RESPONSE OF SEVERAL STRAINS OF CORN (*Zea mays* L.) TO DIFFERENTIAL NUTRIENT UPTAKE UNDER ACIDIC CONDITIONS

by

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I dedicate this thesis to my father, Thar Bdr. Sherchan, and mother, Padma Sherchan for their peaceful and prosperous life.

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INTRODUCTION

Differential response to nutrient uptake among and within various plant species has been noted for a long time. This concept became widely accepted when Beadle and Tatum (1940) adopted Neurospora as their experimental organism showing numerous nutritional deficiencies resulting from a single gene mutation. In plant species exploration of nutrient efficient cultivars would aid in growing them under minimal fertility level conditions without loss of appreciable yield.

Similarly, tolerance to toxic levels of nutrients would allow various species or genotypes within species to grow in those regions where potential toxic situations exist. Soil acidity is a great problem in many tropical and sub-tropical regions of the world. Typical characteristics of these soils are: well drained, highly weathered, poor nutrient status, acidity and with few primary minerals. Aluminum and Mn toxicities are among the main factors causing poor growth in many acid soils particularly when the soil pH is below 5.0. Correction of acidity by liming is not always feasible due to acidity in subsoils and due to economic problems in countries where the economy is at a substandard level. However, plant species and varieties or strains within species do exhibit differential genetic responses ranging from sensitive to tolerant.

Corn (*Zea mays* L.) is the most important cereal crop used for human food in the mountains of Nepal, but yields of corn and other crops are low in soils which are highly weathered and poor in fertility. Difficulty in liming due to topographic and economic constraints has been a problem for the Nepal farmers. An alternative solution would be to identify corn genotypes that are tolerant to acidity and efficient in nutrient uptake, and put them in the crop improvement program to improve the genetic potential.

The specific objectives in this study were (1) to identify corn inbreds, varieties and hybrids with differential nutrient uptake in acid soil, (2) to study the effect of different levels of phosphorus and interaction with liming, and (3) to screen and study corn genotypes tolerant to acid soil primarily due to Al toxicity.

LITERATURE REVIEW

Tailoring plants for efficient nutrient uptake has recently drawn more attention particularly in developing countries. Soil acidity is one of the factors which has been considered in this aspect. Foy (1981) who has worked in screening species and strains within species indicated that soil acidity problems can be caused by a number of potential factors such as Al toxicity, Mn toxicity, Ca deficiency and even by phosphorus, molybdenum and iron deficiency. These factors may act either independently or together to affect plant growth. Toxicity due to Al and Mn are the most important growth limiting factors in many strongly acid soils.

Nutrient Uptake in Acid Soil

Corn genotypes play an important role in the quantitative and qualitative accumulation of nutrients under acidic condition. Differences among plant ability to absorb, utilize and tolerate deficiency and/or toxicity are a matter of concern. Bruetsch et al. (1976) observed significant variability among corn genotypes with respect to dry matter yield and accumulation of P, K, Ca, Mg, Fe and Zn in an acid soil (pH 5.8). Dry matter (DM) yield also showed a significant positive correlation with foliage P concentration indicating that higher P levels occurred in early maturing genotypes.

Lutz et al. (1972) reported that the availability of micro-elements was affected by pH and tended to decrease with an increase in pH except for Mo. Soil pH had a highly significant effect on the concentration of all elements studied except Fe. The genotype X pH interactions were significant only for B and Al concentration. Among the micro-elements, Zn showed a decreasing trend both in average Zn concentration and uptake as pH increased indicating that Zn availability is a function of soil pH.

R. B. Clark (1974) studied the response of several corn inbreds with respect to nutrient deficiency and toxicity using both acidic and alkaline soils. Visual and analytical scorings were made for each element in the tissue of the plant. Aluminum toxicity was evaluated on the basis of phosphorus deficiency since essentially no Al is translocated to maize leaves. Among the nutrients, no visual deficiency and toxicity symptoms were observed for Cu and Mn. For top yield there was a difference of one and one half times between Fe deficient and tolerant lines, and for total nutrient uptake difference as much as five times was recorded between Ca deficient and tolerant lines. Elements such as Fe, Zn, Mg, Ca, Cu, and Al showed increases of both dry matter yield and total uptake in tolerant lines compared to susceptible lines. In this context, Al toxicity was considered as P deficiency in susceptible lines. In a similar experiment using nutrient solution of pH 5.0 Clark (1978) also observed greater changes in concentration of nutrient in susceptible lines than in tolerant lines with respect to variable Zn treatment. Under stress conditions, efficient inbred lines produced more total dry matter, more dry matter per unit Zn, fewer deficiency symptoms and greater Zn concentration in the top than in the roots. However, at higher Zn levels no significant differences between efficient and deficient lines were observed.

Halim et al. (1967) studied Zn deficiency symptoms and interaction with P in several strains of corn using both a nutrient solution (pH 5.5) and field conditions but did not observe any linear relationship between the level of Zn and P accumulation in the leaf tissue and deficiency symptoms. Unlike several reports (Iangin et al., 1962; Ellis et al., 1964) on phosphorus induced Zn deficiency, the uptake of Zn was either inhibited or increased by high P treatment or no noticeable changes did occur in the Zn level. Halim et al. attributed this type of inconsistency between P and Zn to the genetic differences among lines and crosses of the crops involved. High P treatment tended to reduce the dry matter weight of leaves in general, however, resistant lines showed no significant dry weight reduction.

In addition to the interaction effect of nutrients in the soil, nutrient uptake is also influenced by other environmental factors such as temperature, humidity etc. H. A. Knoll et al. (1964) observed P concentration and P uptake of the top of corn genotypes increased with increasing soil temperature and increasing P levels. Great caution should be taken when predicting the nutrient status of a corn plant from plant or leaf analysis data. In an experiment by Baker et al. (1970) designed to determine the interrelationships between P accumulation and other plant responses to the addition of P and other root morphology characters, P concentration in different hybrids and inbreds could not be explained on the basis of P-absorption capacity of roots. However, there was consistency between P accumulation in the corn seedlings and availability of P in the soil.

Physiology of Al Toxicity

In studying soil acidity, influence of Al concentration in the soil is one of the important factors. The exact physiological and biochemical mechanism of Al toxicity is still uncertain but some of the following changes do occur due to the presence of Al in tolerant and susceptible plants. (a) When the pH decreases, Al present in the system changes into soluble forms and causes toxicity to plants. When plants are grown in a system containing exchangeable Al, pH changes do occur in the root zone depending on the degree of tolerance. pH changes induced in the root zone increase with the increased resistance of plant species. (b) Many species and strains within species adapted to highly acidic soils are also capable of tolerating NH_4^+ in the system. Nitrification is inhibited (Raver and Smith, 1976; Foy 1974; Greidamus et al., 1972; Medapa and Dana, 1970 etc.). In plant varieties of some species, for instance in wheat, Al tolerance coincides with accumulation of protein. In the genetic analysis, Mesdag (1970) postulated that the two characteristics were probably linked together. (c) With respect to Al uptake, transport and accumulation, different results have been reported for various species. First group, Al concentration in the top of tolerant plants are not significantly different from those of sensitive plants but roots of tolerant plants often contain less Al than those of sensitive plants. This has been reported in wheat, barley, soybean and snap bean. Second group, Al tolerance is associated with lower level of Al in the top (Azalea, cranberry, rice, triticale, rye, alfalfa, blue grass, etc.). Third group, Al tolerance is directly associated with Al accumulation in the top which includes some dicot plants, rain forest families like tea, certain Hawaiian grasses, pine trees and mangroves (Matsumoto et al., 1976; Moomaw et al., 1959; Jones, 1961; Suchting, 1948 and Hesse, 1963).

In contrast to the above concept that the Al tolerance is associated with pH changes in root zones, Foy et al. (1972) reported that differential Al tolerance among certain varieties of soybean and snap bean do not appear to be related to differential pH changes in the root zones, while Henning (1975) postulated that pH changes associated with differential tolerance are merely consequences of differential death of root meristems.

In several studies, a possible physiological mechanism of tolerance or sensitivity to Al toxicity was reported as the penetration of Al into the root cells. Aluminum tolerance is due to the exclusion of Al at the root cell plasmalemma and that the varietal differences in Al tolerance are due to differences in the molecular construction of this membrane (Henning, 1975). Vose and Randall (1962) found that roots of Al sensitive rye grass have higher cation exchange capacity (CEC) than those of Al tolerant varieties suggesting the Donnon theory as a possible basis for explaining the differential tolerance of varieties to Al. Plant roots with higher CEC absorb Al ions to a greater degree than those with lower CEC, hence, greater Al sensitivity in a variety might be due to greater Al uptake by its roots. This was further supported by the evidence presented by Foy et al. (1967) on wheat and barley. Aluminum tolerance is due to the lower concentration of Al in the tops and higher concentration of Al and in some respects Ca uptake in roots than the sensitive ones. It was also suggested that Ca uptake was one of the factors determining Al tolerance. Calcium is believed to reduce Al toxicity in two ways: partly by reducing Al uptake by roots and partly by immobilizing part of the observed Al in roots, thus preventing its translocation to the plant tops. Clarkson (1965) suggested that Al inhibits cell division in onion. Sampson et al. found that Al altered the type of DNA synthesis by barley roots. However, plant varieties differed widely in P and Ca utilization as a mechanism for Al tolerance.

In general, Al is believed to interfere with cell division, fix P in less available form, decrease root respiration, reduce oxidative phosphoryllization, interfere with certain enzymes governing the deposition of polysaccharide in the cell wall, increase cell viscosity and interfere with uptake, transport and use of several elements and water by plants.

Genotypic Differences to Al Tolerance

Foy et al. (1965) classified wheat and barley varieties with respect to tolerance to acid soils containing high level of KCl-extractable Al. In general, varieties developed in the eastern United States were more tolerant than those developed in the plains and western United States. Wheat varieties from Brazil were exceptionally tolerant. The range between tolerant and susceptible wheat varieties was as much as twelve and seven fold in the top yields and root yields respectively, and in barley nine fold in top yield and about four fold in root yield.

In screening soybean genotypes, Devine et al. (1979) used 6 ppm Al as $AlK(SO_4)_2$ and studied various parameters such as primary root length, length from primary root tip to secondary root and lateral root length. Among these, lateral root length (LRL) was an important factor for measuring the responses of Al stress on the soybean germplasm. Foy et al. (1967) agrees with the finding of Vose and Randall (1962) on rye grass that the sensitive lines contain higher CEC and induced lower pHs in their roots than the Al tolerant varieties. The sensitive varieties could be distinguished from tolerant ones when both were grown in the same container suggesting either the zone of differential pH still exists around roots of different varieties or that the sensitive varieties absorb more Al at the same pH level or both. However, differential Al tolerance of varieties was not closely related to differences in the Al or P content of plant tops.

Aluminum toxicity is a function of Al saturation which is governed by cation exchange complex mainly by Ca and Mg concentration. Hence, as Ca + Mg level increases, Al saturation declines. Although yield responses undoubtedly are in part due to reduced Al saturation, increased Ca and Mg availability contribute to the plant growth. Rhue and Grogan (1977) screened corn genotypes using Ca and Mg concentration as a criteria and found reduced toxicity as Ca or Mg concentration increased. Likewise, at a constant level of Ca or Mg, but at varying levels of adjusted pH, some were more tolerant than others at all pH levels indicating Ca or Mg were responsible for reducing Al toxicity. In some soils where the level of organic matter is low, Al toxicity can be reduced by adding more organic matter to form insoluble organic Al complex. To classify wheat genotypes, Mesdag et al. (1969) screened about three hundred varieties of spring and winter wheat collected from various parts of the world. Irrespective of wheat type, classification could be identified on the basis of geographic location from where the varieties were developed. For instance, varieties developed in Brazil had high degrees of Al tolerance. On the other hand, varieties from Mexico and Argentina showed broad range of variability. In the same experiment twice as much sulfuric acid had to be added to create genetic variability among wheat varieties than among barley varieties indicating wheat species are more tolerant than barley. A very close relationship between exchangeable bases (Ca + Mg) and Al saturation has also been observed by Abruna et al. (1974) and liming responded significantly, particularly in Ultisol soil which had higher exchangeable Al content. Corn yield increased up to a pH of 5.2 at which no exchangeable Al was present and the exchangeable bases reached 70 percent saturation level. Early studies by Adams et al. (1966) in cotton concluded that molar activity of Al in the soil solution is more important than merely the exchangeable Al or Al saturation while correlating with root penetration. However, top yields in field condition were less sensitive to subsoil acidity differences than were the cotton roots in the controlled environment. While evaluating fifty-four cotton genotypes, Foy et al. (1980) concluded that although there were significant genetic variability, differential Al tolerance was not consistently associated with differential concentration of Al, Mn, Ca, or P in the whole plant top. However, concentration of Al and Ca tended to be higher in chlorotic/cupped leaves than in normal leaves. High correlation between top and root yield indicated that measurement of either component could be adequate for screening for Al tolerance. One of the limitations to crop growth caused by Al toxicity is the stunted and shallow root growth. Bouldin's (1979) finding indicates that subsoil acidity in some parts of the world associated with restricted root depth can be a serious problem where water deficit frequently occurs. Foy et al. (1980) also summarized that the failure of resistance to drought is caused by a shallow root system in acidic subsoil as a function of Al toxicity. To the extent that nutrients such as Ca, Mg and K and probably P are available, crops tolerant to subsoil acidity can presumably tap the subsoil water while efficiently using amendments added to the plow layer.

Genetic Makeup - Nutrient Uptake and Al Tolerance

Studies on genetic makeup and inheritance of plant nutrient uptake are still under way. Nevertheless, nutrient uptake and accumulation have been reported, by various workers, to be under genetic control (Gorsline et al., 1961; Epstein et al., 1964; Harvey, 1939; Kerridge et al., 1968; Reid, 1969 etc.). Gorsline et al. studied the mode of inheritance, type of gene action and heritability estimates of 12 mineral elements in corn. Two to three genes were reported to be involved for most of the elemental uptake. Both additive and non-additive gene action were indicated for each leaf concentration and grain concentration depending on a specific element as well as their interaction with environment. Additive gene action and its interaction with environment were more important than non-additive gene action. Heritability in the broad sense was estimated as twice the parent progeny regression ranging from 5.4 to 84%. The highest was for Mg (84%) followed by Cu (77%).

In another study of breeding for Mg, Ca, K and P in tall fescue grass to reduce the incidence of grass tetany disease of livestock, parents and progenies differed significantly in levels of all elements. Heritability estimates for K/Ca + Mg ratio was highly significant and progress could be made in breeding a tall fescue with low hypomagnesaemia (Sleper et al., 1977). Naismith et al. (1974) identified the genetic loci for Ca, P and Mn accumulation in mid leaves of corn inbreds to be chromosomes 9 by using marker genes and supernumerary translocation technique. However, the result could not display the common genetic mechanism for these elements suggesting that the different genetic mechanisms could be involved for different elements. Similarly, at a very high P level, the inheritance study of soybean indicated that the tolerance to very high P level seemed to be controlled by a single major gene $N_p N_p$ (Bernard et al. 1974). On the other hand, in a study of high x high, high x low and low x low crosses of P accumulator of corn genotypes, at least two genetic factors might be involved with the possibility of dominance for the lower P level. These results would possibly suggest that the genetic mechanism for P accumulation in the plant and toxicity tolerance due to very high P level do not seem to have a common relationship.

Heritability estimates have also been reported for Sr-89 and Ca-45 in barley seedling. Broad sense heritability estimates for Sr-89 and Ca-45 ranged from 36% to 58% in F_2, from 50% to 55% for Sr-89 and 41% to 49% for Ca-45 in F_3 generation. The close relationship between the accumulation of Sr-89 and Ca-45 indicated that they perhaps have a common mechanism for accumulation process (Fick et al., 1967). However, these results are inconsistent with the result of Smith et al. (1963).

Studies on genetic control and inheritance of Al toxicity have been done by a number of workers (Rhue et al., 1978; Kerridge et al., 1968; Lafever et al., 1978 etc.). Results obtained by these workers involving Al tolerant and susceptible crosses of various species suggest that there is a complex mechanism of genetic control over Al tolerance rather than a simple one as initially postulated by Kerridge et al. Moore (1977) suggested that at least two major dominant genes control Al tolerance in wheat. In other species where progenies did not segregate distinctly, multigenic control may be involved. But in barley, only one major gene has been reported to have controlled differential Al tolerance (Reid, 1969). Rhue et al. (1978) concluded that, although one major dominant gene is responsible for much of Al tolerance in corn, there are also other minor genes suggesting that Al tolerance in corn is controlled at a single locus by a multiple allelic series. This was further supported by Campbell's finding (1978) involving F_2 and backcrosses that several minor genes could be responsible in addition to the single major gene for the dominant effect of Al tolerance in wheat.

There is evidence that genes for Al tolerance could be linked with other desirable traits. For example, Mesdag et al. (1970) reported that Al tolerance is genetically linked with higher protein content and rust resistance in crosses between "Atlas 66" and hard red winter wheat. However, low correlation between these traits suggested that they may be controlled by more than one gene. This was further supported by the result of Slootmaker (1974) that the D genome is primarily responsible for Al tolerance. Similarly, substitution of chromosome 4D of Thatcher into Chinese Spring wheat indicates that the gene for Al tolerance of Chinese Spring is located in chromosome 4D (Polle et al., 1978).

Screening Techniques for Al Tolerance

Several screening techniques have been attempted to differentiate susceptible lines or strains from tolerant ones ranging from field testing to a dye method. Because one standard technique cannot be followed for all species and under all circumstances, choosing a certain level for Al tolerance is not only affected by species but also by environmental factors under which they are carried out such as temperature, moisture content, light and fertility status of the soil. Foy (1976) indicated that screening for Al tolerance in acid soil can often become difficult to differentiate from Mn toxicity because some acid soils have both Al and Mn at toxic levels. Aluminum toxicity occurs primarily below pH 5.0 but has been reported at soil pH as high as 5.5 but Mn toxicity can easily occur up to pH 5.5 or may not occur even below pH 5.0.

The principal effect of Al toxicity is a severe inhibition of root growth. Hence, several workers (Foy, 1967; Rhue, 1978; Lafever, 1977; Prestes et al., 1975; Konzak et al., 1976; Reid, 1976 etc.) have used nutrient solutions at different levels of Al content for screening several species and measured root growth as a parameter. High correlations between root yield and top yield in barley (r = 0.71 to 0.93) facilitated screen Mg for differential Al tolerance (Reid, 1976).

Reid (1976) used both soil and nutrient solution for screening barley varieties and a significant correlation between root weights in soil and in solution were obtained (r = $\pm$ 0.75). Campbell (1976) correlated relative root length (8 ppm Al/0 ppm Al) in the nutrient solution and the relative yield in the field, and obtained a correlation value of r = 0.51. However, the occurrence of large deviation from the regression equation reflected an inconsistent response to soil changes other than available Al.

As a method of preliminary testing, Polle et al. (1978) used a staining technique on seedling root with the chemical hematoxylin. By this technique, he could screen large populations and remove the most undesirable genotypes at an early stage.

Moore et al. (1976) used a different nutrient solution screening technique based on imposing an Al insult on root cells followed by a recovery period. This technique facilitated classifying wheat varieties more distinctly in large populations.

During screening in nutrient solution culture, control of pH is very essential since raising the pH above 5 to 5.5 can precipitate Al and detoxify its effect. Similarly, to get the best results, several workers have preferred to maintain temperature at 25^{o}C during nutrient solution culture.

Konzak et al. (1976) used a solution paper method instead of nutrient-solution method for screening wheat, barley, rice, sorghum and soybean. Solution paper method permitted the tentative classification of several Al tolerance groups. But, for corn, the influence of Al on its root growth seemed to be more complex; hence, nutrient solution culture was more favorable. Contamination of the root system by micro-organisms both in solution paper method and nutrient solution culture method seemed likely to occur, hence, fungicidal treatment has been suggested to avoid contamination.

On the whole, correlating the other techniques with the field screening method is an essential part to identify and correct the variability present in the soil.

Selecting a stress level is another problem. The stress level may vary depending on soil type and species to be tested. Adams and Lund (1966) found that the level of KCl-extractable Al required to inhibit cotton root growth was 0.1 me/100 g for Norfolk, 1.5 for Dickenson and 2.5 for Bladen soils. Critical pH levels required for tap root penetration were 5.5 for Norfolk and less than 5.0 for Dickenson and Bladen soil, hence, Al saturation of the CEC may be useful. Still, this varies with plant species. For example, Kamprath (1970) reported that corn could tolerate Al saturation up to 44% but soybeans were injured at 20%. Sorghum and alfalfa may be injured at lower levels of Al saturation.

MATERIALS AND METHODS

Two greenhouse studies and one growth chamber study were conducted to study differential responses of corn strains.

Experiment I: Screening Corn Strains for Differential Nutrient Uptake at Various Levels of Phosphorus and Liming

Sixteen corn strains (Table 1) were obtained from CIMMYT, Mexico. Some of the sources originated from Nepal highland and some were elite composite lines from CIMMYT, Mexico. Nepal highland sources were flinty, yellow, white and mixture of yellow and white, early maturing types. The Mexican lines were selected lines from Nepal and different parts of the world. The 3 x 2 factorial combination of treatments of lime and phosphorus were: effective $CaCO_3$ (ECC) of 0, 3250 and 6500 kg/ha as reagent grade $CaCO_3$ and phosphorus of 0 and 100 ppm P as $Ca(HPO_4).2H_2O$. Each treatment was replicated three times.

The soil used for this study was obtained from the southeast Kansas Experiment Field near Parsons in Labette County. The soil chemical characteristics are given in Table 2.

The soil was sieved through a coarse screen and oven dried. Eight hundred grams of dried soil was weighed and placed in a plastic pot. Supplemental amounts of other nutrients were applied as follows:

Nitrogen .... 200 kg/ha as NH_4NO_3

Potassium.................. 100 kg/ha as KCl

The supplemental nutrients and variable treatments were thoroughly mixed with the soil prior to planting.

The pots were arranged in the greenhouse in a completely randomized design. Field capacity of the soil was determined and the uniform amount of tap water was used for each pot throughout the 6 week study. The corn seedlings were thinned to three plants per pot 4 days after emergence.

Table 1. Corn strains used in greenhouse study.

Strains	Source
1. Nepal 211 (yellow)	CIMMYT
2. Nepal 212 "	"
3. Nepal 304 "	"
4. Nepal 608 "	"
5. Nepal 1206 "	"
6. Nepal 101 (white)	"
7. Nepal 103 "	"
8. Nepal 104 "	"
9. Nepal 105 "	"
10. Nepal 107 "	"
11. Khumal 7642	"
12. Khumal 7633	"
13. Thai Composite	"
14. Amarillo Subtropical	"
15. Amarillo Bajio	"
16. Blanco Subtropical	"

Table 2. Chemical characteristics of Parsons soil, Kansas.

pH	5.5
Available N	20 ppm
Available P	3 ppm
Exchangeable K	56 ppm
Organic matter	1.7%

The plants were harvested 6 weeks after planting. Harvesting was done by cutting the plants about one cm above the soil surface with stainless steel scissors. The plants were then placed in a paper bag and dried in a forced air oven at about 45°C for 72 hours. The dried plants were weighed, ground through a Udy mill, and stored in a plastic bottle.

A sulfuric acid digest (Linder and Harley, 1942) was used for nitrogen, phosphorus and potassium determination in the plant samples. A 0.25 gram sample was weighed into 75 ml test tubes. Two ml of concentrated sulfuric acid and one ml of hydrogen peroxide were added to each tube; the materials were digested at a temperature of 375°C for 30 minutes in aluminum digestion blocks. The tubes were removed from the blocks and allowed to cool for 5 minutes; one ml of hydrogen peroxide was added and the digestion was continued for another 20 minutes. Additional digestions were carried out at 15 minute intervals until the samples became clear. The digestion tubes were then cooled; the solution diluted to 50 ml with deionized, distilled water, and stored in polyethylene bottles. Nitrogen and phosphorus were determined in these solutions by the Technicon Industrial Method NO 334-74W/B+ (Appendix) with a Technicon Autoanalyzer system. For the nitrogen determination, one ml aliquot of the stock solution was diluted to 10 ml with deionized distilled water. A half ml of this solution was then diluted to 6 ml with deionized distilled water and mixed well. Both nitrogen and phosphorus determinations were based on colorimetric methods. For nitrogen, an emerald-green color is formed by the reaction of ammonia, sodium hypochlorite in a buffered alkaline medium at a pH of 12.8 - 13.0 and, for phosphorus, a blue color is formed by the reaction of orthophosphate, molybdate and antimony ions followed by reduction with ascorbic acid at an acidic pH. Potassium was determined by flame emission method using the original solution.

A nitric-perchloric acid digestion (E. B. Earley) of the plant samples was used for Ca and Mg determinations. A 0.25 gm of dried plant sample was weighed into 75 ml test tubes and digested with 7.5 ml of 1:1:1 nitric-perchloric $-H_2O$ mixture at about 210°C until heavy white fumes appeared and digestion mixture was clear. The water clear aliquot was then cooled, diluted to 25 ml volume with deionized distilled water, mixed thoroughly, and stored in a polyethylene bottle. From each sample, Ca and Mg were determined with a model 603 Perkin-Elmer atomic absorption spectrophotometer. All the nutrients were expressed in terms of concentration (% of total dry matter) and uptake (mg per pot).

Experiment II: Screening Corn Strains for Al Tolerance in Nutrient Solution

Eighteen corn strains obtained through various sources were screened for Al tolerance in nutrient solution. Strains used for this study are given in Table 3.

The chemical constituents of the nutrient solution used are given in Table 4.

The seeds were first put into a small net and all samples were then placed in a large container with aerated water at about 25°C for 24 hours. Then the seeds from each net were placed on the surface of a moistened filter paper in a petri dish. The seeds were further covered by an additional filter paper on the top and covered with a lid. The petri dishes were incubated at about 25°C in the dark for two days. Then, germinated seeds of similar root length of each variety were planted in the nutrient solution.

Four plastic trays, each containing 10 liters of deionized distilled water were given the above nutrient solution A, solution B, solution C with equal treatments. Each plastic tray was treated with 0, 0.03, 0.06 and 0.09 mM of Al respectively as a variable treatment. Then with a serological pipet, either solution E or solution F was added to adjust the pH of the nutrient

Table 3. Corn strains used in growth chamber screening for Al tolerance.

Strains	Source
1. K 724 x K 695	Kansas
2. K 724 x K 41	"
3. K 731 x H 28	"
4. PI 270081	Pakistan
5. PI 270084	"
6. PI 270083	"
7. Oh 7B	Kansas
8. Va35	"
9. Khumal 7642	CIMMYT, Mexico
10. Khumal 7633	"
11. Thai Composite	"
12. Amarillo Subtropical	"
13. Amarillo Bajio	"
14. Blanco Subtropical	"
15. PI 270101	Pakistan
16. Oh 43	Kansas
17. PI 270071	Pakistan
18. PI 270088	"

Table 4. Chemical composition of nutrient solutions.

