MICRONUTRIENT INTERACTIONS OF TWO IRON DEFICIENT SOILS OF OKLAHOMA

By

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CHAPTER I

INTRODUCTION

Micronutrient research in both soils and plants has been conducted for many years. Many conflicting results have been reported in literature due to different soils and plant species being tested. Since little micronutrient work has been conducted on Fe deficient soils of Oklahoma this research project was designed.

This study was limited to reactions of Fe, Mn, Zn, Cu, Mo and S in two Fe deficient soils of western Oklahoma.

The purpose of this experiment was two-fold. First, to determine if interactions among Fe, Mn, Zn, Cu, Mo and S at three P rates exist in two Fe deficient soils of Oklahoma, and secondly, to determine the differences between DTPA and 0.01M $CaCl_2$ extractable Fe, Mn, Zn and Cu and the differences among DTPA, 0.01M $CaCl_2$ and acid ammonium oxalate extractable Mo.

CHAPTER II

LITERATURE REVIEW

Many researchers (Tisdale and Nelson, 1975; Boawn and Leggett, 1964; DeKock, 1955) have found that the absolute level of a micronutrient in the rooting medium may not necessarily be the most important factor in its relation to plant growth. The relationship of the amount of one element to another may be more important than its absolute level. Epstein and Stout (1951) have found that the exchangeability of a cation is governed by both its absolute amount in the soil and by the nature of the complementary ions.

Fe and Fe Interactions

The amount of Fe absorbed by plants is a function of the amount supplied to the roots (Epstein and Stout, 1951). Dahiya and Singh (1976) worked with pea plants and found that all Fe sources significantly increased yield when applied to the roots. This added Fe also led to high Fe levels in pea tissue. Work performed on five Fe deficient soils by Olsen and Watanabe (1979) demonstrates the positive effect Fe chelates have on yield. On all five soils tested, added Fe chelate increased plant yields.

Research on the interaction of Fe and Mn dates back to 1848 (Twyman, 1946). Some researchers (Dahiya and Singh, 1976; Chaudhry et al., 1977) have reported that $FeSO_4$ decreases Mn availability in soils.

Lingle et al. (1963) reported that Mn interfered with Fe uptake and transport when Fe and Mn were at equimolar concentrations. At lower Mn levels, these researchers found that Mn stimulated Fe absorption. Epstein and Stout (1951) reported that Fe uptake in tomato plants increased when Mn levels in the substrate were increased. They also found that increasing Mn in the system resulted in higher Mn and Fe levels in the supernatant. They attribute these increases to the displacement of Fe from the exchange complex by Mn. Gerloff and coworkers (1959) observed that when Mn levels were increased in culture solution much higher Mn concentrations were found in plant tissue. Olsen and Watanabe (1979) state that Mn reduces the physiological effectiveness of Fe in plants. These varied results are explained by Olsen (1972) who states that Fe and Mn are interrelated in their metabolic functions and the effectiveness of one is determined by the ratio to the other. A ratio of 2:1 has been suggested for Fe to Mn levels.

Olsen and Watanabe (1979) reported results which imply that the level of Fe in sorghum increased with added $SO_4^=$. They suggest a possible mechanism of how $SO_4^=$ could contribute to Fe uptake is that Fe forms an uncharged ion pair with $SO_4^=$ in the soil solution.

In two studies on peas and sorghum (Dahiya and Singh, 1976; Brown and Jones, 1977) the application of Fe to soil resulted in decreased P levels in plant tissue. Bassiri et al. (1979) reported that Fe chlorosis will result when high levels of P are used, but that added Fe had no effect on P levels in mungbeans. Mortvedt and Osborn (1977) report that application of ammonium polyphosphates, (11-37-0) and (10-34-0), result in higher Fe levels in the soil solution especially in acid soil.

Mn and Mn Interactions

Conflicting reports of the effect of incubation time on Mn availability are reported in literature. Mulder and Gerretsen (1952) state that some soils release more exchangeable Mn if they are air dried or stored for any length of time while Dahiya and Singh (1977) found that all forms of Mn decreased in concentration as the incubation time was increased. They attribute this decrease to oxidation and hydration of Mn into insoluble forms. Some researchers (Salcedo and Warncke, 1979) report that the soil to solution ratio and extraction time can be very important for Mn extractions. They found for 0.1N HCl and 0.1N H_3PO_4 these factors significantly influenced extractable Mn, whereas 0.005M DTPA and 1N NH_4OAc extractions were not as sensitive. White et al. (1979) found that plant Mn levels were significantly increased in soybeans by addition of Zn to the soil. These soil Zn additions may result in potentially phytotoxic Mn levels in soybean plant tissue.

In a study on soybeans Hossner and Richards (1968) tested four P sources as to their effectiveness with Mn movement and uptake from the fertilizer band. They found that Mn moved the farthest and recovery was the greatest when it was applied with ammonium polyphosphate (APP). These workers concluded that APP or monoammonium phosphate (MAP) are the most satisfactory P sources with which to band $MnSO_4$. In a later study, Hossner and Blanchar (1970) found that Mn precipitates almost quantitatively as Mn ammonium ortho- and pyrophosphates when Mn and ammonium phosphates are applied together. Mn was unavailable to plants due to the lack of Mn movement in soil and the formation of these precipitates. They found however, that these reaction products are available to plants when blended with soil.

Zn and Zn Interactions

The amount of Zn absorbed by plants is a function of the amount supplied to the roots (Epstein and Stout, 1951). The availability of Zn to plants is dependent not only upon the rate of application, but also the inherent soil properties. For example, as clay content of a soil increases, the availability of added Zn decreases (Kalyanasundaram and Mehta, 1970).

A Zn - S interaction occurs in soils and plants. Lindsay (1972) reported that $SO_4^=$ fertilizers often increased Zn mobility in soils. Olsen and Watanabe (1979) reported that $SO_4^=$ increased the uptake and concentration of plant Zn. They suggest that the uncharged ion pair formed between these two ions may be the mechanism whereby $SO_4^=$ aids in Zn uptake.

Mo and Mo Interactions

Very minute amounts of Mo will affect the amount found in plant tissue. For example, as little as 0.9 kg Mo/ha added to soil as Na_2MoO_4 will greatly increase Mo absorbed by plants (Stout et al., 1951). Gupta and Munro (1969) noted that the amount of exchangeable Mo increased when Mo was added to soil. These researchers also found that Brussels sprouts grown on Mo treated soils increased in their Mo content of the second crop.

Gupta and Munro (1951) also reported that when no Mo was added to the soil, high rates of P increased Mo content of plant tissue only slightly. However, when Mo was added to the soil, high rates of P increased the Mo concentration in Brussels sprouts by several ppm. A mechanism in which a complex phosphomolybdate anion forms which is absorbed more readily by plants has been proposed by Barshad (1951). Because of this interaction between Mo and P Stout and coworkers (1951) have suggested that the P levels in the soil must be taken into account and not only the absolute soil Mo supply.

P and P Interactions

P fertilization has long been known to aid plant growth tremendously. Gupta and Munro (1969) found that as P applications were increased, both yield and P content in Brussels sprouts increased. Recently, ammonium polyphosphate fertilizers have been used with micronutrient applications because of the sequestering affect these phosphate fertilizers have on micronutrients. When the micronutrient cations in soils are sequestered by these ammonium polyphosphate fertilizers, various polyphosphate-metal complexes form resulting in increased micronutrient availability to plants (Mortvedt and Osborn, 1977).

pH Effects on Micronutrients

Micronutrient solubilities are effected by pH levels in soil. Most micronutrients including Fe, Mn, Zn and Cu are more available in soil solution at low pH levels while Mo is more available in basic soils. For example, the solubility of Fe is largely dependent upon the solubility of ferric hydroxide and pH. Above pH 8 the major ion is $Fe(OH)_4^-$. Phase diagrams of various Fe species are reported by Lindsay (1972).

pH also effects the amount of cations various chelating agents will extract from soil. EDTA chelated maximum Fe from pH 4 to pH 6 but decreased rapidly so that at pH 7.5 essentially no Fe was chelated from the soil solution. However, DTPA chelated more Fe at higher pH values than EDTA, hence the pH of soil solution must be considered when chelating agents are to be employed (Norvell, 1972).

CHAPTER III

MATERIALS AND METHODS

Two soils from western Oklahoma, Quinlan and Spur, were chosen to test micronutrient interactions because both soils are Fe deficient. The basic characteristics of these soils are reported in Table I.

TABLE I

BASIC SOIL CHARACTERISTICS OF QUINLAN AND SPUR SOILS

Soil	Classification	pH 1:1	Bray P-1 ug/g	OM %	$CaCO_3$ %
Quinlan	Typic Ustocrept	8.3	18	1.2	15.3
Spur	Fluventic Haplustoll	8.2	3	0.9	5.3

The soils were mixed, sifted and 1 kg soil was placed in plastic pots in the greenhouse. Treatments were arranged in a completely randomized design for each soil. Fertilizer treatments (Table II) were cross-banded on the soil about 2.5 to 3.8 cm below the soil surface to divide the soil into four quadrants. These treatments did not significantly affect the soil pH because of the small amounts of fertilizer used and also because the high percent $CaCO_3$ in these soils acted as a buffer. Equivalent rates for Fe, Mn, Zn, Cu, Mo and S in ug/g were 4.0, 2.5, 5.0, 2.5, 1.0 and 15.0, respectively. Eight sorghum seeds (Golden acres T-E66-B) were placed 0.8 to 1.3 cm below the soil surface and later thinned to a maximum of four plants per pot. Distilled water was used throughout the growing period to water the plants. Plants were clipped once; 56 kg N/ha was added. Regrowth occurred and a second clipping was obtained. The soil was placed in plastic bags to prevent moisture loss.

TABLE II

FERTILIZER TREATMENTS

Source	Treatment	Rate kg/ha
$FeSO_4$	Fe	9.0
$MnSO_4$	Mn	5.6
$ZnSO_4$	Zn	11.2
$CuSO_4$	Cu	5.6
Na_2MoO_4	Mo	2.2
Above + K_2SO_4	S	33.6
As Above	Fe + Mn	As Above
As Above	Fe + Mn + Zn	As Above
As Above	Fe + Mn + Zn + Cu	As Above
As Above	Fe + Mn + Zn + Cu + Mo	As Above
As Above	Fe + Mn + Zn + Cu + Mo + S	As Above
(11-37-0)	P	0.0
		19.6
		39.1
(11-37-0) + NH_4NO_3	N	112.1

Soil Procedures

The soil was mixed thoroughly and some soil from each pot was then oven dried while the remaining soil was kept in sealed plastic bags. Some soil was kept moist for micronutrient determinations since micronutrient levels change when soil is dried as compared to moist soil.

pH (1:1) was determined by adding 15 ml deionized water to 15 g dry soil. The soil and water were stirred and was allowed to equilibrate for 30 minutes, stirred again and pH values were read.

Soil P was determined by a modified Bray P-1 method (0.03N NH_4F in 0.025N HCl) using a 1:20 soil-solution extractant ratio (Bray and Kurtz, 1945). The extractant was prepared by adding 41.7 ml of concentrated HCl and 22.22 g of NH_4F to approximately 5 l water. This solution was then brought to 20 l. Soils were shaken for exactly 5 min and immediately filtered through Whatman No. 5 filter paper. Five milliliters of each sample and 5 ml standard was placed in 50 ml tubes. A blank of 5 ml of extracting solution was used. Ten milliliters of 1% boric acid solution was added (20 g H_3BO_3 in 2 l water) and mixed in. Next 5 ml ascorbic acid solution (prepared daily) was added and mixed. To make the ascorbic acid solution 1.06 g L-ascorbic acid was mixed with 200 ml of the ammonium molybdate-antimony potassium tartarate solution. The ammonium molybdate-antimony potassium tartarate solution was made by dissolving 12 g ammonium molybdate in 250 ml water. Antimony potassium tartarate (0.291 g) was dissolved in 100 ml water. The sulfuric acid solution was prepared by mixing 148 ml concentrated H_2SO_4 in 1000 ml water. These three solutions were mixed together and brought to a volume of 2 l with water and stored in a dark compartment. Color was allowed to develop for 1 hr after adding ascorbic acid solution and percent transmittance was determined on a Bausch and Lomb Spectronic 20 at 882 mu using a red filter. The color was stable for four hours.

Organic matter (% OM) was determined by placing 0.5 g dry soil into a 200 ml tall form beaker and adding 10 ml of 0.4N $K_2Cr_2O_7$ (19.164 g $K_2Cr_2O_7$ dissolved and diluted to 1 l with water). Sulfuric acid (15 ml) was then added. A blank of 10 ml of 0.4N $K_2Cr_2O_7$ was used. Beakers were placed on hot plates and heated to 161°C and stirred slowly while heating. Beakers were removed and cooled. Thermometer and inside of beaker were washed with water. Next, 100 to 125 ml water and 2 drops of ferroin indicator (1.485 g orthophenanthroline and 0.695 g ferrous sulfate dissolved in 100 ml water) were added. Excess dichromate was titrated with 0.2N ferrous ammonium sulfate solution (78.44 g $Fe(NH_4)_2(SO_4)_2$ and 20 ml concentrated H_2SO_4 diluted to 1 l).

