Appendix E. The average Fe:Mn and Fe:(Cu + Zn) values of 1.4 and 3.4, respectively from the cotton tissue samples are 50% and 75% higher than the levels recommended for soybeans; 1.0 and 2.0, respectively. In addition the average Fe:Cu value of 17 from the cotton tissue samples is double the value listed for soybeans. The ratio values suggest some imbalance between Fe and the elements: Zn, Mn and Cu in the leaf blade tissue. Further work is needed to accurately interpret these micronutrient ratio values.

Iron in the leaf blade tissue was also positively correlated to the ratio of P:Fe in the leaf blade tissue (Table 14). Although reports by Olsen (1972) and Gauch (1972) indicate antagonism between P and Fe, these correlation indicates a synergistic relationship between P and Fe.

Since Fe is precipitated as an organic P complex in plants (Gaugh, 1972) and Olsen (1972) recommend using a ratio of P:Fe in plant tissue to determine how much soluble Fe is in the plant as opposed to total Fe concentrations in the tissue. The mean P:Fe ratio

found in the cotton leaf blade samples was 21. A recommended P:Fe value for cotton was not found in the literature.

Manganese

In Cotton Tissue

The distribution of Mn in the leaf blade tissue samples from the first and second sample periods and both samplings combined is shown in Figure 18, Histograms A through C. The range, mean and standard deviation for each period is also included.

All cotton leaf blade samples contained 45 to 331 ppm Mn which is more than adequate when compared with critical levels of 10 to 20 ppm (Tucker, personal communication, 1982; Ohki and Ulrich, 1977; Hinkle and Brown, 1968; Sparr et al., 1968).

In the Soil

The distribution of Mn in the soil samples along with the range, mean and standard deviation is shown in Figure 19.

Soil critical levels for Mn range from 15 to 20 ppm (Cox and Kamprath, 1972). If 15 ppm Mn was used to interpret the test results, then 65% of the samples would be considered low in Mn. If the upper range of 20 ppm is used to interpret the results only, 11% of the soil samples would contain adequate Mn.

Since the cotton tissue samples contained more than adequate Mn compared with published critical levels, Mn does not appear to be limiting. Further work is needed to explain the discrpeancy between the soil and plant tissue results.