Elements	Concentration
Solution A	
Major elements	
$Ca(NO_3)_2.4H_2O$	0.0375 mM
NH_4NO_3	0.025 mM
KCl	0.02 mM
$MgSO_4.7H_2O$	0.01 mM
KH_2PO_4	0.0025 mM
Solution B	
Minor elements	
$MnSO_4.H_2O$	.00655 mM
$CuSO_4.5H_2O$	.00048 mM
$ZnSO_4.7H_2O$	0.00173 mM
H_3BO_3	0.0184 mM
MoO_3	0.00062 mM
Solution C	
330 Fe (chelate)	0.3%
Solution D	
Al as	0, 0.03, 0.06 and
$Al_2(SO_4)_3.18H_2O$	0.9 mM
Solution E	
HCl	0.25 M (approx)
Solution F	
NaOH	0.25 M (approx)

solution to 4 and recorded every day.

One piece of styrofoam carrying 20 planting holes was attached to each tray. The holes were supported by 20 vials (3 cm diameter) fitted with screens at the bottom of each vial. This allowed holding the germinating seeds just on the nutrient solution. Twelve seedlings of each strain were selected and planted 3 in one hole of each tray. The trays were placed in the growth chamber at about 25°C with 12 hours day light. The solutions were aerated continuously.

pHs of the nutrient solutions were recorded every day and adjusted to pH 4. On fourth, eighth and tenth day after transplanting, the old solutions were replaced. On the eleventh day, scoring was done by measuring the length of each root and by observing general growth of lateral roots and plant tops.

Experiment III: Screening Corn Strains for Al Toxicity in Acid Soil

The experiment was conducted in the greenhouse using a completely randomized design in three replications.

Fifteen corn strains comprised of inbreds, single crosses, and open pollinated varieties obtained from various sources were used in this experiment (Table 5). The open pollinated varieties were also used in the previous experiments.

The soil used for this experiment was a mine spoil soil obtained from near Pittsburg in southeastern Kansas. The soil was low in pH and contained appreciable amounts of soluble Al which could cause toxicity in corn genotypes. The important soil chemical characteristics are given in Table 6.

Before adding the treatment variable, about 100 grams of soil were allowed to equilibrate with 2000 ppm, 4000 ppm and 8000 ppm of hundred percent effective $CaCO_3$. The pH was remeasured after one week. On the basis of this study, levels of lime were determined to create variations in pH. The variable treatments

Table 5. Corn strains used in greenhouse study for screening in Al toxic soil.

Strains		Source
1.	Va17	U.S.A.
2.	Co 103	"
3.	W64A	"
4.	W153R	"
5.	PI 270080	Pakistan
6.	PI 270083	"
7.	Mo 17 x A 634	U.S.A.
8.	A632 x W64A	"
9.	A632 x A619	"
10.	Blanco Subtropical	CIMMYT, Mexico
11.	Khumal 7642	"
12.	Khumal 7633	"
13.	Thai Composite	"
14.	Amarillo Subtropical	"
15.	Amarillo Bajio	"

Table 6. Chemical analysis of mine spoil soil; source: Pittsburg, Kansas.

pH (1:1)	4.0
Available N	3 ppm
Available P	20 ppm
Exchangeable K	108 ppm
Ca (NH_4 acetate)	900 ppm
Mg (NH_4 acetate)	250 ppm
Mn (DTPA)	32 ppm
Al (KCl)	284 ppm
O.M.	2.2%
Zn (DTPA)	32 ppm
Cu (DTPA)	2 ppm
Fe (DTPA)	28 ppm
Texture:	
Sand	43%
Silt	51%
Clay	6%

of lime and other fixed inputs were as follows:

Treatment		kg per ha
Effective $CaCO_3$ (reagent grade)	I	0
	II	4000
	III	8000
	IV	16500
N (NH_4NO_3 + $NH_4H_2PO_4$)		200
P ($CaH_4(PO_4)_2$ + $NH_4H_2PO_4$)		200
K (KCl)		100

The soil was air dried, ground and sieved through a coarse screen. Eleven hundred grams of dried soil was weighed into each plastic pot. Lime and half of the phosphorus was thoroughly mixed with the soil before planting whereas K and half of the N was applied as a solution immediately after germination. Remaining half of the nitrogen was applied two weeks after germination. The remaining half of phosphorus was applied when appreciable deficiency symptoms were noticed. This was applied as a solution of $NH_4H_2PO_4$. Eight seeds were planted in each pot and the corn seedlings were thinned to three plants 4 to 5 days after emergence. The time of emergence was not uniform and differed from source to source and were partly affected by response to Al toxicity. For instance, inbred Co103, which was highly sensitive to Al toxicity, germinated last.

The plants were harvested 35 days after planting. Harvesting was done by cutting the plants about 1 cm above the soil surface. Plants were put into a paper bag and dried in a forced air oven at about 50^{o}C for 5 days. The dried samples were finely ground and stored in plastic bottles.

A sulfuric acid digestion was used for N, P and K determinations in the plant tissue whereas a nitric-perchloric digestion was used for Ca, Mg, Al and Mn determinations. Aluminum determination was done with a direct coupling plasma Spectro Span Model III instrument.

For soil chemical analysis, five sources were selected and a complete set of treatments of each source were analyzed for pH, K, P, Ca, Mg, Al and Mn. Ammonium acetate extraction was used for K, Ca and Mg determination by atomic absorption spectrophotometry. For Ca and Mg, the extraction was further diluted 10 times with a 0.5% lanthanium oxide solution. Phosphorus was determined colorometrically using Bray's Sulfonic Acid Reduction method. For Al determination, KCl extraction was used and determined with a model 603 Perkin-Elmer atomic absorption spectrophotometer. Manganese was determined from the DTPA extraction.

Analysis of variance was used for a statistical evaluation of the data. In addition to dry weight, relative dry weight was also expressed which is the ratio of dry matter production at each level of lime to that of highest level of lime treatment.

RESULTS AND DISCUSSION

Experiment I

Two separate analyses were carried out due to the difference in number of levels of lime application. The first analysis will deal with all 16 corn strains which were given zero and high level lime treatments and the second analysis will deal with 6 strains which were given all three levels of lime.

For Sixteen Corn Strains

Dry Matter Weight: Significant variability was found in dry matter weight among corn sources. The greatest influence was observed due to P treatment. With the addition of P to a soil which was primarily poor in soil phosphorus, the overall mean dry matter increased by about 70%. On the other hand, the effect of lime treatment was detrimental to dry matter production particularly at high P rate. Of all the sources, the highest dry matter production was obtained from N-1206, a local indigenous open pollinated variety from Nepal, followed by N-103 and Amarillo Subtropical (Table 7). Although these local strains from Nepal are normally considered poor grain yielders, their initial faster growth characteristics could have contributed to more dry matter production under six weeks' greenhouse experimental conditions. The lowest dry matter yield was obtained from Thai Composite, a relatively stable, better grain yielding, but late maturing variety (Table 8 and Fig. 1).

The effect of phosphorus application was noteworthy. About ten days after seedling emergence, all sources started expressing phosphorus deficiency symptoms at zero level of P treatment, however, the degree of expression was variable. Overall effect of genotype, phosphorus, lime, and genotype by phosphorus and lime by phosphorus interactions were statistically significant suggesting that effect of P application was the most important factor in producing differ-

Table 7. Analysis of variance of dry matter weight.

Sources of Variation	d.f.	S.S.	P >F
Genotype (G)	15	20.77	.0001
Phosphorus (P)	1	99.70	.0001
G x P	15	5.20	.0004
Lime (L)	1	6.9	.0001
G x L	15	2.2	.21
P x L	1	5.8	.0001
G x P x L	15	1.6	.48
Error	128	14.7	

ential dry matter yield (Table 7).

Dry matter production differences among the strains were also calculated separately at two levels of P. All the strains increased their dry matter yield significantly with the addition of P. At both P levels, N-1206 had the highest dry matter yield indicating that this source could be selected at all levels of P treatment. The pattern of variability among sources were not remarkedly distinguishable between the two P levels. For instance, N-1206 was the highest yielder and Thai Composite was the lowest yielder at both levels (Table 8). The average mean yield increased from 1.96 gm per pot with no P treatment to 3.40 gm per pot with P treatment which is an average increase of 73%.

Relative dry matter yield was also calculated which is the ratio of the yield with no P treatment to that with added P. The relative dry matter yield was found to be as low as 45% in case of Thai Composite and as high as 69% in case of Khumal 7633. From this, it may be said that Thai Composite is an

Table 8. Mean dry matter production of 16 strains of corn at two levels of P.

	Dry weight (gm per pot) 0 ppm P	Dry weight (gm per pot) 100 ppm P	Means (gm per pot)	Relative Yield
1. N 211 (yellow)	1.63 fg	3.05 ef	2.34 fg	.53
2. N 212 "	1.89 def	3.23 def	2.56 def	.59
3. N 304 "	1.66 fg	3.51 bcde	2.59 def	.47
4. N 608 "	2.18 abcd	3.76 abcd	2.97 bc	.58
5. N 1206 "	2.40 a	4.19 a	3.30 a	.57
6. N 101 (white)	2.10 abcde	3.12 ef	2.61 def	.67
7. N 103 "	2.27 ab	3.89 ab	3.08 ab	.58
8. N 104 "	2.03 bcde	3.29 cdef	2.66 cde	.62
9. N 105 "	1.79 efg	3.81 abc	2.80 bcd	.47
10. N 107 "	1.81 efg	3.68 abcd	2.74 cd	.49
11. Khumal 7642	1.53 gh	2.88 f	2.20 gh	.53
12. Khumal 7633	1.94 cdef	2.80 f	2.37 efg	.69
13. Thai Composite	1.27 h	2.82 f	2.04 h	.45
14. Amarillo Subtropical	2.36 a	3.78 abc	3.07 ab	.62
15. Amarillo Bajio	2.36 a	3.49 bcde	2.92 bc	.67
16. Blanco Subtropical	2.21 abc	3.21 def	2.71 cd	.69
Means	1.96	3.40	2.68	.58

Means within same column with the same letter are not significantly different at DMRT = .05

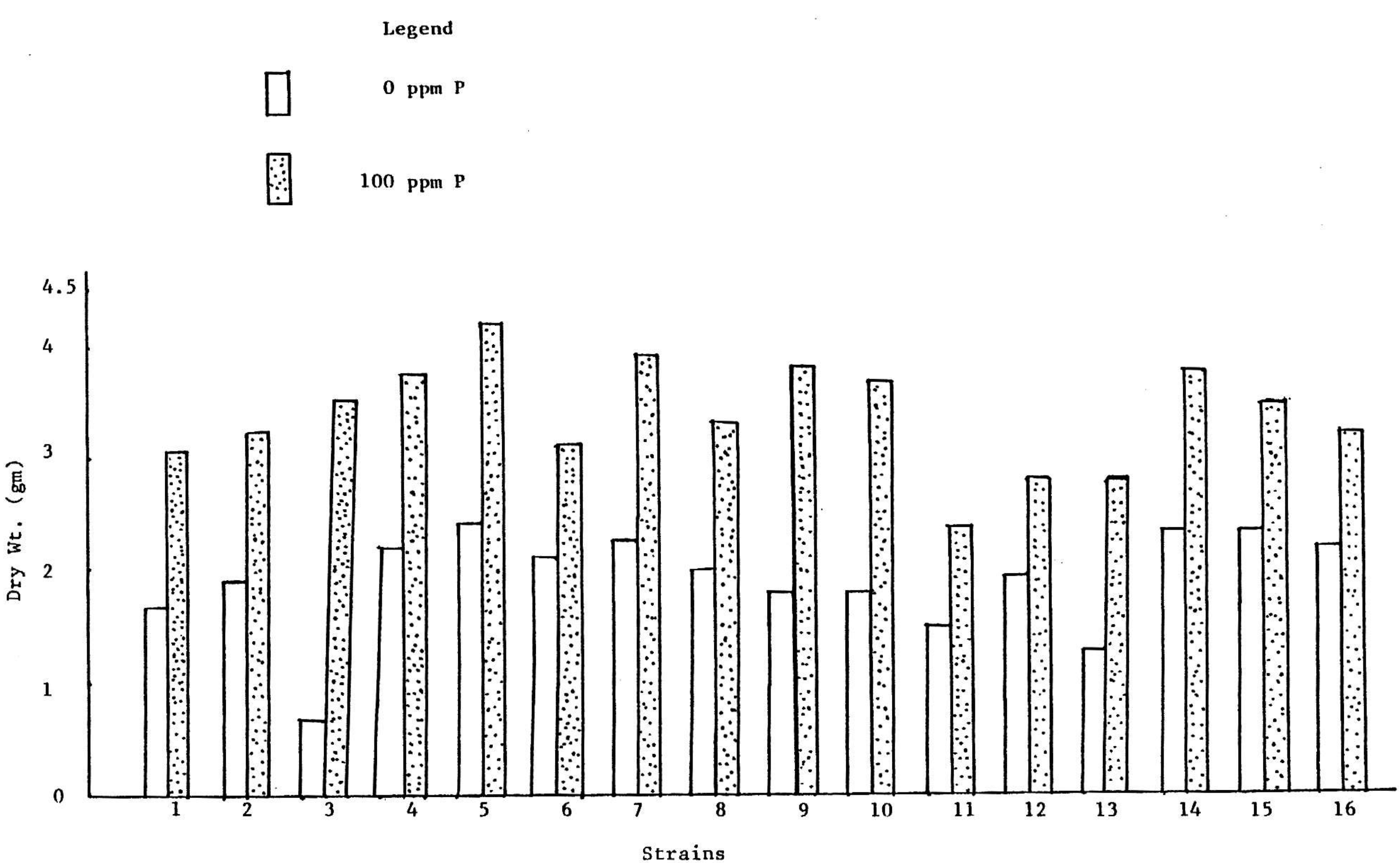

Fig. 1. Genotypic differences for dry weight at two levels of P.

inefficient and Khumal 7633 is an efficient source. However, N-1206 which was the highest yielder showed an intermediate range (Table 8).

The overall effect of liming was detrimental rather than beneficial to plant growth (Table 9). It is noteworthy that, at soil pH 5.5, liming did not produce any positive response. Dry matter yield decreased significantly at the higher lime level suggesting that lime application may have reduced P availability.

Nitrogen Concentration and Uptake: Nitrogen is highly mobile in the nitrate form and is one of the most important elements responsible for dry matter production. Significant genotypic variation has been observed for both N concentration (percentage of total dry matter) and uptake (mg per pot). In general, N concentration varied inversely to dry matter among the sixteen corn strains (Tables 8 and 12). For instance, N-1206 which was the highest yielder had the lowest N concentration and Thai Composite which was the lowest dry matter producer had the highest nitrogen level.

Total N uptake, which depends both on dry matter weight and concentration, showed a narrower pattern of variability among sources suggesting that dry matter weight and N concentration tend to be negatively correlated at a certain level of soil N.

In regard to N concentration and uptake, strain N-101 showed some promising results. Since this source, although placed in the intermediate category for dry matter yield, the significant effect of genotype x P interaction for N concentration gave the highest uptake. Thus N-101 may be an efficient N absorber (Table 11). Similarly, overall effects of P, lime, and variety by P interaction were also significant for N concentration (Table 11).

Although liming significantly increased N concentration at both levels of P application, it was not significant for overall N uptake due to no effect to slight decrease at the higher level of P application (Table 10). Statistical

Table 9. Effect of lime on mean dry matter production at two levels of P.

Lime (kg per ha)	Dry Weight (gm per pot)		
	0 ppm P	100 ppm P	Means
0	1.98 a	3.77 a	2.87 a
6500	1.95 a	3.04 b	2.50 b
Means	1.97 b	3.41 a	2.68

Table 10. Effect of lime on mean N concentration and uptake at two levels of P.

Lime (kg per ha)	N Concentration %			N Uptake (mg per pot)		
	0 ppm P	100 ppm P	Means	0 ppm P	100 ppm P	Means
0	2.15 b	1.40 b	1.77 b	41.56 b	51.42 a	46.49 a
6500	2.30 a	1.66 a	1.98 a	43.84 a	49.07 a	46.45 a
Means	2.23 a	1.53 b	1.88	42.70 b	50.25 a	46.47

Means of each level within same column with the same letter are not significantly different at DMRT = .05.

Table 11. Analysis of variance of nitrogen concentration and uptake.

Sources of Variation	d.f.	N Concentration		N Uptake	
		S.S.	P>F	S.S.	P>F
Genotype (G)	15	7.8	.0001	3.5	.0001
Phosphorus (P)	1	23.8	.0001	89.2	.0001
P x G	15	2.9	.0003	1.7	.06
Lime (L)	1	2.0	.0001	0	.97
L x G	15	1.4	.12	1.7	.06
L x P	1	.2	.12	8.4	.004
L x P x G	15	1.1	.33	1.5	.10
Error	128	7.9		39.9	

analysis at the two levels of P application indicated that average N concentration decreased significantly with the addition of P (Table 14). A similar pattern existed for all sources showing significant genotypic variability for N concentration at each level of phosphorus treatment. However, the pattern of genotypic variability between the two P levels seems to be more inconsistent than for dry matter weight (Table 12). For instance, N 304 and N 107 were efficient in absorbing N per unit dry matter weight when P was not applied than with addition of P whereas Khumal 7633 behaved inversely.

Statistical analysis indicated that significant differential N uptake existed only at the zero P treatment indicating that strains can be screened only under P stress condition for N uptake. But with the addition of P, dry matter production increased and N concentration decreased so the total nitrogen uptake tended to be narrower for all sources (Table 12).

Phosphorus Concentration and Uptake: Significant differences were observed for all treatments except for genotype by lime interaction for both P concentra-

Table 12. Mean plant N concentration and uptake of 16 corn strains at two levels of phosphorus.

	N Concentration %			N Uptake (mg per pot)		
	0 ppm P	100 ppm P	Means	0 ppm P	100 ppm P	Means
1. N 211 (Yellow)	2.32 abc	1.58 bcde	1.95 bcd	36.93 de	47.56 a	42.25 fg
2. N 212 "	2.48 ab	1.72 abc	2.10 ab	46.53 ab	50.97 a	48.75 abcd
3. N 304 "	2.61 a	1.42 def	2.01 abc	43.18 abc	49.10 a	46.01 bcde
4. N 608 "	1.93 d	1.33 ef	1.63 fg	41.43 bcd	48.17 a	44.80 cdef
5. N 1206 "	2.04 cd	1.27 f	1.65 fg	48.37 a	52.66 a	50.51 ab
6. N 101 (White)	2.33 abc	1.79 ab	2.06 abc	48.47 a	55.01 a	51.74 a
7. N 103 "	2.01 cd	1.29 ef	1.65 fg	45.42 ab	49.53 a	47.48 abcd
8. N 104 "	2.04 cd	1.48 cdef	1.76 defg	41.29 bcd	48.45 a	44.87 cdef
9. N 105 "	2.18 bcd	1.26 f	1.72 efg	38.31 cde	47.47 a	42.89 efg
10. N 107 "	2.54 a	1.43 def	1.98 bcd	45.30 ab	50.85 a	48.07 abcd
11. Khumal 7642	2.56 a	1.91 a	2.24 a	38.68 cde	54.64 a	46.66 abcd
12. Khumal 7633	2.01 cd	1.78 ab	1.90 bcde	38.81 cde	49.02 a	43.92 defg
13. Thai Composite	2.66 a	1.77 ab	2.22 a	33.73 e	49.43 a	41.58 g
14. Amarillo Subtropical	2.10 cd	1.33 ef	1.71 efg	48.64 a	48.75 a	48.70 abcd
15. Amarillo Bajio	1.83 d	1.41 def	1.62 g	43.08 abc	48.85 a	45.97 bcde
16. Blanco Subtropical	2.05 cd	1.66 abcd	1.86 cdef	45.10 ab	53.48 a	49.29 abc
Means	2.23	1.53	1.88	42.70	50.24	46.47

Means within same column with the same letter are not significantly different at DMRT = .05.

Table 13. Effect of lime on mean nutrient concentration and uptake.

Lime (kg per ha)	Dry Weight (gm per pot)	Concentration %					Uptake (mg per pot)				
		N	P	K	Ca	Mg	N	P	K	Ca	Mg
0	2.87 a	1.77 b	.113 a	3.52 b	.62 b	.32 b	46.49 a	3.53 a	93.32 a	16.04 b	9.02 b
6500	2.50 b	1.98 a	.100 b	3.64 a	.83 a	.39 a	46.45 a	2.59 b	84.92 b	19.63 a	9.60 a
Means	2.68	1.88	.106	3.58	.72	.35	46.47	3.06	89.12	17.84	9.31

Table 14. Effect of phosphorus on mean nutrient concentration and uptake.

P (ppm)	(gm per pot)	Concentration %					Uptake (mg per pot)				
		N	P	K	Ca	Mg	N	P	K	Ca	Mg
0	1.96 b	2.23 a	.08 b	4.41 a	.88 a	.37 a	42.70 b	1.48 b	85.70 b	16.94 b	7.19
100	3.41 a	1.53 b	.14 a	2.75 b	.57 b	.34 b	50.24 a	4.64 a	92.54 a	18.73 a	11.43
Means	2.68	1.88	.11	3.58	.72	.35	46.47	3.06	89.12	17.84	9.13

Means within same column with the same letter are not significantly different at DMRT = .05.

tion and uptake (Table 15). Phosphorus deficiency symptoms were observed particularly at the zero P level with a great deal of variation in symptoms indicating that the genotypes do vary in tolerance to P deficiency. Dry matter weight and P content and P uptake appeared to correlate well indicating that increase in yield was primarily due to P application for a particular genotype. Among the sources, N 1026, Blanco Subtropical, N-101 and N-608 proved to be superior in average P uptake. Particularly N-1206 and Blanco Subtropical showed the least symptoms of phosphorus deficiency. Higher dry matter weight, less phosphorus deficiency symptoms, greater uptake and greater dry matter per unit P would classify strain N-1206 as more efficient (Table 16).

Table 15. Analysis of variance of P concentration and uptake.

Sources of Variation	d.f.	P Concentration		P Uptake	
		S.S.	P>F	S.S.	P>F
Genotype (G)	15	.01	.0001	.2	.0001
Phosphorus (P)	1	.17	.0001	4.8	.0001
P x G	15	.007	.02	.08	.16
Lime (L)	1	.008	.0001	.42	.0001
L x G	15	.007	.02	.11	.02
L x P	1	.01	.001	.44	.0001
L x P x G	15	.006	.04	.11	.03
Error	128	.03		.50	

Overall P concentration does not look encouraging (Table 16). Possibly the limitation of root growth in a greenhouse pot culture hindered uptake.

Statistical analysis showed that both P content and P uptake progressively increased with the addition of P. On the other hand, the overall effect of lime

Table 16. Mean plant P concentration and uptake of 16 corn strains at two levels of phosphorus.

	P Concentration %			P Uptake (mg per pot)		
	0 ppm P	100 ppm P	Means	0 ppm P	100 ppm P	Means
1. N 211 (Yellow)	.074 bcd	.132 bcd	.103 bcdefg	1.19 de	4.06 cd	2.63 cd
2. N 212 "	.080 abcd	.148 abc	.114 abcde	1.51 abc	4.85 abcd	3.18 abc
3. N 304 "	.089 a	.128 cd	.108 abcde	1.48 abc	4.50 abcd	2.99 bcd
4. N 608 "	.072 bcd	.139 abcd	.105 bcdefg	1.53 abc	5.16 abc	3.35 ab
5. N 1206	.072 bcd	.129 bcd	.101 efg	1.72 a	5.57 a	3.65 a
6. N 101 (White)	.082 abc	.162 a	.122 a	1.71 a	5.03 abc	3.37 ab
7. N 103 "	.075 bcd	.133 bcd	.104 bcdefg	1.70 a	5.27 ab	3.48 ab
8. N 104 "	.073 bcd	.114 d	.093 g	1.47 abc	3.84 d	2.65 cd
9. N 105 "	.080 abcd	.126 cd	.103 cdefg	1.41 bcd	4.83 abcd	3.12 abcd
10. N 107 "	.075 bcd	.128 bcd	.101 defg	1.34 bcd	4.69 abcd	3.01 bcd
11. Khumal 7642	.084 abc	.151 abc	.118 ab	1.27 cde	4.56 abcd	2.92 bcd
12. Khumal 7633	.070 cd	.134 bcd	.102 cdefg	1.35 bcd	3.74 d	2.55 d
13. Thai Composite	.084 ab	.149 abc	.117 abc	1.07 e	4.20 bcd	2.63 cd
14. Amarillo Subtropical	.073 bcd	.113 d	.093 g	1.70 a	4.34 bcd	3.02 bcd
15. Amarillo Bajio	.067 d	.130 bcd	.099 fg	1.59 ab	4.54 abcd	3.07 abcd
16. Blanco Subtropical	.078 abcd	.154 ab	.116 abcd	1.71 a	5.04 abc	3.37 ab
Means	.077	.136	.107	1.48	4.64	3.06

Means within same column with the same letter are not significantly different at DMRT = .05.

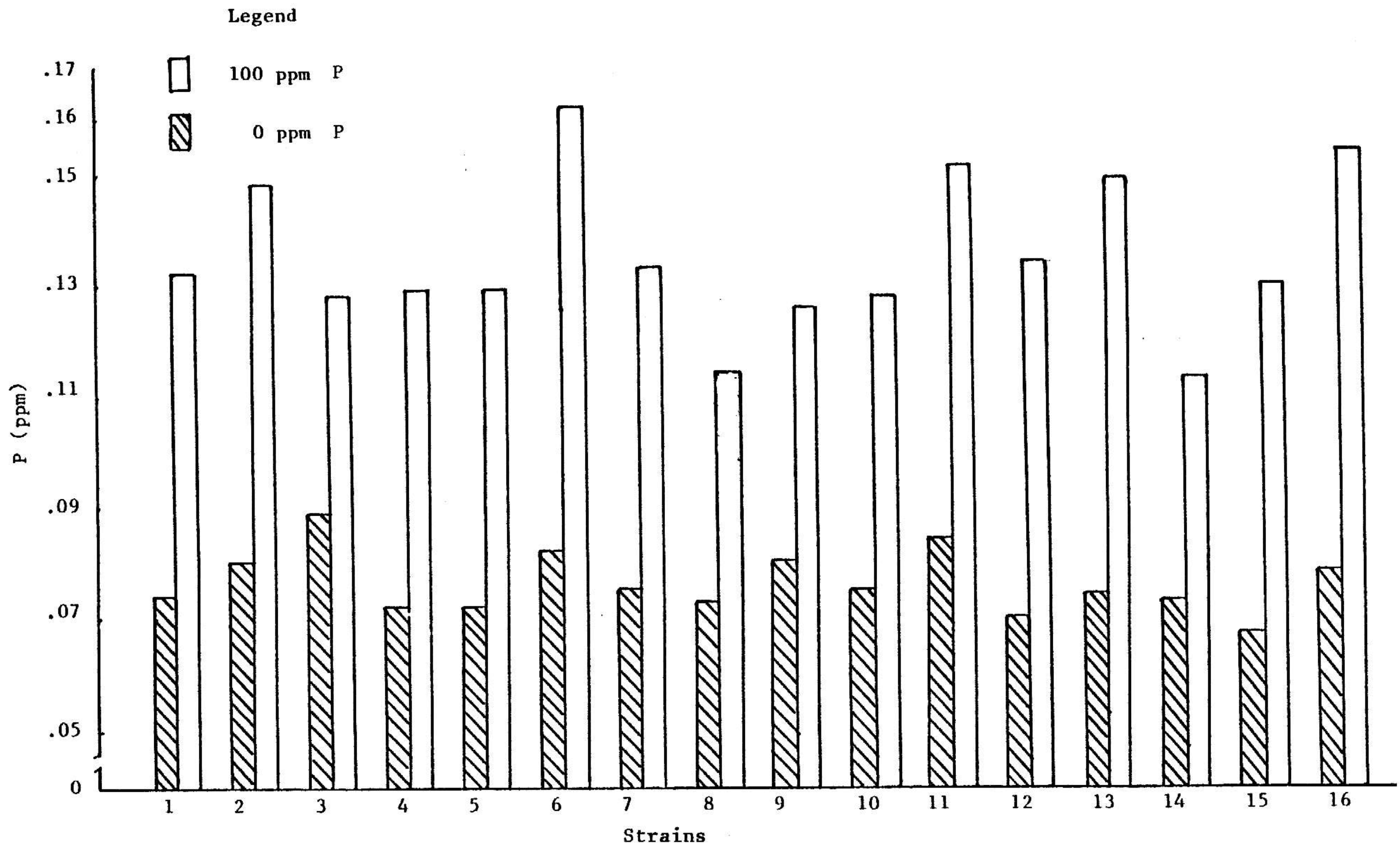

Fig. 2. Genotypic differences for P concentration at two levels of phosphorus.

was detrimental to P. However, while separating the effect of lime at two levels of P application, no significant changes were found for both P concentration and uptake at a zero level of P (Table 17).

