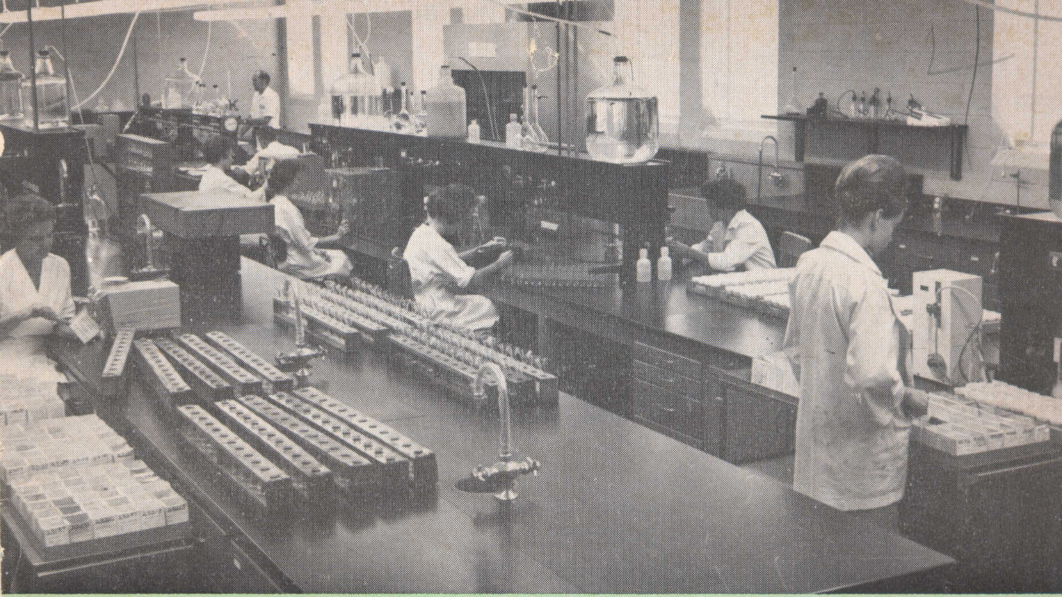

SOIL TEST THEORY and CALIBRATION for Cotton, Corn, Soybeans and Coastal Bermudagrass

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SOIL TEST THEORY and CALIBRATION for Cotton, Corn, Soybeans and Coastal Bermudagrass

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SINCE THE 1930's soil testing has increased steadily in the United States. Nearly 3 million soil samples were tested in this country in 1963 (15), which is twice the number in 1955.

A soil testing laboratory was established for Alabama at Auburn University in February, 1953. The increase in number of samples tested annually is shown in Figure 1.

In 1963 the Alabama State Board of Agriculture and Industries offered a certification program for commercial laboratories operating in Alabama. This program provides a means of officially recognizing laboratories equipped and staffed to produce reliable analyses and to make recommendations based on the latest research available from the Agricultural Experiment Station.

Despite availability of the Auburn University Laboratory and the certified facilities, the number of soil samples submitted for analysis and recommendations has never approached the number needed to provide a reliable guide for use of lime and fertilizers on all fields. For instance, the total number of samples processed in 1965 by the University and commercial laboratories represent only about 1 sample for each 5 farmers, 1 sample for each 200 acres of crop and pasture land. One major reason for this is not understanding the basis for soil testing and the benefits from it in practical farm operations.

Soil scientists recognize that there is nothing comparable to soil testing as a guide for lime and fertilizer use. This bulletin presents a general theory of soil testing as the basis for lime and fertilizer recommendations in Alabama. Four crops are used to represent a wide range of plant requirements and value per acre.

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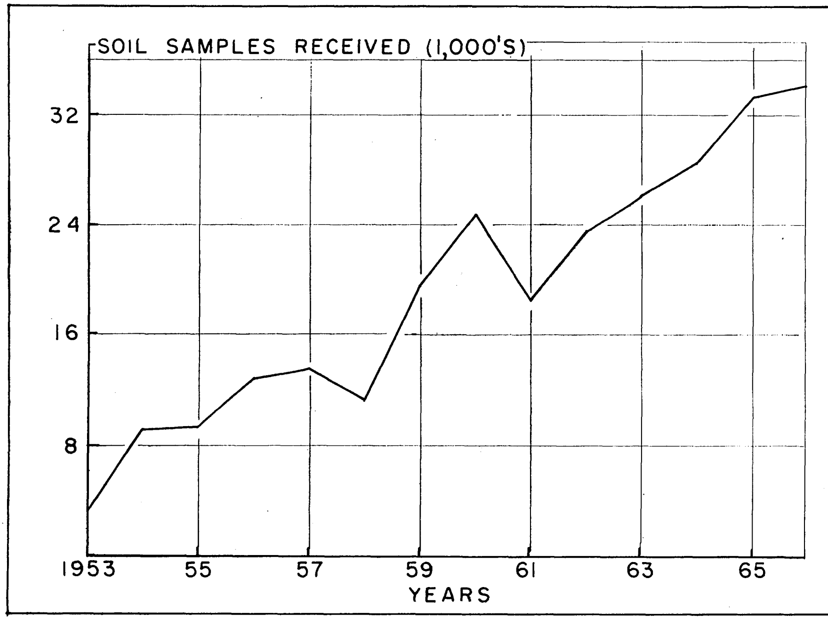

FIG. 1. Annual number of soil samples received in Soil Testing Laboratory at Auburn University.

WHAT IS SOIL TESTING?

To the grower soil testing is the process of collecting a sample of soil, sending it to a laboratory, and receiving an evaluation of fertility together with lime and fertilizer recommendations.

To the soil scientist soil testing involves the process of quantitatively relating all known soil fertility information influencing plant growth to soil properties that can be measured in the laboratory. It also involves consideration of the response of crops to fertilizer materials and how this response is influenced by method and time of application with respect to various soil properties. This is considered in a general way under three headings: (a) The soil sample. How can a sample be collected that will represent a field or plot of ground? (b) The chemical measurement. How can chemical values be obtained that will give an indication of the relative availability of the element in the soil to plants? (c) The recommendation. What is required to arrive at a treatment that will be the best soil fertility management practice?

The Sample

Proper collection of a soil sample is one of the most important steps in soil testing. A valid sample must represent the area that is sampled.

The probability that one scoop of soil from a field will be representative of all soil in that field is extremely small — even in an apparently uniform field. To increase the probability of a sample representing the soil in a field, either size of the sampled area must be reduced or scoops of soil collected from several places in the field and mixed to form a composite sample.

Research conducted to determine practical limits to size of fields and number of places from which soil should be collected to make a composite sample shows that on a field scale regardless of acreage soil from about 20 sites would be required to make a single sample representative of the field *(14,22,27,30,37,46)*. The area that can be fairly represented by one composite sample decreases with increased variability of the soil within the area. It may be a few square feet or a hundred acres. A basic concept of good soil sampling is that one sample can represent only one condition.

Results of soil sampling studies show that, in general, large and apparently uniform fields must be sampled to represent no more than 10 acres at first sampling. If samples from such areas are found similar in soil test values and if the separate areas are subsequently managed similarly, a composite sample can be taken thereafter to represent the larger area. For high value crops or special situations, smaller size sampling areas may be justified. In any field an apparent nonuniformity of significant size would require separate sampling. Frequently a corrective treatment can be made that will justify subsequent treatment of the unusual area the same as the large area.

In short, a soil sample can be collected that represents a field, but for it to be a valid sample of the area it must be deliberately collected to represent the field.

The Measurement

Although soil and plant scientists for more than 100 years have been studying procedures by which chemical characteristics of soil can be related to plant growth, it was not until 1930 when it became apparent that extractions made with salt solution or weak acids gave chemical values of some meaning. With this as a basis, a number of chemical procedures have been devised that give values highly correlated with the soil's capacity to supply a given nutrient. Methods being used currently in the Southern Region are summarized in Southern Cooperative Series Bulletin 102 *(34)*.

The Recommendation

With suitable extractants and analytically accurate methods of analysis, it is possible to relate soil chemical values to lime and fertilizer needs. To accomplish this, the soil test value must give a measure of two interrelated soil properties *(7)*: (a) the severity of the deficiency, i.e., how much yield increase will be obtained if the deficiency of the nutrient is corrected; and (b) the amount of fertilizer required to correct the deficiency. Extensive research is required to accurately relate soil test values to severity of deficiency and to the required addition of fertilizer. The experimental process whereby these two relationships are established and combined to provide the basis for recommendation is termed *soil test calibration.* Discussion of the two primary steps follows.

How Deficient is the Soil? To establish the relationship between a soil test value and response to additions of this nutrient requires that yield responses of a crop be obtained on the same soil type but having a wide range of soil test values. Unfortunately, the necessary range of values cannot usually be obtained at a single experimental site, but results from several locations must be used. Since other environmental conditions vary from site to site, actual yields cannot be used as a basis for comparisons. Yield response can be compared by converting actual yields to relative yields (the highest yield at each location is assigned a value of 100 and all other yields at that location are then related to the highest). Justification for this has been adequately described by Bray *(9)*.

The relationship between chemical soil test values and soil fertility levels are usually described in such terms as low, medium, or high. Additional terms may be desirable sometimes, e.g., very low, low, medium, high, very high, and very, very high. For soil testing to be quantitative, the terms used to describe the chemical values must be defined in terms of sufficiency for plant growth. In Alabama soil test terms have been defined as follows:

(a) "very, very high" means an excessive amount of the nutrient in the soil and further additions may be detrimental; (b) "very high" means the nutrient supply is adequate and further additions should not be made until the soil test value is lowered; (c) "high" means the nutrient supply is adequate for highest yields, but there might be some advantage to a starter application or a maintenance application of fertilizer to keep the soil fertility level high; (d) "medium" means the soil will produce 75 to 100 per cent of the yield potential without addition of the element; (e) "low" means the soil will produce 50 to 75 per cent of the yield potential; (f) "very low" means the soil will yield less than 50 per cent of maximum. Where the value of the crop is high in relation to cost of fertilizer or when only a small amount of fertilizer is needed even for a "low" value, only three categories are needed: (a) "low" to mean that a yield increase is expected from an application of the element; (b) "high" to mean that a maintenance or starter application is desirable; (c) "very high" to mean that no fertilizer is needed.

Use of descriptive terms such as low, medium, and high in soil test calibration has a serious limitation. During the period that soil testing has been developing, varying concepts have been associated with these terms. This problem has been recognized for more than 30 years. In 1935 Morgan *(32)* suggested a scale of 1-10 with 8 equal to the point of no response. Illinois *(7)* has long related soil test to relative yield with 100 assigned to the point of no response. Relative yield was selected as a basis for describing soil test calibration in Alabama. This has the desirable connotation of indicating the expected relative yield without additions of the element whereas above 100 indicates the relative margin of adequacy or the nearness to an excessive level. To eliminate the need for a per cent sign, the values are referred to as "Fertility Index." The Fertility Index can be related to the previous definitions of low, medium, and high as follows: less than 50, very low; 50-75, low; 75-100 medium; 100-300 high; 300-600, very high; and greater than 600 very, very high. Since this will be new to many readers of this publication, both Fertility Index and low, medium, and high are shown in Figure 2a.

Research results have shown that a given chemical value has a different means in regard to crop response to additions of the element for different soils with a given crop and for different crops with a given soil *(16,35,41,49)*. Based on this research, Alabama

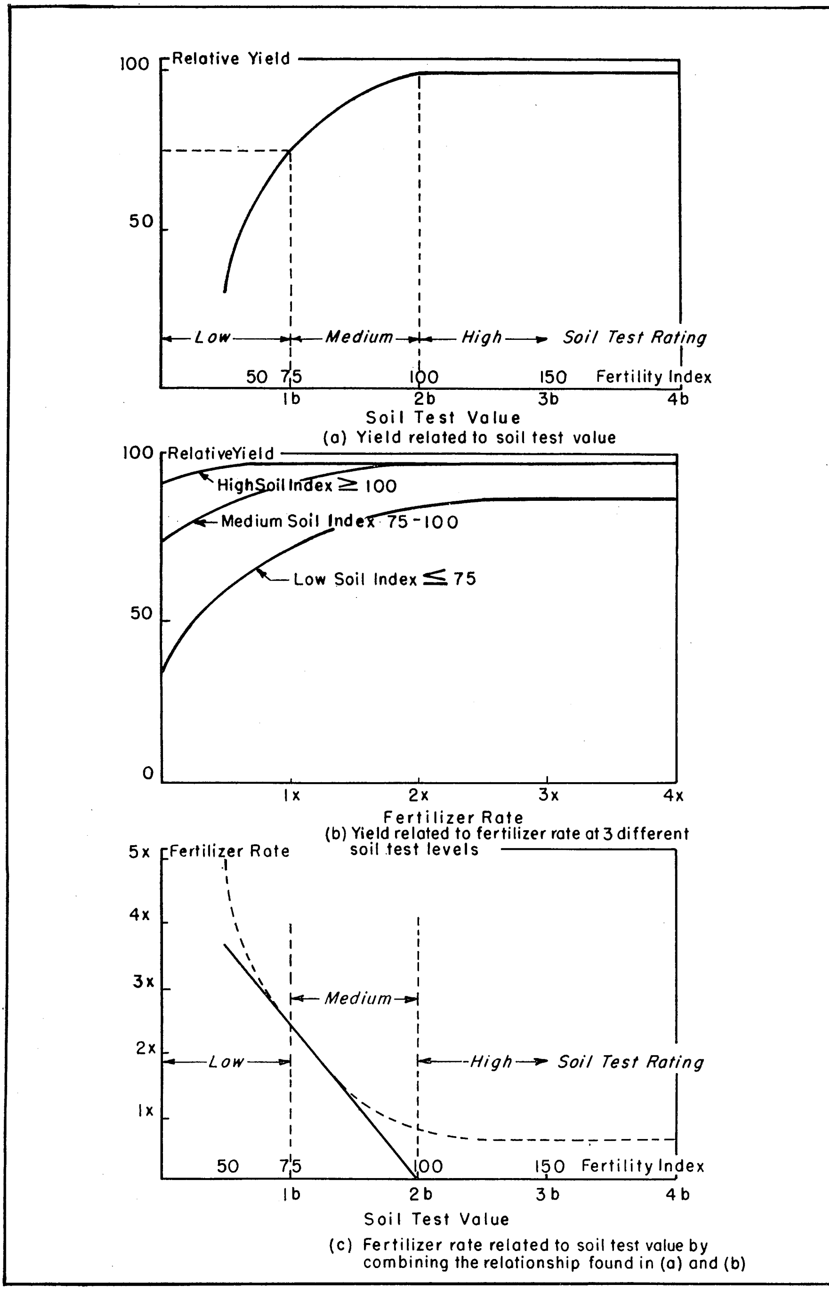

FIG. 2. Three steps in soil calibration.

soils have been grouped into three general categories for the purpose of calibrating chemical soil tests *(41)*.

I. Sandy Coastal Plain soil – Soils of this group have exchange capacities less than 6 meq. per 100 g.

II. Clay Loam Coastal Plain soils, Piedmont soils, Appalachian Plateau soils, grey and brown soils of the Limestone Valleys, Highland Rim soils, and lime soils of the Black Belt and Limestone Valleys – Soils of this group, in general, have exchange capacities between 6 and 12 meq. per 100 g. However, the lime soils of the Black Belt and Limestone Valleys have exchange capacities up to 30 or 40 meq. per 100 g.

III. Red soils of the Limestone Valleys and acid soils of the Black Belt – Soils of this group have exchange capacities greater than 12 meq. per 100 g.; frequently the acid clay soils of the Black Belt will have exchange capacities up to 40 meq. per 100 g.

Results from studies in this laboratory have shown that relationship between these three soil groups change with soil test methods. The phosphorus (P) values obtained from extracting acid soils with a weak acid (0.05 *N* HCl + 0.025 NH_2SO_4) using a 1:4 soil-solution ratio, shaking for 5 minutes, and filtering immediately can be converted to approximate Truog P values by multiplying Group I and II soils by 0.8 and Group III soil by 1.60. Potassium (K) values for acid soils can be converted approximately to exchangeable K values by multiplying Group II soils by 1.25 and Group III soils by 1.33. Group I soils require no factor. The acid-extracting solution is not suitable for use on high lime soils. Sodium bicarbonate (0.5 *N* $NaHCO_3$, pH 8.5) is used for P and ammonium acetate (1.0 *N*, pH 7) is used for K and Mg. Differences in the relationship between chemical soil test values and soil fertility is discussed later by crops.

Yield Response to Application of Fertilizer. After chemical soil test values have been related to relative yield, results of field experiments are needed to show response to applications of the element at various soil test values as shown diagrammatically in Figure 2b. This provides information on efficiency of applied fertilizer at various soil tests for the particular method of fertilizer application employed. The information is necessary to predict the amount of nutrient required to obtain practical maximum yields. Such response studies must be carried out under soil conditions similar to those where the crop will be grown because soil in place has an effect on actual nutrient availability and on root distribution. This means that to recommend a soil management treatment, the chemical values must be related to data collected from field experiments *(10,11)*.

When relative yield of the crop has been related to chemical soil test values and relative yield of the crop related to rate of application of the nutrient needed to obtain maximum response, then the relationship desired for calibration can be described, i.e., soil test value vs. rate of application of the nutrient required for maximum yield. The data available indicate that this is a linear relationship; however, in plotting, the calibration curve, the need for soil fertility buildup with a low fertility index and maintenance under high fertility index are taken into consideration. This is illustrated diagrammatically in Figure 2c.

Data available in Alabama on cotton, corn, soybeans and Coastal bermudagrass are presented similarly. These crops vary in response to applications at given soil test values and in amounts of the elements required to maintain soil levels and yields.

SOIL TEST CALIBRATION for COTTON

The research data on phosphorus (P) and potassium (K) for cotton are more comprehensive than for other crops. It serves as a basis for cotton recommendation and as a guide for research on other crops and other elements. Farmers have not made full use of this information since no more than one sample for each 140 acres of cotton has been tested annually. In spite of this, the state average yield of cotton has increased significantly in recent years. This has been the result of limiting acreage and adoption of several improved production practices. However, considering changes in lime and fertilizer use, there can be no question but soil testing has had its influence.

Relationship Between Soil Test P and Relative Yield

The relationship between soil test P and yield of cotton based on data obtained where yields range between 1¼ and 1¾ bales of cotton per acre is shown in Figure 3. The numbers in the plotted points in the figure refer to the experiments described in Appendix Table 1. The data from Groups I and II and Group III soils have been equated by adjusting the scale of the x-axis. The curve shown is calculated by a modification of Mitcherlich's equation, as proposed by Bray *(8)*. The equation is as follows:

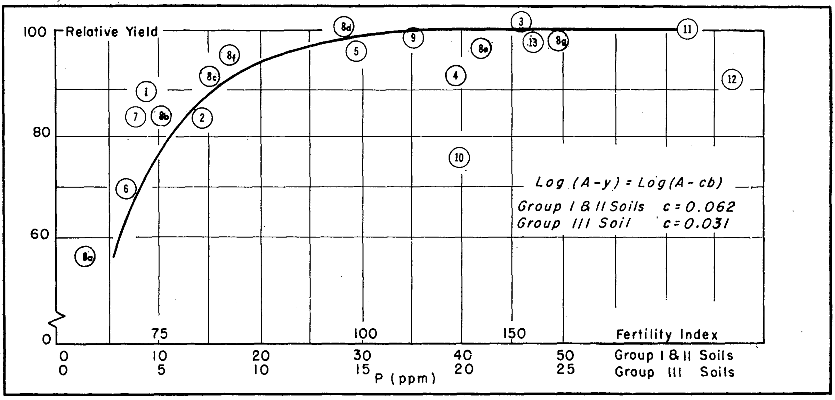

FIG. 3. Relationship between soil test P, and relative yield of cotton.

