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To the Graduate Council:

I am submitting herewith a thesis written by Dan M. Manning entitled "Nutrient Concentration in Corn and Grain Sorghum Tissue as Related to Soil Type, Moisture Regime, and Growth Stage." I recommend that it be accepted for nine quarter hours of credit in partial fulfillment of the requirements for the degree of Master of Science, with a major in Agronomy.

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NUTRIENT CONCENTRATION IN CORN AND GRAIN SORGHUM TISSUE
AS RELATED TO SOIL TYPE, MOISTURE REGIME,
AND GROWTH STAGE

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ABSTRACT

Experiments were conducted to determine the effects of soil type, moisture regime, date of planting, and stage of growth on the nutrient content of corn and grain sorghum tissue. Early and late plantings of the two crops were grown on 12 soils (at six locations) encompassing wide ranges of chemical and physical properties. On five soils (at three locations), irrigation treatments were included. Corn and sorghum tissue samples were collected at three stages of growth (when corn was at eighth to tenth leaf stage, early tassel, and early silking) and analyzed for Ca, Mg, K and P concentrations.

In general, K decreases and Ca and Mg increases occurred during the growing season. Some early plantings were higher in K and P than late plantings but the results for Ca and Mg were not consistent. Corn contained higher percentages of Ca, Mg and K than sorghum, but no conclusive crop difference was observed in the case of P.

In most cases, concentration differences of Ca, Mg and K within plants grown on different soils appeared to be influenced more by the exchangeable K levels of the soils than by their exchangeable Ca and Mg levels. When P concentration differences occurred, higher levels were found in plants grown on soils with higher available P levels.

Few differences resulted from irrigation treatment, and most could be attributed to the effect of higher moisture levels in favoring uptake of K over that of Ca and Mg, and by the effect of moisture on diffusion of P.

TABLE OF CONTENTS

CHAPTER	PAGE
I. INTRODUCTION	1
II. REVIEW OF LITERATURE	2
Soil Effects on Growth and Nutrient Concentration in Plants	2
Moisture Effects on Growth and Nutrient Concentration in Plants	5
Growth Stage Effects on Nutrient Concentration in Plants	13
III. METHODS AND PROCEDURES	19
Field Methods	25
Laboratory Methods	30
Statistical Methods	31
IV. RESULTS	32
Soil Test Results (Table III)	32
Stage of Growth (Tables IV, V, VI, VII, VIII and IX)	35
Planting Date (Tables IV, V, VI, VII, VIII and IX)	48
Stage-Planting Interaction (Tables IV, V, VI, VII, VIII and IX)	48
Crop (Tables IV, V, VI, VII, VIII and IX)	49
Crop, Second and Third Stages (Table X)	50
Stage-Crop Interaction (Tables IV, V, VI, VII, VIII and IX)	50
Planting-Crop Interaction (Tables IV, V, VI, VII, VIII and IX)	52

CHAPTER	PAGE
Soil (Tables XI, XII, XIII, XIV, XV and XVI)	54
Stage-Soil Interaction (Tables XI, XII, XIII, XIV, XV and XVI)	61
Soil-Planting Interaction (Tables XI, XII, XIII, XIV, XV and XVI)	61
Soil-Crop Interaction (Tables XI, XII, XIII, XIV, XV and XVI)	61
Irrigation (Tables XVII, XVIII and XIX)	62
Stage-Irrigation Interaction (Tables XVII, XVIII and XIX)	68
Irrigation-Planting Interaction (Tables XVII, XVIII and XIX)	68
Irrigation-Crop Interaction (Tables XVII, XVIII and XIX)	68
V. DISCUSSION	69
Knoxville	72
Springfield	74
Martin	74
Spring Hill	75
Jackson	76
Crossville	76
VI. SUMMARY	78
LITERATURE CITED	81
APPENDICES	90
Appendix A	91

CHAPTER	PAGE
Appendix B	92
Appendix C	94
Appendix D	95
Appendix E	96
Appendix F	97
Appendix G	98
Appendix H	101
Appendix I	104
Appendix J	107
Appendix K	110
VITA	111

LIST OF TABLES

TABLE	PAGE
I. Soils, Planting Dates, and Irrigation Treatments	20
II. Soil Horizons and Depths	29
III. Average Nutrient Levels and Ranges of pH Values in Surface and Subsurface Horizons of Twelve Soils	33
IV. Mean Concentrations of Calcium, Magnesium, Potassium and Phosphorus in Grain Sorghum and Corn Tissue From Four Experiments at Knoxville	36
V. Mean Concentrations of Calcium, Magnesium, Potassium and Phosphorus in Grain Sorghum and Corn Tissue From Two Experiments at Springfield	38
VI. Mean Concentrations of Calcium, Magnesium, Potassium and Phosphorus in Grain Sorghum and Corn Tissue From Two Experiments at Martin	40
VII. Mean Concentrations of Calcium, Magnesium, Potassium and Phosphorus in Grain Sorghum and Corn Tissue From Four Experiments at Spring Hill	42
VIII. Mean Concentrations of Calcium, Magnesium, Potassium and Phosphorus in Grain Sorghum and Corn Tissue From Three Experiments at Jackson	44
IX. Mean Concentrations of Calcium, Magnesium, Potassium and Phosphorus in Grain Sorghum and Corn Tissue From Two Experiments at Crossville	46
X. Mean Concentrations of Calcium, Magnesium, Potassium	

TABLE	PAGE
and Phosphorus in Sorghum and Corn Tissue From Seventeen Experiments (Second and Third Growth Stages) .	51
XI. Mean Concentrations of Calcium, Magnesium, Potassium and Phosphorus in Tissue of Grain Sorghum and Corn Grown on Two Soils at Knoxville	55
XII. Mean Concentrations of Calcium, Magnesium, Potassium and Phosphorus in Tissue of Grain Sorghum and Corn Grown on Two Soils at Springfield	56
XIII. Mean Concentrations of Calcium, Magnesium, Potassium and Phosphorus in Tissue of Grain Sorghum and Corn Grown on Two Soils at Martin	57
XIV. Mean Concentrations of Calcium, Magnesium, Potassium and Phosphorus in Tissue of Grain Sorghum and Corn Grown on Two Soils at Spring Hill	58
XV. Mean Concentrations of Calcium, Magnesium, Potassium and Phosphorus in Tissue of Grain Sorghum and Corn Grown on Two Soils at Jackson	59
XVI. Mean Concentrations of Calcium, Magnesium, Potassium and Phosphorus in Tissue of Grain Sorghum and Corn Grown on Two Soils at Crossville	60
XVII. Mean Concentrations of Calcium, Magnesium, Potassium and Phosphorus in Tissue of Nonirrigated and Irrigated Grain Sorghum and Corn at Knoxville	63
XVIII. Mean Concentrations of Calcium, Magnesium, Potassium and Phosphorus in Tissue of Nonirrigated and Irrigated Grain Sorghum and Corn at Spring Hill	65

TABLE

PAGE

XIX.	Mean Concentrations of Calcium, Magnesium, Potassium and Phosphorus in Tissue of Nonirrigated and Irrigated Grain Sorghum and Corn at Jackson	67
XX.	Yields of Corn Grain, Corn Silage and Grain Sorghum Silage on Twelve Soils	110

LIST OF FIGURES

FIGURE		PAGE
1.	Locations of Tennessee Agricultural Experiment	
	Stations at Which Experiments Were Conducted	19
2.	Calcium and Potassium Manifold	94
3.	Magnesium Manifold	95
4.	Phosphorus Manifold	96
5.	Calcium Concentration in Leaf Tissue of Early (—)	
	and Late (---) Plantings of Corn (o) and Sorghum (▼) . . .	98
6.	Magnesium Concentration in Leaf Tissue of Early (—)	
	and Late (---) Plantings of Corn (o) and Sorghum (▼) . . .	101
7.	Potassium Concentration in Leaf Tissue of Early (—)	
	and Late (---) Plantings of Corn (o) and Sorghum (▼) . . .	104
8.	Phosphorus Concentration in Leaf Tissue of Early (—)	
	and Late (---) Plantings of Corn (o) and Sorghum (▼) . . .	107

CHAPTER I

INTRODUCTION

These experiments comprised a portion of a three-part summer annuals adaptation study conducted for several years on twelve Tennessee soils encompassing wide ranges of chemical and physical properties. At each of six locations, two soils representative of the soils commonly found in the respective part of the state were chosen for this study.

The purpose of this part of the study was to determine how two important summer annual crops (corn and grain sorghum) might differ in nutrient content (Ca, Mg, K, and P) when grown under a wide range of environmental conditions. It was desired to determine whether concentrations of the four elements change during the growing season and, if so, the manner in which the concentrations would be affected by soil differences, dates of planting, and moisture regimes.

CHAPTER II

REVIEW OF LITERATURE

In a publication by Beeson (8), C. A. Browne summarized the findings of Theodore de Saussure, a Swiss scientist, whose work in 1804 established the following facts:

The mineral constituents are obtained in solution through the roots from the soil.

Plants do not absorb mineral constituents in the same proportion in which they occur in the soil solution, but they have a marked selective power, some elements being assimilated in greater amounts than others.

Different soils have a profound influence upon the quantity and composition of the mineral constituents of the same species of plants.

The different organs of plants differ in the content and composition of their mineral constituents.

The percentage of ash in herbaceous plants reaches its maximum before the flowering stage and thereafter begins to decline.

Soil Effects on Growth and Nutrient Concentration in Plants

Beeson (8) reported chemical composition of numerous crops grown on many soils. He recognized that soil differences could play a great part in determining the chemical composition of plants, but differences due to soil and those due to other factors, such as climate, etc., were often difficult to differentiate.

Data presented by Franklin and McLean (28) have shown that the ionic environment of the soil solution does not always characterize that within the plant root. However, variations in soil fertility often have been shown to have marked effects upon the uptake and

accumulation of the various nutrient elements. Many workers have noted the effects of soil nutrient level on the nutrient level of plants grown on the soil. Effects of certain ions on the uptake of others also have been observed.

Using excised corn roots, Haugold, Danneberg, and Kaindl (42) observed corresponding increases in ^{42}K uptake as the concentration of $^{42}\text{KNO}_3$ in the nutrient solution was increased.

Key and Kurtz (50) obtained higher Mg contents in vegetative parts of corn by increasing the amounts of Mg applied.

Powell (76) obtained increased levels of P and K in corn leaves as a result of increasing the supply of these two elements to the plants. Wittels and Seatz (96) reported similar increases in leaf K levels at all stages of growth resulting from increasing the increments of K applied.

Hipp and Thomas (43) suggested that soil solution K alone was a poor indicator of the amount of K in grain sorghum leaves, and that a good method for predicting K uptake should include both solution and exchangeable K.

Koch, Orchard and Sumner (51) found the relationship between leaf K and soil K could best be described if leaf K was considered as a function of the pool of labile K. The pool of K, as such, was not the important criterion. However, through its effect on K diffusion and mass flow, and thus on the rate of supply of K to the sites of entry on the growing root, the pool was closely related to K uptake.

Kramer (52) reported increased P contents of corn and grain sorghum leaves as the amount of applied P was increased. However, differences

due to added P were noted only during the early growth stages of corn grown on one of the soils which was naturally high in phosphate.

Baker et al. (3) concluded that the P concentration of seedling corn plants could be used to predict the availability of this element in the soil. However, by the time the plants reached ear-leaf stage, leaf tissue composition was greatly affected by hybrid differences and did not accurately reflect P availability differences.

Weeks, Fergus and Karraker (93) reported that the P content of the corn crop varied directly with the amount applied to the soil. However, their studies showed no consistent effect of K fertilization on the K content of corn grain.

Lane and Walker (53) observed not only higher K, but higher P levels as well, in grain sorghum plants which were supplied K.

Nutrient availability to plants is greatly affected by soil pH levels. Sufficient quantities of Ca and Mg are usually available in slightly acid (pH 6.0 to 6.5) to strongly alkaline (pH 8.5 to 9.5) soils if total amounts present are adequate. The range of pH levels at which K is available is greater than that for Ca and Mg, but there is a gradual decline in availability as soil pH decreases below 6.0 (Hanna and Hutcheson, 38).

Soil pH has an especially pronounced effect upon P availability. Below pH 5.5, relatively unavailable iron and aluminum phosphate compounds are formed. On the other hand, if the soil pH is very much higher than 7.0, unavailable calcium phosphates may be formed. Generally speaking, acidity reduces P availability more than does alkalinity (Hanna and Hutcheson, 38). On acid soils, Estrada and Cummings (25)

were unable to increase P content of corn except by applying high rates of P.

Moisture Effects on Growth and Nutrient Concentration in Plants

Corn is quite sensitive to moisture stress throughout its growth period. Moisture deficiencies during early stages may seriously limit leaf growth, thus reducing photosynthetic area, and moisture deficiencies from about the tenth leaf stage (about five weeks after emergence) have marked adverse effects on the growth and development of the ears (Hanway, 39).

According to Taylor and Slater (83), corn requires water at low tensions from seedling to hard dough stage for optimum growth and maximum yield. It is particularly sensitive to drought during and just after the silking stage.

The amount of water transpired by corn is least when the plants are small, increasing as the plant grows. Parks and Lillard (74) and Holt and Van Doren (45) reported maximum rates of water use immediately prior to tasseling and relatively high rates continuing through kernel formation. Rhoades and Nelson (79) reported maximum rates occurring about silking time, with relatively high rates continuing until near maturity.

McKinney (61) studied the water use of corn during nine consecutive 14-day periods from emergence to maturity. During the first period, water use was low. During the second and third periods, as the plants were developing in size, there was a gradual increase in the amount of water used. Water use was highest during the fourth through seventh periods, as the plants were tasseling and silking and

the kernels were developing. During the eights and ninth periods, water use decreased gradually as the ears matured and dried.

Wilson (95) observed that a single drought during grain filling appeared to hasten leaf senescence. He found a drought period between the late vegetative and early grain development stages reduced the number of grains per plant as much as 32 percent, while a drought after flowering limited the grain filling processes, reducing yields as much as 49 percent.

Holt and Timmons (44) divided the growth interval of corn from 30 cm in height to silking into two equal parts for the purpose of studying moisture effects. Precipitation received during the second period (late July and early August) exerted greater influence on yield than that received during the first period (early July).

Voss, Hanway and Fuller (91) reported that earlier planting of corn could be advantageous when subsequent soil moisture levels are likely to become more limiting. This was supported by the work of Genter and Jones (31), who reported yield increases resulting from earlier planting during dry years, but little difference between planting dates during other years.

Doss, King and Patterson (22) found irrigation could result in increased total dry matter yields and higher proportions of plant weight in the ears. Water use efficiency was decreased by irrigation.

MacKay and Leefe (60) reported optimum levels (the concentration in leaf tissue above which no further increase in yield can be expected) of P and K were lower in sweet corn grown under moisture deficiency conditions than when adequate moisture was supplied, probably due to

moisture itself becoming the most limiting factor. These workers reported little change in optimum levels due to excessive irrigation. However, they probably were not working at moisture levels as high as was Lawton (56) who reported that excessively high soil moisture levels (actually poor aeration) resulted in decreased percentages of K, Ca, Mg, and P in corn plant tissues.

Grain sorghum, while naturally performing better when water tension is low throughout its growth period, is much more drought tolerant than corn. Drought studies by Whiteman (94) indicate that sorghum can attain a state of drought induced dormancy, thus surviving extended drought periods during the growing season. Water loss is rapidly reduced by leaf rolling and folding, nutrients and water move out of leaf tissues, and functional leaf area is greatly decreased when sorghum plants are subjected to moisture stress. In such a state of dormancy, sorghums can survive drought periods.

According to Tucker and Bennett (86), grain sorghum has more secondary roots than corn, and because of its greater root surface area can absorb about twice the amount of moisture that the corn plant is capable of absorbing, even though the sorghum plant has a leaf area only half that of corn. These workers credit sorghum's ability to withstand drought to its small leaf area in relation to its root absorption capacity, leaf rolling and wilting, and a waxy covering of the leaves which helps retard transpiration. However, according to these workers, the ability to withstand drought seems to be exhibited mainly before head initiation, after which the moisture requirement appears to be as great as that of corn. Water use increases rapidly after the

seventh leaf stage, reaching a maximum at the boot stage, and moisture stress during heading often results in little or no seed formation.

Irrigation studies by Stone, Griffin and Ott (82) also have shown that yields suffer if the plants are subjected to moisture stress prior to and during the boot stage of development.

While sorghum is more drought tolerant, corn uses the available water more efficiently. Puech et al. (78) grew corn and sorghum under intensive irrigation during a severe drought year, thus being able to control effectively the amounts of water available to the two crops. Total dry matter yield of corn was greater than that of sorghum, these being 18,500 kg/ha and 13,300 kg/ha respectively. Corn used water more efficiently, producing 31.4 kg of dry matter per mm of water used, whereas sorghum produced only 24.5 kg of dry matter per mm of water.

Longo (58) found corn yielded more "herbage" than grain sorghum even under conditions of low availability of water. However, sorghum grain yields were higher than those of corn under such conditions.

Blaney and Criddle (13) presented total, average daily, and peak daily consumptive use of water for a number of crops. The values presented by these workers are generally higher for grain sorghum than for corn. However, these values might not represent a true comparison of the water requirements of corn and grain sorghum, since the two crops were not grown at common locations or during common time periods. Factors such as climate, water supply, soil, topography, irrigation practices, fertilization practices, and stage of growth, as well as kind of crop, influence the amount of water consumed by plants.

Available soil moisture, rate of water usage, and the character of the soil largely determine the depth to which water is extracted from

the soil by a particular crop. Moisture is first removed at a shallow depth immediately below the plant, then laterally until most of the available moisture has been removed from the plow layer, after which removal from successively lower depths occurs. Penetration and removal by corn roots at depths of up to 150 or 180 cm can occur at time of kernel formation in relatively dry, permeable soils, but in constantly moist and/or less permeable soils penetration and extraction might be limited to the upper 60 cm of soil (Holt and Van Doren, 45; Rhoades and Nelson, 79; Doss, Bennett and Ashley, 21).

The previously mentioned factors might be quite important in the nutrition of plants, especially in the case of the less abundant and/or less mobile nutrients. Murdock and Englebert (66) found available P was higher per 15 cm layer in the plow layer than in any other portion of the soil. However, when conditions were favorable for proper development of roots, the plow layer itself contained only a small portion of the available P with which the roots came into contact. They suggested the importance of subsoil P in the P nutrition of corn plants.

However, after experiments involving uptake of radiophosphorus by grain sorghum grown under four different moisture regimes, Nakayama and Van Bavel (67) concluded that 90 percent of the root activity in all treatments was confined to a zone 91 cm deep and 38 cm on either side of the row, even though roots extended at least 150 cm deep. Lavy and Eastin (55) suggested subsoil P might become more important to grain sorghum later in the season. They found grain sorghum took up radiophosphorus later and at greater depths than corn.

Adequate moisture undoubtedly is important in nutrient uptake by plants. Although the mechanisms of water absorption and nutrient absorption differ, some nutrients are nevertheless carried to the vicinity of the root along with the water which is taken up by the plant. Also, nutrient movement by diffusion to the root vicinity occurs. Adequate moisture for the nutrients to be in solution is necessary for either of these phenomena to occur (Hanna and Hutcheson, 38).

Jenne et al. (47) found higher cation contents in irrigated corn than in nonirrigated corn. They reported that total P, K, Mg and Ca contents in corn grown under conditions of decreasing moisture supply during the growth season were 40, 71, 65 and 93 percent, respectively, of the contents of plants which had adequate moisture supply throughout the season. Actual percentage composition of K, Ca and Mg increased as available moisture supply decreased.

Adequate soil moisture is especially important for proper P nutrition of plants. Phosphorus does not move very much within the soil except by diffusion, and supply to plant roots is better when there is adequate moisture for proper diffusion to occur (Taylor and Slater, 83).

A limited example of the interrelationship that exists between soil factors (chemical and physical) and moisture regime, and the effects of these factors upon nutrient uptake, was demonstrated by Mahtab (63). He grew sorghum on four soils differing mainly on the basis of texture; the clay percentages being 12.5, 25.0, 36.0 and 59.0. He imposed four P fertility levels and three moisture levels on the plants, these being 0, 25, 50, 100 ppm and 100, 60 and 50

percent of the available water at field capacity, respectively. He obtained a R^2 of 0.91 (at the one percent level) for P uptake with applied P, clay, and water content. Further, the R^2 for diffusion coefficient with P, clay and water content was 0.89. He concluded that moisture stress caused reduced diffusion of P, directly affecting the P nutrition of the plants. He also found that reduction of available water did not have as great an effect on diffusion in clayey soils as in sandy soils.

Voss et al. (91) reported that, while response to P fertilizer is affected by moisture conditions, response to N fertilizer is affected even more.

Changes in the soil moisture level might be expected to influence the uptake of monovalent and divalent cations differently due to the valence or dilution effect (Bear, 6). When water is added to the soil, making the soil solution more dilute, adsorption of divalent ions by the soil is favored over that of monovalent ions, thus causing the ratio (percent of total R^+ that is dissociated)/(percent of total R^{++} that is dissociated) to increase. Therefore, a preponderance of "available" monovalent ions might be present in the soil solution for ready uptake by plants.

The phenomenon described above might explain some of the results obtained by Gallaher (30). In his three year study, rainfall was considerably higher during the second year than during the first and third years. During the second year, K levels in corn ear leaves were 6-12 me/100 gm higher, and Ca and Mg levels were almost 50 percent lower than during the other two years.

However, this contrasts sharply with the results of Bennett et al. (11). Comparing values of sorghum grown under three different moisture regimes, they found that total K uptake and yield were increased by increasing soil moisture levels, but percent K in the plant tissue was decreased. They did not report Ca and Mg levels.

In the case of Gallaher's experiments (30), it was not possible to separate the effects of moisture from those of temperature. The month of July, when the samples were taken, had 33.6 cm of rain, which was 18.0 to 25.5 cm higher than the same month of the other two years, but temperatures were also considerably different, running about three to six degrees C lower.

The fact that temperature differences can have a considerable effect upon the uptake and accumulation of nutrients was demonstrated by Ketcheson (49). He reported greater P uptake and dry matter production of corn at 20 C than at 13 C. Additions of P resulted in increased P uptake at both temperatures. However, the increased uptake resulted in increased dry matter yields and an actual decrease in P percentages at the higher temperature, rather than an increase in P percentage as occurred at the lower temperature.

Gregory (35) found that corn grown in nutrient solutions took up more P, Mg and K at 25 C than at 20 C, although Ca uptake was somewhat less. Further increases in temperature resulted in decreases in the uptake of P, Mg and K. Dry matter increased as temperature increased in his experiments.

From the foregoing evidence one might conclude that moisture increases favor the absorption of monovalent ions, while temperature

increases (up to a point) favor increased absorption of both monovalent and some divalent ions, but also an increase in dry matter production, thus resulting in a dilution of the ions within the plant.

Growth Stage Effects on Nutrient Concentration in Plants

Large differences in chemical composition exist among different parts of the same plant at a given time and among common plant parts sampled at different stages of the plant's growth. Within a given summer annual crop, the timing of uptake differs from one element to another, and the rate of uptake of a given nutrient element changes throughout the season. Also, the relative accumulation of the various elements varies from organ to organ. As previously pointed out, the interplay of various factors affects the rate and intensity of numerous processes involved and the degree of expression of any of these differences.

In 1936, Macy (62) presented the "critical percentage" concept. He stated that within each kind of plant there is a critical percentage of each nutrient. "Luxury consumption" results in percentages higher than the critical percentages. Below these critical percentages "poverty adjustment," which is almost proportional to the degree of deficiency, occurs until a minimum percentage is reached.

Tyner (87) established critical percentages of 0.295 percent P and 1.3 percent K in the sixth leaf from the base of the corn plant at "bloom" stage. He defined critical percentage as that concentration in the leaf above which there is a low probability of response to further increases in the level of the element in question.

