EVALUATION OF PHOSPHORUS-UPTAKE EFFICIENCY OF SORGHUM GENOTYPES

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INTRODUCTION

Grain sorghum (Sorghum bicolor L.) is one of the most valuable crops of the developing nations of the world, especially in African (approx. 13.73 million hectares) and Asian countries (approx. 18.59 million hectares). It is also an important source of food, feed and industrial material in the developed nations of the world with substantial increases in hectarage reported in countries like the United States of America. Argentina recently introduced sorghum primarily as a feed grain. To meet the expected world demand, there is need for an integrated sorghum improvement program.

An adequate supply of essential crop nutrients is essential for increased stover and grain yields. Of the major macronutrients, phosphorus is second to nitrogen in limiting crop growth. The total amount of phosphorus in the soil is not as important as the phosphorus available to plants, since applied P is rendered unavailable to crops due to fixation into complex compounds in most soils. The availability of soil phosphorus varies with soil type, soil reactions and environmental factors. Although much work still needs to be done on the way phosphorus is retained in the soil, a knowledge of the requirements of the various crops grown on different soils and the mechanisms involved in the uptake of phosphorus by plant roots is equally important. The feasibility of breeding phosphorus efficient plants capable of producing optimum or maximum yield under low available soil phosphorus needs investigation. Such P efficient plants will be highly valuable especially in the African and Asian countries where P supply is limited and the costs of available phosphorus fertilizers are very high. The use of P efficient sorghum genotypes would be highly beneficial in areas

having soils with high P-fixing capacity where P application would be uneconomical.

Differential response of crops to nutrient application under various soil and climatic conditions is well documented. Genetic variability can be an asset in a plant breeding program for selection of responsiveness to specific nutrients limiting crop production.

Research has convincingly shown that sorghum will respond to fertilizer applications under favorable conditions. When nutrients are in limited supply, however, nutrient deficiency symptoms of the crop and reduced dry matter and grain yield are usually observed. Previous research has shown that some sorghum genotypes are more tolerant to low levels of available nutrients than others and maintain a good rate of dry matter and grain production while other genotypes have severely reduced yields under the same limited soil nutrient supply.

The need for a better understanding of the phosphorus efficiency of sorghum genotypes, conditions that enhance P uptake, and mechanisms of its uptake by plants has justified greenhouse and solution culture studies with the following objectives;

1. Evaluate the differential uptake of phosphorus by some selected sorghum genotypes to enable identification of P efficient and P inefficient genotypes.
2. Determine possible mechanisms by which P uptake efficiency is controlled across sorghum genotypes . In particular, the effect that nitrogen source (NH_4^+ vs NO_3^-) may have on rhizosphere pH, and hence on P availability. Determine selectivity of genotypes for N source and its possible effect on P uptake efficiency.
3. Study the differential uptake of zinc by the genotypes in order to assess the ability of the P efficient and P inefficient genotypes to maintain the required P-Zn balance in the plants.

LITERATURE REVIEW

The vital roles of phosphorus in plant growth, development, and quality of crop plants are well known. Such valuable, indidpensable roles are possible only when phosphorus (P) is available to the plants under favorable conditions . Phosphorus is second to nitrogen as the most limiting macronutrient for crop growth . According to Larsen (1974), phosphorus is the most limiting macronutrient when availability in the soil is considered. Unlike nitrogen, readily available fertilizer phosphorus applied to soil is usually quickly converted to unavailable forms. Often less than 100% (Larsen, 1974) of the applied phosphorus is taken up by plants. Long et al (1973) found phosphorus to be the most critical factor limiting plant growth in his study on oats response to lime, phosphorus, and potassium on three Atlantic coast Flatwoods soils .

The major source of phosphorus is the reserve soil phosphorus (Larsen, 1974) which will decline with time from removal by highly productive crops unless replenished by application of P fertilizer. The soil content of P varies with soil type, location and other factors. Wild (1958), in his study of the phosphate content of Australian soils, attributed the generally low P content of the soils to losses by leaching, especially under poor drainage conditions. He recognized the important influence of plant factors which had received little research attention. The phosphate distribution in soils was shown to be related to the parent material from which the soils were derived .

Phosphorus is known to be relatively immobile in soils (Calder and Macleod, 1974; Levesque and Hanna, 1966). The forms of P applied (Bromfield, 1960; Ozanne et al, 1961; Hamilton and Lathwell, 1964; Lewis

and Racz, 1969; Mortvedt and Terman, 1978; and Schield et al, 1978), its distribution in the soil fabric (Qureshi et al, 1978), liming (Paton and Loneragan, 1960; Mendez and Kamprath, 1978), and surface activities of inorganic P sources (Chu and Chang, 1966) are some of the dominant factors affecting phosphorus movement in the soil. On the other hand, residual P availability to crops has been observed (Matocha et al, 1970) to remain high on a Clareville clay loam soil for up to 10 years.

Prediction of P availability is usually based on soil and plant analysis, although soil test extraction procedures (Griffin and Hanna, 1967; Kang and Osiname, 1979) have been demonstrated to give variable prediction. Concentration of P in seedling plants have also been observed (Baker et al, 1970) to be valuable in predicting P availability in the soil.

Factors affecting soil P availability.

Several factors are known to affect the formation of unavailable forms of P in the soil due to P fixation . Shelton et al (1968) observed the rapid conversion of large applications of phosphorus into Al and Fe - phosphates on a soil with a high P fixing capacity . A decrease in Al-P with an increase in Fe-P occurred over an 8-year period and soil test P was reported to be highly correlated with Al-P . In his work on the phosphorus retention capacities of some cocoa-growing soils of Ghana and their relationship with soil properties, Yaw (1968) concluded that soil organic carbon, iron, and their interactions with pH were the dominant factors affecting phosphorus retention by soils . Comparing the reactions of phosphate rock, rhenania phosphate ($CaNaPO_4$), and superphosphate in acid soil, Chien (1978) observed that addition of 150 ppm Si in the form of Na_2SiO_3 to the soil treated with concentrated superphosphate significantly decreased the phosphorus retention capacity of the soil. He suggested the possibility of

rhenania phosphate as a pontential phosphorus fertilizer source for those tropical soils with relatively high P retention capacity in some developing countries provided its cost could be justified.

Aluminum and iron cations are usually implicated in phosphate fixation in acid soils (Bartlett and Riego, 1972) . In a related study Hsu (1965) concluded that the study of the activity of phosphate fixing cations, particularly amorphous aluminum hydroxides and iron oxides, is a more fundamental research approach than the study of the solubility of phosphate compounds formed .

Organic forms of phosphorus affect P availability to crops . Their effectiveness has been found to be affected by the type of predominant vegetation (Enwezor and Moore, 1966) and cultivation (Omotoso, 1971) . Abbott (1978) concluded from his work on P fractions in extracts of calcareous soils, that inclusion of extractable organic P in the evaluation of available P for a given soil is affected by four factors. These are time of sampling, crop to be grown, the method of extraction, and method of converting organic P to a measurable inorganic form in the extract. Abbott and Tucker (1973) also attributed the persistence of manure P availability in calcareous soils to the stable nature of organic matter, stimulation of microbiological activity, and association of P with relatively mineralizable organic components of the soil .

Response of sorghum to phosphorus fertilization .

Although phosphorus studies on grain sorghum are relatively fewer than for other related cereals, there is convincing evidence (Olson et al, 1962; Matocha et al, 1970; Ramanath et al, 1973; De R, 1974; Fuehring and Finkner, 1974; Thompson, 1974; Kapoor, 1976; Schield et al, 1978; and Ajakaiye, 1979) that sorghum will respond to phosphorus application under favorable conditions. The relative grain yield response to P fertilizer is generally less than for

corn . The use of suitable cultivation techniques for maize (corn), sorghum, and millets has been reported in India (De R., 1974) to increase average yield of the crops from 0.97, 0.52, and 0.42 tons to 3.79, 3.60 and 2.88 tons respectively. All the cultivars used for the three crops were found to respond to 40-60 kg P_2O_5/ha on soils low in available phosphorus.

Improvement of dry matter production, calcium and magnesium (Jacques et al, 1975; Schield et al, 1978), phosphorus, potassium and nitrogen content (Findlay and Fulton, 1964; Lockman, 1972) of sorghum have been reported from P application . Response to micronutrient application such as Zn, Fe, Mn and Cu has also been observed (Shukla et al, 1973; Thompson, 1974).

Variability among crop species and varieties in P uptake and utilization.

(i) Species differences.

Differential response of crops to nutrient application under various soil and climatic conditions is well documented. Genetic variability can be an asset in a plant breeding program for selection of desirable responses to specific nutrients limiting crop production . Differences among both crop species and varieties or strains within species have been noted. Asher and Loneragan (1967) confirmed differences among 8 different temperate and annual pasture species in plant phosphorus content in a solution culture study . Similar responses to P were obtained in solution culture when compared to the field . Although Andrew and Robins (1971) observed response of all 9 tropical grasses in his study to phosphate addition, Melinus minutiflora was reported as the most responsive and Pennisetum clandestinum the least responsive species. Similarly, ryegrass (Lolium multiflorum) was found to be more efficient in P uptake than clover (Trifolium species) (Barrow, 1975), and the over-all phosphate requirement of the grass to be less than that for clover (Barrow, 1975) . Such interspecies differential response to phosphorus has also been shown in other studies . McLachlan

(1976) ranked the productivity of four soil situations as buckwheat> rye > crimson clover > subterranean clover. That is, buckwheat obtained more P at all P levels and used it more efficiently in dry matter production than the other species .

In a study with five crop species, Ozanne and Petch (1978) noted the amount of phosphate to produce 90% of maximum yield depended on species and cultivation practices . Even in situations where all species responded well to phosphorus application, marked differences in redistribution of absorbed phosphate were reported . Similar results were obtained by Keay et al (1970) who suggested that differences in P utilization efficiency among species are dependent on physiological and anatomical characteristics . Differences in P utilization efficiency may also vary with the stage of growth . Lockman (1972) studied the mineral composition of grain sorghum and corn plant samples and observed the differences in P levels between the twocrop species to be smallest at the seedling stage and to increase at a later stage.

Available soil phosphorus affects the differential response among crop species to added fertilizer phosphorus . Differential response to P fertilizer was confirmed by Gerloff (1976) who observed that P efficient strains of Snapbeans (Phaseolus vulgaris L.) and tomato (Lycopersicum esculentum Mill.) under phosphorus stress were not the most P efficient under higher levels of phosphorus supply. Edwards and Barber (1976) observed differential response of soybean and corn roots to P uptake .

(ii) Variability within species .

Crop varieties of the same species perform differently under similar conditions of nutrient availability . Brown et al (1977) evaluated the efficiency of phosphorus use by twelve sorghum genotypes on three soil types;

acid-bladden soil (pH 4.3, P-stressed or Al-toxic), limed-bladden soil (pH 5.2, Cu-stressed), and on alkaline Quinlan soil (pH 7.5, Fe-stressed) . The most P efficient genotypes were found to absorb more $_{32}P$ than the most inefficient ones under P stress or Al toxicity conditions and grew normally, while the P inefficient plants developed P deficiency symptoms . In separate experiments under limited P, Clark et al (1978), and Bruetsch et al (1976) observed differences among sorghum genotypes in dry matter production, mg dry matter produced per mg P, P concentration and content, and accumulation of P in roots, lower and upper leaves . Similar differential response to toxic Al , Fe deficiency and low P level among sorghum genotypes (Mikesell et al, 1973; Clark and Brown, 1974; Brown et al, 1977; Maranville et al, 1977) and corn genotypes (Bole and Freyman, 1975) have been reported. Paulsen and Rotimi (1968) reported decreased growth of the P sensitive soybean variety more than the P tolerant variety at high phosphorus levels .

Clark (1970) studied the differential response of maize inbreds to variable zinc levels in solution culture and observed greater changes in P, Ca, Mg, Mn and Fe in some maize inbreds than others .

In some studies, differences among varieties or genotypes were reported to be small or not significant . Jacques et al (1975) observed similar dry matter production and Ca and Mg uptake with two sorghum hybrids . Clark and Brown (1974) also found dry matter yields of two corn inbreds to be comparable or different depending on the available phosphorus level .

Plant uptake of recently applied fertilizer P is usually quite low, and is known to be related to characreristics of the root system and the efficiency of fertilizer P use by the crop as well as soil P fixation properties . Phosphorus fertilizer use may be improved by selecting genotypes with more roots and/or by selecting for improved P uptake characteristics of the roots . Schenk and Barber (1979) tried to determine

the effect of vaying corn (Zea mays L.) root characteristics on P uptake by five corn genotypes. They concluded that the differences observed betwwen genotypes in morphological root characteristics influenced the amount of P absorbed by corn plants . They then speculated the possibility of selecting genotypes that would be more efficient in absorbing P from soil . Barligar and Barber (1979) drew similar conclusions in a separate experiment .

Investigating the influence of root hairs in supplying soil P to wheat, Bole (1973) failed to observe any close relationship between soil P uptake and root-hair density in any of the chromosome substitution lines of wheat (Triticum aestivum L.) . Baker et al (1970) could not explain the concentrations of P accumulated in ear leaves of different corn hybrids on the basis of P absorption characteristics of their roots, but suggested inherent differences among hybrids with respect to depth of rooting as the possible cause.

Jordan et al (1979) observed similar performance of 29 genotypes with regard to their leaf area, crown root length, shoot dry weights, root dry weight, and the ratio of root length to root volume when grown in hydroponics . They suggested that the similarity of genotypes might reflect the narrow genetic base available to breeders when those lines were developed, or similar environments during selection .

Phosphorus content of grain may be affected by differential P uptake and utilization of added fertilizer P by genotypes. Lipsett (1964) observed a wide range of final P concentrations in the grain of all wheat varieties studied when they received a variable P supply . He suggested that the lower P concentrations in the higher-yielding variety may have been due to selection for dry matter yield, where nutrient supply was limited .

Buss et al (1975) observed significant differences in element concentrations in seven alfalfa clones for eleven elements including phosphorus .

Influence of P-Zn interaction on plant P and Zn contents .

The need for proper balance (Boawn and Brown, 1968) between essential nutrient elements has stimulated research on element interactions in plants- antagonistic and synergistic interactions . P-Zn interaction in the plant is usually observed to be antagonistic (Ward et al, 1963; Yates, 1964; Matocha et al, 1970; Lockman, 1972; Racz and Haluschak, 1974; Takkar et al, 1976) although under some conditions the effect can be synergistic depending on growth conditions, (Adriano, 1970; Khan and Zende, 1976; Saeed and Fox, 1979) or both synergistic and antagonistic (Sharma et al, 1968) .

An increase in P available to the crop is known in many cases to cause reduction in plant zinc concentration and perhaps consequent characteristic zinc deficiency symptoms (Halim et al, 1968; Sharma et al, 1968; Carroll and Loneragan, 1969; Adriano, 1970; Long et al, 1973; Takkar et al, 1976). The P depression of Zn uptake may often be great enough to reduce plant growth and dry matter production (Ward et al, 1963; Shukla and Hans, 1976; Takkar et al, 1976) . Zinc deficiency symptoms in some crops have been reported to be induced by the high phosphorus content of plants, usually due to high available soil P levels (Ellis et al, 1964; Hedge and Relwani, 1974; Herrera and Suarez, 1974; Shukla and Hans, 1976; Chaudry et al, 1977; Kang and Osiname, 1979) . Many factors have been identified to be conducive to the development of the P-Zn interaction in plants . In addition to high rates of phosphorus, Ellis et al (1964) observed a decrease in total zinc uptake by corn with decreased soil temperature, aggravating the P-Zn balance in the plant tissue . Racz et al (1974), Saeed and Fox (1979), and Smilde et al (1974) reported soil type and application of lime to also influence the effects of P on Zn uptake . The magnitude of the P induced zinc deficiency in crops is known to vary with crop species (Ward et al, 1963; Sharma et al, 1968; Racz and Haluschak, 1974; Smilde et al, 1974)

and varieties within species (Halim et al, 1968; Shukla and Hans, 1976) . Kang and Osiname (1979) found the depression of the zinc content of the ear leaf of maize from a high rate of P application to be slightly different in the two locations used for the trials . Location and vegetation type were found by Osiname et al (1973) to influence P-Zn interaction in maize due to differential soil availability of nutrients at the various locations. Banding of the phosphorus and cool wet conditions were reported by Adriano (1970) to favor the antagonistic effect of P on Zn in maize, while increased soil compaction and soil moisture level were detected by Ward et al (1963) to aggravate the interaction effects .

Since P-Zn interaction has been confirmed by researchers to be detrimental to crop productivity in many situations, preventive measures are necessary . Exploitation of such preventive or control measures requires, among othe factors, a knowledge of the interactive mechanisms involved. This knowledge would be an asset in improving P efficiency of crop plants developed through plant breeding .

Sharma et al (1968) noticed the P induced zinc deficiency to decrease the zinc concentrations in the tops much more than in the roots . This was confirmed in another experiment by Paulsen and Rotimi (1968) who surmised the effect of P on zinc nutrition was to reduce translocation of zinc to the upper plant parts . Smilde et al (1974) and Langin et al (1962) concluded from separate studies on three different crop species (including sorghum) that P-Zn interaction was a plant physiological characteristic . Khan (1969) and Chaudry et al (1977), on the other hand, concluded the P effect on Zn deficiency in rice was largely due to dilution of Zn from greater dry matter production . Pauli et al (1968) believed their results indicated that the P-Zn interaction problem was not in the soil external to the root . On the contrary, Bingham (1963) suggested that the P induced Zn or Cu

deficiency in corn and tomatoes was due to reactions occurring outside of the physiologically active root . This was supported by Takkar et al (1976) who attributed the main effects of P on Zn utilization to be due to a reduction in the rate of Zn entry into the roots .

Though studies on P-Zn interaction mechanisms in the plant are inconclusive, some effective control measures for P induced zinc deficiency have been suggested . Racz et al (1974) noticed that an increase in microelement concentrations in wheat plants resulted from an increase in microelement concentration of nutrient solutions bathing the plant roots, even at high phosphorus concentrations indicating that ion antagonism was mainly responsible for the lower utilization of microelements in high phosphorus media . Adriano et al (1971) also observed increased shoot growth at high P levels only with corresponding high Zn levels in soil .

A good soil testing program is also valuable in an effective soil fertility program . While comparing 8 soil chemical extractants for the estimation of plant available zinc, Ravikovitch et al (1968) observed significant correlations between zinc extracted from 15 soils with varying calcium carbonate levels .

Influence of ntrogen on phosphorus uptake by plants.

The contribution of nitrogen in enhancing uptake of phosphorus by plants has been well documented . Convincing evidence on the effects of nitrogen source, rate, and method of application on phosphorus uptake are numerous . Appreciable work has also been done by many researchers on the mechanisms causing the increased P uptake in the presence of available nitrogen .

Ramnath et al (1973) recorded a significant increase in both uptake of phosphorus and yield of rainfed jowar (sorghum) when N and P were applied together 2-3 cm below the seed compared to separate placement . Miller (1965 and 1971) concluded that the addition of nitrogen increased the

absorption of fertilizer phosphorus only when the nitrogen is in intimate assiciation with the phosphorus . Herron et al (1960) could not obtain significantly higher yield of grain sorghum with N + P than N or P alone in any of the locations used for their studies . A similar conclusion was made by Duncan and Ohlrogge (1958) on corn. Miller and Ohlrogge (1958) reported that nitrogen had a greater influence in increasing the feeding power of the root system of plants whem mixed with P than when placed in a band 3 to 4 inches from the banded phosphorus . This was supported by the works of Engelstad and Allen (1971), Grunes et al (1958), Olson and Dreir (1956), and Robertson et al (1954) who inferred independently that the position of nitrogen fertilizer was important only when both the N and P fertilizers were banded together .

The magnitude of the effect of the nitrogen fertilizer in promoting phosphorus uptake by crop plants has been found to be dependent also on the relative rate of the nitrogen to those of the phosphorus fertilizer . Sheard (1974) indicated the necessity to provide adequate nitrogen for efficient utilization of surface-applied phosphorus by perennial forage grasses . Higher rates of nitrogen fertilizer in the band were found by Findlay and Fulton (1964) to significantly increase the leaf phosphorus percentages of hybrid corn . Calder and Macleod (1974) observed the greatest response of two barley cultivars from nitrogen fertilizer at 60 and 90 kg N/ha in combination with phosphorus .

The extent to which nitrogen promotes phosphorus uptake varies with the nitrogen source . Ammonium has been found to be more effective than the nitrate source of nitrogen (Lorenz and Johnson, 1953; Grunes et al, 1958; Miller, 1965; Miller et al, 1970; Blair et al, 1971; Engelstad and Allen, 1971; Riley and Barber, 1971; Breteler, 1973; Breteler and Smit, 1974) .

On the other hand, Bennett et al (1964) found nitrate to be superior to ammonium during the first 4-9 weeks of corn growth in a greenhouse . experiment . They attributed the inferiority of the ammonium source to its deleterious effect on the growth and condition of the corn root system . Thien and McFee (1970) could not see any significant difference between ammonium chloride and sodium nitrate on absorption and translocation of P in corn .

Influence of soil pH on plant uptake of phosphorus .

Among the soil factors influencing phosphorus availability is soil pH . Soil pH has been noted in plant breeding programs to influence the phosphorus extraction efficiency of the seleted crop . Buss et al (1975) observed a significant clone by pH interaction in their work on the effect of soil pH and plant genotype on nutrient concentration and uptake by alfalfa . Their data suggested that caution should be exercised to ensure that selection is carried out under conditions similar to those in which the crop is to be grown . Calder and Macleod (1974) found that the yield of two barley cultivars grown at 5 soil pH levels (4.8, 5.1, 5.8, 6.6 and 7.1) and with NPK fertilization increased with an increase in soil pH from 4.8 to 5.8 with no yield increase at higher pH levels .

Though Smith and Clark (1968) found millet to be less sensitive to soil fertility than sudan grass, an increase in the nitrate nitrogen, phosphorus and potassium contents of the millet plants was recorded with increase in soil pH . Walder and others (1975) also observed an increase in sorghum forage yield of 2,000 kg/ha when soil pH increased from 5.2 to 5.6 . Lutz et al (1972) noted the uptake of P, K, Ca, and Mg by maize inbred lines and single crosses to vary with a change in pH .

The level of exchangeable aluminum at given soil pH was noted by Sumner (1979) to reflect the reactivity of the aluminum surfaces in the soil which,

in turn, govern the solubility of phosphorus .

Mechanisms of phosphorus absorption by plant roots .

The influence of soil, environmental, and plant factors on the uptake of phosphorus by plants has revealed the need for a detailed investigation on the possible mechanisms of phosphorus absorption by plant roots . The knowledge attainable from this would be valuable in crop improvement program for more efficient use of soil phosphorus .

Many researchers have investigated the possible mechanisms causing the beneficial effect of nitrogen on phosphorus uptake by plants . With the knowledge of the preferential uptake of either the ammonium nitrogen or the nitrate nitrogen by crops, Minnotti et al (1969) addressed themselves to the reason for the preferential uptake of NH_4^+-N over NO_3^--N by wheat . Their findings prompted the suggestion that ammonium, and to some extent, the high acidity adjacent to cellular boundary membranes resulting from ammonium uptake in excess of nitrate uptake, resulted in alterations in membrane permeability thereby restricting capacity for nitrate adsorption from an ammonium nitrate source . Mamaril and Miller (1970) went further to conclude that the concentration of phosphorus in the soil treated with P or the proportion of the root system exposed to the treated soil determined the influence of NH_4^+ on phosphorus absorption . Olson and Dreir (1956), and Miller (1965) indicated that a physiological function of nitrogen was to stimulate root activity for absorption of fertilizer phosphorus .

Blair et al (1971) and Miller et al (1970), suggested the changes in the soil-root interface pH and the resulting changes in the $H_2PO_4^-$ / $HPO_4^=$ ratio at the root surface may influence P uptake . Riley and Barber (1971), on the other hand, suggested the effect of nitrogen source on the pH of the rhizpsphere soil to be mainly responsible for the increased availability of phosphorus from the soil where ammonium nitrogen was used . Thien and McFee

(1970) could only suggest, from their findings, the existence of a nitrogen-requiring metabolite (independent of N source) influencing the efficiency of phosphorus absorption and translocation mechanisms in corn .

Inherent plant factors also influence phosphorus absorption mechanisms . Loneragan (1976) related differential absorption of phosphorus by plants to three root attributes; (i) ability to absorb phosphorus from dilute solutions, (ii) metabolic activity resulting in solubilization of soil phosphorus, and (iii) ability to explore soil mass . He recognized the importance of metabolic activity of plant roots, physiological acidity from H^+ by micro-organisms or by plants fertilized with NH_4^+ salts, and phosphatase enzyme activities to stimulate the release of phosphorus from soil colloids or insoluble compounds in soil .

Brown and Jones (1975), Barligar and Barber (1979), and Schenk and Barber (1979), found differential phosphorus uptake by sorghum and corn genotypes to be genetically controlled . They suggested the need to breed crop genotypes that are more efficient in absorbing phosphorus from the soil.

Differences among crop plants in their ability to absorb soil phosphorus is usually related to their ability to acidify the root rhizosphere by releasing H^+ ions . Greater phosphorus uptake by buckwheat than the other grasses used was found by McLachlan (1976) to be associated with its ability to acidify the rooting medium due to H^+ ions exchanged for cations - Ca^{++} ion implicated - taken up by the plant roots . Clark and Brown (1974) observed that the roots of WH corn Inbred decreased solution pH faster than Pa 36 corn Inbred roots under the phosphorus stress conditions investigated . On the contrary, Brown and Jones (1975) observed little difference in the release of H^+ by four sorghum lines .