Log $(A\text{-}y) = \log A - cb$; where $A = 100\%$; y = the percentage yield of the no P or no K treatment; b = the soil test value of the corresponding plot; and c = the proportionality constant. By solving for c on each experiment and averaging the values, a mean c value was obtained. This value was used to calculate response curves. The fit of the data around the curve indicates that the equation describes the relationship with reasonable accuracy.

Using the definitions previously given, a soil test P for Group I and II soils below 5 ppm would be very low and have a fertility index of 50 or less, 5 to 10 ppm would be low and have a fertility index between 50 and 75, 10 to 30 ppm between 75 and 100 or medium, 30 to 90 ppm between 100 and 300 or high, 90 to 270 ppm between 300 and 600 or very high. Values for Group III soil would be one-half that of Group I and II soils. This is shown in Figure 3.

Relationship Between Soil Test K and Relative Yield

The relationship between yield and soil test K is shown in Figure 4. The points in the figure refer to experiments described in Appendix Table 2. The three different soil groups are equated by adjusting the scale on the x-axis. The dotted line shown is the curve calculated by Mitscherlich's equation.

The calculated line from Bray's equation does not provide the best possible fit of the data since the equation forces a zero intercept for (x, y). Based on observation and experience of the writer, a soil test K of about 15 ppm for Group I soils is the

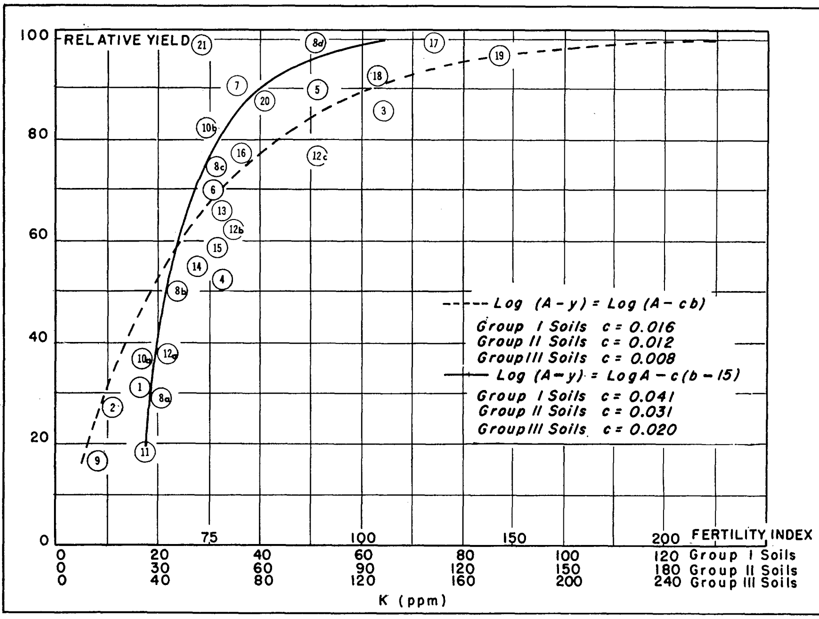

FIG. 4. Relationship between soil test K and relative yield of cotton.

minimum level to which the soil can be depleted by cotton. If Mitscherlich's equation is modified to Log $A-y$ = Log $A-c$ $(b-15)$, then the curve approaches $y = 0$ at $x = 15$ and appears to provide the best estimate of relationship described by available data.

For soil test K on Group I soils using the relationship as calculated by the modified Mitscherlich equation 20 ppm would be assigned a fertility index of 40, 30 ppm would be assigned a fertility index of 75, and 60 ppm would be assigned a fertility index of 100.

Response to P and K at Various Soil Test Levels

The foregoing information provides a basis for describing soil test P and K in terms of sufficiency in the soil for maximum production. It does not indicate the addition needed to produce the yield potential on a soil that is deficient in some degree. To provide a basis for recommending specific rates at certain soil test values, rate studies have been carried out at several soil test levels in recent years. The response to P at different soil test levels is shown in Figure 5 and to K in Figure 6. The differences

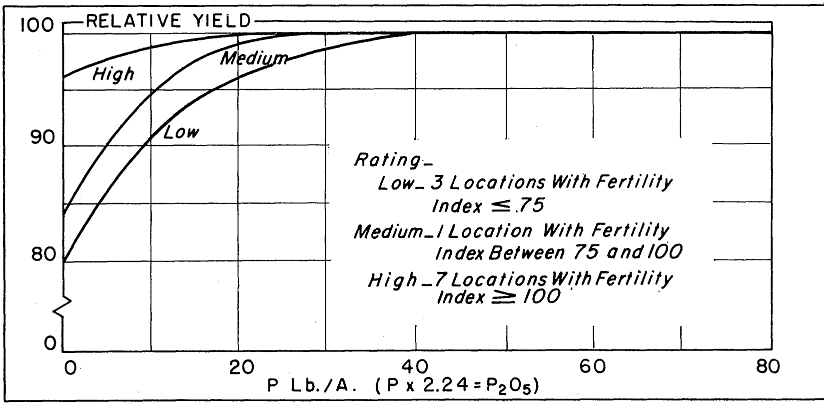

FIG. 5. Response of cotton to rates of P on soils testing low, medium, or high.

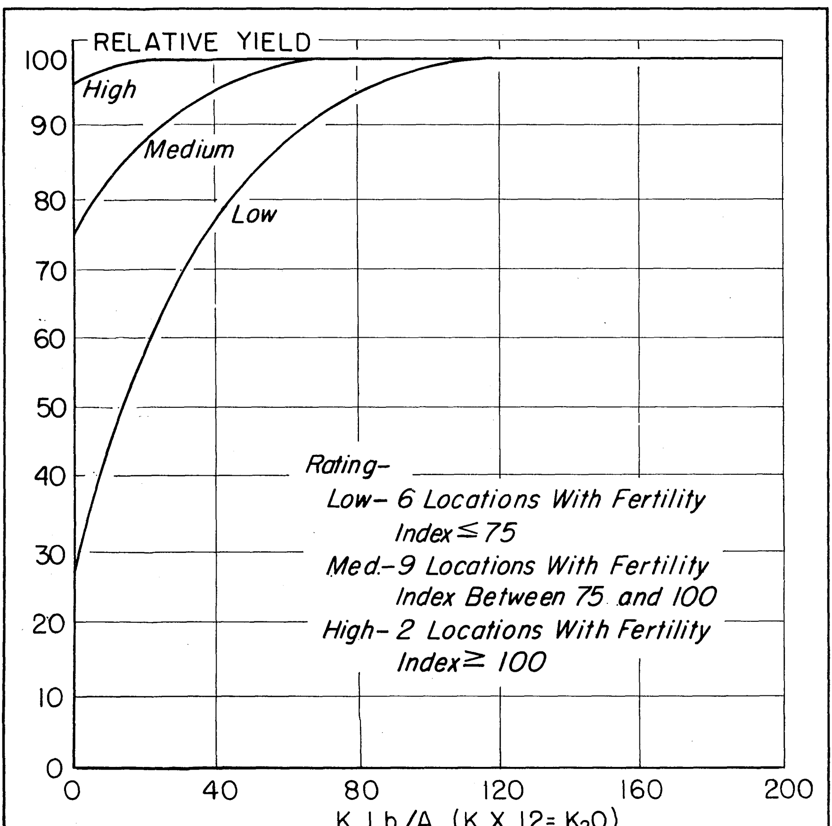

FIG. 6. Response of cotton to rates of K on soils testing low, medium, or high.

in amount of P and amount of K required to correct a deficiency reflects the more usual soil conditions found at the time these studies were initiated, i.e., low P sites were relatively not as deficient in P as low K sites were in K and high P sites were more common than high K. It also reflects a difference in amounts of elements required to cause a given change in production.

With these two sets of results, (a) the relationship between relative yield and soil test value and (b) the amount needed as fertilizer to supplement what the soil can supply, the information needed for making a recommendation is available.

This is true if the yield level is satisfactory. However, since these relationships are presented on the basis of relative yield, no assurance is given in the data as presented that actual yield potential is at the level desired. Therefore, it is logical to ask if there would be a yield or quality advantage for a higher soil test value than that found. This leads to three additional questions: (a) Should the recommendation take into consideration a need for soil fertility building? (b) Is the soil supply sufficient that some soil depletion can be tolerated? (c) Should the recommendation provide for soil fertility maintenance even though none is needed for yield or quality?

Value of Soil Fertility

Studies have been conducted to determine the value of K soil fertility. In general, if the soil level is sufficient to produce 75 per cent or more of the yield potential, there would not be a yield benefit from applying more of the element than needed for direct yield response and to maintain soil fertility. However, if the fertility index is less than 75, a yield benefit to succeeding crops can be expected from applying a treatment to increase soil fertility *(38,41)*.

Data from P studies have not shown the advantage for soil buildup where the fertilizer is drilled, as evidenced in K studies. Considering the difference in the chemistry of these two elements, the need for P buildup using drilled fertilizer should not be as critical as that for K even though the plant obtains both elements primarily by diffusion to the roots. Ensminger and Hood[1] have shown this is not true from broadcast applications. Where P is broadcast fertility buildup is important. There is evidence that continued soil P buildup can have an adverse effect on yield. At location 3 (Prattville) where P was well in

[1] Unpublished data.

the high range, yields of cotton, even after 8 years of continuous cropping, were highest where no P was applied. Earlier studies showed that Fusarium wilt increased as P increased but decreased with increasing K *(48,55)*. There was no indication that this accounted for lower yields in this study where a wilt-resistant variety was used.

Fertility Depletion, Maintenance, and Buildup

The previous sections have shown that soil fertility is important in crop production and that fertility buildup and depletion

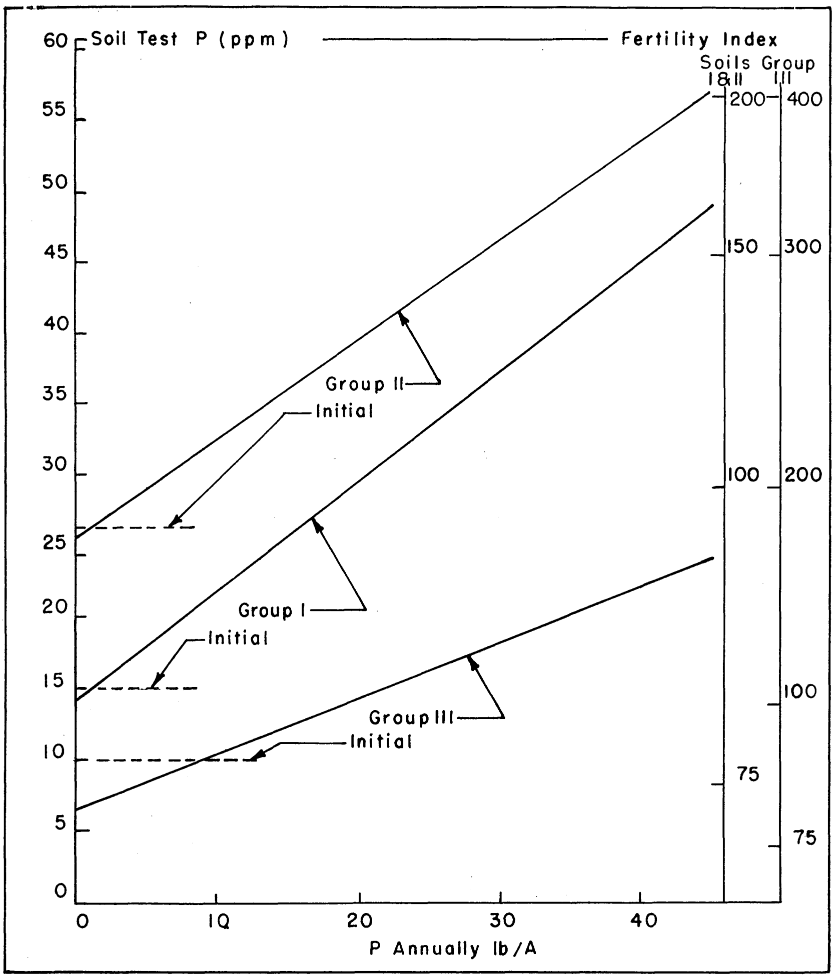

FIG. 7. Change in soil test P from eight annual applications to continuous cotton.

does occur. Therefore, knowledge concerning rate of depletion and buildup under a particular cropping practice is needed to develop a recommendation designed to build, maintain, or prevent depletion of soil fertility to an undesirable level.

The buildup and depletion of P and K associated with cotton grown annually are illustrated in Figures 7 and 8. These show a

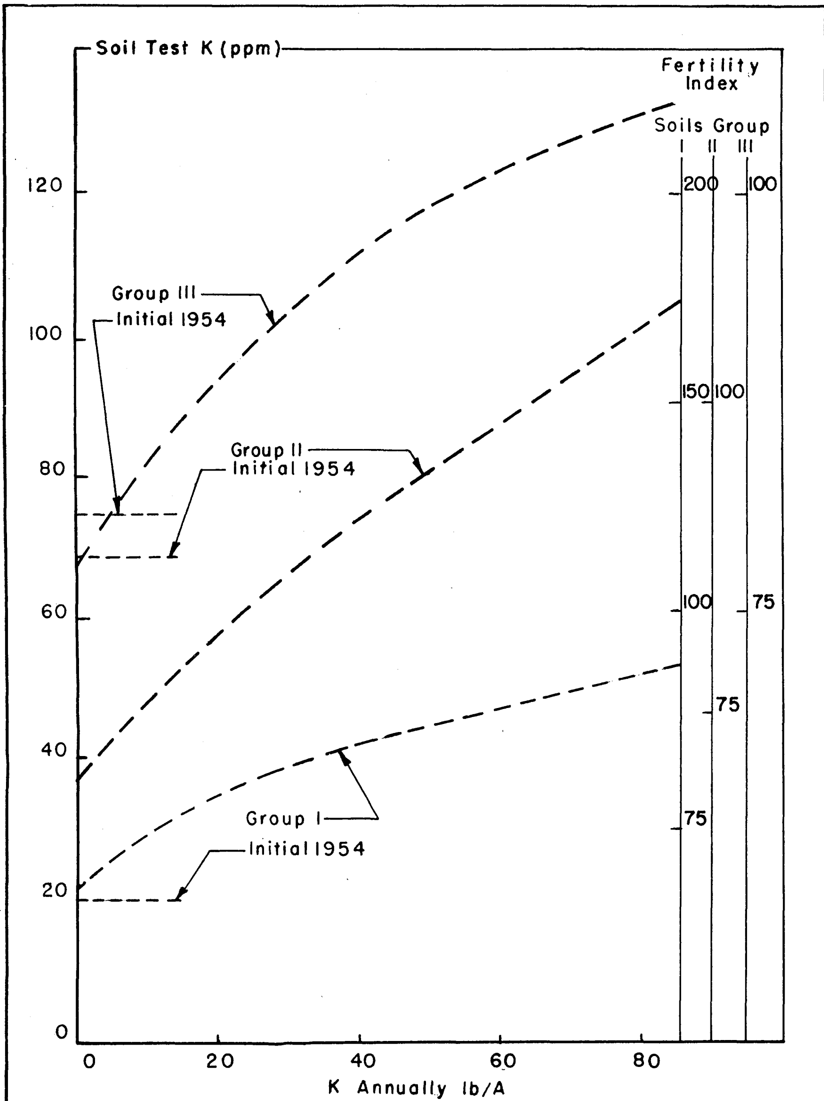

FIG. 8. Change in soil test K from eight annual applications to continuous cotton.

summary of buildup and depletion data at 7 locations over an 8-year cropping period, 1954-61.[2] In this study about 5 pounds of P and 10 pounds of K per acre annually would have prevented depletion. Buildup during 8 years for both P and K averaged approximately 0.2 pounds for each pound applied annually. The comparison of the individual data from these experiments is presented in the Appendix Figures 1-7. Similar results have been shown in previous studies *(16,39,41)*. These data show that buildup and depletion of P and K are gradual processes when rates of application are in the range of 0 to 5 times the annual removal. These elements are held by the soil and are capable of being built-up since cotton is relatively nondepleting. This means (a) if the soil is just above the point where a response to additions is obtained, then an annual maintenance application about equal to that removed by the harvested crop would maintain fertility; and (b) if the soil value is well above the point of no response, there need be no fear or depleting fertility in a single year, and no benefit would be derived from applying a maintenance application if resampling is done every 3 years.

Effect of Fertility on Factors Other Than Yield

Effect of soil fertility level or treatment on quality of product or plant characteristics that affect quality or suitability for harvest is of practical concern. Studies conducted to determine the effect of increasing applications of N and K and irrigation on fiber quality and lint percentage of cotton have shown no effect on fiber quality above a fertility index of 75 or a medium rate of application although lint percentage was decreased by increasing each of these factors *(6,43)*. There has been no indication of the effect of K on resistance to lodging or stem strength as has been reported for some other crops. There has been evidence of delayed maturity from high applications of K, N, and water. However with boll weevil control and timely defoliation to control boll rot, delayed maturity should not necessarily result in an adverse effect on yield or quality.

Rate of Fertilizer Needed vs. Soil Fertility

Soil test values have been related to rates of P and K needed

[2] N-P-K experiments conducted at Brewton Experiment Field, Brewton, Ala.; Monroeville Experiment Field, Monroeville, Ala.; Prattville Experiment Field, Prattville, Ala.; Wiregrass Substation, Headland, Ala.; Upper Coastal Plain Substation, Winfield, Ala.; Sand Mountain Substation, Crossville, Ala.; and Tennessee Valley Substation, Belle Mina, Ala.