The Nepal locals are generally considered early maturing cultivars compared to exotic populations. The previous finding by Bruetsch et al. (1976) that the early maturing genotypes are higher P accumulators does not agree with results found in this study since a wide array in concentration was noticed irrespective of maturity type (Table 16 and Fig. 2).

Average P content and uptake increased by almost 75% and slightly greater than 100% respectively with the application of P. Such a highly significant increase would be expected in a soil which is very deficient in P. However, genotypic response at each level of P treatment should make it possible to select genotypes tolerant to P stress condition. For instance, N 304, N 1206 and Blanco Subtropical did show the least visual deficiency symptoms, however, their P content is variable from source to source (Table 16).

Consistency between P concentration and uptake was found at each level of P and lime suggesting that there should be a positive correlation with dry matter production (Table 17). One important observation could be added; unlike other nutrients under study, P concentration and uptake behaved positively with the dry matter production of any strain. However, the same relationship cannot be established from source to source. Secondly, response of a strain under P stress condition and P non-stress condition are not similar. For instance, N 304 showed significantly higher concentration of P per unit dry matter than other sources under P-stress condition, but not when P was added.

Potassium Concentration and Uptake: Plant material absorbs large amounts of K. The amount of K present in plants varies from genotype to genotype and with environmental conditions under which the plant is grown. For a given level of soil K availability, dry matter production is influenced by levels of

Table 17. Effect of lime on mean P concentration and P uptake at two levels of phosphorus.

Lime	P Concentration %			P Uptake (mg per pot)		
(kg per ha)	0 ppm P	100 ppm P	Means	0 ppm P	100 ppm P	Means
0	.076 a	.149 a	.113 a	1.47 a	5.59 a	3.53 a
6500	.078 a	.122 b	.100 b	1.50 a	3.69 b	2.59 b
Means	.077	.136	.106	1.48	4.64	3.06

Table 18. Effect of lime on K concentration and uptake at two levels of phosphorus.

Lime	K Concentration %			K Uptake (mg per pot)		
(kg per ha)	0 ppm.P	100 ppm P	Means	0 ppm P	100 ppm P	Means
0	4.30 b	2.74 a	3.52 b	84.29 a	102.36 a	93.32 a
6500	4.52 a	2.75 a	3.64 a	87.11 a	82.73 b	84.92 b
Means	4.41	2.75	3.58	85.70	92.55	89.12

Means within same column with the same letter are not significantly different at DMRT = .05.

other factors and increased dry matter tends to lower the potassium concentration of a genotype. For instance, P treatment in this study lowered the K concentration of all sources which could be primarily due to an increase in dry matter (Table 20), because total uptake of K did not increase much at the higher P level.

Table 19. Analysis of variance of K concentration and uptake.

Sources of Variation	d.f.	K Concentration		K Uptake	
		S.S.	P>F	S.S.	P>F
Genotype (G)	15	10.4	.0001	177.5	.0001
Phosphorus (P)	1	132.7	.0001	22.5	.0001
P x G	15	6.0	.0001	48.1	.0003
Lime (L)	1	0.7	.013	33.9	.0001
L x G	15	2.3	.136	34.3	.01
L x P	1	0.5	.028	60.5	.0001
L x P x G	15	3.3	.017	15.3	.492
Error	128	13.8		134.3	

Statistical analysis showed highly significant results for all main effects and their interactions except for the lime by genotype interaction for K concentration and lime by P by genotype interaction for K uptake (Table 19). N 103, a relatively higher dry matter producer, had a high concentration of K in the plant material and thus ranked on the top for K uptake.

The significant result for genotype by phosphorus interaction and non-significant result of genotype by lime interaction is an indication that K content per unit dry matter production of genotypes is affected by P availability in the soil.

Table 20. Mean plant K concentration and uptake of 16 corn strains at two levels of phosphorus.

		K Concentration %			K Uptake (mg per pot)		
		0 ppm P	100 ppm P	Means	0 ppm P	100 ppm P	Means
1.	N 211 (Yellow)	4.44 ab	2.83 abcd	3.63 abcd	72.23 ef	86.05 de	79.14 cd
2.	N 212 "	4.79 ab	2.94 abc	3.86 a	90.56 bcd	91.96 cd	91.26 b
3.	N 304 "	4.88 a	2.60 de	3.74 abc	80.70 de	91.41 cd	86.05 bc
4.	N 608 "	4.57 ab	3.04 ab	3.79 ab	98.96 ab	111.79 ab	105.37 a
5.	N 1206 "	4.35 abc	2.60 de	3.48 cde	104.17 a	108.95 ab	106.56 a
6.	N 101 (White)	4.59 ab	2.83 abcd	3.71 abcd	96.00 abc	88.30 de	92.15 b
7.	N 103 "	4.68 ab	2.65 cde	3.67 abcd	106.71 a	102.74 abc	104.73 a
8.	N 104 "	4.27 bc	2.59 de	3.43 cde	86.28 bcd	84.46 de	85.37 bc
9.	N 105 "	4.53 ab	2.42 e	3.48 cde	80.67 de	92.12 cd	86.39 bc
10.	N 107 "	4.79 ab	2.67 cde	3.73 abcd	85.61 bcde	97.28 bcd	91.45 b
11.	Khumal 7642	4.48 ab	3.11 a	3.79 ab	67.79 fg	89.08 de	78.44 cd
12.	Khumal 7633	4.34 abc	2.73 bcde	3.54 bcd	84.24 cde	75.81 e	80.03 cd
13.	Thai Composite	4.51 ab	3.11 a	3.81 ab	57.21 g	87.41 de	72.31 d
14.	Amarillo Subtropical	3.90 cd	2.50 e	3.20 ef	90.76 bcd	94.11 cd	92.44 b
15.	Amarillo Bajio	3.53 d	2.45 e	2.99 f	82.85 cde	85.20 de	84.02 bc
16.	Blanco Subtropical	3.92 cd	2.92 abc	3.42 de	86.45 bcd	94.03 cd	90.24 b
	Means	4.41	2.75	3.58	85.70	92.54	89.12

Means within same column with the same letter are not significantly different at DMRT = .05.

Overall K concentration and uptake were significantly influenced by levels of lime application. Lime increased K concentration whereas decreased K uptake. On the other hand, P decreased K concentration but increased K uptake indicating the effects of the two treatments on dry matter production (Table 14).

Analysis of variance of 16 corn strains at each level of P indicated that all the strains showed significant depression of K concentration with addition of P whereas K uptake was inconsistent with respect to two levels of soil P. For instance, N 101, N 103, N 104 and Khumal 7633 had higher uptake at zero P than at the higher P level, whereas the others had higher uptake at the higher level of P. Likewise, although the K uptake varied significantly between the two levels of soil P, the marginal differences of strains between the two levels tended to remain narrower for K uptake than for K concentration (Table 20).

The influence of lime levels did not give symmetric results at the two levels of P for K concentration and uptake (Table 18). Levels of lime appear to have resulted in significant differences for K concentration at the zero level of P, but such differences did not exist at the higher level. Lime levels had a significant effect on K uptake only at the higher level of P. Such an asymmetric result is an indication that lime levels had a nonspecific role in K uptake.

Calcium Concentration and Uptake: Calcium along with Mg plays an important role in soil chemistry and plant nutrition. Lime would certainly play a key role in raising the level of Ca in soils and plants.

Although no noticeable Ca deficiency symptoms were observed, strains exhibited variation in Ca concentration and uptake in the plant tops. Among the main effects and their interactions, all interactions which included lime were not statistically significant (Table 21). Thus, although the effect of lime was highly significant in creating differences for Ca, different levels of lime did not react differently with different strains and with levels of P suggesting that lime raised Ca concentration and uptake irrespective of other treatment levels.

Table 21. Analysis of variance of Ca concentration and uptake.

Sources of Variation	d.f.	Ca Concentration		Ca Uptake	
		S.S.	P>F	S.S.	P>F
Genotype (G)	15	.53	.0003	11.06	.0001
Phosphorus (P)	1	4.66	.0001	1.53	.0001
P x G	15	.37	.012	2.01	.015
Lime (L)	1	2.27	.0001	6.17	.0001
L x G	15	.06	.992	1.21	.247
L x P	1	.0001	.898	.03	.463
L x P x G	15	.19	.551	1.19	.260
Error	128	1.48		8.7	

Among the strains, N 211, N 103 and Thai Composite had significantly higher Ca concentration, however, for Ca uptake only N 103 and N 1206 showed profound effect (Table 22). Overall array for Ca concentration and uptake among sources appears to be similar to that of K.

Addition of lime significantly decreased dry matter and increased both Ca concentration and uptake (Table 13). The addition of phosphorus raised the level of dry matter and decreased Ca concentration (Table 14). However, in the first case, increase in Ca uptake and concentration could be a better indication that Ca in the corn plant top increases significantly irrespective of dry matter production. But in the latter case, effect of P levels in changing Ca concentration and uptake could be attributed to the proportional change in dry matter

Table 22. Mean Ca concentration and uptake of 16 corn strains at two levels of phosphorus.

		Ca Concentration %			Ca Uptake (mg per pot)		
		0 ppm P	100 ppm P	Means	0 ppm P	100 ppm P	Means
1.	N 211 (Yellow)	1.02 ab	.57 abcd	.80 a	16.61 cde	17.20 def	16.91 bcd
2.	N 212 "	.89 abcde	.62 abc	.75 ab	16.61 cde	18.39 cdef	17.50 bc
3.	N 304 "	.95 abc	.56 bcd	.75 ab	15.61 cdef	19.29 cde	17.45 bc
4.	N 608 "	.85 cde	.56 bcd	.70 abcd	18.33 bc	20.27 bcd	19.30 b
5.	N 1206 "	.93 abcde	.58 abcd	.75 ab	22.09 a	23.31 ab	22.70 a
6.	N 101 (White)	.83 cde	.68 a	.76 ab	17.58 bc	20.89 bc	19.24 b
7.	N 103 "	.90 abcde	.67 ab	.79 a	20.45 ab	25.21 a	22.83 a
8.	N 104 "	.88 abcde	.55 bcd	.71 abcd	17.72 bc	17.69 cdef	17.70 bc
9.	N 105 "	.80 cde	.54 cd	.67 bcd	14.16 def	20.34 bcd	17.25 bc
10.	N 107 "	.93 abcd	.54 cd	.74 abc	16.61 cde	19.15 cde	17.88 bc
11.	Khumal 7642	.86 bcde	.54 cd	.70 abcd	13.08 f	15.02 fg	14.05 e
12.	Khumal 7633	.82 cde	.50 cd	.66 bcd	15.98 cdef	13.78 g	14.88 de
13.	Thai Composite	1.04 a	.56 bcd	.80 a	13.35 ef	15.36 fg	14.35 e
14.	Amarillo Subtropical	.78 de	.48 d	.63 d	18.04 bc	17.25 def	17.64 bc
15.	Amarillo Bajio	.76 e	.58 abcd	.67 bcd	18.00 bc	20.00 cd	18.99 bc
16.	Blanco Subtropical	.77 de	.52 cd	.65 cd	16.87 cd	16.50 efg	16.68 cd
	Means	.88	.57	.73	16.94	18.73	17.84

Means within same column with the same letter are not significantly different at DMRT = .05.

production.

Significant genotypic variability has also been observed at each level of P treatment for both Ca concentration and Ca uptake (Table 22). As expected, all sources exhibited significant decrease in Ca content per unit dry matter production at the higher level of P. However, the genotypic sequences within each level does not appear to be similar indicating that a genotype by phosphorus level interaction could be possible. On the other hand, order differences for Ca uptake among sources between the two P levels is an indication of significant genotype by P interaction (Table 22). Although P treatment effects are significant for both Ca concentration and Ca uptake, the differences between P levels for Ca uptake among sources tends to be narrower than for Ca concentration.

Thai Composite had a significantly higher Ca concentration at zero level of P as well as for overall means followed by N 103 and N 211. Amarillo Subtropical which had relatively higher dry matter had a significantly less average Ca concentration. But the top dry matter producing strain N 1206 fell in the upper range. N 103 exhibited significantly highest average Ca uptake followed by N 1206. Hence, N 103 could be classified as an efficient source for both Ca concentration and Ca uptake.

Obviously, lime treatment was effective in increasing both Ca concentration and uptake at both levels of P (Table 23). Likewise, at each level of lime, influence of P was equally significant in reducing and increasing the levels of Ca concentration and uptake, respectively, nearly in the same proportion. Thus interaction between lime and P levels for both Ca concentration and uptake should presumably be non-significant (Table 21). However, with the present analysis, it is not possible to determine to what extent the lime application has been effective in increasing Ca levels without lowering the dry matter production.

Table 23. Effect of lime on mean Ca concentration and uptake at two levels of phosphorus.

Lime	Ca Concentration %			Ca Uptake (mg per pot)		
(kg per ha)	0 ppm P	100 ppm P	Means	0 ppm P	100 ppm P	Means
0	.77 b	.46 b	.62 b	15.02 b	17.07 b	16.04 b
6500	.98 a	.68 a	.83 a	18.87 a	20.39 a	19.63 a
Means	.88	.57	.72	16.95	18.73	17.84

Table 24. Effect of lime on mean Mg concentration and uptake at two levels of phosphorus.

Lime	Mg Concentration %			Mg Uptake (mg per pot)		
(kg per ha)	0 ppm P	100 ppm P	Means	0 ppm P	100 ppm P	Means
0	.34 b	.30 b	.32 b	6.81 b	11.22 a	9.02 b
6500	.39 a	.38 a	.39 a	7.56 a	11.65 a	9.60 a
Means	.37	.34	.35	7.19	11.44	9.31

Means within same column with the same letter are not significantly different at DMRT = .05.

Magnesium Concentration and Uptake: As already pointed out, Mg is also an ion available through the cation exchange complex. Application of lime may have an effect on Mg as well as on Ca depending on the type of lime used. Statistical analysis showed main treatment effects on Mg concentration as well as on Mg uptake. The P by genotype interaction failed to affect Mg concentration significantly. On the other hand, lime by P interaction did show a significant result (Table 25).

Table 25. Analysis of variance of Mg concentration and uptake.

Sources of Variance	d.f.	Mg Concentration		Mg Uptake	
		S.S.	P>F	S.S.	P>F
Genotype (G)	15	.078	.0002	3.09	.0001
Phosphorus (P)	1	.029	.0001	8.67	.0001
P x G	15	.033	.175	.59	.0098
Lime (L)	1	.201	.0001	.17	.0028
L x G	15	.017	.769	.37	.169
L x P	1	.017	.001	.01	.411
L x P x G	15	.026	.379	.35	.208
Error	128	.207		2.28	

Average Mg concentration in the corn plant tops was nearly half of Ca and the variability in terms of Mg concentration and uptake did not appear to be similar to Ca from source to source. For instance, Amarillo Bajio which was considered to be inefficient for both Ca concentration and uptake was significantly superior for Mg absorption. But, N 103 remained significantly superior for both Mg concentration and uptake (Table 26).

Overall effect of lime as well as that of P treatments on Mg appear to be similar to Ca. However, the difference between two levels of each factor tended to be narrower for Mg absorption except for the effect of P levels on Mg uptake (Table 14). The shift in differences between two levels of each treatment could possibly be explained by use of a calcium source of lime. If this is true, the shift would be reversed when a magnesium source of lime is used.

Significant genotypic variability was also observed at each level of P for both Mg concentration and uptake (Table 26). Although genotype by P interaction did not appear to be significant for Mg concentration, depressive effect of P application could not be found for all genotypes. N 101, Khumal 7642 and Blanco Subtropical exhibited a somewhat reverse trend. On the other hand, Mg uptake significantly increased at higher level of P although the genotype by P interaction was significant.

Effect of lime was significant at zero level of P for both Mg concentration and uptake. But at higher level of P, significant differences due to lime were observed only for Mg concentration (Table 24). Conversely, for both Mg concentration and uptake significant effect of P treatment could be estimated only at zero level of lime.

For Six Corn Strains

Taking into consideration the six varieties with three levels of lime and two levels of P treatment, genotypic variability due to P does not appear to deviate from what was found in the previous analyses. Changes due to the lime variable would be expected since three levels of lime (zero, medium and high) were introduced instead of two. The logical question is to what extent has the medium dose of lime affected all the dependent variables.

Obviously, mean values for zero and higher levels of lime treatment have decreased except for N and P concentration.

No significant difference between medium and higher level of lime occurred for dry matter production, P and Mg concentration and P uptake (Table 27). Potassium concentration did not show a significant difference between zero and

Table 26. Mean plant Mg concentration and uptake of 16 corn strains at two levels of phosphorus.

		Mg Concentration %			Mg Uptake (mg per pot)		
		0 ppm P	100 ppm P	Means	0 ppm P	100 ppm P	Means
1.	N 211 (Yellow)	.384 ab	.332 bcd	.358 bcde	6.18 def	10.07 efg	8.13 fgh
2.	N 212 "	.390 ab	.345 abcd	.368 abc	7.32 bcd	10.62 defg	8.97 efg
3.	N 304 "	.376 ab	.328 bcd	.352 bcde	6.20 def	11.38 cdef	8.79 efg
4.	N 608 "	.389 ab	.344 abcd	.366 abcd	8.51 ab	12.60 abcd	10.56 bc
5.	N 1206 "	.352 abc	.299 d	.326 e	8.47 ab	12.18 bcd	10.33 cd
6.	N 101 (White)	.349 abc	.379 ab	.364 abcde	7.36 bcd	11.64 bcde	9.50 cde
7.	N 103 "	.404 a	.375 abc	.389 ab	9.21 ab	14.29 ab	11.75 a
8.	N 104 "	.371 ab	.332 bcd	.351 bcde	7.50 bcd	10.75 defg	9.13 def
9.	N 105 "	.362 abc	.350 abcd	.356 bcde	6.48 de	13.19 abc	9.84 cde
10.	N 107 "	.338 bc	.336 bcd	.337 cde	6.06 def	12.13 bcd	9.09 ef
11.	Khumal 7642	.343 bc	.347 abcd	.345 cde	5.21 ef	9.93 efg	7.57 h
12.	Khumal 7633	.348 abc	.323 cd	.336 cde	6.77 cd	8.90 g	7.84 gh
13.	Thai Composite	.387 ab	.342 abcd	.365 abcde	4.95 f	9.51 fg	7.23 h
14.	Amarillo Subtropical	.352 abc	.312 d	.332 cde	8.22 abc	11.35 cdef	9.78 cde
15.	Amarillo Bajio	.406 a	.392 a	.40 a	9.58 a	13.57 ab	11.57 ab
16.	Blanco Subtropical	.314 c	.341 abcd	.327 de	6.94 cd	10.85 defg	8.90 efg
	Means	.367	.342	.345	7.19	11.44	9.32

Means within same column with the same letter are not significantly different at DMRT = .05.

Table 27. Effect of lime on mean nutrient concentration and uptake of six corn strains.

Lime (kg per ha)	Dry Weight (gm per pot)	Concentration %					Uptake (mg per pot)				
		N	P	K	Ca	Mg	N	P	K	Ca	Mg
0	2.71 a	1.84 b	.114 a	3.36 b	.58 c	.32 b	46.22 a	3.36 a	85.01 a	14.34 c	8.53 a
3250	2.35 b	1.72 c	.104 b	3.39 b	.72 b	.37 a	38.20 b	2.59 b	75.23 b	15.72 b	8.48 a
6500	2.39 b	2.01 a	.101 b	3.56 a	.79 a	.38 a	45.82 a	2.49 b	80.81 a	17.86 a	9.10 a
Means	2.48	1.86	.106	3.43	.70	.36	43.41	2.81	80.35	15.98	8.70

Table 28. Effect of phosphorus on mean nutrient concentration and uptake of six corn strains.

Phosphorus (ppm)	Dry Weight (gm per pot)	Concentration %					Uptake (mg per pot)				
		N	P	K	Ca	Mg	N	P	K	Ca	Mg
0	1.88 b	2.13 a	.076 b	4.08 a	.86 a	.37 a	39.09 b	1.41 b	75.47 b	15.74 a	6.99 b
100	3.09 a	1.58 b	.136 a	2.78 b	.54 b	.34 b	47.74 a	4.22 a	85.24 a	16.21 a	10.42 a
Means	2.48	1.86	.106	3.43	.70	.36	43.41	2.81	80.35	15.98	8.70

Means within same columns with the same letter are not significantly different at DMRT = .05.

medium level of lime. Nitrogen and Ca concentration and uptake showed significant difference for all levels of lime. For each increase in lime imput, both Ca concentration and uptake showed a significant increase. Lastly, the only nutrient which did not express any significant difference at all levels was Mg uptake.

Experiment II

Response of corn genotypes to variable levels of Al concentration was measured in terms of root parameters. Since the toxic effect of Al first affects growth of the root system, correlating the effects on roots with plant root growth could be a quick and reliable technique.

This study could not be analyzed statistically primarily due to two reasons: first, the control plot (0 mM Al) could not be evaluated mainly due to contamination with microorganisms after 7 days; and second, there was only one replication per observation. Thus, all the parameter comparisons were based on 0.03 mM Al as a control. In nutrient culture, contamination due to microorganisms was a problem and made the experiment difficult to interpret. Average of initial primary root length of each corn genotype was varied from source to source even under controlled conditions. Thus it was not possible to evaluate the root efficiency of genotypes merely by comparing the root length at each level of Al treatment. A more precise and reliable method to evaluate the root system was measurement with respect to the control within each source and thus comparing the relative scale among sources. The root system is composed of a primary root system and a secondary root system. Combining both systems to get a composite value was more precise in measuring the overall response.

Although Va-35 and Thai Composite produced the highest primary root length at .03 level Al, they showed poorer results at higher concentrations. On the other hand, PI 270071 produced significantly higher average relative root length followed by K724 x K41 and Amarillo Subtropical (Table 29). Similarly, Khumal 7633 showed its highest relative root length at .06 mM Al but was significantly decreased at .09 mM Al. Those which were relatively tolerant to Al toxicity only at .06 mM were H28 x K731, Khumal 7642, Blanco Subtropical and PI-270101. On the other hand, those which were tolerant at both levels were PI 270081, PI 270084, K724 x K41, Khumal 7633 and PI 270071.

Secondary root coefficient was measured at base level .03 mM Al since the control was contaminated (Table 30). The coefficient value varied from 0.25 to 1. However, the coefficient rating did not necessarily correlate with the rating for root length. For instance, Amarillo Subtropical whose average primary root length did not decrease at higher concentration of Al gave only 0.25 secondary root coefficient. On the other hand, PI 270071 correlated well with the average root length. The other sources which gave the highest coefficient at 0.09 mM Al were Khumal 7633 and Amarillo Bajio followed by PI 270083, K724 x K41 and Khumal 7642. Those which had the same level of coefficient at both levels were Thai Composite, Blanco Subtropical and PI 270101 followed by K724 x K695 and PI 270081 indicating that their level of tolerance did not vary between levels of Al.

Composite value for each genotype combines the relative primary root length by corresponding secondary root coefficient which could be a better indicator of genotypic efficiency in response to variable Al concentration. Some sources such as Khumal 7642 and PI 270083 although showing a higher composite value to Al tolerance at .06 mM Al, were not tolerant at the 0.09 mM Al level. On the other hand, PI 270071, Khumal 7633 and K724 x K41 exhibited a relatively stable tolerance level even at higher concentrations. Some showed relatively poor results at all levels. Among sources which exhibited relatively promising tolerance only at higher Al concentration was Amarillo Bajio.

Table 29. Performance of corn strains to differential Al concentration.

	Average Root length (cm) Al Concentration (mM)				Relative Root Length Al Concentration (mM)	
	.03	.06	.09	Means	.06	.09
1. K724 x K695	18	3	2	7.6	.17	.11
2. PI 270088	24	15	13	17.3	.60	.54
3. K731 x H28	15	7	8	10	.47	.53
4. PI 270081	20	17	16	17.6	.85	.80
5. PI 270084	22	15	14	17.0	.68	.64
6. PI 270083	16	15	13	14.7	.94	.81
7. K724 x K41	12	11	12	11.7	.92	1.00
8. Oh7B	9	7	5	7	.78	.56
9. Va 35	28	19	18	21.7	.68	.64
10. Khumal 7642	15	19	12	15.3	1.27	.80
11. Khumal 7633	18	14	15	15.7	.78	.83
12. Thai Composite	28	18	15	20.3	.64	.54
13. Amarillo Subtropical	14	10	14	12.7	.71	1.00
14. Amarillo Bajio	26	15	20	20.3	.58	.77
15. Blanco Subtropical	26	24	16	22	.92	.62
16. PI 270101	18	17	12	15.7	.94	.67
17. Oh 43	18	17	C	17.5	.94	C
18. PI 270071	19	25	20	21.3	1.32	1.05
Means	18.8	14.7	12.9	15.5	.79	.65

C = contaminated

Table 30. Performance of corn strains to differential Al concentration.