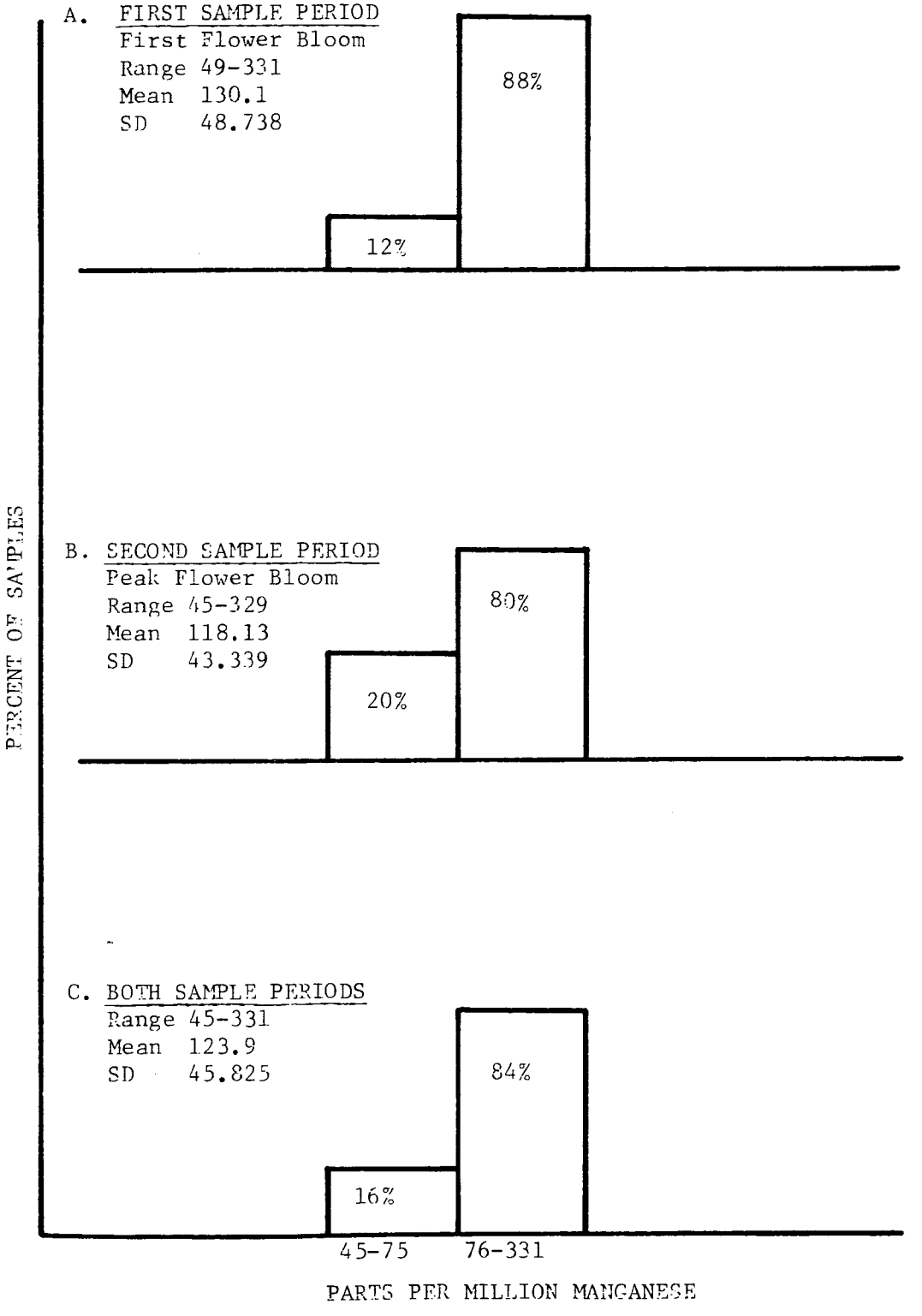

Figure 18. Distribution of Mn in the samples of cotton leaf blade tissue.