Percent $CaCO_3$ was determined by placing 25 g dry soil in a 150 ml beaker and adding 50 ml of 0.5N HCl. The beaker was covered with a watch glass and boiled gently for 5 min, cooled and filtered with Whatman No. 42 filter paper. All acid was washed from soil with 25 ml water. Amount of unused acid was determined by adding 2 drops of 1% phenolphthalein in 60% ethanol and back titrated with 0.25N NaOH. (See United States Salinity Laboratory Staff, 1954.)

The turbidimetric method for determining soil $SO_4^=$ was used (Mehlich and Bowling) by shaking 5 g of dry soil with 25 ml of 0.5N NH_4Cl (26.74 g NH_4Cl was dissolved in 500 ml water and 0.06 g $Ca(OH)_2$ was added and diluted to 1 l with water) for 15 min. The solution was filtered through Whatman No. 5 filter paper. The filtrate was free from all turbidity. Into Spectronic 20 tubes was pipeted 5 ml of soil extractant and 1 ml seed reagent added. (To a 500 ml volumetric flask was added

210 ml of 100 ppm standard $SO_4^{=}$ solution and 2 ml concentrated HCl and diluted to volume with extracting solution.) Then 1 ml precipitating reagent (255 g barium acetate was placed into a 1 l volumetric flask containing 500 ml water and dissolved, 100 ml glacial acetic acid was added and diluted to volume with water) was added and mixed well. This solution was allowed to stand for 10 min and absorbance read on a Bausch and Lomb Spectronic 20 at 520 mu. Readings were taken between 10 and 20 min after the precipitating reagent was added.

Soil nitrogen was determined by adding 100 ml of 1.0N KCl to 20 g dry soil. The soil and KCl were shaken for 30 min and settled over-night. To determine NH_4^+ - N 25 ml of clear solution was placed into a steam distillation flask and 0.2 g MgO was added. The solution was dis-tilled into 5 ml of boric acid indicator. (40 g H_3BO_3 was placed in 2 l flask and approximately 1900 ml water was added and dissolved (heat was applied). The solution was cooled and 40 ml mixed indicator solution was added prepared by dissolving 0.099 g bromocresol green and 0.066 g methyl red in 100 ml ethanol. Then 0.01N NaOH was added to pH of 5.0 and made to volume with water.) A total volume of approximately 35 ml was obtained. Both flasks were removed and 0.2 g Devarda's alloy was added to the distillation flask for NO_3^- - N and returned to steam. The solution was distilled over into 5 ml of boric acid indicator solution to a total volume of approximately 35 ml. Distillate was titrated with 0.03N HCl.

The procedure discussed and tested by Lindsay and Norvell (1978) was used in this experiment to determine DTPA extractable micronutrients. To 10 g moist soil was added 25 ml extracting solution. Extracting solution was prepared by adding 93.1 ml triethanolamine, 10.29 g

$CaCl_2 \cdot 2H_2O$ and 33.6 ml diethylenetriamine pentaacetic acid pentasodium salt. The solution was brought to a volume of 2 l. The pH was adjusted to 7.3 with HCl to a total final volume of 7 l. Soils were shaken for 2 hr and filtered through Whatman No. 42 filter paper. Fe, Mn, Zn and Cu were determined on a Perkin-Elmer 403 Atomic Absorption flame spectrophotometer. Mo was determined on a Perkin-Elmer 272 Atomic Absorption spectrophotometer with the HGA 2200 graphite furnace and Autosampler, AS-1, assembly. The furnace was set to dry at 120°C for 30 sec, char at 1800°C for 22 sec and atomize at 2700°C for 10 sec with t set at 8 sec. The furnace was restandardized after every six samples.

Micronutrients extracted with 0.01M $CaCl_2$ were determined by adding 25 ml of 0.01M $CaCl_2$ to 10 g moist soil. The soil and extractant were shaken for 30 min and then filtered through Whatman No. 42 filter paper and read on atomic absorption units as specified above except the furnace was set to dry at 110°C for 30 sec.

Grigg (1953) found the acid ammonium oxalate method to be the only method out of six tested to agree with the order of Mo response for Australian soils. The procedure used in this study is modified from Reisenauer (1965) by adding 250 ml Tamm's solution to 25.0 g moist soil. Tamm's solution was prepared by dissolving 24.9 g ammonium oxalate and 12.6 g oxalic acid in water and bringing the solution to a volume of 1 l with water.) Samples were shaken 8 to 10 hrs or overnight and filtered through Whatman No. 42 filter paper that had been washed with 6.5M HCl. The first 10 to 15 ml of filtrate was discarded. The Mo was determined with the graphite furnace as listed above except the dry cycle was set at 160°C for 60 sec.

Plant Procedures

Plant samples were dried at 80°C for 12 hrs and ground to pass through a 200 mesh sieve.

A modified microkjeldahl procedure was used to determine plant N by placing 200 ± 3 mg of dry plant material in the bottom of a BD-40 digestion tube and adding 2.1 g catalyst mixture (100 g K_2SO_4, 10 g $CuSO_4$ and 1 g Se mixed and finely ground) and 7 ml of concentrated H_2SO_4. After the sample was thoroughly wet 1 ml of 30% H_2O_2 was added and the tubes were placed in a Tecator BD-40 block digestor that had been preheated to 420°C. Samples were digested for 1 hr, removed and cooled. Water (20 to 25 ml) was then added. Plant nitrogen was determined using steam distillation as reported by Bremner (1965).

Plant micronutrients were determined by placing 0.100 g dried plant tissue into a 50 ml test tube and adding 5 ml of concentrated HNO_3 and 2 ml concentrated $HClO_4$. Samples were heated at 100°C to a straw-yellow color and then temperature was raised to 175°C. Samples were heated to a pale yellow. If any plant tissue remained straw-yellow more HNO_3 was added and reheated at 100°C. When samples became pale yellow the temperature was raised to 230°C to 270°C and heated until 0.5 ml liquid remained in the tubes. Tubes were removed, cooled and 10 to 15 ml water was added. Samples were filtered through Whatman No. 2 filter paper into a 25 ml volumetric flask. Filter paper was washed with water and the flasks were filled to volume with water. K, Fe, Mn, Zn and Cu were read on the Perkin-Elmer 403 Atomic Absorption Spectrophotometer using an acetylene-air flame. Molybdenum was read on a Perkin-Elmer 272 Atomic Absorption Spectrophotometer using the HGA 2200 graphite furnace. The furnace was set to dry at 120°C for 40 sec, char at 1800°C for 22 sec and atomize at 2700°C for 10 sec with t set at 8 sec.

Significance of interactions were determined by using coefficients for orthogonal comparisons in regression. Significant differences between extraction procedures and between soils were determined by the t-test. All statistical methods used were outlined in Steel and Torrie (1960).

CHAPTER IV

RESULTS AND DISCUSSION

The following discussion explains differences within the soils tested due to the various extraction procedures used. Also discussed are the micronutrient interactions which occurred in each soil.

DTPA Extractable Micronutrients

Quinlan Soil

All micronutrients tested in this experiment showed significant differences due to treatment effects in the Quinlan soil DTPA extract except Zn. DTPA extractable micronutrient levels are listed in Table III.

DTPA extractable Fe levels in soils fertilized with three rates of P are shown in Figure 1. Mn applied singly to soil is representative of all singly applied micronutrients except Fe, thus these data points were omitted from this graph. As shown in Figure 1 the Fe + Mn + Zn + Cu treatment at 19.6 and 39.1 kg P/ha yielded the highest amount of Fe in DTPA extract, 2.1 and 2.6 ppm Fe in soil respectively. Fe applied singly to soil resulted in the second highest amount of DTPA extractable Fe at both the 19.6 and 39.1 kg P/ha rates, 2.0 and 2.4 ppm Fe in soil, respectively.

It is significant to note that all Fe treated soils yielded higher levels of DTPA extractable Fe than those soils which received no Fe at

TABLE III

DTPA EXTRACTABLE MICRONUTRIENT CONCENTRATIONS IN QUINLAN SOIL

Treatment	Fe	Mn	Zn	Cu	S	Mo
	------	------	ug/g	------	------	ng/g
			P applied, kg/ha 0			
Check	1.5	1.8	3.4	0.3	8.0	0.2
Fe	1.4	2.0	2.4	0.2	146.6	1.0
Mn	1.5	1.9	2.9	0.2	92.4	0.5
Zn	1.2	1.6	8.4	0.2	22.2	0.7
Cu	1.1	1.6	2.0	1.2	135.6	0.0
Mo	1.2	1.6	2.2	0.3	10.2	65.4
S	1.3	1.8	1.3	0.1	97.4	2.9
Fe + Mn	1.3	2.0	4.0	0.2	157.6	0.0
Fe + Mn + Zn	1.3	1.9	3.3	0.2	73.3	0.0
Fe + Mn + Zn + Cu	1.4	1.4	2.9	1.1	145.8	1.7
Fe + Mn + Zn + Cu + Mo	1.5	1.3	4.0	1.8	0.0	82.2
Fe + Mn + Zn + Cu + Mo + S	1.5	1.7	2.9	1.0	120.5	54.2
			P applied, kg/ha 19.6			
Fe	2.0	2.4	2.7	0.2	0.0	0.0
Mn	1.4	1.6	2.3	0.2	15.6	0.0
Zn	1.3	1.5	3.6	0.2	144.1	0.0
Cu	1.2	1.6	2.1	1.7	95.0	3.2
Mo	1.4	1.5	4.6	0.3	9.3	61.1
S	1.6	1.7	2.7	0.3	55.7	2.1
Fe + Mn	1.8	2.2	3.4	0.3	4.0	5.8
Fe + Mn + Zn	1.9	2.3	3.6	0.3	160.6	1.3
Fe + Mn + Zn + Cu	2.1	1.8	9.7	1.2	148.0	0.1
Fe + Mn + Zn + Cu + Mo	2.1	2.0	4.4	1.2	55.5	53.1
Fe + Mn + Zn + Cu + Mo + S	2.1	2.1	3.3	1.2	166.4	50.6
			P applied, kg/ha 39.1			
Fe	2.4	1.9	3.6	0.3	106.8	1.1
Mn	1.3	1.7	2.0	0.3	24.5	0.0
Zn	1.4	1.6	3.5	0.2	0.0	1.6
Cu	1.3	1.6	2.6	1.3	0.0	0.1
Mo	1.4	1.0	1.7	0.2	0.0	76.1
S	1.4	1.7	2.9	0.3	52.0	3.1
Fe + Mn	2.1	1.4	2.1	0.2	0.0	0.2
Fe + Mn + Zn	2.1	2.0	4.9	0.3	0.0	2.6
Fe + Mn + Zn + Cu	2.6	1.8	3.1	1.1	58.8	1.0
Fe + Mn + Zn + Cu + Mo	2.0	1.4	3.4	1.1	8.7	52.7
Fe + Mn + Zn + Cu + Mo + S	2.0	1.8	5.7	1.3	111.6	75.2

the two highest P rates. However, at the zero P level all treatments ranged from 1.1 to 1.5 ppm Fe with the check pot having the highest amount of Fe. At the 19.6 kg P/ha rate Fe concentrations increased in the DTPA extract over the zero P rate in all treatments except Mn. At the 39.1 kg P/ha rate this separation becomes very pronounced with Fe treated soil DTPA extract ranging from 2.0 to 2.6 ppm Fe and the soils which had no Fe added ranged from 1.3 to 1.4 ppm DTPA extractable Fe in soil.