MacKay and Leefe (60) reported somewhat higher optimum levels of P and K at the tassel emerging stage in sweet corn grown under optimum moisture conditions, these being 0.38 percent P and 2.5 percent K. Their definition of "optimum nutrient level" was essentially the same as Tyner's definition of "critical percentage." These workers found that K levels in leaf tissue decreased from the sixth to seventh leaf stage to the pollen shedding stage, while P levels increased. In grain sorghum, Hipp and Thomas (43) found that growth was reduced if K concentration in the leaves was less than 1.5 percent at full flowering.

Numerous interactions observed by Peck, Walker and Boone (75) indicated that critical levels of particular nutrients varied with the levels of other nutrients in the sixth leaf at early tassel. The linear effect of Ca on yield was one of the most significant factors noted, being exceeded only by that of B. Potassium alone showed no significant effects, but interactions of K and several other nutrients were significant. The linear effects of Mg, P and N were significant, as was the P-N interaction. Wide ranges of certain elements were observed in this study, as follows: percent N, 1.90 to 4.16; percent P, 0.09 to 0.41; percent K, 0.60 to 2.25; percent Ca, 0.38 to 0.90; and percent Mg, 0.13 to 0.76.

Voss, Hanway and Dumenil (90) found that corn grain yields could not be satisfactorily predicted by a regression model containing only leaf N, P, and K values. An acceptable model for nutrient levels associated with 95 percent of maximum predicted yield should include several environmental factors, including soil, management, and climatic

factors. Consistent with the findings of Peck et al. (75), they found it unnecessary to include K levels in the model. Regardless of the environmental conditions, a nearly constant ratio of 10:1 existed for percent N:percent P. For the soils and expected conditions included in their experiments, they arrived at approximate values of 2.9 percent N and 0.28 percent P, in the leaf below and opposite the primary ear at early silking, for 95 percent of maximum yields.

However, by the time plants are in the stages for which these various workers have presented nutrient levels, many changes have already occurred, and many factors such as soil factors, moisture regime, etc., have already entered into the determination of the levels of these particular elements within the plant.

Many workers have found most K uptake to occur early during the growth period of corn. Minar and Lastuvka (65) found the maximum rate of K absorption occurred as early as seven days after germination in corn plants grown in nutrient solutions, while absorption rates of N and P did not reach maxima until about 28 days. Bromfield (16) reported K uptake by corn was more rapid from three to six weeks after emergence than later in the season.

Bartholomew and Janssen (5) found greater differences in K percentages as a result of varying soil K levels in young plants than in older ones. Luxury consumption of K by the fertilized young plants, followed by translocation and reutilization of K as the plants grew older, partially explained their results. The amount of available K in the soil was not sufficient to maintain differences as great as those observed early in the season.

Boswell (15) found K content of corn leaves reached maximum at 28 days after planting and decreased thereafter.

Data presented by Jones (48) indicate that percent K in corn leaves decreases, and percentages of Ca and Mg increase as the plant reaches maturity. Phosphorus levels appear to change little until very late in the season, when P levels in the leaves drop sharply as ear maturation occurs, probably due to translocation of P to the ears. The observation by Benne et al. (10) of increasing $(Ca+Mg)/K$ with increasing age of corn plants is in agreement with the seasonal changes in these three elements noted by Jones.

Sayre (80) reported K concentration in corn leaves decreased considerably during the last half of the growing season, while that of Mg increased markedly. Losses of most of the elements from stems, husks, and cobs were probably due to translocation into the grain, but that K lost from these plant parts appeared to move back into the soil through the root system. Although K loss from the plant was very definite, more careful studies were necessary to explain any movement through the plant back into the soil.

Hanway (39), on the other hand, reported that K was translocated from leaves to the stalk late in the season. He observed that loss of K from leaves began near the time of silking and continued to maturity, with K accumulation in the stalks after mid-August. Little K was lost from cobs, husks and sheaths. In the case of P, however, he agreed that considerable quantities were translocated from other plant parts to the grain. At least half of the P in the grain appeared to represent P from other above ground parts, and about three-fourths of the total P was in the grain at maturity.

Genter, Jones and Carter (32) noted significant decreases in leaf, husk and stem weights from the milk stage of corn to maturity. They attributed most of the ear weight increase after the soft dough stage to translocation of nutrients from other plant parts to the ear.

Melsted, Motto and Peck (64) sampled the leaf opposite and below the ear at two weeks before tasseling, at the tassel stage, and again three weeks after tasseling. They observed some decrease in percent P and increases in Ca and Mg percentages from the first to the third sampling date.

Work dealing with nutrient uptake and accumulation by grain sorghum has not been as extensive as that for corn. However, a study by Kramer (52) determined that the Ca, Mg, K and P composition of young grain sorghum plants was similar to that of young corn plants when grown on the same soils. Corn and grain sorghum plants were sampled at three and four weeks of age, respectively.

Even at such an early age, plant parts differ in composition. Lanning and Garabedian (54) found the Ca content of the above ground parts of three week old sorghum plants averaged 0.31 percent. Ash and Ca were considerably higher in sheaths than in other plant parts. The Ca content of leaf sheaths was two and one half times that of leaf blades, ranging from 0.31 to 0.57 percent.

The results of Lane and Walker (53) indicated that grain sorghum did not accumulate as large a proportion of its total nutrients in early growth stages as has generally been reported for corn. In this study, P and K were absorbed by sorghum throughout its growth cycle, and uptake of these elements by sorghum during its final stages was greater than that reported for corn.

Jacquinet (46) reported a decrease in K levels in sorghum tissues and an increase in Ca and Mg levels as the plants aged. Webster, Sieglinger and Davies (92) reported that percent ash and percent protein in the above ground parts of sorghum plants decreased throughout the season.

CHAPTER III

METHODS AND PROCEDURES

During the spring and summer of 1969, early (April 30 - May 15) and late (June 2 - 12) plantings of both corn (Zea mays L. cv. 'Funk G-4831') and grain sorghum (Sorghum bicolor (L.) Moench. cv. 'AKS 614') were grown on a total of twelve soils; two soils at each of six locations across the state of Tennessee (Figure 1). The cultivars

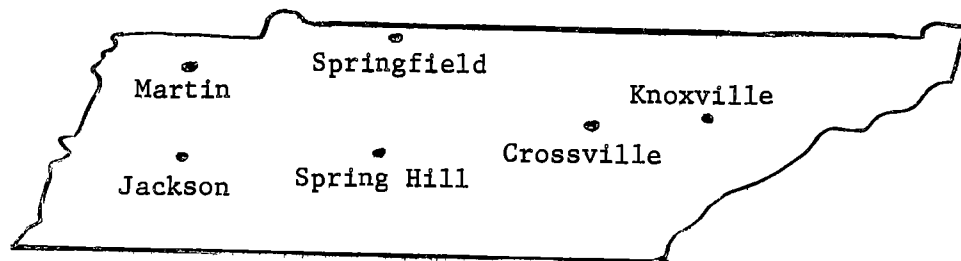


Figure 1. Locations of Tennessee Agricultural Experiment Stations at which experiments were conducted.

used were a white, full-season corn hybrid and a bird resistant, open-headed grain sorghum hybrid of "medium maturity" (Graves, 34). The two soils at each location were selectively "paired" for their expected differences in soil moisture-plant relationships during a year with average rainfall and temperature. The two plantings were made four to five weeks apart at all locations except Spring Hill and Knoxville, where they were four and six weeks apart, respectively. The locations, soils and planting dates are shown in Table I, the soil listed first at each location having the less desirable moisture characteristics of the two.

TABLE I
SOILS, PLANTING DATES, AND IRRIGATION TREATMENTS

Location	Soils Within Location	Planting Dates	Irrigation
1. Knoxville	Sequoia sil (two ranges, designated "Old" and "New")	April 30 and June 12	Sprinkler
	Sequatchie sal		Sprinkler
2. Springfield	Dickson sil	May 3 and June 2	
	Huntington sil		
3. Martin	Grenada sil	May 2 and June 6	
	Collins sil		
4. Spring Hill	Maury sil	May 15 and June 6	Sprinkler
	Emory sil		Sprinkler
5. Jackson	Dexter sil	May 5 and June 2	Furrow
	Loring sil		
6. Crossville	Tilsit sil	May 6 and June 5	
	Hartsells l		

Nonirrigated plots of the two plantings of both crops were grown on all soils. In addition, irrigated plots of the two plantings of both crops were added to five of the soils (Table I). Irrigation water was applied to maintain soil moisture tensions of less than two atmospheres, based on neutron moisture meter readings taken at two week intervals.

The experiments at Knoxville were conducted on the University of Tennessee, Knoxville, Plant Science Farm, in the Great Valley of East Tennessee. Soils in this part of the state were developed primarily in limestone, sandstone and shale residuum and, in places, from old alluvium (Longwell, Parks and Springer, 59).

Soils of the Sequoia series are well-drained and moderately deep. They developed in residuum weathered from soft shale that is leached to a depth of several feet. Depth to bedrock is usually about 60 cm, but ranges from 45 to 120 cm. Sequoia soils are found in areas of undulating to rolling relief, often on the rounded tops of low, rolling hills. They are erosive, low in natural fertility and organic matter and highly acid. Permeability is moderate in the surface horizon but moderately slow in the subsoil (Elder et al., 23).

Soils of the Sequatchie series are deep, well-drained, and fertile. They formed on low stream terraces in general alluvium from various types of material, and are moderately high to high in natural fertility and moderately acid. They have good tilth and high to very high moisture-supplying capacities, yet are permeable enough to permit circulation of air and moisture and extensive root development.

Sequatchie soils often occur with Huntington, but, in comparison with Huntington, they are a little older and have some horizon development (Elder et al., 23).

The experiments at Springfield were conducted on the University of Tennessee Highland Rim Experiment Station. Many of the soils of the Highland Rim were formed from cherty limestone residuum. However, on the broad, gently sloping plateaus, more silty soils have formed from shallow loess. Some of these, such as Dickson, have fragipans (Longwell et al., 59).

Soils of the Dickson series are moderately well drained, upland soils with fragipans at depths of about 60 cm. They developed in loess overlying cherty clay, and are strongly acid, low in natural fertility and moderately low to low in available moisture capacity. The fragipan restricts water and air movement and causes waterlogging in the lower subsoils during wet periods. Slopes range from two to five percent (True et al., 85).

Soils of the Huntington series are deep, well-drained, naturally fertile, dark brown soils, consisting of recent alluvium (60 to 300 plus centimeters in depth) from upland soils derived from limestone. They are slightly acid to neutral in reaction and dominant slopes are less than two percent (True et al., 85; Proffitt et al., 77).

The experiments at Martin were conducted at the University of Tennessee, Martin, Experimental Farm in West Tennessee. The upland soils in this area of the state mainly were developed in medium to deep loess. On these loessal plains, soils with fragipans at about 60 cm are quite extensive (Longwell et al., 59).

Soils of the Grenada series are deep, moderately well drained, level to strongly sloping upland and terrace soils formed in thick loess. These soils have 30 to 150 centimeters thick fragipan at about 60 centimeters, and are likely to be wet in the spring and droughty in late summer. They are strongly acid.

Grenada soils occur on mild slopes with Memphis and Loring, which have better drainage than Grenada, and on more nearly level areas with Calloway and Henry, which are not as well-drained as Grenada (Flowers, 26).

Soils of the Collins series are moderately well drained, nearly level soils, consisting of recent silty and sandy alluvium from soils such as Memphis, Loring, Grenada and Henry (upland soils formed in loess and coastal plain materials). Collins soils are medium to strongly acid, moderate in fertility and high in moisture-supplying capacity (Flowers, 26; Proffitt et al., 77).

The experiments at Spring Hill were conducted on the University of Tennessee, Middle Tennessee Experiment Station, in the Central Basin. Soils of this section of the state developed mainly from limestone residuum (Longwell et al., 59).

Soils of the Maury series are deep, well-drained, brown, upland soils, which have developed from the weathered residuum of phosphatic limestone. They are medium to strongly acid and medium to high in phosphorus content. Dominant slopes are between two and five percent.

Maury soils are associated with Mimosa, Braxton, Hicks, Culleoka, Inman and Hampshire soils of the uplands and the colluvial Armour and Huntington soils (Harmon et al., 41; True et al., 85).

Soils of the Emory series are well-drained, having developed in recent colluvium or local alluvium from adjacent slopes. They are slightly acid, moderately high in organic matter and high in moisture-supplying capacity. Permeability is rapid, and surface runoff and internal drainage are medium. Slopes are usually less than three percent.

Emory soils are similar in many respects to Huntington, but they are more red than brown and are not as likely to be flooded or ponded (Harmon et al., 41; Overton et al., 72).

The experiments at Jackson were conducted on the University of Tennessee West Tennessee Experiment Station. This location is in the same general soil area as Martin, and the soils at these two locations have developed from similar parent material.

Soils of the Dexter series are deep, well-drained terrace soils, developed in old alluvium from upland loess and coastal plain soils. These soils occupy undulating to hilly areas. They are medium to strongly acid, moderate in fertility and organic matter and permeable and friable throughout, with good tilth and a deep root zone (Proffitt et al., 77).

Soils of the Loring series are deep, medium to strongly acid, well to moderately well drained upland soils. These soils have developed in thick loess (105 to 370 centimeters) on level to moderately steep, broad ridge tops and side slopes. They contain a moderate amount of potassium, a small amount of phosphorus and usually a low amount of organic matter. A weak fragipan may be present.

Loring commonly occurs in areas adjacent to Memphis, Grenada, Calloway and Henry soils. It is more poorly drained than Memphis, but

possesses better drainage than Grenada, which has a strongly developed pan (Flowers, 26).

The experiments at Crossville were conducted on the University of Tennessee Plateau Experiment Station. Here on the Cumberland Plateau, shallow and/or rocky soils derived from sandstone and shale are common (Longwell et al., 59).

Soils of the Tilsit series are moderately well drained upland soils underlain by heavy silt loam fragipans at 45 to 70 cm. These soils have developed in silty residuum from acid siltstone or fine grained sandstone, influenced in some places by colluvium or old alluvium. They are strongly acid to extremely acid and moderately permeable in horizons above the fragipan, with slow to medium runoff. They usually occur on upland ridge tops with slopes of one to 15 percent (National Cooperative Soil Survey, U. S. A., Tilsit Series, 69).

Soils of the Hartsells series are well-drained soils with acid sandstone bedrock at about 90 cm (50 to 114 cm). They occur on broad smooth plateaus, mountain tops or hill tops. Slopes are usually between three and eight percent, but range up to 25 percent. Permeability of these soils is moderately rapid and runoff is medium. Reaction ranges from strongly to very strongly acid. Hartsells soils are associated with Tilsit, Ramsey and Crossville soils (National Cooperative Soil Survey, U. S. A., Hartsells Series, 68).

Field Methods

These experiments were conducted as split-plot factorial arrangements of treatments in randomized complete blocks. Each experiment

included four replications of the main treatments, with the exception of those at Spring Hill (Maury and Emory soils), where three replications were grown.

On those soils where irrigated treatments were grown, irrigated and nonirrigated treatments were conducted as separate experiments on adjacent parcels of soil, with the exception of the Dexter series, on which irrigation and nonirrigation treatments were included in a single experiment. On the Dexter soil, irrigation treatments were assigned to the main plots, planting dates to the split-plots, and crops to the split-split plots. In all other irrigated and nonirrigated experiments, planting dates were assigned to the main plots and crops to the split-plots.

Each experiment was conducted on as uniform a parcel of soil as possible, except on Sequoia where one replication each of the irrigated and the nonirrigated experiments was conducted on a separate range of soil. The two ranges, designated "Sequoia, New" and "Sequoia, Old," contained replications one through three and replication four, respectively.

Within each replication of each experiment, the following plots were grown; one plot of corn for tissue sampling and harvest as grain, one plot of grain sorghum for tissue sampling and harvest as silage, and one plot of corn for harvest as silage. These were all four row plots, except on the two soils at Springfield, where the corn for grain and the grain sorghum were grown in three row plots. Since these experiments were conducted in conjunction with another phase of a three part summer annuals adaptation study, three row plots of three other summer

annual forage crops also were grown on all soils except "Sequoia, Old," on which only one other crop was grown.

Each plot contained two guard rows (the two outside rows of the particular crop). In addition, there were two guard rows of corn between planting dates and four guard rows of corn on the outsides of each replication. All rows were spaced 90 centimeters apart. Row length was dictated by the sizes of the uniform parcels of soil available, and varied from experiment to experiment. Turning alleyways of sufficient size to allow for necessary field operations were allowed.

Preparation of plots by mechanical means was accomplished as necessary to provide proper seedbed conditions for crop establishment. Fertilizer application was according to recommendations for high yields based on soil tests.

Corn was planted with a jab type hand planter at the rate of 88,920 plants/hectare, and grain sorghum was planted with a "Planet Junior" seeder at the rate of 111,150 plants/hectare. Three to four weeks after emergence, corn was thinned to 44,460 plants/hectare (12 plants per 300 cm of row). Grain sorghum was thinned to approximately 54,340 plants/hectare by chopping out and leaving alternate 15 centimeter widths. During the growing season, cultivation was performed as necessary for adequate weed control.

After plant emergence, representative samples of the uppermost horizon of each soil were taken on a plot-by-plot basis. The next lower horizon of each soil was sampled on a replication-by-replication basis on the same date on which plots of the first planting were sampled.

The horizon breaks, from Oonmuang's (71) observations of pits adjacent to these experiments, are shown in Table II. The uppermost and shallower second horizon samples were taken with a Hoffer aluminum sampling tube. Deeper second horizon samples were taken with a bucket auger. Soil samples were collected in paper bags, air dried, ground with iron mortar and pestle and stored in heavy plastic bags for subsequent analysis.

At each of the six locations, leaf tissue samples were taken from each corn-for-grain plot at three stages of growth; about the eighth to tenth leaf stage, early tassel and early silking. Grain sorghum samples were taken at the same time the corn plots in the particular experiment were sampled, and the stage of growth at the time of sampling was noted.

Some variation in stage of growth of corn at the time of first sampling existed. Although most plots were at or near the stages noted above, the first plantings at Crossville and the first planting on "Sequoia, Old" were at earlier stages, and the second plantings at Jackson were approaching the early tassel stage when first sampled.

Corn plants were sampled by collecting the most recently fully expanded leaf blade (about the third or fourth leaf out of the whorl) on sampling dates prior to the time ear shoots became visible. On subsequent sampling dates, the uppermost ear leaf blade was taken. Grain sorghum plants were sampled by taking the entire above ground portion on the first sampling date and the blade of the uppermost leaf with visible collar (flag leaf) on subsequent sampling dates. Plants for sampling were selected at random from the third row of the corn and

TABLE II
SOIL HORIZONS AND DEPTHS*

Soil Series	Horizon	Depth (centimeters)
Sequoia	Ap	0-15
	A1-B1	15-24
Sequatchie	Ap	0-28
	B1	28-38
Dickson	Ap	0-30
	B21t	30-56
Huntington	Ap	0-28
	B21	28-43
Grenada	Ap1	0-15
	Ap2	15-30
Collins	Ap	0-15
	IIA1	15-30
Maury	Ap	0-25
	B21t	25-53
Emory	Ap	0-18
	B21t	18-43
Dexter	Ap	0-15
	B21t	15-36
Loring	Ap1	0-15
	Ap2	15-24
Tilsit	Ap	0-13
	A3	13-25
Hartsells	Ap	0-25
	B21	25-46

* Source: Oonmuang, C. (71).

grain sorghum plots, and a minimum of six corn leaves, eight grain sorghum leaves, or six whole grain sorghum plants were taken at each sampling to insure an adequate quantity of dried sample for analysis.

Plant tissue samples were collected in paper bags, dried in a forced air oven at 65 degrees C, ground in a Wiley mill and stored in Nasco "Whirl-Pak" bags for subsequent analysis. The samples were not washed or otherwise cleaned. Baker et al. (2) found that it was generally unnecessary to clean the sixth leaf of the corn plant before analysis.

Laboratory Methods

Leaf tissue samples were digested by a modification of the wet oxidation procedure developed by Gieseking, Snider and Getz (33), as outlined in Appendix A. The digestates were analyzed for Ca, Mg, K and P concentrations by the use of a Technicon "AutoAnalyzer." The Technicon procedures, as modified from those of Steckel and Flannery (81), are outlined in Appendices B, C, D and E. Nutrient levels in plant tissue were reported in percentage composition on a dry weight basis.

Exchangeable ions in the soil samples were extracted by the "North Carolina" method (0.05N HCl and 0.025N H_2SO_4 solution), as described by Page (73) and outlined in Appendix F. This method, in addition to facilitating the determination of both P and exchangeable bases with a single extraction, has been shown to give extractable P values which correlate more highly with total P uptake than those measured by three other procedures. It was approximately equal to the "Morgan" method (ten percent CH_3COONa and CH_3COOH) (Griffin and Lorton, 36). Calcium, Mg, K and P determinations were run on the

AutoAnalyzer by the procedures outlined in Appendices B, C, D and E. Nutrient levels in soils were reported in parts per two million, on an elemental basis.

Soil pH values were determined on 1:1 soil-water suspensions with a glass electrode in conjunction with a potentiometer.

Statistical Methods

Soil and leaf tissue data were tabulated and recorded on computer cards. Various "splatter plots" of percentage composition were made for observations of differences in the levels of Ca, Mg, K and P in plant leaf tissue due to crop differences, soil differences, time of planting, irrigation treatment and growth stage of the plants.

Analyses of variance were run on an individual experiment basis to determine the effects of stage, planting, crop and first-order interactions upon nutrient concentration. In addition, combined analyses of variance were run to determine concentration differences between the two soils at each location and to determine differences between the non-irrigated and the irrigated treatments on those soils where irrigation was involved. First-order interactions between soil or irrigation treatment and the other sources of variation (stage, planting and crop) were observed, but no analysis for the soil-irrigation interaction was conducted. Because of the supposed confounding of actual crop differences by the stage-crop interactions, other analyses of variance were conducted using the data for second and third stages.

Statistical Analysis System (SAS), developed by Barr and Goodnight (4) was used for the computerized statistical portion of this study. Cochran and Cox (18), Guenther (37), and Le Clerg, Leonard and Clark (57) were used as statistical references.

CHAPTER IV

RESULTS

Soil Test Results (Table III)

Sequoia was the highest of the twelve soils in Mg content and the lowest in P content. Based on the North Carolina fertility ratings, it was very high in Mg and low in P. Its Mg content was approximately one and one-half that of the next highest soil (Collins).

Sequatchie was the lowest of the twelve soils in both Ca and K, although, by the North Carolina fertility ratings, it was high in Ca and medium in K.

Dickson had rather low pH levels for optimum growth of corn and sorghum.

Collins was very high in P, being more than twice as high as the next highest soils (Dexter and Tilsit), and about eight times as high as the lowest soil (Sequoia).

Dexter was the highest in K content of the twelve soils tested. The pH levels of this soil also were higher in both horizons than those of most other soils, while the pH levels of Loring, at the same location, were rather low for the proper growth of corn and sorghum.

Tilsit was considerably higher in Ca content than any other soil, and its pH level also was higher than that of most others. Its Mg content was the lowest of the twelve soils, although it was medium by the North Carolina ratings. Both soils at Crossville (Tilsit and Hartsells) were lower in Mg than the other soils.