Though Loneragan (1976) emphasized the importance of the ability of roots to explore soil mass in increasing phosphorus absorption . Omanwar

and Robertson (1970) found root interception to be of least importance in phosphorus movement to roots . They emphasized the importance of the soil solution phosphorus concentration instead .

Bole (1973) investigated the influence of roothairs in supplying soil phosphorus to wheat but concluded that roothair development did not regulate the phosphorus uptake efficiency fo wheat roots .

MATERIALS AND METHODS

Six greenhouse studies were conducted to investigate the response of sorghum genotypes to phosphorus fertilization .

Experiment I . Screening of the sorghum genotypes for phosphorus efficiency.

Sixteen sorghum genotypes (Table 1) were secured from plant breeders in the Department of Soil and Crop Sciences, Texas A & M University, College Station, Texas . The genotypes were indicated to have been selected for phosphorus responsiveness, although no information was available on their differential response to phosphorus application . Two rates of phosphorus (0 and 200 ppm P banded) were used with each genotype as 19% phosphorus commercial grade fertilizer (triple superphosphate, 0-44-0) ground to facilitate weighing of small samples . The experiment was replicated three times .

The soil used for this study consisted of a mixture of Parsons silt loam soil from the Southeast Kansas Experiment Field near Parsons in Labette county and washed silica sand at a ratio of 1:3, respectively .

The soil-sand mixture was used for the phosphorus study for better aeration of the soil and to reduce the phosphorus supply as well as the iron content of the original Parsons silt loam soil . The soil chemical characteristics are given in Table 2 .

The Parsons soil was air-dried, sieved through a coarse screen before mixing with the washed silica sand . The washed silica sand was purchased from a commercial source and was found to contain essentially no nutrients when analysed . Two kilograms of the mixture were weighed into 3 liter plastic pots (cottage cheese containers) perforated in the bottom with four

Table 1 . Sorghum genotypes used in greenhouse studies .

Genotypes	Source
1 BTx378 (Redlan)	Barrell
2 RTx2536 (Yellow endosperm feterita)	78CS5960
3 ATx378 x RTx2536 (Hybrid)	WAC694
4 BTx3197 (Combine Kafir-60)	Barrell
5 RTx7078 (Combine 7078)	78CS9440
6 RS 610 (Hybrid)	
7 BTx399 (Wheatland)	
8 RTAM428 (Zerazera sel)	78CS9230
9 ATx399 x RTAM428 (Hybrid)	WAC692 R
10 RTx7000 (Caprock)	78CS6310
11 ATx378 x RTx7000 (Hybrid)	TE88
12 SC0283-c (Aluminum tolerant)	75SC25
13 SC0048-c (Aluminum tolerant)	75SC169
14 SC0418-c (Aluminum tolerant)	75SC140
15 SC0056-14 (Non-senescent type)	78CS8950
16 SC0599-6 (Non-senescent type)	78CS8910

* Nos 12 - 16 had not been formally released by TAES and their use restricted to this investigation only .

small holes to prevent water saturation . A paper towel was put in the bottom of each pot before adding soil to prevent soil leakage from the pots.

Supplemental amounts of other nutrients were applied as follows;

Nitrogen .....200 ppm as NH_4NO_3 (fertilizer grade)

Potassium .....200 ppm as KCL (fertilizer grade with 50% K)

Magnesium ..... 80 ppm as $MgSO_4.7H_2O$ (reagent grade)

The cottage cheese pots used were soaked over-night in 10% (v/v) HNO_3,

0.1M EDTA and washed with deionized, distilled water . The supplemental nutrients, except phosphorus which was banded, were thoroughly mixed with the soil manually be gently shaking and swirling the soil in the pots prior to planting .

Table 2 . Chemical characteristics of the Parsons silt Loam Soil and the soil:sand mixture .

	Mixture of Parsons Silt Loam and Sand	Parsons Silt Loam
pH	6.3	5.3
Available N	5.8 ppm	14.2 ppm
Available P	3 ppm	3 ppm
Exchangeable K	11.5 ppm	43.5 ppm
Organic matter content	0.9%	1.7%
Available Zn (DTPA)	1.8 ppm	2.09 ppm
Available Fe (DTPA)	22.8 ppm	107 ppm
Magnesium	32 ppm	175 ppm

The sorghum seeds were treated with a fungicide (Vitavax 25 DB) just before planting 10 - 12 seeds per pot about 2 cm deep . The pots were immediately watered with 100 ml of deionized, distilled water and arranged in the greenhouse in a completely random manner . The water holding capacity of the soil was determined and the same amount of deionized, distilled water was used for each pot throughout the 4 weeks of the study . The seedlings were thinned to three plants per pot three days after emergence .

When green bugs were observed on some of the plant leaves, a systemic insecticide, disyston, was applied to the soil just before routine watering and was effective in green bug control .

The plants were harvested 31 days after planting . Harvesting was done by cutting the plants about 1 cm above the soil surface with stainless steel scissors . The plants were lightly rinsed in deionized, distilled water, put in brown paper sacks, and dried in a forced air oven at 70 ^{o}C for 48 hours . The dried plants were weighed to obtain the dry weights before they were ground through a Udy mill and stored in plastic bottles .

A sulfuric acid digest (Linder and Harley 1942) was used for nitrogen and phosphorus determinations . One fourth gram sample of the plant material was weighed into 75 ml test tubes with 2 ml of sulfuric acid and 1 ml of hydrogen peroxide added to each tube and digested at a temperature of 375 ^{o}C for 30 minutes in Al digestion blocks . The tubes were removed from the block and allowed to cool for 5 minutes before one additional ml of peroxide was added and the digestion was continued for 20 minutes . Addition of peroxide, 15 minutes digestion intervals and cooling of the digests continued until the samples were clear . The digestion tubes were then cooled, diluted to 50 ml with deionized, distilled water and stored in polyethylene bottles . Nitrogen and phosphorus were then determined in these solutions by the Technicon Industrial Method No 334 - 74W/B^{+}(Appendix) with a Technicon Autoanalyzer System . For the nitrogen determination, a 1 ml aliquot of the digested plant material 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 .

Phosphorus determination was based on the colorimetric method in which a blue color is formed by the reaction of orthophosphate, molybdate and antimony ions followed by reduction with ascorbic acid at an acidic pH .

A nitric-perchloric acid digestion (J.L Demestrio- appendix) of the plant samples was used for the zinc determination . A 0.5 gm plant sample was weighed into 75 ml test tubes and digested with 15 ml of the nitric-

perchloric mixture at about 375 °C in Al digestion blocks until straw yellow color . The digests were then cooled before washing down the inner sides of the tubes with deionized distilled water . The tubes were then returned to the Al digestion blocks and evaporated to dryness . The digests were cooled and 10-20 ml of .1N HCL was used to wash down residues on the sides of the tubes . The tubes were boiled gently for 5-10 minutes to disintegrate residue before cooling, making them up to 25 ml volume in 25 ml volumetric flasks and filtering the solutions through Whatman 42 filter paper into polyethylene bottles . Zinc was determined on this stock solution by atomic absorption spectrophotometry using a Perkin - Elmer 460 instrument .

Experiment II. Screening of sorghum genotypes for response to zinc .

A Sarpy fine sandy loam soil obtained from the flood plain near Manhattan Kansas, was used for this study . Chemical characteristics of this soil are given in Table 3 . This soil was selected for the zinc study primarily because of its moderately low zinc content .

The soil was dried, sieved the same way as for Experiment I, and 2 kg weighed into each of the cottage cheese plastic pots . Supplemental amounts of nutrients, other than zinc were mixed with the soil as follows;

Nitrogen ..... 100 ppm as NH_4NO_3 (Fertilizer grade)

Phosphorus..... 100 ppm as 0-44-0 (19% P)

Potassium ..... 100 ppm as 0-0-60 (50% K)

Magnesium..... 50 ppm as $MgSO_4$ (Reagent grade)

Sulfur ..... 20 ppm supplied by the magnesium and zinc sources.

All of the genotypes used in Experiment I except No 2 were used in this study each with two rates of zinc -0 and 8 ppm Zn - as reagent grade $ZnSO_4.7H_20$.

The plants were grown for 39 days using a completely random design . Preparation of the treatments, planting and watering of the pots, harvesting

procedure, preparation of the plant materials for nutrient analysis, and methods of analysis were done as described for Experiment I .

Table 3. Chemical characteristics of the Sarpy fine sandy loam soil .

pH	7.5
Available N	4.8 ppm
Exchangeable K	8.5 ppm
Available P	8.5 ppm
Organic matter content	0.4%
Available Zn (DTPA)	0.31 ppm
Available Fe (DTPA)	4.6 ppm
Cation Exchange Capacity (C.E.C)	1.4 me/100 gm

Experiment III. Influence of soil pH on P uptake by sorghum genotypes .

The Parsons silt loam soil was used for this study and the soil chemical characteristics are given in Table 2 . Three pH levels were employed - the original pH of 5.3, the soil test recommended ECC rate (200 ppm), and 5% $CaCO_3$ by weight . The latter two treatments were projected to raise the pH to 6.8 and 8.2, respectively . Two phosphorus levels were used within each lime rate - 0 and 40 ppm P . Phosphorus was supplied as commercial ammonium polyphosphate fertilizer (10-34-0) . An application of nitrogen and potassium at the rate of 100 ppm of each was applied to all pots . The nitrogen supplied by the phosphorus source and NH_4NO_3 and the potassium by muriate of potash (0-0-60) . Enough pots were prepared for three replications of seven genotypes selected from Experiment I . The genotypes for this study were numbers 3, 5, 7, 9, 12, 14, and 15 in Table 1 .

The pots were arranged in a completely random design . Lime was added to the pots just prior to nutrient application with shaking and swirling the

contents of the covered pots to thoroughly mix the lime with the soil . The seeds were planted immediately after mixing the lime with the soil . Planting technique, thinning of the seedlings and watering of the pots with deionized, distilled water were done as described for Experiment I . The plants were harvested four weeks after emergence . The tops and roots were separated after washing in deionized distilled water . Drying of the plant samples, and analysis for nitrogen, phosphorus and zinc were carried out as described for Experiment I .

Soil samples were taken from each pot at the end of the study and the pH determined to observe the ability of the genotypes to change soil pH and lime effects on pH .

Experiment IV . Influence of N and P placement on P uptake by the genotypes.

A mixture of Parsons silt loam soil and washed silica sand as used for Experiment I was used for this study . The soil chemical characteristics are given in Table 2 . Two rates of phosphorus - 50 and 150 ppm P - were employed as triple superphosphate 0-44-0 (19% P). Nitrogen was applied as NH_4NO_3 at the rate of 200 ppm N . Supplemental amounts of other nutrients (K and Mg) were applied in the same manner as described for Experiment I.

Two methods of application of the N & P were employed . One method involved thoroughly mixing the N with the soil along with other nutrients (broadcast) with P banded . The other method involved application of both N and P in the same band . Six sorghum genotypes - numbers 3, 5, 7, 9, 14, and 15 from Table 1 - were used with the treatments replicated three times.

The plants were harvested four weeks after planting. The shoots were separated from the roots . Planting, harvesting, preparation of samples and analysis of the samples were executed in a similar manner as described for Experiment I .

Experiment V. P-Zn interaction study in sorghum.

The mixture of Parsons silt loam soil and washed silica sand used in Experiment I and IV was also used for this experiment .

Three rates of banded phosphorus - 150, 250, and 350 ppm P - and four sorghum genotypes (5, 7, 9, and 14 from Table 1) were used as the treatments, replicated three times . A completely random design was used and the plants were grown for 39 days .

Supplemental amounts of other nutrients were applied the same as indicated under Experiment I except that the N fertilizer was applied in the same band as the P .

Measures were employed to avoid zinc contamination during preparation of the treatments, harvesting of the plants, preparation and analysis of the plant samples for nutrients . For example, containers were washed with 10% (v/v) HNO_3, EDTA and rinsed with deionized, distilled water .

After harvesting, the plant shoots and roots were rinsed in deionized distilled water and dried separately . Similar procedures for drying and analyzing the plant samples as described under Experiment I were used .

Experiment VI. Culture solution study to observe the influence of N sources of P uptake .

A nutrient solution study was conducted in the greenhouse to observe the influence of nitrogen sources on the uptake of P by sorghum genotypes and to investigate the mechanism of P uptake .

Three nitrogen sources were used - NH_4^+, NO_3^- and a combination of equal amounts of both the nitrate and the ammonium sources . Two liter black, plastic pots were used and the nutrient application rates and source employed are given in Table 4. Details of the procedure used in the preparation of the nutrient solutions are available in Appendix I .

Table 4. Nutrient salts used for solution culture .

Salts	Concentration in stock solution	Volume used per 2 liter solution (ml).		
		NH_4^+ form	NO_3^- form	$NH_4^+ + NO_3^-$ form
$(NH_4)_2SO_4$	1 mole	15	-	7.5
$CaCl_2.2H_2O$	1 "	10	-	7.5
K_2SO_4	1 "	5	-	-
KNO_3	1 "	-	10	10
$MgSO_4.7H_2O$	1 "	4	4	4
KH_2PO_4	1 "	.4	.4	.4
$Ca(NO_3)_2.4H_2O$	1 "	-	20	2.5
KCL	3728 mg/liter	2	2	2
H_3BO_3	1546 " "	2	2	2
$MnSO_4.H_2O$	845 " "	2	2	2
$ZnSO_4.7H_2O$	575 " "	2	2	2
$CuSO_4.5H_2O$	125 " "	2	2	2
$Na_2MoO_4.2H_2O$	26.62 " "	2	2	2
$FeSO_4$-Tartarate	6 mg : 4 mg/l	4	4	4

As shown in Table 4, the ammonium form of nitrogen was supplied exclusively by ammonium sulfate . The nitrate form was supplied by potassium and calcium nitrate in such proportions that a sufficient quantity of the calcium nitrate was used to supply the required calcium . For the mixture of the ammonium and nitrate, the NH_4^+-N was supplied by ammonium sulfate and the NO_3^--N by potassium and calcium nitrates . The balance of the calcium requirement was supplied as calcium chloride . Potassium for the ammonium form was supplied by potassium sulfate .

Sodium molybdate was used to supply molybdenum instead of ammonium molybdate as indicated in Appendix I to avoid NH_4^+ in the nitrate treatments though the quantity of ammonium molybdate would be negligible . Iron was supplied twice a week to ensure sufficiency .

Five sorghum genotypes (3, 7, 9, 11, and 14), previously germinated in vermiculite, were used in this study . Four seedlings were transfered to each pot 5 days after germination . The treatments were replicated twice . Air was pumped into the solution from an aquarium pump through a glass and rubber tubings manifold . The nutrient solutions were replaced each week .

The initial pH of each of the three nitrogen form treatments was recorded . The pH of each of the pots was measured each week and milli-equivalents of acid or base required to bring the pH back to the original pH was determined .

Samples of the solutions in each of the pots of the ammonium plus nitrate treatment were taken weekly for the determination of the NH_4^+ and NO_3^- nitrogen content using a micro-Kjeldah procedure (Appendix) .

The plants were grown in the culture solution for four weeks . During harvesting, the roots were separated from the shoot and the roots were rinsed in deionized, distilled water .

The plant and root samples were dried in an oven at 70 ^{o}C for 48 hours . Grinding of the plant samples and nutrient analyses were carried out the same as described under Experiment I .

RESULTS AND DISCUSSION

Experiment I - Effects of phosphorus application on P uptake efficiency of fifteen sorghum genotypes .

By one week after emergence phosphorus deficiency symptoms were observed on those plants that did not receive phosphorus . Purpling of the leaf blade margins and shorter shoot growth were observed . Although these symptoms were exhibited by all genotypes at the zero level of phosphorus application, the degree of purpling of leaf margins varied slightly with genotypes . Genotypes 5, 7, and 12 (Table 1) exhibited the most conspicuous purpling of leaf margins but the reduction in shoot growth was similar for all the genotypes .

Application of phosphorus significantly increased shoot dry matter (Table 5) . Differences among genotypes were not significant at the zero level of phosphorus, whereas, genotype 3 produced significantly higher dry matter than genotypes 13, 8, 4, 11, 10, 12, and 2 when 200 ppm P was applied, although the genotype by phosphorus level interaction was not significant . The significant difference between genotype 1 and 2 does not agree with Jordan et al (1979) who found equal performance of genotypes 1, 2, 4, 5 and 10 in shoot dry weight production .

Application of phosphorus significantly increased plant phosphorus concentrations (Fig. 1 and Appendix Table 5) . The genotype by P level interaction was significant . Genotype 13 was significantly higher in P concentration than 16, 9, 14, 2, and 1 when P was applied but there was no significant difference when no P was applied .

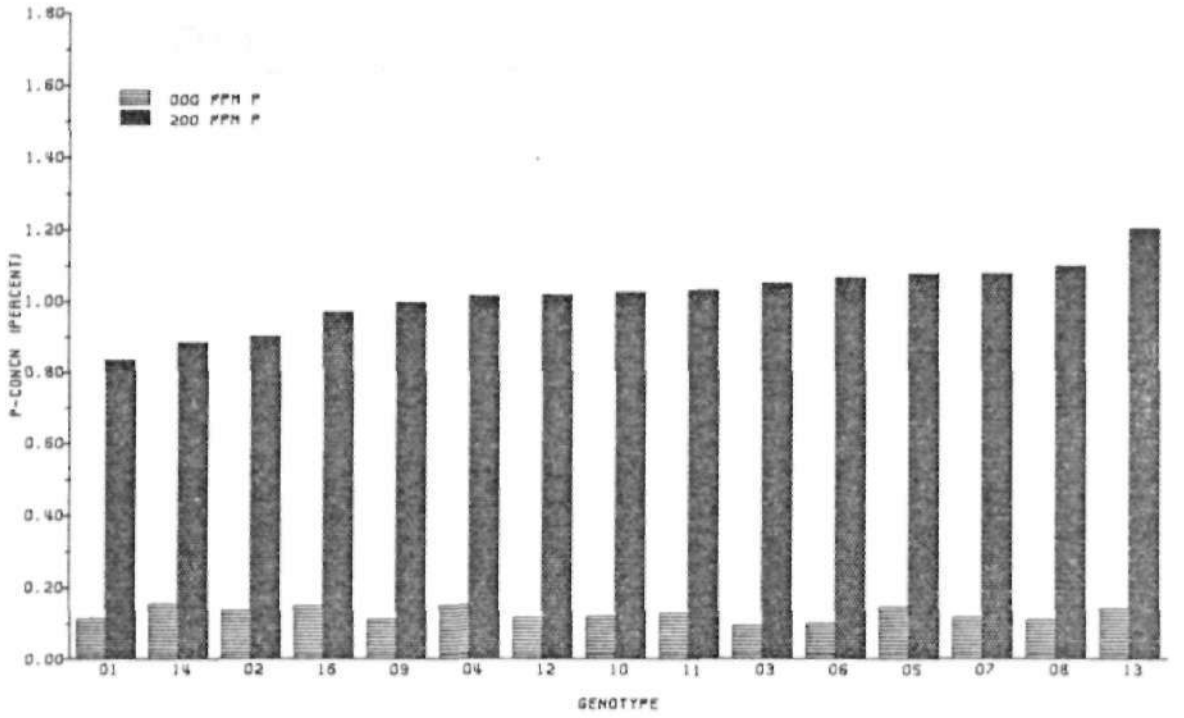
Phosphorus uptake (Fig. 2 and App. Table 5) by the plants was

Table 5 Influence of phosphorus application on plant dry weight and efficiency of P uptake of fifteen sorghum genotypes.

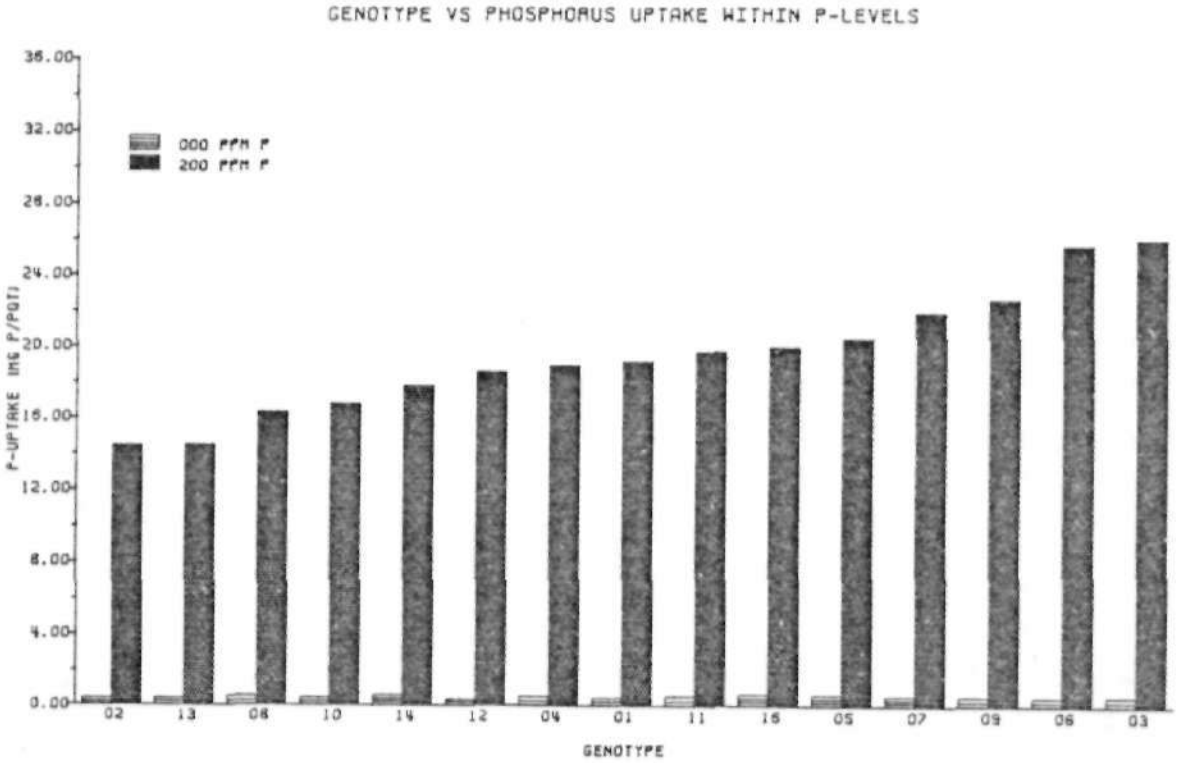
GENOTYPES	Dry weight (gm/pot) 0 ppm P	200 ppm P	MEANS	Increase P uptake (mg P/pot)
1 BTx378	.43	2.27	1.35 ABCD	18.66 A
2 RTx2536	.30	1.60	0.95 EF	14.05 A
3 ATx378 x RTx2536	.63	2.48	1.56 A	25.44 A
4 BTx3197	.43	1.87	1.15 BCDE	18.36 A
5 RTx7078	.47	1.93	1.20 ABCDE	19.80 A
6 RS 610	.53	2.40	1.47 AB	25.15 A
7 BTx399	.52	2.02	1.27 ABCDE	21.34 A
8 RTAM428	.53	1.48	1.01 DEF	15.75 A
9 ATx399 x RTAM428	.50	2.27	1.38 ABC	22.09 A
10 RTx7000	.39	1.63	1.01 DEF	16.35 A
11 ATx378 x RTx7000	.43	1.93	1.18 BCDE	19.15 A
12 SC0283-c	.35	1.83	1.09 CDEF	18.18 A
13 SC0048-c	.30	1.20	0.75 F	14.08 A
14 SC0418-c	.40	2.01	1.21 ABCDE	17.17 A
16 SC0599-6	.47	2.06	1.26 ABCDE	19.31 A
P RATE MEANS	.45 B	1.93 A		

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

GENOTYPE VS P-CONCENTRATION WITHIN P-LEVELS



GENOTYPE VS PHOSPHORUS UPTAKE WITHIN P-LEVELS



significantly increased by P application . Significant differences among the genotypes were found for mean of the two P levels but not at either of the two P levels individually . Genotypes 3 and 6 (both hybrids) took up significantly more phosphorus at the means than 13, 8, 10, and 2 . It is interesting to note that the latter genotype, RTx2536 (2), was poor in taking up applied phosphorus but its ability to absorb P from the soil was improved when crossed with ATx378 since ATx378 x RTx2536 (3) performed much better than RTx2536 in absorbing applied phosphorus . ATx378 (not available for this study) may then be considered to be genetically P responsive and a potential gene source for plant phosphorus improvement .

Considering the data on plant dry weight production, P concentrations, and P uptake increase (App. Table 5), genotypes 2, and 13 could be classified as inefficient P responders and 3, 6, and 9 as efficient P responders . The term 'responder' in this context relates to plant phosphorus concentrations while 'efficiency' relates to the translation of phosphorus absorbed into greater dry matter production . For example, genotypes 13, 3 and 6 performed equally well in plant P concentrations but 3 and 6 were significantly superior to 13 in dry matter production with P applied . Genotypes 2, 3, 6 and 9 were not significantly different in their plant P concentrations but 3, 6, and 9 were significantly superior to 2 in dry matter production . If the classification of the P efficiency of the genotypes were based on the increased phosphorus uptake (Table 5 App.) then all the genorypes would be statistically equally efficient although 3, 8, 6, 9 had the highest overall averages in that order . The lack of significant differences among the genotypes in their efficiency of P uptake supports a similar observation by Maranville et al (1977) . It would, therefore, be logical to attribute the similarity in performance of most of the genotypes to the narrow genetic base available to breeders for their breeding program or similar environments

(Jordan et al 1979) . The consistent good performance of genotypes 3, 6, and 9 (Table 5 App. and Figs. 1 & 2) is, however, noteworthy .

Plant zinc concentrations and uptake were also determined and the results are available in appendix table 6 . Both P level and genotype effects were found to be significant . Genotype by P level interaction was significant for the plant zinc concentrations .