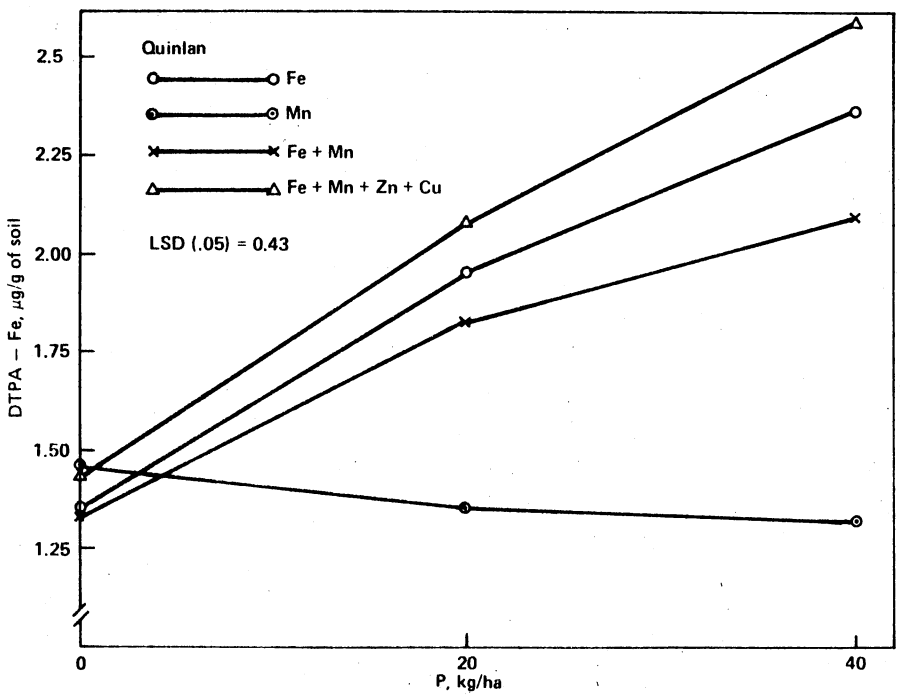

Figure 1. Effect of P on DTPA Extractable Fe In Quinlan Soil

From these results P treatments significantly affected DTPA extractable Fe levels ($LSD_{0.05}$ = 0.6). There are no differences in Fe concentrations among soils receiving no P. All soils treated with P and Fe (applied either singly or in combination with other micronutrients) resulted in significantly more DTPA extractable Fe than soils receiving no P. These results prove that there is a P - Fe interaction with P enhancing the amount of DTPA extractable Fe in Quinlan soil. Results are similar to those reported by Mortvedt and Osborn (1977) that P added in the form of 11-37-0 resulted in higher Fe levels in soil solution.

There are significant differences among treatments with respect to DTPA extractable Mn in Quinlan soil. When no P was applied the Fe and Fe + Mn treatments had the most DTPA extractable Mn (2.0 ppm) while the Fe + Mn + Zn + Cu + Mo and Fe + Mn + Zn + Cu treatments had the lowest Mn levels, 1.3 and 1.4 ppm respectively. At the 19.6 kg P/ha rate all Mn levels in the extract increased for each Mn treatment except for the Mn alone treatment. Then, at the 39.1 kg P/ha rate all of these treatments decreased the amount of DTPA extractable Mn, again with the exception of the Mn alone treatment. The Mn level for this treatment remained about the same as at the 19.6 kg P/ha rate.

At the intermediate P rate the highest amount of Mn was extracted from the Fe treatment. The next four highest Mn levels were found in Mn treated soils. Each of these four treatments contain Mn in combination with other micronutrients. The singly applied Mn treatment had a low Mn level in the extract. Iron treated soils significantly affected DTPA extractable Mn concentrations ($LSD_{0.05}$ = 0.1) at the intermediate P level with the exception of Fe + Mn + Zn + Cu and Fe + Mn + Zn + Cu + Mo treatments. The $FeSO_4$ in the fertilizer treatments may have decreased the availability of Mn to plants, hence there was a corresponding increase of DTPA extractable Mn in Fe treated soils as was discussed by Dahiya and Singh (1976) and Chaudhry et al. (1977).

There were significant differences among treatments with respect to DTPA extractable Cu in Quinlan soil. At all three P rates, a definite break between the Cu and no Cu treated soil occurred. The soils receiving no Cu ranged from 0.1 to 0.3 ppm DTPA extractable Cu whereas the soils treated with Cu ranged from 1.0 to 1.2 ppm Cu in soil at the zero P rate. There are no significant differences among P rates concerning Cu, hence, the differences discussed above are due to treatment differences and not P rates. Thus, added Cu will enhance DTPA extractable Cu in the soil.

Extractable Mo levels follow the same general trend as Cu. There is a dramatic break between Mo and no Mo treatments at all P rates. At the 19.6 kg P/ha rate, those soils receiving no Mo contained from 0 to 5.8 ppb Mo in soil while the Mo treated soils contained from 50.6 to 61.1 ppb DTPA extractable Mo in soil. Thus, added Mo significantly enhances DTPA extractable Mo in Quinlan soil.

Differences among treatments and P levels are significant with S as the dependent variable. The S alone treatment showed intermediate S levels at all three P rates while the Fe + Mn + Zn + Cu + Mo + S treatment had an intermediate S concentration at the zero P rate and the highest amount of S in the extract at the 19.6 and 39.1 kg P/ha rates. It appears that the other micronutrients in the Fe + Mn + Zn + Cu + Mo + S treatment interact with S to allow more S to be extracted from the soil. This effect could also be the result of addition of sulfate salts of the micronutrients.

It is interesting to note that with singly applied micronutrients, the zero P level contained more S than the other P rates except for Zn where the 19.6 kg P/ha rate contained the most S. When micronutrients were applied in combination, the intermediate P rate contained more S than the other P rates except for the Fe + Mn treatment. The Fe + Mn + Zn treatment started this trend having a P curve similar to the Zn applied singly to Quinlan soil.

Spur Soil

DTPA extractable micronutrients from Spur soil are listed in Table IV. Fe levels in Spur soil DTPA extract were significantly different among treatments and P rates. At the zero P rate all treatments are fairly close in Fe concentration with the check pot yielding the highest amount of Fe, 0.9 ppm in soil. At the intermediate P rate, all Fe treatments yielded more Fe in the DTPA extract than the zero Fe treatments. Fe levels in Fe treated soils ranged from 0.9 to 1.0 ppm while the range of Fe in Fe untreated soils was 0.8 to 0.9 ppm in soil. This separation became slightly more pronounced at the highest P rate.

DTPA extractable Fe is significantly different when P is the dependent variable. The treatments in which micronutrients were applied singly show little variation in Fe levels, however, the overall trend shows that there is more DTPA extractable Fe at the 39.1 kg P/ha rate than at the other two P rates. When micronutrients were applied in combination to Spur soil, the zero P rates showed little variation in Fe concentration in the extract and in each treatment contained the lowest amount of DTPA extractable Fe. As P was added, Fe levels increased with

TABLE IV

DTPA EXTRACTABLE MICRONUTRIENT CONCENTRATIONS IN SPUR SOIL

Treatment	Fe	Mn	Zn	Cu	S	Mo
	ug/g					ng/g
P applied, kg/ha 0						
Check	0.9	1.1	3.9	0.3	0	6.0
Fe	0.8	1.1	3.4	0.4	0	1.2
Mn	0.8	1.0	2.7	0.3	0	1.8
Zn	0.8	1.2	9.0	0.3	0	0.2
Cu	0.8	1.1	3.1	0.9	0	2.1
Mo	0.8	1.0	4.4	0.3	0	58.5
S	0.8	1.0	9.3	0.3	0	3.4
Fe + Mn	0.8	1.2	2.9	0.0	0	3.5
Fe + Mn + Zn	0.8	1.1	4.0	0.4	0	2.0
Fe + Mn + Zn + Cu	0.8	1.3	7.9	1.1	0	1.4
Fe + Mn + Zn + Cu + Mo	0.8	1.0	5.8	0.8	0	54.5
Fe + Mn + Zn + Cu + Mo + S	0.8	1.0	4.2	1.1	0	62.8
P applied, kg/ha 19.6						
Fe	0.9	1.0	2.1	0.3	0	3.4
Mn	0.8	1.2	3.4	0.3	0	3.0
Zn	0.9	1.2	3.7	0.3	0	3.8
Cu	0.8	0.9	3.6	1.5	0	7.0
Mo	0.8	0.9	3.3	0.4	0	63.2
S	0.8	1.1	4.5	0.3	0	4.2
Fe + Mn	0.9	1.1	3.9	0.4	0	3.5
Fe + Mn + Zn	0.9	1.2	4.5	0.3	0	1.1
Fe + Mn + Zn + Cu	1.0	1.2	5.2	1.0	0	1.8
Fe + Mn + Zn + Cu + Mo	1.0	1.0	4.6	1.0	0	73.0
Fe + Mn + Zn + Cu + Mo + S	1.0	1.1	3.7	1.0	0	57.3
P applied, kg/ha 39.1						
Fe	1.0	1.0	2.9	0.4	0	0.5
Mn	0.8	1.2	2.0	0.3	0	6.2
Zn	0.9	1.0	6.2	0.3	0	1.0
Cu	0.9	1.1	2.8	0.9	0	1.9
Mo	0.8	1.1	3.2	0.3	0	56.8
S	0.8	1.0	7.5	0.3	0	3.1
Fe + Mn	1.0	1.2	3.8	0.4	0	0.2
Fe + Mn + Zn	1.0	1.2	5.0	0.4	0	12.2
Fe + Mn + Zn + Cu	1.4	1.0	5.4	1.2	0	3.5
Fe + Mn + Zn + Cu + Mo	1.0	1.1	3.5	1.0	0	59.0
Fe + Mn + Zn + Cu + Mo + S	1.0	0.8	7.4	0.9	0	58.5

the highest P rate resulting in the highest Fe levels in the extract except in the Fe + Mn + Zn + Cu + Mo + S treatment.

DTPA extractable Zn concentrations showed significant differences among treatments, but not among P rates. Zinc treated soils yielded the highest amounts of DTPA extractable Zn at the 0 and 39.1 kg P/ha rates with only a few exceptions. At the highest P rate, the Fe + Mn + Zn + Cu + Mo + S treatment yielded a Zn concentration of 7.4 ppm which is just slightly less than the S treatment Zn level of 7.5 ppm in soil.

Copper treated soils were much higher in DTPA extractable Cu than Cu untreated Spur soil. For example, at 39.1 kg P/ha those soils receiving Cu had Cu levels in the soil ranging from 0.9 to 1.2 ppm while those soils receiving no Cu ranged from 0.3 to 0.4 ppm DTPA extractable Cu. Thus, it may be concluded that Spur soils receiving Cu will contain more DTPA extractable Cu than those soils receiving no Cu. There were no significant differences among P levels with Cu as the dependent variable, therefore, the observed differences in the amount of DTPA extractable Cu were a result of treatment differences alone.

Molybdenum treated soils showed much greater Mo concentrations in the DTPA extract than treatments where no Mo was applied to Spur soil. For instance, at the zero P rate, Mo concentrations in treatments containing no Mo ranged from 0.2 to 6.0 ppb Mo while Mo levels in those soils treated with Mo ranged from 54.5 to 62.8 ppb Mo in soil. There were no significant differences in Mo levels at the varying P applications, hence, this great difference in Mo concentration in the DTPA extract was due to treatment differences alone. Where Mo was added to Spur soil, a high level of Mo was found in the DTPA extract. However, where no Mo was added to the soil, very little Mo was found in the DTPA extract.

In all treatments no S was detected in the soil. The turbidimetric method of determining sulfates in soil may not be sensitive with all soils, especially Spur soil.

Quinlan Versus Spur Soil

Quinlan soil contained more DTPA extractable Fe than Spur soil for each treatment and these differences were significant except with the Fe + Mn + Zn + Cu treatment at the highest P rate. (See Table XI, Appendix A.) Quinlan soil also yielded more DTPA extractable Mn than Spur soil in all treatments except Mo at the highest P rate. However, these differences were significant in only about three-fifths of the treatments.

Zinc, Cu and Mo varied with treatment as to which soil contained the most of these micronutrients in DTPA extract. The general trend is for Spur soil to yield more DTPA extractable Zn, Cu and Mo than Quinlan soil. However, these differences are only slight with few being significant.

For each treatment Quinlan soil contained more S, determined by the turbidimetric method, than Spur soil. Slightly more than half of these differences were significant. About half of the pots containing Quinlan soil contained more P than those pots containing Spur soil (Table XXI, Appendix B). Only about one fourth of these differences were significant.

0.01M $CaCl_2$ Extractable Micronutrients

The only micronutrients displaying significant differences when Quinlan soil was extracted with 0.01M $CaCl_2$ were Cu and Mo. In Spur soil Mn concentrations were significantly different with varying micronutrients and P rates while Mo concentrations were significantly different with varying treatments. Dilute $CaCl_2$ extractable micronutrient levels from Quinlan soil are listed in Table V and from Spur soil in Table VI. Addition of $FeSO_4$ did not affect levels of 0.01M $CaCl_2$ extractable Fe (Figure 2).