TABLE III
AVERAGE NUTRIENT LEVELS* AND RANGES OF pH VALUES IN SURFACE
AND SUBSURFACE HORIZONS OF TWELVE SOILS

Soil	Horizon	pH Range	Ca	Mg	K	P
			-----pp2m-----			
Sequoia	Surf	5.1-6.8	2300	1196	144	27
	Sub	4.5-5.5	1451	1048	87	8
Sequatchie	Surf	5.7-6.3	1113	433	86	56
	Sub	5.3-5.8	903	366	48	22
Dickson	Surf	4.9-5.7	1890	222	136	44
	Sub	4.4-4.7	1104	257	66	5
Huntington	Surf	5.5-6.4	2221	212	124	54
	Sub	4.9-5.4	996	191	62	10
Grenada	Surf	5.4-6.6	1899	426	155	40
	Sub	5.8-6.0	1724	520	112	23
Collins	Surf	5.4-6.1	2160	672	236	221
	Sub	6.1-6.2	2136	710	198	163
Maury	Surf	5.3-6.5	2268	452	217	40
	Sub	4.8-6.3	2018	472	89	26
Emory	Surf	5.2-6.0	1996	283	192	62
	Sub	5.7-6.5	2037	314	101	43
Dexter	Surf	5.8-6.6	1800	264	266	95
	Sub	6.0-6.7	1846	296	202	56
Loring	Surf	4.7-5.3	1388	263	154	56
	Sub	5.3-5.5	1422	270	160	58
Tilsit	Surf	6.0-6.8	3410	99	216	98
	Sub	6.1-6.5	2632	87	166	66

TABLE III (continued)

Soil	Horizon	pH Range	Ca	Mg	K	P
-----pp2m-----						
Hartsells	Surf	5.5-6.3	2151	149	166	73
	Sub	4.6-5.2	970	180	66	14

* Fertility classes based on North Carolina method.

	Very Low	Low	Medium	High	Very High
-----pp2m-----					
Ca	0-159	160-399	400-799	800-1599	≥1600
Mg	0-23	24-59	69-119	120-239	≥240
K	0-28	29-71	72-144	145-289	≥290
P	0-11	12-29	30-59	60-119	≥120

Based on the North Carolina ratings, all soils except Tilsit were in the high to very high fertility ranges for both Ca and Mg. Also, all soils were in the medium and high fertility ranges for both K and P, except Sequoia and Collins, which were in the low and very high P ranges, respectively.

Stage of Growth (Tables IV, V, VI, VII, VIII and IX)

Stage differences in Ca concentration occurred in 13 of the 17 experiments (all except Sequoia, Maury-I, Tilsit and Hartsells). Differences were not observed in either experiment at the Crossville location. In general, Ca percentages tended to decrease from first to second stages and increase from second to third stages.

Differences in Mg concentration occurred in nine experiments. Knoxville was the only location at which no differences were observed in any of the experiments. Magnesium concentrations tended to decrease from first to second stages and either to remain stable or increase from second to third stages.

Differences in K concentration were observed in all 17 experiments. Decreases generally occurred throughout the season. However, those decreases observed from first to second stages were of much greater magnitude than those from second to third stages.

Significant stage effects on P concentration occurred in only three experiments (Huntington, Dickson and Loring), two of which were at Springfield. Patterns of concentration change during the season were inconsistent.

TABLE IV

MEAN CONCENTRATIONS OF CALCIUM, MAGNESIUM, POTASSIUM AND PHOSPHORUS IN GRAIN
SORGHUM AND CORN TISSUE FROM FOUR EXPERIMENTS AT KNOXVILLE

Source	D.F.	Percent Ca			Percent Mg			Percent K			Percent P		
		Sa	Sa-I	Se	Sa	Sa-I	Se	Sa	Sa-I	Se	Sa	Sa-I	Se
Stage	2	**	**	**				*	**	**			
First		.36	.31	.38	.44	.45	.55	.51	2.19	2.27	1.78	1.84	**
Second		.37	.36	.52	.37	.39	.45	.48	1.78	1.75	1.38	1.43	
Third		.41	.42	.54	.38	.48	.49	.49	1.71	1.66	1.35	1.38	
Error	9												
Planting	1	**	**	**				**	**	**			
Early		.39	.38	.46	.39	.42	.45	.45	1.98	2.06	1.65	1.74	**
Late		.37	.35	.50	.41	.45	.55	.54	1.81	1.73	1.35	1.36	
Stage-Planting	2	*	*	*									
First		.38	.34	.39	.46	.44	.47	.50	2.26	2.40	1.86	1.96	
Early		.35	.28	.38	.43	.46	.64	.52	2.12	2.14	1.69	1.71	
Late		.39	.37	.48	.38	.41	.45	.42	1.83	1.92	1.57	1.63	
Second		.36	.35	.56	.37	.37	.46	.54	1.74	1.58	1.18	1.22	
Late		.41	.42	.51	.34	.42	.43	.43	1.85	1.85	1.51	1.61	
Third		.40	.43	.58	.43	.53	.55	.56	1.58	1.46	1.18	1.14	
Error	9												
Crop	1	**	**	*	**	*			*	*			
Sorghum		.34	.34	.49	.33	.39	.48	.48	1.89	1.78	1.49	1.46	
Corn		.43	.39	.47	.47	.49	.51	.51	1.91	2.00	1.51	1.63	
Stage-Crop	2	**	**	**	**	**	**	**	**	*	*	*	**
First		.44	.38	.53	.50	.56	.76	.67	2.44	2.31	1.79	1.71	**
Sorghum		.29	.24	.24	.38	.34	.35	.35	1.94	2.23	1.76	1.96	**
Corn													

TABLE IV (continued)

Source	D.F.	Percent Ca			Percent Mg			Percent K			Percent P		
		Sa	Sa-I	Se	Sa	Sa-I	Se	Sa	Sa-I	Se	Sa	Sa-I	Se
Second Sorghum		.26	.28	.47	.50	.24	.26	.30	.38	1.63	1.52	1.36	1.36
Corn		.48	.44	.56	.54	.51	.52	.61	.58	1.94	1.98	1.40	1.49
Third Sorghum		.31	.34	.48	.44	.24	.35	.40	.38	1.59	1.51	1.33	1.31
Corn		.51	.51	.61	.63	.53	.60	.58	.60	1.84	1.80	1.36	1.44
Planting-Crop	1												
Early Sorghum		.36	.33	.46	.45	.33	.36	.40	.41	1.87	1.94	1.58	1.59
Corn		.43	.42	.46	.46	.45	.49	.50	.48	2.09	2.17	1.72	1.88
Late Sorghum		.32	.34	.53	.50	.33	.42	.57	.54	1.90	1.62	1.41	1.34
Corn		.42	.37	.48	.46	.49	.48	.53	.54	1.72	1.83	1.30	1.38
Error	20												
General Mean		.38	.36	.48	.47	.40	.44	.50	.49	1.90	1.89	1.50	1.54

Sa = Sequoia.

Se = Sequatchie.

I = Irrigated.

* = .01 level of significance.

** = .001 level of significance.

TABLE V

MEAN CONCENTRATIONS OF CALCIUM, MAGNESIUM, POTASSIUM AND PHOSPHORUS
IN GRAIN SORGHUM AND CORN TISSUE FROM TWO
EXPERIMENTS AT SPRINGFIELD

Source	D.F.	Percent Ca		Percent Mg		Percent K		Percent P	
		Dn	Hn	Dn	Hn	Dn	Hn	Dn	Hn
Stage	2	**	**		**	**	**	*	**
First		.44	.51	.30	.26	2.74	2.51	.33	.30
Second		.45	.50	.26	.22	2.00	1.73	.33	.38
Third		.60	.63	.29	.28	1.80	1.55	.30	.36
Error	9								
Planting	1	**	**		**	**		**	**
Early		.43	.46	.27	.18	2.46	1.93	.35	.31
Late		.56	.63	.30	.33	1.90	1.92	.28	.38
Stage-Planting	2	**				**			
First Early		.40	.46	.30	.18	3.28	2.54	.36	.25
Late		.47	.56	.31	.34	2.19	2.47	.30	.35
Second Early		.34	.38	.24	.15	2.16	1.82	.38	.35
Late		.56	.62	.28	.29	1.84	1.63	.28	.41
Third Early		.54	.55	.28	.20	1.94	1.43	.32	.33
Late		.67	.70	.30	.36	1.66	1.66	.26	.40
Error	9								
Crop	1	**	*	**				**	*
Sorghum		.52	.58	.26	.24	2.08	1.87	.30	.34
Corn		.48	.52	.30	.27	2.28	1.99	.33	.36
Stage-Crop	2	**	**	**	**	*	**	*	*
First Sorghum		.62	.72	.39	.32	2.88	2.65	.30	.26
Corn		.26	.30	.22	.20	2.59	2.36	.36	.34
Second Sorghum		.40	.41	.19	.17	1.75	1.58	.33	.38
Corn		.51	.58	.32	.27	2.25	1.88	.33	.38
Third Sorghum		.54	.59	.22	.23	1.61	1.37	.29	.36
Corn		.68	.66	.37	.33	1.99	1.72	.30	.36
Planting-Crop	1	*	*	**			**		
Early Sorghum		.46	.52	.28	.17	2.38	1.77	.35	.29
Corn		.39	.40	.27	.18	2.55	2.09	.36	.34

TABLE V (continued)

Source	D.F.	Percent Ca		Percent Mg		Percent K		Percent P	
		Dn	Hn	Dn	Hn	Dn	Hn	Dn	Hn
Late Sorghum		.57	.63	.25	.31	1.79	1.96	.26	.38
Corn		.56	.62	.34	.35	2.01	1.88	.30	.39
Error	20								
General Mean		.50	.54	.28	.25	2.18	1.93	.32	.35

Dn = Dickson.

Hn = Huntington.

* = .01 level of significance.

** = .001 level of significance.

TABLE VI

MEAN CONCENTRATIONS OF CALCIUM, MAGNESIUM, POTASSIUM AND PHOSPHORUS
IN GRAIN SORGHUM AND CORN TISSUE FROM TWO
EXPERIMENTS AT MARTIN

Source	D.F.	Percent Ca		Percent Mg		Percent K		Percent P	
		Ga	Cs	Ga	Cs	Ga	Cs	Ga	Cs
Stage	2	**	**	**	**	**	**		
First		.40	.41	.47	.42	2.67	3.00	.30	.36
Second		.28	.36	.32	.28	1.76	1.87	.34	.36
Third		.50	.52	.46	.36	1.76	1.89	.33	.35
Error	9								
Planting	1			*		*			
Early		.39	.44	.45	.38	2.16	2.21	.33	.36
Late		.39	.42	.38	.33	1.96	2.29	.32	.35
Stage-Planting	2					**	*		*
First Early		.42	.41	.50	.44	2.98	2.71	.29	.35
Late		.37	.41	.44	.39	2.36	3.29	.32	.37
Second Early		.28	.36	.34	.32	1.81	1.97	.35	.36
Late		.29	.36	.29	.24	1.72	1.76	.33	.36
Third Early		.48	.53	.51	.36	1.70	1.96	.34	.38
Late		.52	.50	.40	.36	1.82	1.81	.32	.32
Error	9								
Crop	1				**	**	**		
Sorghum		.41	.45	.42	.40	1.80	1.98	.32	.36
Corn		.38	.41	.41	.30	2.32	2.52	.33	.36
Stage-Crop	2	**	**	**	**	**	**	*	**
First Sorghum		.55	.55	.63	.58	2.63	3.07	.28	.33
Corn		.24	.27	.31	.25	2.71	2.92	.33	.39
Second Sorghum		.24	.33	.28	.27	1.40	1.48	.35	.37
Corn		.33	.39	.35	.29	2.13	2.26	.33	.34
Third Sorghum		.44	.46	.35	.35	1.38	1.39	.33	.36
Corn		.56	.56	.56	.37	2.14	2.38	.33	.34
Planting-Crop	1			*	*				
Early Sorghum		.42	.44	.48	.44	1.84	1.92	.32	.37
Corn		.36	.43	.42	.31	2.49	2.50	.34	.36

TABLE VI (continued)

Source	D.F.	<u>Percent Ca</u>		<u>Percent Mg</u>		<u>Percent K</u>		<u>Percent P</u>	
		Ga	Cs	Ga	Cs	Ga	Cs	Ga	Cs
Late Sorghum		.40	.45	.36	.36	1.77	2.03	.32	.34
Corn		.39	.39	.40	.30	2.16	2.54	.32	.36
Error	20								
General Mean		.39	.43	.41	.35	2.06	2.25	.32	.36

Ga = Grenada.

Cs = Collins.

* = .01 level of significance.

** = .001 level of significance.

TABLE VII

MEAN CONCENTRATIONS OF CALCIUM, MAGNESIUM, POTASSIUM AND PHOSPHORUS IN GRAIN SORGHUM AND CORN TISSUE FROM FOUR EXPERIMENTS AT SPRING HILL

Source	D.F.	Percent Ca			Percent Mg			Percent K			Percent P		
		My	My-I	Ey	My	My-I	Ey	My	My-I	Ey	My	My-I	Ey
Stage	2	*	*	*	*	*	*	**	**	**	*	*	*
First		.42	.47	.38	.43	.36	.40	.36	.305	3.22	2.58	2.99	**
Second		.36	.40	.46	.43	.28	.36	.30	2.20	2.21	1.77	1.97	2.99
Third		.54	.54	.62	.63	.36	.45	.40	1.92	1.92	1.42	1.68	2.99
Error	6												
Planting	1	*	*	*	*	*	*	*	*	*	*	*	*
Early		.42	.42	.41	.44	.33	.37	.36	2.34	2.41	2.08	2.27	2.27
Late		.46	.52	.56	.56	.34	.43	.34	2.44	2.49	1.77	2.16	2.16
Stage-Planting	2	*	*	*	*	*	*	*	*	*	*	*	*
First		.48	.51	.39	.42	.40	.40	.40	3.17	3.41	2.83	3.17	3.17
Early		.35	.42	.37	.44	.33	.37	.40	2.94	3.03	2.34	2.81	2.81
Late		.29	.30	.32	.33	.24	.30	.28	2.06	2.10	1.91	2.03	2.03
Second		.44	.51	.61	.53	.31	.43	.31	2.35	2.32	1.62	1.91	1.91
Early		.49	.47	.52	.56	.35	.43	.41	1.78	1.71	1.50	1.60	1.60
Late		.60	.62	.71	.70	.38	.47	.39	2.05	2.13	1.35	1.75	1.75
Error	6												
Crop	1	*	*	*	*	*	*	*	*	*	*	*	*
Sorghum		.42	.51	.50	.54	.32	.37	.35	2.18	2.23	1.87	1.98	1.98
Corn		.46	.44	.48	.46	.35	.43	.36	2.60	2.67	1.98	2.45	2.45
Stage-Crop	2	**	**	**	**	**	**	**	**	**	*	**	**
First		.51	.63	.54	.59	.43	.53	.46	3.28	3.55	2.76	3.08	3.08
Sorghum		.33	.31	.23	.27	.30	.26	.28	2.82	2.89	2.41	2.90	2.90
Corn													

TABLE VII (continued)

Source	D.F.	Percent Ca			Percent Mg			Percent K			Percent P		
		My	My-I	Ey	My	My-I	Ey	My	My-I	Ey	My	My-I	Ey
Second Sorghum		.29	.39	.40	.24	.29	.30	.26	1.71	1.64	1.58	1.54	.38
Corn		.44	.42	.52	.31	.32	.42	.34	2.70	2.77	1.95	2.41	.36
Third Sorghum		.47	.50	.55	.28	.30	.29	.33	1.56	1.50	1.26	1.32	.38
Corn		.61	.58	.69	.44	.40	.60	.47	2.27	2.34	1.59	2.04	.40
Planting-Crop	1												
Early Sorghum		.39	.47	.41	.30	.37	.35	.36	2.15	2.12	1.95	1.99	.35
Corn		.45	.38	.41	.35	.33	.39	.37	2.53	2.69	2.21	2.55	.39
Late Sorghum		.45	.54	.58	.33	.35	.39	.33	2.22	2.34	1.79	1.97	.36
Corn		.47	.49	.55	.35	.33	.48	.35	2.67	2.64	1.76	2.35	.39
Error	14												
General Mean		.44	.47	.49	.33	.34	.40	.35	2.39	2.45	1.92	2.21	.37

My = Maury.

Ey = Emory.

I = Irrigated.

* = .01 level of significance.

** = .001 level of significance.

TABLE VIII (continued)

Source	D.F.	Percent Ca		Percent Mg		Percent K			Percent P				
		Dr	Dr-I	Lg	Dr	Dr-I	Lg	Dr	Dr-I	Lg			
Second Sorghum		.26	.19	.23	.28	.28	.32	1.53	1.66	1.54	.34	.37	.33
Corn		.38	.34	.40	.36	.34	.42	2.22	2.24	1.86	.30	.32	.28
Third Sorghum		.41	.38	.30	.34	.31	.30	1.40	1.41	1.42	.29	.33	.25
Corn		.58	.53	.56	.45	.46	.58	2.14	2.15	1.78	.29	.29	.27
Planting-Crop	1	*		**	*			*	**				
Early Sorghum		.48	.41	.44	.39	.41	.44	2.03	1.90	1.76	.32	.32	.30
Corn		.42	.38	.42	.35	.37	.45	2.71	2.56	2.18	.33	.34	.33
Late Sorghum		.36	.34	.24	.36	.30	.34	1.72	2.02	1.66	.26	.32	.26
Corn		.39	.34	.38	.37	.35	.43	1.99	2.19	1.76	.29	.30	.25
Error	20												
General Mean		.41	.37	.37	.37	.36	.42	2.11	2.17	1.84	.30	.32	.28

Dr = Dexter.

Lg = Loring.

I = Irrigated.

* = .01 level of significance.

** = .001 level of significance.

TABLE IX

MEAN CONCENTRATIONS OF CALCIUM, MAGNESIUM, POTASSIUM AND PHOSPHORUS
IN GRAIN SORGHUM AND CORN TISSUE FROM TWO
EXPERIMENTS AT CROSSVILLE

Source	D.F.	Percent Ca		Percent Mg		Percent K		Percent P	
		Tt	Hs	Tt	Hs	Tt	Hs	Tt	Hs
Stage	2		**	**	**	**			
First		.57	.56	.33	.40	2.93	2.99	.40	.34
Second		.57	.53	.22	.31	2.01	1.83	.38	.33
Third		.65	.58	.22	.31	1.85	1.70	.41	.34
Error	9								
Planting	1			*				*	*
Early		.60	.56	.28	.36	2.26	2.22	.42	.35
Late		.59	.55	.23	.32	2.27	2.13	.38	.32
Stage-Planting	2	**	**	**	*	**	**		
First Early		.64	.62	.41	.46	3.22	3.38	.41	.35
Late		.50	.49	.26	.33	2.63	2.61	.39	.34
Second Early		.56	.52	.23	.31	1.75	1.62	.40	.33
Late		.57	.54	.21	.31	2.28	2.04	.37	.33
Third Early		.59	.55	.22	.30	1.80	1.67	.44	.36
Late		.70	.61	.23	.32	1.91	1.73	.38	.31
Error	9								
Crop	1				**	**		*	
Sorghum		.61	.54	.25	.30	2.12	2.13	.38	.34
Corn		.58	.56	.27	.38	2.41	2.22	.41	.34
Stage-Crop	2	**	**	**	**	**	**		
First Sorghum		.79	.72	.39	.44	3.05	3.17	.38	.33
Corn		.35	.39	.27	.35	2.80	2.82	.42	.36
Second Sorghum		.48	.44	.18	.23	1.70	1.66	.36	.34
Corn		.66	.62	.27	.39	2.32	2.01	.40	.32
Third Sorghum		.56	.38	.18	.22	1.60	1.56	.41	.34
Corn		.73	.68	.27	.40	2.11	1.84	.41	.32
Planting-Crop	1						**		
Early Sorghum		.61	.57	.27	.32	2.02	2.03	.41	.35
Corn		.59	.55	.30	.40	2.49	2.42	.42	.35

TABLE IX (continued)

Source	D.F.	<u>Percent Ca</u>		<u>Percent Mg</u>		<u>Percent K</u>		<u>Percent P</u>	
		Tt	Hs	Tt	Hs	Tt	Hs	Tt	Hs
Late Sorghum		.61	.52	.23	.27	2.21	2.22	.36	.32
	Corn	.57	.58	.24	.36	2.33	2.03	.40	.32
Error	20								
General Mean		.60	.55	.26	.34	2.26	2.18	.40	.34

Tt = Tilsit.

Hs = Hartsells.

* = .01 level of significance.

** = .001 level of significance.

Planting Date (Tables IV, V, VI, VII, VIII and IX)

In nine of the 17 experiments, significant effects of planting date on Ca concentration were noted. Early plantings of the three experiments at Jackson were higher in Ca, while late plantings of the other six experiments had higher concentrations. No differences were observed in any of the experiments at Martin and Crossville. Only at Springfield were all late plantings higher in Ca.

Early plantings in the Sequatchie, Sequatchie-I and Huntington experiments were lower in Mg, while late plantings of Grenada, Loring, Dexter and Tilsit were lower in this element.

Potassium percentages were higher in the early plantings of nine experiments; Dickson, Grenada, plus all those at Knoxville and Jackson. No differences between plantings occurred at the Spring Hill and Crossville locations or in the experiments on Huntington and Collins.

All early plantings at Jackson and Crossville were higher in P than the later plantings at these locations. In addition, early plantings in the Dickson and Maury experiments were higher. The experiment on Huntington was different from all others in that the late planting had higher P concentrations than the early planting. No differences between plantings occurred at Knoxville and Martin.

Stage-Planting Interaction (Tables IV, V, VI, VII, VIII and IX)

Calcium concentrations were observed to be influenced by stage-planting interactions in 11 experiments. Martin was the only location where no stage-planting differences were noted. In those experiments

where differences occurred, Ca concentrations in early plantings usually decreased from first to second stages and then increased from second to third stages, while concentrations in late plantings increased throughout the season.

Significant differences in Mg concentrations were observed in six experiments; all those at Jackson and Crossville, plus Maury. Types of changes observed were not always consistent, but, in general, early plantings tended to decrease from first to second stages and then to either remain constant or increase to approximately the original concentration from second to third stages. Late plantings tended to remain constant or increase slightly through the three stages.

In nine of the 17 experiments, differences in K concentration occurred. Generally, early plantings were higher in K than late plantings at the first growth stage. Concentration decreases from first through third stages usually were greater in the early plantings.

Stage-planting differences in P concentrations were noted in only two experiments; Dexter and Collins. No consistent pattern of interaction was observed.

The stage-planting interactions for Ca, Mg and K concentrations were characterized by the same type of trends which were observed in the stage-crop interactions. The early plantings changed through the three stages in approximately the same manner as the sorghum crop, and the late plantings followed the trends observed in the corn crop.

Crop (Tables IV, V, VI, VII, VIII and IX)

Calcium percentages were significantly higher in corn in the Sequoia, Sequoia-I and Loring experiments, and in sorghum in the Dickson, Huntington and Emory-I experiments.

Corn had higher concentrations of Mg than sorghum in the five experiments, Sequoia, Sequoia-I, Dickson, Hartsells and Loring. Collins alone had higher average Mg concentrations in sorghum than in corn.

In ten of the 17 experiments, K concentrations were higher in corn than in sorghum. In no case was K concentration higher in sorghum than in corn.

In the two experiments at Springfield, as well as the Maury, Dexter, Emory-I and Tilsit experiments, P levels were higher in corn than in sorghum. No differences between the two crops were observed at Knoxville and Martin.

Crop, Second and Third Stages (Table X)

In analyses of variance including only second and third stage data, corn was found to contain higher Ca concentrations than sorghum in all experiments except Maury-I and Emory-I. Corn also had higher Mg concentrations in all experiments except Collins and higher K concentrations in all except Sequatchie-I. In no case did sorghum contain higher percentages of these three elements than corn.

Phosphorus concentrations were higher in sorghum than corn in the four experiments at Knoxville and the Dexter and Dexter-I experiments. Also, in the Maury-I experiment, sorghum was higher in percent P, but corn was higher in P in the Maury experiment. No significant differences were observed in the other nine experiments.