	Secondary Root Coefficient Al Concentration (mM)			Composite Value Al Concentration (mM)		
	.03	.06	.09	.03	.06	.09
1. K724 x K695	1	.50	.50	1	.08	.09
2. PI 270088	1	.75	.50	1	.47	.27
3. K731 x H28	1	C	C	1	C	C
4. PI 270081	1	.50	.50	1	.43	.40
5. PI 270084	1	.75	.50	1	.51	.32
6. PI 270083	1	1	.75	1	.94	.61
7. K724 x K41	1	1	.75	1	.92	.75
8. Oh7B	1	.75	.25	1	.58	.14
9. Va 35	1	.50	.75	1	.34	.48
10. Khumal 7642	1	1	.75	1	1.0	.60
11. Khumal 7633	1	1	1	1	.78	.83
12. Thai Composite	1	.75	.75	1	.48	.40
13. Amarillo Subtropical	1	.25	.25	1	.18	.40
14. Amarillo Bajio	1	1	1	1	.58	.77
15. Blanco Subtropical	1	.75	.75	1	.69	.46
16. PI 270101	1	.75	.75	1	.71	.50
17. Oh 43	1	.25	C	1	.24	C
18. PI 270071	1	1	1	1	1.0	1.0
Means	1	.74	.67	1	.58	.50

C = contaminated

Fig. 3. Strain Blanco Subtropical in nutrient solution at .03, .06 and .09 mM Al showing relative tolerance to Al toxicity.

Fig. 4. Inbred Va-35 in nutrient solution at .03, .06 and .09 mM Al showing relatively susceptible to Al toxicity.

Fig.3

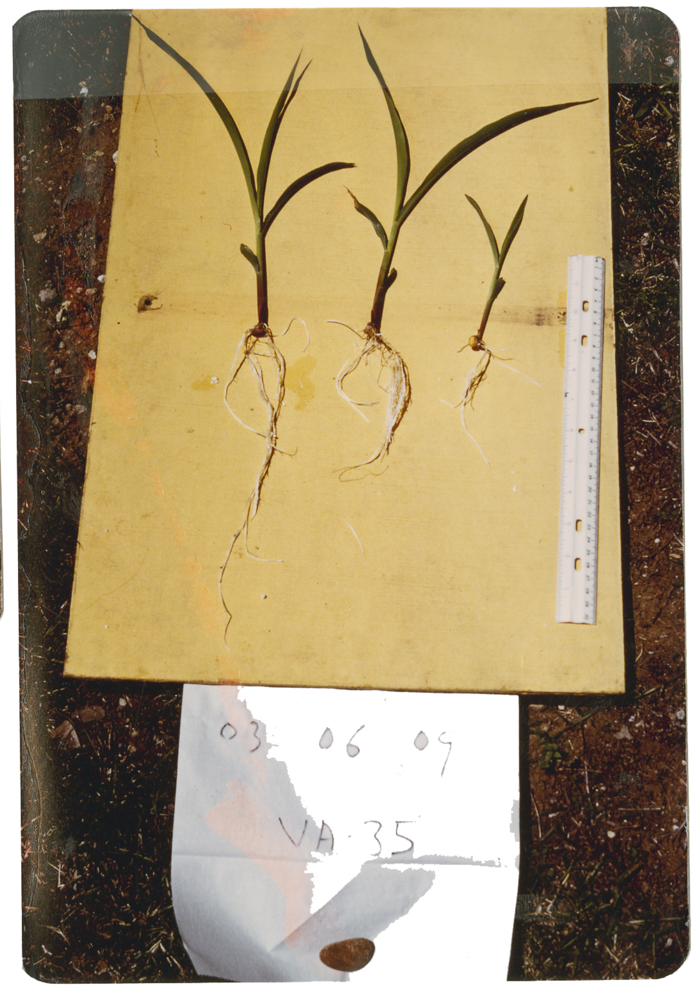

Fig.4

The above results imply that genotypic tolerance to Al toxicity is a relative term and effectiveness of screening can vary from genotype to genotype. However, all genotypes become sensitive to Al toxicity if the level of Al concentration is high. Hence, the level of stress to be imposed is an important factor which may vary within and between species and type of conditions under which the plant is grown.

Experiment III

Dry Weight: Fifteen varieties, inbreds and hybrids used in this study exhibited significant variability for dry matter production (Table 32). However, dry matter yield for plants grown for 35 days under greenhouse conditions was not sufficient to explain directly the efficient yield production in highly acidic soil. Analysis in terms of relative yield value was a better tool for explaining relative tolerance to soil acidity caused by high soluble Al.

Table 31. Analysis of variance of dry weight and its relative value.

Sources of Variation	d.f.	Dry Weight		d.f.	Relative Value	
		S.S.	P>F		S.S.	P>F
Genotype (G)	14	33.5	.0001	14	.59	.4387
Lime (L)	3	21.1	.0001	2	2.68	.0001
G x L	42	6.3	.2344	28	.78	.8874
Error	120	15.1		90	3.74	

Lime had a profound effect on dry matter production. Genotype x lime interaction was not significant indicating that all the sources tended to behave similarly irrespective of lime level (Table 31). Among the 15 sources, Amarillo Bajio produced the highest overall yield but was not significantly different from Amarillo Subtropical, PI 270080, A632 x W64A and Blanco Subtropical.

Table 32. Mean dry weight and relative dry weight of 15 corn strains.

	Mean Dry Weight (gm per pot)	Relative Weight			
		0 kg Lime	4000 kg Lime	8000 kg Lime	Means
1. Va-17	2.40 e	.91	1.0	1.07	.99
2. Co103	2.22 e	.58	1.0	1.37	.99
3. W64A	1.66 f	.64	.87	0.91	.81
4. W153R	2.78 e	.68	1.0	0.99	.89
5. PI 270080	3.01 abc	.93	1.1	1.16	1.06
6. PI 270083	2.46 de	.86	.89	0.97	.91
7. Mo17 x A634	3.13 ab	.67	.98	1.09	.91
8. A632 x W64A	2.72 cd	.70	.96	1.10	.92
9. A632 x A619	3.00 abc	.69	.98	0.94	.87
10. Blanco Subtropical	2.96 abc	.76	.78	1.16	.90
11. Khumal 7642	2.40 e	.74	1.0	1.16	.97
12. Khumal 7633	2.84 bc	.70	.94	1.12	.92
13. Thai Composite	2.16 e	.85	1.09	1.26	1.07
14. Amarillo Subtropical	3.04 abc	.84	.86	1.09	.93
15. Amarillo Bajio	3.19 a	.73	1.02	1.02	.92
Means	2.63	.75	.96	1.09	.94

Means within same column with the same letter are not significantly different at DMRT = .05

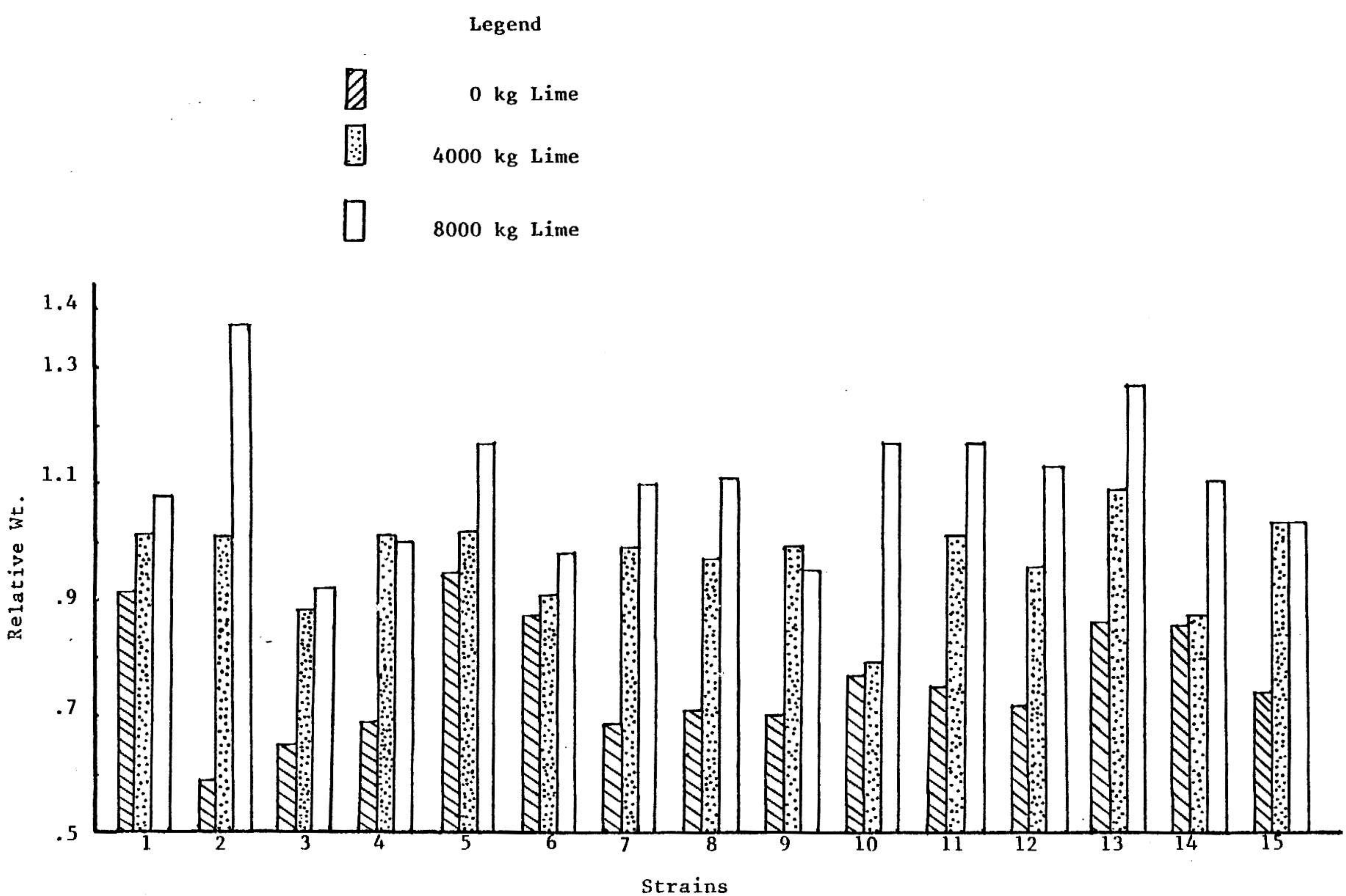

Fig. 5. Genotypic differences to relative weight as measured by the ratio of dry weight produced at each lime level to that produced at the highest lime level.

Fig. 6. Inbred Va-17 in the Greenhouse at 0, 4000, 8000 and 16500 kg/ha lime. Root density at zero level lime did not vary from other levels.

Fig. 7. Inbred Co103 in the Greenhouse at 0, 4000, 8000 and 16500 kg/ha lime. Root density decreased significantly as the level of lime decreased.

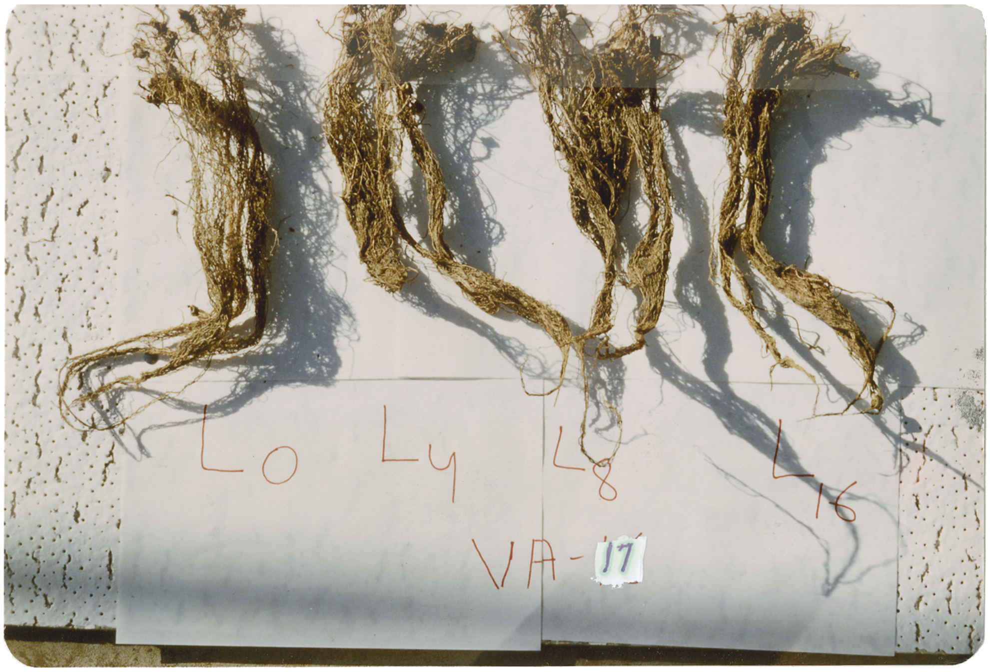

Fig.6.

Fig. 7.

In terms of relative yield, the sources exhibited broader variation under stress condition than under non-stress condition. Relative yield varied from .58 to .93 at zero lime level and tended to be narrower as the lime level increased (Table 32). At zero lime, PI 270080 with its relative weight of .93 was rated the most tolerant to Al toxicity followed by Va-17. Inbred Co103 with its relative weight of .58 was the most susceptible one and responded most significantly to lime treatments. Relative weight of this inbred was 1.37 at 8000 kg/ha lime (Fig. 5).

As in the previous greenhouse study, the yield level did not increase linearly with an increase in lime level (Table 33). After 8000 kg/ha of lime which brought the pH to 5.4, the yield declined significantly with additional lime suggesting that increasing pH further may have been the reason to decrease the P availability. Hence, overall highest dry matter production was achieved at 8000 kg/ha lime application. The soil analysis clearly indicated that the KCl-extractable Al dropped to almost zero at this pH and thus there was little Al toxicity (Table 46). About half of the sources performed as well at the 4000 kg/ha level of lime as at 8000 kg/ha. At 8000 kg per ha level only the sources W153R, PI 270083 and A632 x A619 fell slightly below.

Nitrogen Concentration and Uptake: Both genotype and lime had a significant effect on N concentration, but their interaction was not significant. The genotype, lime and genotype x lime interaction were all significant for N uptake (Table 35).

As already pointed out, nitrogen is an important nutrient and is highly mobile. No significant deficiency symptoms were observed, however, genotypic differences suggest that genotype can be screened for efficient nitrogen uptake. Although lime had a significant effect on both nitrogen concentration and uptake, they tended to change in proportion to dry matter production (Table 37). For instance, inbred W64A, a low dry matter producer, contained the

Table 33. Effect of lime on dry matter production, relative weight, nitrogen, phosphorus and potassium concentration and uptake.

Lime (kg per ha)	Dry Weight (mg per pot)	Relative Weight	Concentration %			Uptake (mg per pot)		
			N	P	K	N	P	K
0	2.08 c	.75	2.82 a	.172 a	3.50 c	57.3 c	3.50 c	71.5 d
4000	2.66 b	.96	2.61 b	.171 ab	4.01 b	67.7 b	4.47 b	104.6 c
8000	3.00 a	1.09	2.47 c	.172 a	4.10 ab	71.9 a	5.08 a	121.1 a
16500	2.80 b	1.00	2.51 c	.164 b	4.21 a	68.6 b	4.52 b	116.5 b
Means	2.63	.94	2.60	.170	3.96	66.4	4.39	103.4

Table 34. Effect of lime on calcium, magnesium, aluminum and manganese concentration and uptake.

Lime (kg per ha)	Concentration				Uptake (mg per pot)			
	Ca	Mg	Al	Mn	Ca	Mg	Al	Mn
	--------%--------		------ppm------					
0	.50 d	.329 a	125a	420 a	10.1 d	6.8 c	.256 b	.853 a
4000	.69 c	.306 b	127 a	301 b	17.9 c	8.2 b	.338 a	.785 b
8000	.80 b	.317 ab	119 a	202 b	23.4 b	9.4 a	.355a	.597 c
16500	.97 a	.328 a	116 a	120 d	26.4 a	9.2 a	.327 a	.339 d
Means	.74	.320	122	261	19.5	8.4	.319	.643

Means within same column with the same letter are not significantly different at DMRT = .05.

Table 35. Analysis of variance of N concentration and uptake.

Sources of Variation	d.f.	N Concentration		N Uptake	
		S.S.	P>F	S.S.	P>F
Genotype (G)	14	14.4	.0001	51.2	.0001
Lime (L)	3	3.3	.0001	53.3	.0001
G x L	42	2.3	.3638	25.5	.0396
Error	120	5.9		47.6	

highest N concentration and Amarillo Bajio, the highest dry matter producer, contained the lowest N concentration. Blanco Subtropical and Amarillo Subtropical, which were on the upper side for dry weight and N concentration, gave the highest N uptake. Since no nitrogen analysis was done for the soil, N uptake with respect to N availability in the soil could not be compared.

Phosphorus Concentration and Uptake: The acid mine soil was primarily critical for available phosphorus for the plant growth. Addition of 100 kg per ha phosphorus was not enough to remove severe P deficiency symptoms because 10 days after emergence, the P deficiency symptoms started appearing in all strains except Co103 and W64A. However, the degree of P deficiency was variable. In general the symptoms were more severe with an increase in lime level (Table 36).

Significant variability among sources and among lime treatments was observed for both P concentration (Table 37) and P deficiency symptoms. Broadly, genotypes could be classified as no visual symptoms, symptoms at all levels of lime or symptoms only at higher levels of lime. Thus, it was clear that P deficiency was under genetic control. For instance, Khumal 7633, PI 270083, Amarillo Subtropical and Blanco Subtropical exhibited relatively severe deficiency symptoms whereas W64A, Co103, Mo17 x A634 and A632 x A619 showed relatively mild deficiency symptoms. Even application of additional phosphorus did not

Table 36. Effect of lime on P deficiency symptoms.

Lime (kg per ha)	*Score (0 to 5)
0	0.78[b]
4000	0.93[b]
8000	1.20[a]
16500	1.42[a]

*0=no deficiency symptoms; 5=severe deficiency symptoms

remove P deficiency symptoms completely on severely affected treatments. Although Blanco Subtropical showed severe deficiency symptoms, the plant tissue analysis did not necessarily indicate lower P concentration. Similarly, although the hybrid A632 x A619 showed relatively less deficiency symptoms, plant tissue analysis indicated the lowest P concentration (Table 37).

Table 38. Analysis of variance of P concentration and uptake.

Sources of Variation	d.f.	P Concentration		P Uptake	
		S.S.	P>F	S.S.	P>F
Genotype (G)	14	.027	.0001	.49	.0001
Lime (L)	3	.002	.0817	.58	.0001
G x L	42	.012	.5047	.22	.0044
Error	120	.035		.34	

In terms of total P uptake, Mo17 x A634, PI 270080, Blanco Subtropical and Amarillo Bajio had significantly higher P uptake (Table 37). Phosphorus uptake was also significantly affected by lime and genotype by lime interaction. Significant effect due to lime was obtained for P concentration, however, both P concentration and uptake decreased significantly when the pH approached nearer

Table 37. Mean nitrogen, phosphorus and potassium concentration and uptake of 15 corn strains.

	Concentration %			Uptake (mg per pot)		
	N	P	K	N	P	K
1. Va-17	2.81 bc	.183 ab	4.04 cd	67.3 bcd	4.38 bcde	96.9 e
2. Co103	2.69 cd	.184 ab	4.47 a	58.3 fg	4.00 def	98.7 e
3. W64A	3.28 a	.188 a	4.37 ab	51.1 g	3.09 g	72.6 g
4. W153R	2.94 b	.185 ab	3.69 ef	66.2 bcde	4.22 cdef	85.3 f
5. PI 270080	2.37 efg	.166 cd	3.57 f	71.1 ab	5.01 a	107.6 cd
6. PI 270083	2.69 cd	.160 de	3.78 def	65.9 bcde	3.95 ef	93.2 ef
7. Mo17 x A634	2.22 g	.161 de	3.73 ef	68.4 abcd	5.04 a	117.3 ab
8. A632 x W64A	2.43 ef	.159 de	3.96 cde	64.9 cde	4.31 bcde	108.1 cd
9. A632 x A619	2.24 fg	.149 e	3.78 def	66.6 bcd	4.48 bcd	114.7 abc
10. Blanco Subtropical	2.52 de	.170 bcd	3.83 def	73.4 a	4.96 a	113.0 abc
11. Khumal 7642	2.68 cd	.182 ab	4.19 bc	63.4 def	4.34 bcde	101.2 de
12. Khumal 7633	2.55 de	.162 de	3.89 de	70.6 abc	4.56 abc	110.0 bc
13. Thai Composite	2.87 bc	.179 abc	4.40 ab	60.8 ef	3.81 f	94.7 e
14. Amarillo Subtropical	2.44 ef	.158 de	3.95 cde	73.1 a	4.77 ab	120.0 a
15. Amarillo Bajio	2.30 fg	.157 de	3.70 ef	71.8 ab	4.95 a	118.1 ab
Means	2.60	.170	3.96	66.4	4.39	103.4

Means within the same column with the same letter are not significantly different at DMRT = .05.

to neutral. On the whole, average P concentration was 0.17 which may not be adequate under field conditions.

Soil analysis showed that lime had a great influence on P concentration (Table 45). With an increase in lime level, available P in the soil increased significantly, indicating that by raising pH to around 5.4, non-labile P can be converted to labile P. Soil test P was also observed to be significantly different under 5 strains tested (Table 39).

Table 39. pH, phosphorus and potassium concentration of mine spoil soil from five strains.

			Concentration (ppm)	
		pH	P	K
3.	W64A	5.13 a	21.7 b	114 a
5.	PI 270080	5.13 a	25.2 a	108 bc
7.	Mo17 x A634	5.14 a	20.8 b	112 ab
10.	Blanco Subtropical	5.06 a	22.9 ab	114 a
14.	Amarillo Subtropical	5.04 a	21.7 b	105 c
	Means	5.10	22.4	111

Potassium Concentration and Uptake: Significant genotypic and lime differences were observed both for K concentration and uptake. However, genotype by lime interaction did not show significant effect for K concentration indicating that genotypic performance for K concentration did not change with respect to lime level (Table 41).

One difference from the previous study is that K concentration tended to increase with an increase in dry matter production. As a result, total uptake of K also increased significantly (Table 33).

Availability of K in the soil increased with increase in lime levels which

Table 40. Calcium, magnesium, aluminum and manganese concentration of mine spoil soil from five strains.

	Concentration (ppm)			
	Ca	Mg	Al	Mn
3. W64A	2129 a	200 a	85 a	25.0 a
5. PI 270080	2129 a	193 ab	89 a	25.2 a
7. Mo17 x A634	2107 a	192 ab	90 a	25.3 a
10. Blanco Subtropical	2156 a	191 b	88 a	25.1 a
14. Amarillo Subtropical	2068 a	191 b	88 a	25.0 a
Means	2118	193	88	25.1

Means within same column with the same letter are not significantly different at DMRT = .05

Table 41. Analysis of variance for K concentration and uptake.

Sources of Variation	d.f.	K Concentration		K Uptake	
		S.S.	P>F	S.S.	P>F
Genotype (G)	14	13.4	.0001	301	.0001
Lime (L)	3	13.2	.0001	677	.0001
G x L	42	3.6	.4602	69	.0142
Error	120	10.1		116	

could presumably be due to the effect of pH on the availability of K. Genotypic effect on the distribution of K in the soil was also observed, although the differences were not pronounced (Table 39).

The range of K concentration and uptake among the sources varied from 3.57 to 4.47% and 85.3 to 120 mg per pot respectively. Among the sources, the highest amount of K concentration was present in Co103, a poor dry matter producer followed by Thai Composite (Table 37). On the other hand, the uptake was significantly more in Amarillo Subtropical followed by Amarillo Bajio. In general, K concentration and uptake tended to reciprocate with each other. Significant genotypic differences in the utilization of K were observed.

Since potassium plays an important role in different metabolic activities, use of those genotypes which are capable of absorbing higher amounts of K could be beneficial for better plant standability and stalk rot diseases.

Calcium Concentration and Uptake: In the present analysis, Ca was the most influential element both in terms of concentration and uptake. Calcium content in the soil increased with the lime application (Table 46 and Fig. 10). There was no influence of genotypes on availability of Ca in the soil (Table 40).

Significant effects were obtained for genotypes and lime for both Ca concentration and uptake. And genotype by lime interaction was significant only for Ca concentration (Table 42).

Table 42. Analysis of variance for Ca concentration and uptake.

Sources of Variation	d.f.	Ca Concentration		Ca Uptake	
		S.S.	P>F	S.S.	P>F
Genotype (G)	14	2.00	.0001	5.1	.0001
Lime (L)	3	5.30	.0001	69.1	.0001
G x L	42	.45	.0003	2.6	.8294
Error	120	.57		9.7	

The highest Ca concentration was obtained in W64A (the poorest dry matter producer), but PI 270080 had the highest Ca uptake and produced higher dry matter.

Mo17 x A634 had the lowest Ca concentration fell in the intermediate range for Ca uptake (Table 43). In terms of efficient utilization of Ca, which is the ratio of dry matter production to per unit Ca uptake, this single cross performed the best followed by W153R.

An increase in lime level resulted in a linear increase in both Ca concentration and uptake in the plant top. Thus, unlike the previous greenhouse study, an increasing effect of lime on both dry matter production and Ca concentration indicated that lime application contributed to raising Ca level in the plant top without lowering dry matter production especially at pH's below 5.5 (Table 34).

The use of lime resulted in higher calcium content in the soil which was higher than other elements. However, Ca contents in the plant tissue were low compared to K. Uptake rate of Ca is usually lower than that of K.

Magnesium Concentration and Uptake: Magnesium is also an integral part of the cation exchange complex. Use of lime could affect both Ca and Mg depending on the type of lime used. On an average, Mg concentration and uptake was nearly half that of Ca. Analysis of variance indicated a significant difference for the genotypes, lime levels and genotype by lime interaction for Mg concentration. However, lime by genotype interaction was not significant for Mg uptake (Table 44).

Although lime had a significant effect on both Mg concentration and uptake, there was no linear consistency due to lime levels. However, Mg uptake tended to rise with an increase in dry matter production which changed with lime levels. Inbred W153R which was a low dry matter producer contained the highest Mg concentration, but had lower Mg uptake. Similarly, Amarillo Bajio, which was the highest yielder, was intermediate in Mg concentration but Mg uptake was highest. Thus, Mg concentration tended to reciprocate with dry matter production. Nevertheless, Mg uptake still showed wider variability among the

Table 43. Mean calcium, magnesium, aluminum and manganese concentration and uptake of 15 corn strains.