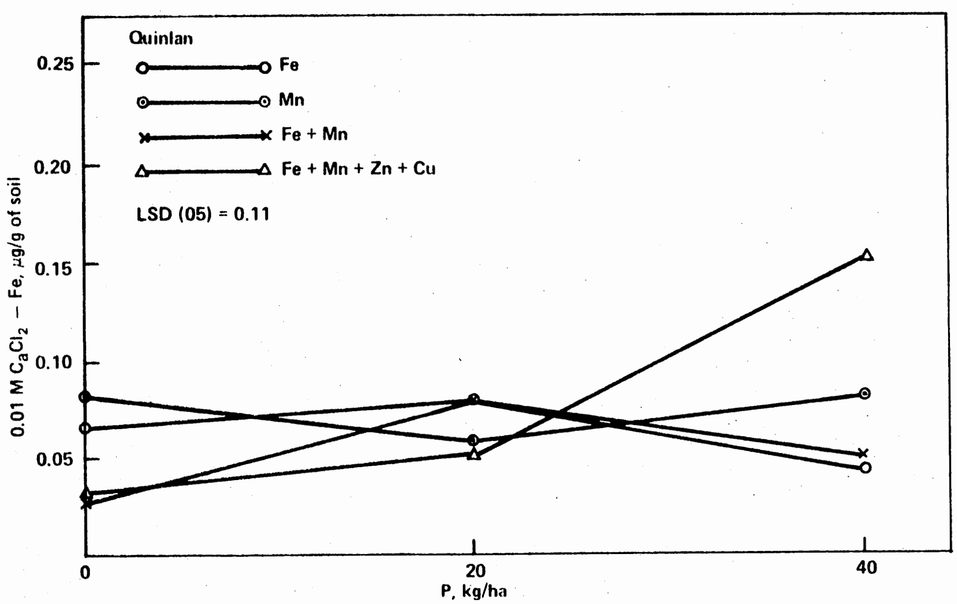

Figure 2. Effect of P on 0.01M $CaCl_2$ Extractable Fe in Quinlan Soil

TABLE V

0.01M $CaCl_2$ EXTRACTABLE MICRONUTRIENT CONCENTRATIONS IN QUINLAN SOIL

	P applied, kg/ha 0				
Treatment	Fe	Mn	Zn	Cu	Mo
	----------------	ug/g	----------		ng/g
Check	0.0	0.0	2.6	0.1	1.5
Fe	0.1	0.0	1.2	0.0	1.1
Mn	0.1	0.0	1.5	0.0	3.4
Zn	0.1	0.0	0.6	0.0	3.1
Cu	0.1	0.0	0.6	0.0	1.5
Mo	0.1	0.0	1.0	0.0	42.0
S	0.1	0.0	2.8	0.1	4.1
Fe + Mn	0.2	0.0	0.8	0.1	0.3
Fe + Mn + Zn	0.0	0.0	0.8	0.0	1.5
Fe + Mn + Zn + Cu	0.0	0.0	0.9	0.0	2.2
Fe + Mn + Zn + Cu + Mo	0.0	0.0	0.4	0.0	36.5
Fe + Mn + Zn + Cu + Mo + S	0.1	0.0	0.7	0.0	41.9
	P applied, kg/ha 19.6				
Fe	0.1	0.0	3.0	0.0	6.5
Mn	0.1	0.0	2.4	0.1	1.9
Zn	0.1	0.0	1.6	0.1	4.2
Cu	0.0	0.0	1.0	0.0	2.4
Mo	0.0	0.0	1.6	0.1	36.0
S	0.1	0.0	1.3	0.1	4.5
Fe + Mn	0.1	0.0	3.2	0.1	4.5
Fe + Mn + Zn	0.0	0.0	1.1	0.1	1.3
Fe + Mn + Zn + Cu	0.0	0.0	1.3	0.1	4.1
Fe + Mn + Zn + Cu + Mo	0.1	0.0	0.7	0.0	39.2
Fe + Mn + Zn + Cu + Mo + S	0.2	0.0	0.3	0.0	39.4
	P applied, kg/ha 39.1				
Fe	0.0	0.0	1.0	0.0	1.8
Mn	0.1	0.0	0.8	0.1	0.7
Zn	0.0	0.0	0.8	0.0	1.6
Cu	0.1	0.0	1.3	0.1	7.9
Mo	0.1	0.0	2.0	0.1	43.6
S	0.1	0.0	0.8	0.1	2.4
Fe + Mn	0.0	0.0	0.9	0.1	3.4
Fe + Mn + Zn	0.2	0.0	0.7	0.1	5.2
Fe + Mn + Zn + Cu	0.2	0.0	0.5	0.1	3.9
Fe + Mn + Zn + Cu + Mo	0.1	0.0	0.9	0.0	45.6
Fe + Mn + Zn + Cu + Mo + S	0.1	0.0	1.0	0.0	34.9

TABLE VI

0.01M $CaCl_2$ EXTRACTABLE MICRONUTRIENT CONCENTRATIONS IN SPUR SOIL

Treatment	Fe	Mn	Zn	Cu	Mo
	ug/g				ng/g
	P applied, kg/ha 0				
Check	0.1	0.0	0.5	0.1	1.0
Fe	0.2	0.0	0.4	0.0	0.0
Mn	0.2	0.0	0.4	0.1	0.8
Zn	0.2	0.0	0.6	0.5	1.3
Cu	0.2	0.0	0.8	0.0	1.5
Mo	0.1	0.0	0.4	0.1	30.5
S	0.2	0.0	0.6	0.1	4.7
Fe + Mn	0.2	0.0	0.6	0.1	2.2
Fe + Mn + Zn	0.2	0.0	0.4	0.1	2.4
Fe + Mn + Zn + Cu	0.1	0.0	0.5	0.0	3.8
Fe + Mn + Zn + Cu + Mo	0.2	0.0	1.1	0.0	39.4
Fe + Mn + Zn + Cu + Mo + S	0.2	0.0	0.6	0.0	11.3
	P applied, kg/ha 19.6				
Fe	0.1	0.0	0.6	0.0	2.3
Mn	0.1	0.0	1.0	0.0	0.9
Zn	0.2	0.1	0.4	0.1	1.1
Cu	0.2	0.0	0.6	0.0	3.4
Mo	0.1	0.0	0.8	0.1	30.2
S	0.1	0.0	0.5	0.1	1.1
Fe + Mn	0.1	0.0	0.8	0.1	2.2
Fe + Mn + Zn	0.2	0.1	0.3	0.1	2.2
Fe + Mn + Zn + Cu	0.1	0.0	0.8	0.1	1.3
Fe + Mn + Zn + Cu + Mo	0.2	0.0	0.4	0.1	26.6
Fe + Mn + Zn + Cu + Mo + S	0.2	0.1	0.6	0.1	41.3
	P applied, kg/ha 39.1				
Fe	0.2	0.0	0.5	0.0	1.1
Mn	0.1	0.0	1.0	0.0	0.0
Zn	0.1	0.0	0.5	0.1	1.3
Cu	0.2	0.0	0.6	0.1	1.6
Mo	0.2	0.0	1.1	0.1	20.1
S	0.1	0.0	0.6	0.1	2.1
Fe + Mn	0.2	0.0	0.5	0.1	0.6
Fe + Mn + Zn	0.2	0.0	0.2	0.0	1.8
Fe + Mn + Zn + Cu	0.1	0.0	2.5	0.1	2.0
Fe + Mn + Zn + Cu + Mo	0.1	0.0	0.4	0.1	18.6
Fe + Mn + Zn + Cu + Mo + S	0.2	0.0	0.7	0.1	39.1

There were significant differences among treatments for 0.01M $CaCl_2$ extractable Cu in Quinlan soil. At the zero P rate, Cu treatments yielded low to intermediate extractable Cu values. At the 19.6 kg P/ha rate all Cu treatments except Fe + Mn + Zn + Cu yielded approximately the same or less amounts of Cu in the 19.6 kg P/ha rate when compared to the zero P rate. At the highest P rate, Cu treatments yielded intermediate Cu values. All soils treated with Cu decreased in the amount of Cu in dilute $CaCl_2$ extract when the P rate was increased from 19.6 to 39.1 kg P/ha except for the Cu alone treatment. Thus, P does not play a significant role in Cu availability in soil to dilute $CaCl_2$.

Applied Mo significantly enhanced $CaCl_2$ extractable Mo at all P levels in both soils ($LSD_{0.05}$ = 4.8 for Quinlan soil). For example, at the zero P rate on Quinlan soil treatments containing no Mo ranged from 0.3 to 3.1 ppb Mo while the Mo treated soils ranged from 36.5 to 42.0 ppb dilute $CaCl_2$ extractable Mo in soil.

Quinlan Versus Spur Soil

When the dilute $CaCl_2$ procedure was used to compare the two soils some interesting trends can be found. In all treatments but two, Fe + Mn + Zn and Fe + Mn + Zn + Cu both at 39.1 kg P/ha, Spur soil contained more dilute $CaCl_2$ extractable Fe than Quinlan soil. (See Table XII, Appendix A.)

This trend holds true for dilute $CaCl_2$ extractable Mn and Cu, while the reverse trend is observed for Zn and Mo. That is, Quinlan soil contained more Zn and Mo in the 0.01M $CaCl_2$ extract than Spur soil. These differences between Zn, Mn, Cu and Mo are only trends with just a few of the treatments showing significance.

DTPA Versus $CaCl_2$ Extractions

The DTPA and 0.01M $CaCl_2$ extraction procedures yielded very different micronutrient levels in their respective extracts. Differences of micronutrients with respect to treatments between DTPA and dilute $CaCl_2$ extractions are listed in Table XIII, Appendix A for Quinlan soil and Table XIV, Appendix A for Spur soil. In every treatment, the DTPA procedure extracted more Fe, Mn and Cu than the dilute $CaCl_2$ procedure except the Mn treatment at the intermediate P rate and the Fe + Mn treatment at the highest P rate on Quinlan soil where no significant differences were found. Zinc demonstrated this same general trend, but the differences were not significant in all treatments.

These results are not surprising when it is remembered that DTPA chelates exchangeable cations and labile organically bound compounds while 0.01M $CaCl_2$ will leach out water soluble micronutrients only. Thus, DTPA will yield higher cation concentrations in the extract than 0.01M $CaCl_2$. From data collected throughout this study 0.01M $CaCl_2$ was not sensitive to various treatment differences when micronutrient levels in the extract are compared. Thus, DTPA was a more sensitive measure of micronutrient levels in soil.

Phosphorus rates affect DTPA extractable micronutrients, but appear to have no affect of 0.01M $CaCl_2$ extractable micronutrients.

Molybdenum Extractions

Molybdenum levels extracted from Quinlan soil by DTPA, 0.01M $CaCl_2$ and ammonium oxalate are shown in Figure 3. Molybdenum showed a reverse trend from the other micronutrients in that the dilute $CaCl_2$ extract yielded approximately the same concentrations in soil as the DTPA procedure on both soils. Only a few treatment differences were significant. (See Tables XV and XVI, Appendix A.)

This difference can be understood when it is remembered that Mo is available in the soil as the molybdate anion, $MoO_4^{=}$, while the other micronutrients in this study are available in their cation states. DTPA chelates cations since it is negatively charged, hence the molybdate anion will not be as attracted to another anion as it will be to 0.01M $CaCl_2$. Thus, DTPA should, and generally does, extract more Fe, Mn, Zn and Cu than 0.01M $CaCl_2$ while dilute $CaCl_2$ should extract more Mo than DTPA.

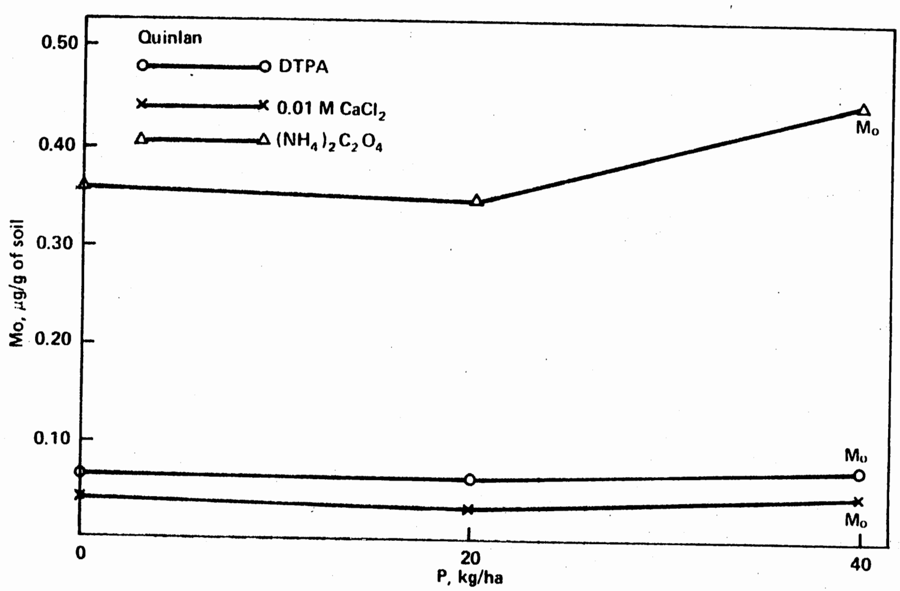

Figure 3. Effect of Mo Extraction Procedures in Quinlan Soil

When the ammonium oxalate procedure is compared with both DTPA and 0.01M $CaCl_2$ the ammonium oxalate method extracted more Mo than either of the other two methods in both soils. (See Tables XV and XVI, Appendix A.) These differences were significant in at least $\frac{1}{2}$ of the treatments. Hence, the effectiveness of these procedures concerning Mo extraction can be ranked as: Ammonium oxalate > 0.01M $CaCl_2$, DTPA.

The reason for DTPA to extract the least amount of Mo was stated previously. It is generally accepted that dilute $CaCl_2$ will leach out the water soluble Mo in soil, whereas the acid ammonium oxalate method is employed to determine exchangeable Mo in soil (Grigg, 1953) hence it will extract the highest amount of Mo when these three methods are considered.