Experiment II - Effects of zinc application on zinc uptake efficiency of fifteen sorghum genotypes .

Although the soil used for this study was moderately low (.31 ppm Zn by the DTPA test) in zinc, no characteristic, conspicuous zinc deficiency symptoms were observed on any of the sorghum genotypes at the zero level of zinc .

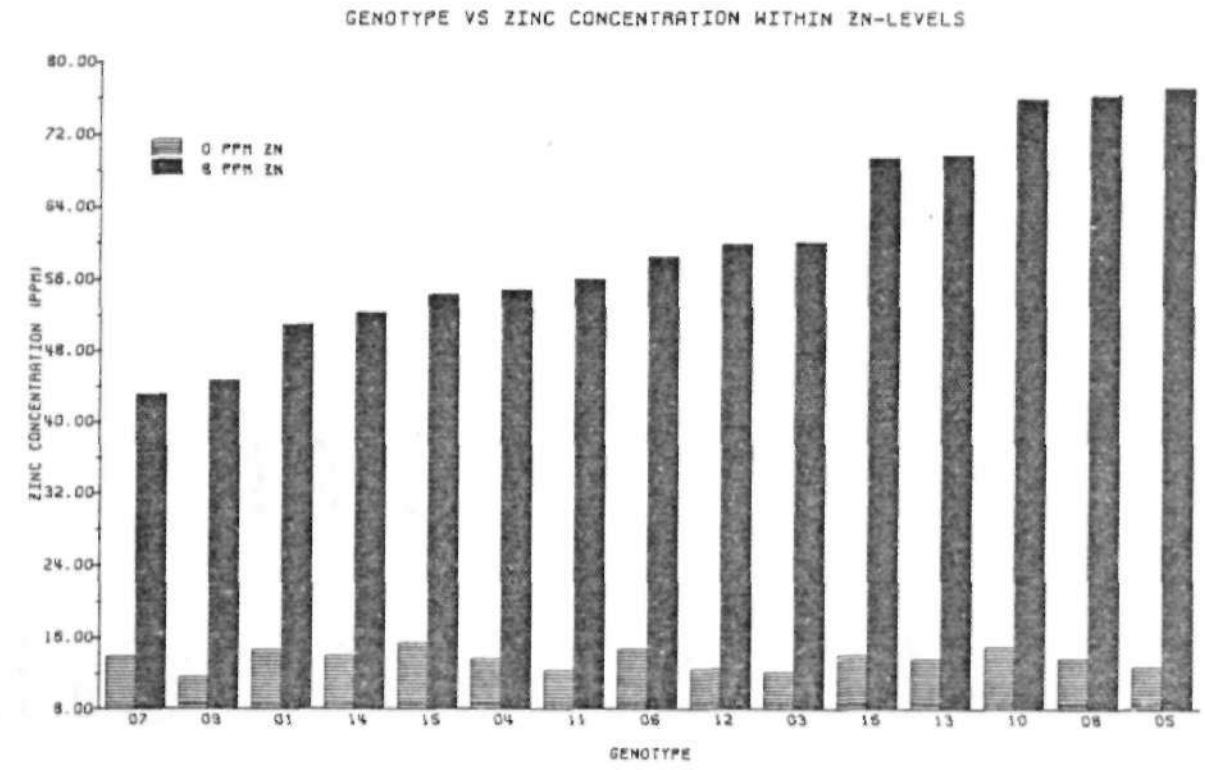
Application of zinc did not produce a significant genotype by zinc level interaction . Plant dry weight was not significantly increased by zinc application (Table 6) . Differences among genotypes at both zinc levels were highly significant . The overall effects of the treatments indicated good performance of three of the four hybrids (3, 6, and 11) while the aluminum tolerant (12, 13, and 14) and the non-senescent types (15, 16) performed poorly . Genotype 3 produced significantly higher dry matter than any of the others except 5, 11 and 1 with genotypes 3, 5 and 11 consistently at the top for both zinc levels .

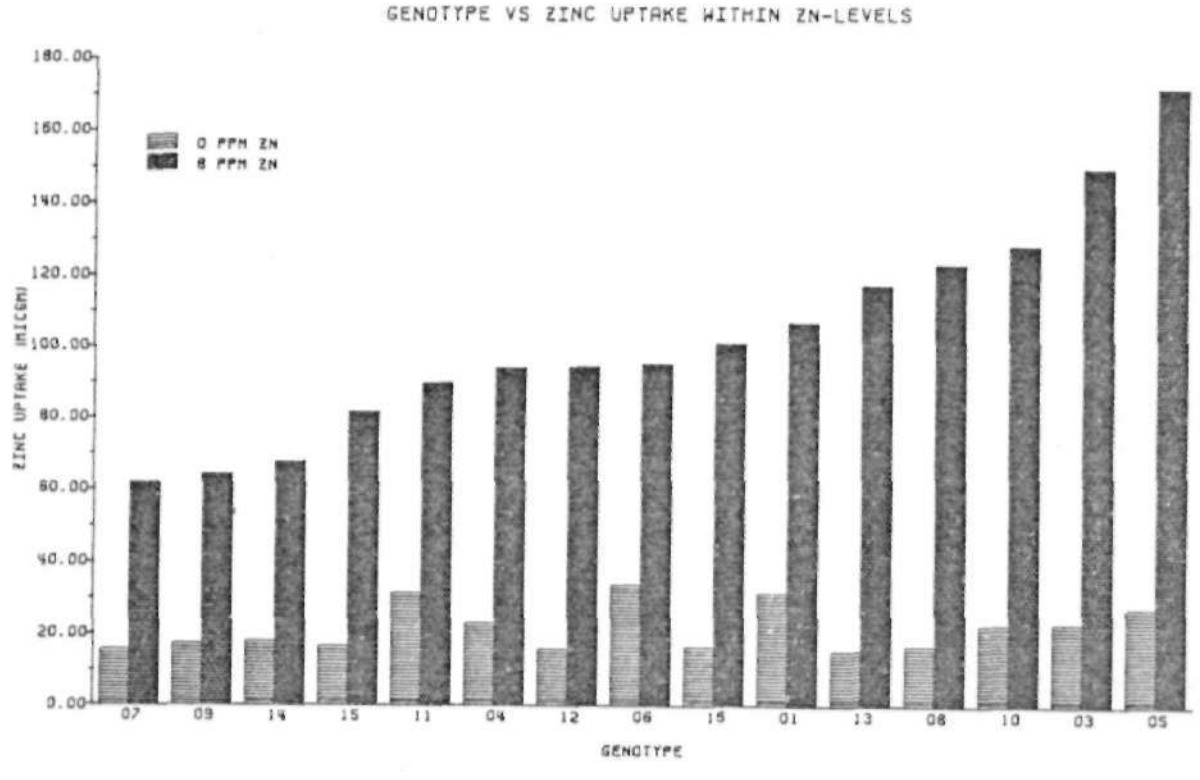
A highly significant increase in plant zinc concentrations (Fig.3 and APP. Table 7) resulted from the zinc application . The genotype by zinc level interaction was highly significant . Genotype 10 was significantly higher in plant zinc concentrations than 14, 1, 7, and 9 when Zn was applied but no difference was found among genotypes when no Zn was applied . Generally, similarity among many genotypes was observed, however, the hybrids were among the lowest and highest for zinc uptake.

Table 6 Effects of zinc application on plant dry weights and efficiency of Zn uptake by fifteen sorghum genotypes.

	Dry weights (gm/pot)			
GENOTYPES	0 ppm Zn	8 ppm Zn	MEANS	Increase Zn uptake (ugm/pot)
1 BTx378	2.2	2.0	1.9 BCD	75.18 BC
3 ATx378 x RTx2536	1.9	2.7	2.3 A	126.43 AB
4 BTx3197	1.7	1.7	1.6 CDE	70.80 BC
5 RTx7078	2.1	2.3	2.2 AB	144.26 A
6 RS 610	2.3	1.6	1.7 BCDE	61.26 C
7 BTx399	1.1	1.4	1.3 E	49.09 C
8 RTAM428	1.2	1.7	1.4 DE	106.20 ABC
9 ATx399 x RTAM428	1.5	1.6	1.4 DE	46.78 C
10 RTx7000	1.5	1.4	1.5 DE	105.56 ABC
11 ATx378 x RTx7000	2.5	1.6	2.1 ABC	58.26 C
12 SC0283-c	1.2	1.5	1.3 E	78.09 BC
13 SC0048-c	1.1	1.6	1.3 E	101.53 ABC
14 SC0418-c	1.1	1.5	1.3 E	49.46 C
15 SC0056-14	1.1	1.4	1.3 E	64.76 BC
16 SC0599-6	1.3	1.3	1.3 E	89.16 ABC
Zn Rate Means	1.6 A	1.7 A		

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


GENOTYPE VS ZINC CONCENTRATION WITHIN ZN-LEVELS
0 PPM ZN
8 PPM ZN
ZINC CONCENTRATION (PPM)
80.00
72.00
64.00
56.00
48.00
40.00
32.00
24.00
16.00
8.00
07 09 01 14 15 04 11 06 12 03 16 13 10 08 05
GENOTYPE


GENOTYPE VS ZINC UPTAKE WITHIN ZN-LEVELS
0 PPM ZN
8 PPM ZN
ZINC UPTAKE (MICGM)
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
07 09 14 15 11 04 12 06 16 01 13 08 10 03 05
GENOTYPE

No genetic grouping of the genotypes was apparent .

The genotype by zinc level interaction was significant for the zinc uptake . Zinc uptake by the plants was also significantly increased by zinc application (Fig. 4 and App. Table 7) . Differences among genotypes were highly significant . A large group of genotypes performed similarly but 5 and 3 contained much more zinc than 15, 14, 9, and 7 for the overall average zinc uptake .

Using the dry weights, zinc concentration, zinc uptake, and zinc uptake increase (Table 6) data as criteria for classification of the genotypes in terms of their response to zinc fertilization, genotypes 3 and 5 may be considered as efficient zinc responders, 6, 8, 9 and 10 moderate responders and 7 and 14 as poor zinc responders . Genotype 3 maintained its good performance noted for the phosphorus study while genotypes 9 and 6 did earlier good performance . These results suggest that efficiency of P uptake by plants may not necessarily result in zinc uptake inefficiency .

The good performance of genotypes 3, 6 and 9 in zinc uptake at zero zinc level does not agree with Clark's (1970) findings that P efficient genotypes may exhibit zinc deficiency symptoms under some conditions .

Plant phosphorus concentrations and uptake were also determined as secondary variables (Appendix Table 8) . Zinc application had no significant effect on P concentration and P uptake . Mean P concentration and P uptake differences among genotypes were significant with very little deviation from the trend observed under Experiment I .

Experiment III - Influence of P application rate and liming on P uptake by seven sorghum genotypes .

Ten days after emergence, genotype 5 started showing characteristic phosphorus deficiency symptoms with zero phosphorus application at all three pH levels . Similar symptoms were observed for genotype 5 at the 40

ppm P application a few days later . Genotypes 7, 12, and 15 also exhibited phosphorus deficiency symptoms at both the zero and 40 ppm P levels at all three pH levels but the symptoms were much less pronounced than those of genotype 5 . Phosphorus deficiency symptoms showing with 40 ppm P application was due to the inadequate phosphorus application to a low available soil P as supported by soil test results in Table 2 . Genotype 14 did not exhibit the characteristic marginal purpling of leaf blades but grew poorly at the zero level of P application .

The genotype by P level and genotype by pH interactions were significant for plant dry weight production . Liming did not have any significant effects on overall liming means plant dry weights (Table 7) . Application of phosphorus significantly increased plant dry weights . Differences among genotypes at both P levels were significant . Genotype 12 performen much better than 15 at the 40 ppm P level, but at the zero P level, genotype 14 produced significantly higher dry weights than 12, 9, 5 and 15 . On the overall effects of the treatments, genotype 12 performed much better than 5 and 15 .

The unlimed soil (pH 5.2) produced significantly higher average plant phosphorus concentrations (Fig. 5 and App. Table 9) than the recommended rate of lime but not significantly different from excess lime . Application of 40 ppm P significantly increased the plant overall average phosphorus concentrations . Differences among sorghum genotypes were not significant but genotype by P level and P level by pH interactions were both significant .

Liming had no significant effect on plant uptake of phosphorus (Table 8) but P uptake was significantly increased by application of 40 ppm P . There were no significant interactions among the independent variables. Differences among lime rates were significant at the zero level of phosphorus where the original soil without lime gave significantly higher P uptake than

Table 7 Influence of P application and liming on plant dry weights of seven sorghum genotypes.

	0 ppm P LIMING RATE				40 ppm P LIMING RATE				
GENOTYPES	x NONE	x RECOM	x EXCESS	MEANS	NONE	RECOM	EXCESS	MEANS	OVERALL MEANS
Dry weights (gm/pot)									
3 ATx378 x RTx2536	.47 A	.33 B	.53 A	.44 AB	5.67 A	4.53 A	4.63 A	4.94 A	2.69 AB
5 RTx7078	.50 A	.37 B	.27 A	.38 B	4.83 A	5.07 A	3.97 A	4.62 AB	2.50 BC
7 BTx399	.67 A	.37 B	.43 A	.49 AB	5.50 A	4.60 A	4.90 A	5.00 A	2.74 AB
9 ATx399 x RTAM428	.23 A	.40 B	.40 A	.34 B	4.63 A	5.80 A	5.03 A	5.16 A	2.75 AB
12 SC0283-c	.43 A	.30 B	.47 A	.40 B	4.97 A	5.27 A	5.77 A	5.33 A	2.87 A
14 SC0418-c	.57 A	.80 A	.37 A	.58 A	5.10 A	5.20 A	4.70 A	5.00 A	2.79 AB
15 SC0056-14	.33 A	.47 B	.43 A	.41 B	4.37 A	4.23 A	3.80 A	4.13 B	2.27 C
LIMING MEANS	.46 A	.43 A	.41 A		5.01 A	4.96 A	4.69 A		
Overall Liming Means	NONE 2.73 A			RECOM 2.70 A			EXCESS 2.55 A		
P Level Means		.43 B				4.88 A			

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

x
NONE - Original soil pH 5.2

x
RECOMMENDED - 4000 lbs/Acre - pH 6.8

x
EXCESS - 5% Lime w/w - pH 8.2

Table 8 Influence of P application and liming on plant phosphorus uptake of seven sorghum genotypes. (mg P/pot)

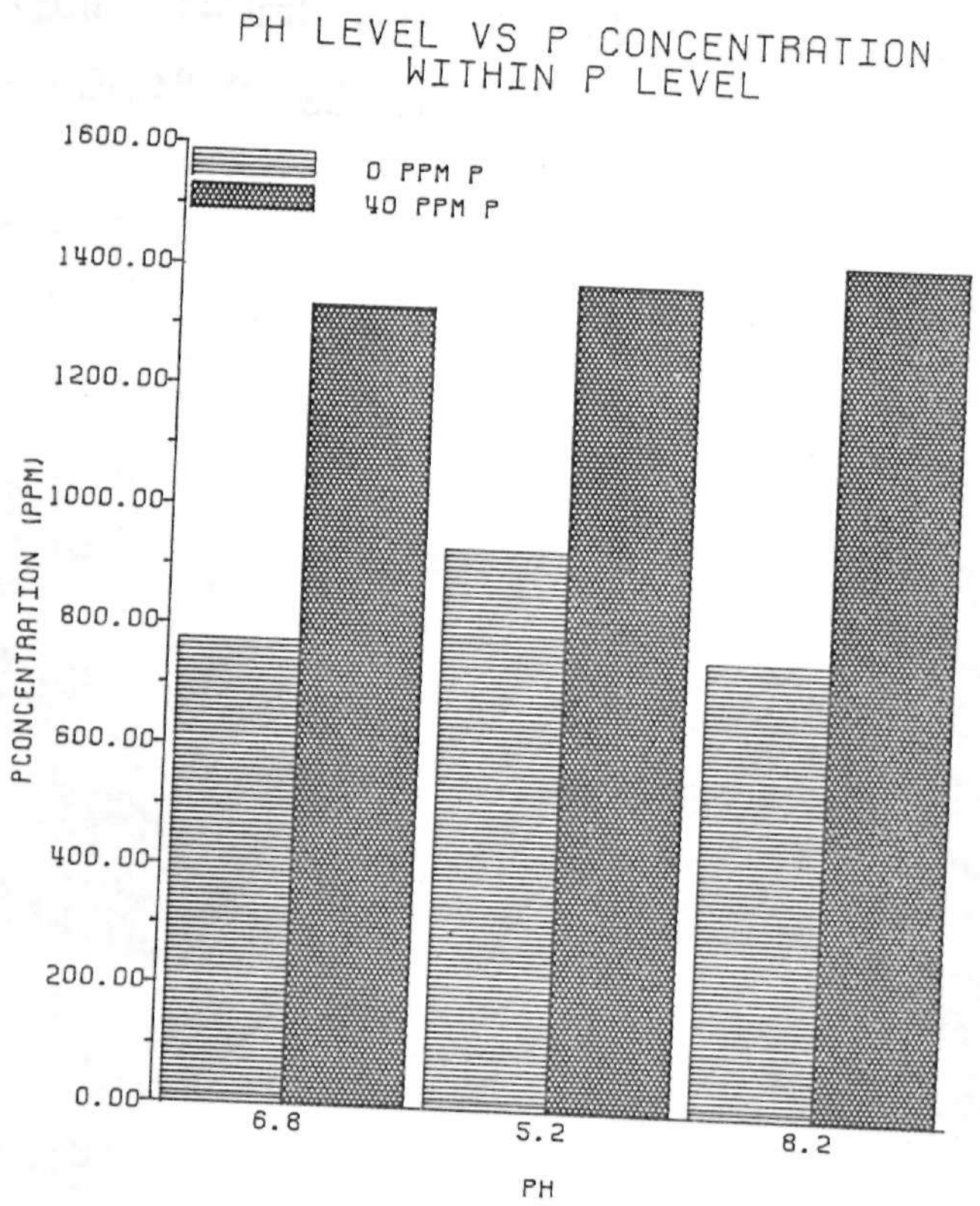
GENOTYPES	0 ppm P LIMING RATE x NONE	x RECOM	x EXCESS	MEANS	40 ppm P LIMING RATE NONE	RECOM	EXCESS	MEANS	OVERALL MEANS
P uptake (mg P/pot)									
3 ATx378 x RTx2536	.52	.26	.37	.38 ABC	7.23	6.11	5.38	6.24 A	3.31 A
5 RTx7078	.42	.25	.20	.29 C	6.33	7.41	5.57	6.43 A	3.36 A
7 BTx399	.85	.30	.30	.48 AB	7.82	6.13	6.52	6.82 A	3.65 A
9 ATx399 x RTAM428	.20	.32	.34	.28 C	6.85	7.13	7.60	7.19 A	3.74 A
12 SC0283-c	.36	.22	.35	.31 BC	7.48	7.25	8.39	7.71 A	4.01 A
SC0418-c	.56	.71	.32	.53 A	6.54	6.95	6.60	6.70 A	3.61 A
SC0056-14	.25	.29	.42	.32 BC	6.16	5.44	5.91	5.84 A	3.08 A
Liming Means	.45 A	.34 B	.33 B		6.91 A	6.63 A	6.57 A		
Overall Liming Means	NONE 3.68 A			RECOM 3.48 A				EXCESS 3.45 A	
P Level Means	.37 B				6.70 A				

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

x
NONE - Original soil pH 5.2

x
RECOMMENDED - 4000 lbs/Acre - pH 6.8

x
EXCESS - 5% Lime w/w - pH 8.2


PH LEVEL VS P CONCENTRATION
WITHIN P LEVEL
0 PPM P
40 PPM P
PCONCENTRATION (PPM)
1600.00
1400.00
1200.00
1000.00
800.00
600.00
400.00
200.00
0.00
6.8
5.2
8.2
PH

the two levels of liming .

Soil pH measurements (Table 9) on soil samples taken at the end of the study reflect the significant influence of both P level and liming . The soil with 40 ppm P application had significantly higher overall average soil pH than the no P treatment . The averages for liming were significantly different in the order; no liming $>$ recommended lime $\geq$ excess lime . The lack of significant differences among the genotypes negates evaluation of the differential ability of the genotypes to acidifythe rhizosphere to influence P uptake . Method of sampling may also influence the observed results since the soil samples were not strictly taken from the rhizosphere . P efficient genotypes have been reported by McLachlan (1976) to possess the ability to acidify the rooting medium . Although the difference is not statistically significant, genotype 3 which had earlier been classified as P efficient, recorded the lowest pH across all lime rates .

Zinc concentrations and uptake in the plants were also determined and the data are available in Appendix Table 10 . The excess lime treatment resulted in a significantly lower than no lime or the recommended rate of lime . Differences among lime rates for zinc uptake were significant with the recommended lime rate better than the other two rates and no lime was better than excess lime . The 40 ppm P treatment was significantly better than the no P treatment .

Experiment IV - Influence of N and P placement on P uptake by the genotypes .

Placement of nitrogen with the phosphorus did not have a significant effect on shoot dry weights over separate broadcast application of the N (Table 10) . Shoot dry weights were significantly increased by 150 ppm P compared to 50 ppm P . Differences among the genotypes were highly significant only at 50 ppm P . Genotypes 9, 3, and 7 produced significantly higher shoot dry weights than 5 . None of the possible interactions among the

Table 9 Influence of genotype, P rate and lime rate on soil pH.

GENOTYPES	0 ppm P LIMING RATE x NONE	x RECOM	x EXCESS	MEANS	40 ppm P LIMING RATE NONE	RECOM	EXCESS	MEANS	OVERALL MEANS
Soil pH									
3 ATx378 x RTx2536	4.6	6.0	7.2	5.9 A	4.7	6.0	7.3	6.0 A	6.0 A
5 RTx7078	4.9	6.1	7.2	6.1 A	4.7	6.1	7.4	6.0 A	6.0 A
7 BTx399	4.8	5.9	7.2	6.0 A	4.7	6.0	7.3	6.0 A	6.0 A
9 ATx399 x RTAM428	4.6	6.0	7.3	5.9 A	5.1	6.0	7.3	6.1 A	6.0 A
12 SC0283-c	4.9	6.0	7.3	6.0 A	4.8	6.1	7.3	6.0 A	6.0 A
14 SC0418-c	4.9	5.9	7.3	6.0 A	4.8	6.3	7.3	6.1 A	6.1 A
15 SC0056-14	4.7	6.0	7.3	6.0 A	4.8	6.1	7.4	6.1 A	6.1 A
LIMING MEANS	4.8 C	6.0 B	7.2 A		4.8 C	6.1 B	7.3 A		

Overall Liming Means	NONE	RECOM	EXCESS
	4.8 C	6.0 B	7.3 A

P Level Means	6.0 B	6.1 A

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

x
NONE - Original soil pH 5.2

x
RECOMMENDED - 4000 lbs/Acre - pH 6.8

x
EXCESS - 5% Lime w/w - pH 8.2

independent variables was significant .

Root dry weights (Table 10) were significantly increased by broadcasting nitrogen with phosphorus banded only at the higher rate (150 ppm P) of P application . The overall method of placement effects showed no difference between the two methods . Differences among genotypes were significant at both levels of phosphorus application . At the 50 ppm P application rate, the genotypes differed significantly when the nitrogen and phosphorus were banded together . Genotypes 9 and 7 performed much better than 3, 14, and 5 .

Total dry weights (roots + shoots - Table 10) were not affected by method of nitrogen placement with the banded phosphorus . Differences among genotypes were significant and followed a similar trend observed for the roots and shoots analyzed separately .

The P level by method of nitrogen placement interaction was significant for the P concentrations in plant shoots (Appendix) . Phosphorus concentrations (Table 11) in plant shoots were significantly increased by banding nitrogen in the same soil zone with the phosphorus compared to broadcasting the nitrogen . The overall mean P concentration for genotypes 7 and 9 that produced the highest dry weights were significantly lower than the other genotypes . One hundred and fifty parts per million P was superior to 50 ppm P application . Only the P level by method of nitrogen placement interaction was significant. The N banded with the P significantly increased P concentration at the higher rate (150 ppm P) of P application, but N placement had no effect at the low P application rate .

The P level by method of N application interaction was significant . Putting nitrogen in the same band with the phosphorus significantly increased shoot uptake of P (Table 11) compared to separate broadcast N at the 150 ppm P rate but had no effect at the low P rate . The increased P

Table 10 Effect of nitrogen placement with two rates of banded P on growth of six sorghum genotypes.

	50 ppm P			150 ppm P			
	METHOD			METHOD			
GENOTYPES	x NbPd	xx NPd	MEANS	NbPd	NPd	MEANS	OVERALL MEANS
Shoot dry weights (gm/pot)							
3 ATx378 x RTx2536	6.2	6.0	6.1 AB	6.0	6.5	6.3 A	6.2 AB
5 RTx7078	5.2	4.9	5.0 C	5.8	5.6	5.7 A	5.4 C
7 BTx399	6.4	6.8	6.6 A	6.6	6.6	6.6 A	6.6 A
9 ATx399 x RTAM428	6.0	7.2	6.6 A	6.4	7.3	6.9 A	6.7 A
14 SC0418-c	6.1	4.9	5.5 BC	6.2	6.2	6.2 A	5.9 BC
15 SC0056-14	5.4	6.0	5.7 BC	6.4	5.7	6.0 A	5.9 BC
Method Means	5.9 A	6.0 A		6.2 A	6.3 A		
Overall Method Means			NbPd 6.1 A			NPd 6.1 A	
P Rate Means		5.9 B			6.3 A		
Roots dry weights (gm/pot)							
3 ATx378 x RTx2536	1.5	1.3	1.4 ABC	1.8	1.5	1.7 AB	1.5 BC
5 RTx7078	1.0	0.8	0.9 C	1.2	1.1	1.2 B	1.0 D
7 BTx399	1.8	2.0	1.9 A	2.1	1.8	2.0 A	1.9 AB
9 ATx399 x RTAM428	1.7	2.1	1.9 A	2.1	2.0	2.1 A	2.0 A
14 SC0418-c	1.3	0.9	1.1 BC	1.5	1.0	1.3 B	1.2 CD
15 SC0056-14	1.5	1.6	1.6 AB	2.6	1.7	2.2 A	1.9 AB
Method Means	1.5 A	1.5 A		1.9 A	1.5 B		
Overall Method Means			NbPd 1.7 A			NPd 1.5 A	
P Rate Means		1.5 B			1.7 A		

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

x NbPd - N broadcast, P banded.

x NPd - N & P banded together.