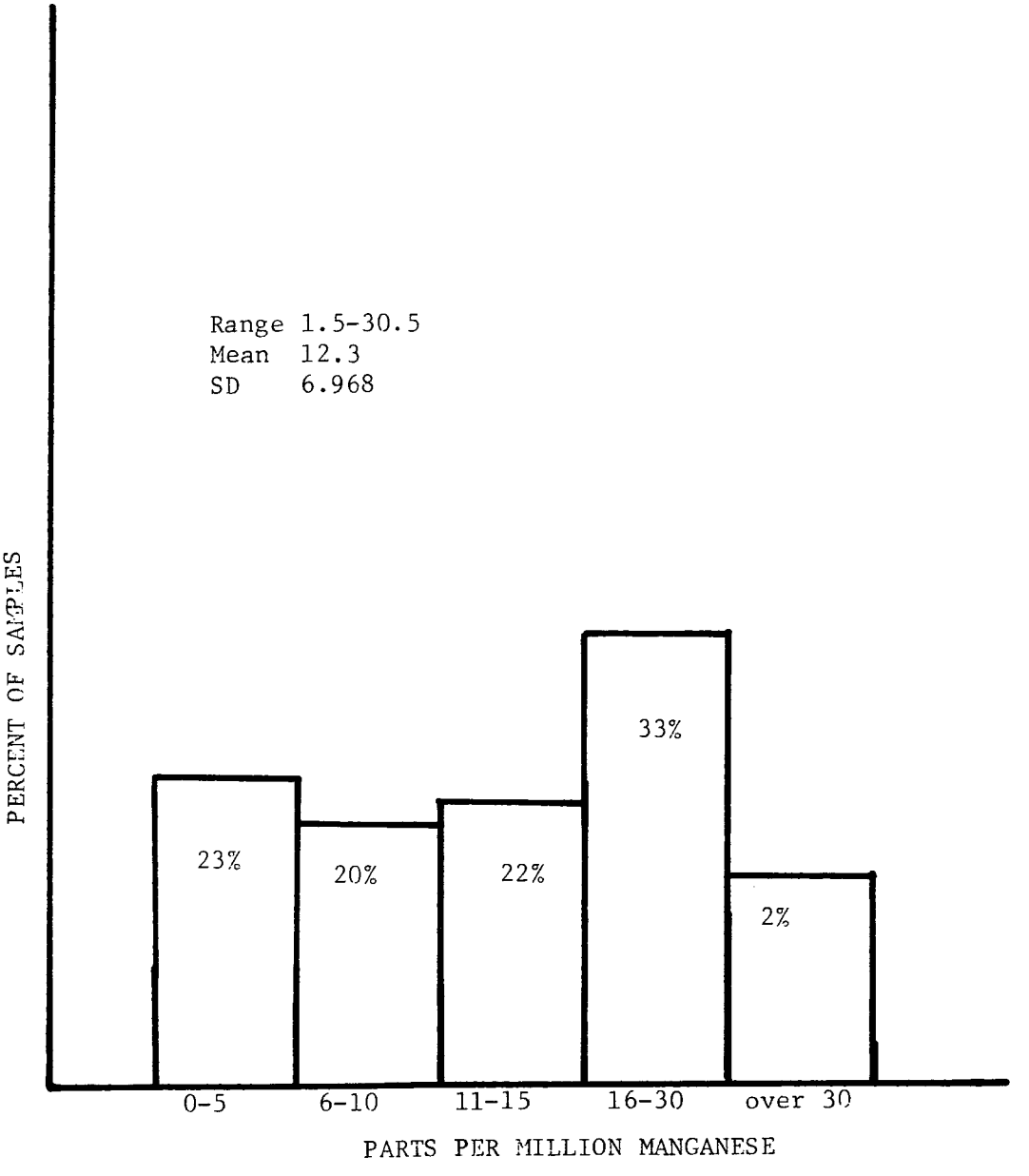

Figure 19. Distribution of Mn in the soil samples (25 cm).

Correlation Analysis

In the first sample period, leaf blade levels of Cu and Al were correlated to the levels of Mn with coefficients of .597** and .613**, respectively (Table 6). Although correlations may represent true relationships they may reflect a general nutrient uptake in response to more favorable growing conditions. Synergistic relationships between Mn and Al in plants is not mentioned in the literature.

While only correlation values less than .550 between Cu in the leaf blade tissue and the soil data for all samples are seen in Tables 9 and 10, correlation coefficients greater than .550 were found when the samples were subdivided according to soil texture (Table 24).

In the clay-textured soils, levels of P and B were correlated to leaf blade Mn the first sample period with coefficients of -.824** and -671*, respectively, and in the second sample period with coefficients of -.700* and -.662*, respectively. These coefficients indicate that soil P and B adversely affect Mn levels in cotton leaf blade tissue. The relationships may indicate Mn was fixed by soil phosphates (Ellis and Knezek, 1972) and possibly borates.

Leaf blade Mn was correlated to Ca in the clay and sandy loam soils with coefficients of .573* and .675* in the first and second sample period, respectively. In the clay loam soils, K was correlated with leaf blade Mn with a coefficient of -.567* in the second sample period.

The ratio of K:Mn was negatively correlated to Mn in the plant leaf blade tissue, in the first and second sample periods with coefficients of -.762** and -.814**, respectively (Tables 13 and 14).

Table 24. Correlation coefficients between leaf blade Mn and soil data (25 cm depth), after subdividing samples by soil texture.

Soil Texture	Sample Period	K	Ca	NO_3	P^1	B
Clay	1		.573*		-.824**	-.671*
	2				-.700*	-.662*
Clay Loam	1			.585*		
	2	-.567*		.555*	-.489*	
Loam	1					
	2					
Sandy Loam	1					
	2		.675*			

[1] CO_2 extraction

* .05
**.01

The correlation coefficients for K:Mn indicate high leaf blade tissue levels of K are associated with low tissue blade levels of Mn. Optimal levels for the ratio of K:Mn in plant tissue are published for various crops other than cotton (Appendix E). This data show the K:Mn level recommend for soybeans is 200 - the smallest of any crop reported. The average K:Mn value for all cotton leaf blade tissue samples in this survey was 28 (Appendix F).

These results suggest their may be excessive levels of Mn relative to K in the cotton leaf blade tissue. Since more than adequate levels of Mn were found in the leaf blade tissue (Figure 19) and some leaf blade samples contained K levels below established sufficiency levels (Figure 6), more work is needed to determine sufficiency/critical K and R:element ratios requires for cotton in Arizona.

Sodium

Since Na is not considered an essential plant nutrient for cotton, there are no published critical levels. However, Chang and Dregne (1955) note that cotton growth is reduced at Na levels of .51 to 2.72 in the leaf blade tissue. The range and mean levels of Na in all cotton tissue samples is .01 to 1.0% and .11% Na, respectively.

Although some leaf blade tissue samples appear high in Na, no significant negative correlations between Na in the leaf blade tissue and other plant tissue elements were found (Tables 6, 7, and 8).

The correlation coefficient between leaf blade Na levels and the soil data from all samples are listed in Tables 9 and 10 for the first and second sample periods, respectively. Tables 13 and 14 list

the correlations coefficients between leaf blade Na and various plant element ratios for the first and second sample periods, respectively.

Leaf blade Na levels are correlated to Na:Zn in both first and second sample periods with coefficients of .958** and .936**, respectively (Tables 13 and 14). The Na:Zn coefficients indicate high leaf blade levels of Na were associated with low tissue levels of Zn. This could further indicate soil conditions favoring Zn uptake were less favorable for Na in solution or on the soil exchange sites. Although the interaction between Zn and Na may involve competition for excudate carriers.