Quinlan Versus Spur Soil

There were very few significant differences among the three Mo extraction procedures when Quinlan soil was compared to Spur soil. (See Table XVII, Appendix A.) The conclusion may be drawn that these soils contain approximately the same amount of DTPA, 0.01M $CaCl_2$ and acid ammonium oxalate extractable Mo. The differences encountered within each extract were small enough to be considered negligible in most treatments.

Initial Growth

Quinlan Soil

Micronutrient levels in the initial plant growth are listed in Table VII. There were no significant differences in Fe and Zn concentrations in plant material grown on Quinlan soil with varying treatments

TABLE VII

YIELDS AND MICRONUTRIENT CONCENTRATIONS IN INITIAL GROWTH OF GRAIN SORGHUM GROWN IN QUINLAN SOIL

Treatment	Fe	Mn	Zn	Cu	Mo	Yield
			ug/g			g/plant
			P applied, kg/ha 0			
Check	79	106	343	13	1.0	0.062
Fe	86	98	146	13	8.6	0.040
Mn	53	91	223	8	0.4	0.056
Zn	69	106	303	8	0.2	0.048
Cu	64	102	70	13	1.2	0.043
Mo	66	77	31	5	4.9	0.049
S	nd	nd	nd	nd	nd	0.039
Fe + Mn	76	89	80	11	0.3	0.054
Fe + Mn + Zn	70	96	142	15	0.4	0.058
Fe + Mn + Zn + Cu	3946	139	212	29	7.5	0.040
Fe + Mn + Zn + Cu + Mo	88	91	58	9	9.4	0.048
Fe + Mn + Zn + Cu + Mo + S	122	96	300	15	5.5	0.046
			P applied, kg/ha 19.6			
Fe	103	88	182	16	2.0	0.090
Mn	110	143	453	17	0.5	0.086
Zn	83	138	229	18	0.5	0.089
Cu	94	131	444	20	0.5	0.095
Mo	74	86	320	11	66.8	0.084
S	54	116	31	5	0.3	0.080
Fe + Mn	109	98	247	11	0.3	0.104
Fe + Mn + Zn	98	108	71	16	0.6	0.099
Fe + Mn + Zn + Cu	94	127	154	16	0.3	0.113
Fe + Mn + Zn + Cu + Mo	83	88	78	15	44.9	0.108
Fe + Mn + Zn + Cu + Mo + S	97	128	155	15	11.7	0.093
			P applied, kg/ha 39.1			
Fe	67	87	141	12	0.7	0.138
Mn	98	138	235	10	0.6	0.092
Zn	118	143	86	14	4.0	0.080
Cu	152	147	464	18	0.4	0.089
Mo	91	162	135	9	100.8	0.086
S	111	135	53	13	0.7	0.092
Fe + Mn	58	92	340	0	1.0	0.154
Fe + Mn + Zn	106	132	129	17	0.8	0.104
Fe + Mn + Zn + Cu	78	122	228	17	0.3	0.122
Fe + Mn + Zn + Cu + Mo	172	131	161	15	17.5	0.117
Fe + Mn + Zn + Cu + Mo + S	99	154	94	15	19.8	0.119

nd - no data

or P rates. There were significant differences concerning Mn with varying P rates but not with different treatments. In all treatments but Fe and Fe + Mn + Zn + Cu, added P resulted in the highest levels of plant Mn. With these two exceptions the pots which had no P added yielded the highest amount of plant Mn. The overall trend is for the 39.1 kg P/ha rate to yield the highest levels of plant Mn and the zero P rate to yield the least amount of plant Mn.

There were significant differences among treatments concerning Cu levels in grain sorghum. At the zero P rate Cu treatments yielded the three highest levels of plant Cu with the Fe + Mn + Zn + Cu treatment yielding the highest level of plant Cu, 29 ppm. At the intermediate P level of this study, Cu applied singly to soil yielded the highest plant Cu level, 20 ppm, while the other Cu treatments yielded intermediate Cu levels. At the highest P rate, Cu treatments yielded the highest concentration of plant Cu with the Cu alone treatment again resulting in the highest plant Cu levels, 18 ppm. Thus, Cu applied to soil will enhance Cu uptake into plants. There were no significant differences among Cu plant levels at the varying P rates, hence these observed differences were due solely to treatment differences.

Potassium levels in grain sorghum varied significantly with different treatments. (See Table XXIII, Appendix C.) The least amount of plant K was obtained when no P was added to soil for every treatment. There were no significant differences between the other two P rates concerning the amount of plant K, thus added P, whether at 19.6 or 39.1 kg/ha, enhances K uptake in grain sorghum.

Grain sorghum grown on Quinlan soil resulted in significantly different concentrations of plant Mo with both varying treatments and P rates. At the lowest P rate there were no real differences among treatments and Mo uptake in plants. However, as P was added a definite separation occurs between soils treated with Mo and those receiving no Mo. At the two highest P rates Mo applied singly to soil yielded the highest concentration of plant Mo. Thus, Mo applied to Quinlan soil enhances plant Mo uptake. However, uptake was depressed somewhat when Mo was applied in combination with other micronutrients. Stout and co-workers (1951) showed that Mo in concentrations of 0.9 kg/ha added as Na_2MoO_4 largely increased the amount of Mo absorbed by plants.

Plant yields varied significantly as treatments and P rates were changed. Figure 4 shows yields plotted for micronutrients applied singly to the soil and Figure 5 presents yields plotted for micronutrients in combination at the three P rates. At the zero P rate yields ranged from 0.039 to 0.062 g/plant. S applied singly resulted in the lowest yield while the check pot resulted in the highest yield. At the 19.6 kg P/ha rate Fe treatments generally gave the highest plant yields and at the 39.1 kg P/ha rate all Fe treatments resulted in the highest plant yields. Fe treated soils have yields ranging from 0.104 to 0.154 g/plant while those soils not receiving Fe showed yields ranging from 0.080 to 0.092 g/plant. Thus, a P - Fe interaction exists where Fe in the presence of P significantly increased grain sorghum yields.

There was a definite break in yield between those plants grown with no P and those which had P added to the soil. It was also interesting to notice that the 39.1 kg P/ha rate greatly enhances grain sorghum yield when Fe or Fe + Mn are applied to Quinlan soil. Thus, it appears that P was most effective in enhancing plant growth at 39.1 kg P/ha when either Fe or Fe + Mn were applied to this soil. For all of the other

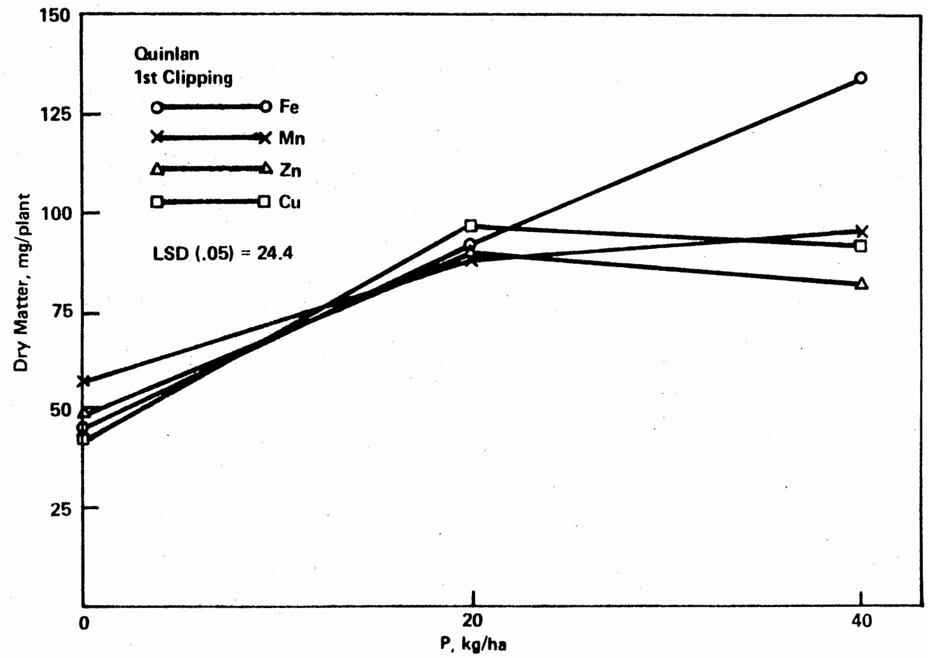

Figure 4. Effect of P and Singly Applied Micronutrients on Initial Yields of Grain Sorghum Grown in Quinlan Soil

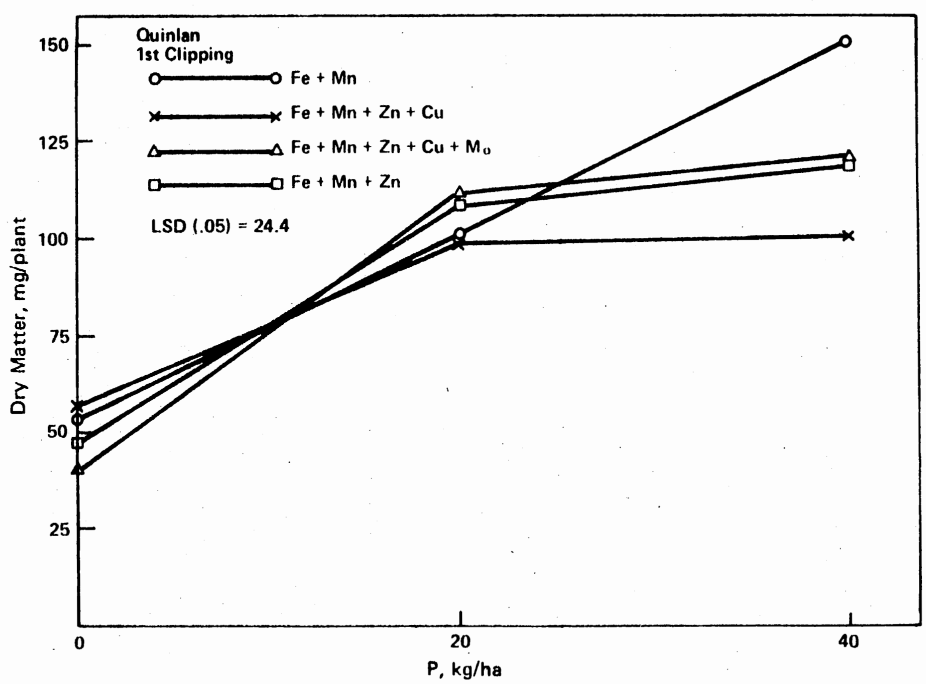

Figure 5. Effect of P and Micronutrients Applied in Combination on Initial Yields of Grain Sorghum Grown in Quinlan Soil

treatments there were no great differences in plant yields at either the 19.6 or 39.1 kg P/ha rates. Many workers hypothesize that there is an Fe - Mn imbalance in Fe deficient soils in which there is a low level of Fe and a high Mn level, thus a way to alleviate this imbalance is to apply Fe to the soil at the right level and yields may be increased.

Spur Soil

Micronutrient levels in the initial plant growth on Spur soil are listed in Table VIII. Grain sorghum grown on Spur soil showed no significant differences in micronutrient content in the plant when either treatments or P rates were varied for Fe, Zn, Cu and K. Mn, on the other hand, varied significantly when different treatments and P rates were applied to the soil.

At the zero P rate Mn treatments gave quite different Mn concentrations in plant tissue. At the intermediate P rate Mn applied singly to soil yielded a Mn level in plant tissue intermediate to the other Mn treatments. Then, at 39.1 kg P/ha the Mn treatment yielded the least amount of plant Mn. Thus, it appears that P plays a depressing role in Mn uptake in grain sorghum when Mn is applied singly to soil.