Stage-Crop Interaction (Tables IV, V, VI, VII, VIII and IX)

Significant stage-crop interactions for both Ca and Mg percentages were observed in all 17 experiments. Calcium and Mg concentrations

TABLE X

MEAN CONCENTRATIONS OF CALCIUM, MAGNESIUM, POTASSIUM, AND PHOSPHORUS IN SORGHUM AND CORN
TISSUE FROM SEVENTEEN EXPERIMENTS (SECOND AND THIRD GROWTH-STAGES)

	Sa	Sa-I	Se	Se-I	Dn	Hn	Ga	Cs	My	My-I	Ey	Ey-I	Dr	Dr-I	Lg	Tt	Hs
<u>Calcium</u>																	
Crop	**	**	**	**	**	**	**	*	**		**		**	**	**	**	**
Sorghum	.28	.31	.47	.47	.46	.50	.34	.40	.38	.45	.48	.51	.33	.29	.26	.52	.46
Corn	.50	.47	.59	.58	.59	.62	.44	.48	.53	.50	.60	.56	.48	.43	.48	.69	.65
<u>Magnesium</u>																	
Crop	**	**	**	**	**	**	**		**	*	**	*	**	**	**	**	**
Sorghum	.24	.30	.35	.38	.20	.20	.32	.31	.26	.29	.29	.30	.30	.31	.31	.18	.22
Corn	.52	.56	.59	.59	.35	.30	.46	.33	.38	.36	.51	.40	.40	.40	.50	.27	.40
<u>Potassium</u>																	
Crop	*	**	**	**	**	**	**	**	**	**	*	**	**	**	**	**	**
Sorghum	1.61	1.52	1.34	1.34	1.68	1.48	1.39	1.43	1.63	1.57	1.42	1.43	1.47	1.53	1.48	1.65	1.61
Corn	1.89	1.89	1.38	1.46	2.12	1.80	2.13	2.32	2.48	2.56	1.77	2.22	2.18	2.20	1.82	2.21	1.92
<u>Phosphorus</u>																	
Crop	*	**	**	**					*	*			*	**			
Sorghum	.28	.28	.32	.31	.31	.37	.34	.37	.28	.34	.33	.38	.31	.35	.29	.38	.34
Corn	.24	.24	.26	.27	.32	.38	.33	.34	.32	.31	.33	.38	.30	.30	.28	.41	.32

Sa = Sequoia.

Cs = Collins.

Tt = Tilsit.

Se = Sequatchie.

My = Maury.

Hs = Hartsells.

Dn = Dickson.

Ey = Emory.

I = Irrigated.

Hn = Huntington.

Dr = Dexter.

* = .01 level of significance.

Ga = Grenada.

Lg = Loring.

** = .001 level of significance.

tended to increase in corn and to decrease in sorghum between first and second stages. Some increase in Ca concentration usually occurred in both crops between the second and third stages, while Mg concentrations either did not change or increased.

In all experiments except Sequoia-I, Sequatchie, Sequatchie-I and Loring, significant effects on K concentrations occurred. In most experiments, K concentrations in first stages were higher in sorghum than in corn, but by second stages had decreased to concentrations lower than those in corn. While K concentrations in both crops decreased throughout the season, with greatest changes occurring between first and second stages, the decreases in corn were more gradual.

In all experiments except Maury and the two at Crossville, stage-crop differences in P concentration occurred. Patterns of change were not always consistent, but sorghum usually was lower in P at first than at second and third stages, while the opposite was true for corn.

Planting-Crop Interaction (Tables IV, V, VI, VII, VIII and IX)

Planting-crop interactions for Ca concentration were observed in the two experiments at Springfield and in the nonirrigated experiments at Jackson, but the types of differences observed were not the same at the two locations. At Springfield, Ca levels in the early plantings of sorghum were higher than in early plantings of corn, but there were no concentration differences between the two crops in the late plantings, although concentrations in both crops were higher in late plantings. At Jackson, however, Ca percentages of both crops

were higher in early plantings than in late plantings, but the highest and lowest concentrations occurred in the early planting of sorghum and the late planting of sorghum, respectively.

In four experiments (both of those at Martin, plus Dickson and Dexter), planting-crop differences in Mg concentrations occurred. In all four of these experiments, Mg concentrations in sorghum were higher in early plantings than in late plantings. In the experiment on Dexter, the Mg concentration in corn was higher in the late planting, but no differences between the two plantings in Mg concentration of corn occurred in the other three experiments.

Differences were observed in K concentration in the Huntington, Dexter-I, Dexter and Hartsells experiments. In the Dexter experiment, concentrations in both crops were lower in the late planting, but the concentration difference between the two plantings was greater in corn than in sorghum. In the other three experiments, the highest K concentration occurred in early planting corn and the lowest in early planting sorghum, while late plantings of both crops had intermediate concentrations.

Phosphorus concentrations were influenced by this interaction in the Sequatchie, Sequatchie-I, Sequoia-I and Maury experiments. In the Maury experiment, P concentration in the late planting of sorghum was lower than in any of the other planting-crop combinations, no other differences being noted. In the three Knoxville experiments, late plantings of sorghum were lower in P, and those of corn were higher in P than the early plantings. The concentration differences between early and late plantings were approximately twice as great in sorghum as in corn.

Soil (Tables XI, XII, XIII, XIV, XV and XVI)

No differences in Ca concentration in plants due to the soil upon which they were grown were observed at Spring Hill or Martin. However, at the other locations, higher concentrations were found in plants grown on Sequatchie, Huntington, Dexter and Tilsit than those grown on the other soil at the respective locations.

In all comparisons except the irrigated comparison of Sequoia and Sequatchie and the irrigated comparison of Maury and Emory, significant differences due to soils were observed in the Mg concentrations. In the nonirrigated comparisons of these soils, Mg levels were higher in plants grown on Sequatchie and Emory. In the other comparisons, plants grown on Dickson, Grenada, Loring and Hartsells contained higher concentrations of Mg than those grown on the other soil at their respective locations.

Differences in K concentration were observed at all locations except Crossville. Potassium levels were higher in plants grown on Sequoia, Dickson, Maury, Dexter and Collins than those grown on the other soil at their respective locations.

No significant P concentration differences due to soil occurred at Springfield or Jackson. Also, no difference was detected in the comparison of the irrigated experiments on Maury and Emory, but higher P levels occurred on Emory in the nonirrigated experiments. In the other comparisons, P percentages in plants were higher on Sequatchie, Collins and Tilsit than on Sequoia, Grenada and Hartsells, respectively.

TABLE XI

MEAN CONCENTRATIONS OF CALCIUM, MAGNESIUM, POTASSIUM AND PHOSPHORUS IN
TISSUE OF GRAIN SORGHUM AND CORN GROWN ON TWO SOILS AT KNOXVILLE

Source	D.F.	Percent Ca		Percent Mg		Percent K		Percent P	
		Sa & Se	Sa-I & Se-I	Sa & Se	Sa-I & Se-I	Sa & Se	Sa-I & Se-I	Sa & Se	Sa-I & Se-I
Soil	1	*	**	**		**	**	*	**
Sequoia		.38	.36	.40	.44	1.90	1.89	.26	.26
Sequatchie		.48	.47	.50	.49	1.50	1.54	.28	.28
Stage-Soil	2								
First Sa		.36	.31	.44	.45	2.19	2.27	.25	.25
Se		.38	.36	.55	.51	1.78	1.84	.28	.28
Second Sa		.37	.36	.37	.39	1.78	1.75	.26	.29
Se		.52	.52	.45	.48	1.38	1.43	.30	.27
Third Sa		.41	.42	.38	.48	1.71	1.66	.26	.28
Se		.54	.53	.49	.49	1.35	1.38	.28	.26
Error	14								
Soil-Planting	1								
Sa Early		.39	.38	.39	.42	1.98	2.06	.26	.26
Late		.37	.35	.41	.45	1.81	1.73	.25	.25
Se Early		.46	.46	.45	.45	1.65	1.74	.29	.29
Late		.50	.48	.55	.54	1.35	1.36	.28	.28
Error	38								
Soil-Crop	1	**	**						
Sa Sorghum		.34	.34	.33	.39	1.89	1.78	.26	.25
Corn		.43	.39	.47	.49	1.91	2.00	.25	.26
Se Sorghum		.49	.48	.48	.48	1.49	1.46	.29	.28
Corn		.47	.46	.51	.51	1.51	1.63	.28	.29
Error	58								
General Mean		.43	.42	.45	.46	1.70	1.72	.27	.27

Sa = Sequoia.

Se = Sequatchie.

I = Irrigated.

* = .01 level of significance.

** = .001 level of significance.

TABLE XII

MEAN CONCENTRATIONS OF CALCIUM, MAGNESIUM, POTASSIUM AND PHOSPHORUS IN
TISSUE OF GRAIN SORGHUM AND CORN GROWN ON TWO SOILS AT SPRINGFIELD

Source	D.F.	Percent Ca	Percent Mg	Percent K	Percent P
		Dn & Hn	Dn & Hn	Dn & Hn	Dn & Hn
Soil	1	*	**	**	
Dickson		.50	.28	2.18	.32
Huntington		.54	.25	1.93	.35
Stage-Soil	2				
First Dn		.44	.30	2.74	.33
Hn		.51	.26	2.51	.30
Second Dn		.45	.26	2.00	.33
Hn		.50	.22	1.73	.38
Third Dn		.61	.29	1.80	.30
Hn		.63	.28	1.55	.36
Error	14				
Soil-Planting	1		**	**	**
Dn Early		.43	.27	2.46	.35
Late		.56	.30	1.90	.28
Hn Early		.46	.18	1.93	.31
Late		.63	.33	1.92	.83
Error	38				
Soil-Crop	1				
Dn Sorghum		.52	.26	2.08	.30
Corn		.48	.30	2.28	.33
Hn Sorghum		.58	.24	1.87	.34
Corn		.52	.27	1.99	.36
Error	58				
General Mean		.52	.27	2.05	.33

Dn - Dickson.

Hn = Huntington.

* = .01 level of significance.

** = .001 level of significance.

TABLE XIII

MEAN CONCENTRATIONS OF CALCIUM, MAGNESIUM, POTASSIUM AND PHOSPHORUS IN
TISSUE OF GRAIN SORGHUM AND CORN GROWN ON TWO SOILS AT MARTIN

Source	D.F.	<u>Percent Ca</u> Ga & Cs	<u>Percent Mg</u> Ga & Cs	<u>Percent K</u> Ga & Cs	<u>Percent P</u> Ga & Cs
Soil	1		**	*	**
Grenada		.39	.41	2.06	.32
Collins		.43	.35	2.25	.36
Stage-Soil	2				
First Ga		.40	.47	2.67	.30
Cs		.41	.42	3.00	.36
Second Ga		.28	.32	1.76	.34
Cs		.36	.28	1.87	.36
Third Ga		.50	.46	1.76	.33
Cs		.52	.36	1.89	.35
Error	14				
Soil-Planting	1				
Ga Early		.39	.45	2.16	.33
Late		.39	.38	1.96	.32
Cs Early		.44	.38	2.21	.36
Late		.42	.33	2.29	.35
Error	38				
Soil-Crop	1		*		
Ga Sorghum		.41	.42	1.80	.32
Corn		.38	.41	2.32	.33
Cs Sorghum		.45	.40	1.98	.36
Corn		.41	.30	2.52	.36
Error	58				
General Mean		.41	.38	2.16	.34

Ga = Grenada.

Cs = Collins.

* = .01 level of significance.

** = .001 level of significance.

TABLE XIV

MEAN CONCENTRATIONS OF CALCIUM, MAGNESIUM, POTASSIUM AND PHOSPHORUS IN
TISSUE OF GRAIN SORGHUM AND CORN GROWN ON TWO SOILS AT SPRING HILL

Source	D.F.	Percent Ca		Percent Mg		Percent K		Percent P	
		My & Ey	My-I & Ey-I	My & Ey	My-I & Ey-I	My & Ey	My-I & Ey-I	My & Ey	My-I & Ey-I
Soil	1			**		**	**		*
Maury		.44	.47	.33	.34	2.39	2.45	.31	.33
Emory		.49	.50	.40	.35	1.92	2.21	.34	.37
Stage-Soil	2								
First My		.42	.47	.36	.38	3.05	3.22	.32	.34
Ey		.38	.43	.40	.36	2.58	2.99	.35	.36
Second My		.36	.40	.28	.30	2.20	2.21	.31	.33
Ey		.46	.43	.36	.30	1.77	1.97	.32	.37
Third My		.54	.54	.36	.35	1.92	1.92	.30	.32
Ey		.62	.63	.45	.40	1.42	1.68	.34	.39
Error	10								
Soil-Planting	1	*				*			
My Early		.42	.42	.33	.35	2.34	2.41	.33	.33
Late		.46	.52	.34	.34	2.44	2.49	.29	.33
Ey Early		.41	.44	.37	.36	2.08	2.27	.36	.37
Late		.56	.56	.43	.34	1.77	2.16	.32	.38
Error	26								
Soil-Crop	1								
My Sorghum		.42	.51	.32	.36	2.18	2.23	.28	.33
Corn		.46	.44	.35	.33	2.60	2.67	.34	.34
Ey Sorghum		.50	.54	.37	.35	1.87	1.98	.32	.36
Corn		.48	.46	.43	.36	1.98	2.45	.35	.39
Error	41								
General Mean		.46	.48	.37	.35	2.16	2.33	.32	.35

My = Maury.

Ey = Emory.

I = Irrigated.

* = .01 level of significance.

** = .001 level of significance.

TABLE XV

MEAN CONCENTRATIONS OF CALCIUM, MAGNESIUM, POTASSIUM AND PHOSPHORUS IN
TISSUE OF GRAIN SORGHUM AND CORN GROWN ON TWO SOILS AT JACKSON

Source	D.F.	Percent Ca Dr & Lg	Percent Mg Dr & Lg	Percent K Dr & Lg	Percent P Dr & Lg
Soil	1	*	**	**	
Dexter		.41	.36	2.11	.30
Loring		.37	.42	1.84	.28
Stage-Soil	2				
First Dr		.43	.38	2.69	.29
Lg		.37	.43	2.22	.29
Second Dr		.32	.31	1.88	.32
Lg		.32	.37	1.70	.30
Third Dr		.49	.39	1.77	.29
Lg		.43	.44	1.60	.26
Error	14				
Soil-Planting	1			**	
Dr Early		.45	.39	2.37	.32
Late		.38	.32	1.85	.27
Lg Early		.43	.44	1.97	.31
Late		.31	.38	1.71	.26
Error	38				
Soil-Crop	1	**			
Dr Sorghum		.42	.36	1.88	.28
Corn		.40	.36	2.35	.31
Lg Sorghum		.34	.39	1.71	.28
Corn		.40	.44	1.97	.29
Error	58				
General Mean		.39	.39	1.98	.29

Dr = Dexter.

Lg = Loring.

* = .01 level of significance.

** = .001 level of significance.

TABLE XVI

MEAN CONCENTRATIONS OF CALCIUM, MAGNESIUM, POTASSIUM AND PHOSPHORUS IN
TISSUE OF GRAIN SORGHUM AND CORN GROWN ON TWO SOILS AT CROSSVILLE

Source	D.F.	Percent Ca Tt & Hs	Percent Mg Tt & Hs	Percent K Tt & Hs	Percent P Tt & Hs
Soil	1	*	**		**
Tilsit		.60	.26	2.26	.40
Hartsells		.55	.34	2.18	.34
Stage-Soil	2				
First Tt		.57	.33	2.93	.40
Hs		.56	.40	2.99	.34
Second Tt		.57	.22	2.01	.38
Hs		.53	.31	1.83	.33
Third Tt		.65	.22	1.85	.41
Hs		.58	.31	1.70	.34
Error	14				
Soil-Planting	1				
Tt Early		.60	.28	2.26	.42
Late		.59	.23	2.27	.38
Hs Early		.56	.36	2.22	.35
Late		.55	.32	2.13	.32
Error	38				
Soil-Crop	1		**	*	*
Tt Sorghum		.61	.25	2.12	.38
Corn		.58	.27	2.41	.41
Hs Sorghum		.54	.30	2.13	.34
Corn		.56	.38	2.22	.34
Error	58				
General Mean		.58	.30	2.22	.37

Tt = Tilsit.

Hs = Hartsells.

* = .01 level of significance.

** = .001 level of significance.

Stage-Soil Interaction (Tables XI, XII, XIII, XIV, XV and XVI)

No significant stage-soil interactions were detected in any of the comparisons for the four elements.

Soil-Planting Interaction (Tables XI, XII, XIII, XIV, XV and XVI)

Only in the comparison of the nonirrigated experiments of Maury and Emory was a difference in Ca concentration observed. There was no difference in the concentrations occurring in the early plantings of the two soils, but the late planting on Emory was higher in Ca than the late planting on Maury.

A significant interaction was observed at Springfield for Mg concentration. The Mg concentration in the early planting on Huntington was little more than half that occurring in the late planting, but there was no significant difference between the concentrations in the two plantings on Dickson.

Potassium levels were influenced by this interaction at Springfield and Jackson, and also in the nonirrigated experiments at Spring Hill. The most noticeable differences were the higher concentrations in early plantings on Dickson, Dexter and Emory soils than in the late plantings of the soils.

At Springfield, a soil-planting effect on P percentages also occurred. The early planting of Dickson and the late planting of Huntington had the higher P concentrations.

Soil-Crop Interaction (Tables XI, XII, XIII, XIV, XV and XVI)

Calcium concentrations were affected by soil-crop interactions at Knoxville and Jackson. At Knoxville, the concentration in sorghum

on Sequoia was lower than the concentration in corn on the same soil while there was no difference between the crop concentrations on Sequatchie. At Jackson, the Ca concentration in sorghum grown on Loring was lower than any of the other soil-crop combinations, but no other differences were observed.

Significant interactions affecting Mg concentrations occurred at Crossville and Jackson. At Crossville, the corn grown on Hartsells was higher in Mg than sorghum grown on the same soil, while there was no difference between the Mg concentrations of the two crops grown on Tilsit. At Martin, however, the corn grown on Collins was lower in Mg concentration than the other three soil-crop combinations, none of which was significantly different from the others.

Differences in K concentrations were observed at Crossville. Concentrations in sorghum were the same on both soils, but those in corn were higher on Tilsit than on Hartsells.

Phosphorus concentration differences also were observed at Crossville. The P concentrations of the two crops were not different when grown on Hartsells, but the concentration in corn was higher than that in sorghum when grown on Tilsit.

Irrigation (Tables XVII, XVIII and XIX)

The nonirrigated treatment on Dexter was higher in percent Ca than the irrigated treatment. On Emory, nonirrigated plants were higher in Mg and lower in K than those which were irrigated. Irrigation resulted in higher P levels in the plants on both Dexter and Emory.

TABLE XVII

MEAN CONCENTRATIONS OF CALCIUM, MAGNESIUM, POTASSIUM AND PHOSPHORUS IN TISSUE
OF NONIRRIGATED AND IRRIGATED GRAIN SORGHUM AND CORN AT KNOXVILLE

Source	D.F.	Percent Ca		Percent Mg		Percent K		Percent P	
		Sa & Sa-I	Se & Se-I	Sa & Sa-I	Se & Se-I	Sa & Sa-I	Se & Se-I	Sa & Sa-I	Se & Se-I
Irrigation	1								
Not irrigated		.38	.48	.40	.50	1.90	1.50	.26	.28
Irrigated		.36	.47	.44	.49	1.89	1.54	.26	.28
Stage-Irrigation	2								
First Not irr.		.36	.38	.44	.55	2.19	1.78	.25	.28
Irr.		.31	.36	.45	.51	2.27	1.84	.25	.28
Second Not irr.		.37	.52	.37	.45	1.78	1.38	.26	.30
Irr.		.36	.52	.39	.48	1.75	1.43	.26	.30
Third Not irr.		.41	.54	.38	.49	1.71	1.35	.26	.28
Irr.		.42	.53	.48	.49	1.66	1.38	.26	.28
Error	14								
Irr.-Planting	1								
Not irr. Early		.39	.46	.39	.45	1.98	1.65	.26	.29
Late		.37	.50	.41	.55	1.81	1.35	.25	.28
Irr. Early		.38	.46	.42	.45	2.05	1.74	.26	.29
Late		.35	.48	.45	.54	1.73	1.36	.25	.28
Error	38								
Irr.-Crop	1								
Not irr. Sorghum		.34	.49	.33	.48	1.89	1.49	.26	.29
Corn		.43	.47	.47	.51	1.91	1.51	.25	.28

TABLE XVII (continued)

Source	D.F.	Percent Ca		Percent Mg		Percent K		Percent P	
		Sa & Sa-I	Se & Se-I	Sa & Sa-I	Se & Se-I	Sa & Sa-I	Se & Se-I	Sa & Sa-I	Se & Se-I
Irr.									
Sorghum		.34	.48	.39	.48	1.78	1.46	.25	.28
Corn		.39	.46	.49	.51	2.00	1.63	.26	.29
Error	58								
General Mean		.37	.48	.42	.50	1.90	1.52	.26	.28

Sa = Sequoia.

Se = Sequatchie.

I = Irrigated.

TABLE XVIII

MEAN CONCENTRATIONS OF CALCIUM, MAGNESIUM, POTASSIUM AND PHOSPHORUS IN TISSUE
OF NONIRRIGATED AND IRRIGATED GRAIN SORGHUM AND CORN AT SPRING HILL.

Source	D.F.	Percent Ca		Percent Mg		Percent K		Percent P	
		My & My-I	Ey & Ey-I	My & My-I	Ey & Ey-I	My & My-I	Ey & Ey-I	My & My-I	Ey & Ey-I
Irrigation Not irrigated Irrigated	1	.44	.49	.33	*	2.39	1.92	.31	*
		.47	.50	.34	.35	2.45	2.21	.33	.34
Stage-Irrigation First Not irr. Irr. Second Not irr. Irr. Third Not irr. Irr.	2	.42	.38	.36	.40	3.05	2.58	.32	.35
		.47	.43	.38	.36	3.22	2.99	.34	.36
		.36	.46	.28	.36	2.20	1.77	.31	.32
		.40	.43	.30	.30	2.21	1.97	.33	.37
Error	10	.54	.62	.36	.45	1.92	1.42	.30	.34
		.54	.63	.35	.40	1.92	1.68	.32	.39
Irr.-Planting Not irr. Early Late Irr. Early Late	1	.42	.41	.33	.37	2.34	2.08	.33	.36
		.46	.56	.34	.43	2.44	1.77	.29	.32
		.42	.44	.35	.36	2.41	2.27	.33	.37
		.52	.56	.34	.34	2.49	2.16	.33	.38
Error	26								
Irr.-Crop Not irr. Sorghum Corn	1	*		*			*		
		.42	.50	.32	.37	2.18	1.87	.28	.32
		.46	.48	.35	.43	2.60	1.98	.34	.35

TABLE XVIII (continued)

Source	D.F.	Percent Ca		Percent Mg		Percent K		Percent P	
		My & My-I	Ey & Ey-I	My & My-I	Ey & Ey-I	My & My-I	Ey & Ey-I	My & My-I	Ey & Ey-I
Irr.		.51	.54	.36	.35	2.23	1.98	.33	.36
Sorghum		.44	.46	.33	.36	2.67	2.45	.34	.39
Corn									
Error	41								
General Mean		.46	.49	.40	.38	2.42	2.07	.32	.36

My = Maury.

Ey = Emory.

* = .01 level of significance.

** = .001 level of significance.

TABLE XIX

MEAN CONCENTRATIONS OF CALCIUM, MAGNESIUM, POTASSIUM AND PHOSPHORUS
IN TISSUE OF NONIRRIGATED AND IRRIGATED GRAIN
SORGHUM AND CORN AT JACKSON

Source	D.F.	Percent Ca Dr & Dr-I	Percent Mg Dr & Dr-I	Percent K Dr & Dr-I	Percent P Dr & Dr-I
Irrigation	1	**			*
Not irrigated		.41	.36	2.11	.30
Irrigated		.37	.37	2.17	.32
Stage-Irrigation	2				
First Not irr.		.43	.38	2.69	.29
Irr.		.38	.39	2.78	.30
Second Not irr.		.32	.31	1.88	.32
Irr.		.26	.32	1.95	.34
Third Not irr.		.49	.39	1.77	.29
Irr.		.46	.40	1.78	.31
Error	9				
Irr.-Planting	1		*	**	*
Not irr. Early		.45	.39	2.37	.32
Late		.38	.32	1.85	.27
Irr. Early		.39	.37	2.23	.33
Late		.34	.36	2.10	.31
Error	20				
Irr.-Crop	1				
Not irr. Sorghum		.42	.36	1.88	.28
Corn		.40	.36	2.35	.31
Irr. Sorghum		.37	.37	1.96	.32
Corn		.36	.36	2.38	.32
Error	43				
General Mean		.39	.36	2.14	.31

Dr = Dexter.