Zinc

In Cotton Tissue

The distribution of Zn in the leaf blade samples from the first and second sample periods and both periods combined is shown in Figure 20, Histograms A through C. The range, mean and standard deviation for each period is also included.

Although published critical levels for Zn in cotton leaf blade tissue only range from 10 to 11 ppm (Ohki and Ulrich, 1977; Tucker, personal communication, 1982; Castenson, personal communication, 1967; Sparr et al., 1968). Sabbe et al. (1972) reports the Zn sufficiency range is 20 to 60 ppm. In addition, Ohki and Ulrich (1977) recently determined the critical Zn toxicity level in cotton is 200 ppm. Figure 21 shows that all leaf blade samples contained more than 10 ppm Zn. However 11% of the tissue samples in the second sample period contained

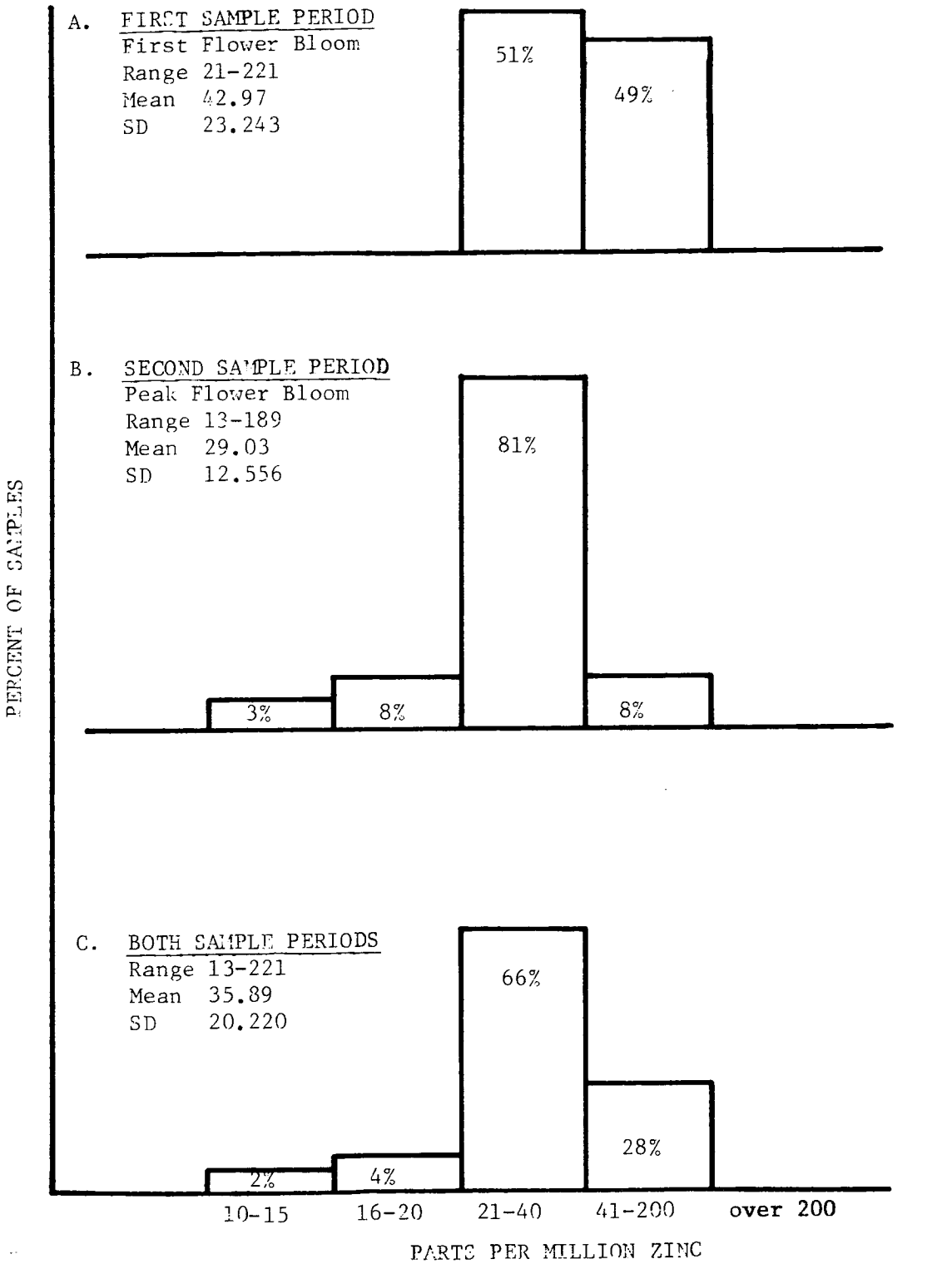

Figure 20. Distribution of Zn in the samples of cotton leaf blade tissue.

between 10 to 20 ppm Zn, which is below the sufficiency range suggested by Sabbe et al. (1972). All 12 leaf blade tissue samples containing 10 to 20 ppm Zn, except for 1, represented fields in the Willcox-Safford farm areas of Arizona.