		Concentration				Uptake			
		Ca	Mg	Al	Mn	Ca	Mg	Al	Mn
		%		ppm		mg per pot			
1.	Va-17	.772 b	.302 cde	97	304 a	18.7 cdef	7.2 f	.235	.716 bc
2.	Co103	.784 b	.280 e	106	253 bcd	18.1 def	6.1 g	.230	.487 fg
3.	W64A	1.082 a	.326 bc	147	333 a	18.6 cdef	5.4 g	.240	.500 fg
4.	W153R	.774 b	.376 a	124	209 e	18.1 def	8.5 cde	.278	.442 g
5.	PI 270080	.776 b	.338 b	123	317 a	23.2 a	10.1 ab	.372	.939 a
6.	PI 270083	.684 cdef	.295 de	136	237 bcde	17.2 f	7.3 f	.333	.566 ef
7.	Mo17 x A634	.628 f	.305 cde	114	258 bcd	20.2 bcde	9.5 bcd	.363	.751 b
8.	A632 x W64A	.738 bc	.307 cd	120	265 bc	20.6 bcd	8.4 def	.331	.676 bcd
9.	A632 x A619	.640 ef	.320 bcd	130	227 de	19.7 bcdef	9.7 abc	.394	.646 cde
10.	Blanco Subtropical	.652 ef	.314 bcd	115	242 bcde	19.6 bcdef	9.2 bcd	.349	.668 bcd
11.	Khumal 7642	.726 bcd	.317 bcd	124	266 bc	17.7 ef	7.6 ef	.294	.597 de
12.	Khumal 7633	.700 cde	.320 bcd	111	246 bcd	20.4 bcde	9.2 bcd	.321	.658 bcd
13.	Thai Composite	.783 b	.338 b	135	268 b	17.3 f	7.3 ef	.286	.566 ef
14.	Amarillo Subtropical	.683 cdef	.321 bcd	124	257 bcd	21.0 abc	9.7 abc	.367	.740 b
15.	Amarillo Bajio	.671 def	.337 b	123	231 cde	21.7 ab	10.8 a	.384	.698 bc
	Means	.74	.320	122	261	19.5	8.4	.319	.643

Means within the same column with the same letter are not significantly different at DMRT = .05.

sources (Table 43).

Table 44. Analysis of variance for Mg concentration and uptake.

Sources of Variation	d.f.	Mg Concentration		Mg Uptake	
		S.S.	P>F	S.S.	P>F
Genotype (G)	14	.08	.0001	4.03	.0001
Lime (L)	3	.02	.0001	1.95	.0001
G x L	42	.06	.01	.85	.3480
Error	120	.10		2.22	

Lime levels had a significant effect on Mg content of soil which showed a linear decreasing trend with increasing lime level (Table 46). Such type of reverse trend could be explained by the antagonistic effect between Mg^{++} and Ca^{++} for exchange sites. Clearly depressive effect of acidity (H^{+}) or even possibly of Al^{+++} for Mg^{++} could not be explained in the presence of increasing levels of Ca^{++} in the soil. The level of exchangeable Mg present in the soil before and after liming indicated that Mg was sufficient for crop growth.

Aluminum Concentration and Uptake: Al toxicity due to low soil pH was evident as it was shown by the exposure of injured root system above the surface of soil. Root injury was more serious in susceptible strains such as Co103 than in resistant ones such as Va17 (Fig. 6 and 7). In general, the degree of root injury decreased as the level of lime was increased indicating that root injury was primarily due to the toxic effect of Al in the system. This was further supported by the analytical result. Exchangeable Al in the soil dropped drastically when the soil pH was raised from 3.9 to 5.4 by the addition of 8000 kg per ha of lime (Fig. 11). It was below detectable limits with the

Table 45. Effect of lime on pH, phosphorus and potassium concentration of mine spoil soil.

Lime (kg per ha)	pH	Concentration (ppm)	
		P	K
0	3.9 d	194 c	102 c
4000	4.4 c	208 c	109 b
8000	5.4 b	262 a	113 b
16500	6.7 a	235 b	120 a
Means	5.1	224	111

Table 46. Effect of lime on calcium, magnesium, aluminum and manganese concentration of mine spoil soil.

(kg per ha)	Concentration			
	Ca	Mg	Al	Mn
	ppm			
0	723 d	217 a	230 a	40.3 a
4000	1495 c	208 b	101 b	34.9 b
8000	2378 b	194 c	<10 c	19.4 c
16500	3875 a	155 d	<10 c	5.7 d
Means	2118	193	88	25.1

Means within same column with the same letter are not significantly different at DMRT = .05.

atomic absorption spectrophotometer (Table 46). This result agrees with other findings that Al in the soil is precipitated at pH 5.2 or above. There were no significant differences in Al content in the soil due to genotypic effect

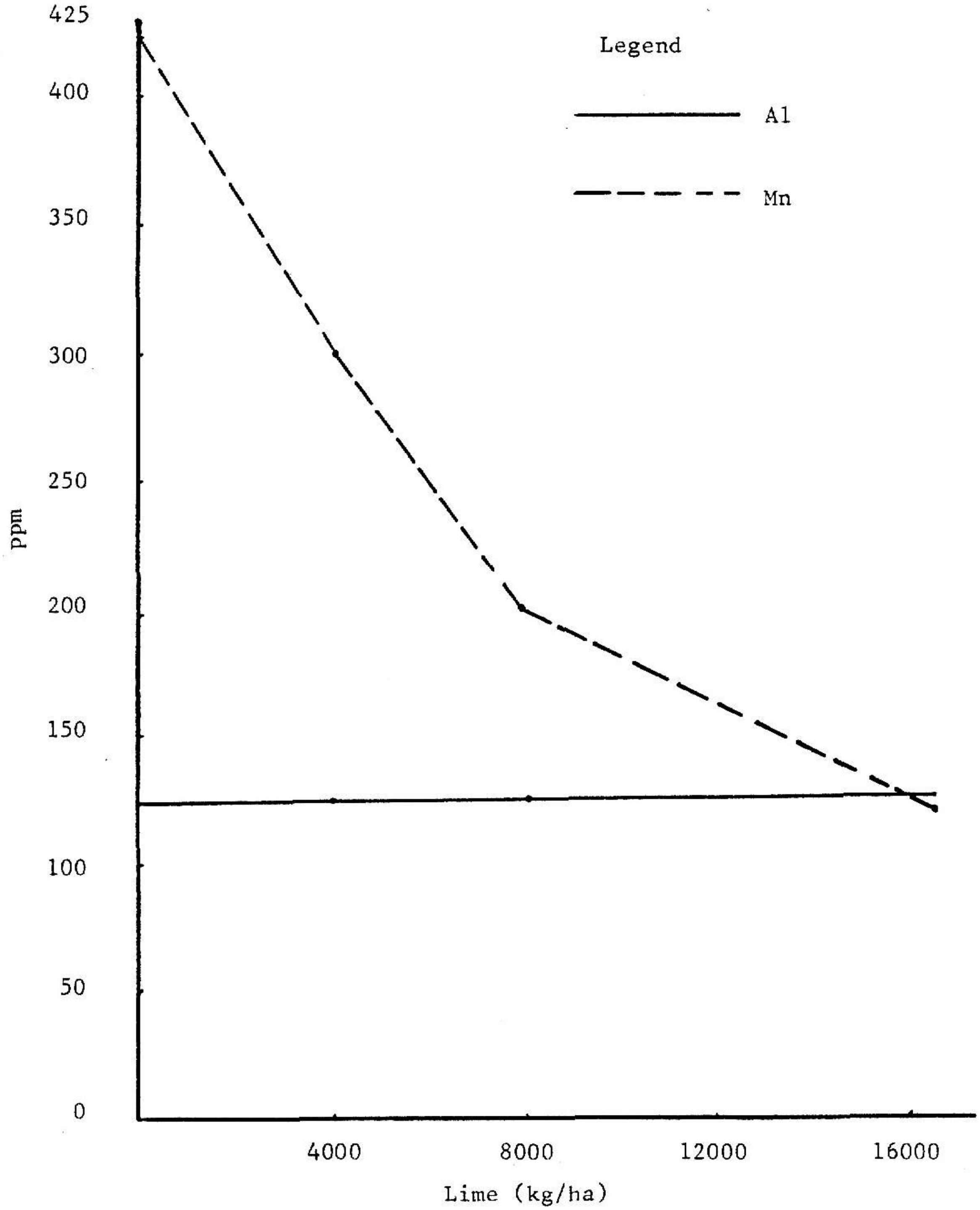

Fig. 8. Effect of lime on Al and Mn concentration of corn plant tissue grown in mine spoil soil.

(Table 40).

Statistical analysis of Al concentration and uptake in the plant top revealed that genotypic differences were not significant for Al concentration. However, some contamination was suspected in the tissue analysis due to excessive Al detection in some samples. Thus, when a missing plot technique was applied in the analysis, the results were significant for both genotypes and genotype by lime interaction (Table 47). Both the analysis techniques indicated significant differences among genotypes for Al uptake which is likely due to the differences in dry matter production.

Table 47. Analysis of variance of Al concentration and uptake using missing plot technique.

Sources of Variations	d.f.	Al Concentration		Al Uptake	
		S.S.	P >F	S.S.	P >F
Genotype (G)	14	24354	.001	491885	.0001
Lime (L)	3	2923	.190	238815	.0001
G x L	42	46521	.007	426444	.0194
Error	110	66573		674033	

Lime effect as well as genotype by lime interaction were also significant for Al uptake. Aluminum uptake tended to increase as long as lime was effective in raising dry matter production (Table 34).

Aluminum concentration in the tops did not show any clear cut differences between tolerant and susceptible sources. For instance, inbred Va17, a relatively tolerant line had the lowest Al concentration. Likewise, the more susceptible inbred Co103 has a relatively low Al concentration in contrast to Va17. Because Al content of roots was not determined, no specific conclusion can be made in regard to the absorption and translocation of Al through the root system.

High Al uptake was obtained with A632 x A619 followed by Amarillo Bajio which were relatively high in dry matter production as well as in Al concentration (Table 43).

In a separate analysis at each level of lime treatment, no significant genotypic difference was revealed thus indicating that Al concentration remained the same irrespective of lime levels.

Manganese Concentration and Uptake: Manganese toxicity can also be a problem in acid soil and may be difficult in distinguishing from Al toxicity. Highly significant differences were obtained for all the variables except for genotype by lime interaction for Mn uptake (Table 48) although the plants did not show apparent Mn toxicity symptoms.

Table 48. *Analysis of variance of* Mn concentration and uptake.

Sources of Variation	d.f.	Mn Concentration		Mn Uptake	
		S.S.	P>F	S.S.	P>F
Genotype (G)	14	193783	.0001	2624949	.0001
Lime (L)	3	2266103	.0001	7140262	.0001
G x L	42	213230	.0001	481509	.2886
Error	120	168875		1207909	

Thus, level of Mn concentration might be a better indication of toxic effect due to excess Mn in the plant tissue. However, no linear association between susceptible and tolerant genotypes was found at the same level of lime application (Table 43). Sources both with higher relative weight and lower relative weight tended to fall in the same range of Mn concentration. For instance, sources PI 270080, Va-17 and W64A whose relative weights varied greatly but all fell in the upper range for Mn concentration.

On the other hand, effect of lime application was highly significant in decreasing Mn concentration and uptake (Table 34 and Fig. 8). This was not true for Al concentration. The level of Mn concentration decreased significantly in a linear fashion with an increase in lime level or pH of the soil (Fig. 9) suggesting that Mn concentration in the plant top is more closely related to lime application than Al concentration. Average Mn concentration was in the excessive range up to 8000 kg per ha of lime application.

Likewise in the soil analysis, Mn concentration decreased significantly as the level of lime increased (Table 46 and Fig. 11). However, no significant result was obtained in the soil with respect to genotypic difference (Table 40).

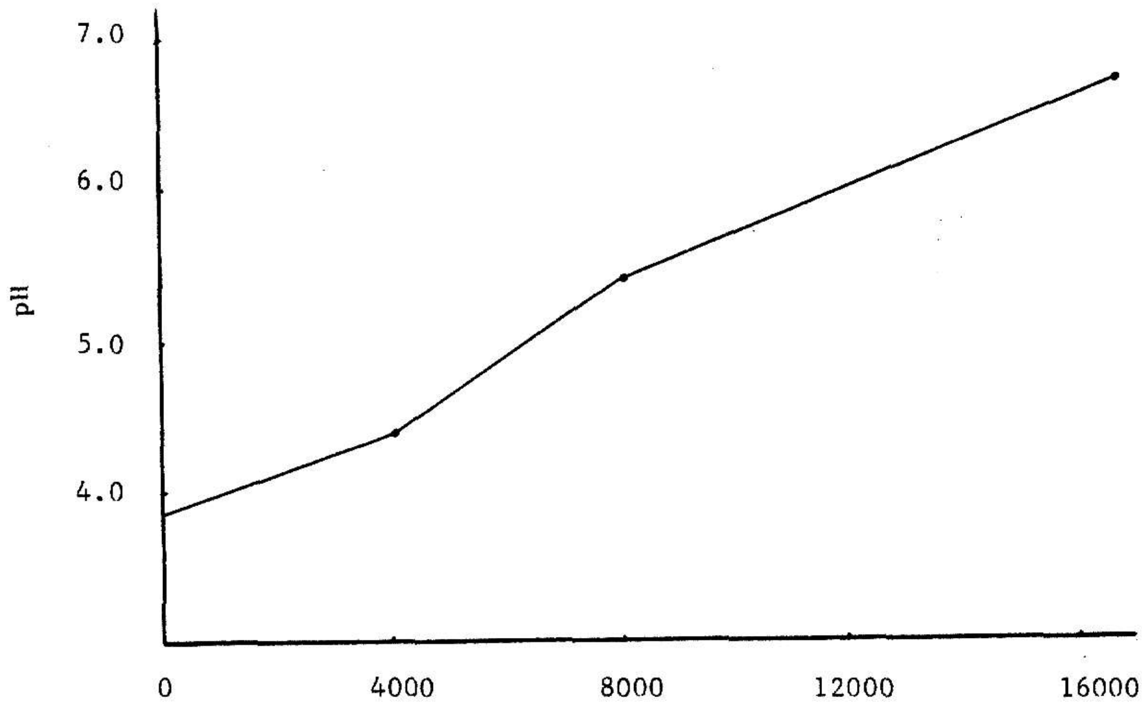

Fig. 9. Effect of lime on pH of mine spoil soil.

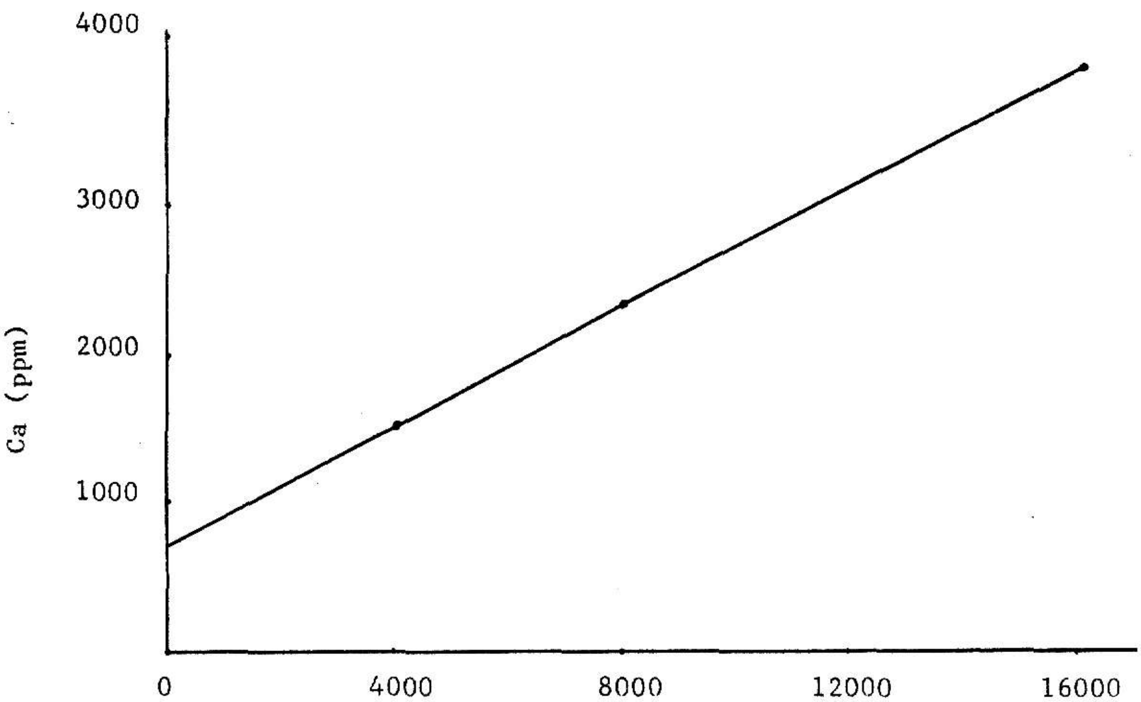

Fig. 10. Effect of lime on Ca concentration of mine spoil soil.

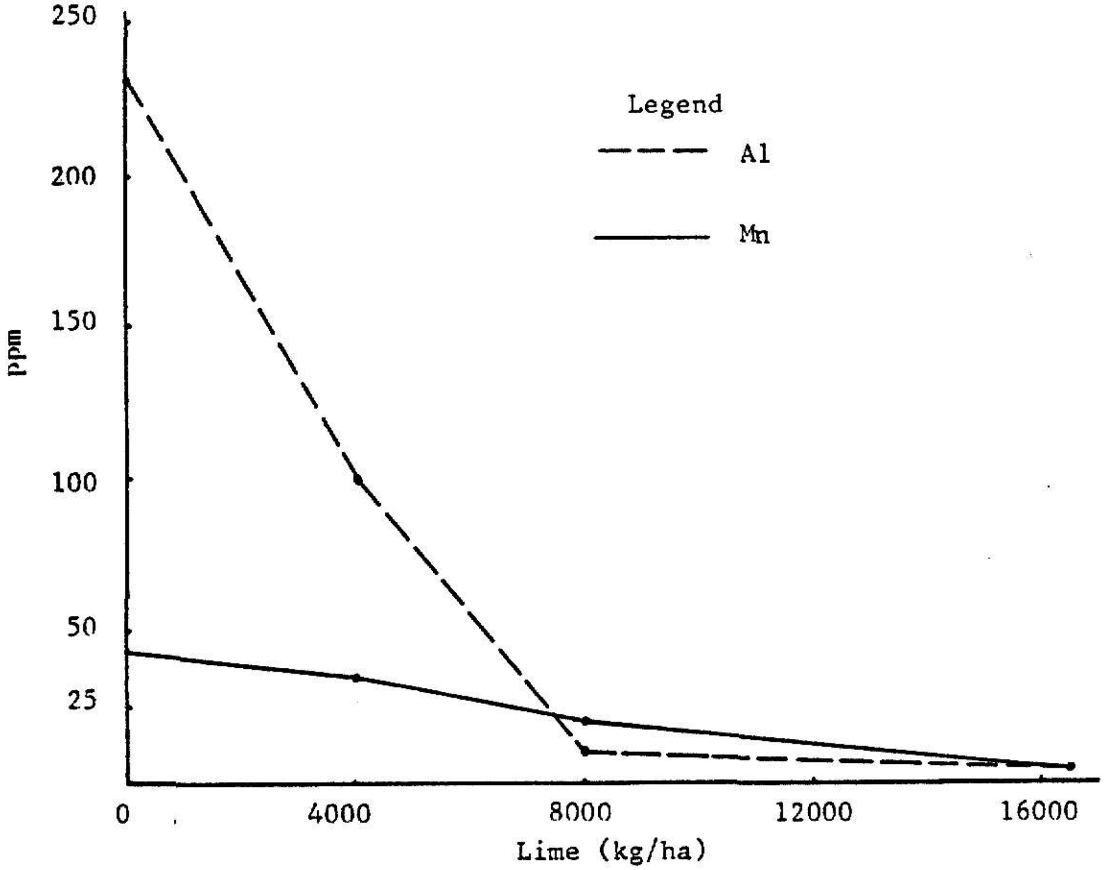

Fig. 11. Effect of lime on Al and Mn concentration of mine spoil soil.

SUMMARY AND CONCLUSIONS

A soil (pH 5.5) obtained from the Southeastern Kansas Experiment Field, Parsons, Kansas, and a soil (pH 3.9) obtained from near Pittsburg, Kansas and a solution culture method were used to study nutrient absorption in different corn sources.

In the greenhouse studies, plants were grown, harvested, dried, weighed and analyzed for various nutrients. In the growth chamber study, root parameters were studied. Elements determined were N, P, K, Ca, Mg, Mn and Al. Corn genotypes used were open pollinated varieties, inbreds and single crosses. In the first study lime and phosphorus treatments were used, but in the second study, only lime was used as a variable. In the nutrient solution culture, Al level was varied to study the effect of Al concentration on root growth.

Significant variability due to genotypes, lime and phosphorus treatments were noticed in the first greenhouse study. Phosphorus increased dry matter production more than other treatments. Addition of lime decreased dry matter production. Strain N1206 ranked highest in dry matter production at both P levels. Although genotypic variability did exist for P concentration in the plants, there was negative relationship between dry matter production and P content. In terms of relative weight, Blanco Subtropical performed the best and showed the least P deficiency symptoms.

The concentration of other nutrients (N, K, Ca and Mg) showed a decreasing trend at the high level of P compared with the zero P treatment. Calcium concentration increased significantly at the higher levels of lime. Lime also raised Mg concentration in the first greenhouse study, but did not in the second study. This could possibly be due to the change in dry matter production at different levels of lime.

Effect of lime in the second greenhouse study was highly significant in increasing dry matter production up to pH 5.4. Relative weights for the sources were more differential under stress conditions than non-stress conditions. Among them, PI 270080 and Va-17 performed very well under stress conditions and showed least toxic effect. On the other hand, inbred Co103 was highly susceptible to Al toxicity. Toxicity due to excess exchangeable Al in the soil solution could be seen on the root systems of the susceptible plants. Toxicity due to excess Al decreased significantly as the level of lime increased. Use of lime was more effective for Al susceptible strains than for tolerant ones.

As the level of lime increased, changes in pH, Ca, Mn and Al concentration in the soil were highly significant. However, Al concentration in the plant tissue did not show significant differences with respect to lime level. Genotypic variability which could also depend on the absorption, translocation capacity of the root system and Al concentration in the root system need to be determined.

In the nutrient solution culture experiment, the effect of Al toxicity was measured in terms of root parameters. Among them, the composite value defined in the above discussion was the most important parameter.

From these studies, it is clear that selection of stress level is an important factor. Genotypes performed differently under different stress conditions. Use of tolerant genotypes may be an alternative way of solving the acidity problem particularly in those regions where liming is not feasible from an economic standpoint.

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APPENDIX

EXPERIMENT I Table 1.

DATA FROM 1980

OBS	LIME	PHOS	V	R	W	N	P	K	CA	MG	TN	TP	TK	TCA	TMG
					-gm-	%					10^{-1} x mg				
1	0	0	1	1	2.14	1.88	0.068	4.32	0.952	0.324	4.02	0.146	9.24	2.04	0.69
2	0	0	1	2	1.90	2.00	0.060	4.48	0.909	0.335	3.80	0.114	8.51	1.73	0.64
3	0	0	1	3	1.47	2.58	0.088	4.60	0.885	0.365	3.79	0.129	6.76	1.30	0.54
4	0	0	2	1	2.41	2.08	0.072	5.05	0.741	0.357	5.01	0.174	12.17	1.79	0.86
5	0	0	2	2	1.63	2.38	0.079	5.20	0.687	0.318	4.00	0.133	8.74	1.15	0.53
6	0	0	2	3	1.57	2.45	0.080	5.28	1.028	0.441	3.85	0.126	8.29	1.61	0.69
7	0	0	3	1	1.73	2.48	0.088	5.18	0.887	0.371	4.29	0.152	8.96	1.53	0.64
8	0	0	3	2	1.99	2.62	0.098	4.52	0.719	0.338	5.21	0.195	8.99	1.43	0.67
9	0	0	3	3	1.54	2.58	0.092	4.10	0.781	0.347	3.97	0.142	6.31	1.20	0.53
10	0	0	4	1	2.34	1.94	0.078	4.50	0.745	0.383	4.54	0.183	10.53	1.74	0.90
11	0	0	4	2	1.80	2.39	0.094	4.86	0.864	0.333	4.30	0.169	8.75	1.56	0.60
12	0	0	4	3	2.36	1.62	0.060	4.02	0.630	0.327	3.82	0.142	9.49	1.49	0.77
13	0	0	5	1	2.63	1.92	0.072	3.90	0.760	0.373	5.05	0.189	10.26	2.00	0.98
14	0	0	5	2	2.49	1.70	0.064	4.46	0.811	0.362	4.23	0.159	11.11	2.02	0.90
15	0	0	5	3	2.64	1.79	0.063	4.43	0.855	0.348	4.73	0.166	11.70	2.26	0.92
16	0	0	6	1	1.95	2.75	0.090	4.24	0.759	0.349	5.36	0.175	8.27	1.48	0.68
17	0	0	6	2	1.87	2.68	0.090	5.13	0.859	0.311	5.01	0.168	9.59	1.61	0.58
18	0	0	6	3	1.90	2.25	0.080	4.76	0.839	0.395	4.27	0.152	9.04	1.59	0.75
19	0	0	7	1	2.49	1.60	0.050	4.70	0.861	0.442	3.98	0.124	11.70	2.14	1.10
20	0	0	7	2	1.89	2.10	0.074	4.48	0.960	0.349	3.97	0.140	8.47	1.81	0.66
21	0	0	7	3	2.35	2.14	0.090	4.33	0.606	0.249	5.03	0.211	10.18	1.42	0.59
22	0	0	8	1	1.87	2.21	0.069	4.39	0.750	0.379	4.13	0.129	8.21	1.40	0.71
23	0	0	8	2	1.92	2.00	0.069	4.38	0.905	0.369	3.84	0.132	8.41	1.74	0.71
24	0	0	8	3	2.19	1.95	0.075	4.38	0.637	0.327	4.27	0.164	9.59	1.40	0.72
25	0	0	9	1	1.68	2.20	0.100	4.19	0.662	0.331	3.70	0.168	7.04	1.11	0.56
26	0	0	9	2	2.22	1.62	0.068	4.28	0.678	0.375	3.60	0.151	9.50	1.51	0.83
27	0	0	9	3	1.55	2.55	0.092	4.37	0.648	0.348	3.95	0.143	6.77	1.00	0.54
28	0	0	10	1	2.12	1.92	0.055	3.98	0.700	0.285	4.07	0.117	8.44	1.48	0.60
29	0	0	10	2	1.84	2.20	0.062	4.40	0.755	0.328	4.05	0.114	8.10	1.39	0.60
30	0	0	10	3	1.92	2.60	0.080	4.56	0.811	0.332	4.99	0.154	8.76	1.56	0.64
31	0	0	11	1	1.67	2.51	0.082	4.02	0.791	0.304	4.19	0.137	6.71	1.32	0.51
32	0	0	11	2	1.38	2.53	0.080	4.90	0.776	0.301	3.49	0.110	6.76	1.07	0.42
33	0	0	11	3	1.72	2.20	0.070	3.96	0.748	0.319	3.78	0.120	6.81	1.29	0.55
34	0	0	12	1	1.55	2.10	0.070	4.07	0.766	0.308	3.25	0.108	6.31	1.19	0.48
35	0	0	12	2	1.91	2.11	0.073	4.50	0.763	0.309	4.03	0.139	8.59	1.46	0.59
36	0	0	12	3	2.06	1.84	0.067	4.38	0.717	0.337	3.79	0.138	9.02	1.48	0.69
37	0	0	13	1	1.29	2.40	0.086	3.84	0.946	0.370	3.10	0.111	4.95	1.22	0.48
38	0	0	13	2	1.12	2.78	0.088	3.90	0.836	0.334	3.11	0.099	4.37	0.94	0.37
39	0	0	13	3	1.20	2.71	0.070	5.25	0.951	0.343	3.25	0.084	6.30	1.14	0.41
40	0	0	14	1	1.87	2.41	0.085	4.17	0.717	0.387	4.51	0.159	7.80	1.34	0.72
41	0	0	14	2	2.14	1.89	0.055	3.52	0.687	0.302	4.04	0.118	7.53	1.47	0.65
42	0	0	14	3	3.01	1.59	0.063	3.05	0.477	0.292	4.79	0.190	9.18	1.44	0.88
43	0	0	15	1	2.18	2.00	0.068	3.46	0.729	0.424	4.36	0.148	7.54	1.59	0.92
44	0	0	15	2	2.41	1.62	0.056	3.39	0.649	0.432	3.90	0.135	8.17	1.56	1.04
45	0	0	15	3	2.34	1.56	0.059	3.69	0.712	0.387	3.65	0.138	8.63	1.67	0.91
46	0	0	16	1	2.00	2.08	0.092	3.69	0.662	0.281	4.16	0.184	7.38	1.32	0.56
47	0	0	16	2	2.24	2.08	0.080	3.86	0.753	0.301	4.66	0.179	8.65	1.69	0.67
48	0	0	16	3	2.51	1.82	0.080	3.18	0.559	0.284	4.57	0.201	7.98	1.40	0.71
49	3	0	1	1	1.49	2.21	0.067	4.45	1.134	0.509	3.29	0.100	6.63	1.69	0.76
50	3	0	1	2	1.57	2.52	0.077	4.25	1.295	0.400	3.96	0.121	6.67	2.03	0.63
51	3	0	1	3	1.22	2.70	0.065	4.52	0.965	0.373	3.29	0.104	5.51	1.18	0.46
52	3	0	2	1	1.75	2.75	0.088	3.98	1.098	0.494	4.81	0.154	6.96	1.92	0.86
53	3	0	2	2	1.96	2.59	0.080	4.45	1.057	0.427	5.08	0.157	8.72	2.07	0.84
54	3	0	2	3	1.99	2.60	0.083	4.75	0.714	0.303	5.17	0.165	9.45	1.42	0.60
55	3	0	3	1	1.58	2.30	0.080	4.75	0.916	0.390	3.63	0.126	7.50	1.45	0.62