Lg = Loring.

* = .01 level of significance.

** = .001 level of significance.

Stage-Irrigation Interaction (Tables XVII, XVIII and XIX)

No significant stage-irrigation differences occurred on any of the five soils.

Irrigation-Planting Interaction (Tables XVII, XVIII and XIX)

In the cases of Mg, K and P concentrations, irrigation-planting interactions occurred on Dexter. The concentrations of all three elements were lower in the nonirrigated late plantings than in the other irrigation-planting combinations.

Irrigation-Crop Interaction (Tables XVII, XVIII and XIX)

Differences in Ca, Mg and K concentrations due to this interaction occurred at Spring Hill. On Maury, irrigation resulted in higher percentages of both Ca and Mg in sorghum but not in corn. On Emory, the K concentration in irrigated corn was higher than those in the other three irrigation-crop combinations.

No irrigation-crop differences in P concentration were noted.

CHAPTER V

DISCUSSION

The significant stage differences in the concentrations of Ca, Mg and K which occurred in a majority of the experiments probably were overshadowed in importance by the stage-crop interactions.

The observed stage-crop interactions for Ca, Mg and K concentrations brought up a question concerning the sampling procedure used. Both Gallaher (30) and Ashburn (1) sampled corn in the same manner used for sorghum in this study and found the same trends in corn that were observed in sorghum in this study. These workers sampled the whole plant of corn at the "thinning" stage (38 days after planting) and only leaf tissue on subsequent sampling dates. Both workers observed large reductions in K, Ca and Mg percentages between the "thinning" stage and the "waist high" sampling date.

Perhaps the sampling procedure used for sorghum in this study and for corn in Gallaher's (30) and Ashburn's (1) studies accounted for the higher Ca, Mg and K levels observed in the plants at younger stages of growth than later in the season. Lanning and Garabedian (54) reported that ash and Ca were considerably higher in leaf sheaths than in other plant parts, the Ca levels in sheaths being two and one-half times those in leaf blades.

Further support to the above assumption was contributed by Jacquinet (46) who reported that K levels decreased and Ca and Mg levels increased as sorghum plants aged, while various workers (10,15, 24,27,48,60,64,80) have reported K decreases and Ca and Mg increases

in corn similar to those found in this study. (Appendix G, Figure 5; Appendix H, Figure 6; Appendix I, Figure 7.)

The observed stage-crop interactions, and the resulting inconclusiveness of crop comparisons when all three growth stages were considered, led to comparisons of the two crops considering only second and third stages. The latter comparisons revealed that Ca, Mg and K levels in leaf tissue tended to be higher in corn than in sorghum. This probably indicated a difference in the ability of the two crops to accumulate these elements or in the time of uptake and/or translocation of these elements from leaves to other plant parts. The results for P concentration did not show a conclusive crop difference.

The higher K concentrations in nine of the early plantings (Appendix I, Figure 7) possibly can be explained by the higher soil moisture which normally would have existed. This is also a probable explanation for the higher P concentrations which existed in seven of the early plantings (Appendix J, Figure 8). Most Ca and Mg concentration differences could be explained by the dilution effect. Certain exceptions will be discussed on a location basis.

The late planting on Huntington was higher in P than the early planting. This situation, which did not occur in any other experiment (Appendix J, Figure 8), could not be explained readily. Perhaps uptake was great in the early planting, but for some reason translocation to the ear may have occurred early. Such an occurrence might have contributed to the exceptionally high yield of corn grain (17,005 kg/ha) in the early planting (Appendix K, Table XX).

At every location except Crossville, crops grown on soils with higher exchangeable K contained higher K percentages. At Crossville,

Tilsit was higher in K than Hartsells, but it also was exceptionally high in Ca content and, perhaps as a result of competition between these two elements, no difference in K concentrations in plants grown on the two soils at this location was observed.

Apparently, the difference between two soils at a location in their K content was more influential than differences in their content of Ca or Mg in determining the comparative levels of Ca or Mg within plants grown on the two soils. This seemed to hold true except when the difference between the Ca or Mg contents of the two soils was quite large. The observed relationships among these three elements, as affected by the soils upon which the plants were grown, will be discussed on a location basis.

Most of the soil-planting differences related to K concentration could be attributed to the seasonal variations in the moisture supplies within the two soils at a location.

A moisture difference, and the resulting dilution effect, also could explain the higher Ca concentration of the late planting on Maury. However, the reason for the soil-planting interaction for Mg concentration at Springfield (low in early planting on Huntington) could not be explained by this phenomenon.

No significant irrigation effects or interactions of irrigation treatment with other factors occurred at Knoxville, probably due to the greater amount of precipitation at this location than at the other two locations where irrigation treatments were involved. Knoxville received 43.1 cm of rainfall during the June through August sampling period, as compared to 22.4 cm at Spring Hill and 22.8 cm at Jackson.

Moreover, 47 percent and 34 percent of these totals fell on August 19 at Spring Hill and Jackson, respectively (as dying tropical storm "Camille" passed through the state), perhaps too late to have any meaningful effect on uptake. Knoxville received only 17 percent of its total June through August rainfall from this storm (U. S. Department of Commerce, 88).

At the Jackson and Spring Hill locations, no differences occurred as a result of irrigation which could not be explained by the dilution or valence effect in the cases of Ca, Mg and K concentrations or by the effect of higher moisture levels on diffusion in the case of P.

On Dexter, however, the nonirrigated late plantings were low in Mg, K and P. These irrigation-planting interactions were most likely related to an inadequate water supply for proper dissolution and/or movement of the nutrients within the soil, resulting in decreased uptake.

The reasons for the observed irrigation-crop interactions were not readily apparent.

Knoxville

The soils at this location represented some of the extreme values in available nutrient content. The lower K content of Sequatchie was in agreement with the findings of Bell (9) who reported that "bottomland" or low terrace soils often contained less K than upland soils, perhaps due to both the amount and type of clay present.

The higher K concentrations in plants grown on Sequoia than in those grown on Sequatchie could be explained by the difference in the

K content of the two soils. On Sequoia, there should have been a more plentiful supply of this element during the early part of the growing season, when the rate of K uptake was greatest, than during the corresponding period on Sequatchie.

The lower Ca and Mg concentrations in plants grown on Sequoia, could not be explained by the soil test values, since this soil also was higher than Sequatchie in these two elements. However, bearing in mind the earlier uptake of K in large amounts and the K-Ca-Mg relationships reported by various workers (5,15,16,29,30,48,65,70,80,89, 96), such results are reconcilable.

The comparatively low K content of the Sequatchie soil resulted in the two experiments on this soil having the lowest general means for plant K concentrations of the 17 experiments. Since low K levels in plants have been associated with lodging (12,15,19,84), the very low K averages in the late plantings of corn on this soil (1.30 and 1.38 percent in nonirrigated and irrigated experiments, respectively) were thought to have had some effect on the severe lodging which resulted in the very low corn grain yields of 2,187 kg/ha on Sequatchie and 3,293 kg/ha on Sequatchie-I (Appendix K, Table XX). The (Ca+Mg)/K ratio (as calculated from general means) was quite high for the experiments on Sequatchie, being 0.645 as compared to 0.416 for those experiments on Sequoia.

The general mean for P concentration for everything grown on Sequoia (0.26 percent) was the lowest general mean which occurred in this series of experiments. This was attributed to the low P content of this soil which was only about three-fourths that of the next higher soil.

Springfield

Differences in plant concentrations of Ca, Mg and K due to soils at this location directly reflected the differences between the two soils in their contents of these three elements. In each case, higher soil content of a particular element resulted in higher plant concentration.

The early planting on Huntington (Appendix H, Figure 6) differed from that on Dickson in that Mg level averaged only 0.18 percent (about half as high as in most other experiments). The experiment on Huntington also was the only one with lower P in the early plantings (Appendix J, Figure 8). The high yields of corn grain and those of corn silage in the early planting on this soil were the highest obtained in the 17 experiments. These results indicated that a considerable dilution of Mg and P within the plants could have occurred as dry matter yields increased.

Martin

No differences due to planting date occurred on Collins, while differences between plantings in their concentrations of Mg and K were observed on Grenada. This was probably due to the higher moisture-supplying capacity of the former, a "bottom soil," as compared to that of the latter, which was influenced by a pan at a depth of approximately 60 cm.

The higher K and P concentrations in plants grown on Collins could be explained by higher contents of these elements in the Collins soil than in Grenada. The lower Mg percentages occurring on Collins probably were because of the inverse relationship of Mg and K.

High P levels are commonly associated with early maturity (12,19), and such an effect was observed at this location. The very high P content of Collins soil resulted in higher P concentrations in plants grown on this soil than on Grenada. Consistent with the findings of Baker et al. (3) and Black (12), the P concentration differences were more pronounced at the first stage than later at the second and third stages. These early high P levels resulted in the early-planted-corn on Collins reaching the silking stage two weeks earlier than that on Grenada, although both were planted on the same date.

Spring Hill

The higher K content of the Maury soil resulted in higher K concentrations in plants grown on this soil than in those grown on Emory. In the comparison of the nonirrigated experiments on the two soils, the higher Mg concentrations in plants grown on Emory, which was the lower of the soils in Mg content, were attributed to the inverse K-Mg relationship. The higher P levels which occurred on the Emory soil (in the irrigated comparisons) probably were due to the higher available P content of this soil.

The higher Mg and lower K in plants grown in the nonirrigated experiment on Emory, as compared to those in the irrigated experiment, were attributed to a more concentrated soil solution (less moisture) in the former, which should have resulted in less uptake of the monovalent K. The lower P in plants grown in the nonirrigated experiment on this soil probably resulted from the adverse effect of low soil moisture on the diffusion of P, and thus on the supply to plant roots.

Jackson

The reason for all early plantings at Jackson being higher in K and P probably was higher moisture levels during the early part of the growing season. The reasons for all early plantings being higher in Ca and for all except that on Dexter-I being higher in Mg as well, were not readily apparent. However, the combinations of moisture and temperature to which the two plantings were subjected, and the effects of these factors on both uptake and dry matter production could have been important.

The higher Ca and K concentrations and the lower Mg concentration of plants grown on Dexter than in those grown on Loring probably were due to the comparative amounts of these three elements in the two soils. Dexter had higher contents of both Ca and K than Loring, but differed little from Loring in its Mg content. The lower Mg concentrations which occurred on Dexter probably were due to the inverse relationship between Mg and the other two elements.

The higher P concentrations which resulted from irrigation on the Dexter soil probably were due to enhancement of diffusion of this element, while the lower Ca concentrations were attributed to the valence effect.

Crossville

The higher P concentrations in plants of the early plantings at Crossville were attributed to the greater moisture supply during the May through July period (38.3 cm of precipitation) than during the June through August growth period of the late planting (29.8 cm of precipitation) (88).

The higher Ca and P concentrations which occurred in plants grown on Tilsit than in those grown on Hartsells were attributed to the higher contents of these elements in the Tilsit soil. The lower Mg concentrations were explained by the lower Mg content of this soil.

In agreement with Beasley (7), the Cumberland Plateau soils were lower in Mg content than those of the Highland Rim and the Central Basin. The Tilsit soil had the highest Ca content and the lowest Mg content of the twelve soils used in this study. Perhaps the relative content of these two elements in this soil was due, in large part, to the highly calcitic local lime supply. These extremes of Ca and Mg content were reflected in the tissue concentrations which occurred on this soil (Appendix G, Figure 5 and Appendix H, Figure 6). The general mean for Ca concentration (0.60 percent) was the highest observed, and that for Mg concentration (0.26 percent) was one of the lowest.

Phosphorus concentrations which occurred on Tilsit were quite high (Appendix J, Figure 8). The general mean of 0.40 percent was the highest observed. Perhaps the pH of this soil, which was higher than that of any other in both horizons, contributed to a greater concentration of P.

Other factors possibly could have contributed to the high P levels on Tilsit. Rainfall was adequate at this location, and temperatures averaged several degrees lower than at other locations (88), perhaps resulting in higher "effective moisture" levels in the soil because of reduced evaporation rates. The relatively high P concentrations which occurred on both soils at this location indicated that such could have been the case.

CHAPTER VI

SUMMARY

Separate experiments were conducted on each of twelve soils, two at each of six locations in Tennessee. On five of the soils (at three locations) irrigated experiments also were conducted, making a total of 17 experiments. Within each experiment, early and late plantings of corn and grain sorghum were grown.

Tissue samples were collected from each corn and grain sorghum plot at three stages of crop growth. The samples were wet-ashed by the nitric-perchloric method, and analyzed for Ca, Mg, K and P concentrations on a Technicon AutoAnalyzer.

Available Ca, Mg, K and P were extracted with a double acid solution, 0.025N H_2SO_4 and 0.05N HCl, and analyses were run on an AutoAnalyzer. Soil pH values also were determined.

Significant stage-crop interactions for Ca and Mg concentrations occurred in all experiments. In most cases stage-crop differences for K concentrations also were observed. In general, K concentrations in both crops decreased throughout the season, with greater increases occurring in grain sorghum than in corn. Calcium and Mg concentrations in corn usually increased throughout the season, while those in grain sorghum usually decreased and then either stabilized or increased.

The stage-crop interactions were considered to have resulted from the sampling procedures employed for the two crops. Corn was sampled by collecting only leaf blade tissue at all three growth stages. However, since young grain sorghum plants contain such a high proportion

of leaf, sorghum was sampled by collecting the entire above ground portion of plants at the first growth stage and leaf blade tissue only at the later stages. The higher Ca, Mg and K concentrations observed in the first stage samples of grain sorghum probably resulted from higher concentrations of these elements in plant parts other than leaf blades, since plant parts differ in composition at all stages of growth.

It was believed that crop differences were confounded with the stage-crop effects resulting from the aforementioned sampling peculiarity. When these effects were eliminated by dropping the first stage data (sampling procedures for the two crops differed at this stage), corn was found to contain higher concentrations of Ca, Mg and K than grain sorghum. Analyses for other observations included data from all three growth stages. In general, higher K concentrations tended to occur in early plantings, perhaps due to higher moisture levels than those to which late plantings were subjected. Early plantings also tended to contain higher P percentages, perhaps for the same reason.

Plants grown on the soil at a location which contained more exchangeable K tended to exhibit higher K concentrations. In most cases, differences between two soils at a location in their K content appeared to exert more influence than differences in their Ca or Mg content on determining the comparative levels of Ca or Mg within plants grown on the two soils. This may have occurred because of the earlier uptake of K and the inverse relationship between K and both Ca and Mg within the plants.

Few differences in nutrient concentration resulted from irrigation. Most of those differences observed could be attributed to increased K uptake, decreased Ca and Mg uptake, and increased diffusion of P as soil moisture levels were increased.

The conclusions supported by this portion of a comprehensive summer annuals adaptation study were:

1. Corn leaf tissue contains higher concentrations of Ca, Mg and K than leaf tissue of grain sorghum of the same chronological age.
2. In most cases, the difference between the K contents of two soils plays a more important role in determining the comparative levels of each of the elements K, Ca and Mg within plants grown on the soils than differences between the Ca or Mg contents of the soils.

LITERATURE CITED

LITERATURE CITED

1. Ashburn, E. L. 1970. The yield and uptake of nutrients by selected corn genotypes as influenced by nitrogen fertilization. Ph.D. Dissertation. University of Tennessee, Knoxville.
2. Baker, D. E., G. W. Gorsline, C. B. Smith, W. I. Thomas, W. E. Grube, and J. L. Ragland. 1964. Technique for rapid analyses of corn leaves for eleven elements. Agron. J. 56:133-136.
3. Baker, D. E., A. E. Jarrell, L. E. Marshall, and W. I. Thomas. 1970. Phosphorus uptake from soils by corn hybrids selected for high and low phosphorus accumulation. Agron. J. 62:103-106.
4. Barr, A. J., and J. H. Goodnight. 1970. Statistical analysis system (SAS). North Carolina State University, Raleigh.
5. Bartholomew, R. P., and G. Janssen. 1929. Luxury consumption of potassium by plants and its significance. J. Amer. Soc. of Agron. 21:751-765.
6. Bear, F. E. 1964. Chemistry of the soil. 2nd Ed. Reinhold Publishing Corporation, New York. 515 pp.
7. Beasley, A. B. 1950. Magnesium levels of Tennessee soils in relation to crop growth. M.S. Thesis. University of Tennessee, Knoxville.
8. Beeson, K. C. 1941. The mineral composition of crops with particular reference to the soils in which they were grown. USDA Misc. Pub. 369.
9. Bell, F. F. 1956. Characteristics and productive capacity of Grenada and related soils in Western Tennessee. Ph.D. Dissertation. Iowa State College, Ames. pp. 50-51.
10. Benne, E. J., E. Linden, J. D. Grier, and K. Spike. 1964. Composition of corn plants at different stages of growth and per acre accumulation of essential nutrients. Mich. Quar. Bull. 47:69-85.
11. Bennett, O. L., B. D. Doss, D. A. Ashley, V. J. Kilmer, and E. C. Richardson. 1964. Effects of soil moisture regime on yield, nutrient content, and evapotranspiration for three annual forage species. Agron. J. 56:195-198.
12. Black, C. A. 1968. Soil-plant relationships. 2nd Ed. John Wiley and Sons, Inc., New York. 792 pp.
13. Blaney, H. F., and W. D. Criddle. 1962. Determining consumptive use and irrigation water requirements. USDA Agr. Res. Ser. Tech. Bull. 1275.

14. Bonds, E., and J. C. O'Kelley. 1969. Effect of Ca and Sr on Zea mays seedling primary root growth. Am. J. Botany. 56: 271-274.
15. Boswell, F. C. 1956. The effect of soil potassium levels on yield, lodging and mineral composition of corn. M.S. Thesis. University of Tennessee, Knoxville.
16. Bromfield, A. R. 1969. Uptake of phosphorus and other nutrients by maize in Western Nigeria. Exp. Agric. 5:91-100.
17. Carmona-Ruiz, G. 1963. K uptake and distribution in corn plants as influenced by rates of K and N fertilization. M.S. Thesis. University of Tennessee, Knoxville.
18. Cochran, W. G., and G. M. Cox. 1957. Experimental designs. 2nd Ed. John Wiley and Sons, Inc., New York. 611 pp.
19. Cunard, A. C. 1967. Maize agronomy, part 2. Nutrients and nutrient uptake. World Crops. 19(3):24-28.
20. Doggett, H. 1970. Sorghum. Longmans, Green and Co. Ltd., Great Britain. 403 pp.
21. Doss, B. D., O. L. Bennet, and D. A. Ashley. 1962. Evapotranspiration by irrigated corn. Agron. J. 54:497-498.
22. Doss, B. D., C. C. King, and R. M. Patterson. 1970. Yield components and water use by silage corn with irrigation, plastic mulch, nitrogen fertilization, and plant spacing. Agron. J. 62:541-543.
23. Elder, J. A., T. R. Love, W. H. Proffitt, C. C. Cox, H. D. Waller, and J. F. Campbell. 1961. Soil Survey of Loudon County, Tennessee. U. S. Government Printing Office, Washington.
24. Ellis, B. G., C. J. Krauss, and F. W. Smith. 1956. Nutrient content of corn as related to fertilizer application and soil fertility. Agron. J. 48:455-459.
25. Estrada, J., and G. A. Cummings. 1968. Effects of lime and phosphorus treatments in specific horizons of acid soil on growth and chemical content of corn (Zea mays L.). Agron. J. 60:447-450.
26. Flowers, R. L. 1964. Soil Survey of Fayette County, Tennessee. U. S. Government Printing Office, Washington.
27. Foy, C. D., and S. A. Barber. 1958. Magnesium absorption and utilization by two inbred lines of corn. Soil Sci. Soc. Am. Proc. 22:57-62.

28. Franklin, R. E., Jr., and E. O. McLean. 1963. Effect of electrolyte concentration on Donnan systems and the resulting uptake of cations by plants. *Soil Sci. Soc. Am. Proc.* 27:137-141.
29. Freeman, C. E. 1965. The effect of potassium fertility levels on the uptake and utilization of potassium, calcium, and magnesium by corn inbreds and hybrids. M.S. Thesis, University of Tennessee, Knoxville.
30. Gallaher, R. N. 1969. The uptake and utilization of K by corn inbreds and hybrids. M.S. Thesis. University of Tennessee, Knoxville.
31. Genter, C. F., and G. D. Jones. 1970. Planting date and growing season effects and interactions on growth and yield of maize. *Agron. J.* 62:760-761.
32. Genter, C. F., G. D. Jones, and M. T. Carter. 1970. Dry matter accumulation and depletion in leaves, stems, and ears of maturing maize. *Agron. J.* 62:535-537.
33. Gieseking, J. E., H. J. Snider, and C. A. Getz. 1935. Destruction of organic matter in plants by the use of nitric and perchloric acids. *Ind. and Eng. Chem. Anal. Ed.* 7:185-186.
34. Graves, C. R. 1968. 1968 performance of field crops varieties. *Tennessee Agric. Exp. Sta. Bull.* 450.
35. Gregory, Charles F. 1963. Yield and chemical composition of corn and oats grown at different root temperatures in soil and nutrient solutions at different phosphorus levels. M.S. Thesis. University of Tennessee, Knoxville.
36. Griffin, G. F., and R. E. Lorton. 1970. Phosphorus availability on two soils as determined by several methods. *Agron. J.* 62:336-341.
37. Guenther, W. C. 1964. Analysis of variance. Prentice-Hall, Inc., Englewood Cliffs, N. J. 199 pp.
38. Hanna, W. J., and T. B. Hutcheson, Jr. 1968. Soil-plant relationships. pp. 141-162. In L. B. Nelson (Ed.), Changing patterns in fertilizer use. *Soil Sci. Soc. of Am., Madison.*
39. Hanway, J. J. 1962. Corn growth and composition in relation to soil fertility: II. Uptake of N, P, and K and their distribution in different plant parts during the growing season. *Agron. J.* 54:217-222.
40. Hanway, J. J. 1966. How a corn plant develops. Special Report No. 48, Iowa State University Cooperative Extension Service, 17 pp.

41. Harmon, A. B., Jr., E. Lusk, J. Overton, J. H. Elder, Jr., and L. D. Williams. 1959. Soil survey of Maury County, Tennessee. U. S. Government Printing Office, Washington.
42. Haunold, E., O. Danneberg, and K. Kaindl. 1965. Potassium-42 uptake by maize roots. In Isotopes and radiation in soil-plant nutrition studies. Proc. Symp. FAO/IAEA, Ankara. pp. 311-320.
43. Hipp, B. W., and G. W. Thomas. 1968. Method for predicting potassium uptake by grain sorghum. Agron. J. 60:467-469.
44. Holt, R. F., and D. R. Timmons. 1968. Influence of precipitation soil water, and plant population interactions on corn grain yields. Agron. J. 60:379-381.
45. Holt, R. F., and C. A. Van Doren. 1961. Water utilization by field corn in western Minnesota. Agron. J. 53:43-45.
46. Jacquinet, L. 1964. Contribution to the study of the mineral nutrition of congossane sorghum (Sorghum vulgare var. guineense). (Abstr.) Soils and Fert. 28:289.
47. Jenne, E. A., H. F. Rhodes, C. H. Yien, and O. W. Howe. 1958. Change in nutrient element accumulation by corn with depletion of soil moisture. Agron. J. 50:71-74.
48. Jones, J. B., Jr. 1969. Physiological bases for plant analysis. In Proceedings from a symposium on plant analysis. Intern. Min. and Chem. Corp. pp. 10-23.
49. Ketcheson, J. W. 1957. Some effects of soil temperature on phosphorus requirements of young corn plants in the greenhouse. Can. J. Soil Sci. 37:41-47.
50. Key, J. L., and L. T. Kurtz. 1960. Response of corn and soybeans to magnesium fertilizers. Agron. J. 52:300.
51. Koch, J. T., E. R. Orchard, and M. E. Sumner. 1970. Leaf composition and yield response of corn in relation to quantity-intensity parameters for potassium. Soil Sci. Soc. Am. Proc. 34:94-98.
52. Kramer, James C. 1959. Crop yield and chemical composition as affected by zinc fertilization at different soil pH and phosphorus levels. M.S. Thesis. University of Tennessee, Knoxville.
53. Lane, H. C., and H. J. Walker. 1961. Mineral accumulation and distribution in grain sorghum. Texas Agric. Exp. Sta. MP-533.
54. Lanning, F. C., and T. Garabedian. 1963. Distribution of ash, calcium, iron, and silica in the tissues of young sorghum plants. Trans. Kans. Acad. Sci. 66:443-448.