Although these data indicate most cotton leaf blade samples contained adequate Zn, some samples representing specific regions in Southern Arizona may be borderline low in Zn.

In the Soil

Zinc was extracted from the soils by a method developed by Nelson et al. (1959). Unfortunately, this method is inadequate, resulting in low Zn values (Nelson et al., 1959). Therefore, Zn levels extracted from the soil samples are not presented.

Correlation Analysis

As shown in Tables 6, 7, 8, 9 and 10, no correlation coefficients greater than .550 were found between leaf blade levels of Zn and the other plant or soil data.

The results of a correlation analysis between leaf blade Zn and soil data after the samples were subdivided by soil texture are shown in Table 25. In the clay-texture soils, leaf blade Zn levels were correlated to soil Na in the first and second periods with coefficients of -.870** and -.840**, respectively. This indicates that as the levels of Na in the soil increases, leaf blade Zn levels decreased.

In the clay loam soils, leaf blade Zn was correlated to soil P levels in the second sample period with a coefficient of -.556*. Since

Table 25. Correlation coefficients between leaf blade Zn and soil data (25 cm depth), after subdividing samples by soil texture.

Soil Texture	Sample Period	NO_3	P^1	Cu	K^2	Na
Clay	1					-.870**
	2					-.840**
Clay Loam	1	.626*				
	2		-.556*			
Loam	1	.532		-.429		
	2			-.579*		-.453
Sandy Loam	1		-.403		.545	
	2					

[1] CO_2 extraction

[2] Calculated saturation value

* .05
**.01

antagonism of P on Zn absorption and translocation is well documented (Olsen, 1972), the correlation coefficient probably reflect a true relationship. The correlation coefficient of -.579* was found with Cu levels in the loam soils. This may reflect competition with Zn for excudate carriers at the root or chelation sites in the soil.

The results of a correlation analysis between various plant elements ratios and the leaf blade levels of Zn are shown in Tables 13 and 14 for the first and second sample periods, respectively.

In the first and second sample period, respectively, leaf blade Zn levels were correlated to K:Zn with coefficients of -.679** and -.691** and to P:Zn with coefficients of -.614** and -.568**. The coefficients indicate low levels of Zn in the leaf blade tissue are associated with high levels of P or K in the tissue. Although P and Zn are known to be antagonistic within the plant (Olsen, 1972) synergistic or antagonistic relationships between K and Zn were not found in the literature.

SUMMARY

Soil and cotton plant tissue samples from major production areas throughout Southern Arizona were analyzed and the results evaluated on the basis of published critical and/or sufficiency levels. Irrigation waters were evaluated for their capacity to supply some nutrients to cotton.

In this section, the status of each element measured in the cotton tissue and soil samples as discussed previously will be reiterated.

Magnesium

The cotton petiole and leaf blade samples contained more than adequate amounts of Mg when compared with published critical levels. The amount of Mg in the soil appeared adequate to sustain high yields, and in some cases irrigation water alone could supply enough Mg to replace Mg lost by cropping.

Potassium

All cotton leaf blade samples contained adequate amounts of K when compared with published critical levels. The levels of K found in the soil were more than adequate for plant growth and crop removal.

Phosphorus

The cotton leaf blade samples taken during the first flower period contained adequate P when compared with published sufficiency

levels. Approximately 50% of the tissue samples representing the peak flower bloom contained P levels below published sufficiency levels.

A critical level of P in the soil must be established for cotton grown in Arizona before a definite evaluation can be made on the status of P in the soil samples. The recommended P levels widely vary.

Nitrogen

A large percentage of the cotton petiole tissue and soil samples contained low to marginal levels of N when compared to published sufficiency levels established in Arizona. Soil analysis results indicate 50% of the soils analyzed were insufficient in NO_3 so far as needed to produce a two-bale-per-acre yield.

Calcium

The cotton leaf blade samples contained adequate amounts of Ca when compared with published critical and sufficiency levels.

Boron

All cotton leaf blade samples contained adequate amounts of B when compared with published critical levels. Approximately 60% of the soil samples contained B levels below the published critical levels.