Table 10 (continued)

GENOTYPES	50 ppm P METHOD x NbPd	50 ppm P METHOD xx NPd	50 ppm P MEANS	150 ppm P NbPd	150 ppm P NPd	150 ppm P MEANS	OVERALL MEANS
Total (Roots + shoots) dry weights (gm/pot).							
3 ATx378 x RTx2536	7.7	7.3	7.5 AB	7.8	8.0	7.9 ABC	7.7 BC
5 RTx7078	6.2	5.7	6.0 C	7.0	6.8	6.9 C	6.4 D
7 BTx399	8.2	8.8	8.5 A	8.7	8.4	8.5 AB	8.5 AB
9 ATx399 x RTAM428	7.7	9.3	8.5 A	8.6	9.3	9.0 A	8.7 A
14 SC0418-c	7.3	5.9	6.6 BC	7.8	7.1	7.5 BC	7.0 CD
15 SC0056-14	6.9	7.7	7.3 ABC	9.0	7.4	8.2 ABC	7.7 BC
Method Means	7.3 A	7.4 A		8.1 A	7.8 A		
Overall Method Means		NbPd 7.7 A				NPd 7.6 A	
P Rate Means	7.4 B			8.0 A			

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

x NbPd - N broadcast, P banded.

xx NPd - N & P banded together.

Table 11 Effect of nitrogen placement with two rates of banded P on P concentration and P uptake in six sorghum genotypes.

	50 ppm P			150 ppm P			
	METHOD			METHOD			
GENOTYPES	x NbPd	xx NPd	MEANS	NbPd	NPd	MEANS	OVERALL MEANS
Phosphorus concentration (%) in the shoots.							
3 ATx378 x RTx2536	.25	.28	.27 A	.43	.62	.53 A	.40 A
5 RTx7078	.27	.25	.26 A	.53	.65	.59 A	.43 A
7 BTx399	.21	.20	.21 A	.41	.52	.47 A	.34 B
9 ATx399 x RTAM428	.19	.23	.21 A	.46	.43	.45 A	.33 B
14 SC0418-c	.25	.33	.29 A	.50	.60	.55 A	.42 A
15 SC0056-14	.24	.27	.26 A	.43	.65	.54 A	.40 A
Method Means	.24 A	.26 A		.46 B	.58 A		
Overall Method Means		NbPd .35 B				NPd .42 A	
P Rate Means	.25 B				.52 A		
P uptake (mg P/pot) in the shoots.							
3 ATx378 x RTx2536	15.6	17.0	16.3 A	25.8	40.7	33.3 A	24.8 A
5 RTx7078	14.4	12.4	13.4 A	30.9	36.8	33.8 A	23.6 A
7 BTx399	13.2	13.5	13.4 A	27.5	34.2	30.8 A	22.1 A
9 ATx399 x RTAM428	11.2	16.1	13.6 A	28.8	31.9	30.3 A	22.0 A
14 SC0418-c	15.1	16.0	15.6 A	31.5	37.1	34.3 A	24.9 A
15 SC0056-14	13.2	16.3	14.7 A	27.3	35.2	31.3 A	23.0 A
Method Means	13.8 A	15.2 A		28.6 B	36.0 A		
Overall Method Means		NbPd 21.2 B				NPd 25.6 A	
P Rate Means	14.5 B				32.3 A		

Means within same column with the same letter are not significantly different at DMRT .05
x N broadcast, P banded. xxNPd - N & P banded together.

Table 12 Effect of nitrogen placement with two rates of banded P and P concentration and P uptake in the roots of six sorghum genotypes.

	50 ppm P			150 ppm P			
	METHOD			METHOD			
GENOTYPES	x NbPd	xx NPd	MEANS	NbPd	NPd	MEANS	OVERALL MEANS
Phosphorus concentration (%) in the roots.							
3 ATx378 x RTx2536	.13	.12	.13 ABC	.23	.32	.27 A	.20 A
5 RTx7078	.16	.13	.14 A	.26	.35	.31 A	.23 A
7 BTx399	.12	.09	.11 BC	.23	.31	.27 A	.19 A
9 ATx399 x RTAM428	.11	.12	.11 BC	.27	.25	.26 A	.19 A
14 SC0418-c	.11	.12	.12 ABC	.25	.28	.26 A	.19 A
15 SC0056-14	.15	.13	.14 AB	.22	.31	.27 A	.20 A
Method Means	.13 A	.12 A		.24 B	.30 A		
Overall Method Means		NbPd .19 B				NPd .21 A	
P Rate Means	.13 B			.27 A			
P uptake (mg P/pot) in the roots.							
3 ATx378 x RTx2536	1.9	1.6	1.8 AB	4.2	4.8	4.5 ABC	3.1 AB
5 RTx7078	1.6	1.1	1.3 B	3.2	4.0	3.6 BC	2.5 BC
7 BTx399	2.1	1.9	2.0 A	4.7	5.6	5.2 AB	3.6 A
9 ATx399 x RTAM428	1.8	2.5	2.2 A	5.7	5.0	5.4 A	3.8 A
14 SC0418-c	1.4	1.1	1.2 B	3.8	2.7	3.3 C	2.3 C
15 SC0056-14	2.2	2.0	2.1 A	5.9	4.8	5.3 A	3.7 A
Method Means	1.8 A	1.7 A		4.6 A	4.5 A		
Overall Method Means		NbPd 3.2 A				NPd 3.1 A	
P Rate Means	1.8 B			4.5 A			

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

x NbPd - N broadcast, P banded.

x NPd - N & P banded together.

Table 12 (continued)

GENOTYPES	50 ppm P METHOD x NbPd	50 ppm P METHOD xx NPd	50 ppm P MEANS	150 ppm P METHOD NbPd	150 ppm P METHOD NPd	150 ppm P MEANS	OVERALL MEANS
Total (Shoots + roots) P uptake (mg P/pot)							
3 ATx378 x RTx2536	17.5	18.6	18.1 A	30.0	45.6	37.8 A	27.9 A
5 RTx7078	15.9	13.5	14.7 A	34.1	40.8	37.4 A	26.1 A
7 BTx399	15.3	15.4	15.4 A	32.2	39.8	36.0 A	25.7 A
9 ATx399 x RTAM428	13.0	18.7	15.8 A	34.4	36.9	35.7 A	25.7 A
14 SC0418-c	16.5	17.1	16.8 A	35.3	39.7	37.5 A	27.2 A
15 SC0056-14	15.4	18.3	16.8 A	33.2	40.0	36.6 A	26.7 A
Method Means	15.6 A	16.9 A		33.2 B	40.5 A		
Overall Method Means			NbPd 24.4 B			NPd 28.7 A	
P Rate Means	16.3 B			36.8 A			

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

x NbPd - N broadcast, P banded.

xx NPd - N & P banded together.

uptake with banding of N and P together, confirms the findings of Miller et al (1958 and 1971) in which they attributed such response to P to the influence of nitrogen in increasing the feeding power of the root system . Differences among genotypes were not significant suggesting that the response to P, as influenced by placement with nitrogen, may not be genetically controlled .

Root phosphorus concentrations (Table 12) were significantly increased by 150 ppm P compared to 50 ppm P application . Differences among genotypes were not significant but the interaction between P level and method of N placement was sgnificant . The influence of the method of N placement was evident at the higher rate of P application only, suggesting the dependency of such response to rate of P applied or amount of P available in the rhizosphere .

Method of N placement had no significant effect on total root uptake of P (Table 12) but was significantly increased by application of 150 ppm P compared to 50 ppm P . Differences among sorghum genotypes were significant at both levels of phosphorus application . This suggests that the ability of plant roots to absorb P from the soil may be genetically controlled independent of available P level .

Total ,roots plus shoots, phosphorus uptake (Table 12) was significantly increased by putting N in the same band with the P over broadcasting the N with application of 150 ppm P but not significantly different at 50 ppm P .

Zinc concentrations and uptake in both roots and shoots were also determined and the data are available in Appendix Table 11 . Method of N placement with P banded had no effect on plant zinc concentrations and uptake .

Experiment V - P-Zn interaction in sorghum .

Shoot dry weight (Table 13) was significantly increased by application of 250 and 350 ppm P over 150 ppm P, but there was no different between these two rates . Differences among the four genotypes for overall dry matter production were significant with genotype 9 performing better than 5 and 7 . The genotype by P level interaction was not significant . Similar trends in response were observed for root dry weights as well as the total dry weights , roots + shoots (Table 13) .

Phosphorus concentration in the plant shoots and roots (Table 14) were significantly increased by P rate in the order 350 $>$ 250 $>$ 150 ppm P. Differencws among the four genotypes were not significant .

Phosphorus uptake in the shoots and roots (Table 14) were significantly increased by P application to P concentrations . However, the ability of the genotypes roots to absorb P appeared to differ significantly as indicated by the root P concentrations .

Influence of phosphorus application rates on total P uptake , shoots plus roots, (Table 14) followed a similar pattern as observed for the P concentrations in the shoots and roots analyzed separately . Differences among genotypes were significant . The significant differences among the sorghum genotypes for the root P uptake and total P uptake suggest that P uptake in the plant is genetically controlled . This supports a similar observation recorded with the dual N and P placement study .

Zinc concentrations in both shoots and roots (Table 15) were not affected by P application rates but difference among genotypes were significant . In the shoot, genotype 5 and 7 had significantly higher zinc concentrations than 14 . In the roots genotypes 7 and 9 performed well next to 14 which had the highest Zn concentration .

Zinc uptake in the plant shoots (Table 15) was not significantly influenced by increasing P application rates . Differences among genotypes

Table 13 Effects of P application rate on plant dry weight of four sorghum genotypes.

GENOTYPES	P Levels (ppm P) 150	250	350	MEANS
Shoot dry weights (gm/pot).				
5 RTx7078	3.1	3.8	3.9	3.6 C
7 BTx399	3.5	4.1	4.1	3.9 B
9 ATx399 x RTAM428	4.2	4.5	4.2	4.3 A
14 SC0418-c	3.9	4.4	4.0	4.1 AB
P Level Means	3.7 B	4.2 A	4.1 A	
Roots dry weights (gm/pot).				
5 RTx7078	0.9	1.2	1.1	1.0 C
7 BTx399	1.2	1.8	1.9	1.6 AB
9 ATx399 x RTAM428	1.6	1.9	1.9	1.8 A
14 SC0418-c	1.2	1.7	1.7	1.5 B
P Level Means	1.2 B	1.7 A	1.7 A	
Total (Roots + shoots) dry weights (gm/pot).				
5 RTx7078	4.0	5.0	5.0	4.6 C
7 BTx399	4.7	5.6	6.0	5.4 B
9 ATx399 x RTAM428	5.8	6.4	6.1	6.1 A
14 SC0418-c	5.1	6.0	5.7	5.6 AB
P Level Means	4.9 B	5.8 A	5.7 A	

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

Table 14 Effects of P application rate on plant phosphorus concentration and uptake of four sorghum genotypes.

	P Levels (ppm P)			
GENOTYPES	150	250	350	MEANS
Phosphorus concentration (%) in the shoots.				
5 RTx7078	1.01	1.26	1.41	1.22 A
7 BTx399	0.98	1.23	1.51	1.24 A
9 ATx399 x RTAM428	0.91	1.23	1.37	1.17 A
14 SC0418-c	0.90	1.23	1.33	1.15 A
P Level Means	0.95 C	1.24 B	1.41 A	
P concentration in the roots (%)				
5 RTx7078	.38	.50	.65	.51 A
7 BTx399	.43	.52	.72	.56 A
9 ATx399 x RTAM428	.34	.49	.55	.46 A
14 SC0418-c	.38	.46	.51	.45 A
P Level Means	.38 C	.49 B	.61 A	
P uptake (mg P/pot) in the shoots.				
5 RTx7078	30.93	48.34	55.14	44.80 A
7 BTx399	33.83	50.77	61.16	48.85 A
9 ATx399 x RTAM428	38.00	54.94	57.10	50.01 A
14 SC0418-c	35.00	53.69	53.83	47.48 A
P Level Means	34.44 C	51.91 B	57.01 A	

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

Table 14 (continued)

GENOTYPES	P Levels (ppm P) 150	250	350	MEANS
P uptake (mg P/pot) in the roots.				
5 RTx7078	3.43	5.78	6.82	5.34 C
7 BTx399	5.05	9.51	13.57	9.38 A
9 ATx399 x RTAM428	5.33	9.48	10.58	8.46 A
14 SC0418-c	4.64	7.66	8.57	6.97 B
P Level Means	4.61 C	8.11 B	9.88 A	
Total (shoots + roots) P uptake (mg P/pot).				
5 RTx7078	34.35	54.12	61.96	50.14 B
7 BTx399	38.88	60.28	75.53	58.23 A
9 ATx399 x RTAM428	43.33	64.42	67.68	58.47 A
14 SC0418-c	39.64	61.26	62.04	54.43 AB
P Level Means	39.05 C	60.02 B	66.89 A	

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

Table 15 Effects of P application rate on plant zinc concentration and uptake of four sorghum genotypes.

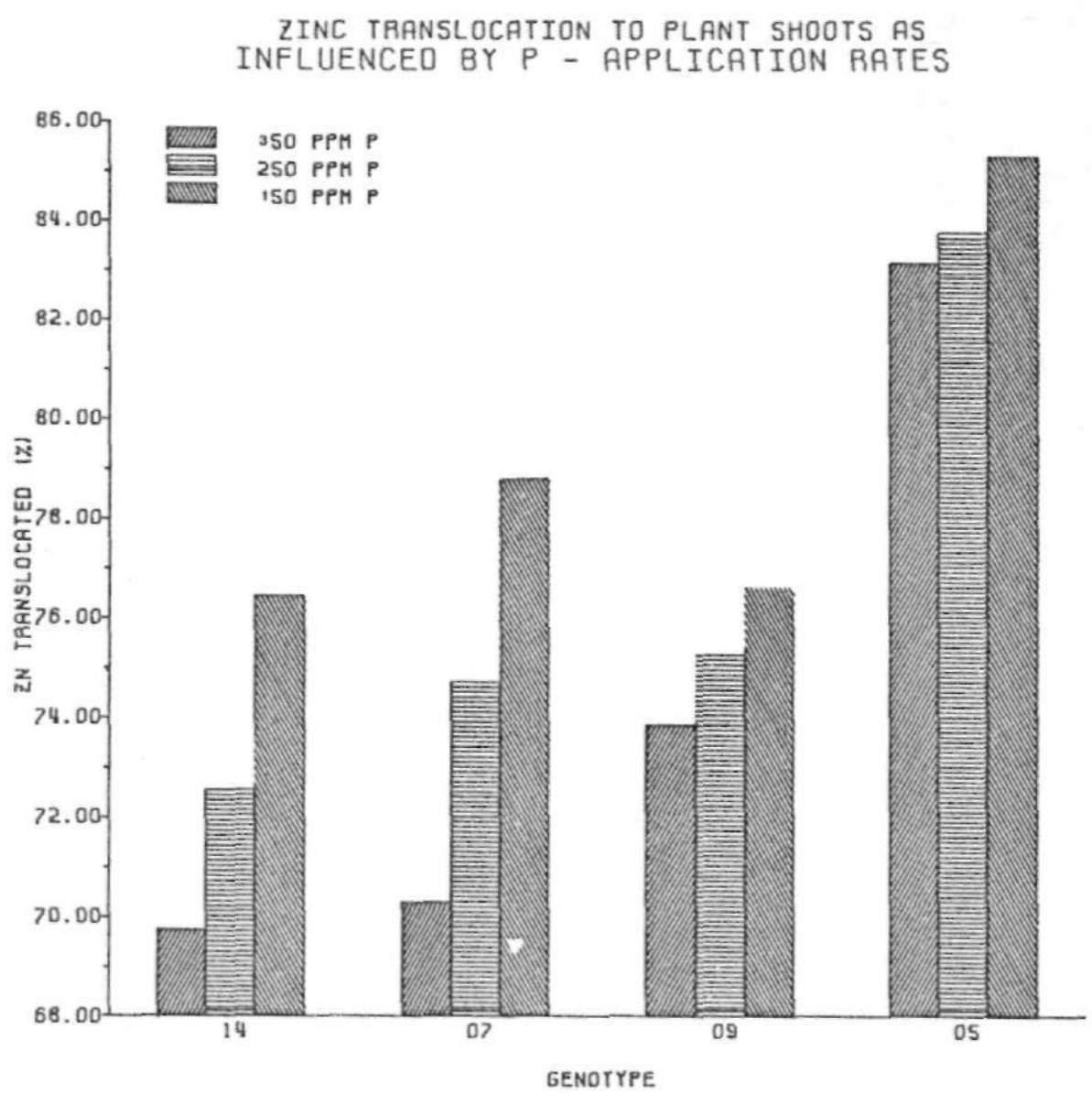
	P Levels (ppm P)			
GENOTYPES	150	250	350	MEANS
Zinc concentration (ppm) in the shoots.				
5 RTx7078	105.0	88.0	105.0	99.3 A
7 BTx399	89.3	88.3	86.0	87.9 B
9 ATx399 x RTAM428	84.3	84.7	85.7	84.9 BC
14 SC0418-c	81.7	78.0	73.0	77.6 C
P Level Means	90.1 A	84.8 A	87.5 A	
Zinc concentration (ppm) in the roots.				
5 RTx7078	61.7	58.7	73.3	64.6 C
7 BTx399	70.3	68.7	78.3	72.4 AB
9 ATx399 x RTAM428	68.7	64.3	65.3	66.1 BC
14 SC0418-c	80.7	77.7	76.7	83.3 A
P Level Means	70.3 A	67.3 A	73.4 A	
Zinc uptake (ugm Zn/pot) in the shoots.				
5 RTx7078	320.6	337.2	407.9	355.2 A
7 BTx399	311.7	362.9	353.1	342.6 AB
9 ATx399 x RTAM428	351.3	380.9	357.0	363.1 A
14 SC0418-c	317.5	341.3	294.9	318.1 B
P Level Means	325.3 A	355.7 A	353.2 A	

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

Table 15 (continued)

GENOTYPES	P Levels (ppm P) 150	250	350	MEANS
Zinc uptake (ugm Zn/pot) in the roots.				
5 RTx7078	56.3	68.4	78.1	67.6 B
7 BTx399	83.7	122.5	148.7	118.3 A
9 ATx399 x RTAM428	107.1	124.5	126.2	119.3 A
14 SC0418-c	94.7	127.9	130.5	118.7 A
P Level Means	86.2	110.8 A	120.9 A	
Total (Roots + shoots) zinc uptake (ugm Zn/pot).				
5 RTx7078	376.9	405.6	486.1	422.8 B
7 BTx399	395.4	485.4	501.8	460.9 AB
9 ATx399 x RTAM428	458.4	505.4	483.2	482.3 A
14 SC0418-c	415.2	469.8	425.2	436.8 B
P Level Means	411.5 B	466.5 A	474.1 A	

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


ZINC TRANSLOCATION TO PLANT SHOOTS AS
INFLUENCED BY P - APPLICATION RATES
350 PPM P
250 PPM P
150 PPM P
86.00
84.00
82.00
80.00
78.00
76.00
74.00
72.00
70.00
68.00
ZN TRANSLOCATED (%)
14
07
09
05
GENOTYPE

were significant with 14 being significantly lower than 3 and 5 for overall mean Zn uptake .

Root uptake of zinc (Table 15) was significantly increased by application of 250 and 350 ppm P over 150 ppm P but no difference between these two rates . Genotype 5 was significantly lower in root zinc uptake than 9, 7, and 14 at all the three levels of P application . Total (roots + shoots) zinc uptake (Table 15) followed a similar pattern as observed for the roots alone .

High plant P content has been known to depress zinc translocation from roots to shoots . This is confirmed by the results in Fig. 6 and Table 16 in which a significant negative correlation between amount of Zn translocated and P levels was observed . Since the highest P rates were superior in increasing shoot P uptake, the observed response on zinc translocation confirms the antagonistic effects of P-Zn interaction reported by Lockman (1972), Matocha et al (1970), and Racz and Haluschak (1974) . Genotype 5 significantly translocated more zinc than 7, 9, and 14 . From tables 14, 13, and 15, it is evident that P uptake efficiency results in inefficient zinc translocation by the plants and that P-Zn interaction in plants is probably genetically controlled .

The ratios of total (roots + shoots) and shoots alone zinc uptake to P uptake (Table 16) followed similar pattern observed for the zinc translocation except that differences among genotypes were not significant for ratio of the total uptake of Zn to P .

Experiment VI - Influence of nitrogen sources on P uptake by five sorghum genotypes in a solution culture study .

Sources of nitrogen used had no significant effects on dry weights of shoots and roots or on total plant dry weights (Table 17), and differences in dry weights among the genotypes were not significant .

Table 16 Influence of P application rate on P-Zn ratios and zinc translocation within the plants of four sorghum genotypes.

GENOTYPES	P Levels (ppm) 150	250	350	MEANS
Zn translocation to shoots ($\frac{\text{mg Zn shoots}}{\text{mg total Zn}} \times 100$) %				
5 RTx7078	85.3	83.2	83.8	84.1 A
7 BTx399	78.8	74.7	70.3	74.6 B
9 ATx399 x RTAM428	76.6	79.4	73.9	75.3 B
14 SC0418-c	76.5	72.6	69.8	72.9 B
P Level Means	79.3 A	76.5 B	74.4 B	
P-Zn Ratio on total uptake ($\frac{\text{mg Zn}}{\text{mg P}}$)				
5 RTx7078	.011	.008	.008	.009 A
7 BTx399	.010	.008	.007	.008 A
9 ATx399 x RTAM428	.011	.008	.007	.009 A
14 SC0418-c	.011	.008	.007	.009 A
P Level Means	.011 A	.008 B	.007 B	
P-Zn Ratio on uptake in the shoots ($\frac{\text{mg Zn shoots}}{\text{mg P shoots}}$)				
5 RTx7078	.010	.007	.008	.008 A
7 BTx399	.009	.007	.006	.007 B
9 ATx399 x RTAM428	.009	.007	.006	.007 B
14 SC0418-c	.009	.006	.006	.007 B
P Level Means	.009 A	.007 B	.006 B	

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

Ammonium and the combination of ammonium plus nitrate sources significantly increased P concentrations in the shoots when compared to the nitrate source, but such differences were not significant in the root (Table 18) . Differences among genotypes were not significant for either shoot or root P concentrations . Shoot uptake of P was not significantly influenced by nitrogen source or genotype(Table 18) . The nitrate source was significantly better than both the ammonium and mixture of ammonium and nitrate in increasing root P uptake (Table 18) but differences among the genotypes were not significant . The significant differences among the nitrogen sources in root uptake of P indicate the important influence of nitrogen source in enhancing P uptake by the roots .

Amount of P translocated to the shoots (Table 18) was significantly influenced by nitrogen source . The ammonium and mixture of the ammonium and nitrate sources were superior to the nitrate source . The performance of the genotypes were similar. The higher average for the ammonium source, though not significantly different from that for the mixture of ammonium and nitrate , makes it logical to attribute the influence of nitrogen on P translocation in the plant to a specific physiological effect of the ammonium form of N .

Plant nitrogen concentrations and uptake were also determined and the data are available in Appendix Table 12 . The mixture of ammonium and nitrate source was significantly better than both the ammonium and nitrate sources in increasing nitrogen concentrations . Genotype 9 was significantly lower in mean N concentration tha 7, 3, 11, and 14 . The nitrogen sources and genotype effects were not significant for N uptake .

Acidity of the culture solution was measured each week prior to changing the solution and milliequivalents of change in hydrogen proton determined as shown in Table 19 . During the first week, milliequivalents

of hydrogen ions were recorded in the solutions for the three sources of nitrogen except for genotype 7 that gave a net release of hydroxyl ions with the ammonium and nitrate treatment . Interaction between genotype and N source was not significant . Differences in the acidity of the solutions among the nitrogen sources werw highly significant in the order $NH_4^+ > NO_3^- > NH_4^+ + NO_3^-$. This trend of results suggests the probability of the ammonium source being superior to the other two in acidifying the rhizosphere .

The effects of the nitrogen sources in scidifying the nutrient solutions observed during the first week was consistent throughout the experimental period with the ammonium alone having the greatest influence as indicated for the first week . However, during the 2nd, 3rd, and 4th weeks both the ammonium and the mixture of ammonium and nitrate sources consistently released hydrogen ions into solution while the nitrate maintained the release of hydroxyl ions . The net change in proton was calculated for ease of statistical analysis. Except for the 4th week genotype by nitrogen source interaction (Appendix) was highly significant. Differences among genotypes were significant following similar patterns through the four weeks period .

Generally, the acidifying effects of the N source due to plant growth activities, increased during the second week (Table 10) but decreased during the third week before rising again the 4th week of the study . With increased plant growth with time, the acidifying effect would be excepted to increase steadily through the four weeks . This may be influenced by some climatic factors, particularly cloudiness, which may have significant influence on the photosynthetic activities of the plants which are expected to be lower on cloudy days . The average weekly direct and diffuse solar radiation data obtained for the study period from the meterological section

Table 17 Effects of nitrogen source on plant dry matter production of five sorghum genotypes.