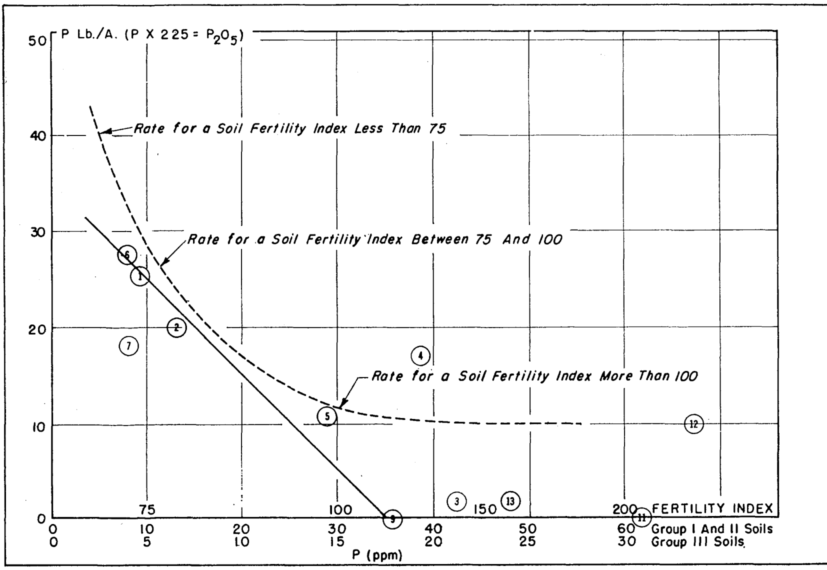

FIG. 9. **Annual rate of P for various soil test values—cotton.**

by considering the rate of fertilizer from which a response is obtained at various soil test values and need for soil fertility improvement and maintenance. In Figures 9 and 10 the points

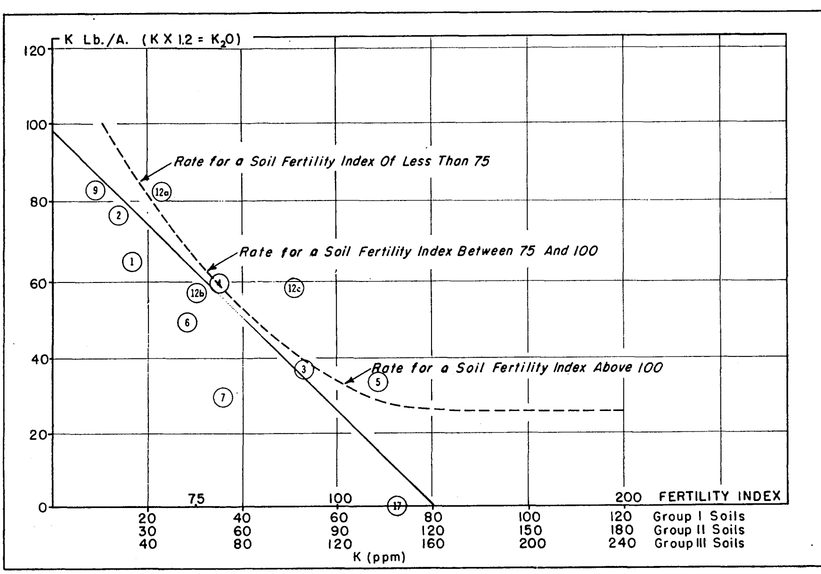

FIG. 10. **Annual rate of K for various soil test values—cotton.**

show rate to which a response was obtained. The straight line is the best estimate of average yield response to direct application. The scatter of points about this line indicates the need for further research to define the exact position of this line. The line is drawn without giving weight to the points where only 1-year yield response was obtained. The calibration curve is drawn to allow for needed buildup at low soil test values and maintenance at high values. It is deliberately drawn above the line showing actual yield response as a safety precaution to allow for some field variation and sampling error.

Method of Fertilizer Application

Data reported here were obtained in experiments with all of the fertilizer except N applied in a band at planting time. Usually one-third or one-fourth of the N was applied at planting and the remaining N was applied as sidedressing 4 to 6 weeks after planting. For other methods all factors influencing fertilizer needs of the crop would be expected to be the same except where method of application changes response to rate of application. Studies have shown that fertilizer applied in a band at planting should be applied 2 to 3 inches to the side and 2 to 3 inches below the seed to promote early growth and prevent salt injury, especially fertilizer containing ammonium phosphate *(17,18,25,26)*). Studies to compare the efficiencies of broadcast and drill applied fertilizers have shown that phosphorus efficiency on soils low in P is 3 times greater for drill than for broadcast application *(25)*. The difference decreases as P fertility increases. The effect of placements is much less for other elements.

Sidedress application of N after plants are up to a stand has been a standard practice. Sidedress application of P would not be expected to be effective in supplying P. Part of the K needs can be met by sidedress application *(41)*, but except on very sandy soils broadcast or drill applications are more effective.

Studies were conducted on soil medium or high in P and K, where little or no response to applications of these elements would be expected, to determine if method of application affected yields. Two years results, Table 1, show little or no yield advantage to drill application of P or K over broadcast application. There was no advantage in applying all P and K at planting over applying most of the P and K broadcast and only a starter application of N-P-K at planting time. An early growth response

TABLE 1. EFFECT OF N-P-K PLACEMENT ON YIELD OF SEED COTTON, SIX LOCATIONS IN 1964 AND ANOTHER SIX LOCATIONS IN 1965[1]

No.	Broadcast	At planting	Side-dress	Yield of treatment 1 and relative yield of all other treatments — Locations A	B	C	D	E	F	Av.
	N-P-K	*N-P-K*	*N*	*Pounds per acre*						
1.	0-0-0	20-18-50	70	2,600	2,359	2,963	2,724	2,736	1,997	2,576
				Relative yield pct.						
2.	0-9-30	20-9-20	70	100	102	100	101	93	102	100
3.	0-18-50	20-9-20	70	100	98	98	102	95	106	100
4.	0-18-50	0-0-0	90	94	97	96	96	88	100	95
5.	0-27-75	0-0-0	90	101	102	95	96	98	99	99
6.	0-0-0	20-0-50	70	96	100	96	101	88	103	97
7.	0-0-0	20-18-0	70	87	99	98	97	96	101	96
8.	90-18-50	0-0-0	0	87[2]	98[2]	101[2]	103	98	96	99

[1] All treatments at each location were applied on basis of soil test and soil type. Soil test treatment listed is a typical example for a Coastal Plain soil with a high P, medium K soil test rating. All locations were high in P except one that was medium. Three locations were high in K and three were medium.

[2] Second year only. Locations: A—Norfolk fsl, Headland, Ala., Soil Test HM; B—Magnolia, fsl, Monroeville, Ala., Soil Test HH; C—Norfolk, sl, Auburn, Ala., Soil Test HM; D—Greenville, scl, Prattville, Ala., Soil Test HH; E—Decatur, cl, Belle Mina, Ala., Soil Test MM; and F—Hartsells, fsl, Crossville, Ala., Soil Test HH.

occurred on sandy soils to a starter application of nitrogen in 1964 when temperature and moisture were favorable. This response was reflected in final yield. Based on this study for soils with a medium or high soil test for P and K, all P and K may be applied broadcast as needed for yield and to build or maintain fertility. The N may be applied broadcast before planting or as a sidedressing early after emergence.

Effect of Weather on Response

Concern is often expressed that the response data obtained under average weather conditions may not apply for better than average weather conditions. The data in Figure 11 showing the average yield for seven locations indicate that under a normal range of weather conditions this is not a valid concern; the magnitude of yield response varies slightly with weather conditions but the rate of fertilizer from which a response is obtained does not vary. Bray *(9,12)* explains this as a characteristic of immobile nutrients. In more favorable seasons root ramification is increased so that the soil supplies a proportionally larger amount. That this does not hold once an environmental factor is markedly

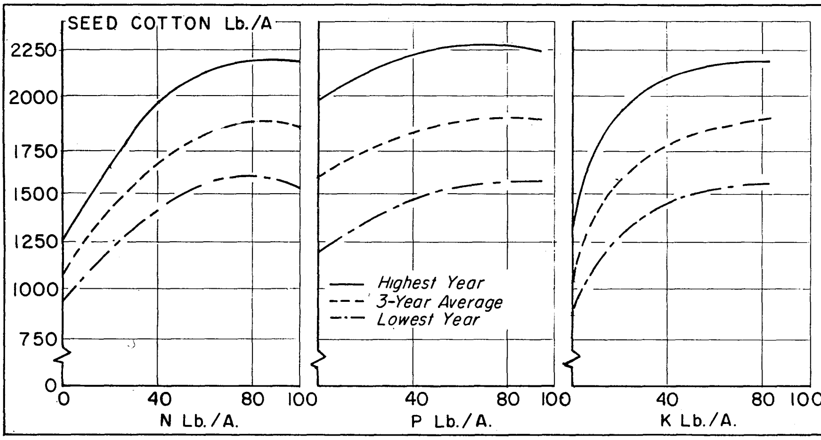

FIG. 11. Effect of yield level on response from N, P, and K in a 3-year period at seven locations.

altered is illustrated by the response obtained under irrigation in a later section of this report.

Skip-Row Planting

All work cited has been with solid planted cotton with stands between 20,000 and 40,000 plants per acre. Data obtained from skip-row planting show that skip-2-plant-2 can result in yields about one-third higher per allotted acre *(47)* than solid planted cotton. Rates studies with the individual elements have not been made under skip-row conditions. Considering the mobility concepts of nutrients and the basis on which plants absorbed nutrients, there should be no need to change the rate of application of P and K per allotted acre. However, because of higher yield potential, the rate of N should be increased.

Irrigation

The elimination of soil moisture as a factor limiting plant growth might be expected to change fertilizer requirements. The yields obtained from irrigation experiments *(36,45)* showed that the yield potential was increased from about 2 bales per acre for solid-planted cotton in Alabama to nearly 4 bales, Figure 12. When the environment is modified sufficiently to result in yield differences of this magnitude, interpretations of soil test must be changed. Above ground portion of plants from irrigated plots contained as much as 400 pounds of K per acre as compared

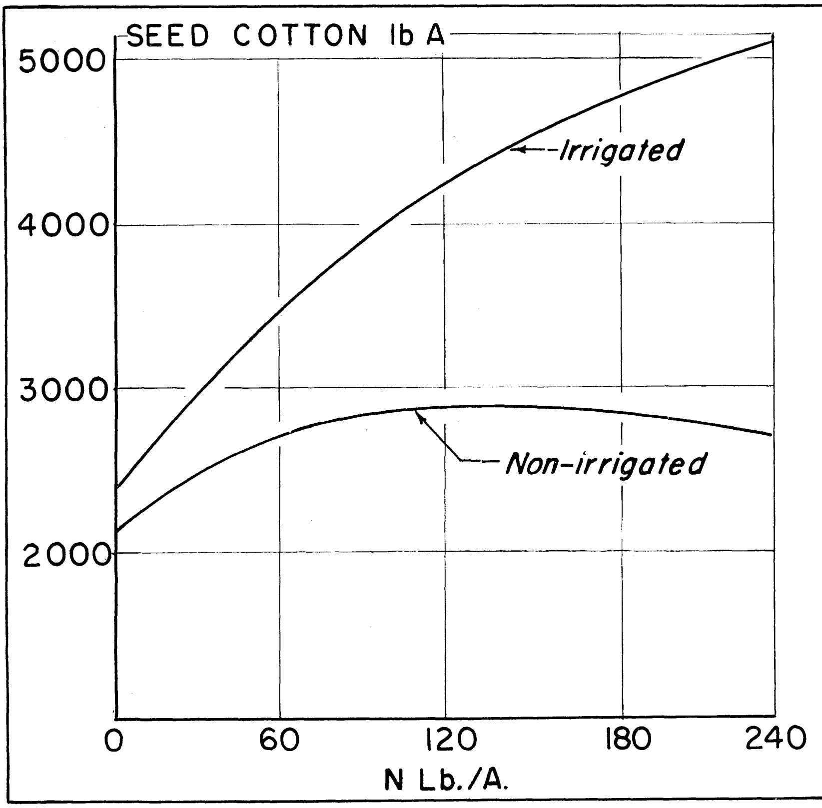

FIG. 12. Cotton response to rates of N with and without irrigation, 3-year average, Thorsby, Alabama (Ref. 26).

with 100 pounds per acre in those from unirrigated plots *(6)*. Even though relative yield and soil test calibration data obtained under a wide range of natural climatic conditions can be pooled, a different calibration must be developed when the environment is changed appreciably such as with irrigation.

Nitrogen

Soil test procedures have not been developed that provide information on soil N available to meet requirements of crops under soil and climatic conditions prevailing in Alabama. All recommendations that are made for N are general and assume the normal range of weather conditions and good management practices conducive to yields of 1½ to 2 bales per acre. The

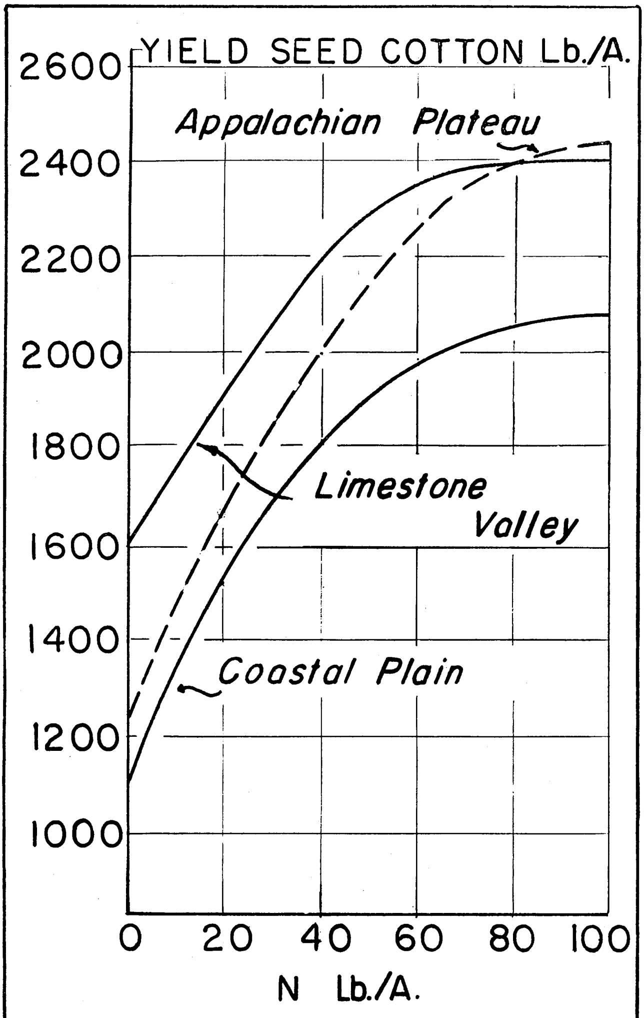

FIG. 13. Response of cotton to applications of N, 1959-1961.

yield response obtained in recent cotton experiments is shown in Figure 13 for three different general groups of soils. When better adapted varieties are available and better means of reducing boll rot and insects are developed, higher rates of N may be justified.

Soil Acidity

Research over the years has shown that soil acidity is important in crop production *(1)*. Figure 14 shows the relationship between soil acidity and cotton yield on two Coastal Plain soils *(2)*. In addition to its general effect on yield, soil acidity has an adverse effect on stand under certain weather conditions *(40)*. On some soils cotton is tolerant of a wide range of soil acidity conditions, but, because of the effect of acidity on leaching losses *(33)* and the availability of plant nutrients soils at a pH of less than 5.8 generally would need to be limed.

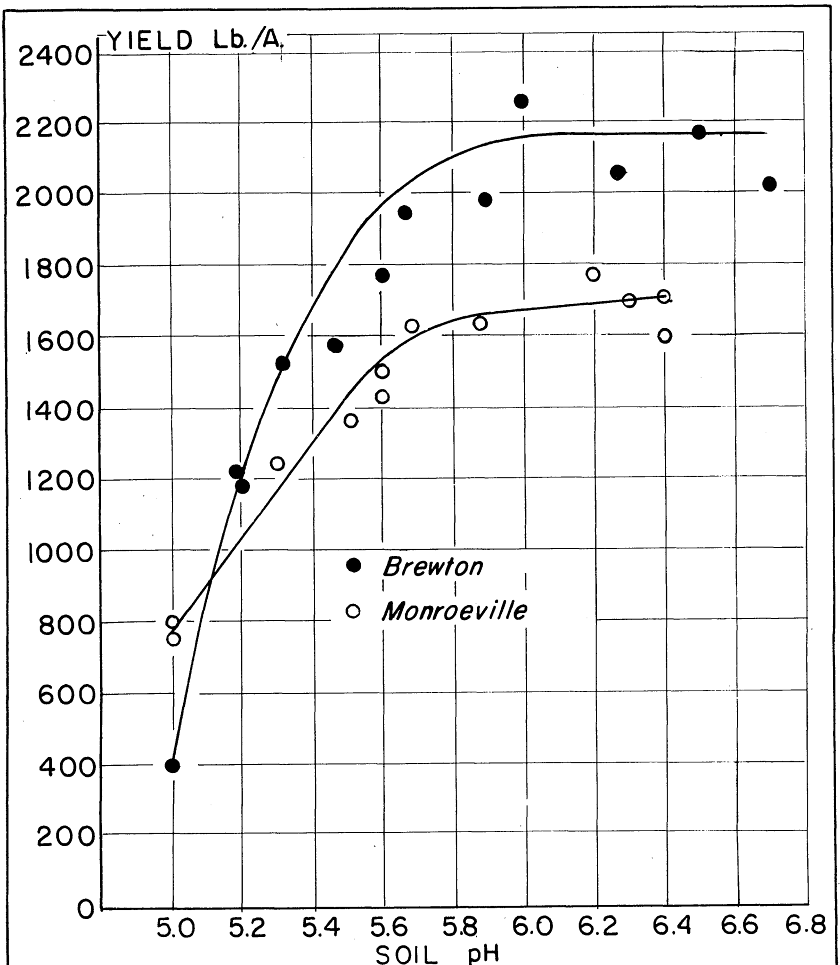

FIG. 14. Yields of cotton at various soil pH levels, Brewton and Monroeville Experiment Fields (Ref. 2).

Magnesium

Studies have shown that magnesium (Mg) deficiency occurs in cotton on certain soils in Alabama. The point of deficiency has not been accurately calibrated, but it appears to be near 5 per cent Mg saturation of cation-exchange capacity of the soil.

The typical response pattern for Mg *(3)* is presented in Table 2. The most economical source of Mg for cotton is dolomitic lime. However, where soil pH is above 6.2, dolomite will not react sufficiently with the soil, and other sources of Mg must be used.

TABLE 2. YIELD INCREASE OF SEED COTTON FROM ADDITION OF MAGNESIUM SULFATE AT 4 LOCATIONS, 2-YEAR AVERAGE

Location and soil type	Exchangeable magnesium	Yield increase
	p.p.m.	*Pounds per acre*
Alexandria Experiment Field, Decatur clay loam	55	0
Monroeville Experiment Field, Magnolia fine sandy loam	20	80
Sand Mtn. Substation, Crossville Hartsells fine sandy loam	14	280
Brewton Experiment Field, Kalmia sandy loam	10	360

Micronutrients

Boron. Boron (B) deficiency occurs in cotton on many soils of the State *(52,53)*. Since analysis for B is expensive and the amount of the element needed per acre is small, the practical solution would be to add one-half pound of B per acre annually. This can be applied in the starter fertilizer, in the preemerge herbicide, or at a rate of one-tenth pound per acre for not more than five applications in the insecticide.

Other Elements. Examples of deficiency of Mn, Zn, or Mo have not been observed on cotton in Alabama. Manganese (Mn) toxicity has been observed on very acid soils. The practical solution to this is liming to desirable pH range.