DATA FROM 1980

OBS	LIME	PHOS	V	R	W	N	P	K	CA	MG	TN	TP	TK	TCA	TMG
56	3	0	3	2	1.53	3.08	0.086	5.09	1.213	0.418	4.71	0.132	7.79	1.86	0.64
57	3	0	3	3	1.57	2.60	0.090	5.64	1.207	0.393	4.08	0.141	8.85	1.89	0.62
58	3	0	4	1	2.16	1.90	0.078	5.10	1.016	0.454	4.10	0.168	11.02	2.19	0.98
59	3	0	4	2	2.44	1.54	0.048	4.14	0.794	0.442	3.76	0.117	10.10	1.94	1.08
60	3	0	4	3	1.97	2.20	0.071	4.82	1.057	0.395	4.33	0.140	9.50	2.08	0.78
61	3	0	5	1	2.17	2.58	0.072	4.75	1.375	0.347	5.60	0.156	10.31	2.98	0.75
62	3	0	5	2	2.34	1.80	0.080	3.89	0.861	0.341	4.21	0.187	9.10	2.01	0.80
63	3	0	5	3	2.14	2.43	0.082	4.69	0.925	0.342	5.20	0.175	10.04	1.98	0.73
64	3	0	6	1	2.16	2.20	0.075	4.90	0.756	0.292	4.75	0.162	10.58	1.63	0.63
65	3	0	6	2	2.42	2.11	0.075	4.30	1.024	0.394	5.11	0.181	10.41	2.48	0.95
66	3	0	6	3	2.31	1.98	0.080	4.20	0.761	0.354	4.57	0.185	9.70	1.76	0.82
67	3	0	7	1	2.19	1.95	0.078	4.97	0.868	0.458	4.27	0.171	10.88	1.90	1.00
68	3	0	7	2	2.56	2.10	0.072	5.16	0.983	0.478	5.38	0.184	13.21	2.52	1.22
69	3	0	7	3	2.15	2.15	0.087	4.46	1.149	0.445	4.62	0.187	9.59	2.47	0.96
70	3	0	8	1	2.23	2.09	0.080	3.91	0.991	0.415	4.66	0.178	8.72	2.21	0.93
71	3	0	8	2	1.91	2.10	0.072	4.17	1.093	0.433	4.01	0.138	7.96	2.09	0.83
72	3	0	8	3	2.03	1.90	0.070	4.37	0.885	0.304	3.86	0.142	8.87	1.80	0.62
73	3	0	9	1	1.93	1.79	0.060	4.34	0.871	0.364	3.45	0.116	8.38	1.68	0.70
74	3	0	9	2	1.40	2.30	0.069	5.02	1.091	0.379	3.22	0.097	7.03	1.53	0.53
75	3	0	9	3	1.94	2.61	0.088	4.99	0.858	0.376	5.06	0.171	9.68	1.66	0.73
76	3	0	10	1	1.65	2.80	0.086	5.70	1.150	0.413	4.62	0.142	9.40	1.90	0.68
77	3	0	10	2	1.75	2.90	0.088	4.65	1.161	0.326	5.07	0.154	8.14	2.03	0.57
78	3	0	10	3	1.56	2.80	0.079	5.47	1.030	0.346	4.37	0.123	8.53	1.61	0.54
79	3	0	11	1	1.21	3.31	0.100	5.15	1.097	0.397	4.01	0.121	6.23	1.33	0.48
80	3	0	11	2	1.76	2.59	0.090	4.59	0.967	0.370	4.56	0.158	8.08	1.70	0.65
81	3	0	11	3	1.43	2.22	0.080	4.25	0.799	0.365	3.17	0.114	6.08	1.14	0.52
82	3	0	12	1	1.82	2.20	0.070	4.39	0.972	0.399	4.00	0.127	7.99	1.77	0.73
83	3	0	12	2	2.05	1.95	0.075	4.63	0.875	0.397	4.00	0.154	9.49	1.79	0.81
84	3	0	12	3	2.24	1.88	0.065	4.08	0.850	0.340	4.21	0.146	9.14	1.90	0.76
85	3	0	13	1	1.50	2.60	0.090	3.96	1.264	0.376	3.90	0.135	5.94	1.90	0.56
86	3	0	13	2	1.35	2.58	0.080	5.38	1.158	0.486	3.48	0.108	7.26	1.56	0.66
87	3	0	13	3	1.17	2.90	0.090	4.70	1.069	0.414	3.39	0.105	5.50	1.25	0.48
88	3	0	14	1	2.50	2.12	0.081	4.20	0.809	0.398	5.30	0.202	10.50	2.02	0.99
89	3	0	14	2	2.34	2.15	0.064	4.10	1.022	0.380	5.03	0.150	9.59	2.39	0.89
90	3	0	14	3	2.27	2.43	0.088	4.34	0.953	0.351	5.52	0.200	9.85	2.16	0.80
91	3	0	15	1	2.53	1.98	0.071	3.38	0.852	0.439	5.01	0.180	8.55	2.16	1.11
92	3	0	15	2	2.60	1.81	0.072	3.18	0.732	0.367	4.71	0.187	8.27	1.90	0.95
93	3	0	15	3	2.11	2.00	0.078	4.05	0.910	0.384	4.22	0.165	8.55	1.92	0.81
94	3	0	16	1	2.30	2.12	0.070	4.52	0.864	0.375	4.88	0.161	10.40	1.99	0.86
95	3	0	16	2	2.24	1.78	0.059	4.04	0.824	0.316	3.99	0.132	9.05	1.85	0.71
96	3	0	16	3	1.98	2.43	0.084	4.25	0.947	0.327	4.81	0.166	8.41	1.89	0.65
97	0	3	1	1	3.48	1.26	0.148	2.68	0.443	0.282	4.38	0.515	9.33	1.54	0.98
98	0	3	1	2	2.77	1.52	0.128	3.22	0.511	0.306	4.21	0.355	8.92	1.42	0.85
99	0	3	1	3	3.38	1.60	0.158	3.23	0.478	0.321	5.41	0.534	10.92	1.62	1.08
100	0	3	2	1	4.23	1.50	0.178	2.67	0.409	0.296	6.34	0.753	11.29	1.73	1.25
101	0	3	2	2	3.63	1.19	0.158	2.98	0.515	0.275	4.32	0.574	10.82	1.87	1.00
102	0	3	2	3	4.23	1.25	0.145	2.76	0.542	0.310	5.29	0.613	11.67	2.29	1.31
103	0	3	3	1	3.66	1.32	0.148	3.00	0.450	0.259	4.83	0.542	10.98	1.65	0.95
104	0	3	3	2	3.87	1.22	0.132	2.52	0.472	0.306	4.72	0.511	9.75	1.83	1.18
105	0	3	3	3	3.83	1.38	0.138	2.52	0.499	0.312	5.29	0.529	9.65	1.91	1.19
106	0	3	4	1	4.29	1.10	0.152	3.03	0.441	0.322	4.72	0.652	13.00	1.89	1.38
107	0	3	4	2	3.19	1.70	0.180	3.64	0.565	0.312	5.42	0.574	11.61	1.80	1.00
108	0	3	4	3	4.49	0.92	0.140	3.09	0.391	0.230	4.13	0.629	13.87	1.76	1.03
109	0	3	5	1	5.18	1.19	0.178	2.56	0.372	0.197	6.16	0.922	13.36	1.93	1.02
110	0	3	5	2	4.69	1.28	0.160	2.68	0.451	0.269	6.00	0.750	12.57	2.12	1.26

DATA FROM 1980

OBS	LIME	PHOS	V	R	W	N	P	K	CA	MG	TN	TP	TK	TCA	TMG
111	0	3	5	3	4.14	1.10	0.108	2.49	0.420	0.260	4.55	0.447	10.31	1.74	1.08
112	0	3	6	1	3.36	1.28	0.119	2.58	0.456	0.315	4.30	0.400	8.67	1.53	1.06
113	0	3	6	2	3.42	1.90	0.195	2.88	0.554	0.322	6.50	0.667	9.85	1.89	1.10
114	0	3	6	3	3.22	1.54	0.183	3.13	0.555	0.348	4.96	0.589	10.08	1.79	1.12
115	0	3	7	1	4.26	1.00	0.160	2.90	0.547	0.307	4.26	0.682	12.35	2.33	1.31
116	0	3	7	2	4.46	1.21	0.148	2.40	0.504	0.324	5.40	0.660	10.70	2.25	1.45
117	0	3	7	3	4.17	1.25	0.155	2.48	0.552	0.346	5.21	0.646	10.34	2.30	1.44
118	0	3	8	1	3.81	1.52	0.140	2.12	0.421	0.336	5.79	0.533	8.08	1.60	1.28
119	0	3	8	2	3.42	1.55	0.140	2.52	0.495	0.311	5.30	0.479	8.62	1.69	1.06
120	0	3	8	3	3.94	1.25	0.123	2.57	0.423	0.239	4.92	0.485	10.13	1.67	0.94
121	0	3	9	1	4.44	1.02	0.116	2.26	0.407	0.283	4.53	0.515	10.03	1.81	1.26
122	0	3	9	2	3.44	1.26	0.128	2.45	0.413	0.331	4.33	0.440	8.43	1.42	1.14
123	0	3	9	3	4.20	1.25	0.161	2.43	0.525	0.305	5.25	0.676	10.21	2.20	1.28
124	0	3	10	1	4.02	1.41	0.145	2.87	0.469	0.325	5.67	0.583	11.54	1.89	1.31
125	0	3	10	2	4.09	0.98	0.112	2.35	0.440	0.325	4.01	0.458	9.61	1.80	1.33
126	0	3	10	3	4.44	1.09	0.120	2.54	0.370	0.241	4.84	0.533	11.28	1.64	1.07
127	0	3	11	1	2.98	2.16	0.205	3.17	0.437	0.351	6.44	0.611	9.45	1.30	1.05
128	0	3	11	2	3.31	1.88	0.161	3.13	0.490	0.311	6.22	0.533	10.36	1.62	1.03
129	0	3	11	3	3.92	1.85	0.210	3.05	0.458	0.334	7.25	0.823	11.96	1.80	1.31
130	0	3	12	1	2.82	1.88	0.160	2.73	0.398	0.309	5.30	0.451	7.70	1.12	0.87
131	0	3	12	2	3.44	1.25	0.102	2.33	0.338	0.221	4.30	0.351	8.02	1.16	0.76
132	0	3	12	3	2.82	1.68	0.153	2.48	0.427	0.299	4.74	0.431	6.99	1.20	0.84
133	0	3	13	1	3.08	1.75	0.152	3.32	0.480	0.298	5.39	0.468	10.23	1.48	0.92
134	0	3	13	2	3.29	1.50	0.148	2.82	0.368	0.283	4.93	0.487	9.28	1.21	0.93
135	0	3	13	3	2.61	1.70	0.160	3.24	0.561	0.335	4.44	0.418	8.46	1.46	0.87
136	0	3	14	1	4.73	0.90	0.100	2.13	0.335	0.244	4.26	0.473	10.07	1.58	1.15
137	0	3	14	2	4.53	1.28	0.128	2.57	0.433	0.271	5.80	0.580	11.64	1.96	1.23
138	0	3	14	3	3.84	1.19	0.120	2.59	0.371	0.251	4.57	0.461	9.95	1.42	0.96
139	0	3	15	1	3.69	1.38	0.142	2.40	0.414	0.342	5.09	0.524	8.86	1.53	1.26
140	0	3	15	2	3.76	1.09	0.133	2.48	0.458	0.340	4.10	0.500	9.32	1.72	1.28
141	0	3	15	3	3.88	1.38	0.145	2.43	0.480	0.374	5.35	0.563	9.43	1.86	1.45
142	0	3	16	1	3.45	1.70	0.201	2.81	0.506	0.350	5.86	0.653	9.69	1.75	1.21
143	0	3	16	2	3.59	1.60	0.163	2.96	0.374	0.290	5.74	0.585	10.63	1.34	1.04
144	0	3	16	3	3.38	1.76	0.189	3.35	0.447	0.290	5.95	0.639	11.32	1.51	0.98
145	3	3	1	1	2.86	1.70	0.122	2.42	0.589	0.386	4.86	0.349	6.92	1.68	1.10
146	3	3	1	2	3.29	1.50	0.110	2.48	0.665	0.343	4.93	0.362	8.16	2.19	1.13
147	3	3	1	3	2.52	1.88	0.128	2.93	0.745	0.355	4.74	0.323	7.38	1.88	0.89
148	3	3	2	1	3.51	1.65	0.127	2.50	0.548	0.354	5.79	0.446	8.77	1.92	1.24
149	3	3	2	2	1.87	2.25	0.120	3.22	0.942	0.415	4.21	0.224	6.02	1.76	0.78
150	3	3	2	3	1.89	2.45	0.160	3.49	0.771	0.420	4.63	0.302	6.60	1.46	0.79
151	3	3	3	1	2.71	1.87	0.128	2.65	0.643	0.398	5.07	0.347	7.18	1.74	1.08
152	3	3	3	2	3.43	1.15	0.080	2.22	0.599	0.375	3.94	0.274	7.61	2.05	1.29
153	3	3	3	3	3.58	1.55	0.139	2.70	0.669	0.318	5.55	0.498	9.67	2.40	1.14
154	3	3	4	1	2.73	1.78	0.140	3.20	0.784	0.458	4.86	0.382	8.74	2.14	1.25
155	3	3	4	2	3.79	1.16	0.110	2.85	0.547	0.351	4.40	0.417	10.80	2.07	1.33
156	3	3	4	3	4.04	1.33	0.110	2.24	0.619	0.389	5.37	0.444	9.05	2.50	1.57
157	3	3	5	1	3.83	1.21	0.118	2.75	0.711	0.301	4.63	0.452	10.53	2.72	1.15
158	3	3	5	2	3.66	1.39	0.110	2.68	0.784	0.372	5.09	0.403	9.81	2.87	1.36
159	3	3	5	3	3.63	1.42	0.101	2.42	0.720	0.395	5.15	0.367	8.78	2.61	1.43
160	3	3	6	1	2.78	2.49	0.185	2.74	1.012	0.501	6.92	0.514	7.62	2.81	1.39
161	3	3	6	2	2.80	1.90	0.155	2.88	0.721	0.434	5.32	0.434	8.06	2.02	1.22
162	3	3	6	3	3.13	1.60	0.132	2.78	0.795	0.351	5.01	0.413	8.70	2.49	1.10
163	3	3	7	1	3.42	1.40	0.115	2.37	0.786	0.447	4.79	0.393	8.11	2.69	1.53
164	3	3	7	2	3.12	1.50	0.108	2.98	0.993	0.473	4.68	0.337	9.30	3.10	1.48

DATA FROM 1980

OBS	LIME	PHOS	V	R	W	N	P	K	CA	MG	TN	TP	TK	TCA	TMG
165	3	3	7	3	3.90	1.38	0.114	2.78	0.631	0.352	5.38	0.445	10.84	2.46	1.37
166	3	3	8	1	2.60	1.61	0.098	2.86	0.621	0.368	4.19	0.255	7.44	1.61	0.96
167	3	3	8	2	3.05	1.48	0.082	2.78	0.664	0.389	4.51	0.250	8.48	2.03	1.19
168	3	3	8	3	2.94	1.48	0.102	2.70	0.683	0.347	4.35	0.300	7.94	2.01	1.02
169	3	3	9	1	3.17	1.62	0.110	2.39	0.616	0.379	5.14	0.349	7.58	1.95	1.20
170	3	3	9	2	4.07	1.30	0.130	2.53	0.654	0.394	5.29	0.529	10.30	2.66	1.60
171	3	3	9	3	3.52	1.12	0.111	2.48	0.613	0.407	3.94	0.391	8.73	2.16	1.43
172	3	3	10	1	3.54	1.58	0.130	2.70	0.638	0.365	5.59	0.460	9.56	2.26	1.29
173	3	3	10	2	3.30	1.68	0.135	2.53	0.674	0.400	5.54	0.445	8.35	2.22	1.32
174	3	3	10	3	2.67	1.82	0.125	3.01	0.630	0.359	4.86	0.334	8.04	1.68	0.96
175	3	3	11	1	1.89	2.14	0.124	3.35	0.671	0.331	4.04	0.234	6.33	1.27	0.63
176	3	3	11	2	2.75	1.71	0.105	3.00	0.537	0.378	4.70	0.289	8.25	1.48	1.04
177	3	3	11	3	2.40	1.72	0.103	2.96	0.644	0.378	4.13	0.247	7.10	1.55	0.91
178	3	3	12	1	2.53	1.95	0.110	2.90	0.594	0.332	4.93	0.278	7.34	1.50	0.84
179	3	3	12	2	2.60	2.02	0.161	3.17	0.736	0.388	5.25	0.419	8.24	1.91	1.01
180	3	3	12	3	2.60	1.88	0.120	2.77	0.524	0.391	4.89	0.312	7.20	1.36	1.02
181	3	3	13	1	2.45	2.02	0.138	3.14	0.694	0.424	4.95	0.338	7.69	1.70	1.04
182	3	3	13	2	2.93	1.84	0.145	3.09	0.586	0.361	5.39	0.425	9.05	1.72	1.06
183	3	3	13	3	2.53	1.80	0.151	3.06	0.651	0.351	4.55	0.382	7.74	1.65	0.89
184	3	3	14	1	2.40	1.60	0.088	2.45	0.720	0.415	3.84	0.211	5.88	1.73	1.00
185	3	3	14	2	3.86	1.53	0.133	2.58	0.500	0.328	5.91	0.513	9.96	1.93	1.27
186	3	3	14	3	3.32	1.47	0.111	2.70	0.518	0.362	4.88	0.369	8.96	1.72	1.20
187	3	3	15	1	2.98	1.61	0.130	2.44	0.544	0.358	4.80	0.387	7.27	1.62	1.07
188	3	3	15	2	3.32	1.60	0.120	2.48	0.690	0.450	5.31	0.398	8.23	2.29	1.49
189	3	3	15	3	3.28	1.42	0.108	2.44	0.906	0.485	4.66	0.354	8.00	2.97	1.59
190	3	3	16	1	2.70	1.69	0.111	2.80	0.750	0.398	4.56	0.300	7.56	2.02	1.07
191	3	3	16	2	3.22	1.73	0.140	2.78	0.546	0.376	5.57	0.451	8.95	1.76	1.21
192	3	3	16	3	2.93	1.50	0.122	2.82	0.518	0.340	4.39	0.357	8.26	1.52	1.00

S T A T I S T I C A L   A N A L Y S I S   S Y S T E M   11:16 FRIDAY, MARCH 26, 1982

EXPERIMENT III   Table 2.

DATA FROM 1982

OBS	V	L	R	W	N	P	K	CA	MG	AL	MN	PD	TN	TP	TK	TCA	TMG	TAL	TMN
				-gm-	----------	---------- %	----------	----------	----------	----ppm	---	score	----------	---------- 10^{-1}	x mg	----------	----------	--- micro	gm-
1	1	0	1	2.53	3.00	0.185	3.37	0.507	0.321	93	457	1.0	7.59	0.468	8.53	1.28	0.81	235	1156
2	1	0	2	2.05	2.98	0.200	3.59	0.525	0.340	109	518	0.0	6.10	0.410	7.35	1.08	0.70	223	1061
3	1	0	3	1.98	2.90	0.179	3.51	0.533	0.281	80	411	0.0	5.75	0.355	6.96	1.06	0.56	159	815
4	2	0	1	1.53	2.49	0.158	3.45	0.531	0.356	126	537	0.0	3.82	0.243	5.30	0.82	0.55	193	824
5	2	0	2	1.18	3.06	0.222	4.19	0.460	0.317	188	406	0.0	3.62	0.263	4.96	0.54	0.38	222	480
6	2	0	3	1.14	3.18	0.214	4.54	0.544	0.302	101	483	0.0	3.63	0.244	5.18	0.62	0.34	115	552
7	3	0	1	1.32	3.50	0.215	3.34	0.730	0.373	182	670	0.0	4.62	0.284	4.41	0.96	0.49	240	884
8	3	0	2	1.21	3.60	0.201	4.54	0.729	0.356	138	639	0.0	4.37	0.244	5.52	0.89	0.43	168	776
9	3	0	3	1.19	3.45	0.225	4.53	0.724	0.357	167	620	0.0	4.11	0.268	5.40	0.86	0.43	199	739
10	4	0	1	1.72	3.22	0.180	2.93	0.522	0.381	126	412	1.0	5.54	0.310	5.05	0.90	0.66	217	709
11	4	0	2	1.68	3.38	0.185	3.06	0.480	0.396	146	297	0.0	5.68	0.311	5.14	0.81	0.67	245	499
12	4	0	3	1.63	3.10	0.180	3.04	0.558	0.415	162	435	0.0	5.07	0.294	4.97	0.91	0.68	265	711
13	5	0	1	2.39	2.62	0.171	3.25	0.572	0.399	133	533	0.0	6.27	0.410	7.78	1.37	0.96	319	1277
14	5	0	2	2.87	2.50	0.170	2.80	0.418	0.388	117	395	0.0	7.18	0.489	8.05	1.20	1.12	336	1135
15	5	0	3	2.75	2.21	0.148	2.86	0.590	0.329	72	448	0.0	6.07	0.407	7.86	1.62	0.90	198	1231
16	6	0	1	2.13	2.78	0.143	3.09	0.392	0.311	161	337	3.0	5.92	0.304	6.58	0.83	0.66	343	717

* W = Dry weight, PD = P deficiency, T = Total; V = Strain, L = Lime, R = Replication