Copper

A critical level for Cu must be established for cotton grown in Arizona before a definite evaluation can be made on the status of Cu in the leaf blade samples. The published critical levels for Cu in the leaf blade tissue widely vary. The soil samples contained

adequate levels of Cu when compared with published sufficiency levels.

Iron

The cotton leaf blade samples contained adequate levels of Fe when compared with published critical/sufficiency levels.

Manganese

All cotton leaf blade samples contained adequate amounts of Mn when compared with published critical levels, however, 65-90% of the soil samples contained low to marginal Mn when compared with published critical levels.

Zinc

All cotton leaf blade samples contained adequate levels of Zn when compared with published critical levels, however, approximately 10% of the tissue samples contained Zn levels approaching the critical level and thus may be marginal.

Aluminum and Barium

There were no unusual levels of Al or Ba found in the cotton leaf blade samples that could affect plant growth. The Na levels in the cotton leaf blade samples ranged from .01 to 1.0%. Sodium may have affected the growth of some plants and the level of other elements in the plant tissue.

APPENDIX A

THE SOIL TYPES AND NUMBER OF FIELDS REPRESENTED

IN EACH ARIZONA COUNTY INCLUDED IN THE NUTRIENT SURVEY

County	No. of Cotton Fields Sampled	Soil Types
Yuma	17	Hortville clay Gilman loam Tucson loam Indio silt loam Antho fine sandy loam Valencia sandy loam
Maricopa	20	Vecont clay Mohall clay loam Gilman loam Mohall loam Casa Grande sandy loam Coolidge sandy loam Laveen sandy loam Perryville sandy loam Valencia sandy loam Antho fine sandy loam
Pinal[1]	24	Contine clay loam Gilman loam Mohall sandy loam Valencia sandy loam
Pima	19	Mohave clay Tubac clay Mohave clay loam Anway loam Gilman loam Anway silt clay loam Tubac sandy clay loam Anway sandy loam Anway sandy

County	No. of Cotton Fields Sampled	Soil Types
Cochise	16	Grabe loam Karro loam McAllister loam Gothard fine sandy loam Grabe sandy loam Sonoita sandy loam
Graham	13	Guest clay Anthony clay loam Grabe clay loam Anthony loam Gila loam

[1]Soil classifications were not available for 70% of the fields sampled in this area.

APPENDIX B

WATER ANALYSIS DATA

EC[1]	K	Na	Mg	pH	HCO_3	Ca
3.01	5.1	287	16	6.9	488	19
1.04	4.4	124	19	6.9	366	8
0.99	3.8	126	10	7.1	366	12
1.58	6.9	176	12	7.0	366	12
2.16	7.3	202	26	7.0	305	22
5.00	7.7	203	72	6.8	305	22
4.32	6.5	314	47	7.0	737	27
6.91	4.9	501	55	7.0	671	34
9.17	13.0	650	9	7.0	305	41
3.83	6.1	216	78	7.2	795	48
2.08	6.1	165	35	7.4	366	22
1.89	2.9	233	1	7.6	122	6
2.61	6.4	195	33	7.0	305	32
2.66	6.8	168	36	6.9	305	44
1.68	5.9	168	30	7.0	274	52
1.08	4.9	126	26	7.2	305	40
1.54	2.6	93	14	7.4	305	24
0.63	4.1	110	24	7.0	305	29
0.68	2.1	51	6	7.0	244	11
0.65	2.6	51	8	7.2	244	14
0.58	2.1	55	6	7.4	244	12
0.57	2.1	57	4	7.3	244	8
1.13	2.4	93	15	6.9	305	24
1.12	5.2	185	82	6.9	427	51
0.91	2.5	42	31	7.2	488	23
1.08	3.1	63	35	7.1	549	22
1.10	2.6	70	5	7.5	366	14
0.72	2.2	66	3	7.7	366	12
0.66	2.4	55	6	7.1	305	21
0.81	2.3	58	2	7.3	244	6
0.63	2.8	49	15	7.2	427	25
0.89	4.8	136	24	7.2	488	23
1.63	2.9	56	12	7.4	488	17
0.84	4.9	98	13	7.6	549	14
0.95						

[1]Electrical conductivity

APPENDIX C

CORRELATION COEFFICIENTS BETWEEN ELEMENTS ANALYZED IN COTTON LEAF TISSUE FROM THE FIRST SAMPLE PERIOD AND ALL SOIL SAMPLE DATA (26-50 cm depth)