GENOTYPES	Nitrogen Source NH_4^+	NO_3^-	$NH_4^+ + NO_3^-$	MEANS
Shoot dry weights (gm/pot).				
3 ATx378 x RTx2536	2.0	2.6	3.2	2.6 A
7 BTx399	2.1	2.3	1.5	1.9 A
9 ATx399 x RTAM428	2.4	2.7	2.8	2.6 A
11 ATx378 x RTx7000	1.7	1.9	2.8	2.1 A
14 SC0418-c	1.7	1.3	1.9	1.6 A
N Source Means	2.0 A	2.2 A	2.4 A	
Roots dry weights (gm/pot).				
3 ATx378 x RTx2536	.6	.8	.6	.7 A
7 BTx399	.5	.7	.4	.5 A
9 ATx399 x RTAM428	.7	.7	.6	.7 A
11 ATx378 x RTx7000	.3	.5	.7	.5 A
14 SC0418-c	.3	.5	.5	.4 A
N Source Means	.5 A	.6 A	.6 A	
Total (Shoots + roots) dry weights (gm/pot).				
3 ATx378 x RTx2536	2.6	3.4	3.8	3.2 A
7 BTx399	2.6	2.9	1.8	2.4 A
9 ATx399 x RTAM428	3.1	3.4	3.3	3.3 A
11 ATx378 x RTx7000	2.5	2.4	3.5	2.8 A
14 SC0418-c	2.0	1.7	2.4	2.0 A
N Source Means	2.6 A	2.8 A	2.9 A	

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

Table 18 Effects of nitrogen source on plant phosphorus concentration and uptake of five sorghum genotypes.

GENOTYPES	Nitrogen Source NH_4^+	NO_3^-	$NH_4^+ + NO_3^-$	MEANS
Phosphorus concentration (%) in the shoots.				
3 ATx378 x RTx2536	.86	.68	.71	.75 A
7 BTx399	.95	.75	1.03	.91 A
9 ATx399 x RTAM428	.88	.71	.80	.80 A
11 ATx378 x RTx7000	1.00	.73	.81	.84 A
14 SC0418-c	.89	.79	.87	.85 A
N Source Means	.92 A	.73 B	.84 A	
Phosphorus concentration (%) in the roots.				
3 ATx378 x RTx2536	.61	1.13	.97	.90 A
7 BTx399	.63	1.17	1.17	.99 A
9 ATx399 x RTAM428	.79	.98	1.29	1.02 A
11 ATx378 x RTx7000	1.07	1.21	.93	1.07 A
14 SC0418-c	1.09	1.72	1.21	1.34 A
N Source Means	.84 A	1.24 A	1.12 A	
Phosphorus uptake (mg P/pot) in the shoots.				
3 ATx378 x RTx2536	17.41	17.40	22.42	19.07 A
7 BTx399	20.03	16.47	13.81	16.77 A
9 ATx399 x RTAM428	20.78	19.25	20.67	20.23 A
11 ATx378 x RTx7000	16.87	13.89	19.81	16.85 A
14 SC0418-c	15.81	17.48	16.45	16.37 A
N Source Means	18.05 A	16.90 A	18.63 A	

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

Table 18 (continued)

GENOTYPES	Nitrogen Source NH_4^+	NO_3^-	$NH_4^+ + NO_3^-$	MEANS
Phosphorus uptake in the roots (mg P/pot).				
3 ATx378 x RTx2536	3.60	8.20	5.84	5.88 A
7 BTx399	3.00	7.29	3.63	4.64 A
9 ATx399 x RTAM428	5.53	6.09	5.03	5.82 A
11 ATx378 x RTx7000	3.21	6.39	5.16	4.92 A
14 SC0418-c	3.27	6.87	5.53	5.22 A
N Source Means	3.72 B	7.13 A	5.04 B	
Total (shoots + roots) P uptake (mg P/pot).				
3 ATx378 x RTx2536	21.26	25.60	28.26	25.05 A
7 BTx399	23.03	23.76	17.44	21.41 A
9 ATx399 x RTAM428	26.31	26.13	25.70	26.05 A
11 ATx378 x RTx7000	20.08	19.96	24.97	21.67 A
14 SC0418-c	18.45	17.13	21.98	19.19 A
N Source Means	21.83 A	22.52 A	23.67 A	
Phosphorus translocated ($\frac{\text{mg P shoots}}{\text{mg total P}} \times 100$) %				
3 ATx378 x RTx2536	81.50	68.20	79.32	76.34 A
7 BTx399	86.97	69.20	75.89	77.35 A
9 ATx399 x RTAM428	79.00	73.69	79.76	77.48 A
11 ATx378 x RTx7000	84.12	69.56	81.09	78.26 A
14 SC0418-c	82.44	59.41	75.29	72.38 A
N Source Means	82.80 A	68.01 A	78.27 A	

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

of the Department of Physics were 162.6, 183.4, 153.1, and 297.7 gm-cal per cm^2 for the four weeks, respectively . This trend follows the same pattern noted for the acidity measurements (Table 19) suggesting that the amount of solar radiation obtained during the third week may accord partial explanation to the anomaly in acidity with time .

When time was introduced in the data as a third independent variable, its effect was highly significant . All the possible interactions such as genotype by time, N source by time and genotype by time by N source were highly significant suggesting that the ability of any genotype to increase solution acidity, with any N source, is highly influenced by stage of plant growth (time) .

The weekly NH_4^+-N and NO_3^--N determinations in the solutions with the mixture of NH_4^+ plus NO_3^- were to help explain the degree of increase acidity the potential P efficient genotypes might have on the mixture as compared with the potential P inefficient genotypes . The larger the NH_4^+-N remaining in solution relative to the NO_3^--N , the greater the increase acidity expected for that genotype . This would help conclude more confidently which of the two N sources has the greater tendency to increase acidity of the rhizosphere.

Unfortunately, the differences among the genotypes on the NH_4^+-N and NO_3^- (data not reported) were not significant for any of the four weeks . Since the concentrations of both the NH_4^+-N and NO_3^- -N in the solutions were always equal, the larger ratios recorded for the 2nd, 3rd, and 4th weeks indicate the possibility of sorghum prefering the NO_3^- source of N to the NH_4^+ . When time effect was observed, especially for the NH_4^+-N: NO_3^- ratio, he following overall means were recorded; 1st week 0.02C, 2nd week 1.79B, 3rd week 2.65A, 4th week 2.81A . The significant differences observed with time further indicate rather inconclusively the preference of

Table 19 Influence of plant nutrition on acidity of culture solution as measured be milliequivalence of change in proton .

GENOTYPES	Nitrogen Source NH_4^+	NO_3^-	$NH_4^+ + NO_3^-$	MEANS
Milliequivalence of change in proton. 1st Week.				
3 ATx378 x RTx2356	.484 A	.124 A	.084 AB	.231 AB
7 BTx399	.465 A	.163 A	-.104 C	.175 CD
9 ATx399 x RTAM428	.504 A	.133 A	.165 A	.267 A
11 ATx378 x RTx7000	.287 B	.099 A	.021 B	.135 D
14 SC0418-c	.455 A	.129 A	.035 B	.206 BC
N Source Means	.439 A	.129 B	.040 C	
Millieq. 2nd Week.				
3 ATx378 x RTx2536	12.95 A	-4.09 C	0.75 A	2.93 AB
7 BTx399	11.90 A	-4.85 C	0.50 A	2.52 ABC
9 ATx399 x RTAM428	13.80 A	-4.95 C	1.10 A	3.32 A
11 ATx378 x RTx7000	7.10 B	-3.05 B	0.85 A	1.63 C
14 SC0418-c	7.60 B	-1.65 A	0.45 A	2.13 BC
N Source Means	10.67 A	-3.88 C	0.73 B	
Millieq. 3rd Week.				
3 ATx378 x RTx2536	1.798 A	-0.592 A	.287 A	.498 A
7 BTx399	1.729 A	-0.397 A	.183 A	.505 A
9 ATx399 x RTAM428	1.751 A	-0.565 A	.267 A	.484 A
11 ATx378 x RTx7000	0.850 B	-0.386 A	.277 A	.247 B
14 SC0418-c	0.914 B	-0.376 A	.148 A	.229 B
N Source Means	1.408 A	-0.463 C	.232 B	
Millieq. 4th Week.				
3 ATx378 x RTx2536	5.76	-1.43	.67	1.67 A
7 BTx399	5.76	-1.12	.39	1.44 A
9 ATx399 x RTAM428	4.44	-1.00	.59	1.34 A
11 ATx378 x RTx7000	4.56	-0.87	.65	1.45 A
14 SC0418-c	4.35	-0.64	.41	1.37 A
N Source Means	4.83 A	-1.01 C	.54 B	

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

NH_4^+-N to NO_3^--N during the early stage (1st week) of sorghum growth.

Efficiency of phosphorus uptake is known to be related to the ability of the plant to acidify the root medium by releasing hydrogen ions in the rhizosphere . Genotypes 3 and 9, which had been reported in earlier studies to perform well in their uptake of phosphorus, significantly acidified the solution (Table 19) better than 11 and 14 . Although differences among the genotypes in their efficiency of P uptake were not significant for this study(Table 18), a relationship between the high averages recorded for genotypes 3 and 9 and their dignificant acidifying effect of the root medium makes it logical to conclude that P efficiency may relate to the plants' ability to release hydrogen ions into the rhizosphere . This inference tends to confirm the observations of McLachlan (1976) associating the greater P uptake by buckwheat to its ability to acidify the root medium due to ion exchanged for cations taken up by the plant roots .

The lack of statistically significant differences among the sorghum genotypes in their uptake of phosphorus in this study,indicates that P uptake may not be genetically controlled . However, the results that generated the conclusion in this study might be influenced by certain obscure factors in the methodology of the study since the conclusions from Expriments II and V suggested otherwise .

SUMMARY AND CONCLUSIONS

The results of the investigations revealed the differential ability of sorghum genotypes to absorb soil phosphorus efficiently. Phosphorus uptake efficiency was found to be influenced by nitrogen form and method of nitrogen placement in relationship to phosphorus, soil pH, and ability of the genotypes to acidify the rhizosphere .

The significant differences observed among genotypes in the amount of phosphorus absorbed from the soil indicated that their response to P may be genetically controlled . The lack of significant differences among the genotypes intheir P uptake efficiency in terms of dry matter production (Expt. I) may be related to a possible narrow genetic base available to breeders during the breeding program or similar environments as previously observed by Jordan et al 1979 in a similar study .

The good performance of some genotypes in both P and Zn use efficiency observed in Experiment II indicated that P uptake efficiency may not necessarily result in Zn uptake inefficiency . The significant differential performance of the genotypes in Zn uptake efficiency suggests that this characteristic (Zn use efficiency) may be genetically controlled .

The significant depression of plant phosphorus concentration due to liming was evident of the influence of soil pH on plant phosphorus nutrition. Though performance of the genotypes was similar, the important influence of phosphorus level was indicated by the significant effects of the genotype by P level interaction . The significant P level by pH interaction was an indication that the influence of liming (soil pH effects) on the phosphorus nutrition of the genotypes is dependent on available soil P level.

Putting nitrogen together in the same band with the phosphorus was found to be more effective in increasing plant phosphorus concentration and uptake than broadcasting the N and banding P .

The superiority of the lowest P rate over the other two P rates (Expt. V) in translocating absorbed zinc from the roots to the plant shoots confirmed the antagonistic effects of P on Zn in the plants . Phosphorus efficiency was observed to result in inefficient zinc translocation which is believed to be due to dilution effect in the P efficient genotypes . The significant differences among the genotypes indicated the possibility of P-Zn interaction in sorghum to be genetically controlled .

The important influence of the form of nitrogen applied in enhancing P uptake by the plants was shown by the superiority of both the NH_4^+ and the mixture of $NH_4^+ + NO_3^-$ forms over the nitrate form . The lack of significant difference between the NH_4^+ and the mixture of $NH_4^+ + NO_3^-$ might be due to the ability of the sorghum plant to utilize either the NH_4^+ or $NO3^-$ forms of nitrogen . This was confirmed by the similar influence of both the nitrate and the mixture of ammonium and nitrate forms observed on the efficiency of P use in shoot dry weight production . The poor performance of the ammonium form could be related to its acidic effect, supporting the reasoning of many scientists for their preference for a mixture of NH_4^+ and NO_3^- as the nitrogen source in culture solution studies .

A few genotypes, particularly ATx378 x RTx2536 maintained their good performance in P uptake in all the investigations . The lack of significant differences among ATx378 x RTx2536, RS 610 and ATx399 xRTAM428 - all hybrids - in most of the separate investigations, and the similarity of genotypes 6 and 9 with others in some cases, might not be unrelated to the

narrow genetic base available to the breeders during the breeding program or similar environments (Jordan et al - 1979) . Relating the significant increase in acidity (Table 19) of the rhizosphere of genotype ATx378 x RTx2536 with its P uptake efficiency (Tables 12, 14, and App. Table 5), it may be logical to infer that Puptake efficiency is influenced by the ability of the genotype to acidify the rhizosphere due to H^+ ion exchange for cation taken up which may be influenced by root characteristics.

The results of these separate investigations highlighted, although partially, the invaluable contribution of the breeding of P efficient sorghum genotypes in improving their phosphorus nutrition under limiting available soil P conditions .

LITERATURE CITED

Abbott J.L. and Tucker T.C. 1973. Persistence of manure phosphorus availability in calcareous soil. Soil Sci. Soc. Am. Proc. 37 : 60-63.

Abbott J.L. 1978. Importance of the organic phosphorus fraction in extracts of calcareous soil. Soil Sci. Soc. Am. Proc. 42 : 81-85.

Adriano D.C. 1970. P-Zn interaction in Zea mays and phaseolus vulgaris. PHD Dissertation, Kansas State University, Manhattan, Kansas.

Adriano D.C, Paulsen G.M, and Murphy L.S 1971. Phosphorus-Iron and phosphorus-Zinc relationship in corn (Zea mays L.) seedlings as affected by mineral nutrition. Agron. J. 63 : 36-37.

Ajakaiye C.O. 1979. Effect of phosphorus on growth and Iron nutrition of millet and sorghum. Plant and Soil. 51 : 551-561.

Andrew C.S. and Robins M.F. 1971. The effect of phosphorus on the growth, chemical composition, and critical phosphorus percentages of some Tropical Pasture grasses. Aust.J. Agric Res. 22 : 693-706.

Asher C.J. and Loneragan J.F. 1967. Response of plants to Phosphate concentration in solution culture : I. Growth and phosphorus content. Soil Sci. 103 : 225-233.

Baker D.E, Jarrell A.E, Marshall L.E and Thomas W.I. 1970. Phosphorus uptake from soils by corn hybrids selected for high and low phosphorus accumulation. Agron.J. 62 : 103-106.

Baligar V.C and Barber S.A. 1979. Genotypic differences of corn for ion uptake. Agron.J. 71 : 870-873.

Barrow N.J. 1975. The response to phosphate of two annual pasture species. II. The epecific rate of uptake of phosphate, its distribution and use for growth. Aust. J. Agric. Res. 26 : 145-156.

Barrow N.J. 1975. The response to phosphate of two annual pasture species. I. Effect of the soil's ability to adsorb phosphate on comparative phosphate requirement. Aust. J. Agric. Res. 26 : 137-143.

Bartlett R.J. and Riego D.C. 1972. Toxicity of hydroxy aluminum in ralation to pH and phosphorus . Soil Sci. 114 : 194-200.

Bennett W.F., Pesek J., and Hanway J.J. 1964. Effect of nitrate and ammonium on growth of corn in nutrient solution sand culture. Agron. J. 56 : 342-345.

Bingham F.T. 1963. Relation between phosphorus and micro-nutrients in plants. Soil Sci. Soc. Amer. Proc. 27 : 389-391.

Blair G.J, Mamaril C.P, and Miller M.H. 1971. Influence of nitrogen source on phosphorus uptake by corn from soils differing in pH. Agron. J. 63 : 235-238.

Boawn L.C. and Brown J.C. 1968. Further evidence for a P-Zn imbalance in plants. Soil Sci. Soc. Amer. Proc. 32 : 94-97.

Bole J.B. 1973. Influence of root hairs in supplying soil phosphorus to wheat. Can. J. Soil Sci. 53 : 169-175.

Bole J.B. and Freyman. 1975. Response of irrigated and sweet corn to nitrogen and phosphorus fertilizers in Southern Alberta. Can. J. Soil Sci. 55 : 137-143.

Breteler H. 1973. A comparison between ammonium and nitrate nutrition of young sugar-beet plants grown in nutrient solutions at constant acidity. I. Production of dry matter, ionic balance and chemical composition. Neth. J. Agric. Sci. 22 : 227-244.

Breteler H. and Smit A.L. 1974. Effect of ammonium nutrition on uptake and metabolism of nitrate in wheat. Neth. J. Agric. Sci. 22 : 73-81.

Bromefield S.M. 1960. Some factors affecting the solubility of phosphates during the microbial decomposition of plant material. Aust. J. Agric. Res. 3 : 304-316.

Brown J.C. and Jones W.E. 1975. Phosphorus efficiency as related to iron inefficiency in sorghum. Agron. J. 67 : 468-472.

Brown J.C and Jones W.E. 1977. Fitting plants nutritionally to soils. III. Sorghum. Agron.J. 69 : 410-414.

Brown J.C, Clark R.B, and Jones W.E. 1977. Efficient and inefficient use of phosphorus by sorghum. Soil Sci. Soc. Amer. Proc. 41 : 747-750.

Bruetsch T.F. and Estes G.O. 1976. Genotype variation in nutrient uptake efficiency in corn. Agron.J. 68 : 521-523.

Buss G.R., Lutz J.A, Jr., and Hawkins G.W. 1975. Effect of soil pH and plant genotype on element concentration and uptake by Alfalfa. Crop Sci. 15 : 614-617.

Calder F.W. and Macleod L.B. 1974. Effects of soil pH and NPK fertilization on yield and quality of two barley cultivars. Can.J. Soil Sci. 54 : 1-6.

Carroll M.D. and Loneragan J.F. 1969. Response of plant species to concentrations of zinc in solution . II. Rates of zinc absorption and their relation to growth. Aust. J.Agric.Res. 20 : 457-463.

Chaudry F.M, Hussain F., and Rashid A. 1977. Micronutrient availability to cereals from calcareous soils. Plant and Soil. 47 : 297-302.

Chien S.H. 1978. Reactions of phosphate rocks, rhenania phosphate, and superphosphate in acid soil. Soil Sci. Soc. Amer. Proc. 42 : 705-708.

Chu W.K. and Chang S.C. 1966. Surface acidity of inorganic soil phosphorus. Soil Sci. 101 : 459-464.

Clark R.B. 1970. Differential response of maize inbreds to zinc. Agron.J. 70 : 1057-1060.

Clark R.B. and Brown J.C. 1974. Differential phosphorus uptake by phosphorus-stressed corn inbreds. Crop Sci. 14 : 505-508.

Clark R.B., Maranville J.W., and Gorz H.J. 1978. Phosphorus efficiency of sorghum grown with limited phosphorus. Proc. 8th International Colloq. on plant analysis and fertilizer problems.

De R. 1974. Cultural Practices for maize, sorghum and millets. Proceedings of the first FAO/SIDA seminar on improvement

and production of field food crops for plant scientists from Africa and the Near East at the Indian Agric. Res. Inst., New Delhi, India.

Duncan W.G. and Ohlrogge A.J. 1958. Principles of nutrient uptake from fertilizer bands. II. Root development in the band. Agron. J. 50 : 605-608.

Edwards J.H. and Barber S.A. 1976. Phosphorus uptake rate of soybean roots as influenced by plant age, root trimming, and solution P concentration. Agron. J. 68 : 973-975.

Ellis Roscoe,Jr, Davis J.F. and Thurlow D.L. 1964. Zinc availability in calcareous Michian soils as influenced by phosphorus level and temperature. Soil Sci. Amer. Proc. 28 : 83-86.

Engelstad O.P. and Allen S.E. 1971. Effect of form and proximity of added N on crop uptake of P. Soil Sci. 112 : 330-337.

Enwezor W.O and Moore A.W. 1966. Phosphorus Status of some Nigerian soils. Soil Sci. 102 : 322-328.

Findlay W.I and Fulton J.M. 1964. The nutrient composition of Hybrid corn as influenced by fertilization. II. The Phosphorus percentage. Can.J.Soil Sci. 44 : 217-222.

Fuehring H.D., and Finkner R.E. 1974. Grain sorghum production with different nutrients populations, and irrigation frequencies. Bulletin, New Mexico State University. Agric. Expt. Station 613 : pp 24.

Gerloff G.C. 1976. Plant efficiencies in the use of nitrogen phosphorus, and potassium. Proceedings of workshop on plant adaptation to mineral stress in problem soils. Beltsville, Maryland. Nov. 22-23. pp 161-174.

Griffin G.F. and Hanna W.J. 1967. Phosphorus fixation and profitable fertilization. I. Fixation in New Jersey soils. Soil Sci. 103 : 202-208.

Grunes D.L., Viets F.G., Jr., and Shih S.H. 1958. Proportionate uptake of soil and fertilizer phosphorus by plants as affected by nitrogen fertilization: I. Growth Chamber Experiment. Soil Sci. Soc. Amer. Proc. 22 : 43-48.

Halim A.H, Wassom C.E. and Ellis R.Jr. 1968. Zinc deficiency symptoms and zinc and phosphorus interactions in several

strains of corn (Zea mays L.). Agron.J. 60 : 267-271.

Hamilton A. Herman and Lathwell D.J. 1964. Investigation of some factors important in differential crop response to diammonium and monocalcium phosphates. Can.J.Soil Sci. 44 : 14-21.

Hedge B.P. and Relwani L.L. 1974. Effect of different levels of nitrogen and zinc on yield and quality of jowar (sorghum bicolor) fodder. Indian J.Agric. Res. 8 : 17-24.

Herrera D. and Suarez J.J. 1974. The effect of Zn at high P levels on the yield of grain sorghum (sorghum vulgare). Cuban Journal Agric. Sci. 8 : 273-278.

Herron G.M and Erhart A.B. 1960. Effects of nitrogen and phosphorus fertilizers on the yield of irrigated grain sorghum in Southwestern Kansas. Agron.J. 52 : 499-501.

HSU PA HO . 1965. Fixation of phosphate by Aluminum and iron in acidic soils. Soil Sci. 99 : 398-402.

Jacques G.L., Vanderlip R.L., and Whitney D.A. 1975. Growth and nutrient accumulation and distribution in grain sorghum. I. Dry matter production and Ca and Mg uptake and distribution. Agron.J. 67 : 607-616.

Jordan W.R., Miller F.R., and Morris D.E. 1979. Genetic variation in root and shoot growth of sorghum in hydroponics. Crop Sci. Soc. Amer. 19 : 468-472.

Kang B.T. and Osiname O.A. 1979. Phosphorus response of of maize grown on alfisols of southern Nigeria. Agron.J. 71 : 873-877.

Kapoor O.P. 1976. Effect of foliar application of plant nutrients and planofix on the seed yield of sudangrass, sorghum sudanense L. var. "piper". Pantnagar J. of Res. 2 : 254.

Keay J., Biddiscombe E.F., and Ozanne P.G. 1970. The comparative rates of phosphate absorption by eight annual pasture species. Aust.J. Agric. Res. 21 : 33-44.

Khan D.H. 1969. Response of sweet corn and rice to phosphorus, zinc, and calcium carbonate on acid Glenview soil of California. Soil Sci. 108 : 424-428.

Khan A.A., and Zende G.K. 1976. Correlation of soil-test values with the response of maize and sorghum to available Zn and P. Indian J. Agric. Sci. 46 : 259-265.

Langin E.J., Ward R.C., Olson R.A., and Rhoades H.F. 1962. Factors responsible for poor response of corn and grain sorghum to phosphorus fertilization . II. Lime and P placement effects on P-Zn relations. Soil Sci. Soc. Amer. Proc. 26 : 574-578.

Larsen Sigurd. 1974. Phosphorus - a limiting factor in future food production. Neth. J. Agric. Sci. 22 : 270-274.

Levesque M. and Hanna W.J. 1966. Downward movement of phosphorus and Iron in some podzolic soils of New Jersey. Can. J. Soil Sci. 46 : 53-60.

Lewis E.T and Racz G.J. 1969. Phosphorus movement in some calcareous and non-calcareous Manitoba soils. Can. J. Soil Sci. 49 : 305-312.

Lipsett J. 1964. The phosphorus content and yield of grain of different wheat varieties in relation to phosphorus deficiency. Aust.J. Agric. Res. 15 : 1-8.

Lockman R.B. 1972. Mineral composition of grain sorghum plant samples. I. Comparative analysis with corn at various stages of growth and under different environments. Comm. in Soil Sci. and plant Analysis 3,4, 271-281.

Lockman R.B. 1972. Mineral composition of grain sorghum plant samples. Suggested nutrient sufficiency limits at various stages of growth. Communications in Soil Sci. and Plant An. 3 vol. 4 295-303.

Loneragan J.F. - Crop Tolerance to Suboptimal Land conditions. p 329-343. Publication of ASA, SSSA, CSSA. (1976).

Loneragan J.F., Grove T.S., A.D. Robson, and Snowball K. 1979. Phosphorus toxicity as a factor in zinc-phosphorus interactions in plants. Soil Sci. Soc. Amer. Proc. 43 : 966-972.

Long F.L., Langdale G.W., and Myhre D.L. 1973. Response of an Al-tolerant and Al-sensitive genotype to lime, P, and K on three Atlantic Coast Flatwoods Soils. Agron. J. 65 : 30-36.

Lorenz O.A. and Johnson C.M. 1953. Nitrogen fertilization as related to the availability of phosphorus in certain California soils. Soil Sci. 75, 119-129.