DATA FROM 1982

OBS	V	L	R	W	N	P	K	CA	MG	AL	MN	PD	TN	TP	TK	TCA	TMG	TAL	TMN
17	6	0	2	2.43	2.58	0.148	2.74	0.483	0.315	350	419	3.0	6.27	0.360	6.66	1.17	0.77	850	1018
18	6	0	3	2.25	2.68	0.150	3.37	0.474	0.336	102	350	2.0	6.02	0.337	7.57	1.06	0.75	229	786
19	7	0	1	2.20	2.39	0.138	3.32	0.436	0.295	267	439	0.0	5.26	0.303	7.30	0.96	0.65	587	965
20	7	0	2	2.60	2.30	0.148	3.11	0.430	0.321	104	407	0.0	5.99	0.385	8.10	1.12	0.84	271	1060
21	7	0	3	1.93	2.76	0.169	3.90	0.486	0.323	96	454	0.0	5.33	0.327	7.53	0.94	0.62	185	877
22	8	0	1	2.43	2.50	0.160	3.26	0.510	0.284	103	390	1.0	6.07	0.389	7.92	1.24	0.69	250	948
23	8	0	2	1.65	2.88	0.152	3.82	0.533	0.310	117	443	0.0	4.76	0.251	6.32	0.88	0.51	194	733
24	8	0	3	2.02	2.53	0.148	3.54	0.484	0.327	131	445	0.0	5.11	0.299	7.15	0.98	0.66	264	858
25	9	0	1	2.18	2.48	0.136	2.97	0.404	0.321	145	397	0.0	5.40	0.296	6.47	0.88	0.70	316	864
26	9	0	2	2.43	2.30	0.150	3.37	0.407	0.312	123	350	0.0	5.60	0.365	8.20	0.99	0.76	299	852
27	9	0	3	2.24	2.30	0.130	3.26	0.395	0.275	120	337	0.0	5.15	0.291	7.31	0.89	0.62	269	755
28	10	0	1	2.31	3.28	0.200	3.66	0.475	0.313	105	339	1.0	7.57	0.462	8.45	1.10	0.72	242	782
29	10	0	2	2.49	2.76	0.180	3.50	0.415	0.305	79	294	1.0	6.87	0.448	8.71	1.03	0.76	197	732
30	10	0	3	2.42	2.51	0.146	3.27	0.421	0.273	112	357	1.0	6.06	0.353	7.90	1.02	0.66	271	863
31	11	0	1	2.03	3.00	0.200	3.73	0.493	0.326	131	445	1.0	6.10	0.407	7.59	1.00	0.66	266	905
32	11	0	2	1.60	3.00	0.192	3.65	0.666	0.384	149	478	1.0	4.81	0.308	5.85	1.07	0.62	239	767
33	11	0	3	1.83	3.00	0.180	3.67	0.530	0.354	155	467	1.0	5.50	0.330	6.73	0.97	0.65	284	857
34	12	0	1	2.15	2.88	0.174	3.41	0.419	0.305	103	370	2.0	6.21	0.375	7.35	0.90	0.66	222	797
35	12	0	2	2.01	3.00	0.180	4.04	0.430	0.258	76	345	2.0	6.04	0.363	8.14	0.87	0.52	153	695
36	12	0	3	2.23	2.72	0.160	3.68	0.483	0.316	95	356	2.0	6.08	0.357	8.22	1.08	0.71	212	795
37	13	0	1	1.93	2.90	0.168	4.03	0.431	0.327	169	402	0.0	5.60	0.324	7.78	0.83	0.63	326	776
38	13	0	2	1.61	3.28	0.200	4.00	0.444	0.340	142	400	2.0	5.27	0.321	6.43	0.71	0.55	228	643
39	13	0	3	1.68	2.90	0.159	3.81	0.506	0.299	116	346	1.0	4.87	0.267	6.40	0.85	0.50	195	582
40	14	0	1	3.09	2.20	0.140	3.31	0.458	0.326	104	321	2.0	6.80	0.432	10.22	1.41	1.01	321	992
41	14	0	2	2.38	3.10	0.190	3.90	0.540	0.325	160	462	1.0	7.39	0.453	9.30	1.29	0.77	381	1101
42	14	0	3	2.53	2.60	0.156	3.31	0.440	0.312	150	395	2.0	6.58	0.395	8.37	1.11	0.79	379	999
43	15	0	1	2.67	2.61	0.165	3.21	0.472	0.313	134	390	1.0	6.96	0.440	8.56	1.26	0.83	357	1040
44	15	0	2	2.58	2.80	0.170	3.26	0.414	0.319	198	323	1.0	7.22	0.438	8.40	1.07	0.82	510	833
45	15	0	3	2.21	2.62	0.160	3.50	0.500	0.355	141	403	2.0	5.80	0.354	7.74	1.11	0.79	312	891
46	1	2	1	2.33	2.85	0.190	4.21	0.748	0.301	232	359	0.0	6.63	0.442	9.80	1.74	0.70	540	835
47	1	2	2	2.38	2.80	0.190	3.95	0.733	0.295	83	339	0.0	6.67	0.453	9.41	1.75	0.70	198	808
48	1	2	3	2.53	2.52	0.165	3.91	0.583	0.244	137	364	0.0	6.37	0.417	9.88	1.47	0.62	346	920
49	2	2	1	2.60	3.41	0.162	4.17	0.677	0.214	72	255	0.0	8.88	0.422	10.85	1.76	0.56	187	664
50	2	2	2	1.93	2.72	0.180	4.67	0.743	0.240	120	313	0.0	5.26	0.348	9.03	1.44	0.46	232	605
51	2	2	3	2.06	2.68	0.191	4.78	0.724	0.260	159	270	0.0	5.52	0.393	9.85	1.49	0.54	328	556
52	3	2	1	1.66	3.12	0.170	4.43	0.982	0.279	103	410	0.0	5.17	0.282	7.34	1.63	0.46	171	679
53	3	2	2	1.60	3.20	0.169	4.50	0.960	0.293	144	376	0.0	5.14	0.271	7.22	1.54	0.47	231	603
54	3	2	3	1.79	3.08	0.169	4.27	0.810	0.295	233	336	0.0	5.52	0.303	7.65	1.45	0.53	418	602
55	4	2	1	2.56	2.90	0.192	3.80	0.700	0.367	140	263	2.0	7.44	0.492	9.75	1.80	0.94	359	675
56	4	2	2	2.49	2.71	0.172	3.96	0.673	0.378	114	268	1.0	6.76	0.429	9.88	1.68	0.94	284	669
57	4	2	3	2.39	2.72	0.180	3.62	0.688	0.334	104	220	0.0	6.51	0.431	8.66	1.65	0.80	249	526
58	5	2	1	3.46	2.10	0.150	3.00	0.705	0.316	142	333	0.0	7.27	0.519	10.38	2.44	1.09	491	1152
59	5	2	2	3.05	2.40	0.173	3.97	0.747	0.295	110	371	0.0	7.31	0.527	12.09	2.28	0.90	335	1130
60	5	2	3	2.95	2.53	0.190	3.74	0.726	0.347	140	385	1.0	7.46	0.560	11.02	2.14	1.02	413	1135
61	6	2	1	2.20	2.80	0.170	4.05	0.670	0.285	118	300	2.0	6.17	0.375	8.92	1.48	0.63	260	661
62	6	2	2	2.60	2.51	0.145	3.76	0.654	0.259	85	231	3.0	6.52	0.377	9.77	1.70	0.67	221	600
63	6	2	3	2.27	2.95	0.188	4.05	0.661	0.270	147	235	1.0	6.69	0.426	9.18	1.50	0.61	333	533
64	7	2	1	3.64	2.10	0.159	3.66	0.562	0.295	161	241	0.0	7.64	0.578	13.31	2.04	1.07	586	877
65	7	2	2	3.09	2.40	0.190	4.05	0.594	0.296	86	285	0.0	7.41	0.586	12.50	1.83	0.91	265	880
66	7	2	3	3.13	2.28	0.160	3.72	0.585	0.296	144	281	0.0	7.12	0.500	11.62	1.83	0.92	450	878
67	8	2	1	2.33	2.68	0.170	3.99	0.718	0.248	103	299	1.0	6.25	0.397	9.31	1.68	0.58	240	698
68	8	2	2	2.94	2.41	0.169	3.95	0.750	0.371	150	293	0.0	7.09	0.497	11.62	2.21	1.09	441	862
69	8	2	3	3.05	2.32	0.170	4.02	0.707	0.309	129	325	1.0	7.07	0.518	12.26	2.16	0.94	393	991
70	9	2	1	3.05	2.40	0.148	3.91	0.614	0.275	121	224	0.0	7.31	0.451	11.91	1.87	0.84	369	682
71	9	2	2	3.04	2.40	0.170	3.57	0.619	0.308	148	270	0.0	7.30	0.517	10.65	1.88	0.94	450	821

DATA FROM 1982

OBS	V	L	R	W	N	P	K	CA	MG	AL	MN	PD	TN	TP	TK	TCA	TMG	TAL	TMN
72	9	2	3	3.71	2.10	0.145	3.38	0.579	0.306	160	267	0.0	7.78	0.537	12.53	2.15	1.13	593	990
73	10	2	1	2.39	2.80	0.171	4.04	0.692	0.348	159	362	2.0	6.68	0.408	9.64	1.65	0.83	380	864
74	10	2	2	2.11	2.98	0.201	4.49	0.748	0.340	305	329	1.0	6.29	0.424	9.47	1.58	0.72	644	694
75	10	2	3	3.12	2.46	0.150	3.73	0.676	0.321	93	318	3.0	7.68	0.468	11.64	2.11	1.00	290	992
76	11	2	1	2.72	2.55	0.188	4.24	0.651	0.305	122	327	1.0	6.93	0.511	11.52	1.77	0.83	332	889
77	11	2	2	2.36	2.52	0.160	4.48	0.645	0.253	113	187	2.0	5.94	0.377	10.56	1.52	0.60	266	441
78	11	2	3	2.24	2.82	0.180	4.58	0.625	0.300	105	315	0.0	6.31	0.403	10.25	1.40	0.67	235	705
79	12	2	1	2.43	3.00	0.190	4.18	0.666	0.351	126	305	2.0	7.29	0.462	10.16	1.62	0.65	306	741
80	12	2	2	2.17	2.68	0.161	4.12	0.752	0.289	115	341	2.0	5.81	0.349	8.94	1.63	0.63	249	740
81	12	2	3	3.70	2.20	0.140	3.21	0.651	0.332	152	266	2.0	8.14	0.518	11.88	2.41	1.23	563	985
82	13	2	1	2.24	2.70	0.175	4.34	0.764	0.345	147	333	1.0	6.04	0.392	9.71	1.71	0.77	329	745
83	13	2	2	2.00	3.20	0.201	4.84	0.737	0.313	189	281	2.0	6.40	0.402	9.68	1.47	0.63	378	562
84	13	2	3	2.47	2.92	0.192	4.32	0.776	0.372	210	375	2.0	7.21	0.474	10.67	1.92	0.92	518	926
85	14	2	1	2.40	2.76	0.175	4.01	0.830	0.376	106	405	1.0	6.63	0.421	9.64	1.99	0.90	255	973
86	14	2	2	2.70	2.42	0.158	4.15	0.648	0.318	166	321	2.0	6.55	0.427	11.23	1.75	0.86	449	868
87	14	2	3	3.24	2.28	0.150	3.85	0.570	0.321	104	190	3.0	7.39	0.486	12.47	1.85	1.04	337	616
88	15	2	1	3.33	2.08	0.145	3.57	0.610	0.272	86	280	1.0	6.93	0.483	11.90	2.03	0.91	287	933
89	15	2	2	2.93	2.43	0.175	3.81	0.659	0.313	134	296	1.0	7.13	0.513	11.18	1.93	0.92	393	868
90	15	2	3	4.12	1.72	0.138	3.28	0.411	0.320	95	185	2.0	7.08	0.568	13.51	1.69	1.32	391	762
91	1	4	1	2.52	2.76	0.188	4.41	0.980	0.308	107	277	1.0	6.94	0.473	11.10	2.47	0.77	269	697
92	1	4	2	2.25	2.72	0.190	4.34	0.750	0.309	84	216	0.0	6.11	0.427	9.75	1.69	0.69	189	485
93	1	4	3	2.97	2.60	0.168	3.74	0.783	0.291	89	216	0.0	7.72	0.499	11.10	2.32	0.86	264	641
94	2	4	1	3.22	2.30	0.200	4.09	0.808	0.329	92	180	0.0	7.41	0.644	13.18	2.60	1.06	296	580
95	2	4	2	3.20	2.28	0.167	4.26	0.857	0.235	112	133	0.0	7.30	0.534	13.63	2.74	0.75	358	426
96	2	4	3	2.68	2.51	0.182	4.89	0.854	0.257	75	176	0.0	6.72	0.487	13.09	2.29	0.69	201	471
97	3	4	1	1.83	3.11	0.180	4.58	1.200	0.306	158	225	0.0	5.70	0.330	8.40	2.20	0.56	290	413
98	3	4	2	1.62	3.22	0.190	4.69	1.130	0.378	125	231	0.0	5.21	0.307	7.58	1.83	0.61	202	374
99	3	4	3	1.85	3.40	0.198	4.26	1.250	0.326	145	228	0.0	6.28	0.366	7.87	2.31	0.60	268	421
100	4	4	1	2.28	2.90	0.180	4.16	0.920	0.396	166	155	1.0	6.61	0.410	9.48	2.10	0.90	378	353
101	4	4	2	2.46	2.82	0.190	4.13	0.770	0.342	72	119	1.0	6.95	0.468	10.18	1.90	0.84	177	293
102	4	4	3	2.60	2.80	0.189	4.11	0.822	0.371	106	144	1.0	7.28	0.491	10.69	2.14	0.96	276	374
103	5	4	1	3.65	2.30	0.180	3.88	0.900	0.287	133	288	1.0	8.39	0.657	14.16	3.28	1.05	485	1051
104	5	4	2	2.96	2.61	0.198	4.20	0.800	0.316	152	254	1.0	7.73	0.586	12.44	2.37	0.94	450	752
105	5	4	3	3.41	2.20	0.162	3.47	0.690	0.281	106	245	1.0	7.50	0.552	11.83	2.35	0.96	361	835
106	6	4	1	2.80	2.88	0.180	4.04	0.800	0.312	202	220	3.0	8.05	0.503	11.30	2.24	0.87	565	615
107	6	4	2	2.77	2.68	0.180	3.95	0.850	0.312	181	176	2.0	7.42	0.498	10.93	2.35	0.86	501	487
108	6	4	3	2.17	3.11	0.189	4.35	0.475	0.309	144	285	1.0	6.74	0.410	9.43	1.03	0.67	312	618
109	7	4	1	3.78	2.08	0.162	3.70	0.695	0.244	119	207	0.0	7.87	0.613	14.00	2.63	0.92	450	783
110	7	4	2	3.71	1.92	0.150	3.67	0.591	0.356	107	193	0.0	7.12	0.556	13.60	2.19	1.32	397	715
111	7	4	3	3.45	2.00	0.160	3.78	0.682	0.317	127	179	0.0	6.90	0.552	13.03	2.35	1.09	438	617
112	8	4	1	3.49	1.87	0.120	3.82	0.736	0.280	128	200	0.0	6.52	0.419	13.33	2.57	0.98	447	698
113	8	4	2	2.57	2.50	0.190	4.18	0.820	0.298	101	233	0.0	6.44	0.489	10.76	2.11	0.77	260	600
114	8	4	3	3.46	2.27	0.168	3.85	0.796	0.284	160	180	1.0	7.85	0.581	13.31	2.75	0.98	553	622
115	9	4	1	3.05	2.11	0.148	4.21	0.840	0.323	91	214	0.0	6.43	0.451	12.82	2.56	0.98	277	652
116	9	4	2	3.60	2.08	0.147	3.99	0.673	0.316	108	158	0.0	7.50	0.530	14.38	2.43	1.14	389	570
117	9	4	3	2.75	2.40	0.171	4.37	0.736	0.311	81	188	0.0	6.59	0.470	12.00	2.02	0.85	223	516
118	10	4	1	3.82	2.12	0.179	3.88	0.650	0.314	112	182	3.0	8.10	0.684	14.82	2.48	1.20	428	695
119	10	4	2	3.61	2.11	0.160	3.67	0.675	0.331	171	175	2.0	7.61	0.577	13.24	2.43	1.19	617	631
120	10	4	3	3.57	2.30	0.162	3.61	0.674	0.223	119	110	2.0	8.21	0.578	12.89	2.41	0.80	425	393
121	11	4	1	3.19	2.50	0.168	4.04	0.765	0.332	135	161	2.0	7.97	0.536	12.88	2.44	1.06	431	513
122	11	4	2	2.67	2.60	0.206	4.33	0.708	0.268	185	223	2.0	6.93	0.549	11.54	1.89	0.71	493	595
123	11	4	3	2.67	2.72	0.200	4.33	0.861	0.321	88	228	2.0	7.25	0.533	11.54	2.30	0.66	235	608
124	12	4	1	2.64	2.70	0.149	4.17	0.850	0.339	124	211	3.0	7.13	0.394	11.02	2.25	0.90	328	557
125	12	4	2	3.82	1.90	0.150	3.65	0.608	0.300	81	154	3.0	7.25	0.572	13.93	2.32	1.14	309	588
126	12	4	3	3.61	2.30	0.180	3.90	0.832	0.391	128	232	3.0	8.31	0.650	14.09	3.01	1.41	462	838

DATA FROM 1982

OBS	V	L	R	W	N	P	K	CA	MG	AL	MN	PD	TN	TP	TK	TCA	TMG	TAL	TMN
127	13	4	1	3.30	2.18	0.142	4.02	0.830	0.349	69	211	1.0	7.20	0.469	13.28	2.74	1.15	228	697
128	13	4	2	2.15	3.10	0.200	4.95	0.922	0.363	111	290	1.0	6.66	0.429	10.63	1.98	0.78	238	623
129	13	4	3	2.13	2.75	0.190	4.69	0.790	0.313	113	220	3.0	5.85	0.405	9.99	1.68	0.67	241	468
130	14	4	1	3.55	2.34	0.159	3.92	0.713	0.334	201	208	2.0	8.30	0.564	13.90	2.53	1.18	713	738
131	14	4	2	2.97	2.40	0.142	4.12	0.598	0.306	111	219	3.0	7.14	0.422	12.25	1.78	0.91	320	651
132	14	4	3	3.91	2.06	0.134	3.69	0.830	0.290	88	198	2.0	8.05	0.524	14.43	3.25	1.13	344	774
133	15	4	1	2.94	2.35	0.180	4.34	0.820	0.331	100	184	2.0	6.92	0.530	12.77	2.41	0.97	294	542
134	15	4	2	3.78	1.92	0.160	4.02	0.797	0.399	114	198	2.0	7.25	0.604	15.19	3.01	1.51	431	748
135	15	4	3	3.47	2.31	0.150	3.85	0.790	0.352	146	154	2.0	8.01	0.520	13.36	2.74	1.22	506	534
136	1	8	1	2.33	2.90	0.180	4.54	1.082	0.289	91	195	0.0	6.75	0.419	10.56	2.52	0.67	212	454
137	1	8	2	2.58	2.75	0.182	4.18	1.000	0.340	92	149	1.0	7.11	0.470	10.80	2.58	0.88	238	385
138	1	8	3	2.35	2.98	0.180	4.68	1.040	0.310	94	142	0.0	6.99	0.422	10.98	2.44	0.73	221	333
139	2	8	1	2.83	2.52	0.165	4.40	1.075	0.241	90	104	0.0	7.14	0.467	12.47	3.05	0.68	255	295
140	2	8	2	2.70	2.50	0.180	4.74	1.000	0.299	106	101	0.0	6.76	0.487	12.82	2.70	0.81	287	273
141	2	8	3	1.49	2.62	0.182	5.40	1.140	0.306	105	79	0.0	3.91	0.272	8.06	1.70	0.46	157	118
142	3	8	1	2.04	3.20	0.190	4.29	1.460	0.317	177	94	0.0	6.52	0.387	8.73	2.97	0.65	360	191
143	3	8	2	1.82	3.30	0.160	4.61	1.510	0.310	139	64	0.0	6.02	0.292	8.41	2.75	0.57	254	117
144	3	8	3	1.96	3.20	0.192	4.42	1.500	0.324	262	101	0.0	6.26	0.376	8.65	2.93	0.63	512	198
145	4	8	1	2.44	3.00	0.200	3.92	1.060	0.383	129	72	1.0	7.33	0.489	9.58	2.59	0.94	315	176
146	4	8	2	2.27	2.90	0.179	3.87	1.089	0.390	102	73	1.0	6.60	0.407	8.80	2.48	0.89	232	166
147	4	8	3	2.76	2.79	0.192	3.69	1.000	0.355	124	54	1.0	7.69	0.530	10.18	2.76	0.98	342	149
148	5	8	1	3.07	2.12	0.148	3.65	1.040	0.355	122	191	1.0	6.51	0.455	11.21	3.19	1.09	375	587
149	5	8	2	2.71	2.39	0.158	4.04	1.030	0.318	123	190	2.0	6.48	0.428	10.95	2.79	0.86	333	515
150	5	8	3	2.87	2.47	0.148	3.93	0.973	0.428	126	165	1.0	7.09	0.425	11.28	2.79	1.23	362	474
151	6	8	1	2.68	2.32	0.140	3.81	0.870	0.299	133	120	2.0	6.22	0.375	10.21	2.33	0.80	356	322
152	6	8	2	2.78	2.70	0.170	4.33	0.980	0.294	123	80	2.0	7.51	0.473	12.05	2.73	0.82	342	223
153	6	8	3	2.46	2.26	0.121	3.78	0.895	0.243	101	87	2.0	5.56	0.297	9.29	2.20	0.60	248	214
154	7	8	1	3.23	2.06	0.160	4.13	0.800	0.303	91	129	1.0	6.65	0.516	13.33	2.58	0.98	294	416
155	7	8	2	3.53	2.21	0.171	3.85	0.880	0.315	123	120	1.0	7.79	0.603	13.58	3.10	1.11	434	423
156	7	8	3	3.30	2.12	0.160	3.88	0.800	0.298	305	158	0.0	7.00	0.528	12.81	2.64	0.98	1007	522
157	8	8	1	2.90	2.40	0.161	4.37	0.950	0.327	117	131	1.0	6.95	0.466	12.66	2.75	0.95	339	380
158	8	8	2	2.96	2.38	0.150	4.44	0.900	0.369	97	98	1.0	7.04	0.444	13.13	2.66	1.09	287	290
159	8	8	3	2.82	2.40	0.151	4.24	0.952	0.275	106	140	1.0	6.78	0.426	11.97	2.69	0.78	299	395
160	9	8	1	3.37	2.19	0.161	4.18	0.792	0.377	167	104	0.0	7.38	0.543	14.09	2.67	1.27	563	351
161	9	8	2	3.28	2.08	0.148	4.10	0.792	0.342	120	91	1.0	6.82	0.485	13.44	2.60	1.12	393	298
162	9	8	3	3.35	2.00	0.131	4.06	0.827	0.375	177	120	0.0	6.69	0.438	13.59	2.77	1.26	592	402
163	10	8	1	2.89	2.60	0.198	4.27	0.800	0.392	121	173	2.0	7.51	0.572	12.34	2.31	1.13	350	500
164	10	8	2	2.89	2.50	0.160	4.20	0.870	0.323	206	152	3.0	7.22	0.462	12.13	2.51	0.93	595	439
165	10	8	3	3.93	2.09	0.132	3.66	0.731	0.283	82	111	3.0	8.22	0.519	14.40	2.88	1.11	323	437
166	11	8	1	2.24	2.50	0.152	4.38	0.910	0.311	93	94	2.0	5.61	0.341	9.82	2.04	0.70	209	211
167	11	8	2	2.30	2.68	0.195	4.55	0.949	0.319	123	140	1.0	6.17	0.449	10.47	2.18	0.73	283	322
168	11	8	3	2.93	2.22	0.160	4.32	0.910	0.334	89	122	2.0	6.50	0.469	12.66	2.67	0.98	261	357
169	12	8	1	3.67	2.18	0.150	3.72	0.795	0.279	98	117	3.0	8.01	0.551	13.67	2.92	1.03	360	430
170	12	8	2	3.11	2.50	0.165	4.52	0.940	0.349	132	129	3.0	7.79	0.514	14.08	2.93	1.09	411	402
171	12	8	3	2.56	2.58	0.143	4.10	0.978	0.328	107	130	2.0	6.60	0.366	10.48	2.50	0.84	274	332
172	13	8	1	1.69	3.20	0.198	4.90	1.040	0.355	110	118	3.0	5.40	0.334	8.26	1.75	0.60	185	199
173	13	8	2	2.57	2.68	0.161	4.21	1.044	0.334	118	112	3.0	6.88	0.413	10.81	2.68	0.86	303	288
174	13	8	3	2.14	2.58	0.158	4.69	1.109	0.340	120	132	1.0	5.52	0.338	10.04	2.37	0.73	257	282
175	14	8	1	2.93	2.42	0.180	4.66	0.940	0.330	156	136	3.0	7.10	0.528	13.67	2.76	0.97	458	399
176	14	8	2	3.61	2.26	0.148	3.99	0.730	0.304	123	104	3.0	8.16	0.534	14.40	2.63	1.10	444	375
177	14	8	3	3.19	2.40	0.168	4.45	0.900	0.304	115	125	2.0	7.65	0.536	14.19	2.87	0.97	367	398
178	15	8	1	3.97	1.93	0.126	3.49	0.747	0.319	114	106	3.0	7.67	0.500	13.86	2.97	1.27	453	421
179	15	8	2	2.98	2.62	0.180	4.17	0.840	0.371	105	118	2.0	7.81	0.536	12.43	2.50	1.11	313	352
180	15	8	3	3.33	2.20	0.136	3.84	0.990	0.384	108	136	3.0	7.33	0.453	12.79	3.30	1.28	360	453

Table 3 . Field corn (01), cucumbers (16), muskmelon (21), sorghum-sudan (37), sweet corn (41), watermelon (45), pumpkin (50), and squash (53).

Nutrient		Nutrient concentration in tissue				
		Deficient	Low	Sufficient	High	Excessive
Nitrogen	%	< 1.75	1.75-2.49	2.50-3.50	3.51-4.00	> 4.00
Phosphorus	%	< 0.16	0.16-0.24	0.25-0.50	0.51-0.80	> 0.80
Potassium	%	< 1.25	1.25-1.74	1.75-2.25	2.26-2.75	> 2.75
Calcium	%	< 0.10	0.10-0.29	0.30-0.60	0.61-0.90	> 0.90
Magnesium	%	< 0.10	0.10-0.19	0.20-0.40	0.41-0.55	> 0.55
Sulphur	%	< 0.10	0.10-0.20	0.21-0.50	0.51-0.80	> 0.80
Zinc	ppm	< 15	15-25	26-75	76-150	> 150
Boron	ppm	< 2.0	2.0-5.0	5.1-40.0	40.1-55.0	> 55.0
Manganese	ppm	< 15	15-25	26-150	151-200	> 200
Iron	ppm	< 10	10-49	50-250	251-350	> 350
Copper	ppm	< 2.0	2.0-5.0	5.1-20.0	20.1-50.0	> 50.0
Aluminum	ppm		< 10	11-300	301-500	> 500

ANALYTICAL PROCEDURES USED
IN NUTRIENT DETERMINATION

INDIVIDUAL/SIMULTANEOUS DETERMINATION OF NITROGEN AND/OR PHOSPHORUS IN BD ACID DIGESTS

RANGE: Nitrogen 1-50 mg/l; 20-1000 mg/l
Phosphorus 1-50 mg/l; 20-1000 mg/l

BD-20/BD-40 (DIALYZER)

GENERAL DESCRIPTION

NITROGEN

The determination of nitrogen is based on a colorimetric method in which an emerald-green color is formed by the reaction of ammonia, sodium salicylate, sodium nitroprusside and sodium hypochlorite (chlorine source) in a buffered alkaline medium at a pH of 12.8-13.0. The ammonia-salicylate complex is read at 660 nm.

PHOSPHORUS

The determination of phosphorus is based on the colorimetric method in which a blue color is formed by the reaction of ortho phosphate, molybdate ion and antimony ion followed by reduction with ascorbic acid at an acidic pH. The phosphomolybdenum complex is read at 660 nm.

The acid digest samples are prepared by digestion with the Technicon BD-40 or BD-20 Block Digestor. Refer to Manual No. TA4-0323-11 for sample preparation.

PERFORMANCE AT 40 SAMPLES PER HOUR

MANUALLY PREPARED STANDARDS

NITROGEN	1-50 mg/l	20-1000 mg/l
Sensitivity	at 50 mg/l 0.20 absorbance unit	at 1000 mg/l 1.00 absorbance unit
Coefficient of Variation	at 25 mg/l ±0.6%	at 500 mg/l ±0.4%
Detection Limit	1.0 mg/l	20 mg/l

PHOSPHORUS	1-50 mg/l	20-1000 mg/l
Sensitivity	at 50 mg/l 0.20 absorbance unit	at 1000 mg/l 0.60 absorbance unit
Coefficient of Variation	at 25 mg/l ±0.5%	at 500 mg/l ±0.6%
Detection Limit	1.0 mg/l	20 mg/l

*See Operating Note 7.

REAGENTS

Unless otherwise specified, all reagents should be of ACS quality or equivalent.

GENERAL REAGENTS

TRITON X-100 SOLUTION (50% in Methanol)

Triton X-100** (Technicon No. T21-0188)	50 ml
Methanol (CH_3OH)	50 ml

Preparation:
Add 50 ml of Triton X-100 to 50 ml of methanol and mix thoroughly.

SYSTEM WASH WATER SOLUTION
(For System Shut-Down and Start-Up Only)

Triton X-100 Solution	1.0 ml
Distilled Water	1000 ml

Preparation:
Add 1.0 ml of Triton X-100 solution to one liter of distilled water and mix.

SAMPLER IV WASH RECEPTACLE SOLUTION

Distilled Water

Note: This reagent contains *no* wetting agent.