At 39.1 kg P/ha the treatments tend to pair up. For instance, the Fe + Mn + Zn + Cu + Mo and Mo treatments yielded the two highest levels of plant Mn. Next, the Fe + Mn + Zn + Cu and Cu treatments were paired up with the S treatment in between. Then the S and Fe + Mn + Zn + Cu + Mo + S treatments were paired up with only the Cu treatment in between them. The Fe + Mn and Fe treatments have the Fe + Mn + Zn and Zn treatments in between them, and lastly, the Fe and Mn applied singly to soil resulted in the two lowest levels of Mn in plant tissue. Thus, an

TABLE VIII

YIELDS AND MICRONUTRIENT CONCENTRATIONS IN INITIAL GROWTH OF GRAIN SORGHUM GROWN IN SPUR SOIL

Treatment	Fe	Mn	Zn	Cu	Mo	Yield
	ug/g					g/plant
P applied, kg/ha 0						
Check	69	93	192	17	1.1	0.075
Fe	79	76	215	12	2.8	0.113
Mn	256	105	232	17	1.0	0.065
Zn	32	207	329	12	1.4	0.065
Cu	42	104	208	16	1.1	0.072
Mo	52	108	138	19	164.0	0.100
S	62	102	193	15	1.3	0.089
Fe + Mn	80	78	258	16	1.2	0.115
Fe + Mn + Zn	58	100	145	12	1.8	0.137
Fe + Mn + Zn + Cu	75	78	282	12	1.5	0.088
Fe + Mn + Zn + Cu + Mo	0	91	166	14	78.6	0.138
Fe + Mn + Zn + Cu + Mo + S	75	109	106	19	25.2	0.131
P applied, kg/ha 19.6						
Fe	34	32	358	12	0.7	0.197
Mn	62	63	212	11	1.5	0.172
Zn	100	60	140	10	0.8	0.087
Cu	149	97	312	17	3.4	0.098
Mo	98	80	328	8	70.6	0.111
S	385	71	152	11	1.8	0.122
Fe + Mn	93	44	183	16	1.0	0.277
Fe + Mn + Zn	26	68	158	12	1.1	0.288
Fe + Mn + Zn + Cu	25	62	60	12	0.0	0.154
Fe + Mn + Zn + Cu + Mo	139	78	325	22	53.1	0.216
Fe + Mn + Zn + Cu + Mo + S	31	65	103	15	58.1	0.220
P applied, kg/ha 39.1						
Fe	15	44	204	14	0.2	0.496
Mn	0	42	208	15	00.1	0.395
Zn	108	48	435	15	17.0	0.096
Cu	162	68	125	612	1.7	0.075
Mo	94	93	160	16	148.0	0.106
S	36	81	250	14	1.1	0.139
Fe + Mn	72	55	128	13	1.0	0.270
Fe + Mn + Zn	6	52	188	14	0.7	0.231
Fe + Mn + Zn + Cu	36	81	79	14	0.7	0.165
Fe + Mn + Zn + Cu + Mo	68	98	260	18	54.2	0.259
Fe + Mn + Zn + Cu + Mo + S	38	59	390	14	75.5	0.172

order may be established among these micronutrients concerning their effect to aid Mn uptake in plants. It is as follows:

$$Mo > Cu > S > Zn > Fe > Mn.$$

Molybdenum again showed the same general trend for Mo uptake in plants on Spur soil as it did on Quinlan soil. There was a definite break in the curve between Mo treatments and those plants grown in soil not treated with Mo. Thus, Mo added to soil will enhance Mo uptake in grain sorghum with Mo being applied singly to the soil demonstrating the greatest amount of plant Mo uptake.

Plant dry matter yield varied significantly when both treatments and P rates were changed. As shown in Figure 6 the Fe treatments resulted in the highest plant yields at all P rates except for the Mn alone treatment at the 39.1 kg P/ha rate. Thus, Fe applied to Spur soil singly or in combination with other micronutrients will enhance plant growth.

Phosphorus played an important role in plant yield, also. Figure 6 shows that when no P was applied to soil, plant growth was not aided by applied micronutrients. However, when Fe was added to soil singly or in combination with other micronutrients, P enhanced plant growth. Generally, there were no significant differences between plant yields at either the 19.6 or 39.1 kg P/ha rates. When Zn, Cu, Mo or S were applied singly to soil very little difference was observed in yield at the differing P levels. Thus, Fe significantly enhanced plant growth in the presence of P ($LSD_{0.05} = 0.04$).

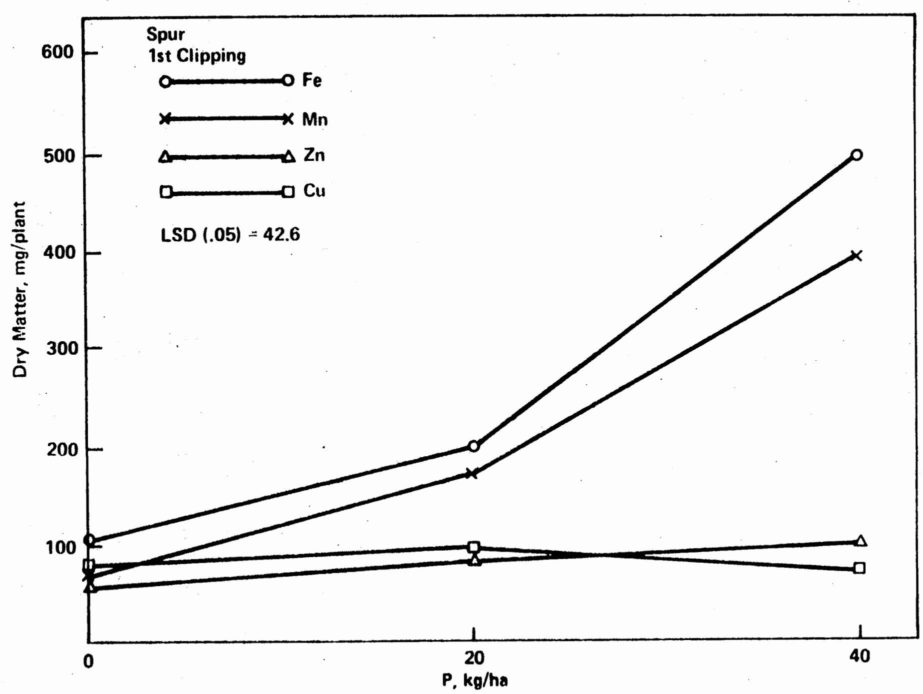

Figure 6. Effect of P and Singly Applied Micronutrients on Initial Yields of Grain Sorghum Grown in Spur Soil

Quinlan Versus Spur Soil

Significantly higher levels of K were found in plants grown in Quinlan soil than those grown in Spur soil (Table XVIII, Appendix A). The differences between plant Fe, Mn, Zn, Cu and Mo were essentially the same from the initial harvest on both soils.

Regrowth

Quinlan Soil

Micronutrient levels in the regrowth in Quinlan soil are listed in Table IX. There were no significant differences among treatments or P rates for Fe, Zn, Cu or K concentrations in the sorghum regrowth.

TABLE IX

YIELDS AND MICRONUTRIENT CONCENTRATIONS IN REGROWTH OF GRAIN SORGHUM GROWN IN QUINLAN SOIL

Treatment	Fe	Mn	Zn	Cu	Mo	Yield
	ug/g					g/plant
	P applied, kg/ha 0					
Check	172	108	280	9	0.4	0.049
Fe	183	82	572	9	2.4	0.059
Mn	110	81	446	7	0.4	0.045
Zn	211	82	165	8	0.0	0.035
Cu	35	78	50	5	0.5	0.027
Mo	132	89	802	7	3.4	0.043
S	62	75	172	8	0.0	0.029
Fe + Mn	265	73	75	7	0.6	0.059
Fe + Mn + Zn	133	72	93	7	0.3	0.048
Fe + Mn + Zn + Cu	162	108	88	8	0.7	0.036
Fe + Mn + Zn + Cu + Mo	78	85	125	8	11.0	0.048
Fe + Mn + Zn + Cu + Mo + S	nd	nd	nd	nd	nd	0.027
	P applied, kg/ha 19.6					
Fe	77	43	347	7	0.2	0.331
Mn	143	106	356	6	1.2	0.108
Zn	122	100	518	8	0.9	0.078
Cu	136	111	232	10	0.2	0.057
Mo	91	88	255	24	15.6	0.057
S	125	50	115	8	0.0	0.048
Fe + Mn	101	55	100	5	0.3	0.355
Fe + Mn + Zn	85	72	132	8	0.2	0.390
Fe + Mn + Zn + Cu	124	68	246	8	0.2	0.302
Fe + Mn + Zn + Cu + Mo	114	63	685	9	9.9	0.394
Fe + Mn + Zn + Cu + Mo + S	188	86	533	8	5.9	0.259
	P applied, kg/ha 39.1					
Fe	129	52	892	9	0.2	0.586
Mn	351	89	64	6	0.6	0.056
Zn	72	122	318	8	0.5	0.047
Cu	155	85	118	10	0.4	0.056
Mo	231	108	1299	10	51.8	0.065
S	320	72	68	10	0.2	0.042
Fe + Mn	79	48	92	6	0.1	0.765
Fe + Mn + Zn	82	52	210	8	0.0	0.431
Fe + Mn + Zn + Cu	98	64	193	8	0.9	0.586
Fe + Mn + Zn + Cu + Mo	140	70	86	7	15.0	0.371
Fe + Mn + Zn + Cu + Mo + S	120	66	260	8	6.7	0.448

nd - no data

Manganese, however, showed significant differences in concentration in grain sorghum with both varying treatments and P rates. When no P was applied to the soil, levels of Mn in plants varied greatly with different Mn treated soils from having the least amount of Mn, 73 ppm, to having the most Mn, 108 ppm, in plant tissue. At the 19.6 kg P/ha rate, most Mn treatments yielded intermediate to low levels of plant Mn with the exception of Mn applied singly to soil. This treatment resulted in the second highest level of plant Mn at this P rate. At the highest P rate all Mn treatments except Mn alone resulted in low Mn concentrations in the plant. At 19.6 and 39.1 kg P/ha Fe applied to soil singly resulted in very low Mn levels in the plant. Again, this could be due to an Fe - Mn imbalance which, when the imbalance is equaled out, the level of Mn in grain sorghum was lowered.

For each Fe treatment, the zero P rate resulted in the highest amount of plant Mn, followed next by the 19.6 kg P/ha rate for most treatments and the 39.1 kg P/ha rate generally yielded the least amount of plant Mn for those plants grown in Fe treated soil. Generally, the Mn, Zn, Cu and Mo treatments showed a reverse trend with the zero P rate yielding the least amount of plant Mn. Thus, there appears to be a three way effect among Fe, Mn and P where Fe at high P rates decreases Mn uptake in plants as compared to Fe treatments when no P is applied.

Levels of Mo in plants were significantly different with both varying treatments and P rates. Each Mo treatment at all P levels resulted in higher plant Mo concentrations than those plants grown in soils which received no Mo. Thus, added Mo to Quinlan soil enhances plant Mo uptake at all P rates tested in this study.

When no Mo was added to the soil approximately the same concentration of Mo in the plant was found at all P rates. On those soils receiving Mo the highest P rate resulted in the highest levels of plant Mo.

There were no differences in plant yield regardless of treatment unless P was added. Fe in the presence of P aids plant growth (Figures 7 and 8). For each treatment soils receiving no P resulted in the lowest plant yields. The Fe treated soils at 39.1 kg P/ha resulted in the highest plant yields except for the Fe + Mn + Zn + Cu + Mo treatment in which the 19.6 and 39.1 kg P/ha rates resulted in essentially the same plant yields. These results agree with many other researcher's findings on the advantageous effect P plays in the presence of Fe to increase plant yields (Bassiri, 1979) and demonstrates an Fe - P interaction.

As observed with the initial plant growth, Fe + Mn at 39.1 kg P/ha resulted in the highest yield. This excellent growth may again be attributed to a good Fe - Mn balance (Olsen, 1972).

Another interesting trend which also agrees with findings of other researchers is the inverse relationship N levels in plants show when compared to yields. Plant N levels are listed in Tables XXIII and XXIV, Appendix C. Those plants experiencing stress, the Mn, Zn, Cu, Mo and S treated plants, exhibited high levels of plant N while healthy plants, all Fe treated plants at 39.1 kg P/ha, resulted in low plant N levels. Thus, plants under stress will absorb more N than healthy plants (Tisdale and Nelson, 1975).

There was a yield correlation between the second clipping from Quinlan soil and DTPA extractable Fe. Figure 9 shows this correlation curve with $r^2 = 0.81$. Thus, there was a direct relationship between DTPA extractable Fe and yield where yield increased dramatically as Fe levels in soil increased slightly.