Lutz J.A., Jr., Genter C.F. and Hawkins G.W. 1972. Effect of soil pH on element concentration and uptake by maize. I. P, K, Ca, Mg and Na. Agron. J. 64 : 581-583.

Mamaril C. P. and Miller M.H. 1970. Effects of ammonium on the uptake of phosphorus, sulfur, and rubidium by corn. Agron. J. 62 : 753-758.

Maranville J.W., Ross W.M. and R.B. Clark. 1977. Differential phosphorus efficiency in sorghum. Proc. 10th Grain sorghum Res. Conf., Wichita, Kansas. p. 1-2.

Matocha J.E., Conrad B.E., Reyes E.L., and Thomas G.W. 1970. Influence of Zn, Fe, K, and P on yield and chemical composition of grain sorghum. Progress Report- Texas A & M University, Texas Agric. Experiment Station. PR - 2839 Oct.

Mclachlan K.D. 1976. Comparative Phosphorus responses in plants to a range of available phosphorus situations. Aust.J. Agric. Res. 27 : 323-341.

Mendez J. and Kamprath E.J. 1978. Liming of Latisols and the effect on phosphorus response. Soil Sci. Soc. Amer. Proc. 42 : 86-88.

Mikesell M.E., Paulsen G.M, Ellis R. Jr., and Cassady A.J. 1973. Iron utilization by efficient and inefficient sorghum lines. Agron. J. 65 : 77-80.

Miller M.H and Ohlrogge A.J. 1958. Principles of nutrient uptake from fertilizer bands. I. Effect of placement of nitrogen fertilizer on the uptake of band-placed phosphorus at different soil phosphorus levels. Agron.J. 50 : 95-97.

Miller M.H. 1965. Influence of $(NH_4)_2SO_4$ on root growth and P absorption by corn from fertilizer band. Agron.J. 57 : 393- 396.

Miller M.H., Mamaril C.P, and Blair G.J. 1970. Ammonium effects on phosphorus absorption at the soil-root interface. Agron. J. 62 : 524-527.

Miller M.H. 1971. Effects of nitrogen on phosphorus absorption by plants. Proceedings of an institute held at Virginia polytechnic Institute and State University, July 5-16.

Millikan C.R. 1963. Effects of different levels of Zn and P on the growth of subterranean clover (Trifolium subterraneum L.). Aust.J. Agric. Res. 14: 180-205.

Minotti P.L, Williams C.D and Jackson W.A. 1969. Nitrate uptake by wheat as influenced by ammonium and other cations. Crop Sci. 9, 9-14.

Mortvedt J.J and Terman G.L. 1978. Nutrient effectiveness in relation to rates applied for pot experiments : II. Phosphorus source. Soil Sci. Soc. Amer. Proc. 42 : 302-306.

Mugwira L.M., Elgarwhary S.M, and Patel K.I. 1976. Differential tolerances of triticale, wheat, rye, and barley to aluminum in nutrient solution. Agron.J 68 : 782-787.

Olson R.A and Drier A.F. 1956. Nitrogen, a Key factor in fertilizer phosphorus efficiency. Soil Sci. Soc. Amer. Proc. 20 : 509-514.

Olson R.A, Dreir A.F, Hoover C.A and Rhoades H.F. 1962. Factors responsible for poor response of corn and grain sorghum to P fertilization: I. Soil P level and climatic factors. Soil Sci. Soc. Amer. Proc. 26 : 571-574.

Omanwar P.K and Robertson J.A. 1970. Movement of phosphorus to barley roots growing in soil. Can. J. Soil Sci. 50 : 57-64.

Omotoso T.I. 1971. Organic phosphorus contents of some cocoa growing soils of southern Nigeria. Soil Sci. 112 : 195-199.

Osiname O.A, Kang B.T, Schulte E.E, and Corey R.B. 1973. Zinc response of maize (Zea mays L.) grown on sandy inceptisols in Western Nigeria. Agron. J. 65 : 875-877.

Ozanne P.G, Kirton D.J, and Shaw T.C. 1961. The loss of phosphorus from sandy soils. Aust. J. Agric. Res. 12 : 409-412.

Ozanne P.G, and Ann Petch. 1978. Effect of species and cultivation on the responses to phosphate of annual pastures and crops. Aust. J Agric. Res. 29 : 225-233.

Paton D.F, and Loneragon J.F. 1960. An effect of lime on residual phosphorus in soil. Aust. J. Agric. Res. 4 : 524-529.

Pauli A.W, Roscoe Ellis,Jr. and Moser H.C. 1968. Zinc uptake and translocation as influenced by phosphorus and calcium carbonate. Agron. J. 60 : 394-396.

Paulsen G.M. and Rotimi O.A. 1968. Phosphorus - Zn interaction in two soybean varieties differing in sensitivity to phosphorus nutrition. Soil Sci. Soc. Amer. Proc. 32 : 73-76.

Quereshi. R.H., Jenkins D.A. and R.I. Davies. 1978. Electron probe microanalytical studies of phosphorus distribution with soil fabric. Soil Sci. Soc. Amer. Proc. 42 : 698-703.

Racs G.J. and Haluschak P.W. 1974. Effects of phosphorus concentration on Cu, Zn, Fe and Mn utilization by wheat. Can. J. Soil Sci. 54 : 357-367.

Ramanath B., Javaram N.S., Mittal S.P., and Verma B. 1973. Effect of advancing the sowing date and placement of fertilizer on rainfed jowar in the black cotton soils of Bellary tract. Current Research. 9 : 70-73.

Ravikovitch S., Margolin M., and Navrot J. 1968. Zinc availability in calcareous soils: I. Comparison of chemical extraction methods for estimation of plant " Available " zinc. Soil Sci. 105 : 57-61.

Recommended Chemical Soil Test Procedures for the North Central Region. A North Central Regional Publication No 221, Bulletin No 499 - North Dakota Agricultura Experiment Station, North Dakota State University - Fargo, North Dakota 58102.

Riley D. and Barber S.A. 1971. Effect of ammonium and nitrate fertilization on phosphorus uptake as related to root-induced pH changes at the root-soil interface. Soil Sci. Soc. Amer. Proc. 35 : 301-306.

Robertson W.K, Smith P.M, Ohlrogge A.J. and Kinch D.M. 1954. Phosphorus utilization by corn as affected by placement and nitrogen and potassium fertilization. Soil Sci. 77 : 219-226.

Saeed M. and R.L. Fox. 1979. Influence of phosphate fertilization on zinc adsorption by tropical soils. Soil Sci. Soc. Amer. Proc. 43 : 683-686.

Schenk M.K and S.A. Barber. 1979. Phosphate uptake by corn as affected by soil characteristics and root morphology. Soil Sci. Soc. Amer. Proc. 43 : 880-883.

Schenk M.K and Barber S.A. 1979. Root characteristics of corn genotypes as related to P uptake. Agron. J. 71 : 921-924.

Schield S.J., Murphy L.S. , Herron G.M, and Gwin R.E Jr. 1978. Comparative performance of polyphosphate fertilizers for row crops. Comm. in Soil Sci. and plant analysis. 9 : 47-58.

Sharma K.C., Krantz B.A, Brown A.L and Quick J. 1968. Interaction of Zn and P in top and root of corn and tomato. Agron. J. 60 : 453-456.

Sheard R.W. 1974. Nitrogen enhancement of surface applied fertilizer phosphorus uptake by forage species. Can. J. Soil Sci. 54 : 89-104.

Shelton J.E.and Coleman N.T. 1968. Inorganic phosphorus fractions and their relationship to residual value of large applications of phosphorus on high phosphorus fixing soils. Soil Sci. Soc. Amer. Proc. 32 : 91-94.

Shukla U.C, Arora S.K, Zile Singh, Prasad K.G, and Safaya N.M. 1973. Differential susceptibility in some sorghum (sorghum vulgare) genotypes to zinc deficiency in soil. Plant and Soil 39 : 423-427.

Shukla U.C, and Raj Hans. 1976. Zinc response in corn as influenced by genetic variability. Agron. J. 68 : 20-22.

Smilde K.W, Koukoulakis P, and Luit B. van. 1974. Crop response to phosphate and lime on acid sandy soils high in zinc. Plant and Soil 41 : 445-457.

Smith D.T, and Clark N.A. 1968. Effect of soil nutrients and pH on nitrate nitrogen and growth of pearl millet (Pennisetum typhoides (Burm.) Staph and Hubbard) and sudangrass (sorghum sudanese (piper) staph).Agron. J. 60 : 38-40.

Sumner M.E. 1979. Response of Alfalfa and sorghum to lime and P on highly weathered soils. Agron. J. 71 : 763-766.

Takkar P.N, Mann M.S, Bansal R.L, Randhawa N.S, and Singh Hardev. 1976. Yield and uptake response of corn to zinc as influenced by phosphorus fertilization. Agron. J. 68 : 942-946.

Thien S.J, and McFee W.W. 1970. Influence of nitrogen on phosphorus absorption and translocation in Zea mays. Soil Sci. Soc. Amer. Proc. 34 : 87-90.

Thompson C.A. 1974. Fertilizing dryland grain sorghum on upland soils in the 20-26 inch rainfall area in Kansas. Bulletin, Agric. Expt. Station, Kansas State University, No 579.

Walker M.E, Marchant W.H, and Ethredge W.J. 1975. Effects of soil pH on forage yield, and chemical composition of sorghum and millet. Agron. J. 67 : 191-192.

Ward R.C., Langin E.J, Olson R.A., and Stukenholtz D.D. 1963. Factors responsible for poor response of corn and sorghum to phosphorus fertilization : III. Effects of soil compaction moisture level and other properties on P-Zn relations. Soil Sci. Soc. Amer. Proc. 27 : 326-330.

Wild A. 1958. The phosphate content of Australian soils. Aust. J. Agric. Res. 2 : 193-204.

Yates R.A. 1964. Yield depression due to phosphate fertilizer in sugar-cane. Aust. J. Agric. Res. 15 : 537-547.

Yaw Ahenkorah. 1968. Phosphorus-retension capacities of some cocoa-growing soils of Ghana and their relationship with soil properties. Soil Sci. 105 : 24-30.

APPENDIX

Procedures for Plant Tissue Testing

J.L. Demeteric
(1964-1966, 1967-1969)

PERCHLORIC ACID WET ASHING- for Zn,Cu, Fe, Mn, Ca, Mg, P and K- based on the procedure outlined by E.B. Earley, "Oxidation of plant material with a mixture of nitric acid, perchloric acid, and water".

Reagents needed:

1. Ternary digestion mixture (1:1:1 ration) - 70% $HClO_4$-Conc. HNO_3 - deionized distilled H_2O.
2. o.1 N HCl- 18 liter stock solution-to dissolve residue and make up to volume.

Glassware and equipment needed:

1. Automatic delivery buret to dispense ternary mixture
2. 200-ml tall beakers
3. Ribbed-watch glasses to fit 200-ml beakers
4. Polyethylene tipped policeman
5. Filtering rack
6. Whatman 42 filter paper
7. Polyethylene bottles to collect and store sample filtrate
8. Polyethylene wash bottles for deionized distilled water and 0.1 N HCl.

   Avoid use of rubber (zinc contamination) when working with microelements.
9. 25 and/or 50-ml volumetric flasks

Procedure:

1. Using an analytical balance, weigh 1.000 g. of ground plant tissue (previously dried at 70° C overnight) and transfer to 200-ml tall beakers.

2. Slowly add 45-ml of ternary mixture, cover with watch glass and place on hot plate previously turned on for at least 30 minutes at the 2 mark (12" x 24" hot plate in Waters 246).

   When all samples are on hot plate (about 50 when using tall-form 200-ml beakers) turn temperature control knob to a position between 5 and 6. (Note:- temperature knob control settings are based on hot plate used in Waters 246 - settings for other hot-plates must be determined).

   Let sample digest until straw yellow (30 min. to 1 hour)

3. Flip hot plate switch to OFF position when samples turn yellow.

   Using a crucible tong, lift each beaker, swirling it while keeping the watch glass in place with one finger. (This is to wash down plant material sticking on the side of the beaker).

   Put beaker aside (not on hot plate) to cool for 5 minutes or until all beakers are removed from hot plate.

   When beakers are sufficiently cool - wash down watch glass and the inner side of tall beaker with deionized distilled water.

   Place open beaker on top of hot plate, and when all beakers are in place flip hot plate switch to ON (hot plate temperature control knob still between 5 and 6).

4. Evaporate to complete dryness (2-3 hours).

5. Remove beakers and let cool for 2-3 minutes.

   Using a polyethylene wash bottle, add 10-20 ml of .1 N HCl - taking care to wash down residues on the sides of the beaker.

   Place on hot plate for 5 to 10 min. Boil gently to disintegrate residue.

   Remove beakers from hot plate and cool.

6. Using Whatman 42 filter paper - filter solution into polyethylene bottles.

   This is the stock solution to be used for Cu, Zn, Fe, Mn, Cu, Mg, K and P determinations.

7. Carry a blank (everything minus sample) for each set of samples.

Notes:

1. Amount of $HClO_4$ used was based on 15 ml $HClO_4$/gram sample. To cut down on $HClO_4$ going up the hood, 0.5 g samples were digested with 22.5 ml ternary mixture and the resulting residue was taken up to 25 ml.

2. Beakers should be watched closely when all HNO_3 has evaporated. If a beaker starts bumping - usually after washing down sides with deionized distilled water - take beaker off the hot plate immediately and let stand until cool - then put beaker back on hot plate.

3. When watch glasses are taken off - the swirling should be done so as to get the residue sticking on the sides down into the acid. Black residues usually occur when residue dries on the sides of the beaker.

4. The digestion is not complete - if the solution which should gradually turn white from straw yellow - turns black. If this occurs take beaker off, let cool, and add increments of 15 ml ternary mixture, place on hot plate again, until complete oxidation occurs.

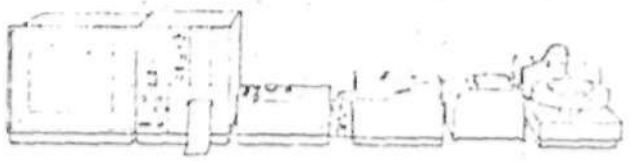
The following elements - Zn, Cu, Fe, Mn, Ca and Mg - can be assayed using the Perkin-Elmer 303 A.A. Spectrophotometer. The original undiluted stock solutions are used in the analyses for Zn, Cu, Fe and Mn. For Cu, the scale should be set at 2X on the Model 303.

A 1 to 50 dilution using .1 N HCl usually gives the correct concentration range for Ca, Mg, and K. Potassium and Mg were analyzed from the diluted samples using the flame photometer in the Soil Testing Laboratory and the Perkin-Elmer 303 A.A. Spectrophotometer, respectively.

For Ca, 4 ml of the diluted sample is pipetted into 10-ml beakers. One ml of a 5% La_2O_3 (25% HCl v/v - see - Perkin-Elmer Handbook for Analytical methods for A.A. Spectrophotometry) is added and the resulting solution swirled (to completely mix). The dilution factor for calcium is 50 $(\frac{50}{1}) \times \frac{5}{4}$. Standards for calcium should also be made up with La_2O_3. (10 ml of 5% La_2O_3 per 50 ml volume to give resulting solution concentration of 1% La_2O_3 in 5% (v/v) HCl).

Phosphorus Determination:

Note:- The procedure for phosphorus is Jackson's (p. 151) Vanadomolybdophosphoric yellow color Method in Nitric Acid System (Method V). The only modification being that 200 ml of the vandomolybdate reagent was premixed with 600-ml deionized distilled water giving a 2/6 ratio. This is used to make 2 ml sample to volume in a 10-ml volumetric flask.



INDUSTRIAL METHOD No. 334-74W/B+ RELEASED: JANUARY, 1976/REVISED: MARCH 1977

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.

TECHNICON INDUSTRIAL SYSTEMS / TARRYTOWN, N.Y. 10591
A DIVISION OF TECHNICON INSTRUMENTS CORPORATION

PRINTING CODE:
A/11/a/1

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.

Reagents:

1. Add 600 ml deionized distilled water to 200 ml of a HNO_3 - Vanadate - molybdate solution (see Jackson) = 2/6 vanadate solution.

Glasswares needed:

1. 10-ml volumetric flasks
2. 2-ml volumetric pipets
3. Polyethylene wash bottle for 2/6 vanadate solution.

Standard curve preparation:

1. Measured amounts (1, 2, 4, 6 and 8 ml from a 20 ppm phosphorus stock solution to give a series of 2, 4, 8, 12 and 16 ppm phosphorus) are pipetted into 10-ml volumetric flasks. Two blanks are likewise prepared (2 ml from perchloric ashing blank) and used to zero the Beckman D B spectrophotometer (Crop Physio. Lab.)
2. Add 2-ml of HNO_3-Vanadate-molybdate stock solution and make up to volume with deionized distilled water.
3. Cover with parafilm and shake solution. Full color development takes 10 minutes. Color is stable for 24 hours.

Sample analysis:

1. Pipette out 2 ml from the undiluted sample stock solution into 10-ml volumetric flasks.
2. Make up to volume with 2/6 vanadate solution (use fine tipped wash bottle to deliver solution).
3. Cover with parafilm and shake to mix sample and vanadate solution.
4. Absorbance values are measured at 470 mμ.

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 —	2.0 g
Araboascorbic Acid ($C_6H_8O_6$)	
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).

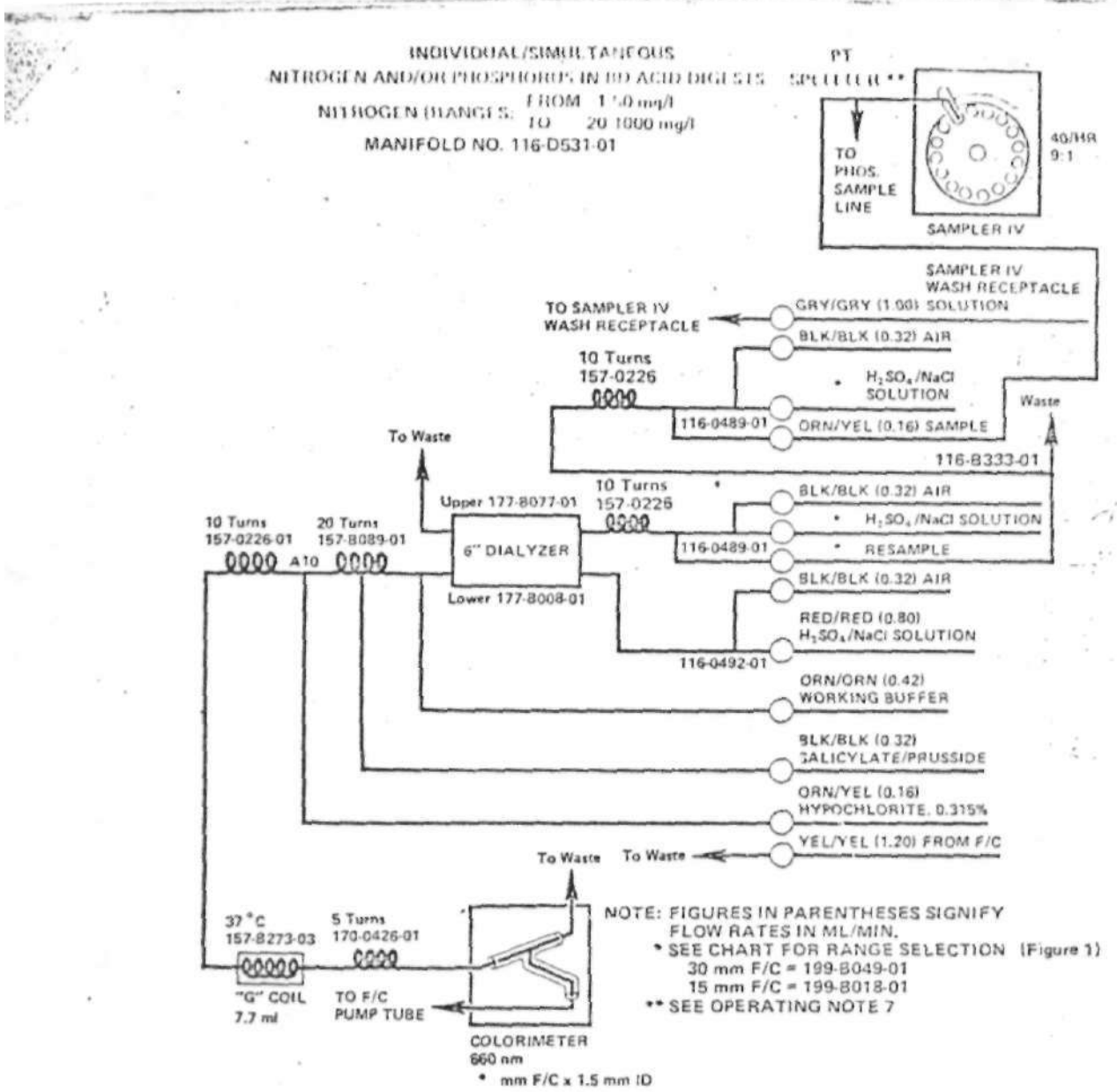


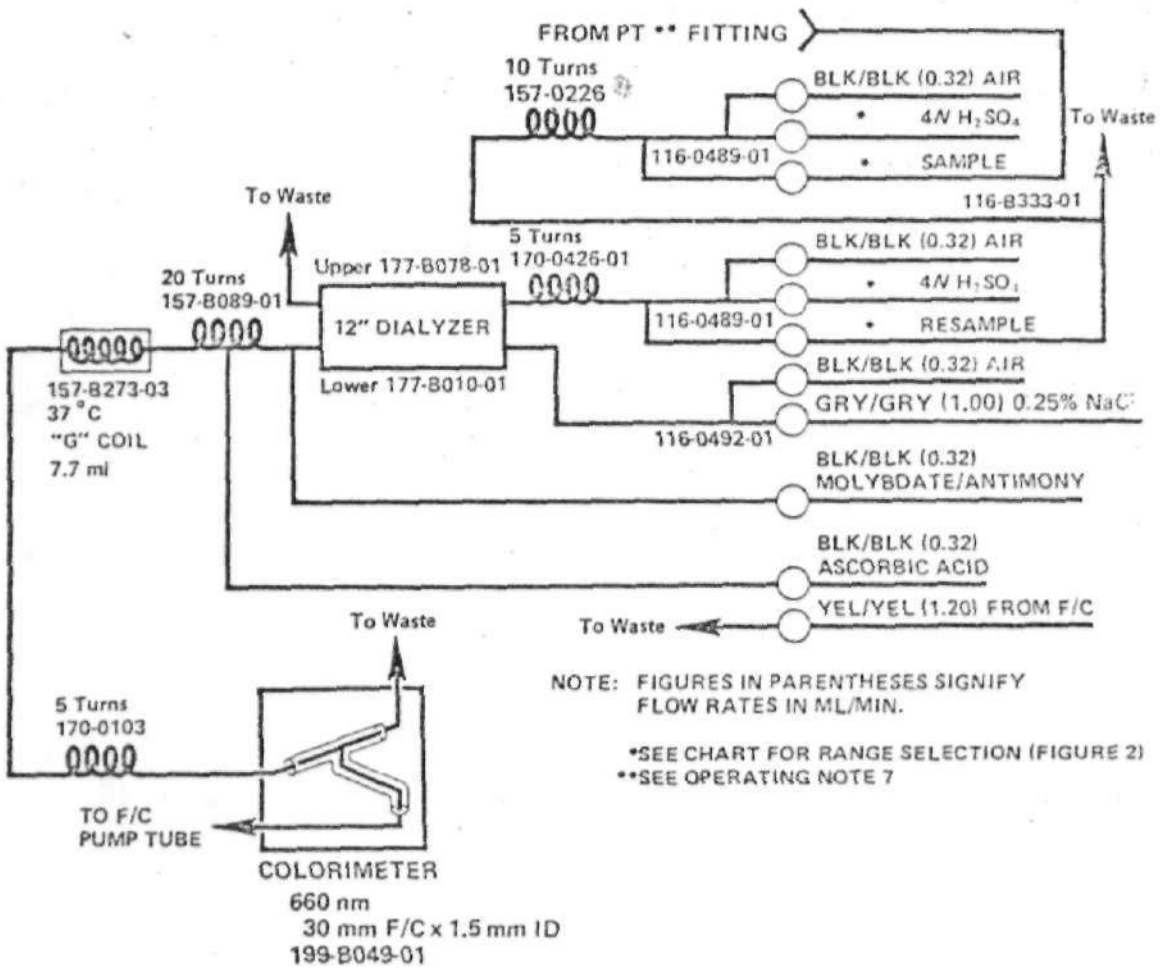
Figure 1. CONCENTRATION RANGES (NITROGEN)

DILUTION LOOPS				FLOWCELL PATH LENGTH (mm)	APPROX. STD CAL SETTING	RANGE PPM N (±10%)
INITIAL SAMPLE		RESAMPLE				
SAMPLE LINE	H_2SO_4/NaCl LINE	RESAMPLE LINE	H_2SO_4/NaCl LINE			
.16 (Orn/Yel)	1.20 Yel/Yel)	.32 (Blk/Blk)	0.80 (Red/Red)	30	7.30 1.00	.7-35 1.4-170
.16 (Orn/Yel)	1.20 Yel/Yel)	.16 (Orn/Yel)	1.00 (Gry/Gry)	30	7.30 1.00	1.2-60 -300
.16 (Orn/Yel)	2.00 (Grn/Grn)	.16 (Orn/Yel)	1.00 (Gry/Gry)	30	7.30 1.00	2-100 10-500
.16 (Orn/Yel)	1.20 (Yel/Yel)	.32 (Blk/Blk)	0.80 (Red/Red)	15	7.30 1.00	1.2-60 6-300
.16 (Orn/Yel)	1.20 (Yel/Yel)	.16 (Orn/Yel)	1.00 (Gry/Gry)	15	7.30 1.00	2.4-120 12-600
.16 (Orn/Yel)	2.00 (Grn/Grn)	.16 (Orn/Yel)	1.00 (Gry/Gry)	15	7.30 1.00	4-200 20-1000

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

PHOSPHORUS RANGES: FROM 1-50 mg/l
TO 20-1000 mg/l

MANIFOLD NO. 116-D541-01



NOTE: FIGURES IN PARENTHESES SIGNIFY FLOW RATES IN ML/MIN.