55. Lavy, T. L., and J. D. Eastin. 1969. Effect of soil depth and plant age on 32 phosphorus uptake by corn and sorghum. *Agron. J.* 61(5):677-680.
56. Lawton, K. 1945. The influence of soil aeration on the growth and absorption of nutrients by corn plants. *Soil Sci. Soc. Am. Proc.* 10:263-268.
57. LeClerc, E. L., W. H. and A. G. Clark. 1962. Field plot technique. 2nd Ed. Burgess Pub. Co., Minneapolis. 373 pp.
58. Longo, G. 1968. Water availability, transpiration coefficients and yield of grain sorghum and grain maize. Four year's trials. (Abstr.) *Field Crop Abstr.* 22:369.
59. Longwell, T. J., W. L. Parks, and M. E. Springer. 1963. Moisture characteristics of Tennessee soils. *Tennessee Agric. Exp. Sta. Bull.* 367. 46 pp.
60. MacKay, D. C., and J. S. Leefe. 1962. Optimum leaf levels of nitrogen, phosphorus, and potassium in sweet corn and in snap beans. *Can. J. Plant Sci.* 42:238-246.
61. McKinney, D. E. 1968. The effects of several climatic factors and several nitrogen and moisture levels on the yield and evapotranspiration of corn. M.S. Thesis. University of Tennessee, Knoxville.
62. Macy, P. 1936. The quantitative mineral nutrient requirements of plants. *Plant Physiol.* 11:749-764.
63. Mahtab, S. K. 1969. Plant uptake vs. diffusion of phosphorus as related to texture, applied P, and water content of soil. Ph.D. Dissertation. Texas A & M University, College Station. (Dis. Abstr. 30(11):4873B).
64. Melsted, S. W., H. L. Motto, and T. R. Peck. 1969. Critical plant nutrient composition values useful for interpreting plant analysis data. *Agron. J.* 61:17-20.
65. Minar, J., and Z. Lastuvka. 1969. The dynamics of the accumulation of nitrogen, phosphorus and potassium in maize and peas in the first growth phases at constant mineral nutrition. *Biol. Plant.* 11:149-157.
66. Murdock, J. T., and L. E. Engelbert. 1958. The importance of sub-soil phosphorus to corn. *Soil Sci. Soc. Am. Proc.* 22:53-57.
67. Nakayama, F. S., and C. H. M. Van Bavel. 1963. Root activity distribution pattern of sorghum and soil moisture conditions. *Agron. J.* 55:271-274.

68. National Cooperative Soil Survey, U. S. A. 1964. Hartsells Series.
69. National Cooperative Soil Survey, U. S. A. 1970. Tilsit Series.
70. Nelson, L. B. 1956. The mineral nutrition of corn as related to its growth and culture. pp. 321-375. In Advances in agronomy VIII, Academic Press, Inc., New York.
71. Oonmuang, C. 1970. Some chemical and morphological characteristics of twelve Tennessee soils. M.S. Thesis. University of Tennessee, Knoxville.
72. Overton, J. R., I. B. Epley, J. A. Blanton, D. D. Walker, and R. Wildermuth. 1959. Soil survey of Lawrence County, Tennessee. U.S. Government Printing Office, Washington.
73. Page, N. R. 1965. Procedures used by state soil-testing laboratories in the southern region of the United States. So. Co-op. Ser. Bull. 102.
74. Parks, W. L., and J. H. Lillard. 1963. Efficient utilization of water by crops. Assn. of Sq. Agric. Workers Inc. Proc. 60:59-60.
75. Peck, T. R., W. M. Walker, and L. V. Boone. 1969. Relationship between corn yield and leaf levels of ten elements. Agron. J. 61:299-301.
76. Powell, R. D. 1968. The yield, growth and chemical composition of corn as influenced by hybrids and high rates of nitrogen, phosphorus, and potassium fertilizers. Ph.D. Dissertation. Iowa State University, Ames. (Dis. Abstr. 29(4):1238B).
77. Proffitt, W. H., T. R. Love, E. T. Lampley, O. W. Rice, and B. B. Hinton. 1963. Soil survey of Hardin County, Tennessee. U.S. Government Printing Office, Washington.
78. Puech, J., C. Maertens, S. Fioramonti, J. R. Marty, and M. Courau. 1968. Comparison between the uptake and the dry matter production of some irrigated crops. (In French, English summary). Ann. Agron. 19:365-377.
79. Rhoades, H. F., and L. B. Nelson. 1955. Growing 100-bushel corn with irrigation. pp. 394-400. In Water. USDA Yearbook of Agriculture. U.S. Government Printing Office, Washington.
80. Sayre, J. D. 1955. Mineral nutrition of corn. In George F. Sprague (ed.), Corn and corn improvement. Agron. 5:293-314. Academic Press, New York.

81. Steckel, J. E., and R. L. Flannery. 1965. Automatic determination of phosphorus, potassium, calcium, and magnesium in wet digestion solutions of plant tissue. Proceedings of the Technicon Symposium: Automation in Analytical Chemistry, New York, N. Y.
82. Stone, J. F., R. H. Griffin, II, and B. J. Ott. 1964. Irrigation studies of grain sorghum in the Oklahoma Panhandle 1958 to 1962. Oklahoma State University Exp. Bull. B-619.
83. Taylor, S. A., and C. S. Slater. 1955. When to irrigate and how much water to apply. pp. 372-376. In Water. USDA Yearbook of Agriculture. U.S. Government Printing Office, Washington.
84. Tisdale, S. L., and W. L. Nelson. 1966. Soil fertility and fertilizers. 2nd Ed. The Macmillan Co., Collier-Macmillan Limited, London. 694 pp.
85. True, J. C., J. F. Campbell, E. P. Davis, O. G. Sprouse, Jr., J. F. Brasfield, and I. D. Howell. 1964. Soil survey of Williamson County, Tennessee. U.S. Government Printing Office, Washington.
86. Tucker, B. B., and W. F. Bennett. 1968. Fertilizer use on grain sorghum. pp. 189-220. In Nelson, L. B. (ed.), Changing patterns in fertilizer use. Soil Sci. Soc. Am., Inc., Madison.
87. Tyner, E. H. 1946. The relation of corn yields on leaf nitrogen, phosphorus, and potassium content. Soil Sci. Soc. Am. Proc. 11:317-323.
88. U. S. Department of Commerce. 1969. Climatological Data (Tennessee). Volume 74.
89. Viets, F. G., Jr., C. E. Nelson, and C. L. Crawford. 1954. The relationship among corn yields, leaf composition and fertilizers applied. Soil Sci. Soc. Am. Proc. 18:297-301.
90. Voss, R. E., J. J. Hanway, and L. C. Dumenil. Relationship between grain yield and leaf N, P, and K concentrations for corn (Zea mays L.) and the factors that influence this relationship. Agron. J. 62:726-728.
91. Voss, R. E., J. J. Hanway, and W. A. Fuller. 1970. Influence of soil management, and climatic factors on the yield response by corn (Zea mays L.) to N, P, and K fertilizer. Agron. J. 62:736-740.
92. Webster, J. E., J. B. Sieglinger, and F. Davies. 1945. Chemical composition of sorghum forage at various stages of vegetative growth. Proc. Okla. Acad. Sci. 26:36-39.

93. Weeks, M. E., E. N. Fergus, and P. E. Karraker. 1940. The composition of the corn plant grown under field conditions in relation to the soil and its treatment. Soil Sci. Soc. Am. Proc. 5:140-146.
94. Whiteman, P. C. 1963. Studies of drought resistance of sorghum species. J. Austral. Inst. Agric. Sci., 29:245-246.
95. Wilson, J. H. 1968. Water relations of maize. Part 1. Effects of severe soil moisture stress imposed at different stages of growth on grain yields of maize. Rhod. J. Agric. Res., 6:103-105.
96. Wittels, H., and L. F. Seatz. 1953. Effect of potash fertilization on yield, stalk breakage and mineral composition of corn. Soil Sci. Soc. Am. Proc. 17:369-371.

APPENDICES

APPENDIX A

Procedure for the aluminum heating block method of wet ashing of plant tissue for Ca, Mg, K, and P analysis.

1. Weigh 0.5000 gm of each oven dry, ground sample into a 50 ml tube containing two small glass beads.
2. Add three ml of concentrated nitric acid to each sample, and place a small glass funnel in the mouth of each tube to act as a condenser. Allow the samples to pre-digest at room temperature overnight in the aluminum heating block.
3. Place the heating block on hotplate, heat to 150°C , and digest at this temperature for one hour. Allow samples to cool to room temperature.
4. Add two ml of 60 to 70 percent perchloric acid to each tube through the funnel, and digest at 235°C for two hours or until the liquid in each sample is clear. Remove funnels and allow to cool to room temperature.
5. Add one ml of hydrochloric acid, and digest at 150°C for 15 to 20 minutes.
6. Transfer the cooled samples to 100 ml volumetric flasks and bring to volume with distilled water.
7. Shake flasks to mix contents, and let stand overnight before analysis on the AutoAnalyzer.

APPENDIX B

I. Simultaneous determination of Ca, K, Mg, and P concentrations by Autoanalysis.

A. The instrumentation for the Technicon AutoAnalyzer employed consisted of 14 separate modules as follows: small automatic sampler equipped with a liquid wash system; meters equipped with continuous tubular flow cells; one dual-channel flame photometer; two two-pen recorders; two voltage stabilizers; one time-delay coil; and two range expanders.

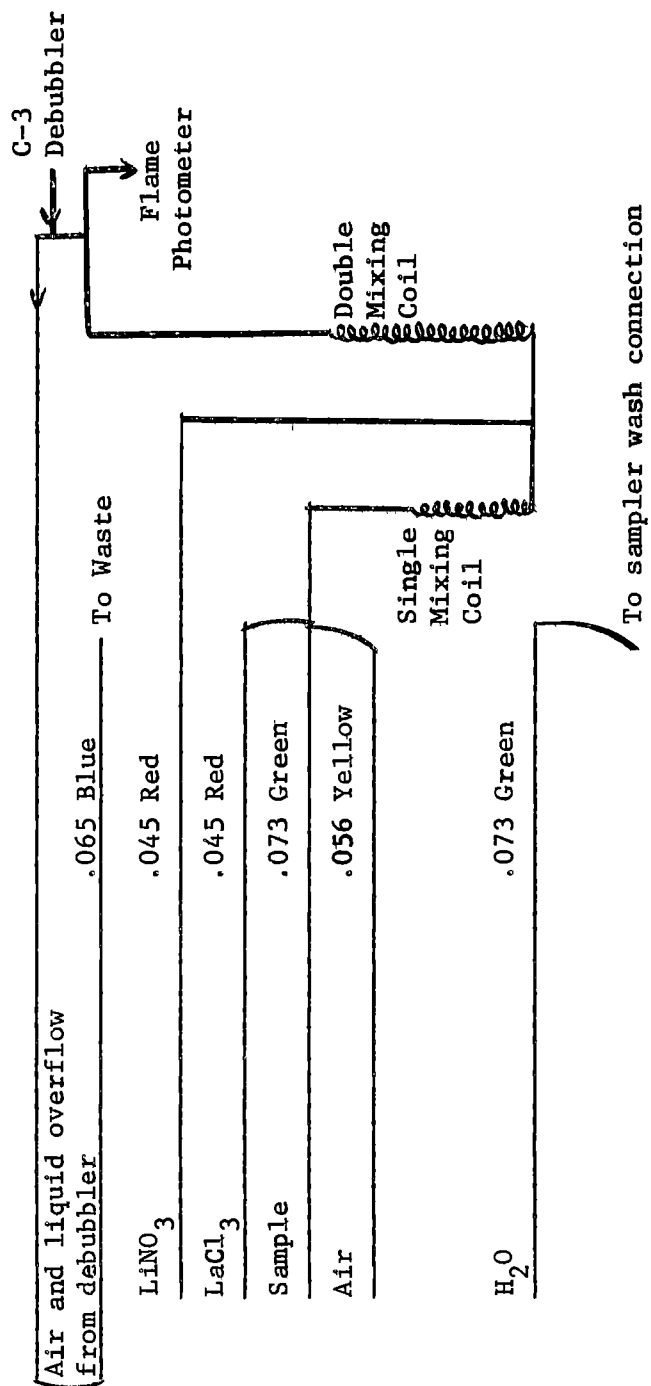
B. Calcium and potassium determinations were made by using the Technicon III dual-channel flame photometer. Lithium nitrate (.525 g in one liter of water) is used as an internal standard and lanthanum chloride (five gm in one liter of water) is used to increase the calcium flame response. The proportioning-pump manifold designed to supply the correct volume of sample, LiNO_3 and LaCl_3 to the dual-channel flame photometer is shown in Appendix C.

C. Magnesium concentrations were determined in a colorimeter by a modified lake procedure in which $\text{Mg}(\text{OH})_2$ is precipitated in an alkaline solution and Magnesium Blue dye (.02 percent) is adsorbed on the $\text{Mg}(\text{OH})_2$ in the presence of a detergent (.05 percent Brij 35 in water) and a suspending material (two gm EGTA and two gm polyvinyl alcohol in one liter H_2O). The proportioning-pump manifold designed to supply the correct volumes of sample, PVA-EGTA, Magnesium Blue, and

NaOH (2N) to the flow cell of the colorimeter is shown in Appendix D. The colorimeter used in this procedure was equipped with a 630 m μ filter.

D. Phosphorus determinations were made using a colorimeter. The sample is first diluted with .05N HCl. The diluted sample stream is then joined by a stream of ammonium vanadate (25 gm ammonium molybdate in 400 ml of H₂O mixed with an equal volume of a solution of 1.25 gm ammonium metavanadate in 300 ml of water with a few drops of concentrated NH₄OH and 250 ml of concentrated HNO₃). The stream then passes through the colorimeter, equipped with a 420 m μ filter, where phosphorus is determined as PO₄⁻³. The proportioning-pump manifold designed to supply the correct volumes of sample, HCl, and ammonium vanadate to the colorimeter is shown in Appendix E.

APPENDIX C



COLOR	I.D.	CC/MIN.
Red	.045	0.80
Yellow	.056	1.20
Blue	.065	1.60
Green	.073	2.00

Figure 2. Calcium and potassium manifold.

APPENDIX D

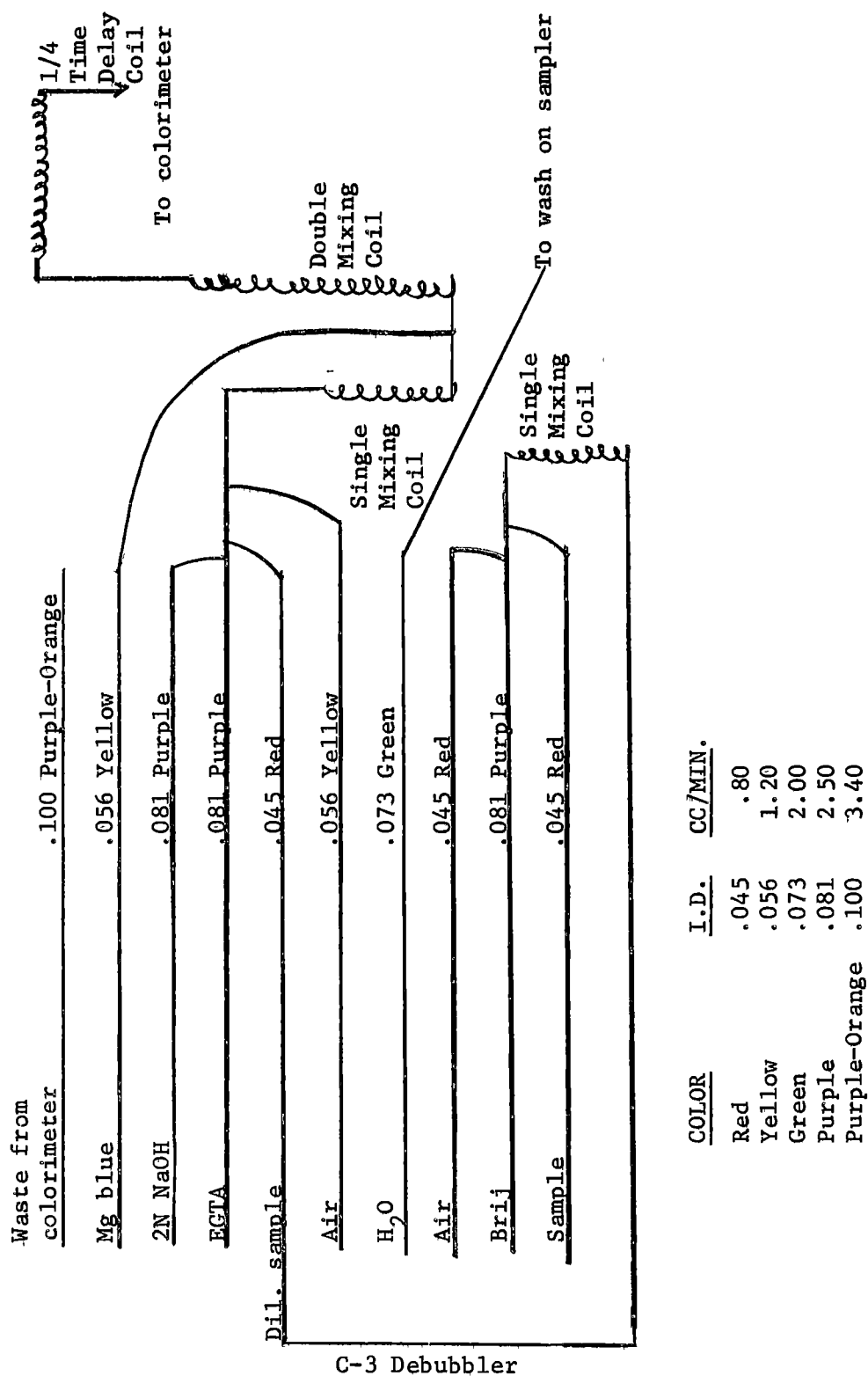


Figure 3. Magnesium manifold.

APPENDIX E

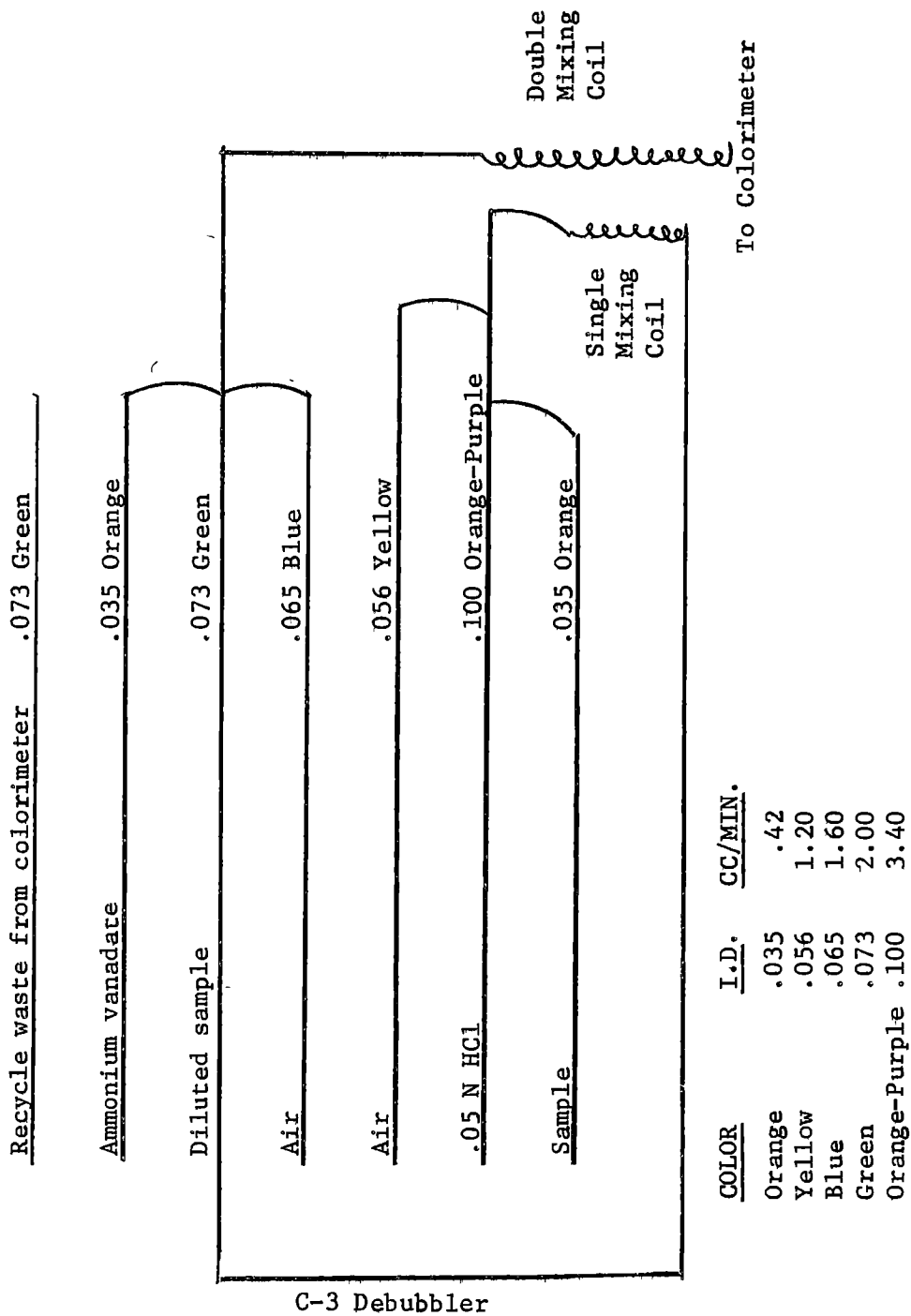


Figure 4. Phosphorus manifold.

APPENDIX F

I. Preparation of extracting reagent (0.05N HCl and 0.025N H₂SO₄) for "North Carolina" extraction method.

A. Add separately 73 ml of concentrated HCl and 12 ml of concentrated H₂SO₄ to approximately ten liters of distilled water.

B. Dilute to 18 liters with distilled water, and mix thoroughly.

II. Extraction of exchangeable ions by "North Carolina" method.

A. Weigh 5.0 g of soil into a container, and add 20 ml of the above extracting solution.

B. Shake the soil extracting solution mixture (1:4 soil-solution ratio) in a mechanical shaker for five minutes, and filter immediately through retentive filter paper into an appropriate container.