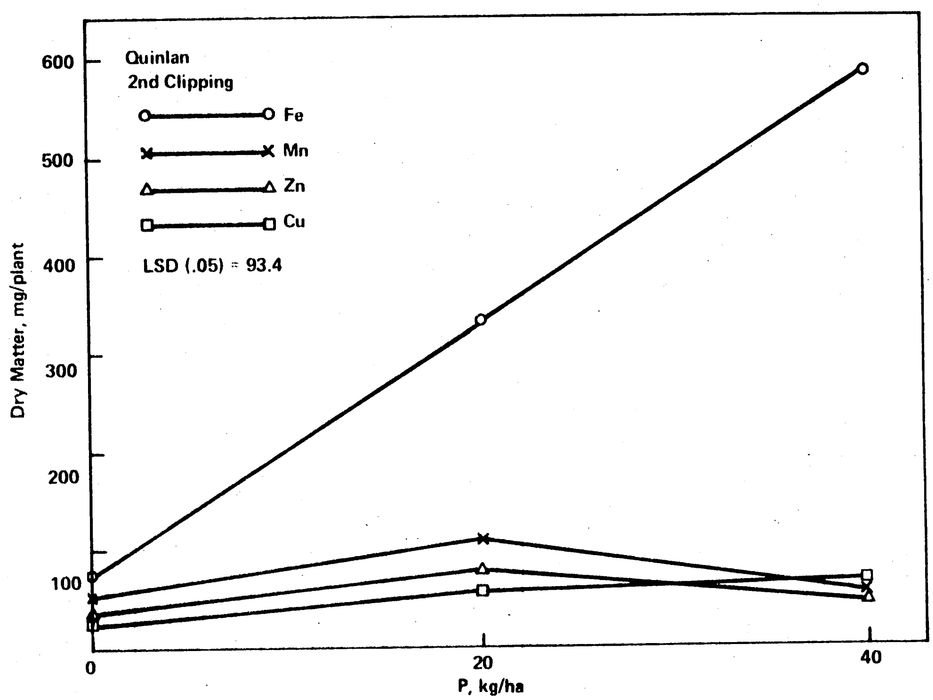

Figure 7. Effect of P and Singly Applied Micronutrients on Regrowth Yields of Grain Sorghum Grown in Quinlan Soil

Spur Soil

Micronutrient levels in the regrowth in Spur soil are listed in Table X. There were no significant differences in plant Zn, Cu or K levels grown in Spur soil after the plants had been clipped when treatments or P rates were changed. Plant Fe levels showed significant differences when treatments, but not when P rates were varied. Sulfur applied singly to the soil resulted in the highest levels of plant Fe at 0 and 19.6 kg P/ha and the second highest levels of plant Fe at 39.1 kg P/ha. Thus, S applied singly to Spur soil aids Fe uptake in clipped grain sorghum.

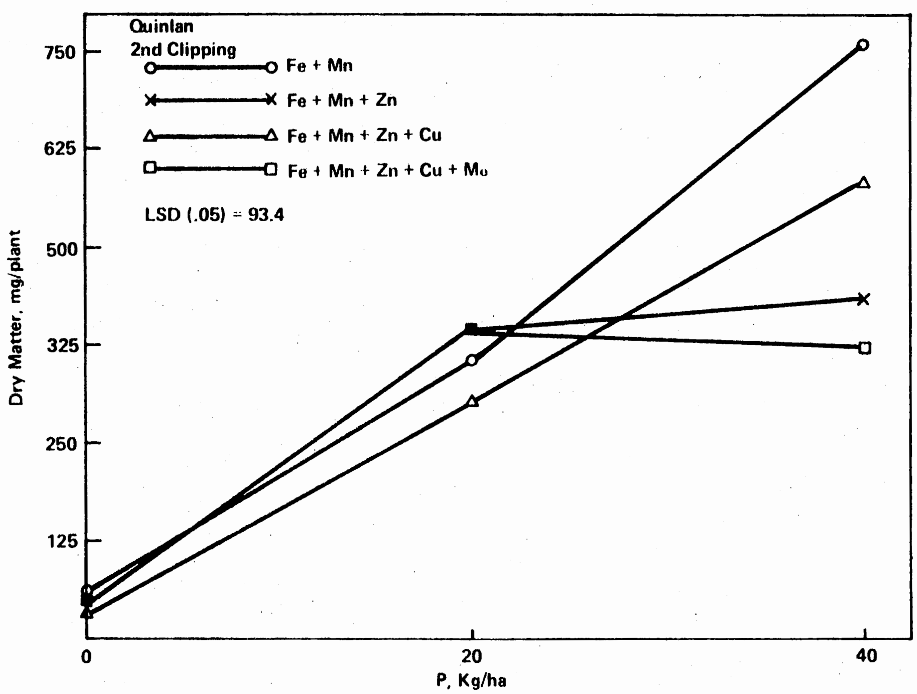

Figure 8. Effect of P and Micronutrients Applied in Combination on Regrowth Yields of Grain Sorghum Grown in Quinlan Soil

Manganese levels in plant tissue varied significantly when P rates were varied. The highest Mn levels in plant tissue were found when no P was applied to soil. Then, as P was added, Mn uptake by grain sorghum was depressed. In all treatments where data was available, the 19.6 kg P/ha rate enhanced Mn uptake more than the 39.1 kg P/ha rate except for the Fe + Mn + Zn + Cu treatment. Thus, P inhibits Mn uptake by grain sorghum.

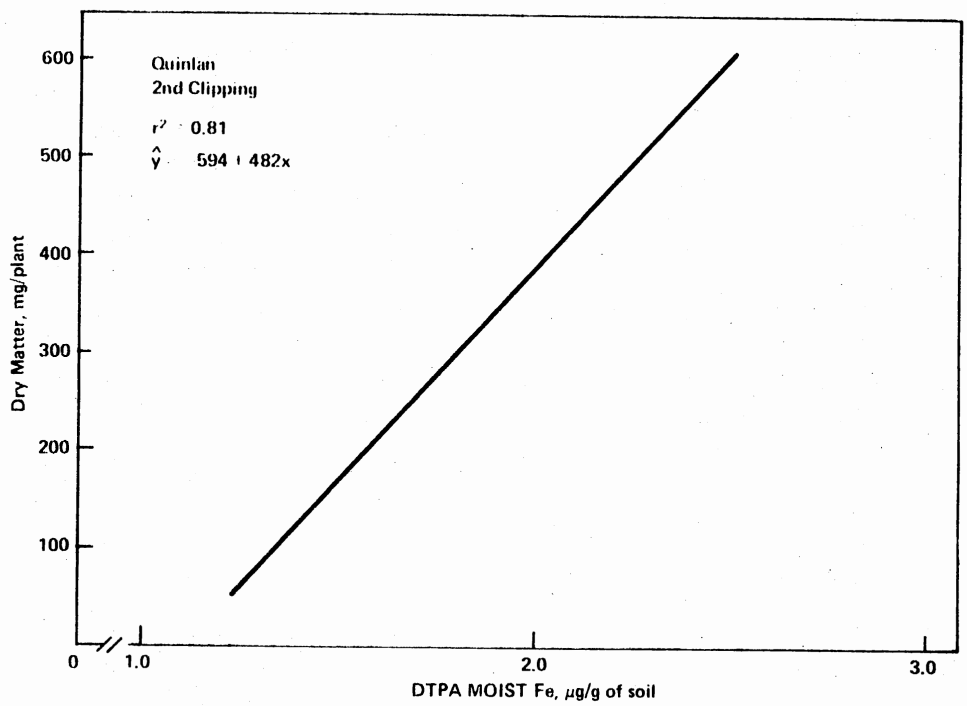

Figure 9. Regrowth Correlation Curve of Grain Sorghum Yield and DTPA Extractable Fe in Quinlan Soil

Yield differences varied significantly when treatments or P rates were changed. At the zero P rate yields were essentially the same, but the four highest yields were grown in Fe treated soils. At the 19.6 kg P/ha rate all Fe treated soils resulted in the highest plant yields as

TABLE X

YIELDS AND MICRONUTRIENT CONCENTRATIONS IN REGROWTH OF GRAIN SORGHUM GROWN IN SPUR SOIL

Treatment	Fe	Mn	Zn	Cu	Mo	Yield
	ug/g					g/plant
P applied, kg/ha 0						
Check	165	105	280	12	0.8	0.026
Fe	115	120	170	12	0.6	0.049
Mn	150	96	156	14	1.0	0.021
Zn	nd	nd	nd	nd	nd	0.019
Cu	nd	nd	nd	nd	nd	0.024
Mo	nd	nd	nd	nd	nd	0.023
S	191	121	196	14	2.2	0.032
Fe + Mn	98	82	95	16	1.6	0.068
Fe + Mn + Zn	nd	nd	nd	nd	nd	0.015
Fe + Mn + Zn + Cu	nd	nd	nd	nd	nd	0.041
Fe + Mn + Zn + Cu + Mo	nd	nd	nd	nd	nd	0.047
Fe + Mn + Zn + Cu + Mo + S	nd	nd	nd	nd	nd	0.022
P applied, kg/ha 19.6						
Fe	89	78	202	11	1.4	0.164
Mn	nd	nd	nd	nd	nd	0.039
Zn	nd	nd	nd	nd	nd	0.023
Cu	nd	nd	nd	nd	nd	0.026
Mo	nd	nd	nd	nd	nd	0.020
S	625	112	108	12	1.9	0.050
Fe + Mn	122	70	199	12	1.6	0.149
Fe + Mn + Zn	135	100	252	10	1.1	0.049
Fe + Mn + Zn + Cu	110	50	102	10	2.7	0.155
Fe + Mn + Zn + Cu + Mo	nd	nd	nd	nd	nd	0.052
Fe + Mn + Zn + Cu + Mo + S	113	95	278	14	9.9	0.090
P applied, kg/ha 39.1						
Fe	80	59	139	10	0.9	0.332
Mn	82	65	130	12	0.8	0.157
Zn	nd	nd	nd	nd	nd	0.025
Cu	nd	nd	nd	nd	nd	0.010
Mo	nd	nd	nd	nd	nd	0.020
S	125	82	202	10	0.8	0.054
Fe + Mn	89	60	1164	13	1.3	0.216
Fe + Mn + Zn	106	81	141	11	1.9	0.081
Fe + Mn + Zn + Cu	151	75	1990	26	1.4	0.064
Fe + Mn + Zn + Cu + Mo	110	62	158	10	22.8	0.087
Fe + Mn + Zn + Cu + Mo + S	110	60	240	15	44.2	0.087

nd - no data

is shown in Figure 10. This trend holds true at the highest P rate also, except the Mn treatment resulted in the third highest plant yield with the highest yield coming from the Fe treatment, 0.332 g/plant. Thus, Fe definitely aids plant growth for grain sorghum grown in Spur soil after having been clipped once. The results show a significant Fe - yield interaction.

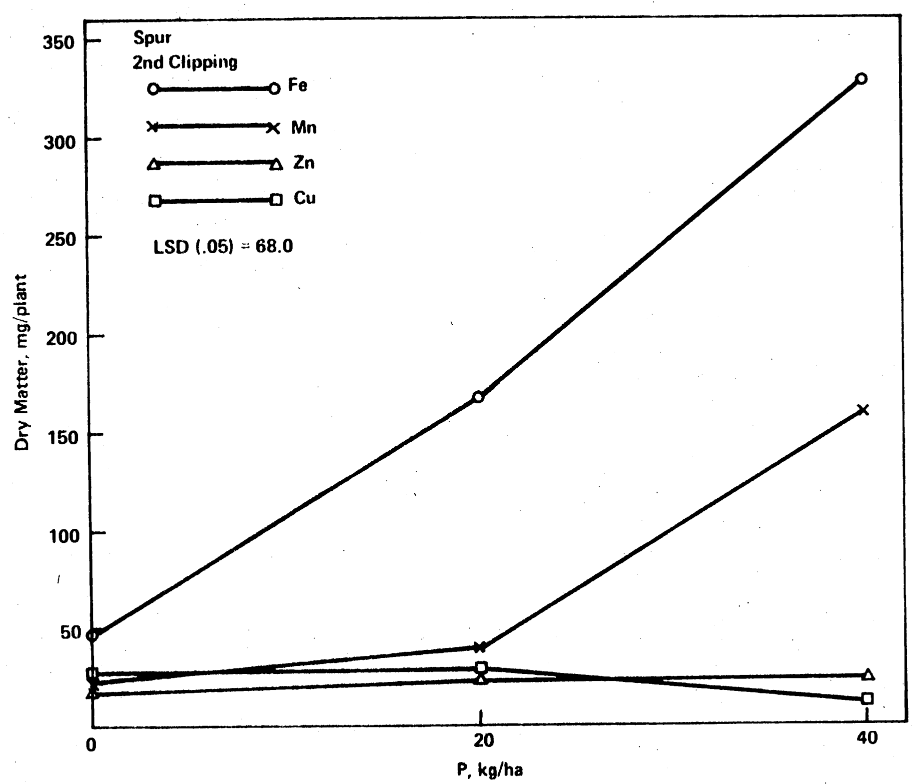

Figure 10. Effect of P and Singly Applied Micronutrients on Regrowth Yields of Grain Sorghum Grown in Spur Soil

Again, an Fe - P interaction exists where P aided plant growth when Fe was added to Spur soil as can be seen in Figure 10. When no P was added to the soil, very slight differences in plant yield were observed. However, when Fe or Mn was added to soil in the presence of P, plant growth was enhanced. When Zn, Cu, Mo or S were applied singly to soil, very little differences in plant yield were observed.

Quinlan Versus Spur Soil

Very little data was available to compare the regrowth of grain sorghum between Quinlan and Spur soils (Table XIX, Appendix A). Very few differences were significant, with no significant differences between Fe levels in plant tissue. Hence, there were few differences among micronutrient levels in plant tissue from the regrowth when Quinlan and Spur soils were compared.

Comparison of Initial Growth Versus Regrowth

Quinlan Soil

Very few differences were significant when micronutrient levels between the initial growth and regrowth in Quinlan soil are considered, but some interesting trends developed (Table XX, Appendix A). In almost every treatment the original plant growth resulted in lower Fe concentrations than the regrowth. This trend reversed for Mn, Cu, Mo and K. That is, the initial plant growth yielded more of these four micronutrients than the regrowth. Again, these differences were general trends since not all of them were significant.