FIRST SAMPLE PERIOD

Soil Data (26-cm depth)														
	P^2	-.201**	-.161*	.120	-.026	.087	-.046	-.099	.125	-.123	-.185*	-.052	.038	-.094	-.013
	K	-.240**	-.129	-.140	.068	.215**	-.048	.033	-.042	-.052	.014	.015	.005	.062	-.148
	Ca	-.303**	-.109	-.135	-.025	.220**	-.124	.027	.049	-.125	-.176*	-.049	-.046	.196*	-.163*
	Mg	.172*	.062	.005	.170*	.283**	.200**	.178*	.128	-.157	.057	.201*	-.131	-.011	-.177*
	Mn	.045	-.008	.252**	.042	-.045	.236**	-.010	-.250**	.021	-.133	.199*	.017	-.071	.025
	Cu	.157	-.292**	-.374**	.309**	-.216**	-.297**	.146	-.139	-.194*	-.145	.261**	-.228**	-.149	.125
	B	.318**	.263**	.006	.210*	-.069	.112	.155	.052	.376**	.673**	.081	-.053	-.207**	.056
	Na	.039	.072	-.258	-.032	.166	-.059	.095	-.102	.130	.369**	-.012	-.079	-.178	.149
	K^3	-.064	-.076	.000	.053	-.037	-.033	-.051	-.019	-.001	.177*	-.033	.067	-.065	.091
	Ca^3	-.437**	-.153	-.168*	-.222**	-.055	-.263**	-.129	-.174*	-.254**	.180*	-.200*	.042	.159	-.285**
	Mg^3	.502**	.196*	.182*	.223**	.073	.300**	.160*	.198*	.278**	.132	.231**	-.073	-.148	.346**
	CEC^4	-.240**	-.083	-.121	.031	.306**	-.052	.107	-.010	-.068	-.146	.018	-.072	.161	-.114
	pH^5	.181*	.077	-.158	-.027	-.237**	-.108	-.027	-.104	.085	.193*	-.129	-.084	-.238**	.075

SECOND SAMPLE PERIOD

Soil Data (26-cm depth)														
	P^2	-.181*	-.195*	.114	-.028	.067	.039	.071	.169*	-.090	.184*	-.016	.064	-.154	.004
	K	-.267**	.009	-.079	.280**	.220**	.253**	-.071	-.155*	-.049	.119	-.193	-.029	.011	-.185*
	Ca	-.148	.254**	.013	.133	.423**	-.107	.286**	.073	.013	-.241**	-.077	.098	-.007	-.023
	Mg	.139	.164*	.015	.034	.176*	.189*	.123	.024	.126	.037	.234**	-.079	.079	.012
	Mn	.058	.068	.155	.206**	-.061	.205*	-.024	.078	.065	-.176*	.139	.023	-.042	-.033
	Cu	.022	.226**	-.145	-.149	.056	-.174*	.206*	-.153	.323**	.164*	.086	-.059	-.202*	.205*
	B	.196	.011	-.141	-.039	-.266**	.112	.091	.078	.234**	.591**	.160*	-.203*	.091	.003
	Na	.081	.161	.150	.050	.047	-.005	.330**	-.021	.218*	.535**	.112	.039	.034	.104
	K^3	-.170	-.238**	-.042	.224**	-.136	-.188*	-.223**	-.089	-.113	.048	.188**	.083	.031	-.187*
	Ca^3	.310**	.077	.013	-.014	.214**	-.214**	.152	-.091	.095	-.207**	.227**	.168*	-.105	.031
	Mg^3	.405**	.007	.003	.070	-.183**	.306**	.081	.134	.147	.208**	.320**	-.153	.102	.103
	CEC^4	-.127	.240**	.006	.123	.401**	.068	.261**	.063	.018	-.228**	-.032	.063	.022	-.051
	pH^5	.239**	.072	-.184*	-.007	-.253**	.046	.076	.052	.226**	.415**	.073	-.097	.015	.194*

APPENDIX D

STEPWISE MULTIPLE REGRESSION EQUATIONS FOR EACH ELEMENT ANALYZED IN THE COTTON TISSUE

Stepwise multiple regression equations were determined on each plant element in the cotton tissue to try to account for as much of the elements variation as possible with the soil and plant factors measured. The equations presented may aid future research in cotton nutrition.

Phosphorus = .252 - .056 (Mg/P) + 1.042 (P/K) + .002 (Fe/Cu)

r = .8683

CV = 12.8 pct.

Mg = petiole tissue P = Bray P-1 extract

All other elements represent leaf blade tissue levels.

Potassium = 3.687 - .354 (Mg/P) - 6.317 (P/K) + .013 (Fe/Cu)

r = .8137

CV = 11.8 pct.

Mg = petiole tissue P = Bray P-1 extract

All other elements represent leaf blade tissue levels.