*SEE CHART FOR RANGE SELECTION (FIGURE 2)
**SEE OPERATING NOTE 7

Figure 2. CONCENTRATION RANGES (PHOSPHORUS)

DILUTION LOOPS				APPROX. STD CAL SETTING	RANGE mg/l P (±10%)
INITIAL SAMPLE		RESAMPLE			
SAMPLE LINE	4N H_2SO_4 LINE	RESAMPLE LINE	4N H_2SO_4 LINE		
0.32 (Blk/Blk)	1.00 (Gry/Gry)	0.32 (Blk/Blk)	0.80 (Red/Red)	7.30 2.20	1-50 3-150
0.32 (Blk/Blk)	1.00 (Gry/Gry)	0.16 (Orn/Yel)	1.00 (Gry/Gry)	7.30 2.20	2-100 6-300
0.16 (Orn/Yel)	1.60 (Blu/Blu)	0.16 (Orn/Yel)	1.00 (Gry/Gry)	7.30 2.20	6-300 20-1000

NUTRIENT SALTS USED FOR SOLUTION CULTURES (REVISED)

Macronutrient Solutions

Specific salts used			Conc. of individual elements in final sol.		
Compounds	Ml. molar stock soln. per liter culture solution	Mol. wt.	Elements	µg atoms per liter	p.p.m.
KNO_3	5.0	101.1	N	15000	210
			K	5200	210
$Ca(NO_3)_2 \cdot 4H_2O$	5.0	236.2	Ca	5000	200
			P	200	6
$MgSO_4 \cdot 7H_2O$	2.0	246.5	S	2000	64
			Mg	2000	48
KH_2PO_4	0.2	136.1			

Micronutrient Solutions

Specific salts used				Conc. of individual elements in final solution	
Compounds	Ml. stock sol. per liter culture sol.	Mol. wt.	Mg. per liter of stock sol.	Elements	ug atoms per liter	p.p.m.
KCl	1	74.6	3728	Cl	50	1.77
H_3BO_3	1	61.8	1546	B	25	0.27
$MnSO_4 \cdot H_2O$	1	169.0	845	Mn	5.0	0.27
$ZnSO_4 \cdot 7H_2O$	1	287.6	575	Zn	2.0	0.13
$CuSO_4 \cdot 5H_2O$	1	249.7	125	Cu	0.5	0.03
$(NH_4)_6Mo_7O_{24} \cdot 4H_2O$	1	1236	18.4	Mo	0.1	0.01

Iron Solutions

Many different iron sources are used for nutrient solution culture of plants. It is usually most desirable to use an iron source that remains available for the maximum time. Purity of iron sources varies, however, and is a more important consideration than availability in micronutrient deficiency studies. The most available source, commensurate with purity, should be used.

$FeSO_4$-H_2SO_4. Prepare a 0.002 M $FeSO_4 \cdot 7H_2O$ solution adjusted to pH 3.5 with H_2SO_4. Add 2 ml of this solution per liter of nutrient solution twice weekly.

$FeSO_4$-Tartrate - Prepare a 0.6% $FeSO_4 \cdot 7H_2O$ - 0.4% tartaric acid solution. Add 1 ml of this solution per liter of nutrient solution twice weekly.

$FeSO_4$-EDTA. Prepare a 0.01 M FeEDTA solution by dissolving 3.72 g Na_2EDTA and 2.78 g $FeSO_4 \cdot 7H_2O$ in 1000 ml of double distilled water and heating to approximately 80C. Add 1 ml of this solution per liter of nutrient solution weekly or whenever the pH of the nutrient solution is adjusted. Use for nutrient cultures below pH 7.0.

$FeSO_4$-EDDHA. Prepare a 0.001 M FeEDDHA solution by dissolving 140 mg KOH and 360 mg EDDHA in 500 ml of double distilled water. Add 278 mg $FeSO_4 \cdot 7H_2O$ dissolved in 400 ml of double distilled water and dilute to one liter. Add 10^2 ml of this solution per liter of nutrient solution weekly or whenever the pH of the nutrient solution is adjusted. Use for nutrient cultures above pH 7.0.

Commercial Fe Chelates. Prepare 0.01 to 0.001 M solutions of the chelates and add to the nutrient solutions as above. Commercial iron chelates are not as pure as those prepared from reagent quality chemicals, however, and should not be used for micronutrient deficiency studies.

References

1. Hoagland, D. R. and D. I. Arnon. 1950. The water-culture method for growing plants without soil. California Agr. Exp. Sta. Cir. 347.

2. Hoagland, D. R. and W. C. Snyder. 1933. Nutrition of strawberry plant under controlled conditions. Proc. Amer. Soc. Hort. Sci. 30:288-296.

3. Johnson, C. M., P. R. Stout, T. C. Broyer, and A. B. Carlton. 1957. Comparative chlorine requirements of different plant species. Plant and Soil 8:337-353.

4. Withrow, R. B. and A. P. Withrow. 1948. Nutriculture. Indiana Agr. Exp. Sta. Bul. 328.

Nitrogen Determination:

Note:- Tissue nitrogen was determined using a micro-Kjeldahl unit.

A. Sample Digestion

1. Place a glass bead and a piece of Cu wire (about 1/8" in length) in flat-bottom 50-ml Florence flasks. Allow one extra flask for a blank for every batch of samples. (Adding the glass bead and Cu wire prior to adding the sample insures that all flasks contain glass beads and Cu wires).

2. 0.1 g samples are weighed and added into the flasks.

3. Three ml concentrated H_2SO_4 is added and the flasks are covered with watch glasses.

4. The samples are then digested on a hot plate. Temperature settings should be controlled so the sample solution is just-boiling. Digestion usually takes 8-12 hours or overnight. A tinge of greenish solution indicates complete digestion. (The plate of the hot plate unit can be removed and an aluminum sheet can be placed over the heating coil - this results in faster digestion).

5. About 5 to 10 ml deionized distilled water from a polyethylene wash bottle is added to get the residue formed into solution.

B. Distillation

1. The digest is transferred to a distilling flask. The Florence flask is rinsed several times with deionized water to insure full transfer of the distillate.

2. Distillation of NH_3 is accomplished using a micro-Kjeldahl distilling unit.

3. Titrate distillate using standard acid delivered from a 10-ml automatic delivery micro-buret.

Note:- See Hanway's mimeographed notes for reagents (Dr. Whitney). This procedure used varies from Hanway's in that Florence flasks are used instead of volumetric flasks and the whole sample is used for nitrogen determination alone. Each micro-Kjeldahl distilling unit has its own peculiarities - check with the individual in charge of the distilling unit being used.

Table 5 Influence of phosphorus application on plant phosphorus concentration and uptake of fifteen sorghum genotypes.

GENOTYPES	0 ppm P	200 ppm P	MEANS	0 ppm P	200 ppm P	MEANS
	P Concentration (%)			P uptake (mg P/pot)		
1 BTx378	.11	.83	.47 C	.48	19.14	9.81 ABC
2 RTx2536	.14	.90	.52 BC	.41	14.45	7.43 C
3 ATx378 x RTx2536	.09	1.05	.57 ABC	.59	26.03	13.31 A
4 BTx3197	.15	1.01	.58 ABC	.55	18.91	9.73 ABC
5 RTx7078	.15	1.08	.61 AB	.67	20.47	10.57 ABC
6 RS 610	.10	1.07	.58 ABC	.53	25.67	13.10 A
7 BTx399	.12	1.08	.60 AB	.61	21.95	11.28 ABC
8 RTAM428	.11	1.10	.61 AB	.55	16.30	8.43 BC
9 ATx399 x RTAM428	.11	1.00	.55 BC	.56	22.64	11.60 AB
10 RTx7000	.12	1.03	.57 ABC	.44	16.79	8.61 BC
11 ATx378 x RTx7000	.13	1.03	.58 ABC	.58	19.72	10.15 ABC
12 SC0283-c	.12	1.01	.57 ABC	.41	18.58	9.49 ABC
13 SC0048-c	.14	1.20	.67 A	.42	14.50	7.46 C
14 SC0418-c	.16	.89	.52 BC	.62	17.79	9.21 ABC
16 SC0599-6	.15	.97	.56 BC	.68	19.98	10.33 ABC
P Rate Means	.13 B	1.02 A		.54 B	19.53 A	

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

Table 6 Influence of phosphorus application on plant zinc concentrations and uptake of fifteen sorghum genotypes.

GENOTYPES	0 ppm P	200 ppm P	MEANS	0 ppm P	200 ppm P	MEANS
	Zn concentration (ppm)			Zn uptake (ugm Zn/pot)		
1 BTx378	86.3	67.0	76.7 F	37.7	151.9	94.8 ABC
2 RTx2536	87.0	65.0	76.2 F	26.3	104.3	65.3 C
3 ATx378 x RTx2536	77.0	65.0	71.2 F	49.0	172.8	110.9 A
4 BTx3197	89.7	60.3	75.0 F	39.0	112.6	75.8 BC
5 RTx7078	79.0	74.0	76.5 F	36.9	142.4	89.6 ABC
6 RS 610	99.3	75.0	87.5 DE	52.4	181.5	117.0 A
7 BTx399	110.0	76.0	93.0 CD	58.4	153.6	106.0 ABC
8 RTAM428	129.3	76.0	102.7 BC	68.4	112.4	90.4 ABC
9 ATx399 x RTAM428	98.3	78.0	88.2 DE	49.1	176.8	112.9 ABC
10 RTx7000	147.7	81.0	114.3 A	59.4	132.7	96.0 ABC
11 ATx378 x RTx7000	109.7	74.7	92.2 CD	47.3	146.3	98.8 ABC
12 SC0283-c	139.3	70.7	105.0 AB	47.5	130.0	88.7 ABC
13 SC0048-c	116.3	79.7	98.0 BCD	35.3	96.2	65.8 C
14 SC0418-c	115.0	69.7	92.3 CD	46.0	143.0	94.5 ABC
16 SC0599-6	79.7	77.2	78.3 EF	37.3	157.8	97.5 ABC
P Rate Means	104.2 A	72.7 B		46.0 B	140.9 A	

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

Table 7 Effects of zinc application on plant zinc concentrations and uptake of fifteen sorghum genotypes.

GENOTYPES	0 ppm Zn	8 ppm	MEANS	0 ppm Zn	8 ppm Zn	MEANS
	Zn concentrations (ppm)			Zn uptake (ugm Zn/pot)		
1 BTx378	14.7	51.0	32.8 CD	31.5	106.7	69.1 BCD
3 ATx378 x RTx2536	12.1	60.1	36.2 ABCD	23.2	149.6	86.4 AB
4 BTx3197	13.6	54.9	34.3 ABCD	23.0	93.8	58.4 BCD
5 RTx7078	12.7	77.1	44.9 AB	27.4	171.6	99.5 A
6 RS 610	14.7	58.5	36.6 ABCD	33.7	94.9	64.3 BCD
7 BTx399	13.9	43.1	28.5 D	15.7	61.8	40.7 D
8 RTAM428	13.7	76.3	45.0 AB	16.9	123.1	70.0 BCD
9 ATx399 x RTAM428	11.6	44.7	28.1 D	17.3	64.1	40.7 D
10 RTx7000	14.9	75.9	45.4 A	22.7	128.3	75.5 ABC
11 ATx378 x RTx7000	12.4	56.0	34.2 ABCD	31.4	89.6	60.5 BCD
12 SC0283-c	12.5	59.9	36.2 ABCD	16.0	94.0	55.0 BCD
13 SC0048-c	13.6	69.7	41.7 ABC	15.4	116.9	66.2 BCD
14 SC0418-c	14.0	52.3	33.2 BCD	18.1	67.5	42.8 D
15 SC0056-14	15.4	54.3	34.9 ABCD	16.7	81.4	49.1 CD
16 SC0599-6	14.1	69.4	41.7 ABC	16.6	100.7	58.7 BCD
Zn Rate Means	13.6 B	60.2 A		21.7 B	103.0 A	

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

Table 8 Effects of zinc application on plant phosphorus concentrations and uptake of fifteen sorghum genotypes.

GENOTYPES	0 ppm Zn	8 ppm Zn	MEANS	0 ppm Zn	8 ppm ZN	MEANS
	P concentration (%)			P uptake (mg P/pot)		
1 BTx378	.23	.25	.24 BCD	5.0	5.0	5.0 ABC
3 ATx378 x RTx2536	.24	.23	.23 CD	4.6	6.1	5.3 A
4 BTx3197	.23	.25	.24 BCD	3.8	4.2	4.0 ABCDE
5 RTx7078	.22	.26	.24 BCD	4.5	5.8	5.2 AB
6 RS 610	.23	.28	.25 ABCD	5.2	4.5	4.8 ABCD
7 BTx399	.26	.24	.25 ABCD	3.0	3.3	3.1 E
8 RTAM428	.25	.22	.24 BCD	3.1	3.6	3.4 DE
9 ATx399 x RTAM428	.24	.26	.25 ABCD	3.6	3.7	3.7 BCDE
10 RTx7000	.25	.22	.24 BCD	3.8	3.7	3.7 BCDE
11 ATx378 x RTx7000	.22	.23	.22 D	5.5	3.8	4.6 ABCDE
12 SC0283-c	.29	.26	.27 AB	3.0	4.1	3.6 CDE
13 SC0048-c	.29	.28	.28 A	3.2	4.6	3.9 ABCDE
14 SC0418-c	.25	.28	.27 ABC	3.3	3.6	3.5 CDE
15 SC0056-14	.25	.25	.25 ABCD	2.7	3.7	3.2 E
16 SC0599-6	.26	.23	.25 ABCD	3.1	3.3	3.2 E
Zn Rate Means	.25 A	.25 A		3.8 A	4.2 A	

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

Table 9 Influence of P application and liming on plant phosphorus concentration and uptake of seven sorghum genotypes.

	0 ppm P LIMING RATE				40 ppm P LIMING RATE				
GENOTYPES	x NONE	X RECOM	x EXCESS	MEANS	NONE	RECOM	EXCESS	MEANS	OVERALL MEANS
Phosphorus concentrations (%).									
3 ATx378 x RTx2536	.10	.08	.07	.08 A	.13	.13	.12	.13 A	.11 A
5 RTx7078	.09	.07	.07	.08 A	.13	.15	.14	.14 A	.11 A
7 BTx399	.13	.08	.07	.09 A	.14	.13	.13	.14 A	.12 A
9 ATx399 x RTAM428	.09	.09	.08	.08 A	.15	.12	.15	.14 A	.11 A
12 SC0283-c	.08	.08	.08	.08 A	.15	.14	.16	.15 A	.12 A
14 SC0418-c	.10	.09	.09	.09 A	.13	.13	.14	.13 A	.11 A
15 SC0056-14	.08	.06	.07	.07 A	.14	.13	.16	.14 A	.11 A
Liming Means	.09 A	.08 B	.07 B		.14 A	.13 A	.14 A		

Overall Liming Means	NONE	RECOM	EXCESS
	.12 A	.10 B	.11 AB

P Level Means	.08 B	.14 A

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

x NONE - Original soil pH 5.2

x RECOMMENDED - 4000 lbs/Acre - pH 6.8

x EXCESS - 5% Lime w/w - pH 8.2

Table 10 Effects of P application and liming on plant zinc concentration and uptake of seven sorghum genotypes.

GENOTYPES	0 ppm P LIMING RATE x NONE	x RECOM	x EXCESS	MEANS	40 ppm P LIMING RATE NONE	RECOM	EXCESS	MEANS	OVERALL MEANS
Zinc concentrations (ppm).									
3 ATx378 x RTx2536	138.0	106.0	78.0	107.3 BC	106.7	171.3	74.0	117.3 A	112.3 AB
5 RTx7078	206.0	145.3	102.7	151.3 A	95.3	185.3	86.0	122.2 A	136.8 A
7 BTx399	115.3	126.0	75.3	105.6 C	75.3	126.7	72.7	91.6 A	98.6 B
9 ATx399 x RTAM428	198.3	150.0	88.7	146.7 AB	145.3	82.0	82.0	103.1 A	124.4 AB
12 SC0283-c	253.3	118.7	72.7	148.2 A	102.7	112.7	74.0	96.4 A	122.3 AB
14 SC0418-c	138.7	219.3	84.7	147.6 A	92.7	122.0	66.7	89.8 A	118.7 AB
15 SC0056-14	147.3	146.7	74.7	122.9 ABC	80.7	100.7	70.7	88.0 A	105.4 B
Liming Means	171.0 A	144.6 B	82.4 C		99.8 B	128.7 A	75.1 C		
Overall Liming Means		NONE 135.4 A				RECOM 136.6 A			EXCESS 78.8 B
P Level Means	132.7 A						101.2 B		
Zinc uptake (ugm Zn/pot).									
3 ATx378 x RTx2536	644	360	416	473 B	6023	7550	3341	5638 A	3056 A
5 RTx7078	1064	531	273	623 B	4587	9438	3423	5816 A	3219 A
7 BTx399	771	450	327	516 B	4137	5937	3563	4546 A	2531 A
9 ATx399 x RTAM428	575	669	344	529 B	6725	4716	4009	5150 A	2840 A
12 SC0283-c	1161	347	341	616 B	5006	5827	4277	5037 A	2827 A
14 SC0418-c	776	1782	304	954 A	4065	6247	3051	4455 A	2704 A
15 SC0056-14	484	679	326	496 B	4033	4341	2641	3672 A	2084 A
Liming Means	782 A	688 A	333 B		4940 B	6294 A	3472 C		
Overall Liming Means		NONE 2861 B				RECOM 3491 A			EXCESS 1903 C
P Level Means	601 B						4902 A		

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

Table 11 Effect of nitrogen placement with two rates of banded P on plant zinc concentration and uptake of six sorghum genotypes.

	50 ppm P			150 ppm P			
	METHOD			METHOD			OVERALL
GENOTYPES	[x]NbPd	[xx]NPd	MEANS	NbPd	NPd	MEANS	MEANS
Zinc concentration (ppm) in the shoots.							
3 ATx378 x RTx2536	105.3	99.0	102.2 A	54.0	80.7	67.3 A	84.8 A
5 RTx7078	130.7	62.3	96.5 A	71.7	86.0	78.8 A	87.7 A
7 BTx399	120.7	106.3	113.5 A	53.0	75.0	64.0 A	88.8 A
9 ATx399 x RTAM428	64.0	106.3	85.2 A	88.7	62.0	75.3 A	80.3 A
14 SC0418-c	90.7	101.3	96.0 A	74.7	67.3	71.0 A	83.5 A
15 SC0056-14	107.0	88.0	97.5 A	53.0	62.0	57.5 A	77.5 A
Method Means	103.1 A	93.9 A		65.8 A	62.0 A		
Overall Method Means		NbPd 84.4 A				NPd 83.0 A	
P Rate Means	98.5 A			69.0 B			
Zinc uptake (ugm Zn/pot) in the shoot.							
3 ATx378 x RTx2536	653.6	642.5	648.0 A	323.9	533.3	428.6 A	538.3 A
5 RTx7078	681.7	491.7	586.7 A	414.1	491.4	452.7 A	519.7 A
7 BTx399	763.1	419.2	591.2 A	348.9	481.7	415.3 A	503.2 A
9 ATx399 x RTAM428	511.7	760.8	636.3 A	556.7	454.7	505.7 A	571.0 A
14 SC0418-c	478.6	505.2	491.9 A	465.7	416.0	440.8 A	466.4 A
15 SC0056-14	490.4	532.7	511.6 A	339.1	343.7	341.4 A	426.5 A
Method Means	596.5 A	558.7 A		408.1 A	453.5 A		
Overall Method Means		NbPd 502.3 A				NPd 506.1 A	
P Rate Means	577.6 A			430.8 B			

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

x NbPd - N broadcast, P banded.

xx NPd - N & P banded together.

Table 12 Effect of nitrogen placement with two rates of banded P on plant zinc concentration and uptake of six sorghum genotypes.

	50 ppm P			150 ppm P			
		METHOD			METHOD		OVERALL
GENOTYPES	xNbPd	xNPd	MEANS	NbPd	NPd	MEANS	MEANS
Zinc concentration (ppm) in the roots.							
3 ATx378 x RTx2536	90.0	73.0	81.5 A	33.0	64.3	48.7 A	65.1 A
5 RTx7078	101.0	45.3	73.2 A	44.3	44.3	44.3 A	58.8 A
7 BTx399	92.9	29.7	61.2 A	38.0	49.3	43.7 A	52.4 A
9 ATx399 x RTAM428	48.7	61.7	55.2 A	51.0	29.0	40.0 A	47.6 A
14 SC0418-c	65.7	72.0	68.8 A	69.7	50.0	59.8 A	64.3 A
15 SC0056-14	95.3	57.3	76.3 A	39.3	42.7	41.0 A	58.7 A
Method Means	82.2 A	56.5 B		45.9 A	46.6 A		
Overall Method Means		NbPd 64.1 A			NPd 51.6 B		
P Rate Means	69.4 A			46.3 B			
Zinc uptake (ugm Zn/pot) in the roots.							
3 ATx378 x RTx2536	130.7	98.7	114.7 A	62.4	101.1	81.8 A	98.2 A
5 RTx7078	101.3	37.0	69.1 A	53.3	52.7	53.0 A	61.1 A
7 BTx399	155.7	58.9	107.3 A	75.4	85.4	80.4 A	93.9 A
9 ATx399 x RTAM428	72.1	128.0	100.1 A	103.0	57.8	80.4 A	90.3 A
14 SC0418-c	80.6	59.5	70.1 A	120.6	48.5	84.6 A	77.3 A
15 SC0056-14	139.1	86.9	113.0 A	103.0	69.6	86.4 A	99.7 A
Method Means	113.3 A	78.2 B		86.3 A	69.2 A		
Overall Method Means		NbPd 99.8 A			NPd 73.7 B		
P Rate Means	95.7 A			77.8 A			

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

x NbPd - N broadcast, P banded.

xNPd - N & P banded together.

Table 12 (continued)

GENOTYPES	50 ppm P METHOD [x]NbPd	[x]NPd	MEANS	150 ppm P METHOD NbPd	NPd	MEANS	OVERALL MEANS
Total (shoots + roots) zinc uptake (ugm Zn/pot).							
3 ATx378 x RTx2536	784.2	741.1	762.7 A	386.3	634.5	510.4 A	636.5 A
5 RTx7078	783.0	528.7	655.9 A	467.3	544.1	505.7 A	580.8 A
7 BTx399	918.8	478.1	698.5 A	424.3	567.1	495.7 A	597.1 A
9 ATx399 x RTAM428	583.8	888.9	736.4 A	659.6	512.5	586.1 A	661.2 A
14 SC0418-c	559.2	564.7	562.0 A	586.2	331.2	458.7 A	510.3 A
15 SC0056-14	629.5	619.6	624.6 A	442.2	413.3	427.7 A	526.2 A
Method Means	709.8 A	636.9 A		494.3 A	500.4 A		
Overall Method Means		NbPd 602.1 A			NPd 568.6 A		
P Rate Means	673.3 A			497.4 B			

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

[x] NbPd - N broadcast, P banded.

[x] NPd - N & P banded together.

Table 13 Effects of the nitrogen sources on plant nitrogen content of five sorghum genotypes.

GENOTYPES	Nitrogen Sources NH_4^+	NO_3^-	$NH_4^+ + NO_3^-$	MEANS
Nitrogen concentration in shoots (%).				
3 ATx378 x RTx2536	4.4	4.4	4.6	4.5 A
7 BTx399	4.7	4.3	4.8	4.6 A
9 ATx399 xRTAM428	3.8	4.2	4.6	4.2 B
11 ATx378 x RTx7000	4.9	4.5	4.6	4.7 A
14 SC0418-c	4.4	4.3	4.7	4.5 A
N Source Means	4.4 B	4.3 B	4.7 A	
Nitrogen concentration in the roots (%).				
3 ATx378 x RTx2536	3.2	2.7	2.8	2.9 A
7 BTx399	2.9	2.8	3.1	2.9 A
9 ATx399 x RTAM428	3.1	2.7	2.9	2.9 A
11 ATx378 x RTx7000	2.8	2.8	3.0	2.9 A
14 SC0418-c	2.9	2.7	3.0	2.9 A
N Source Means	3.0 A	2.7 B	3.0 A	
Nitrogen uptake in the shoots (mg N/pot).				
3 ATx378 x RTx2536	89.1	112.4	143.6	115.0 A
7 BTx399	97.9	98.4	70.9	89.1 A
9 ATx399 x RTAM428	90.1	113.9	124.7	109.5 A
11 ATx378 x RTx7000	82.6	85.9	129.6	99.4 A
14 SC0418-c	83.8	56.2	88.5	76.2 A
N Source Means	88.7 A	93.3 A	111.4 A	

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

Table 13 (continued)

GENOTYPES	Nitrogen Source NH_4^+	NO_3^-	$NH_4^+ + NO_3^-$	MEANS
Nitrogen uptake in the roots (mg N/pot).				
3 ATx378 x RTx2536	19.2	20.2	17.0	18.8 A
7 BTx399	14.3	18.3	10.6	14.4 A
9 ATx399 x RTAM428	21.6	19.0	15.8	18.8 A
11 ATx378 x RTx7000	8.3	14.1	19.2	13.9 A
14 SC0418-c	15.0	10.7	13.5	13.0 A
N Source Means	15.7 A	16.4 A	15.2 A	
Total N uptake (shoots + roots) (mg N/pot).				
3 ATx378 x RTx2536	108.3	132.5	160.5	133.8 A
7 BTx399	103.6	116.6	81.5	100.6 A
9 ATx399 x RTAM428	111.8	133.0	140.1	128.3 A
11 ATx378 x RTx7000	90.9	100.0	148.8	113.2 A
14 SC0418-c	90.2	66.8	102.0	86.3 A
N Source Means	100.9 A	109.8 A	126.6 A	

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

Table 14 Influence of plant nutrition on culture solution pH.