NITROGEN REAGENTS

STOCK SODIUM HYDROXIDE SOLUTION, 20%

Sodium Hydroxide Solution, 50% w/w	400 g
Distilled Water, q.s.	1000 ml

Preparation:
To 600 ml of distilled water, add 400 g of sodium hydroxide solution, 50% w/w. Cool to room temperature and dilute to one liter with distilled water.

STOCK SODIUM POTASSIUM TARTRATE SOLUTION, 20%

Sodium Potassium Tartrate ($NaKC_4H_4O_6 \cdot 4H_2O$)	200 g
Distilled Water, q.s.	1000 ml

Preparation:
Dissolve 200 g of sodium potassium tartrate in about 600 ml of distilled water. Dilute to one liter with distilled water and mix thoroughly.

STOCK BUFFER SOLUTION 0.5*M*

Sodium Phosphate, Dibasic, crystal ($Na_2HPO_4 \cdot 7H_2O$)	134 g
[Sodium Phosphate, Dibasic, anhydrous (Na_2HPO_4)]	[71 g]
Sodium Hydroxide Solution, 50% w/w	40 g
Distilled Water, q.s.	1000 ml

Preparation:
Dissolve 134 g of sodium phosphate, dibasic, crystal (or 71 g of sodium phosphate, dibasic, anhydrous) in about 800 ml of distilled water. Add 40 g of sodium hydroxide solution, 50% w/w, dilute to one liter with distilled water and mix thoroughly.

WORKING BUFFER SOLUTION

Stock Buffer Solution, 0.5*M*	200 ml
Stock Sodium Potassium Tartrate Solution, 20%	250 ml
Stock Sodium Hydroxide Solution, 20%	250 ml
Distilled Water, q.s.	1000 ml
Brij-35,*** 30% Solution (Technicon No. T21-0110)	1.0 ml

Preparation:
Combine the reagents in the stated order: add 250 ml of stock sodium potassium tartrate solution, 20%, to 200 ml of stock buffer solution, 0.5*M*, with swirling. Slowly, with swirling, add 250 ml of sodium hydroxide solution, 20%. Dilute to one liter with distilled water, add 1.0 ml of Brij-35, 30% solution, (20-25 drops) and mix thoroughly.

SULFURIC ACID/SODIUM CHLORIDE SOLUTION

Sulfuric Acid, 95-98% (H_2SO_4)	7.5 ml
Sodium Chloride (NaCl)	100 g
Distilled Water, q.s.	1000 ml
Brij-35, 30% Solution	1.0 ml

Preparation:
Dissolve 100 g of sodium chloride in about 600 ml of distilled water. Add 7.5 ml of sulfuric acid and dilute to one liter with distilled water. Add 1.0 ml of Brij-35 (about 20 drops) and mix thoroughly.

SODIUM SALICYLATE/SODIUM NITROPRUSSIDE SOLUTION

Sodium Salicylate ($NaC_7H_5O_3$)	150 g
Sodium Nitroprusside [$Na_2Fe(CN)_5NO \cdot 2H_2O$]	0.30 g
Distilled Water, q.s.	1000 ml
Brij-35, 30% solution	1.0 ml

**Trademark of Rohm and Haas Company.

***Trademark of Atlas Chemical Industries, Inc.

Preparation:
Dissolve 150 g of sodium salicylate and 0.30 g of sodium nitroprusside in about 600 ml of distilled water. Filter through fast filter paper into a one liter volumetric flask and dilute to volume with distilled water. Add 1.0 ml of Brij-35 and mix thoroughly. Store in a light-resistant container.

SODIUM HYPOCHLORITE SOLUTION, 0.315%

Sodium Hypochlorite Solution, 5.25%	6.0 ml
Distilled Water, q.s.	100 ml
Brij-35, 30% Solution	0.1 ml

Preparation:
Dilute 6.0 ml of sodium hypochlorite solution to 100 ml with distilled water. Add 0.1 ml (2 drops) of Brij-35 and mix thoroughly. Prepare fresh daily. [Any commercial bleach solution (e.g. Clorox) containing 5.25% available chlorine is satisfactory.]

PHOSPHORUS REAGENTS

SULFURIC ACID SOLUTION, 4.0*N*

Sulfuric Acid, 95-98% (H_2SO_4)	111 ml
Distilled Water, q.s.	1000 ml
Triton X-100 Solution	1.0 ml

Preparation:
While swirling, cautiously add 111 ml of sulfuric acid to about 600 ml of distilled water. Cool to room temperature and dilute to one liter with distilled water. Add 1.0 ml of Triton X-100 solution and mix thoroughly.

SODIUM CHLORIDE SOLUTION, 0.25%

Sodium Chloride (NaCl)	2.5 g
Distilled Water, q.s.	1000 ml
Aerosol-22****	5.0

Preparation:
Dissolve 2.5 g of sodium chloride in about 600 ml of distilled water. Dilute to one liter with distilled water. Add 5.0 ml of Aerosol-22 and mix thoroughly.

MOLYBDATE/ANTIMONY SOLUTION

Ammonium Molybdate [$(NH_4)_6Mo_7O_{24} \cdot 4H_2O$]	10.0 g
Antimony Potassium Tartrate [$K(SbO)C_4H_4O_6 \cdot 1/2H_2O$]	0.15 g
Sulfuric Acid, 95-98% (H_2SO_4)	60 ml
Distilled Water, q.s.	1000 ml

Preparation:
Dissolve 10.0 g of ammonium molybdate and 0.15 g of antimony potassium tartrate in about 800 ml of distilled water. While swirling, cautiously add 60 ml of sulfuric acid. Cool to room temperature, dilute to one liter with distilled water and mix thoroughly. Transfer to a light-resistant container. This solution is stable for about one month.

****Trademark of American Cyanamid Company.

ASCORBIC ACID SOLUTION, 1.0%

Ascorbic Acid ($C_6H_8O_6$) – OR – Araboascorbic Acid ($C_6H_8O_6$)	2.0 g
Distilled Water, q.s.	200 ml

Preparation:
Dissolve 2.0 g of ascorbic acid or araboascorbic acid in about 150 ml of distilled water. Dilute to 200 ml with distilled water and mix thoroughly. Transfer to a light-resistant container. If kept refrigerated and tightly stoppered when not in use, this solution is stable for at least two days.

OPERATING NOTES

1. Start-Up
   a. Check the level of all reagents to ensure an adequate supply.
   b. Excluding the salicylate and molybdate/antimony lines, place all reagent lines in their respective containers.
   c. When reagents have been pumping for at least five minutes, place the salicylate and molybdate/antimony lines in their respective containers and allow the system to equilibrate for 10 minutes.

   NOTE: If a precipitate appears after the addition of salicylate, immediately stop the proportioning pump and flush the coils with water using a syringe. Precipitation of salicylic acid is caused by a low pH. Before restarting the system, check the concentration of the sulfuric acid solution and/or the working buffer solution.

   d. To prevent precipitation of salicylic acid in the waste tray (which can clog the tray outlet), keep the nitrogen flowcell pump tube and the nitrogen colorimeter TO WASTE tube separate from all other lines or keep tap water flowing in the waste tray.

2. Shut-Down
   a. Remove the salicylate and molybdate/antimony lines from their containers and allow them to pump air. When the air bubbles enter the analytical system, place all reagent lines (excluding the Sampler IV Wash Receptacle Solution line) in the System Wash Water Solution.
   b. After 15 minutes, stop the proportioning pump and remove the platen.

3. System Operation
   a. Be sure the plastic cover of the analytical cartridge is in place when operating the system.
   b. At STD CAL settings of 6.00 or more, the system may be operated in the DAMP 1 position, if necessary.

4. Manifold Connections

   To avoid the possibility of airborne contamination, the air lines of the nitrogen channel should be attached to an air scrubber containing dilute sulfuric acid (10% v/v).

5. Reagent Background Color
   a. Place all lines in the system wash water container and start the proportioning pump. After making the necessary adjustments on the colorimeters set the STD CAL control of the nitrogen colorimeter to 1.00 and the STD CAL control of the phosphorus colorimeter to 2.90. Adjust the water baseline on both colorimeters to zero with the BLANK control.
   b. Following the start-up procedure, place all reagent lines in the proper order in their respective containers and allow the system to equilibrate.
   c. The reading of the reagents compared to distilled water should not be more than 14 units (0.140 absorbance) for the nitrogen channel and not more than 5 units (0.25 absorbance) for the phosphorus channel. If the absorbance of either channel is much higher than the above values, one or more of the reagents or the water used to make up the reagents is probably contaminated.

6. Concentration Ranges
   a. All concentration ranges refer to the concentration of components in the digestion tube after diluting to volume with distilled water.
   b. Nitrogen Channel
      1. Concentration ranges from 1-50 mg/l to 20-1000 mg/l can be accommodated by changing the size of the flowcell and the sample, resample and diluent lines as designated in the concentration ranges table (refer to Figure 1 and flow diagram).
      2. For any one manifold configuration, an approximate five-fold change in concentration can be accommodated by use of the STD CAL control. The system is linear when operated at a STD CAL setting of 1.00 or higher.
   c. Phosphorus Channel
      1. Concentration ranges from 1-50 mg/l to 20-1000 mg/l can be accommodated by changing the size of the sample, resample and diluent lines as designated in the concentration ranges table (refer to Figure 2 and flow diagram).
      2. For any one manifold configuration, an approximate three-fold change in concentration can be accommodated by use of the STD CAL control. The system is linear when operated at a STD CAL setting of 2.00 or higher.

7. Manifold Configurations
   a. Individual Determination of N or P

      When N or P is being determined individually, the PT fitting is omitted and the sample line is attached directly to the sample probe of the Sampler IV.
   b. Simultaneous Determination of N and P

      When N and P are being determined simultaneously, both initial sample lines are connected to a PT stream-splitter fitting which is in turn connected to the sample probe on the Sampler IV.

8. Sample Probe and PT Stream-Splitter

   Because stainless steel is susceptible to attack by sulfuric acid solutions, this method utilizes a special Kel-F sample probe (Technicon No. 171-0745) and a special PT stream-splitter with platinum nipples (Technicon No. 116-B331).

9. Phosphorus Channel (only)
   a. Cleansing Procedure

      Before initially operating the system, the following procedure should be performed to cleanse the system. Once a week thereafter, this procedure should be repeated during system start-up.

      With the exception of the ascorbic acid and molybdate/antimony lines, place all phosphorus reagent lines into their respective containers. Start the proportioning pump and allow five minute pumping time. Place both the ascorbic acid and molybdate/antimony lines in sodium hydroxide solution, 20% for five minutes, then into hydrogen peroxide, 50% for five minutes, then into distilled water. After five minutes follow the start-up procedure (Operating Note 1) and allow the system to equilibrate.

b. Conditioning Procedure

After the initial cleansing of the system is performed, condition the phosphorus channel as described below. Once this channel has been conditioned, there is no need to repeat the procedure; only the cleansing procedure need be performed once each week during start-up.

Following the Start-Up procedure (Operating Note #1), place all reagent lines for phosphorus in their respective containers and allow the system to equilibrate. Place three sample cups containing midscale standard solution on the Sampler IV tray (with a stop-pin at the third cup) and start the sampler. Aspirate the set of standards three times, allowing five minutes of wash between each set. After the Recorder traces the last standard peak, wait ten minutes and adjust the baseline tracing to zero using the BASELINE control.

10. Crude Protein Determination -- AOAC

When this methodology is utilized to assay acid digestates for the determination of Crude Protein in Feeds by the official AOAC procedure, the following hardware changes must be incorporated into the system:

a. Sampler IV — Sampler IV cam must be 40/hour with a sample-to-wash ratio of 2:1 (cam is included in the accessories and spares kit).

b. Analytical Cartridge — dilution loop pump tubes must be of the following size:

INITIAL SAMPLE DILUTION

Sample Line	0.16 ml/min (Orn/Yel)
H_2SO_4/NaCl Line	1.20 ml/min (Yel/Yel)

RESAMPLE DILUTION

Resample Line	0.16 ml/min (Orn/Yel)
H_2SO_4/NaCl Line	0.80 ml/min (Red/Red)

c. Colorimeter — must be equipped with 15 mm pathlength flowcell (1.5 or 2.0 mm ID).

PROCEDURE FOR AVAILABLE PHOSPHORUS IN SOILS

1. Weigh 5 grams of dry soil into an Erlenmeyer flask.

2. Add 50 ml. of P-A (0.025 N HCl and 0.03 N NH_4F Bray's phosphorus extracting solution.)

3. Stopper the flask and shake for 1 minute.

4. Filter the suspension through a Whatman 41 filter paper of a similar quality.

5. Pipette 25 ml. of the filtrate into an Erlenmeyer flask.

6. Add 1 ml. of P-B (ammonium molybdate solution) and swirl to mix.

7. Add 1 ml. of P-C (reducing reagent) and swirl to mix.

8. Fifteen minutes after adding the P-C reagent, read the optical density of the solution in a spectrophotometer at 660 mu wavelength.

Prepare standard solutions containing 0, 1, 2, 3, and 4 ppm of P, and

Run a standard curve by following steps 5 through 8 in the above procedure.

PHOSPHORUS PROCEDURE FOR PHOTOMETER

(Bray's sulfonic acid reduction method.)

A. **Reagents:**

1. Reducing reagent, amino-naphthol-sulfonic acid (P-C).

   2.5 gm. 1-amino-2-naphthol-4-sulfonic acid (Eastman 360)

   5.0 gm. Na_2SO_3

   146.25 gm. sodium meta bisulfite ($Na_2S_2O_5$)

   Mix dry materials thoroughly and grind to a fine powder. Dissolve 8.0 gm. of powder mixture in 50 ml. of warm distilled water. Allow the solution to stand overnight before using. Make up fresh every three weeks.

2. Ammonium fluoride stock solution (approx. N NH_4F).

   Dissolve 37 gm. of NH_4F in water and dilute to 1 liter. Store in a wax-lined bottle.

3. Ammonium fluoride extracting solution (P-A) (0.03 N NH_4F, 0.025 N HCl).

   Add 15 ml. of NH_4F stock solution and 25 ml. of 0.5 N HCl to 385 ml. of distilled water.

4. Approx. 0.5 N HCl. Dilute 20.2 ml. of concentrated HCl to 500 ml. with distilled water.

5. Ammonium molybdate - HCl - H_3BO_3 solution (P-B).

   Dissolve 100 gm. ammonium molybdate in 850 ml. of distilled water. Filter and cool. Make a second solution of 1700 ml. of concentrated HCl. mixed with 160 ml. of water, cool. Add the first solution slowly to the second solution, stirring constantly. Add 110 grams of reagent grade boric acid.

B. Standard Phosphorus Solution

1. Standard phosphorus stock solution (100 p.p.m. of P solution).

   Dissolve exactly 0.4389 gm. of dry KH_2PO_4 in distilled water and dilute to 1 liter.

COLORADO STATE UNIVERSITY

New DTPA-TEA Soil Test for Zn, Fe, Mn and Cu

W. L. Lindsay and W. A. Norvell

June 1967

EXTRACTANT

1.	DTPA Acid	0.005 M (1.965 gm./liter)
2.	$CaCl_2$	0.01 M (1.11 gm./liter)
3.	TEA Buffer	0.1 M (triethenolamine) (14.9 gm./liter)

4. Adjust pH to 7.30 with HCl. This is critical since it influences the amount of metal extracted.

Notes:

DTPA is not soluble in water. Place DTPA in a small amount of H_2O. Add solution of TEA to bring DTPA into solution, then add H_2O and adjust to volume.

PROCEDURE

1. Add 20 ml of extractant to 10 gm soil.
2. Shake for 2 hours and filter
3. Measure Zn, Fe, Mn and Cu contents of the filtrate directly by Atomic Absorption Spectrometer.

Note:

Make standards up in DTPA extractant.

OXIDATION OF PLANT MATERIAL WITH A MIXTURE OF NITRIC ACID, WATER AND PERCHLORIC ACID

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Use of perchloric acid in mixtures of other acids as an oxidizing agent for plant tissues is gaining in favor. One of the latest papers on this subject is that of Gieseking et al.* They state that cold perchloric acid, either diluted or concentrated, is not affected by ordinary reducing agents, whereas hot concentrated perchloric acid may react violently with organic substances, making it imperative to pre-treat the sample with nitric acid.

Perhaps more significant is the fact that a cold or hot dilute water solution of perchloric acid is not a strong oxidizing agent and may, therefore, be placed safely in contact with plant materials. The following method takes advantage of this fact by recommending a mixture of nitric acid, water, and perchloric acid as a safe and rapid means of oxidizing organic matter without lengthy pre-treatment with nitric acid.

Theory Underlying Oxidation of Plant Material with Nitric Acid, Water, and Perchloric Acid

Concentrated nitric acid is thoroughly mixed with the plant material for the purpose of oxidizing the most easily oxidizable compounds, one class of which are the aldehydes. Concentrated nitric acid oxidizes these compounds slowly enough for safety, whereas perchloric acid may possibly cause an explosion. The nitric acid also oxidizes these easily oxidizable compounds within a few minutes after it is thoroughly mixed with the sample. Therefore no delay or heating of the sample is necessary before adding the water and perchloric acid.

Experience shows that adding H_2O to the sample before adding perchloric acid not only makes it safer to add the perchloric acid, but the slow evaporation of the H_2O on the steam bath also permits the sample to be further oxidized by the nitric acid, gradually concentrating the perchloric acid and in turn oxidizing most of the plant material. By the time all of the water has evaporated and the perchloric acid is concentrated, all of the organic matter except the most resistant has been destroyed.

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* Gieseking, J. E., Snider, H. J., and Getz, C. A. Destruction of organic matter in plant material by the use of nitric and perchloric acids. Ind. and Eng. Chem., Anal. Ed., V. 7, P. 185-6, 1935.

The use of concentrated perchloric acid in contact with this type of organic matter is quite safe. As the temperature on the hot plate is raised to the boiling point of perchloric acid, the organic matter which is resistant to perchloric acid at the temperature of the steam bath is readily oxidized. The rate of oxidation of the plant material on the hot plate is proportional to the heat applied. Consequently it is advisable not to boil the perchloric acid solution too vigorously at any time.

METHOD

Proportions of Materials to Use in Oxidizing Grain Samples

1 g. sample	10 ml. HNO_3	10 ml. H_2O	10 ml. $HClO_4$)	
2 g. sample	15 ml. HNO_3	15 ml. H_2O	15 ml. $HClO_4$)	Use 250 ml. beakers
3 g. sample	20 ml. HNO_3	20 ml. H_2O	15 ml. $HClO_4$)	
4 g. sample	25 ml. HNO_3	25 ml. H_2O	20 ml. $HClO_4$)	
5 g. sample	30 ml. HNO_3	30 ml. H_2O	20 ml. $HClO_4$)	
6 g. sample	30 ml. HNO_3	30 ml. H_2O	20 ml. $HClO_4$)	
7 g. sample	35 ml. HNO_3	35 ml. H_2O	25 ml. $HClO_4$)	Use 400 ml. beakers
8 g. sample	35 ml. HNO_3	35 ml. H_2O	25 ml. $HClO_4$)	
9 g. sample	40 ml. HNO_3	40 ml. H_2O	30 ml. $HClO_4$)	
10 g. sample	40 ml. HNO_3	40 ml. H_2O	30 ml. $HClO_4$)	

Proportion of Materials to Use in Oxidizing Vegetative Samples

1 g. sample	10 ml. HNO_3	10 ml. H_2O	10 ml. $HClO_4$)	
2 g. sample	20 ml. HNO_3	20 ml. H_2O	15 ml. $HClO_4$)	Use 250 ml. beakers
3 g. sample	30 ml. HNO_3	30 ml. H_2O	20 ml. $HClO_4$)	
4 g. sample	40 ml. HNO_3	40 ml. H_2O	25 ml. $HClO_4$)	
5 g. sample	50 ml. HNO_3	50 ml. H_2O	30 ml. $HClO_4$)	Use 400 ml. beakers
6 g. sample	60 ml. HNO_3	60 ml. H_2O	35 ml. $HClO_4$)	
7 g. sample	70 ml. HNO_3	70 ml. H_2O	40 ml. $HClO_4$)	
8 g. sample	80 ml. HNO_3	80 ml. H_2O	45 ml. $HClO_4$)	Use 600 ml. beakers
9 g. sample	90 ml. HNO_3	90 ml. H_2O	50 ml. $HClO_4$)	
10 g. sample	90 ml. HNO_3	90 ml. H_2O	50 ml. $HClO_4$)	

PROCEDURE

(Read through carefully before starting on oxidation)

Place sample in beaker, add the concentrated nitric acid, and mix it thoroughly with the sample, using a glass stirring rod. Remove the stirring rod and rinse any adhering sample into the beaker with a small amount of distilled water. Add the distilled water and then the perchloric acid. Pour both down the side of the beaker and not directly on the plant material. Place a watch glass on the beaker and not directly on the plant material. Place a watch glass on the beaker, set it on the steam bath, and heat it slowly until there is no danger of serious foaming. Use a ribbed watch glass or a watch glass on a glass support for all samples except the 1- and 2-gram samples.

Continue to heat the beaker on the steam bath until the sample is thoroughly disintegrated and partly oxidized. Heating overnight on the steam bath is recommended for all samples except the 1-, 2-, and 3-gram samples. Two or 3 hours on the steam bath are usually long enough for these small samples.

Remove the beaker from the steam bath and rinse the watch glass and the sides of the beaker with a small amount of distilled water. If this does not transfer the adhering plant material from the sides of the beaker to the acid solution, use a policeman and an additional small amount of distilled water.

Cover the beaker with a plain watch glass, place it on the hot plate, and gently boil the solution until all organic matter is oxidized and the solution becomes straw yellow. Continue to boil the straw yellow solution for about one-half hour. If bumping occurs, add a few glass beads. When oxidation is complete, reduce the temperature of the hot plate, remove the beaker, and let it cool. Rinse the watch glass and sides of the beaker with a small amount of distilled water and remove the watch glass.

Place the beaker on the hot plate and evaporate the perchloric acid to dryness below its boiling point. Remove the beaker and let cool.

PRECAUTION

Never transfer a sample with a thick, syrupy consistency from the steam bath to the hot plate. If for any reason a sample is not largely oxidized and liquid-like at the completion of the steam bath treatment, add one-half of the original quantity of nitric acid, water, and perchloric acid and continue to heat on the steam bath until the sample is largely oxidized and liquid-like. Only then should it be transferred to the hot plate. Observe samples on the hot plate occasionally to see if any of them are boiling down to a viscous condition. If any are, remove them and give them another acid treatment on the steam bath.

Preparation of the Oxidized Sample for Chemical Analysis

There is no single procedure for preparing the oxidized plant residue for chemical analysis. The residue is usually taken up in 25 ml. of approximately one normal acid and heated below the boiling point on the steam bath or hot plate for about one-half hour to completely dissolve the plant residue and convert the metaphosphate to the Ortho form. The kind of acid to use in taking up the residue is specified in the method of analysis. After the plant residue has been treated with the correct acid, the solution is transferred to a volumetric flask. If silica is present, the solution should be filtered. The solution is made to volume with distilled water and thoroughly shaken, after which it is ready to be analyzed.

EBE:ps 12-19-50 AG1476

RESPONSE OF SEVERAL STRAINS OF CORN (<u>Zea mays</u> L.)

TO DIFFERENTIAL NUTRIENT UPTAKE

UNDER ACIDIC CONDITIONS

by

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B.Sc. in Agric. (Hons.), Haryana Agric. University, 1972

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirement for the degree

MASTER OF SCIENCE

Department of Agronomy

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Manhattan, Kansas

1982

ABSTRACT

Three separate experiments were carried out; two under greenhouse conditions and one in the growth chamber. All three studies were designed to determine the response of different corn sources under slightly and highly acidic conditions. The variables chosen were: lime and phosphorus treatments in the first greenhouse study, only lime in the second greenhouse study, and aluminum in the growth chamber study with a nutrient solution culture.

Genotype variability was much more pronounced under stress conditions than under non-stress conditions. In the first greenhouse study, effect of lime treatment was more detrimental than beneficial for dry matter production. Increasing pH from 5.5 to near neutral may have decreased the availability of other nutrients in the soil which suggests that other nutrients should be sufficient in the soil to get a positive response from liming.

Effect of P was highly significant in raising the level of P in the plant material as well as dry matter production. Genotypic variability was more pronounced under P stress conditions than non-stress conditions. N1206 ranked top in dry matter production at both levels of P, however, P concentration and P uptake were not influenced. Under stress conditions, N304 was highest for P concentration. However, strain Blanco Subtropical showed fewer deficiency symptoms under stress conditions. In general, dry matter production of a genotype and P content in the plant tissue was negatively correlated. Nevertheless, genotypic variability for the relationship did exist suggesting that P absorption and utilization may be under genetic control. Even with the application of 100 ppm P, average P concentration in the plant tissue was not sufficient for maximum growth. This may possibly be due to restricted root growth in the pot.

Among the nutrients, K was the highest in the plant tissue followed by nitrogen. N, K, Ca and Mg content significantly decreased with P treatment.

Total uptake tended to be related to the increase in dry matter production.

Calcium concentration significantly increased at higher levels of lime in both greenhouse studies. Calcium concentration in the first study increased by approximately 25% at the higher level of lime and Ca uptake increased by approximately 20%. Effect of lime on Mg concentration was less than for Ca concentration. In the second greenhouse study, Mg concentration tended to decrease probably due to increased dry matter production.

The effect of lime was more pronounced in the second greenhouse study. Highly significant results were obtained to differentiate the relative yield of different genotypes particularly under stress conditions. This might be useful in picking tolerant genotypes under highly acidic conditions as influenced by Al toxicity. Among the sources, PI 270080 and Va-17 performed very well under stress conditions and showed the least effects of toxicity. Toxicity due to Al present in the soil was clearly visible on the root systems growing in the soil. Highly susceptible inbreds like Co103 showed increased root damage as well as the lowest relative yield. In general, toxicity due to exchangeable Al in terms of root damage disappeared as the level of lime increased. Dry matter production did not increase at the highest level of lime treatment which agrees with the finding in the first greenhouse study. In soil analysis as the lime level increased, pH increased significantly and exchangeable Al and Mn concentration decreased. Al content in the soil at 8000 kg and 16500 kg per ha of lime was almost undetectable by atomic absorption spectrophotometry suggesting that Al present in the soil was precipitated and detoxified at pH 5.4 and above. Aluminum concentration in the plant tissue did not show significant differences with respect to lime level. Genotypic variability did exist but did not give a close relationship between Al tolerant and susceptible genotypes. Such a relationship could not be explained due to the lack of study of root absorption and translocation capacity under genetic control. Manganese concentration and uptake showed a better relationship.

In the growth chamber study, effect of Al toxicity was measured in terms of primary root length, relative root length, secondary root coefficient and composite value. Composite value was the most important factor.

One important result obtained from these studies is that tolerance to Al toxicity could be relative. Thus, selection of stress level is an important factor. Stress level may vary from genotype to genotype, species to species and conditions under which the plant is grown.