APPENDIX G

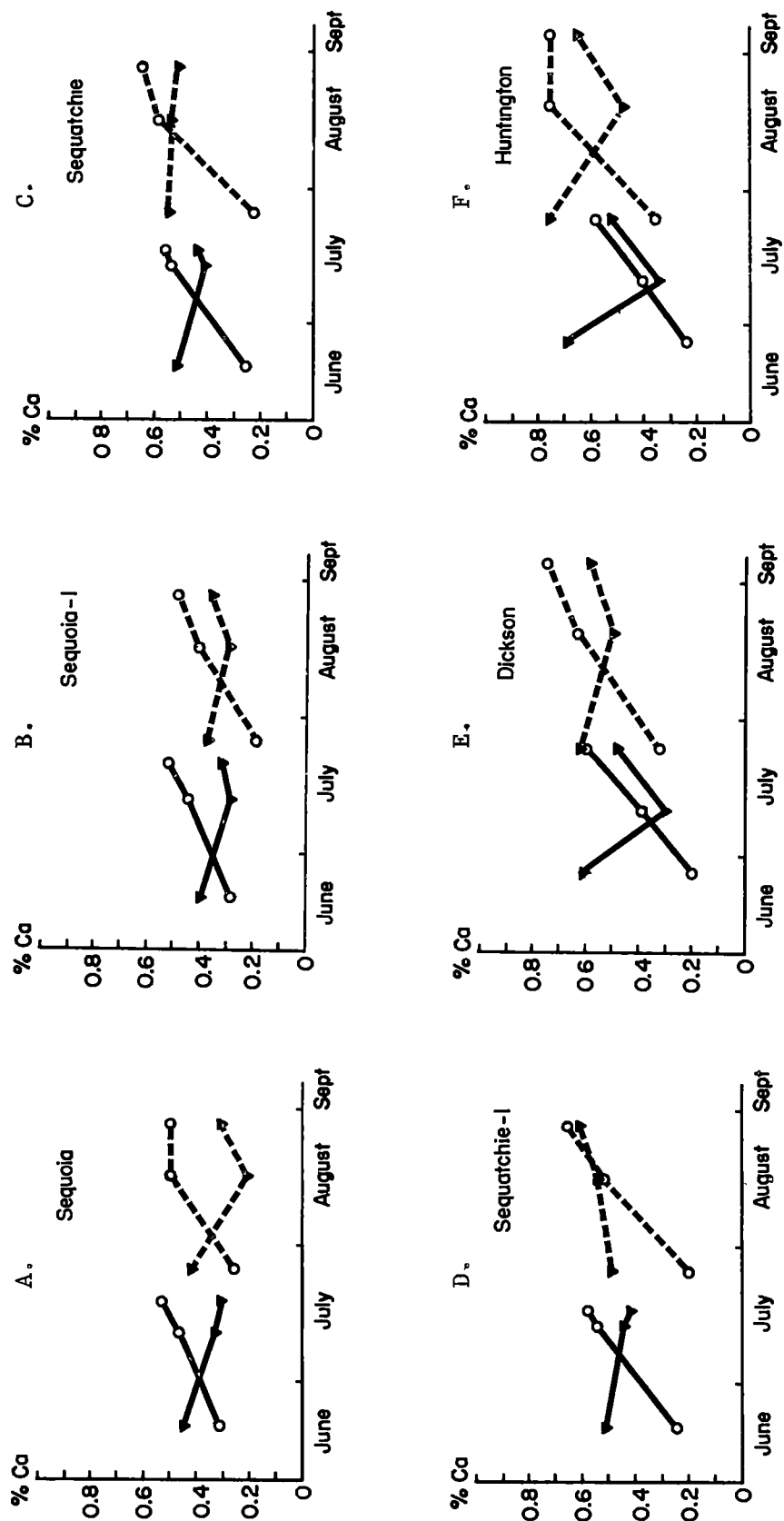


Figure 5. Calcium concentration in leaf tissue of early (—) and late (---) plantings of corn (o) and sorghum (▽).

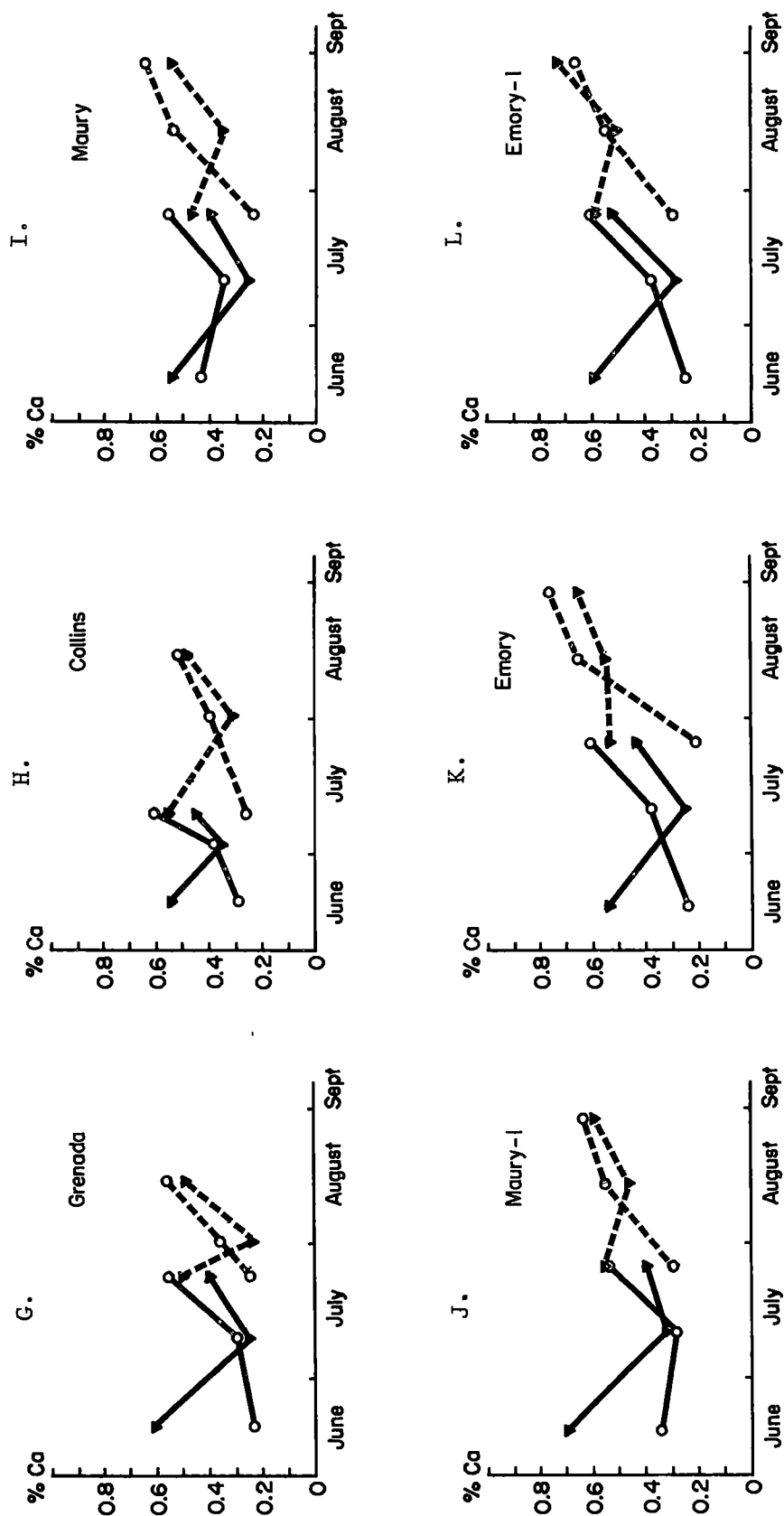


Figure 5. (continued)

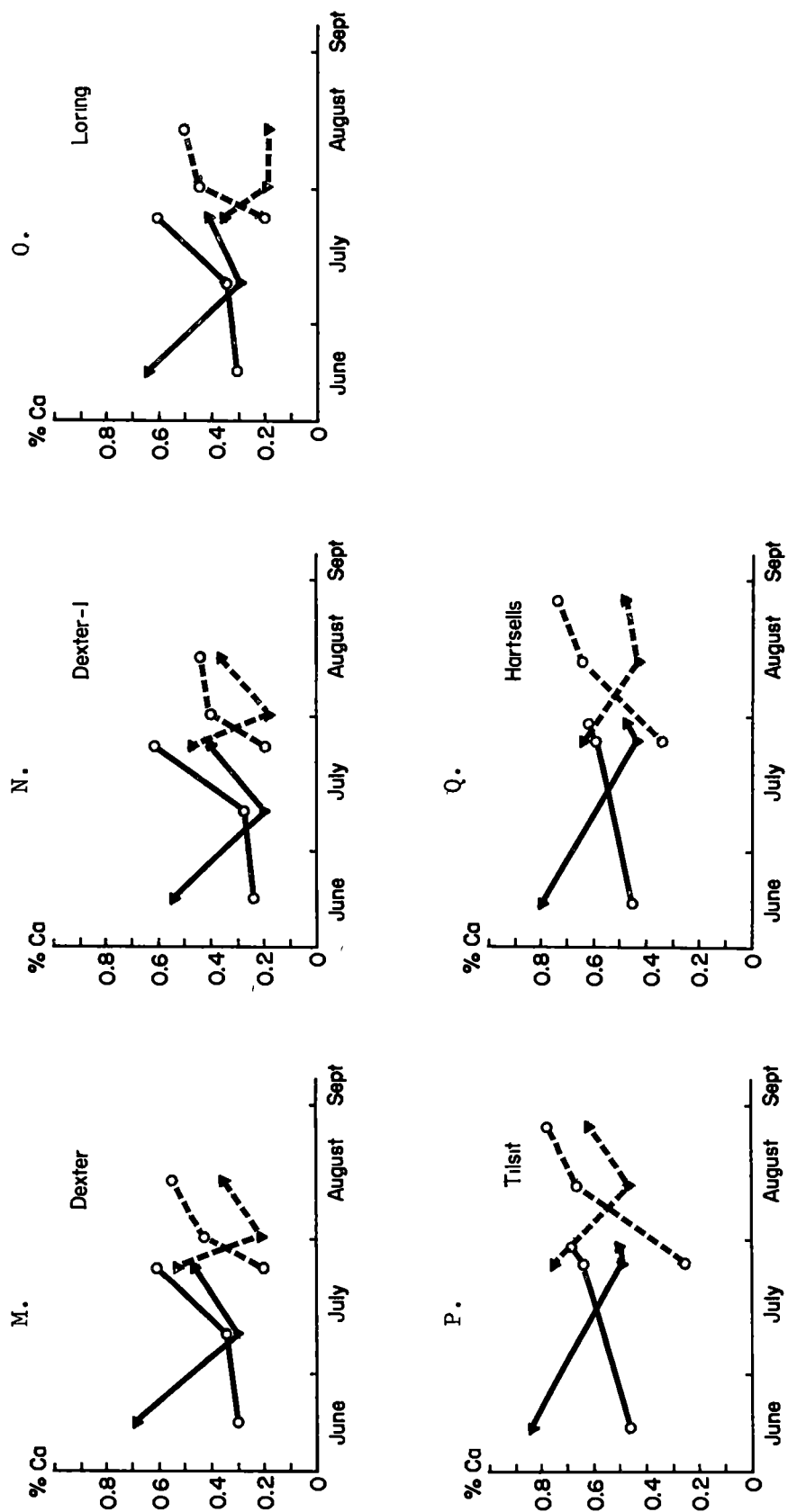


Figure 5. (continued)

APPENDIX H

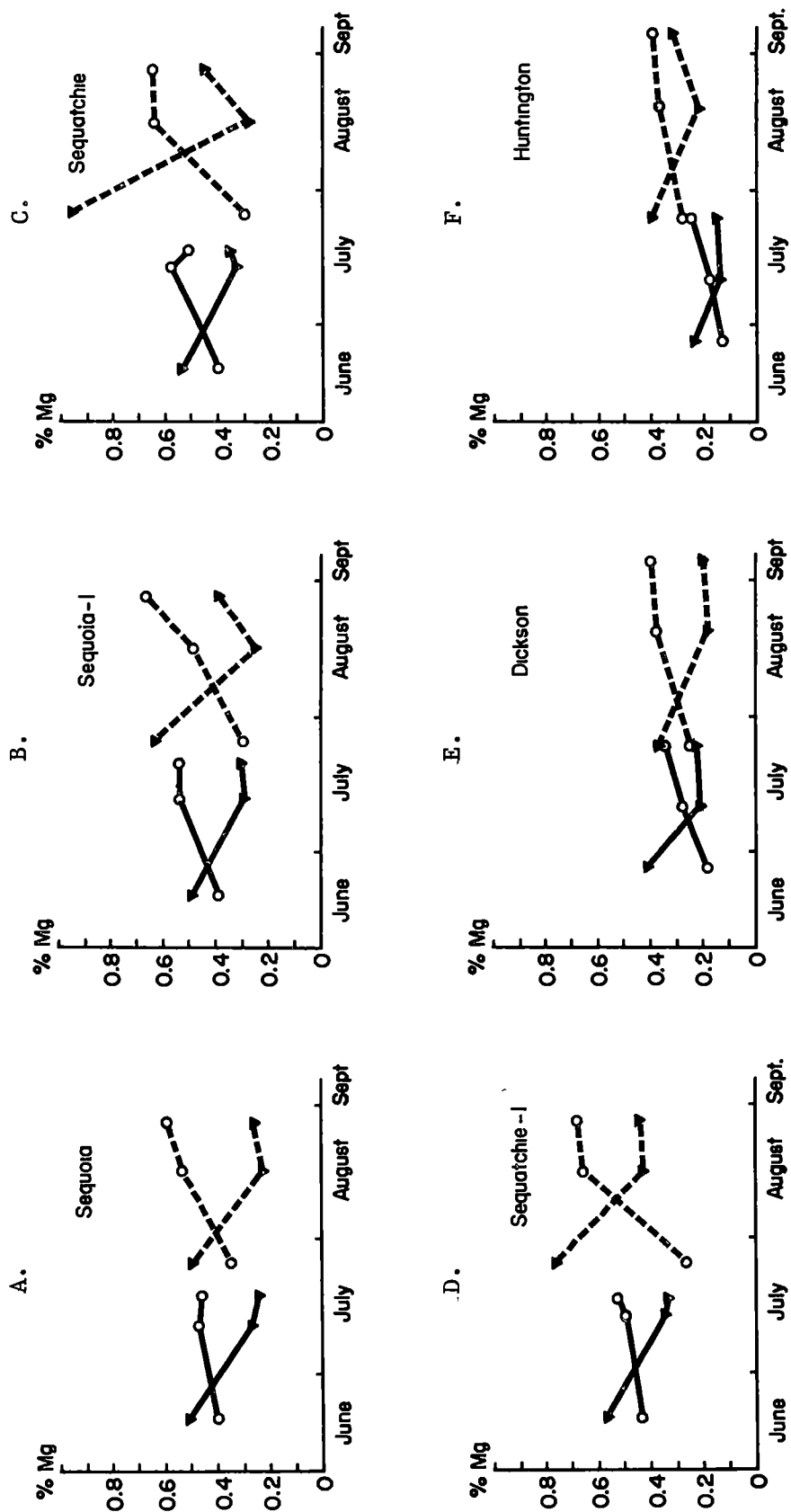


Figure 6. Magnesium concentration in leaf tissue of early (—) and late (---) plantings of corn (o) and sorghum (▽).

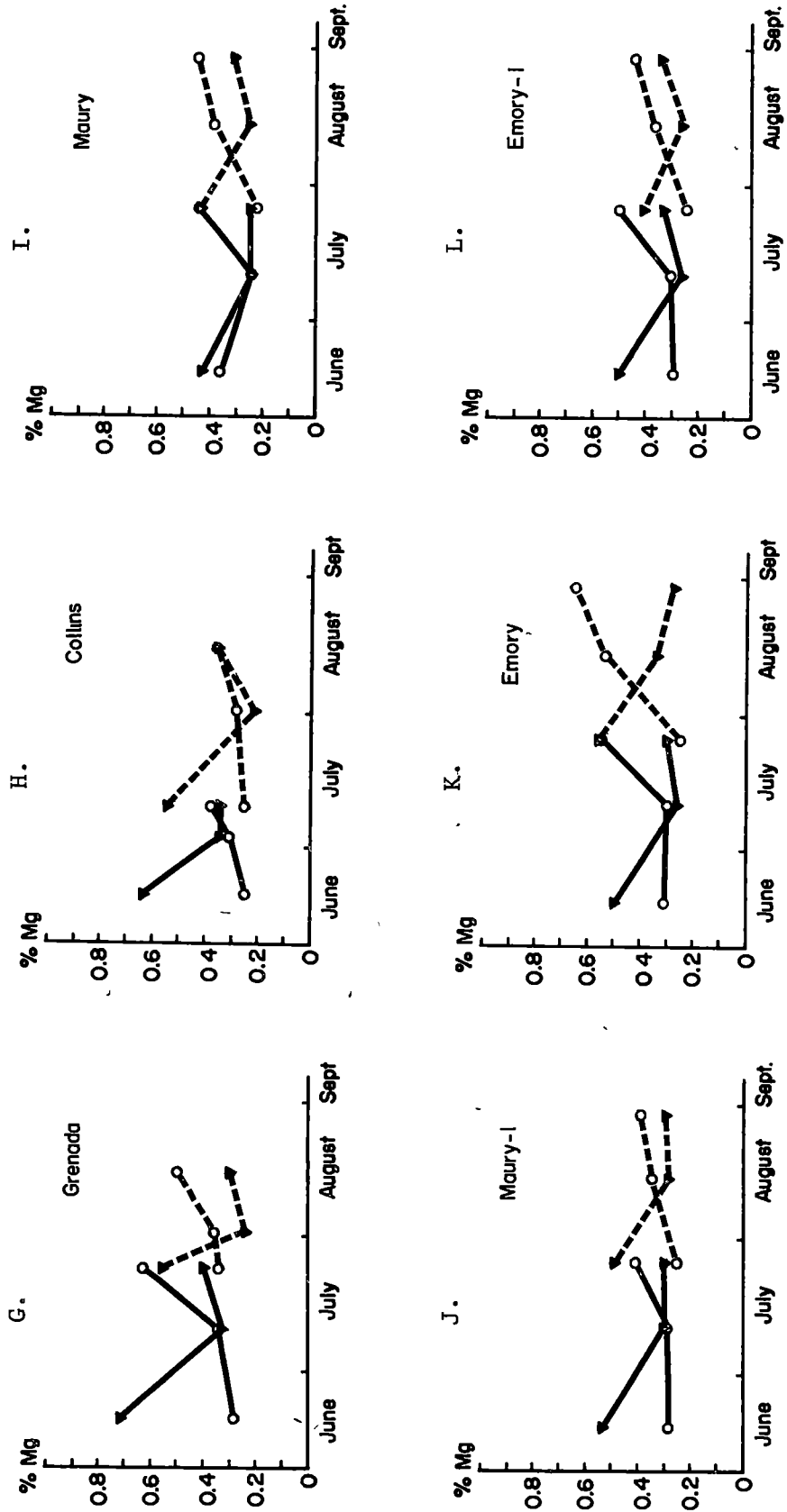


Figure 6. (continued)

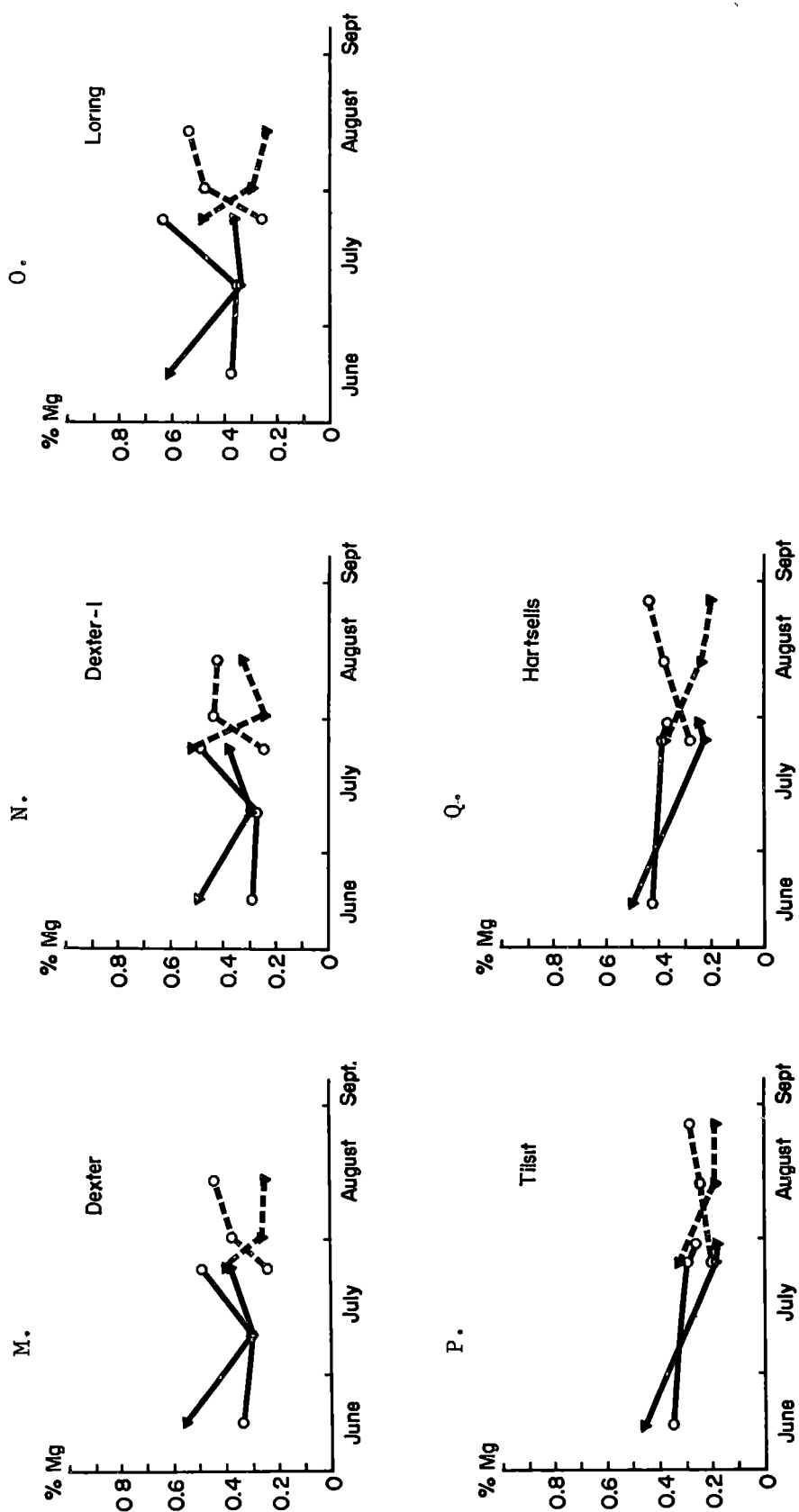


Figure 6. (continued)

APPENDIX I

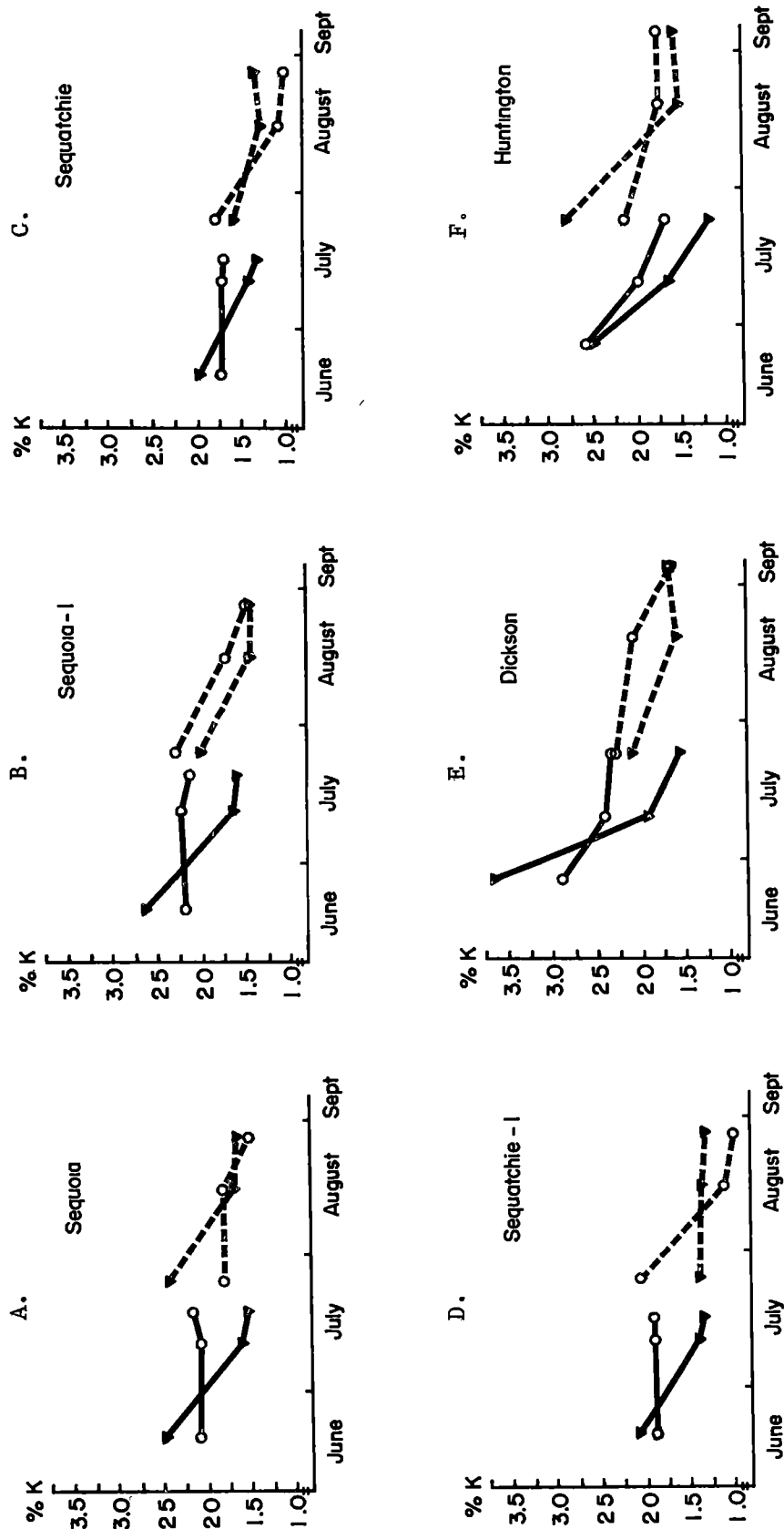


Figure 7. Potassium concentration in leaf tissue of early (—) and late (---) plantings of corn (o) and sorghum (▼).