GENOTYPES	Nitrogen Source NH_4^+	NO_3^-	$NH_4^+ + NO_3^-$	MEANS
pH 1st Week of plant growth.				
3 ATx378 x RTx2536	3.8	4.2	5.6	4.6 A
7 BTx399	3.8	4.1	5.2	4.4 A
9 ATx399 x RTAM428	3.8	4.2	5.7	4.5 A
11 ATx378 x RTx7000	4.5	4.3	4.8	4.5 A
14 SC0418-c	3.9	4.2	4.8	4.3 A
N Source Means	4.0 C	4.2 B	5.2 A	
pH 2nd Week.				
3 ATx378 x RTx2536	3.7	6.6	4.4	4.9 A
7 BTx399	3.8	6.6	4.4	4.9 A
9 ATx399 x RTAM428	3.7	6.8	4.4	5.0 A
11 ATx378 x RTx7000	4.0	6.6	4.4	5.0 A
14 SC0418-c	3.9	6.2	4.5	4.9 A
N Source Means	3.8 C	6.6 A	4.4 B	
pH 3rd Week				
3 ATx378 x RTx2536	3.8	7.2	4.6	5.2 A
7 BTx399	3.9	7.1	5.6	5.5 A
9 ATx399 x RTAM428	3.8	7.3	5.2	5.4 A
11 ATx378 x RTx7000	4.2	7.2	5.3	5.6 A
14 SC0418-c	4.1	7.1	5.7	5.6 A
N Source Means	3.9 C	7.2 A	5.3 B	
pH 4th Week				
3 ATx378 x RTx2536	3.3	7.7	4.0	5.0 A
7 BTx399	3.4	7.6	4.3	5.1 A
9 ATx399 x RTAM428	3.4	7.6	4.1	5.0 A
11 ATx378 x RTx7000	3.4	7.6	4.0	5.0 A
14 SC0418-c	3.4	7.6	4.3	5.1 A
N Source Means	3.4 C	7.6 A	4.1 B	

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

FIG-1

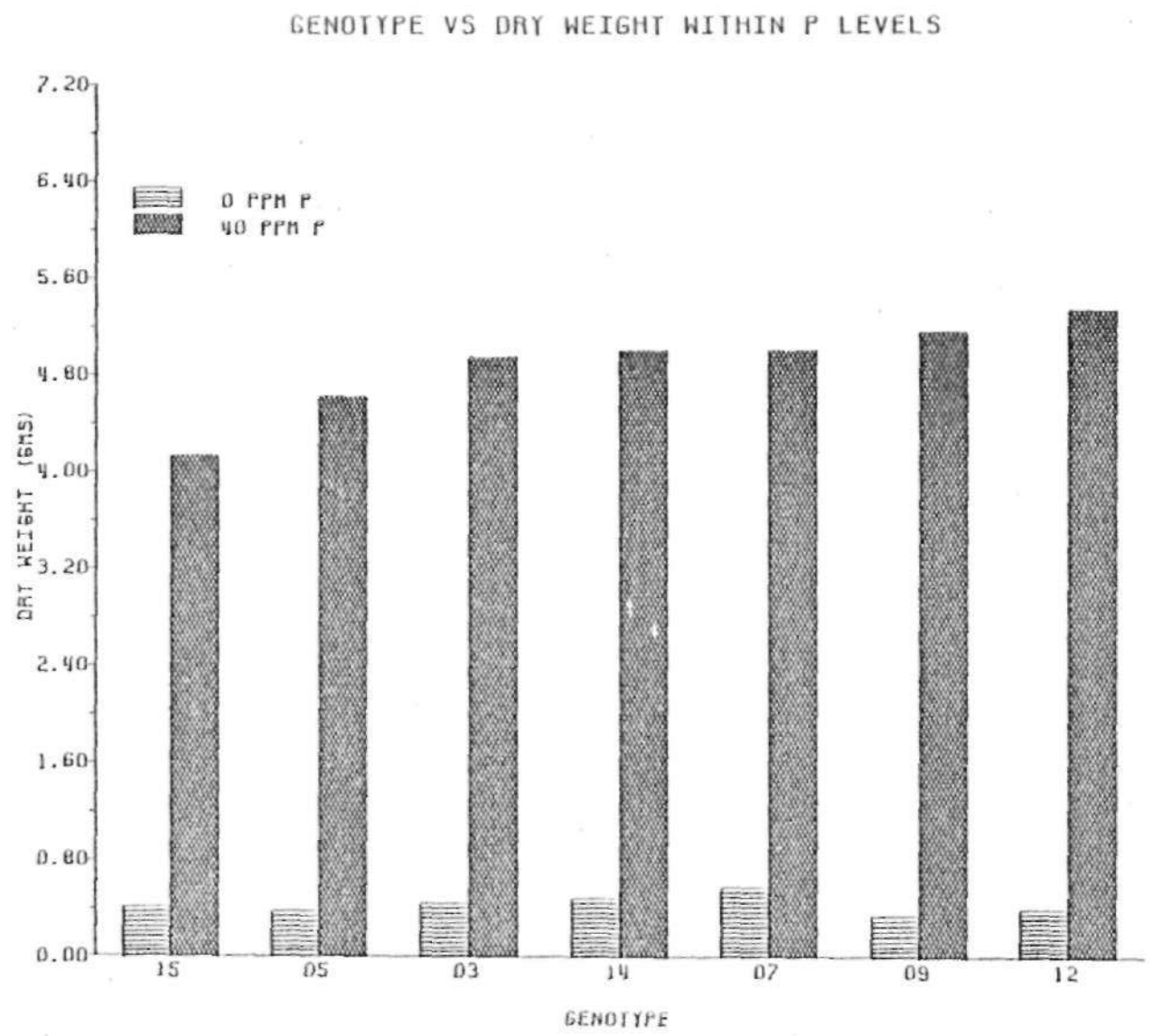
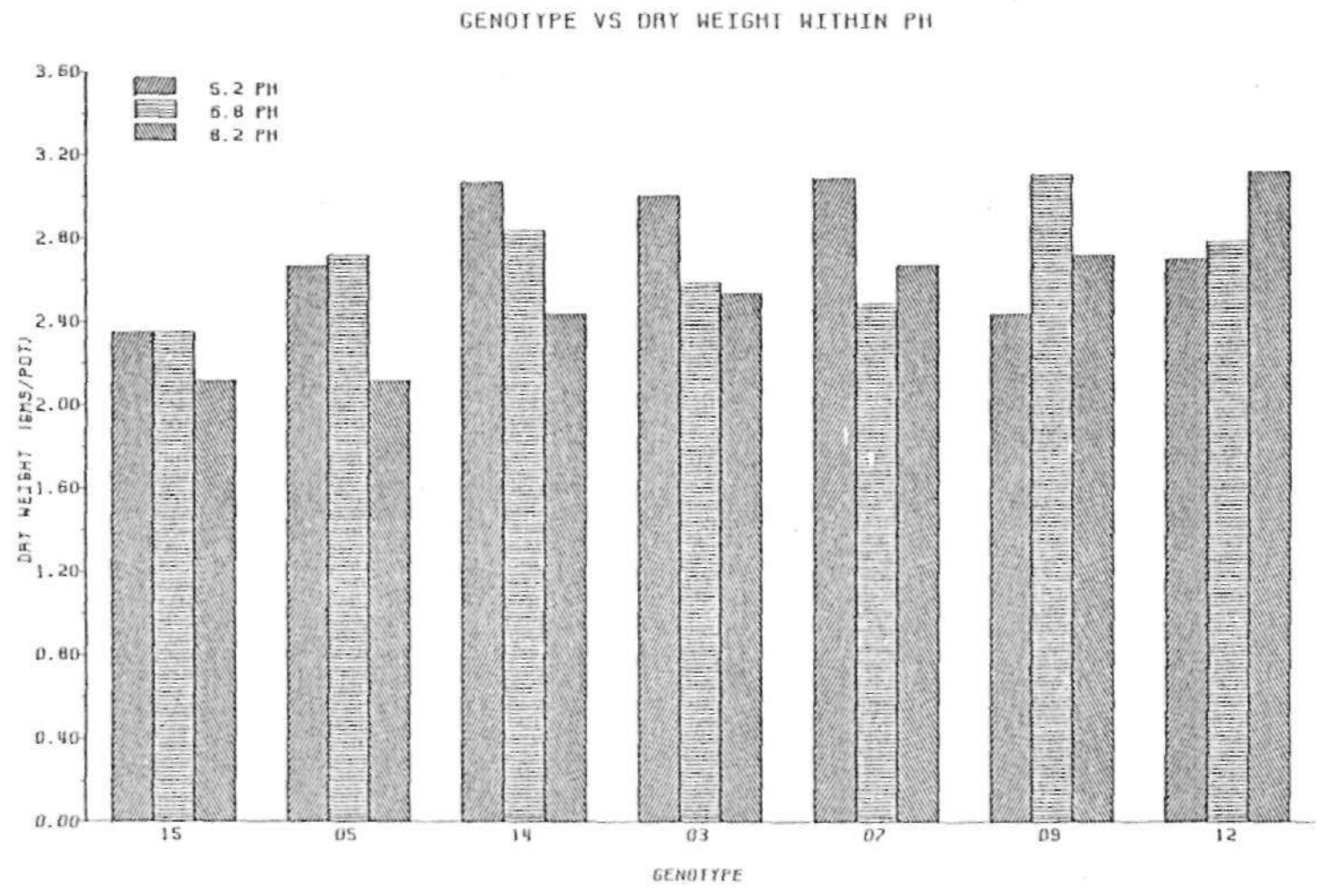

GENOTYPE VS DRY WEIGHT WITHIN P LEVELS
0 PPM P
40 PPM P
DRY WEIGHT (GMS)
7.20
6.40
5.60
4.80
4.00
3.20
2.40
1.60
0.80
0.00
15
05
03
14
07
09
12
GENOTYPE

FIG 2


GENOTYPE VS DRY WEIGHT WITHIN PH
5.2 PH
6.8 PH
8.2 PH
DRY WEIGHT (GMS/POT)
3.60
3.20
2.80
2.40
2.00
1.60
1.20
0.80
0.40
0.00
15
05
14
03
07
09
12
GENOTYPE

TABLES OF ANALYSIS OF VARIANCE PROCEDURE.

Experiment I Screening sorghum genotypes for P uptake efficiency.

DRY WEIGHTS.

ANOVA

SOURCE	DF	SUM OF SQUARES	F	PR>F
Genotype	14	3.68	3.61	.0002 xx
P Level	1	49.67	682.07	.0001 xx
Geno x P Level	14	1.85	1.81	.058
Error	60	4.37		
Phosphorus concentration (%)				
Genotype	14	0.176	1.94	.0396 x
P Level	1	17.850	2750.23	.0001 xx
Geno x P level	14	0.198	2.18	.0189 x
Error	60	0.389		
Phosphorus uptake (mg P/pot).				
Genotype	14	262.05	2.08	.026 x
P Level	1	8114.05	903.81	.0001 xx
Geno x P Level	14	248.76	1.98	.0352 x
Error	60	538.659		

Experiment II. Screening sorghum genotypes for response to zinc.

DRY WEIGHT.

A N O V A

SOURCE	DF	SUM OF SQUARES	F	PR>F
Genotype	14	11.45	4.58	.0001 xx
Zn Level	1	0.28	1.59	.2125
Geno x Zn Level	14	4.23	1.69	.0814
Error	60	10.706		

Zinc concentration (ppm).

Genotype	14	2671.70	2.53	.0066 xx
Zn Level	1	48888.06	648.48	.0001 xx
Geno x Zn Level	14	2568.39	2.43	.0089 xx
Error	60	4523.00		

Zinc uptake (ugm Zn/pot).

Genotype	14	23557.17	3.14	.0010 xx
Zn Level	1	148537.59	276.95	.0001 xx
Geno x Zn Level	14	18656.25	2.48	.0076 xx
Error	60	32180.33		

Experiment III. Influence of P application and liming on growth of seven sorghum genotypes.

A N O V A

DRY WEIGHT.

SOURCE	DF	SUM OF SQUARES	F	PR > F
Genotype	6	4.531	3.22	.0068 xx
P Level	1	623.56	2659.72	.0001 xx
Geno x P Level	6	4.24	3.02	.0102 xx
pH	2	0.79	1.68	.193
Geno x pH	12	5.81	2.06	.0281 x
P Level x pH	2	0.50	1.07	.3474
Geno x P Lev x pH	12	3.28	1.17	.3200
Error	84	19.69		
Phosphorus concentration.				
Genotype	6	15.86	0.76	.601
P Level	1	978.90	282.62	.0001 xx
Geno x P Level	6	46.51	2.24	.0470 x
pH	2	22.89	3.30	.0416 x
Geno x pH	12	46.79	1.13	.3509
P Level x pH	2	25.76	3.72	.0284 x
Geno x P Lev x pH	12	20.01	0.48	.9200
Error	84	290.95		

Experiment III. (continued).

P uptake.

SOURCE	DF	SUM OF SQUARES	F	PR > F
Genotype	6	1031.65	1.77	.1149
P Level	1	126322.76	1301.14	.0001 xx
Geno x P Level	6	1086.56	1.87	.0964
pH	2	134.35	0.69	.5034
Geno x pH	12	1148.66	0.99	.4691
P Level x pH	2	29.57	0.15	.8590
Geno x P Lev x pH	12	715.44	0.61	.8247
Error	84	8155.26		

Soil pH measurement.

Genotype	6	0.174	1.61	.154
P Level	1	0.103	5.71	.019 x
Geno x P Level	6	0.147	1.36	.240
pH	2	132.50	3677.40	.0001 xx
Geno x pH	12	0.13	0.61	.8255
P Level x pH	2	0.034	0.89	.416
Geno x P Lev x pH	12	0.53	2.44	.0089 xx
Error	84	1.51		

Experiment IV. Effect of nitrogen placement with two rates of banded phosphorus on plant growth.

A N O V A

SOURCE	DF	SUM OF SQUARES	F	PR>F
DRY WEIGHT(SHOOT)				
Genotype	5	14.98	6.84	.0001 xx
P Level	1	2.24	5.12	.0283 x
Geno x P Level	5	1.12	0.51	.7654
Method	1	0.10	0.23	.6328
Geno x Method	5	4.53	2.07	.0856
P Level x Method	1	0.00	0.00	.9576
Geno x P Lev x Meth	5	2.87	1.31	.2751
Error	48	21.02		
DRY WEIGHT (ROOTS).				
Genotype	5	9.86	8.51	.0001 xx
P Level	1	1.05	4.54	.0384 x
Geno x P Level	5	0.61	0.52	.7587
Method	1	0.59	2.53	.1182
Geno x Method	5	0.77	0.66	.6550
P Level x Method	1	0.70	3.02	.0886
Geno x P Lev x Meth	5	0.63	0.54	.7429
Error	48	11.13		
Phosphorus concentrations in the shoots.				
Geno	5	1075.20	4.42	.0022 xx
P Level	1	13491.77	277.13	.0001 xx
Geno x P Level	5	148.02	0.61	.6940
Method	1	891.83	18.32	.0001 xx
Geno x Method	5	291.45	1.20	.3247
P Level x Method	1	416.64	8.56	.0052 xx
Geno x P Lev x Meth	5	353.29	1.45	.2233
Error	48	2336.85		

Experiment IV (continued)

ANOVA

SOURCE	DF	SUM OF SQUARES	F	PR > F	
P uptake in shoots.					
Genotype	5	97690.7	1.26	.2970	
P Level	1	5699062.3	367.22	.0001	xx
Geno x P Level	5	34755.4	0.45	.8127	
Method	1	349827.7	22.54	.0001	xx
Geno x Method	5	70218.8	0.90	.4858	
P Level x Method	1	155249.8	10.00	.0027	xx
Geno x P Lev x Meth	5	94339.1	1.22	.3162	
Error	48	7449351.1			
Phosphorus concentration in roots.					
Genotype	5	114.8	1.66	.1618	
P Level	1	4023.0	291.19	.0001	xx
Geno x P Level	5	26.4	0.39	.8552	
Method	1	103.2	7.47	.0088	xx
Geno x Method	5	32.4	0.47	.7979	
P Level x Method	1	231.1	16.73	.0002	xx
Geno x P Lev x Meth	5	147.9	2.14	.0765	
Error	48	663.2			
P uptake in roots.					
Genotype	5	26012.7	5.40	.0005	xx
P Level	1	138747.3	143.98	.0001	xx
Geno x P Level	5	4116.4	0.85	.5185	
Method	1	272.9	0.28	.5971	
Geno x Method	5	3343.2	0.69	.6306	
P Level x Method	1	18.5	0.02	.8903	
Geno x P Lev x Meth	5	5380.4	1.12	.3642	
Error	48	46256.8			
Total P uptake (roots + shoots).					
Genotype	5	47202.7	0.44	.8156	
P Level	1	7616268.8	358.11	.0001	xx
Geno x P Level	5	19809.5	0.19	.9664	
Method	1	330557.8	15.54	.0003	xx
Geno x Method	5	73087.4	0.69	.6354	
P Level x Method	1	158660.4	7.46	.0088	xx
Geno x P Lev x Meth	5	134324.1	1.26	.2952	
Error	48	1020859.5			

P-Zn Interaction study in sorghum genotypes.

ROOT DRY WEIGHT.

A N O V A

SOURCE	DF	SUM OF SQUARES	F	PR > F
Genotype	3	2.934	17.34	.0001 xx
P Level	2	1.445	12.81	.0002 xx
Geno x P Level	6	0.235	0.69	.6563
Error	24	1.353		

SHOOT DRY WEIGHT.

Genotype	3	2.268	8.95	.0004 xx
P Level	2	1.924	11.39	.0003 xx
Geno x P Level	6	0.694	1.37	.2668
Error	24	2.027		

P CONCENTRATION IN THE SHOOT.

Genotype	3	0.046	2.35	.0977
P Level	2	1.287	97.78	.0001 xx
Geno x P Level	6	0.031	0.79	.5845
Error	24	0.158		

P CONCENTRATION IN THE ROOT.

Genotype	3	0.061	2.26	.1078
P Level	2	0.294	16.20	.0001 xx
Geno x P Level	6	0.033	0.61	.7224
Error	24	0.218		

P UPTAKE IN THE SHOOT.

Genotype	3	135900651	2.57	.0778
P Level	2	3362717437	95.43	.0001 xx
Geno x P Level	6	133994939	1.27	.3090
Error	24	422849578		

P UPTAKE IN THE ROOT.

Genotype	3	84690772	12.55	.0001 xx
P Level	2	172775391	38.41	.0001 xx
Geno x P Level	6	25748375	1.91	.1207
Error	24	53975268		

P-ZN Interaction study (continued)

SOURCE	DF	SUM OF SQUARES	F	PR>F
ZINC CONCENTRATION IN THE SHOOT.				
Genotype	3	2212.75	12.11	.0001 xx
P Level	2	170.68	1.40	.2658
Geno x P Level	6	541.33	1.48	.2268
Error	24	1462.00		
ZINC CONCENTRATION IN THE ROOT.				
Genotype	3	1076.97	6.99	.0015 xx
P Level	2	222.06	2.16	.1369
Geno x P Level	6	355.28	1.15	.3630
Error	24	1232.00		
ZINC UPTAKE IN THE SHOOT.				
Genotype	3	10461.07	3.02	.0493 x
P Level	2	6857.63	2.97	.0702
Geno x P Level	6	15279.12	2.21	.0775
Error	24	27680.72		
ZINC UPTAKE IN THE ROOT.				
Genotype	3	17657.93	20.85	.0001 xx
P Level	2	7641.01	13.53	.0001 xx
Geno x P Level	6	2162.50	1.28	.3049
Error	24	6774.68		

Influence of nitrogen sources on plant phosphorus uptake .

A N O V A

SOURCE	DF	SUM OF SQUARES	F	PR > F
DRY WEIGHT OF SHOOT.				
Genotype	4	4.205	1.96	.1526
Nitrogen Source(NS)	2	0.979	0.91	.4227
Geno x NS	8	3.005	0.70	.6872
Error	15	8.045		
PHOSPHORUS CONCENTRATION IN THE SHOOT.				
Genotype	4	0.085	1.67	.2099
NS	2	0.178	6.98	.0072 xx
Geno x NS	8	0.064	0.62	.7457
Error	15	0.192		
P UPTAKE IN THE SHOOT.				
Genotype	4	69.087	0.99	.4420
NS	2	15.602	0.45	.6473
Geno x NS	8	100.207	0.72	.6728
Error	15	261.268		
DRY WEIGHT OF ROOT.				
Genotype	4	0.291	1.45	.2672
NS	2	0.089	0.88	.4348
Geno x NS	8	0.215	0.53	.8141
Error	15	0.755		
PHOSPHORUS CONCENTRATION IN THE ROOTS.				
Genotype	4	0.647	0.93	.4703
NS	2	0.847	2.43	.1217
Geno x NS	8	0.599	0.43	.8832
Error	15	2.595		
PHOSPHORUS UPTAKE IN THE ROOT.				
Genotype	4	7.131	0.45	.7680
NS	2	58.952	7.51	.0055 xx
Geno x NS	8	10.899	0.35	.9327
Error	15	58.881		
TOTAL DRY WEIGHT.				
Genotype	4	6.735	1.98	.1486
NS	2	0.723	0.43	.6608
Geno x NS	8	3.831	0.56	.7909
Error	15	12.725		

Influence of nitrogen source (continued)

SOURCE	DF	SUM OF SQUARES	F	PR F
TOTAL P UPTAKE				
Genotype	4	190.385	2.88	.0594
NS	2	17.362	0.53	.6020
Geno x NS	8	138.652	1.05	.4450
Error	15	247.977		
Millieq. change in proton. 1 st Week.				
Geno	4	.0616	10.40	.0003 xx
NS	2	.8743	295.21	.0001 xx
Geno x NS	8	.0804	6.79	.0008 xx
Error	15	.0222		
Millieq. 2nd Week.				
Genotype	4	10.442	3.66	.0285 x
NS	2	1105.861	775.14	.0001 xx
Geno x NS	8	85.056	14.90	.0001 xx
Error	15	10.7000		
Millieq. 3rd Week.				
Genotype	4	0.481	3.87	.0237 x
NS	2	17.896	287.75	.0001 xx
Geno x NS	8	1.498	6.02	.0015 xx
Error	15	0.466		
Millieq. 4th Week.				
Genotype	4	0.393	0.54	.7114
NS	2	183.090	499.11	.0001 xx
Geno x NS	8	3.162	2.15	.0952
Error	15			

EVALUATION OF PHOSPHORUS-UPTAKE EFFICENCY OF SORGHUM GENOTYPES

BY

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AN ABSTRACT OF A DOCTOR'S DISSERTATION

submitted in partial fulfillment of the

requirements for the degree

DOCTOR OF PHILOSOPHY

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1980

Greenhouse studies were conducted to evaluate phosphorus uptake efficiency of sixteen sorghum genotypes. The influence of soil pH, source of nitrogen, method of placement of nitrogen with the banded phosphorus, zinc uptake efficiency and the effect of P uptake efficiency on Zn translocation were investigated.

Two levels of phosphorus (0 and 200 ppm P) were used in the initial study to compare P uptake efficiency by genotypes which were grown for four weeks. The significant differential response of the genotypes to P uptake suggested that the response to P may be genetically controlled.

The similar performance of some genotypes in P and Zn uptake efficiency, in a separate investigation with 0 and 8 ppm Zn levels, indicated that P uptake efficiency may not necessarily result in Zn uptake inefficiency. The significant differential performance of the genotypes in Zn uptake efficiency suggested that this characteristic may be genetically controlled.

The influence of liming (changing soil pH) on the phosphorus nutrition of the genotypes was investigated in a separate study. The significant depression of plant phosphorus concentration due to liming was apparently due to the influence of soil pH on plant P nutrition . The effect of liming on the P nutrition of the sorghum genotypes was found to be dependent on available soil phosphorus level.

In a separate study, application of phosphorus with the nitrogen in the same band was found to increase plant P uptake when compared to broadcasting the nitrogen with the banded P. The differential response observed among the genotypes suggests that their ability to absorb phosphorus under the beneficial effects of banding of N and P together in the same soil zone, may be genetically controlled.

When three high rates (150, 250, and 350 ppm P) of phosphorus were applied to a soil with uniform, but sufficient, zinc content, P-Zn interaction

was observed in the sorghum plants. The observed superiority of the lowest P rate in translocating absorbed soil zinc from the roots to the plant shoots, confirmed the antagonistic effects of P and Zn in the plants. Phosphorus uptake efficiency was found to result in inefficient zinc translocation, possibly due to a dilution effect in the P efficient genotypes that produced more dry matter.

Ammonium and the mixture of ammonium plus nitrate sources of nitrogen increased P uptake much better than the nitrate source. Both the nitrate and the mixture of nitrate plus ammonium sources were equally effective in improving the efficiency of P use in dry matter production and were better than the ammonium source . The poor performance of the ammonium source could be related to its acidic effect on the nutrient solution.

The results of these separate investigations showed the invaluable contribution of the breeding of P-efficient sorghum genotypes in improving their phosphorus nutrition under limiting available soil P conditions .