SOIL TEST CALIBRATION for CORN

Research data for corn are sufficient to provide a dependable recommendations based on soil tests for yields up to 100 bushels per acre. During the past 10 to 12 years, State average corn yields have increased from less than 20 bushels to more than 40 bushels per acre. Some factors which have been responsible for this were a reduction in total acreage, an increase in use of hybrid seed, closer spacing, and higher rates of N. In 1965 soil samples for corn recommendations were received for less than 10 per cent of the corn acreage planted in the State. Therefore, maximum use was not being made of information that could be provided by soil test.

Corn Response to N-P-K Compared with Cotton

The response characteristics of corn to N, P, and K as compared with those of cotton at the same test sites are shown in Figure 15. These are the average relative yields of the two crops at seven locations in the State where cotton was grown one year and followed by corn the next. The figure shows that the response characteristics of corn are different than those of cotton; therefore soil test calibration developed for cotton cannot be applied to corn. The response characteristics of the two crops to P are similar. Corn gave greater relative total response to N than cotton particularly at high rates. The greatest difference between the two crops was in response to K. Corn shows little response and to only a small rate of application at soil levels where cotton almost completely failed without the addition of K.

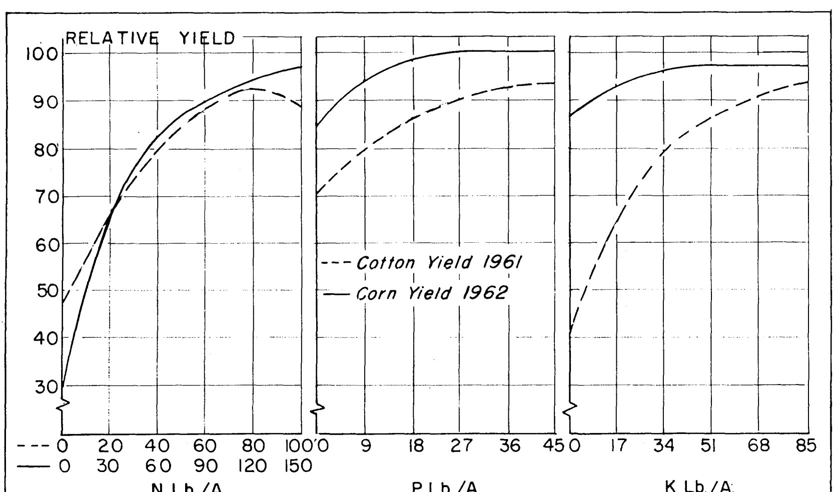

FIG. 15. Comparative response of cotton and corn to N, P, and K, average of seven locations.

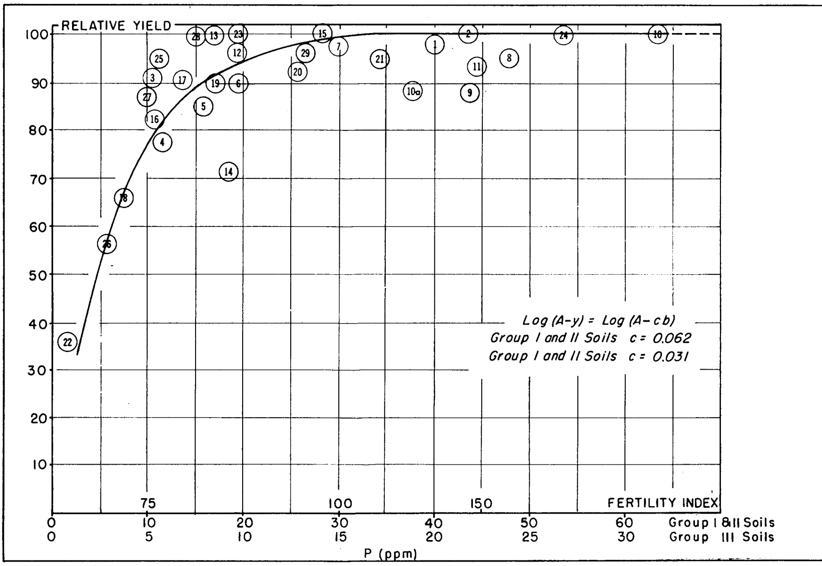

FIG. 16. Relationship between soil test P and relative yield of corn.

Relationship Between Soil Test P and Relative Yield

Using data obtained from sites where yields above 40 bushels per acre were produced, the relationship between soil test P and yield of corn is shown in Figure 16. The points in the figure refer to experiments described in Appendix Table 3. This relationship practically duplicates that shown in text Figure 3 for cotton. This would be expected considering the similarity in response of the two crops to this element.

Relationship Between Soil Test K and Relative Yield

The relationship between yield and soil test K is shown in Fgure 17. The points in the figure refer to experiments described in Appendix Table 4. Sufficient data were not available to provide a reliable estimate of the minimum K values for corn. However, based on data from other crops, the minimum value was estimated to be 10 ppm K. Using the modified Mitscherlich equation of the form Log (A-y) = Log A-c(b-10), "c" values were calculated. The curve obtained using average "c" value of the unadjusted data is represented by a dotted line. The solid line obtained using the modified equation appears to provide the best estimate of the relationship. Compared with cotton,

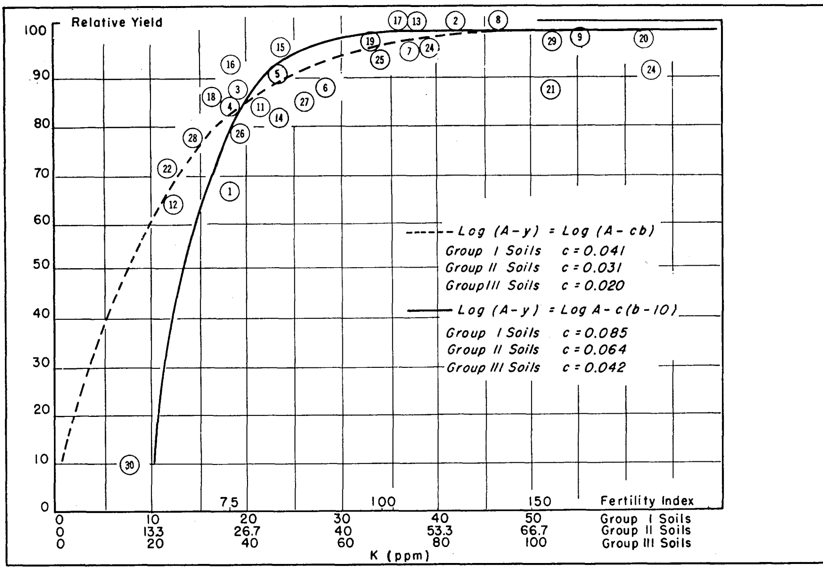

FIG. 17. Relationship between soil test K and relative yield of corn.

the same relative yield of corn could be expected with a soil K level almost one-half of that required for cotton. These data show that 34 ppm K represents a fertility index of 100 and 17 ppm a fertility index of 75.

Response to P and to K at Various Soil Test Levels

Responses to rates of application of P and K at certain soil test values are shown in Figues 18 and 19. These data indicate

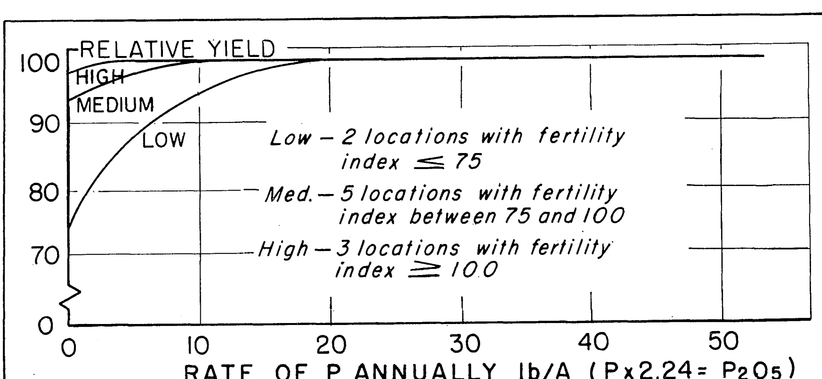

FIG. 18. Response of corn to rates of P on soils testing low, medium, or high.

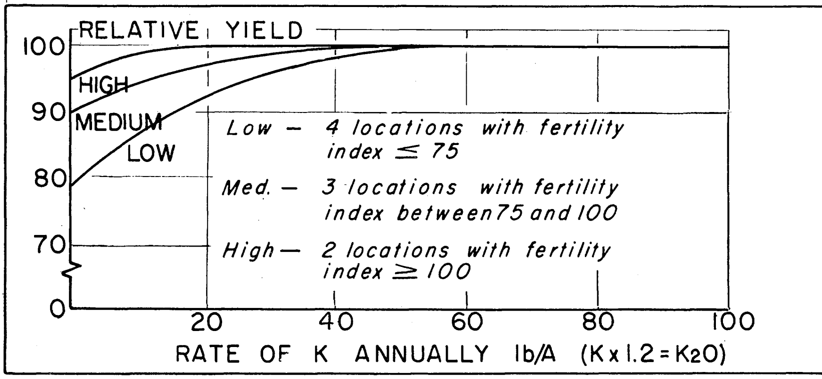

FIG. 19. Response of corn to rates of K on soils testing low, medium, or high.

that the efficiency with which corn is able to use soil K is carried over to applied K; however, studies are not available showing response where soil levels of K are too low to support relative yields of more than 15 to 20 per cent. Data from such soils are needed to better characterize the efficiency with which corn can utilize applied K.

Fertility Depletion, Maintenance, and Buildup

Critical studies showing the value of soil fertility buildup of P and K for corn are not available. Soil buildup and depletion by corn has been found to be similar to cotton. Figures 7 and 8 previously presented showing a summary of buildup and depletion for 7 locations over an 8-year cropping period was with cotton. This study was followed by 3 years cropping to corn. There was no apparent change in rate of buildup or depletion under corn.

Effect of Fertility on Factors Other Than Yield

Lodging of corn probably affects harvest more than any other one factor. K fertility has been credited with affecting lodging. Studies in Alabama have shown this effect only at very deficient K levels. When K is sufficient for 50 per cent relative yields additional K has not influenced lodging.

Nutritional studies with swine have shown corn grown on low-zinc (Zn) soils may not contain sufficient amount of the micronutrient to prevent development of Zn deficiency *(49)*. Other characteristics such as oil content or protein content of grain may be modified slightly by fertility, but these are primarily varietial characteristics.

Rate of Fertilizer Needed vs. Soil Fertility

The relationship between soil test value and rate of fertilizer P and K needed to prevent these elements from limiting yield is illustrated in Figure 20 and 21. The straight line shows actual response. Data are not available to show that corn yields are influenced by soil buildup of P and K. Therefore, only rates to

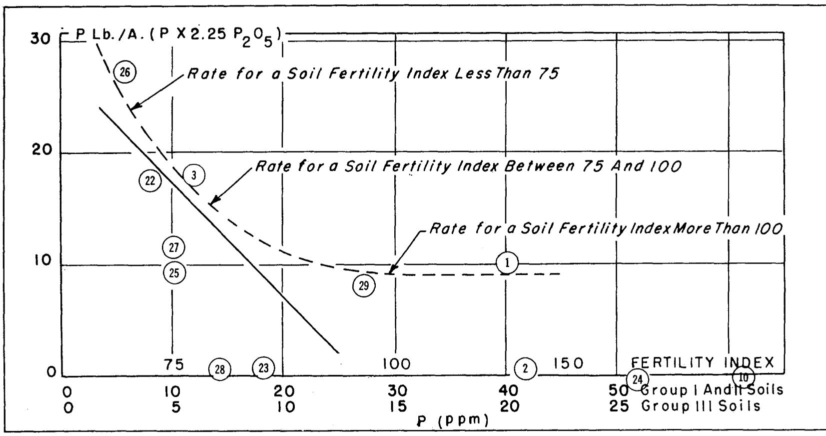

FIG. 20. Annual rate of P for various soil test values—corn.

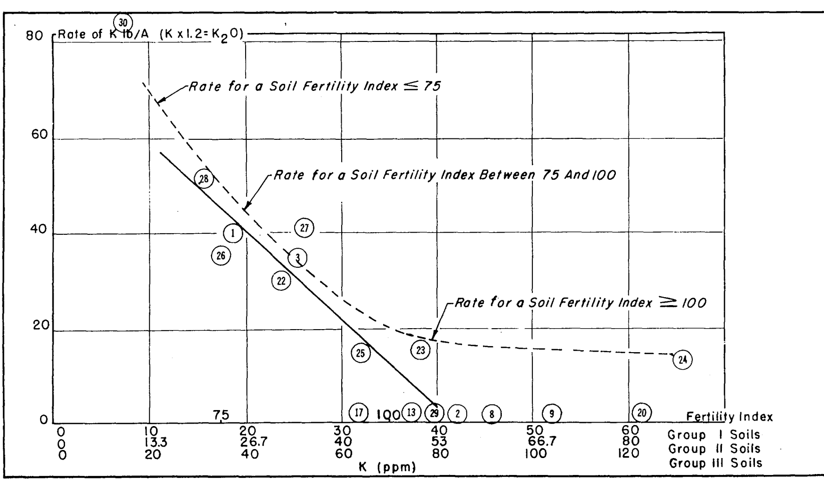

FIG. 21. Annual rate of K for various soil test values—corn.

which a response can be obtained plus allowance for maintenance can be justified. However, considering that rates data are available only from soils containing sufficient P and K for 60 per cent or more relative yield, the curve is drawn to allow for soil buildup for soil test values below 8 ppm P or 18 ppm K. It is also drawn above the actual yield response line as a safety precaution to allow for some field variation and sampling error.

Method of Fertilizer Application

Data reported here were obtained in experiments with all P and K together with 20 to 30 pounds of N applied as a band application at or before planting. The remainder of the N was applied as a side application. Other methods of application would be expected to result in similar response patterns provided placement did not damage seedling and the rate of application was adjusted where broadcast applications of P were substituted for drill applications on soils low in P. Studies showing comparative effectiveness of sidedressed K with drill K are not available, but, considering that 90 per cent of the plant's total K needs are required by tasseling *(23,24,31)*, it is reasonable to expect that for a sidedressing of K to be as efficient as drill applications it would have to be applied within 30 days of planting. Broadcast applications of K before planting should be as effective as drill applications.

Effect of Weather on Response

Yield data from seven locations comparing response when yields were highest with that when yields were lowest in a 3-year period on the same locations, Figure 22, shows that under a normal range of weather conditions the rate of application of P and K to which a response was obtained did not vary appreciably. Although the fertilizer rate to which a yield response would be obtained at any particular soil level might not be changed appreciably by weather differences, the greater crop removal associated with higher yields would need to be offset in the rate of fertilizer applied to maintain fertility.

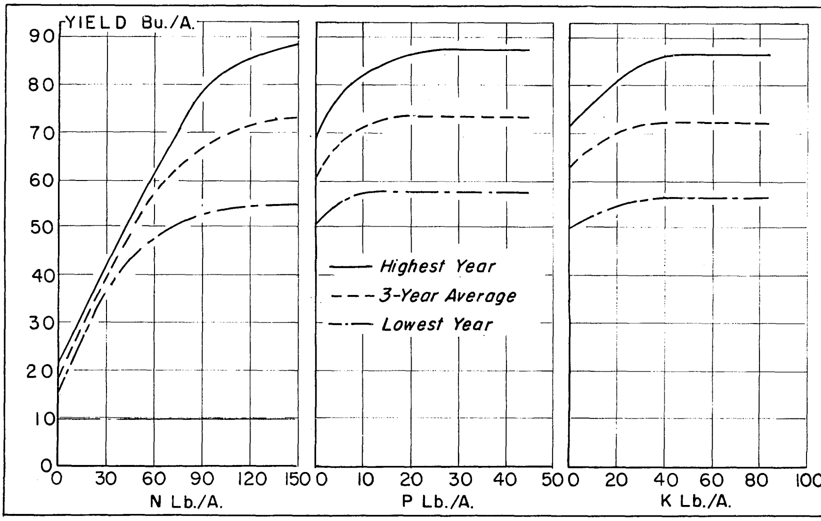

FIG. 22. Effect of yield level for a 3-year period on response of corn to N, P, and K, average of seven locations.

Irrigation

All data referred to concerning yield have been obtained without irrigation. With irrigation to maintain a high level of moisture, yield responses from an additional 50 to 100 pounds N have been obtained.[3] Studies have not been made to determine the phosphorus and potassium requirements for sustained corn yields greater than 100 bushels per acre. However, under irrigation, in view of the added investment in the crop and the limited data, it has been considered practical to increase the normal rate of P and K.

Corn Silage

The fertilizer required to produce corn for silage is no different than that required to produce corn for gain. The difference is in crop removal, hence soil depletion. With corn for grain the minerals contained in the stover is left on the land whereas when harvested for silage, the entire above ground portion of the plant is removed. Thus, an adjustment should be made in the rate of fertilizer to take into consideration removal. If the soil is already in a good state of fertility, the adjustment can be most efficiently made to the following crop.

[3] Unpublished data.

Nitrogen and Spacing

Recent studies in Alabama have shown that increasing plant population up to 16,000 plants per acre increases the yield potential with present varieties *(44)*. With stands of 16,000 stalks per acre, N rates of 100 to 150 pounds per acre are required for maximum yields, depending on the yield potential of the field. The interaction between stand and rate of N for two different yield potentials are shown in Figure 23 *(44)*. This shows that

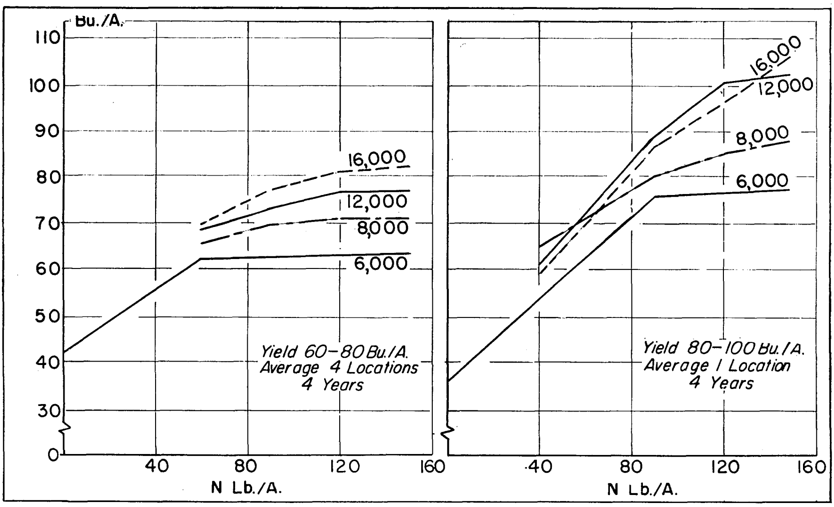

FIG. 23. Response of corn to N at different plant populations under two yield levels (Ref. 44).

yield in the range of 60 to 80 bushels per acre 120 pounds is adequate for top yields even with 12,000 to 16,000 plants per acre; however, where the yield potential is 100 bushels, a response may be obtained to 150 pounds N. Studies are in progress to determine response at higher populations.