Calcium = 6.261 - 18.434 (Mg/Ca) + .589 (Mg/P) - 10.573 (K/Zn) + .082 (Fe/Zn)

r = .8264

CV = 10.9

Mg = petiole tissue P = Bray P-1 extract

All other elements represent leaf blade tissue levels.

Magnesium* = .518 + .196 (Mg/P) - .114 (Mg/P) - 2.506 (K/Zn) + .0067 (Mg**) + .0155 (Fe/Zn)

Mg* = petiole tissue Mg** = percent saturation of CEC (1 ft)

r = .8412

CV = 11.0 pct.

Mg = petiole tissue P = Bray P-1 extract

All other elements represent leaf blade tissue levels.

Manganese - 294.049 - 5314.20 (K/Mn) - 18.202 (Mg/P) - 290.828 (P/K) + 4.549 (Fe/(Cu + Zn).

r = .8662

CV = 18.7 pct.

Mg = petiole tissue P = Bray P-1 extract

All other elements represent leaf blade tissue levels.

Iron = 142.162 + 54.303 (F/(Cu + Zn)) - 2065.286 (K/Zn) - 15.492 (Mg/P)

r = .9203

CV = 26.9 pct.

Mg = petiole tissue P = Bray P-1 extract

All other elements represent leaf blade tissue levels.

Nitrate* = 3814.380 + 29.483 (NO_3/Zn) - 56414.342 (K/Zn) + 58.843 (Fe/Cu)

r = .9519

CV = 23.1 pct.

NO_3 = petiole tissue

All other elements represent leaf blade tissue levels.

Magnesium = .0641 + .1260 (Mg/P) + .885 (P/K) + .003 (Fe/Cu) + .807 (Mg/Ca)

r = 8759

CV = 11 pct.

Mg = petiole tissue P = Bray P-1 extract

All other elements represent leaf blade tissue levels.

Copper = 19.727 - 84.637 (K/Zn) + 7.439 (Fe/Zn) - 9.337 (F/(Cu + Zn)) - 1.241 (Mg/P)

r = .7382

CV = 20.4 pct.

P = Bray P-1 extract

All other elements represent leaf blade tissue levels.

Zinc = 103.295 - 369.04 (K/Zn) - 9.083 (Mg/P) - 2441.264 (P/Zn) + 2442.801 (K/NO_3)

r = 7490

CV = 37.8 pct.

NO_3-N and Mg = petiole tissue P = Bray P-1 extract

All other elements represent leaf blade tissue levels.

Boron = 309.121 - 3520.908 (Ca/B) - 514.361 (Mg/Ca) + 15.208 (Mg/P) - 303.864 (K/Zn) + 2.529 (Fe/Zn)

r = .9182

CV = 12.5 pct.

Mg = petiole tissue P = Bray P-1 extract

All other elements represent leaf blade tissue levels.

Sodium = .0283 + 4.490 (Na/Ca) - .280 (Mg/Ca)

r = .9834

Mg = petiole tissue CV = 16.3 pct.

All other elements represent leaf blade tissue levels.

Aluminum = 525.226 + 75.574 (Fe/(Cu + Zn)) - 2474.301 (K/Zn) + .0865 (K*) - 66.972 (PH)

r = .9058

CV = 41.0 pct.

K* = total soil K PH = paste extract

All other elements represent leaf blade tissue levels.

APPENDIX E

NORMAL RATIOS FOR MICRONUTRIENTS IN VARIOUS AGRONOMIC CROPS

Crop	N/Zn	P/Zn	Ca/B	Fe/Mn	S/Zn	S/Mn	K/Mn	Fe/Cu	Fe/Cu + Zn
		ppm							
Corn	1,000	100	300	2	80	30	400	12.5	3.5
Soybeans	900	90	500	1	100	40	200	8.0	2.0
Sorghum	800	125	400	2	80	50	400	10.0	2.5
Wheat	750	140	600	0.5	100	30	350	4.0	1.0
Alfalfa	1,000	130	750	1.5	70	50	550	6.0	2.0
Sugar Beets	1,200	110	350	1.5	130	30	225	13.0	3.0

Castenson, personal communication, 1967.

APPENDIX F

NUTRIENT RATIOS IN COTTON LEAF

TISSUE SAMPLES AT FIRST FLOWER

	NO_3-N/Zn	P/Zn	Ca/B	Fe/Mn	K/Mn	Fe/Cu	Fe/(Cu + Zn)
Mean	192	10	35	1.4	19	17	3.4
Minimum[1]	.9	.72	10	0.2	3.5	3.5	0.2
Maximum[2]	1600	59	144	18	80	275	51.0

Castenson, personal communication, 1967.

[1]Smallest theoretical value from all leaf blade sample data

[2]Largest " " " " " " " "

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