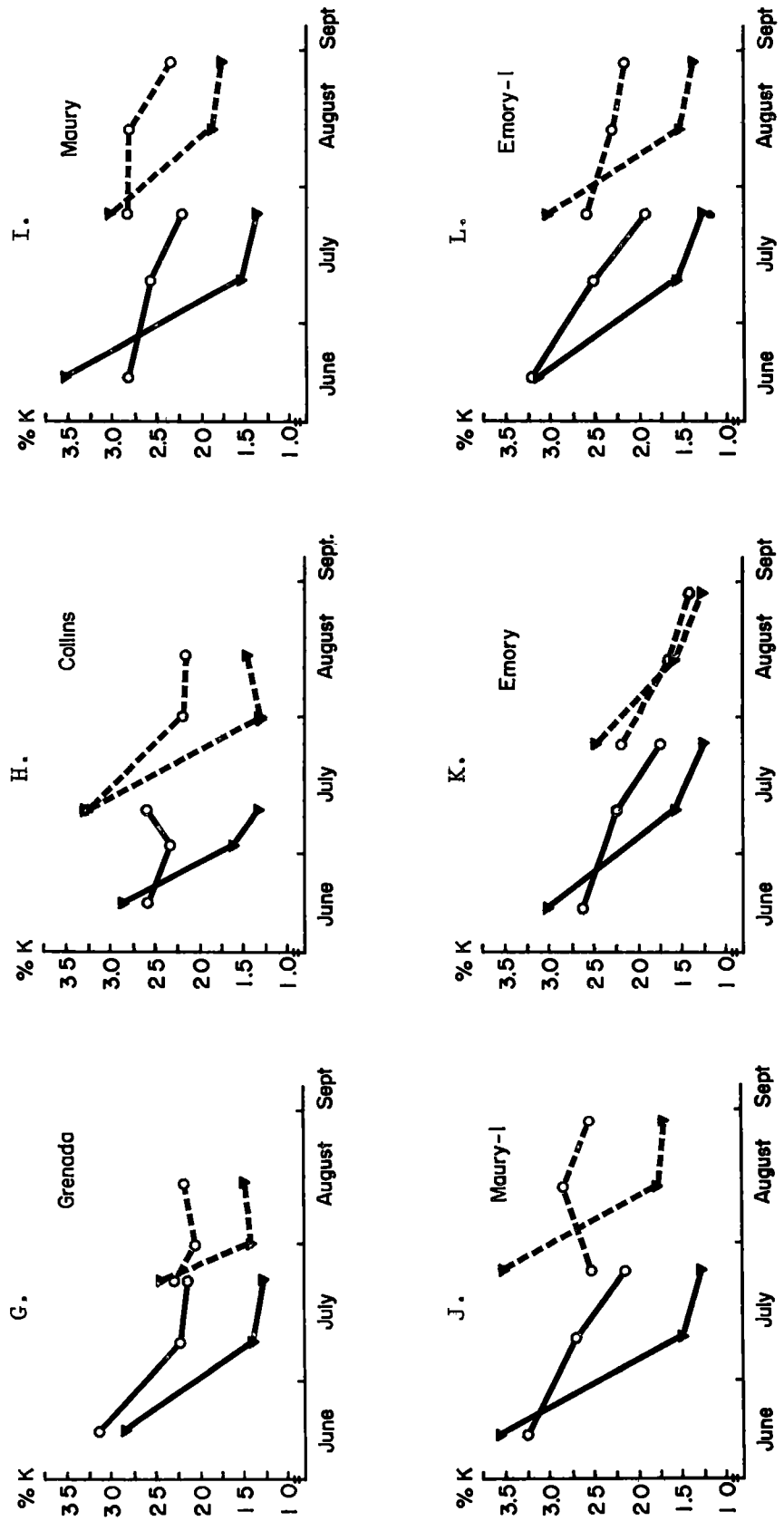


Figure 7. (continued)

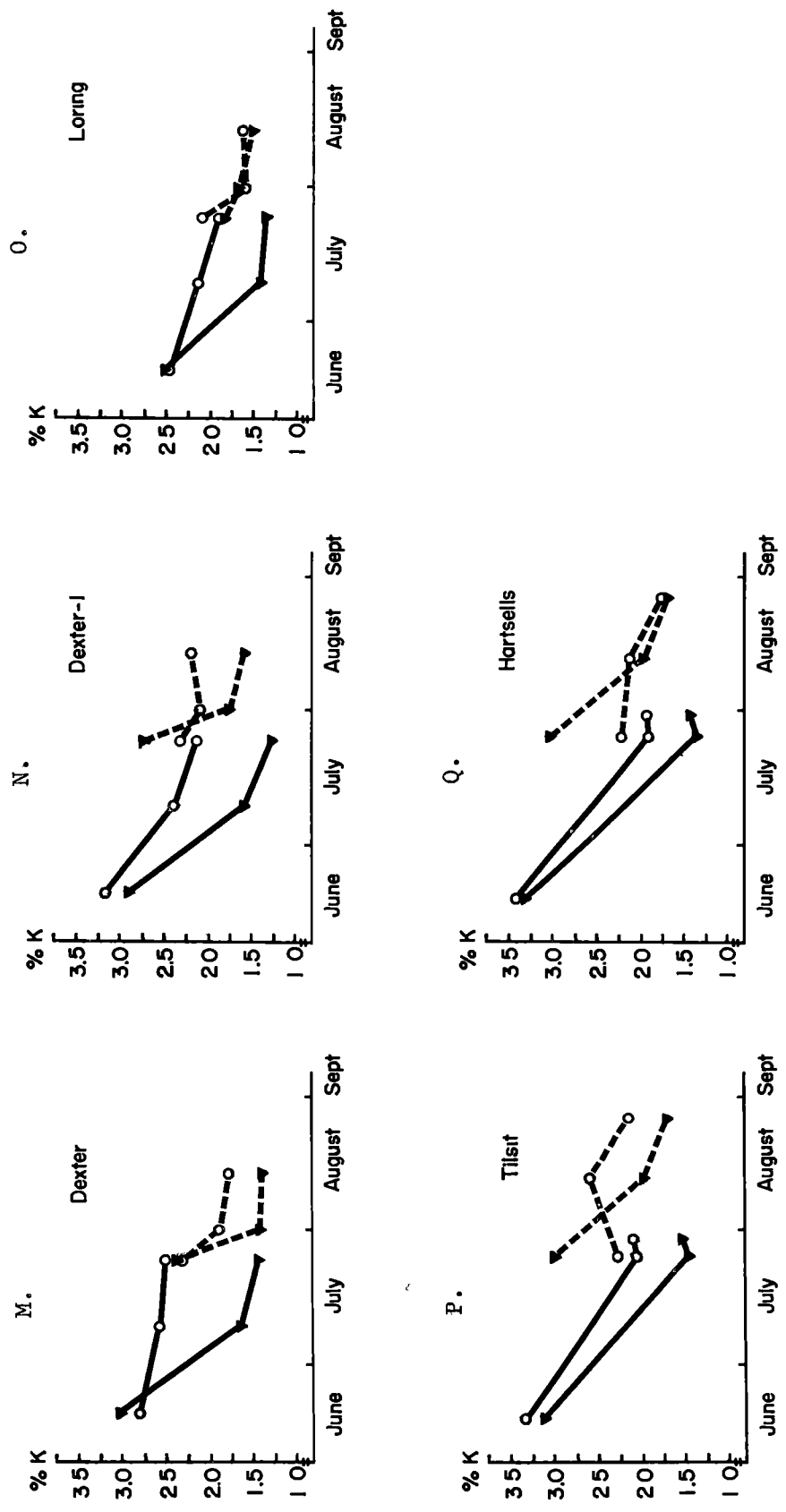


Figure 7. (continued)

APPENDIX J

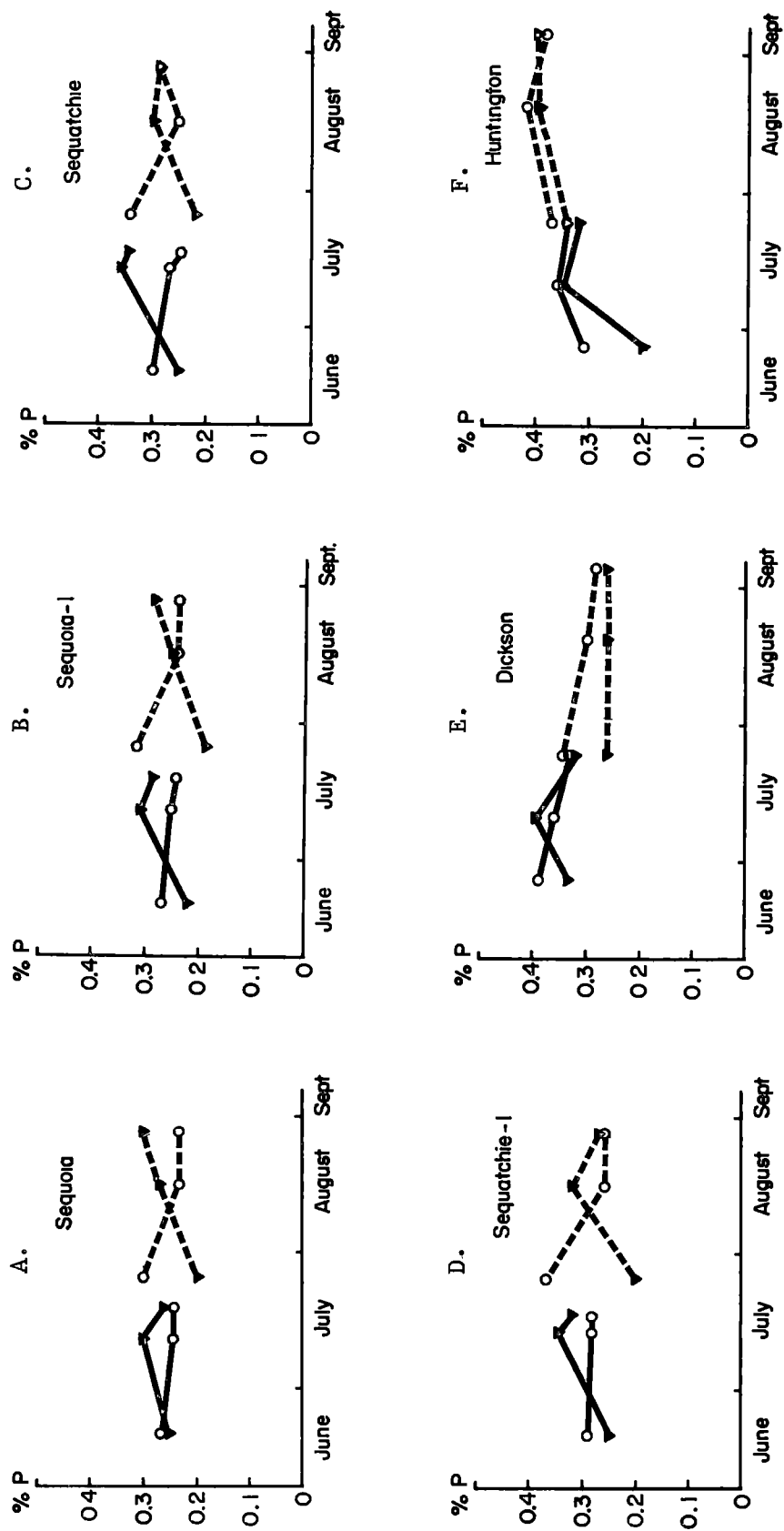


Figure 8. Phosphorus concentration in leaf tissue of early (—) and late (---) plantings of corn (o) and sorghum (▽).

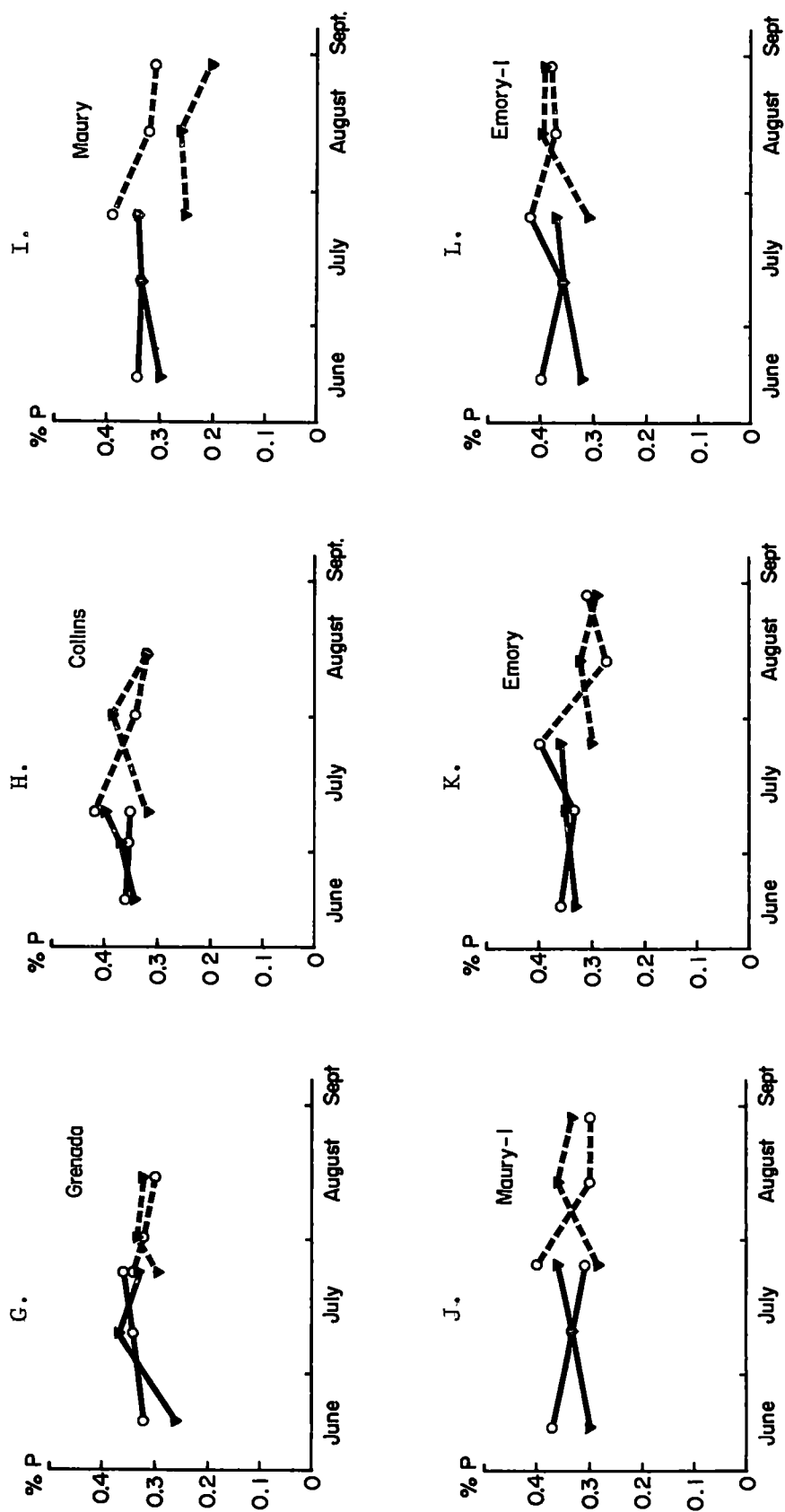


Figure 8. (continued)

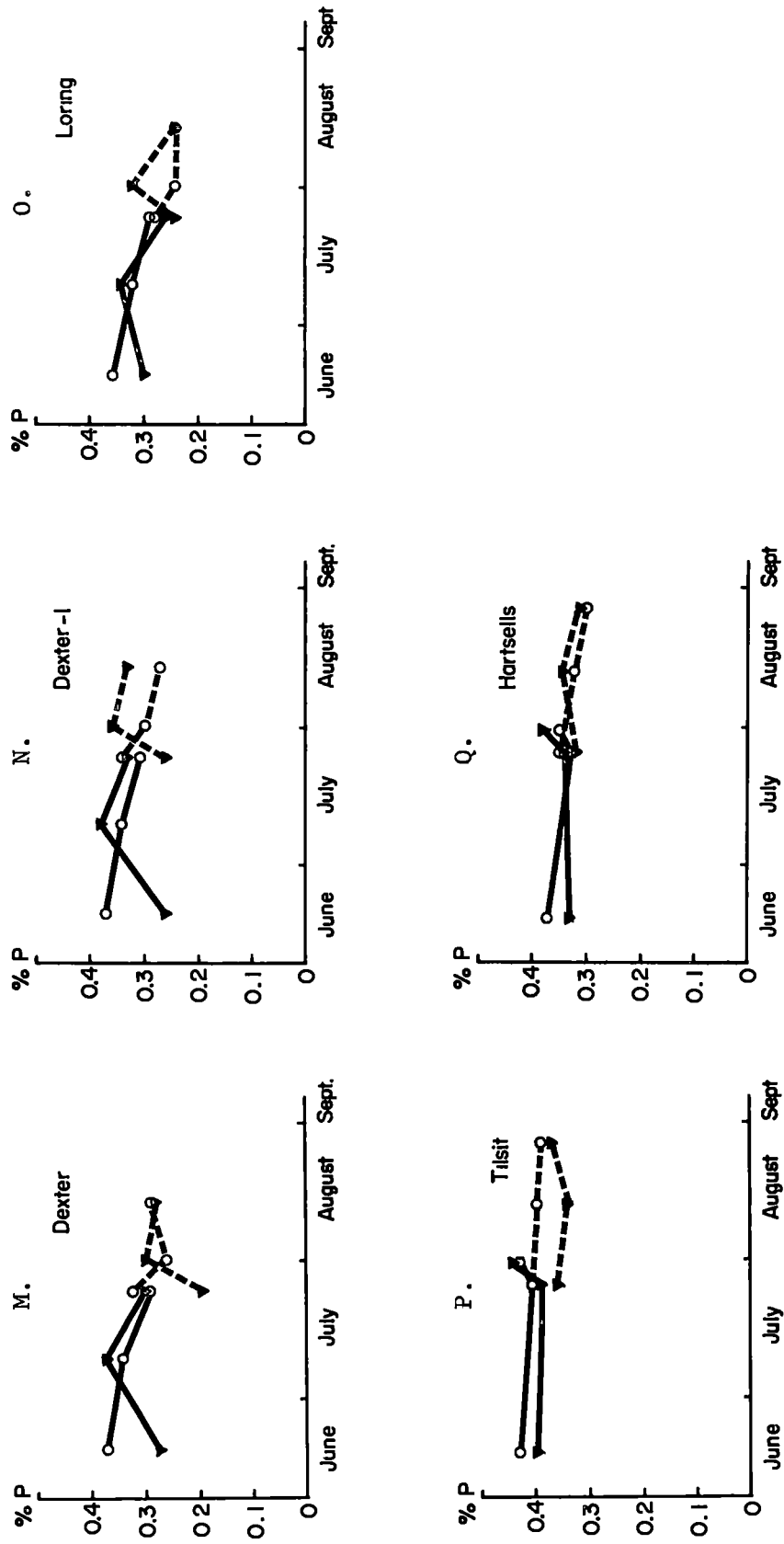


Figure 8. (continued)

APPENDIX K

TABLE XX
YIELDS OF CORN GRAIN*, CORN SILAGE** AND GRAIN SORGHUM SILAGE** ON TWELVE SOILS

Location and Soil	Early Plantings			Late Plantings		
	Corn (Grain)	Corn (Silage)	Grain Sorghum (Silage)	Corn (Grain)	Corn (Silage)	Grain Sorghum (Silage)
-----kg/ha-----						
<u>Knoxville</u>						
Sequoia	4,737	9,019	11,969	4,067	7,932	7,067
Sequoia-I	7,328	14,349	10,948	5,504	11,526	10,256
Sequatchie	8,796	18,151	11,630	2,187	6,281	11,034
Sequatchie-I	11,117	15,709	12,620	3,293	7,533	9,466
<u>Springfield</u>						
Dickson	6,005	15,615	12,044	4,955	21,154	11,074
Huntington	17,005	28,199	14,900	14,096	23,905	15,127
<u>Martin</u>						
Grenada	9,243	13,839	14,970	5,700	13,910	13,408
Collins	12,230	15,985	17,653	10,184	15,579	15,492
<u>Spring Hill</u>						
Maury	6,217	9,804	10,517	3,638	9,666	8,042
Maury-I	9,424	11,939	10,595	6,593	13,467	13,180
Emory	9,016	15,328	12,611	9,557	13,796	12,239
Emory-I	11,603	16,323	12,647	8,256	15,212	15,373
<u>Jackson</u>						
Dexter	3,983	7,374	13,115	5,731	9,303	8,823
Dexter-I	8,585	11,484	14,636	7,934	13,453	9,450
Loring	5,919	8,452	12,934	5,316	10,248	8,552
<u>Crossville</u>						
Tilsit	6,593	16,999	10,868	6,342	14,228	13,960
Hartsells	6,492	14,000	12,143	5,841	12,226	12,927

I = Irrigated.

* = 14% moisture.

** = Oven-dry weight.

VITA

Dan Malcolm Manning was born in Jefferson County, Tennessee, on September 20, 1939. In 1957 he graduated from Carter High School in Knox County, Tennessee. In 1968 he received the Bachelor of Science degree from the University of Tennessee with a major in Agronomy.

He is a member of the American Society of Agronomy and the Soil Science Society of America. He is a member of Gamma Sigma Delta and Phi Sigma honor societies.

He is an officer in the Tennessee Air National Guard, with the specialty of Weapons Controller. During a break in his graduate studies he attended the USAF ECCM Operations Officer School.