Soil Acidity

Corn is recognized as a crop with a wide tolerance to soil acidity. However, yield is limited on some soils because of acidity when the pH drops below 5.4 (Figure 24)). Data are not available from a sufficient number of experiments to define a critical point. This exact point would be expected to vary with soil because it is governed by soil characteristics that determine the

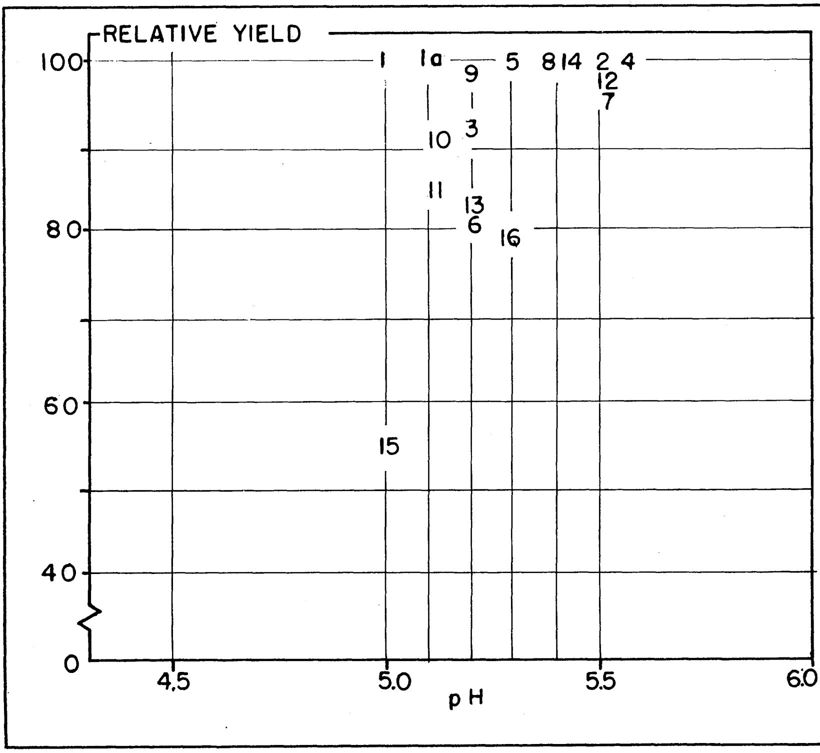

FIG. 24. Relationship of soil pH and yield of corn as compared with yields where acidity was not a limiting factor.

amount of aluminum (Al) becoming active. Considering all factors associated with soil acidity, the practical solution is to apply lime as needed to maintain pH in the range of 5.5 to 6.5.

Magnesium

Magnesium (Mg) deficiency has been observed on corn as the visual deficiency symptom of chlorosis between veins. This deficiency has not been calibrated sufficiently to indicate limiting values.

Micronutrients

Zinc. Zinc (Zn) defficiency occurs in corn on many of Alabama's sandy soils that have been limed to pH 6.0 and above or soil P is high or both *(50,51)*. Studies are currently underway to calibrate soil level with response and thus to provide a basis for recommending Zn based on soil test for Zn. Presently, recommendations for Zn are based on soil texture, pH, and soil test P. When Zn is recommended, 3 pounds per acre per year is sufficient. After 2 or 3 applications of 3 pounds of Zn per acre, the soil level will usually be sufficient to prevent deficiency in corn.

Other Elements. Examples of deficiencies of manganese (Mn), boron (B), molybdenum (Mo), or copper (Cu) on corn have not been reported in Alabama.

SOIL TEST CALIBRATION for SOYBEANS

Compared with the calibration data for cotton and corn, data available on soybeans is limited *(5,42);* however, the data on soybeans appear to agree with calibration data for cotton and corn. Because of this apparent agreement, greater weight can be assigned than if no comparison could be made. Soybeans is recognized as a crop influenced by soil fertility but where direct application of fertilizer is not a critical production factor. Research results show that many acres of soybeans are being grown below optimum levels of soil fertility or rates of fertilizer application.

Very few soil samples are received annually in the Auburn Soil Testing Laboratory for soybeans. This indicates very little consideration is given to direct fertilization of soybeans by most growers.

Relationship Between Soil Test P and K, and Relative Yield Response at Various Soil Levels

Data available relating soil test P and K needs are shown in Figures 25 and 26, and response to direct application of these elements at various fertility levels in Figures 27 and 28. The points in the figures refer to experiments described in Appendix Tables 5 and 6. These data show that soybeans are similar to corn and cotton in soil fertility requirements and in response to applications of P. The response to K appears to be intermediate between these two crops.

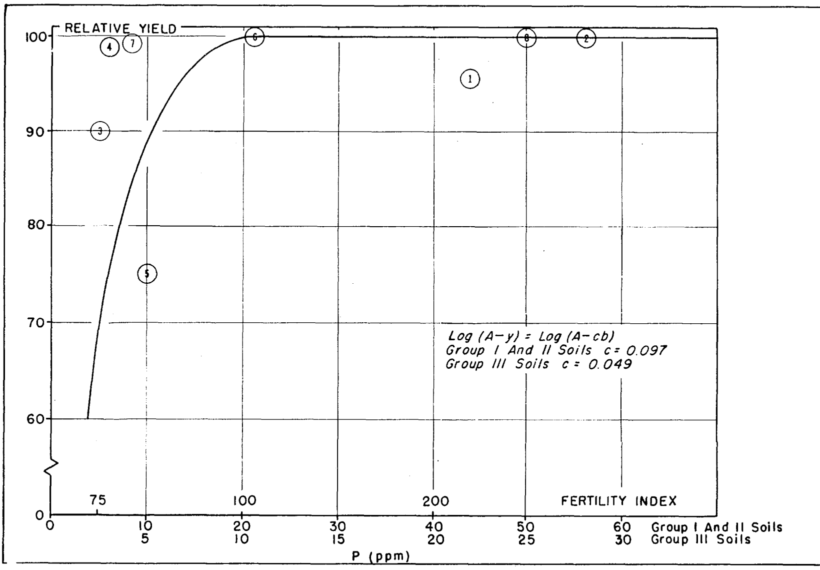

FIG. 25. Relationship between soil test P and relative yield of soybeans.

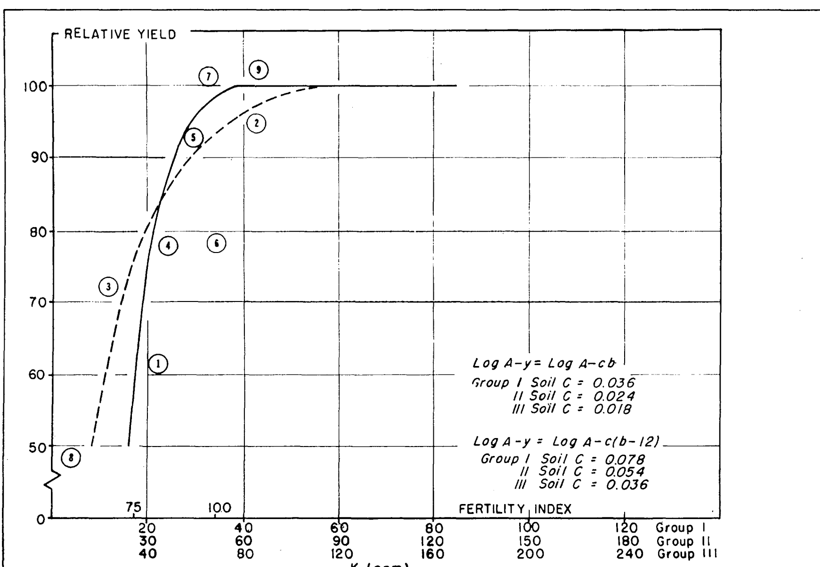

Fig. 26. Relationship between soil test K and relative yield of soybeans.

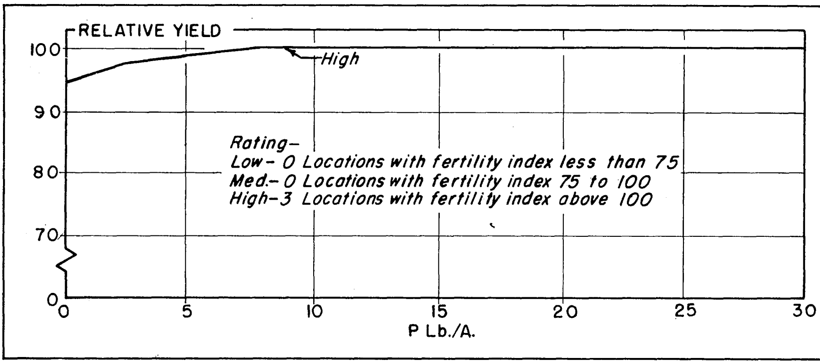

FIG. 27. Response of soybeans to rates of P on soils testing low, medium, or high.

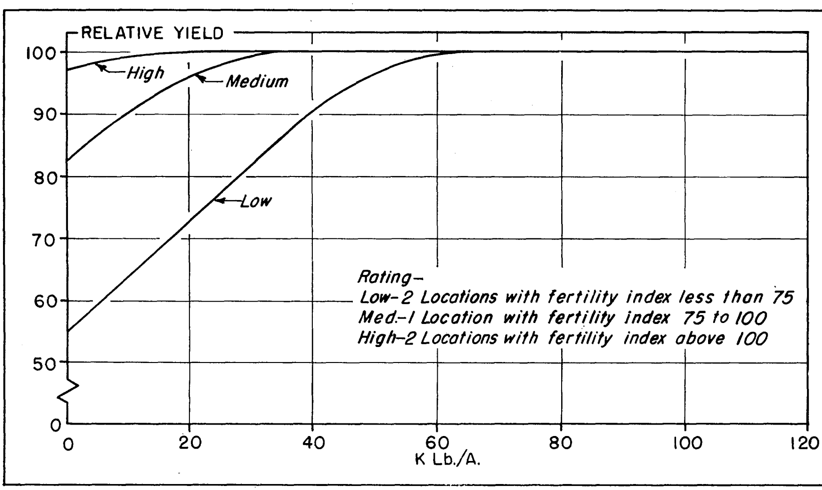

FIG. 28. Response of soybeans to rates of K on soils testing low, medium, or high.

Fertility Depletion, Maintenance, and Buildup

Based on removal in harvested crops, P buildup and depletion with soybeans should be comparable to that with cotton and corn for grain. Potassium removal is greater by soybeans than by either cotton and corn. Therefore, a higher rate of application may be required for maintenance and buildup. The limited data available indicate about one-tenth pound buildup per pound applied annually over the 4- or 5-year-period as compared with one-fifth pound in cases of cotton and corn.

Rate of Fertilizer Needed vs. Soil Test

Rate response data have not been obtained at a sufficient range in soil levels to define completely the relationship between soil test level and rate at which a response can be obtained. However, the data available indicate that rates of P and K adequate for cotton would be sufficient for soybeans.

Method of Application

Method of applying fertilizer to soybeans is extremely important, not because of the need for proper placement for response but because of the sensitivity of the seed to salt injury. Obtaining a stand is of major significance with this crop because extreme sensitivity of germinating soybean seed to even low concentration of soluble salt, fertilizer for soybeans applied at planting must be broadcast or placed 2 or more inches to the side of seed *(42)*.

Nitrogen

Crop yields in the favorable range of 35 bushels per acre require approximately 200 pound N per acre just to provide that contained in the soybean seed at harvest. Properly inoculated soybeans can fix atmospheric N to meet most of this need. Research has not often shown a yield response to application of nitrogen, either from starter applications or from applications at blooming time when the soil is inoculated from previous soybean crops or when the seed are properly inoculated. It is not unusual to observe a visual response in plant growth to a starter application of N, but as a rule this does not result in increased seed yield. About the only exception is on very sandy soils where soybeans have not grown previously. Even under this condition yield increases of only 2 or 3 bushels have been obtained from application of N. This has led to the belief that a starter application may decrease fixation of atmospheric N. However, no yield response has been obtained from nitrogen applications made at blooming time. *(42)*.[4]

Soil Acidity

Soybeans like most other N-fixing leguminous crops will not produce top yields at extreme levels of acidity except on soil

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[4] Also more recent unpublished data.

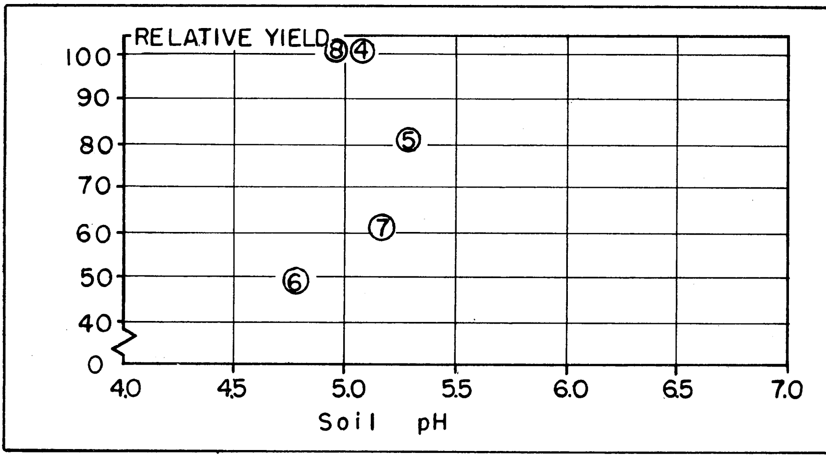

FIG. 29. Relationship between soil pH and relative yield of soybeans.

with very low capacity to release Al into the soil solution. Fig. 29 indicates that soybean yields are influenced by acidity below 5.4 but this varies with location.

Micronutrients

Molybdenum. Molybdenum (Mo) is one of the micronutrients that has been added to the list of essential elements sometimes deficient in soils. For many years it has been known that Mo was required in the process of N fixation by bacteria. Only in recent years has it been shown to be deficient for growth of certain plants on some soils. Response in soybean yields from applications of Mo have been reported in other Southeastern States on very acid soils. Several experiments have been conducted in Alabama to determine the likelihood of a Mo deficiency; to date no response has been obtained.

Other Elements. Examples of deficiencies of other elements have not been observed in Alabama with the exception of Mg. Deficiency of this element probably falls in the same category as that with cotton and corn; for this reason consideration is given to use of dolomitic limestone on soils low in Mg when liming is needed.

SOIL TEST CALIBRATION for COASTAL BERMUDAGRASS

Coastal bermudagrass is one crop in the broad category of summergrass pasture ranging from carpetgrass and crabgrass through forage sorghum, millets, sudan and johnsongrass, bahiagrass, and various bermudagrasses. Some data are available on all of these crops, but not enough to provide complete calibration. The data available indicate some variation in calibration depending on rooting characteristics and total removal of harvested plant parts. Because of the interest in livestock production in this State, the fact that this category of crops is supported by A.S.C.C. assistance and perhaps other reasons, the number of soil samples sent to Auburn Soil Testing Laboratory for summergrass pastures is appreciable. There is an estimated 1,500,000 acres devoted to production of summergrass pasture. Samples tested in 1965 averaged one for each 220 acres.

The calibration of Coastal bermudagrass will be limited to loamy sand and sandy loam soils of the Coastal Plains where this crop is well adapted and where an intensive study has been made during the past 5 years *(29)*.

Relationship Between Soil Test P and K, and Relative Yield Response at Various Soil Levels

The relationship between soil P and K in the surface 2 inches and relative yield is presented in Figures 30 and 31. The points

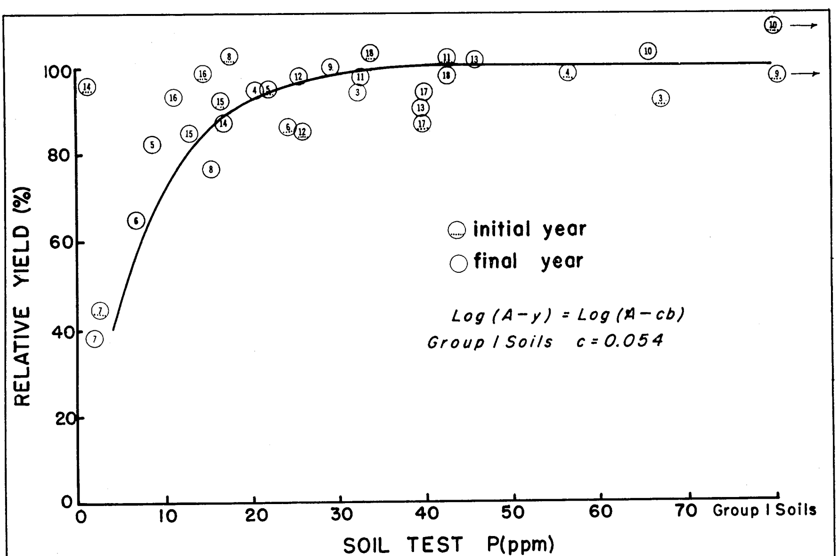

FIG. 30. Relationship between soil test P in the top 2 inches of soil and relative yield of Coastal bermudagrass.

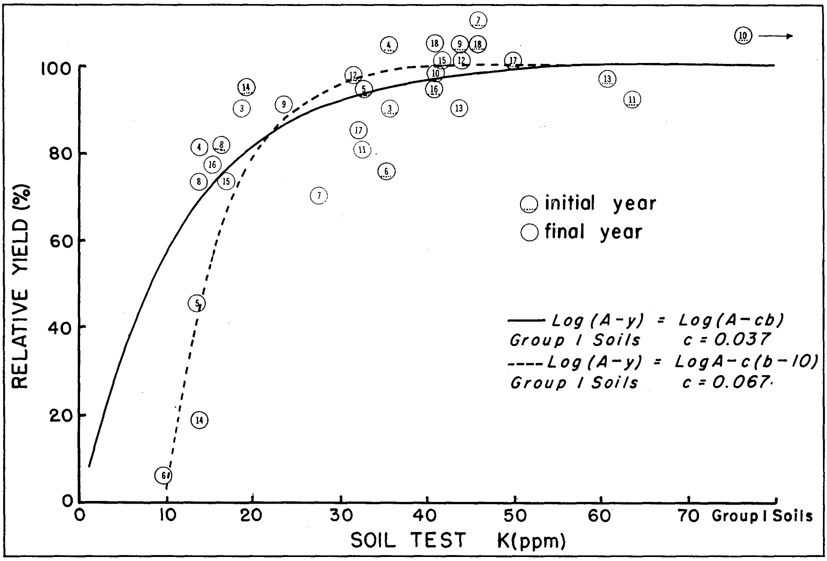

FIG. 31. Relationship between soil test K in the top 2 inches of soil and relative yield of Coastal bermudagrass.

in the figures refer to Appendix Tables 7 and 8. Since Coastal bermudagrass is a deep rooted crop, a question of depth of sample is frequently raised. Studies have been conducted to determine if the calibration could be improved by analyzing other fractions of the surface 24 inches. It was found samples of the surface 2 inches from established stands of Coastal on sandy Coastal Plain soils that had not received unusual treatments in the last few years gave as good an indication of expected response as the 0-6, 0-12 or 0-24 inches of the profile *(29)*. Therefore, from a practical standpoint, calibration for this and all other sod crops is based on the analysis of the surface 2 inches of soil. Such samples cannot be expected to give a valid indication of the available supply of the nutrients in the soil when radical changes in treatment have been recently made.

Several experiments have been conducted and others are in progress to determine rate of application needed at various initial soil levels. It appears that when the soil level is in the range where a response can be expected the rate of application will need to approach rate of removal.

Fertility Depletion, Maintenance, and Buildup

No benefit has resulted from applying a sufficiently high rate to maintain the soil at a level of fertility above the point where a response to application is no longer obtained. When the soil level is above this point, it appears that the most profitable practice is to apply less than that removed until the soil level approaches the value where a response will be obtained and then apply amounts required to offset removal. The effect of 4 years treatment and removal of hay with 200 pounds of N is shown in Figures 32 and 33. The intermediate rate was planned to approximate rate of removal. The average data for all locations indicate this was accomplished. The data show that at a

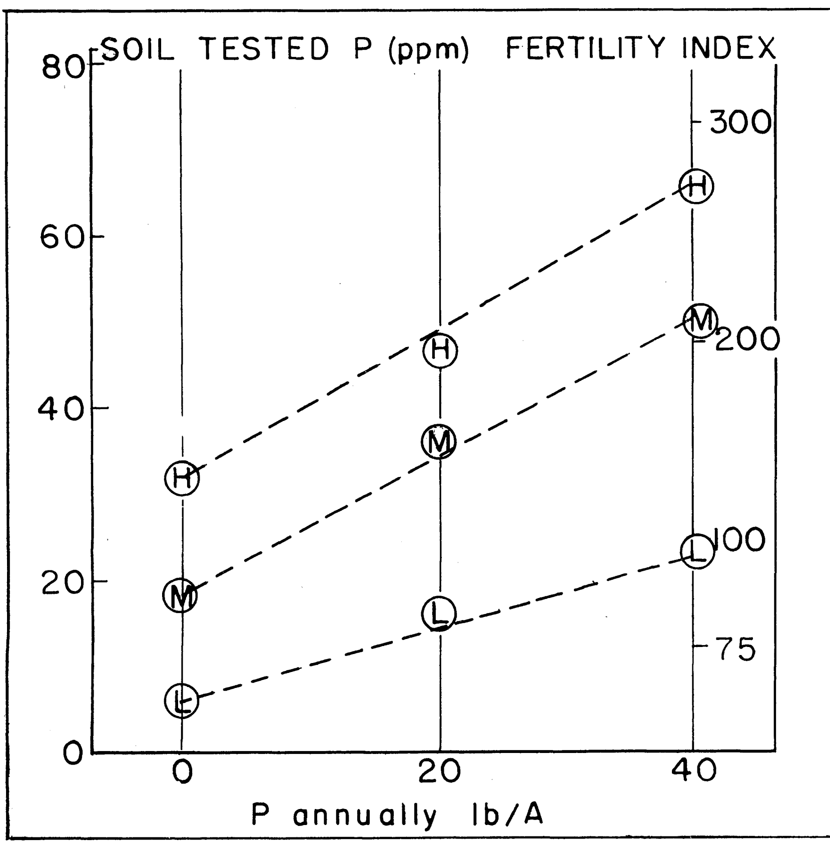

FIG. 32. Change in soil test P from four annual applications to Coastal bermudagrass.

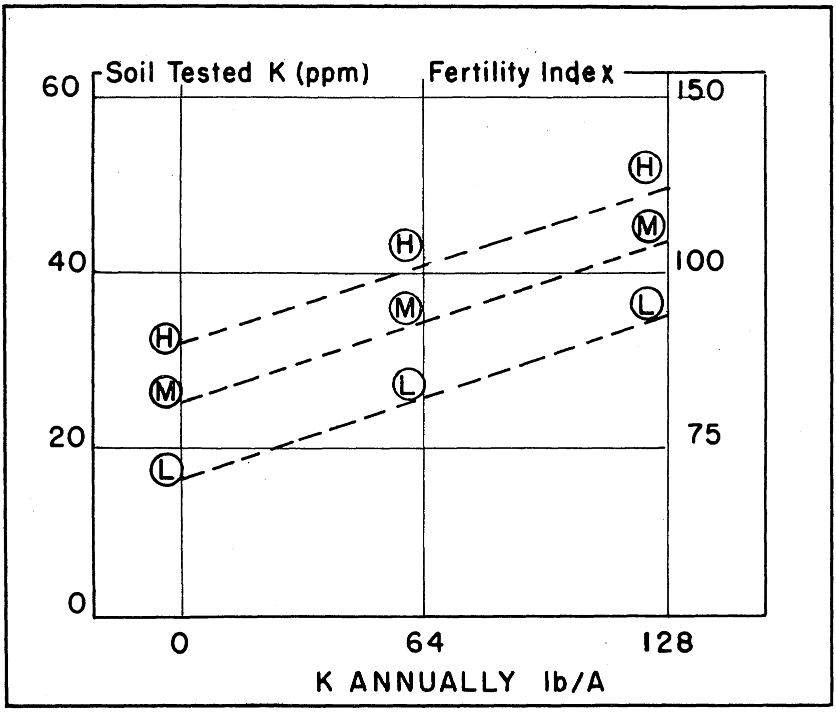

FIG. 33. Change in soil test K from four annual applications to Coastal bermudagrass.

high soil level there was a decrease from a rate equal to removal, but at low soil levels there was an increase; the medium soil level did not change.

Effect of Fertility on Factors Other Than Yield

Luxury consumption of both P and K occurs when the amount available is in excess of the amount required for maximum growth as is indicated in Figures 34 and 35. The amount of P involved is small and may be beneficial for animal nutrition. The amount of K removal in excess of needs can be appreciable. This study shows that where hay production without irrigation is not more than 5 tons per acre 20 pounds P per acre would more than offset removal, for K about 80 pound per acre would be needed. These data suggest that after a medium or high level of P and K is obtained, the use of N, P, and K in the ratio of 10-1-4 (N, P_2O_5, K_2O in ratio of 4-1-2) should provide adequate amounts of each

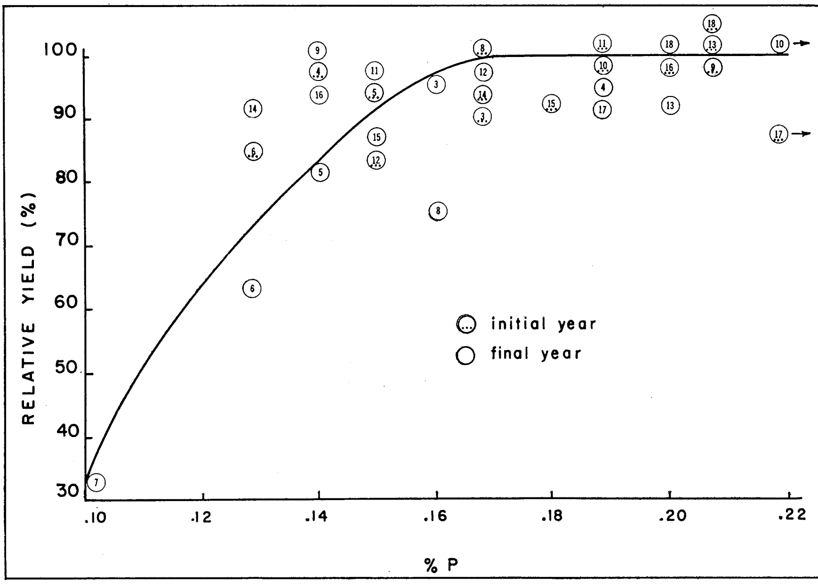

FIG. 34. Relationship between P content of Coastal bermudagrass and relative yield showing luxury consumption above 0.16 per cent P.

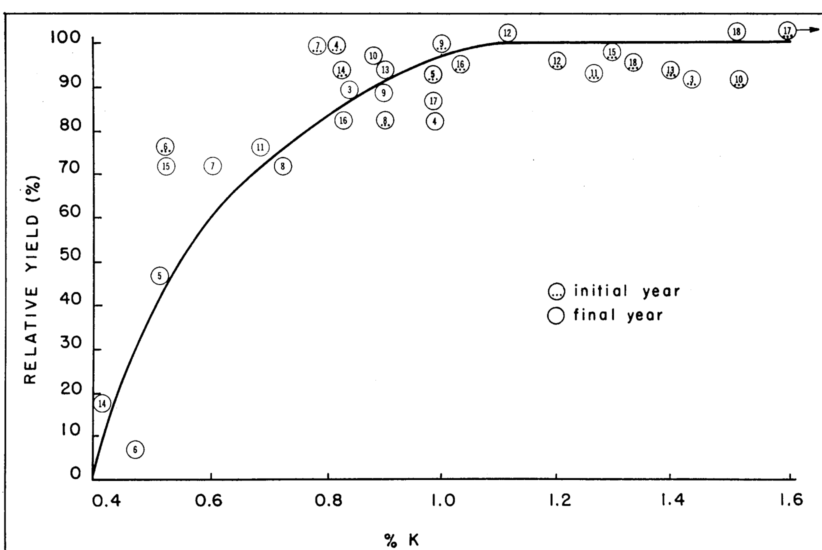

FIG. 35. Relationship between K content of Coastal bermudagrass and relative yield showing luxury consumption above 1.0 per cent K.

element. This has been predicted by several writers. *(13,21,28, 29,54)*. However, the data suggest that this will not hold over a wide range of N rates and will vary with production and utilization of forage.

It has been established that a fungus disease attacks Coastal bermudagrass and other grasses when available K is below the amount required for top production at the rate of N and level of moisture available *(20)*. This weakens the stem and root system to such an extent that stands are reduced. These studies have shown that if K levels are kept sufficiently high to maintain yield that the stand reductions does not occur *(4,20)*. Maximum yield can be obtained from K applied as needed. These same studies show that K efficiency is increased by dividing the annual application.

Nitrogen

Grasses such as Coastal bermuda have production potentials that are limited essentially by the rate of N applied and the amount of available water. Evans et al. *(19)* reported that under normal climatic conditions of Alabama, except where very high protein levels are desired, N applications in the range of 200 to 400 pounds per acre give the highest return for investment. Higher rates are profitable only where available moisture is high and the forage is utilized to take advantage of high N content. These studies show that yields are limited more by N than by water under Alabama rainfall conditions. However, there are years when moisture definitely limits yield.

Soil Acidity

Coastal bermuda is very tolerant to soil acidity. A response to lime was not obtained in the studies reported in Figures 30 and 31, although the minimum soil pH was about 5.0. Response to lime has been obtained in other studies where the pH of the total profile approaches 4.5.[5] Where the rate of N applied is 200 pounds per acre or more annually, the soil can become very acid throughout the profile. Since it is normally impractical to incorporate lime into the subsoil once it becomes very acid, the question is should not an effort be made to maintain soil pH in a reasonable range to prevent very acid conditions developing in the subsoil. Over a long period subsoil acidity will become a

[5] Unpublished ARS-USDA research.

factor in production of this crop. Consideration might also be given to change of crop that is not as tolerant to acidity. Some of the other summer grass crops in the millet and sorghum families are more sensitive to acidity. Considering these factors, lime is presently recommended for Coastal bermudagrass when soil acidity is below 5.5.

Other Elements

Examples of deficiency of any of the secondary or minor elements under normal management have not been demonstrated at this time.

SUMMARY and CONCLUSIONS

A theory of soil test calibration presented here relates chemical soil test values to relative yield and expresses these fertility levels as a "Fertility Index" in which 100 represents the soil value where a yield response to application of the element is no longer obtained. The response to applications of the mineral element is then related to Fertility Index. This information along with other factors considered in arriving at a soil fertility program is presented for cotton, corn, soybeans and Coastal bermudagrass.

The research reported here shows that chemical soil test values can be related to crop response in the field and to rate of application of mineral elements needed to prevent limiting yield.

ACKNOWLEDGMENTS

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The N-P-K study with cotton and corn was jointly planned and supervised by J. T. Cope, Jr., L. E. Ensminger, C. E. Scarsbrook, and the author. Most of the corn calibration data was collected by J. I. Wear and Doyle Ashley. The Coastal bermudagrass study reported was conducted by C. E. Evans, C. W. Jordan, G. W. Crowley, J. T. Eason, and the author.

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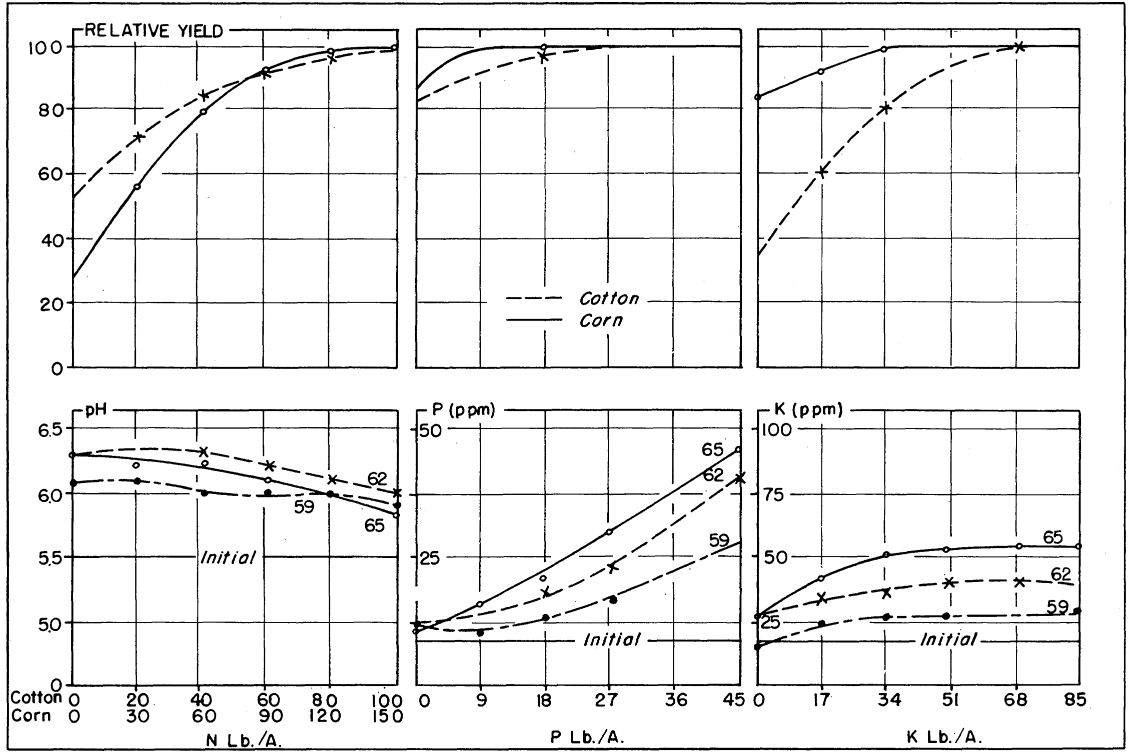
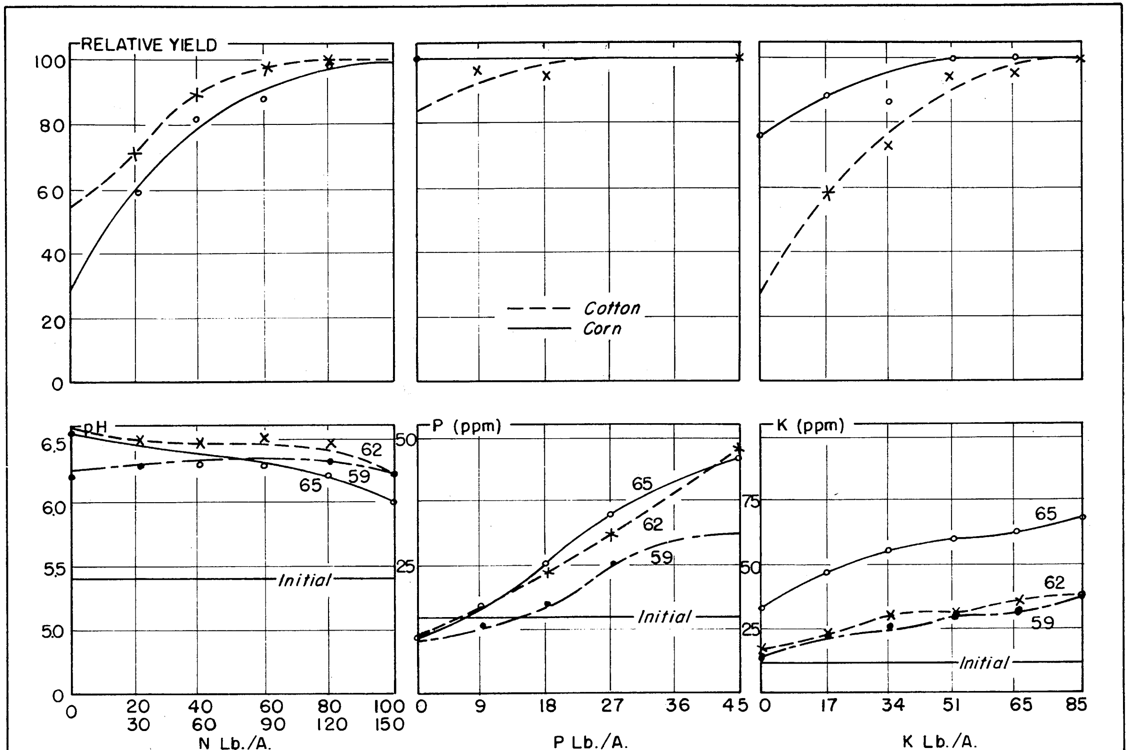
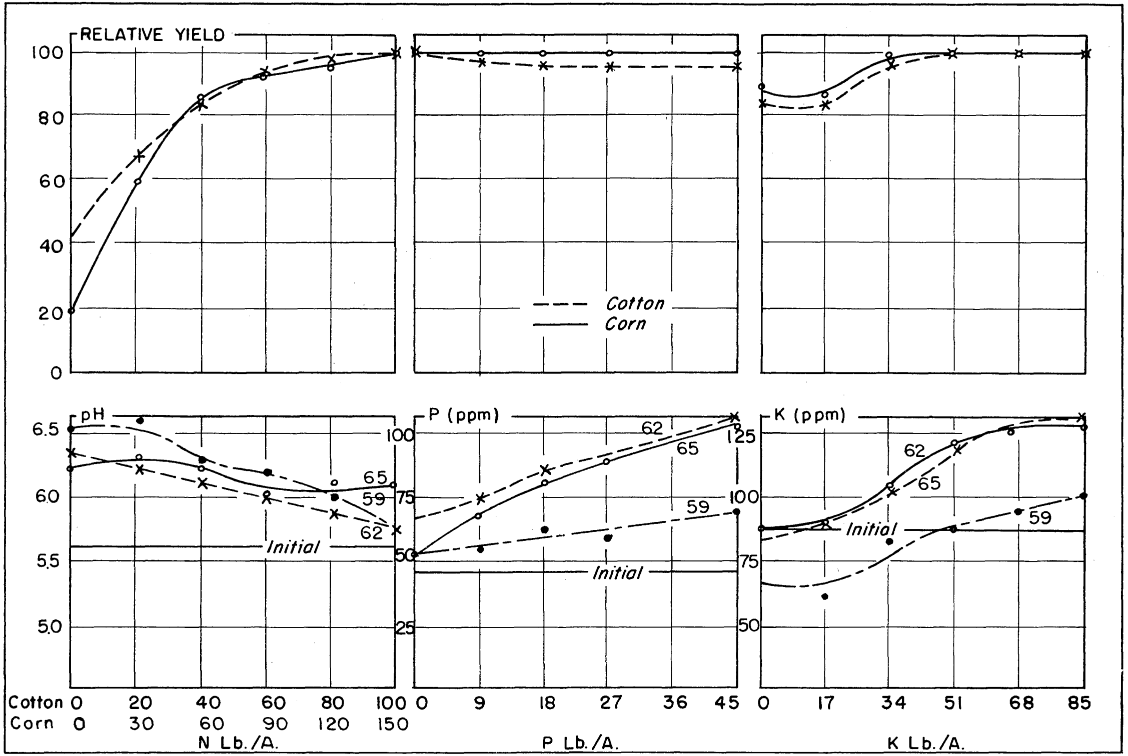


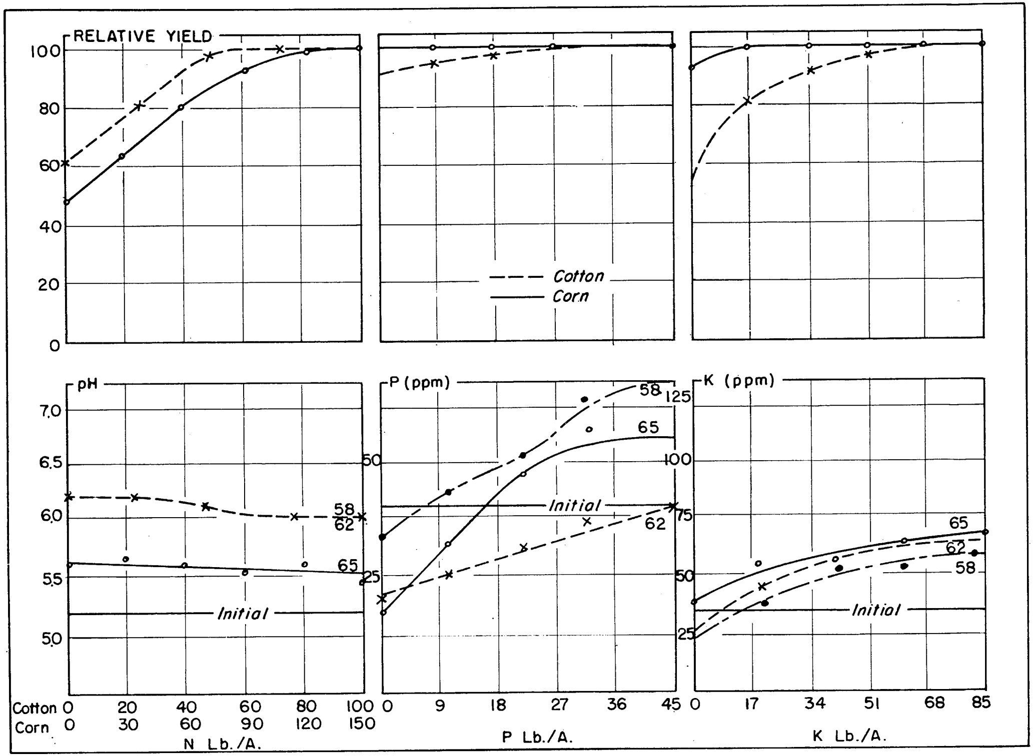
APPENDIX FIG. 1. N-P-K experiment at Brewton Experiment Field; Cotton Index, Location 1, App. Table 1; Corn Index, Location 27, App. Table 3; soil, Kalmia sandy loam, limed 1954. Average from highest yielding treatments: seed cotton (8 yr.) 1,874 lb.; corn (3 yr.) 70 bu.



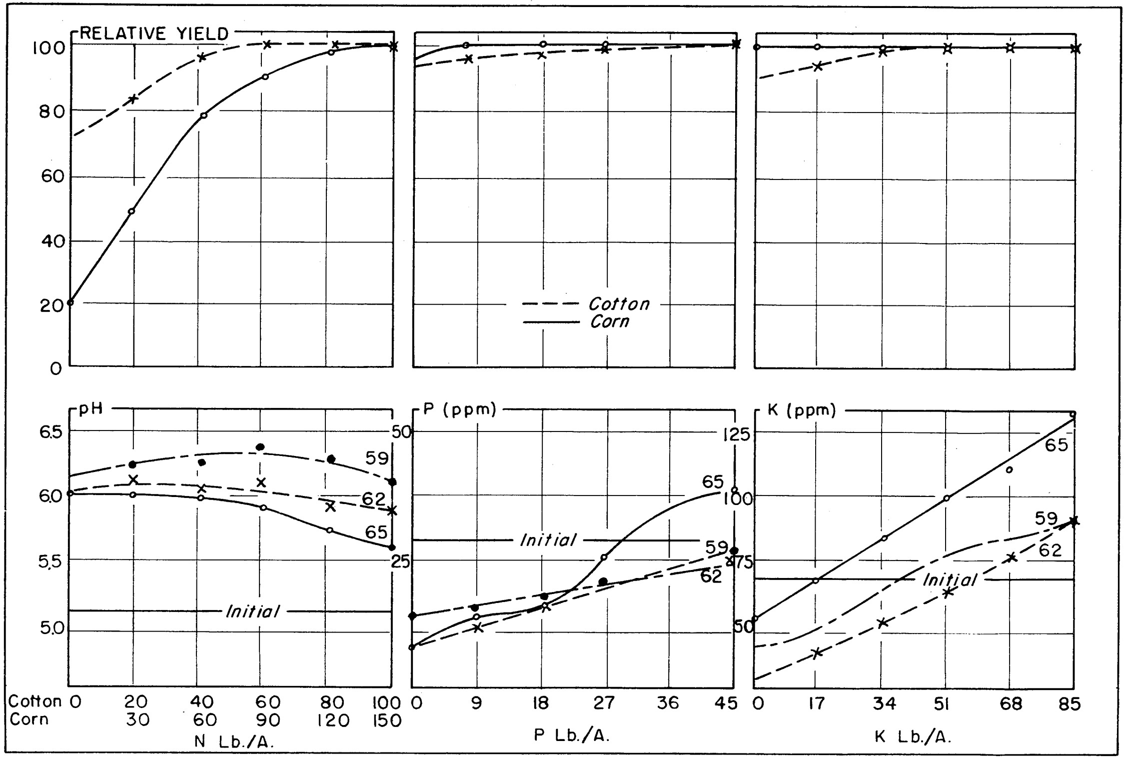
APPENDIX FIG. 2. N-P-K experiment at Monroeville Experiment Field; Cotton Index, Location 2, App. Table 1; Corn Index, Location 28, App. Table 3; soil, Magnolia sandy loam, limed 1954. Average from highest yielding treatments: seed cotton (8 yr.) 1,675 lb.; corn (3 yr.) 47 bu.



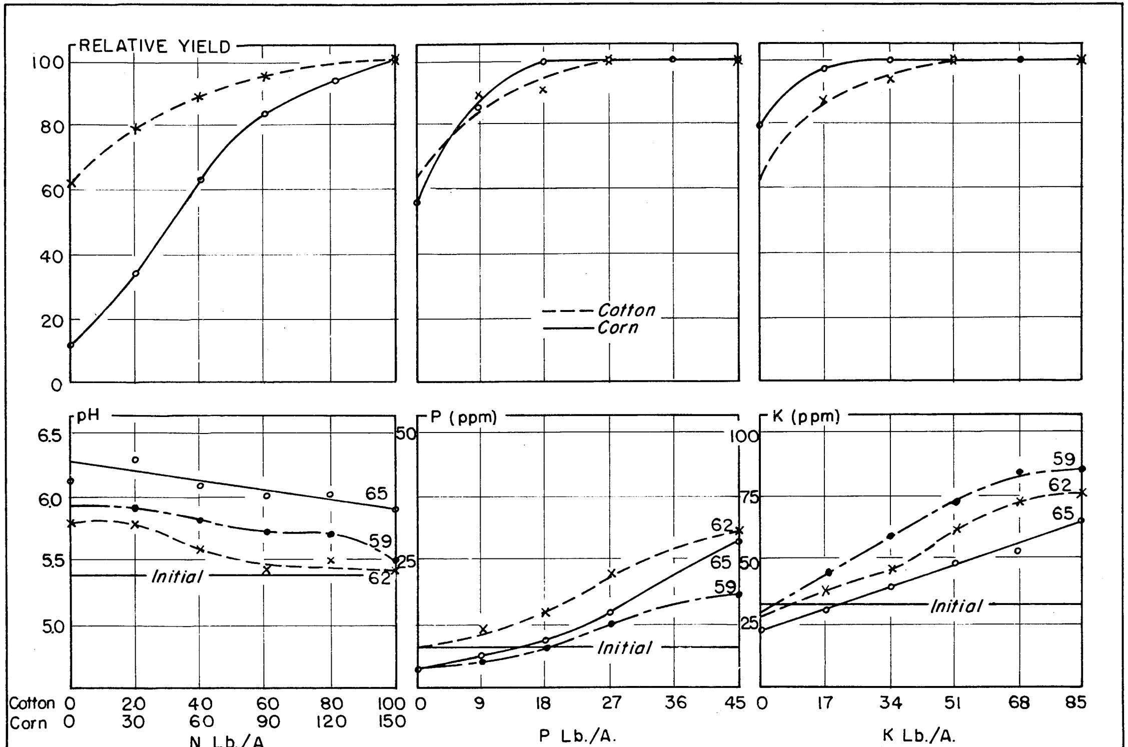
APPENDIX FIG. 3. N-P-K experiment at Prattville Experiment Field; Cotton Index, Location 3, App. Table 1; Corn Index, Location 24, App. Table 3; soil, Greenville sandy clay loam, limed 1954, 1962. Average from highest yielding treatments: seed cotton (8 yr.) 1,806 lb., corn (3 yr.) 43 bu.



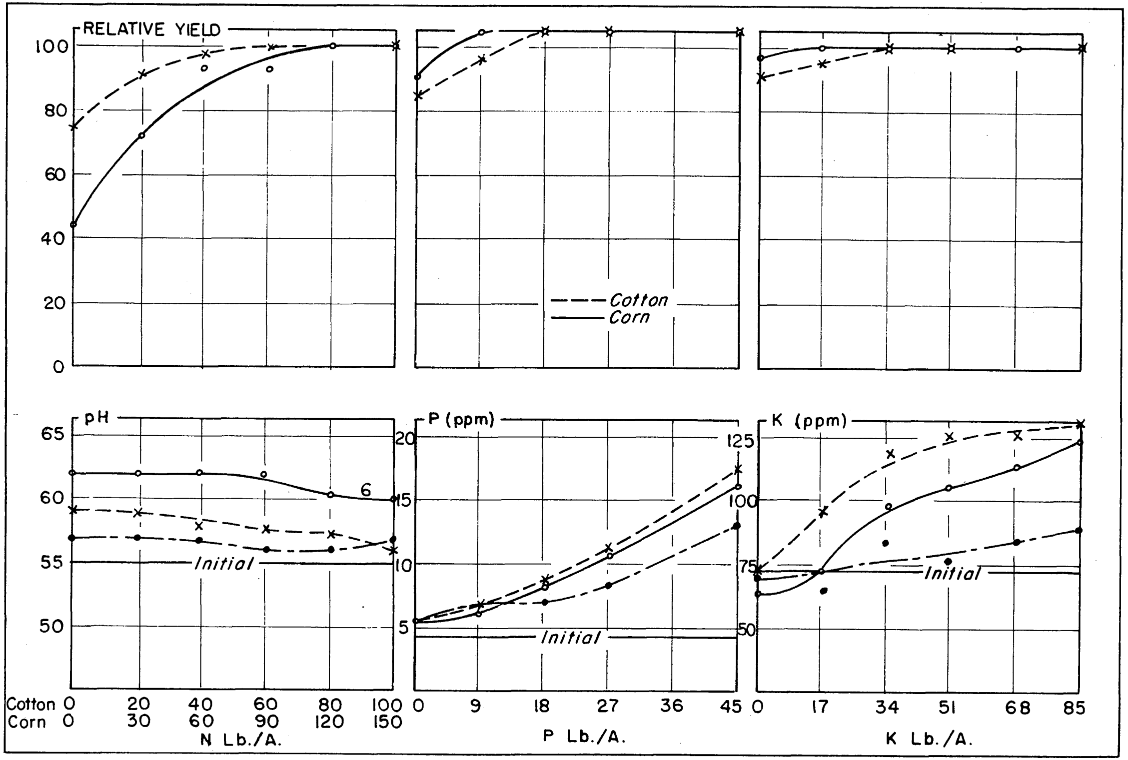
APPENDIX FIG. 4. N-P-K experiment at Wiregrass Substation; Cotton Index, Location 4, App. Table 1; Corn Index, Location 23, App. Table 3; soil, Norfolk sandy loam, limed 1954. Average from highest yielding treatments, seed cotton (8 yr.) 1,947 lb; corn (3 yr.) 88 bu.



APPENDIX FIG. 5. N-P-K experiment at Upper Coastal Plain Substation; Cotton Index, Location 5, App. Table 1; Corn Index, Location 29, App. Table 3; soil, Savannah silt loam, limed 1964. Average from highest yielding treatments: seed cotton (8 yr.) 1,559 lb.; corn (3 yr.) 82 bu.



APPENDIX FIG. 6. N-P-K experiment at Sand Mountain Substation; Cotton Index, Location 6, App. Table 1; Corn Index, Location 26, App. Table 3; soil, Hartsells fine sandy loam, limed 1954, 1963. Average from highest yielding treatments: seed cotton (8 yr.) 2,056 lb.; corn (3 yr.) 114 bu.



APPENDIX FIG. 7. N-P-K experiment at Tennessee Valley Substation; Cotton Index, Location 7, App. Table 1; Corn Index, Location 25, App. Table 3; soil, Decatur silty clay loam, limed 1954, 1962. Average from highest yielding treatments: seed cotton (8 yr.) 1,677 lb.; corn (3 yr.) 64 bu.

APPENDIX TABLE 1. INDEX OF P CALIBRATION DATA FOR COTTON[1]

	Location	Soil type		Soil P[2]	Seed cotton yield/acre			Category	Rates	"C" Value[3]
					Relative	No P	Maximum P			
				p.p.m.	*Pct.*	*Lb.*	*Lb.*		*No.*	
1	Brewton '60	Kalmia	sl	9	88	1,656	1,874	I	6	.1024
2	Monroeville '60	Magnolia	sl	14	84	1,426	1,675	I	6	.0548
3	Prattville '60	Greenville	scl	46	100	1,806	1,753	II	6	.0430
4	Wiregrass '60	Norfolk	sl	39	92	1,784	1,947	I	6	.0506
5	Upper Coastal Plain '60	Savannah	tl	29	95	1,478	1,559	II	6	.0690
6	Sand Mt. '60	Hartsells	fsl	8	68	1,396	2,056	II	6	.0618
7	Tenn. Valley '60	Decatur	tcl	4	85	1,435	1,677	III	6	.1030
8a	Sand Mt. '57	Hartsells	fsl	3	57	1,062	1,850	II	2	.1322
8b	Sand Mt. '57	Hartsells	fsl	8	84	1,555	1,850	II	2	.0396
8c	Sand Mt. '57	Hartsells	fsl	16	92	1,710	1,850	II	2	.1212
8d	Sand Mt. '57	Hartsells	fsl	28	100	1,850	1,850	II	2	.0702
8e	Sand Mt. '57	Hartsells	fsl	43	99	1,845	1,850	II	2	.0460
9	Monroeville '64	Magnolia	sl	35	100	1,992	1,894	I	2	.0572
10	Tenn. Valley '64	Decatur	cl	20	77	2,168	2,830	III	2	.0160
11	Prattville '64	Greenville	scl	62	100	2,549	2,513	II	2	.0322
12	Wiregrass '64	Norfolk	sl	67	92	2,561	2,784	I	2	.0164
13	Main Station '64	Norfolk	sl	47	100	3,050	3,030	I	2	.0426
	AVERAGE									.062

[1] Summary of experimental data on file in Soil Testing Laboratory. Detailed data in Annual Report, Agronomy and Soils Department, Auburn University Agricultural Experiment Station.
[2] Extraction 1 + 4 with 0.05 N HCl + 0.025 N H_2SO_4 not corrected for soil category.
[3] Coastal Plain equivalent.

APPENDIX TABLE 2. INDEX OF K CALIBBATION DATA FOR COTTON[1]

	Location	Soil type		Soil K[2]	Yield seed cotton			Category	Rates	"C" Value[3]	"C" Value[4]
					Relative	No K	Maximum K				
				p.p.m.	*Pct.*	*Lb.*	*Lb.*		*No.*		
1	Brewton '60	Kalmia	sl	17	32	608	1,874	I	7	.0098	.0825
2	Monroeville '60	Magnolia	sl	11	27	458	1,675	II	7	.0125	
3	Prattville '60	Greenville	sl	84	84	1,456	1,742	II	7	.0090	.0186
4	Wiregrass '60	Norfolk	sl	34	53	1,072	2,030	1	7	.0096	.0174
5	Upper C. Plain '60	Savannah	tl	69	90	1,404	1,562	II	7	.0194	.0306
6	Sand Mt. '60	Holstun	fsl	42	67	1,413	2,096	II	7	.0196	.0328
7	Tenn. Valley '60	Decatur	tcl	72	91	1,531	1,681	III	7	.0290	.0446
8a	Sand Mt. '57	Hartsells	fsl	23	28	510	1,816	II	2	.0082	.0328
8b	Sand Mt. '57	Hartsells	fsl	29	50	915	1,816	II	2	.0136	.0501
8c	Sand Mt. '57	Hartsells	fsl	41	74	1,346	1,816	II	2	.0196	.0418
8d	Sand Mt. '57	Hartsells	fsl	66	100	1,816	1,816	II	2	.0404	.0345
9	Auburn (6.2) '57	Norfolk	sl	8	17	370	2,126	I	5	.0096	
10a	Sand Mt. '57	Hartsells	fsl	24	37	484	1,303	II	4	.0108	.0753
10b	Sand Mt. '57	Hartsells	fsl	41	82	1,265	1,536	II	4	.0240	.0432
11	Auburn (7.0) '57	Chesterfield	sl	17	20	333	1,679	I	5	.0056	.0484
12a	Brewton '59	Kalmia	sl	20	38	542	1,438	I	5	.0102	.0415
12b	Brewton '59	Kalmia	sl	33	65	934	1,437	I	5	.0136	.0253
12c	Brewton '59	Kalmia	sl	53	76	1,151	1,523	I	5	.0116	.0163
13	Tenn. Valley '49	Decatur	tl	61	65	1,380	2,135	III	5	.0148	.0254
14	Thorsby (Irrigated)	Orangeburg	sl	27	55	2,657	4,866	I	7	.0126	.0289
15	Tenn. Valley '50	Decatur	tcl	61	52	757	1,460	III	4	.0104	.0178
16	Tenn. Valley '51	Decatur	tcl	71	77	1,411	1,827	III	2	.0177	.0276
17	Monroeville '64	Magnolia	sl	72	100	1,892	1,894	I	3	.0277	.0351
18	Tenn. Valley '64	Decatur	cl	120	93	2,646	2,830	III	3	.0194	.0244
19	Prattville '64	Greenville	scl	132	96	2,411	2,513	II	3	.0160	.0188
20	Wiregrass '64	Norfolk	sl	42	86	2,387	2,784	I	3	.0204	.0316
21	Main Station '64	Norfolk	sl	27	100	3,188	3,030	I	3	.0074	.1670
	AVERAGE									.016	.041

[1] Summary of experimental data on file in Soil Testing Laboratory. Detailed data in Annual Report, Agronomy and Soils Department, Auburn University Agricultural Experiment Station.

[2] Extraction 1 + 4 with 0.05 *N* HCl + 0.025 *N* H_2SO_4 not corrected for soil category.

[3] Coastal Plain equivalents.

[4] Coastal Plain equivalents (b−15).

APPENDIX TABLE 3. INDEX OF P CALIBRATION DATA FOR CORN[1]

	Location	Soil type		Soil P[2]	Corn yield/acre: Relative	Corn yield/acre: No P	Corn yield/acre: Maximum P	Category	Rates	"C" value[3]
				p.p.m.	*Pct.*	*Bu.*	*Bu.*		*No.*	
1	Brewton '59	Kalmia	sl	40	93	79.4	85.0	I	3	.029
2	Wiregrass '59	Norfolk	sl	42	100	70.4	70.8	I	3	.048
3	Gulfcoast '57	Marlboro	fsl	11	86	56.0	65.0	II	4	.078
4	Gulfcoast '59	Marlboro	fsl	11	77	60.5	78.2	II	2	.080
5	Gulfcoast '59	Marlboro	fsl	16	84	65.4	78.2	II	2	.050
6	Gulfcoast '59	Marlboro	fsl	19	89	69.8	78.2	II	2	.050
7	Gulfcoast '59	Marlboro	fsl	29	99	77.1	78.2	II	2	.068
8	Coop. '56	Kalmia	sl	48	95	58.8	63.6	I	2	.026
9	Coop. '56	Norfolk	sl	43	87	51.0	63.8	I	2	.020
10	Coop. '56	Appling	sl	62	105	68.0	64.8	II	2	.032
10a	Coop. '56	Ruston	sl	35	87	50.3	57.7	I	2	.024
11	Coop. '55	Kalmia	sl	43	94	105.8	112.0	I	2	.028
12	Coop. '56	Norfolk	sl	19	97	61.0	62.9	I	2	.078
13	Coop. '55	Greenville	sl	16	100	77.4	88.9	I	2	.122
14	Coop. '55	Kalmia	fsl	17	70	51.3	72.8	I	2	.030
15	Coop. '55	Norfolk	fsl	28	102	65.8	64.6	I	2	.072
16	Coop. '56	Norfolk	sl	11	82	61.0	74.1	I	2	.068
17	Coop. '56	Kalmia	sl	15	91	85.1	99.7	I	2	.072
18	Sand Mt. '59	Hartsells	fsl	8	66	56.8	85.9	II	2	.058
19	Sand Mt. '59	Hartsells	fsl	17	89	76.4	85.9	II	2	.056
20	Sand Mt. '59	Hartsells	fsl	26	93	79.8	85.9	II	2	.044
21	Sand Mt. '59	Hartsells	fsl	34	94	81.1	85.9	II	2	.036
22	Sand Mt. 57	Hartsells	fsl	8	90	65.0	72.0	II	2	.080
23	Wiregrass '64	Norfolk	sl	19	100	88.0	86.0	I	3	.106
24	Prattville '64	Greenville	scl	52	100	43.0	38.0	II	3	.038
25	Tenn. Valley '64	Decatur	cl	5	92	59.0	64.0	III	3	.100
26	Sand Mt. '64	Hartsells	fsl	5	56	64.0	114.0	II	4	.071
27	Brewton '64	Kalmia	sl	10	87	61.0	70.0	I	3	.088
28	Monroeville '64	Magnolia	sl	14	100	50.0	47.0	I	2	.150
29	Upper C. Plain '64	Savannah	tl	27	96	80.0	82.0	II	3	.052
	AVERAGE									.062

[1] Summary of experimental data on file in Soil Testing Laboratory. Detailed data in Annual Report, Agronomy and Soils Department, Auburn University Agricultural Experiment Station.

[2] Extraction 1 + 4 with 0.05 *N* HCl + 0.025 *N* H_2SO_4 not corrected for soil category.

[3] Coastal Plain equivalent.

	Location	Soil type		Soil K[2]	Corn yield/acre Relative	No K	Maximum K	Category	Rates	"C" Value[3]	"C" Value[4]
				p.p.m.	*Pct.*	*Bu.*	*Bu.*		*No.*		
1	Brewton '59	Kalmia	sl	19	58	49.1	85.0	1	3	.020	.041
2	Wiregrass '59	Norfolk	sl	42	100	70.0	60.5	I	3	.048	.062
3	Gulfcoast '57	Marlboro	fsl	25	88	57.0	65.0	II	4	.058	.153
4	Gulfcoast '59	Marlboro	fsl	25	86	67.6	78.2	II	1	.053	.143
5	Gulfcoast '59	Marlboro	fsl	31	90	70.2	78.2	II	1	.050	.100
6	Gulfcoast '59	Marlboro	fsl	38	89	69.6	78.2	II	1	.038	.064
7	Gulfcoast '59	Marlboro	fsl	53	94	73.4	78.2	I	1	.035	.049
8	Coop. '56	Kalmia	sl	47	100	63.6	62.0	I	1	.042	.054
9	Coop. '56	Norfolk	sl	53	100	63.8	58.9	I	1	.036	.047
10	Coop. '56	Appling	sl	90	90	58.6	64.8	II	1	.018	.020
11	Coop. '55	Kalmia	sl	22	84	94.1	112.0	I	1	.038	.066
12	Coop. '56	Norfolk	sl	12	64	40.0	62.9	I	1	.038	.222
13	Coop. '55	Greenville	sl	38	100	88.9	77.3	I	1	.052	.071
14	Coop. '55	Kalmia	sl	24	83	60.2	72.8	I	1	.032	.055
15	Coop. '55	Norfolk	sl	24	96	62.2	64.6	I	1	.060	.100
16	Coop. '56	Norfolk	sl	19	93	69.0	74.1	I	1	.060	.128
17	Coop. '56	Kalmia	sl	35	100	99.7	93.4	I	1	.056	.080
18	Sand Mt. '59	Hartsells	fsl	24	87	75.1	85.9	II	4	.055	.147
19	Sand Mt. '59	Hartsells	fsl	43	97	83.0	85.9	II	1	.053	.083
20	Sand Mt. '59	Hartsells	fsl	86	100	85.6	85.9	II	1	.035	.043
21	Coop. '56	Ruston	sl	44	87	50.4	57.7	I	1	.020	.026
22	Sand Mt. '57	Hartsells	fsl	24	93	67.0	72.0	II	1	.072	.092
23	Wiregrass '64	Norfolk	sl	39	94	80.0	86.0	I	3	.032	.042
24	Prattville '64	Greenville	sl	87	90	34.0	38.0	II	4	.017	.204
25	Tenn. Valley '64	Decatur	cl	64	96	62.0	64.0	III	3	.044	.063
26	Sand Mt. '64	Hartsells	fsl	24	78	89.0	114.0	II	4	.041	.110
27	Brewton '64	Kalmia	sl	26	84	57.0	70.0	I	4	.030	.050
28	Monroeville '64	Magnolia	sl	15	76	35.0	47.0	I	5	.042	.124
29	Upper C. Plain '64	Savannah	tl	53	100	84.0	82.0	II	3	.050	.067
30	Auburn '58	Norfolk	sl	8	10	7.0	68.0	I	4	.006	.046
	AVERAGE									.041	.085

[1] Summary of experimental data on file in Soil Testing Laboratory. Detailed data in Annual Report, Agronomy and Soils Department, Auburn University Agricultural Experiment Station.

[2] Extraction 1 + 4 with 0.05 *N* HCl + 0.025 *N* H_2SO_4 not corrected for soil category.

[3] Coastal Plain equivalents.

[4] Coastal Plain equivalents (b—10).

Appendix Table 5. Index of P Calibration Data for Soybeans[1]

	Location	Soil type		Soil P[2]	Soybean yield/acre: Relative	Soybean yield/acre: No P	Soybean yield/acre: Maximum P	Category	Rates	"C" Value[3]
				p.p.m.	*Pct.*	*Bu.*	*Bu.*		*No.*	
1	Brewton	Kalmia	ls	44	93	25	27	I	4	.026
2	Gulfcoast	Marlboro	fsl	57	100	34	34	II	4	.035
3	C. N. Cook	Colbert	tl	5	90	17	19	II	2	.200
4	C. N. Cook	Lindside	tl	6	97	27	28	II	2	.254
5	McCarva	Hollywood	clay	5	74	18	25	III	2	.058
6	Whitcher	Robertsville	tl	21	100	18	17	II	2	.095
7	Clements	Talbott	cl	11	100	20	18	II	2	.081
8	Gulfcoast	Marlboro	fsl	50	97	37	38	II	4	.030
	Average									.097

[1] Summary of experimental data on file in Soil Testing Laboratory. Detailed data in Annual Report, Agronomy and Soils Department, Auburn University Agricultural Experiment Station.

[2] Extraction 1 + 4 with 0.05 N HCl + 0.025 N H_2SO_4, not corrected for soil category.

[3] Coastal Plain equivalent.

APPENDIX TABLE 6. INDEX OF K CALIBRATION DATA FOR SOYBEANS[1]

	Location	Soil type		Soil K[2]	Soybean yield/ acre Relative	No K	Maximum K	Category	Rates	"C" Value[3]	"C" Value[4]
				p.p.m.	*Pct.*	*Bu.*	*Bu.*		*No.*		
1	Brewton	Kalmia	ls	17	63	17	27	I	3	.025	.086
2	Gulfcoast	Marlboro	fsl	58	97	33	34	II	3	.035	.056
3	C. N. Cook	Colbert	tl	22	71	13	19	II	2	.032	.179
4	C. N. Cook	Lindside	tl	34	80	22	28	II	2	.028	.063
5	McCarva	Hollywood	c	37	89	22	25	II	2	.035	.073
6	Whitcher	Robertsville	tc	44	80	14	17	II	2	.021	.041
7	Clements	Talbott	cl	40	100	20	20	II	2	.067	.133
8	L. K. Bins	Lakeland	ls	9	47	14	30	I	4	.031	------
9	Gulfcoast	Marlboro	fsl	63	100	38	38	II	4	.048	.067
	AVERAGE									.036	.078

[1] Summary of experimental data on file in Soil Testing Laboratory. Detailed data in Annual Report, Agronomy and Soils Department, Auburn University Agricultural Experiment Station.

[2] Extraction 1 + 4 with 0.05 N HCl + 0.025 N H_2SO_4 not corrected for soil category.

[3] Coastal Plain equivalents.

[4] Coastal Plain equivalents (b—12).

APPENDIX TABLE 7. INDEX OF P CALIBRATION DATA FOR COASTAL BERMUDAGRASS[1]

	Location		Soil type		Soil P[2]	Yield/acre Relative	Yield/acre No P	Yield/acre Maximum P	Category	Rates	"C" Value[3]
					p.p.m.	*Pct.*	*Tons*	*Tons*		*No.*	
1	Auburn '60	3 Initial	Norfolk	sl	67	92	6.2	6.8	I	3	.016
2		4	Norfolk	sl	57	99	6.8	6.9	I	3	.035
3		5	Norfolk	sl	34	94	6.8	7.2	I	3	.036
4		6	Norfolk	sl	25	86	5.6	6.5	I	3	.034
5		7	Norfolk	sl	3	45	3.0	6.6	I	3	.087
6		8	Norfolk	sl	18	100	6.6	6.6	I	3	.111
7		9	Norfolk	sl	86	98	7.3	7.5	I	3	.020
8	Auburn '61	10	Norfolk	sl	89	100	8.6	8.6	I	2	.022
9		11	Norfolk	sl	43	100	6.2	6.2	I	3	.047
10		12	Norfolk	sl	26	85	3.1	3.6	I	3	.032
11		13	Norfolk	sl	46	100	7.0	7.0	I	3	.044
12		14	Norfolk	sl	1	95	7.5	7.9	I	3	----
13		15	Norfolk	sl	17	92	5.9	6.4	I	3	.065
14		16	Norfolk	sl	15	99	6.0	6.1	I	3	.133
15		17	Norfolk	sl	40	86	4.5	5.3	I	3	.021
16		18	Norfolk	sl	34	100	4.7	4.7	I	3	.059
17	Auburn '63	3 Final	Norfolk	sl	33	94	3.4	3.6	I	3	.037
18		4	Norfolk	sl	21	94	3.5	3.7	I	3	.058
19		5	Norfolk	sl	9	82	3.6	4.4	I	3	.083
20		6	Norfolk	sl	7	65	2.3	3.5	I	3	.065
21		7	Norfolk	sl	2	38	1.9	5.0	I	3	.104
22		8	Norfolk	sl	16	76	3.4	4.5	I	3	.039
23		9	Norfolk	sl	30	100	5.1	5.1	I	3	.067

(Continued)

APPENDIX TABLE 7. *(Cont'd.)* INDEX OF P CALIBRATION DATA FOR COASTAL BERMUDAGRASS[1]

	Location	Soil type		Soil P[2]	Yield/acre			Category	Rates	"C" Value[3]
					Relative	No P	Maximum P			
				p.p.m.	*Pct.*	*Tons*	*Tons*		*No.*	
24	Auburn '64 10	Norfolk	sl	66	100	5.3	5.3	I	3	.033
25	11	Norfolk	sl	33	98	4.6	4.7	I	3	.053
26	12	Norfolk	sl	26	97	4.8	5.0	I	3	.059
27	13	Norfolk	sl	40	91	4.7	5.2	I	3	.026
28	14	Norfolk	sl	17	89	5.6	6.3	I	3	.056
29	15	Norfolk	sl	13	85	4.6	5.4	I	3	.063
30	16	Norfolk	sl	11	93	4.2	4.5	I	3	.105
31	17	Norfolk	sl	40	94	4.0	4.3	I	3	.036
32	18	Norfolk	sl	43	100	5.6	5.6	I	3	.047
	AVERAGE									.054

[1] Summary of experimental data on file in Soil Testing Laboratory. Detailed data in Annual Report, Agronomy and Soils Department, Auburn University Agricultural Experiment Station.
[2] Extraction 1 + 4 with 0.05 *N* HCl + 0.025 *N* H_2SO_4, not corrected for soil category.
[3] Coastal Plain equivalents.

Appendix Table 8. Index of K Calibration Data for Coastal Bermudagrass[1]

	Location		Soil type		Soil K[2]	Yield/acre			Category	Rates	"C" Value[3]	"C" Value[4]
						Relative	No K	Maximum K				
					p.p.m.	*Pct.*	*Tons*	*Tons*		*No.*		
1	Auburn '60	3 Initial	Norfolk	sl	36	90	6.0	6.7	I	3	.028	.039
2		4	Norfolk	sl	36	100	6.9	6.9	I	3	.056	.077
3		5	Norfolk	sl	33	95	6.8	7.2	I	3	.039	.057
4		6	Norfolk	sl	36	95	6.0	6.3	I	3	.017	----
5		7	Norfolk	sl	46	100	5.7	5.7	I	3	.044	.056
6		8	Norfolk	sl	17	81	5.2	6.4	I	3	.042	.103
7		9	Norfolk	sl	44	100	7.5	7.5	I	3	.046	.059
8	Auburn '61	10	Norfolk	sl	86	100	8.6	8.6	I	3	.023	.026
9		11	Norfolk	sl	59	92	5.7	6.2	I	3	.058	.122
10		12	Norfolk	sl	32	97	3.5	3.6	I	3	.048	.069
11		13	Norfolk	sl	61	97	6.8	7.0	I	3	.025	.030
12		14	Norfolk	sl	19	94	7.2	7.7	I	3	.064	.122
13		15	Norfolk	sl	42	100	6.4	6.4	I	3	.048	.063
14		16	Norfolk	sl	41	95	5.8	6.1	I	3	.032	.042
15		17	Norfolk	sl	50	100	5.3	5.3	I	3	.040	.050
16		18	Norfolk	sl	46	100	4.7	4.8	I	3	.044	.056
17	Auburn '63	3 Final	Norfolk	sl	19	90	3.3	3.7	I	3	.053	.111
18		4	Norfolk	sl	14	81	3.0	3.7	I	3	.052	.180
19		5	Norfolk	sl	14	45	2.0	4.8	I	3	.012	.065
20		6	Norfolk	sl	10	6	0.2	3.4	I	3	.003	----
21		7	Norfolk	sl	28	70	3.5	5.0	I	3	.028	.029
22		8	Norfolk	sl	14	73	2.8	4.0	I	3	.041	.142
23		9	Norfolk	sl	24	91	4.7	5.2	I	3	.043	.075

(Continued)

APPENDIX TABLE 8. *(Cont'd.)* INDEX OF K CALIBRATIONS FOR COASTAL BERMUDAGRASS[1]

	Location		Soil type		Soil K[2]	Yield/acre Relative	Yield/acre No K	Yield/acre Maximum K	Category	Rates	"C" Value[3]	"C" Value[4]
					p.p.m.	*Pct.*	*Tons*	*Tons*		*No.*		
24	Auburn '64	10	Norfolk	sl	41	98	5.2	5.3	I	3	.041	.055
25		11	Norfolk	sl	33	80	3.8	4.7	I	3	.021	.030
26		12	Norfolk	sl	44	100	5.0	5.0	I	3	.045	.059
27		13	Norfolk	sl	44	90	4.8	5.3	I	3	.022	.029
28		14	Norfolk	sl	14	18	1.1	6.3	I	3	.006	.021
29		15	Norfolk	sl	14	73	3.9	5.4	I	3	.041	.142
30		16	Norfolk	sl	14	74	3.3	4.5	I	3	.042	.146
31		17	Norfolk	sl	32	85	3.7	4.3	I	3	.026	.037
32		18	Norfolk	sl	41	100	5.5	5.5	I	3	.039	.065
	AVERAGE										.037	.067

[1] Summary of experimental data on file in Soil Testing Laboratory. Detailed data in Annual Report, Agromony and Soils Department, Auburn University Agricultural Experiment Station.

[2] Extraction 1 + 4 with 0.05 *N* HCl + 0.025 *N* H_2SO_4, not corrected for soil category.

[3] Coastal Plain equivalents.

[4] Coastal Plain equivalents (b-10).