Differences in yield between initial plant growth and regrowth in Quinlan soil were very interesting. With only a few exceptions, those soils treated with Fe resulted in more growth after the plants were clipped than the initial growth. Thus, applied Fe will continue to aid plant growth over a period of time.

CHAPTER V

SUMMARY AND CONCLUSIONS

The purposes of this study were to determine if interactions among Fe, Mn, Zn, Cu, Mo and S at three P rates exist in two Fe deficient soils of Oklahoma and to determine the differences between DTPA and 0.01M $CaCl_2$ extractable Fe, Mn, Zn and Cu and the differences among DTPA, 0.01M $CaCl_2$ and acid ammonium oxalate extractable Mo.

Eleven fertilizer treatments at three P levels were applied to a Spur and Quinlan soil. Sorghum seeds were planted and allowed to grow in a greenhouse. Plants were harvested once, allowed to regrow and harvested a second time. After the second harvest soils were collected from each pot with some soil being oven dried and the remainder kept moist from each pot.

Many interactions were found in both soils and plants. An Fe - P interaction exists in Quinlan soil where P enhanced the amount of DTPA extractable Fe. There was an Fe - yield interaction for all harvests except the initial growth in Spur soil where Fe added to the soil significantly increased yields. There was also an Fe - P interaction for these same harvests where Fe in the presence of P increased plant yields. Thus, grain sorghum yields may be increased most effectively in Fe deficient soils by applying Fe at 9 kg/ha and P at 39.1 kg/ha to soil.

For both soils, DTPA extracted more Fe, Mn, Zn and Cu than did the

0.01M $CaCl_2$ procedure. DTPA extraction procedure was a more sensitive test for micronutrient levels in soil than dilute $CaCl_2$. Hence, the DTPA procedure should be used to estimate plant available micronutrient levels in soil. Where Mo was concerned, the acid ammonium oxalate method extracted the most Mo from both soils while dilute $CaCl_2$ and DTPA extracted essentially the same amounts of Mo.

LITERATURE CITED

1. Barshad, I. 1951. Factors affecting the molybdenum content of pasture plants: II. Effect of soluble phosphates, available nitrogen, and soluble sulfates. Soil Sci. 71:387-398.

2. Bassiri, A., A. Kashirad, and M. Kheradnam. 1979. Growth and mineral composition of mungbeans as influenced by P and Fe fertilization. Agron. J. 71:139-141.

3. Boawn, Louis C., and G. E. Leggett. 1964. Phosphorus and zinc concentrations in Russet Burbank potato tissues in relation to development of zinc deficiency symptoms. Soil Sci. Soc. Amer. Proc. 28:229-232.

4. Bray, Roger H. and L. T. Kurtz. 1945. Determination of total, organic, and available forms of phosphorus in soils. Soil Sci. 59:39-45.

5. Bremner, J. M. 1965. Total nitrogen. Agronomy 9:1145-1171.

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

7. Chaudhry, F. M., S.M. Alan, A. Rashid and A. Latif. 1977. Mechanism of differential susceptibility of two rice varieties to zinc deficiency. Plant Soil 46:637-642.

8. Dahiya, S. S. and Mahendra Singh. 1976. Effect of salinity, alkalinity and iron application of the availability of iron, manganese, phosphorus and sodium in pea (Pisum sativum L.) crop. Plant Soil 44:697-702.

9. Dahiya, S. S. and Mahendra Singh. 1977. Effect of $CaCO_3$ and iron application on the availability of manganese in light-textured soil. Plant Soil 46:239-243.

10. DeKock, P. C. 1955. Iron nutrition of plants at high pH. Soil Sci. 79:167-175.

11. Epstein, Emanual, and Perry R. Stout. 1951. Micronutrient cations iron, manganese, zinc and copper: Their uptake by plants from the adsorbed state. Soil Sci. 72:47-65.

12. Gerloff, Gerald C., P. R. Stout and L. H. P. Jones. 1959. Molybdenum-manganese-iron antagonisms in the nutrition of tomato plants. Pl. Physiol. 34:608-613.

13. Grigg, J. L. 1953. Determination of the available molybdenum of of soils. N. Z. J. Sci. Technol. A34:405-414.

14. Gupta, Umech C. and D. C. Munro. 1969. Influence of sulfur, molybdenum and phosphorus on chemical composition and yields of Brussels sprouts and of molybdenum on sulfur contents of several plant species grown in the greenhouse. Soil Sci. 107:114-118.

15. Hossner. L. R. and R. W. Blanchar. 1970. Manganese reactions and availability as influenced by pH and pyrophosphate content of ammonium phosphate fertilizers. Soil Sci. Soc. Amer. Proc. 34:509-512.

16. Hossner, L. R. and G. E. Richards. 1968. The effect of phosphorus source on the movement and uptake of band applied manganese. Soil Sci. Soc. Amer. Proc. 32:83-85.

17. Kalyanasundaram, N. K. and B. V. Mehta. 1970. Availability of zinc, phosphorus and calcium in soils treated with varying levels of zinc and phosphate--A soil incubation study. Plant Soil 33:699-706.

18. Lindsay, W. L. 1972. Inorganic phase equilibria of micronutrients in soils. In J. J. Mortvedt, P. M. Giordano and W. L. Lindsay (eds.) Micronutrients in Agriculture, Soil Science Society of America, Inc., Madison, Wis.

19. Lindsay, W. L. and W. A. Norvell. 1978. Development of a DTPA soil test for zinc, iron, manganese, and copper. Soil Sci. Soc. Am. J. 42:421-428.

20. Lingle, John C., Lee O. Tiffin, and John C. Brown. 1963. Iron uptake-transport of soybeans as influenced by other cations. Pl. Physiol. 38:71-76.

21. Mehlich, A. and S. S. Bowling. North Carolina Department of Agriculture. Direct correspondence to Dr. Gordon Johnson, soil testing laboratory, Oklahoma State University.

22. Mortvedt, J. J. and G. Osborn. 1977. Micronutrient concentrations in soil solution after ammonium phosphate applications. Soil Sci. Soc. Am. J. 41:1004-1008.

23. Mulder, E. G. and F. C. Gerretsen. 1952. Soil manganese in relation to plant growth. Adv. Agron. 4:221-277.

24. Norvell, W. A. 1972. Equilibria of metal chelates in soil solution. In J. J. Mortvedt, P. M. Giordano and W. L. Lindsay (eds.) Micronutrients in Agriculture, Soil Science Society of America, Inc., Madison, Wis.

25. Olsen, S. R. 1972. Micronutrient interactions. Agronomy 9:243-264.

26. Olsen, S. R. and F. S. Watanabe. 1979. Interaction of added gypsum in alkaline soils with uptake of iron, molybdenum, manganese and zinc by sorghum. Soil Sci. Soc. Amer. J. 43:125-130.

27. Reisenauer, H. M. 1965. Molybdenum. Agronomy 9:1050-1058.

28. Salcedo, I. H. and D. D. Warncke. 1979. Studies in soil manganese: I. Factors affecting manganese extractability. Soil Sci. Soc. Amer. J. 43:135-138.

29. Steel, Robert G. D. and James H. Torrie. 1960. Principles and Procedures of Statistics. McGraw-Hill Book Co. Inc., New York.

30. Stout, P. R., W. R. Meagher, G. A. Pearson and C. M. Johnson. 1951. Molybdenum nutrition of crop plants. I. The influence of phosphate and sulfate on the absorption of molybdenum from soils and solution cultures. Plant Soil 3:51-87.

31. Tisdale, S. L. and W. L. Nelson. 1975. Soil Fertility and Fertilizers. Macmillan Publishing Co., Inc., New York.

32. Twyman, E. S. 1946. The iron-manganese balance and its effect on the growth and development of plants. New Phytol. 45:18-24.

33. United States Salinity Laboratory Staff. 1954. Diagnosis and improvement of saline and alkali soils. United States Department of Agriculture, Handbook 60.

34. White M. C., A. M. Decker and R. L. Chaney. 1979. Differential cultivar tolerance in soybean to phytotoxic levels of soil Zn. I. Range of cultivar response. Agron. J. 71:121-126.

APPENDIXES

APPENDIX A

STATISTICAL COMPARISONS

TABLE XI

STATISTICAL COMPARISON OF DTPA EXTRACTION PROCEDURE ON QUINLAN AND SPUR SOILS

Treatment	P kg/ha	Fe	Mn	Zn	Cu
Check	0	**	*	ns	ns
Fe	0	**	*	ns	*
	19.6	**	**	ns	ns
	39.1	**	*	ns	ns
Mn	0	**	**	ns	ns
	19.6	**	ns	ns	ns
	39.1	**	**	ns	ns
Zn	0	*	ns	ns	ns
	19.6	**	ns	ns	ns
	39.1	**	ns	ns	ns
Cu	0	**	**	ns	ns
	19.6	**	**	ns	ns
	39.1	*	*	ns	ns
Mo	0	**	ns	*	ns
	19.6	**	*	ns	ns
	39.1	**	ns	ns	ns
S	0	**	*	*	**
	19.6	*	ns	ns	ns
	39.1	**	*	ns	**
Fe + Mn	0	**	**	ns	ns
	19.6	**	**	ns	**
	39.1	*	ns	ns	*
Fe + Mn + Zn	0	*	*	ns	**
	19.6	**	**	ns	ns
	39.1	**	*	ns	*
Fe + Mn + Zn + Cu	0	**	ns	ns	ns
	19.6	**	ns	ns	ns
	39.1	ns	*	ns	ns
Fe + Mn + Zn + Cu + Mo	0	**	ns	ns	ns
	19.6	**	**	ns	ns
	39.1	**	ns	ns	ns
Fe + Mn + Zn + Cu + Mo + S	0	**	**	ns	ns
	19.6	**	**	ns	ns
	39.1	**	**	ns	ns

* Significant at 0.05
** Significant at 0.01
ns No significance

TABLE XII

STATISTICAL COMPARISON OF 0.01M $CaCl_2$ EXTRACTION PROCEDURE ON QUINLAN AND SPUR SOILS

Treatment	P kg/ha	Fe	Mn	Zn	Cu
Check	0	*	ns	ns	ns
Fe	0	**	ns	ns	ns
	19.6	ns	ns	ns	ns
	39.1	*	ns	ns	ns
Mn	0	ns	ns	**	ns
	19.6	ns	ns	*	ns
	39.1	ns	ns	ns	ns
Zn	0	ns	ns	ns	ns
	19.6	**	**	ns	ns
	39.1	*	ns	ns	**
Cu	0	ns	ns	ns	ns
	19.6	*	ns	ns	ns
	39.1	ns	*	ns	ns
Mo	0	*	ns	ns	ns
	19.6	ns	ns	ns	ns
	39.1	*	**	ns	ns
S	0	ns	ns	ns	ns
	19.6	ns	ns	ns	ns
	39.1	ns	*	ns	ns
Fe + Mn	0	ns	ns	ns	ns
	19.6	ns	ns	ns	ns
	39.1	**	ns	ns	ns
Fe + Mn + Zn	0	**	ns	*	ns
	19.6	**	ns	**	ns
	39.1	ns	ns	*	ns
Fe + Mn + Zn + Cu	0	**	ns	ns	ns
	19.6	*	ns	ns	ns
	39.1	ns	ns	ns	ns
Fe + Mn + Zn + Cu + Mo	0	*	**	ns	ns
	19.6	ns	ns	ns	ns
	39.1	ns	ns	ns	ns
Fe + Mn + Zn + Cu + Mo + S	0	**	ns	ns	ns
	19.6	ns	ns	ns	ns
	39.1	ns	ns	ns	*

* Significant at 0.05
** Significant at 0.01
ns No Significance

TABLE XIII

STATISTICAL COMPARISON OF DTPA AND 0.01M $CaCl_2$ EXTRACTION PROCEDURES ON QUINLAN SOIL

Treatment	P kg/ha	Fe	Mn	Zn	Cu
Check	0	**	**	ns	**
Fe	0	**	**	ns	**
	19.6	**	**	ns	**
	39.1	**	**	ns	**
Mn	0	**	**	ns	**
	19.6	**	**	ns	ns
	39.1	**	**	*	**
Zn	0	**	**	ns	**
	19.6	**	**	ns	*
	39.1	**	**	ns	**
Cu	0	**	**	ns	**
	19.6	**	**	ns	**
	39.1	**	**	ns	**
Mo	0	**	**	*	**
	19.6	**	**	ns	**
	39.1	**	**	ns	*
S	0	**	**	ns	**
	19.6	**	**	ns	**
	39.1	**	**	*	**
Fe + Mn	0	**	**	ns	**
	19.6	**	**	ns	**
	39.1	**	**	ns	ns
Fe + Mn + Zn	0	**	**	**	*
	19.6	**	**	*	**
	39.1	**	**	**	**
Fe + Mn + Zn + Cu	0	**	**	*	**
	19.6	**	**	ns	**
	39.1	**	**	**	**
Fe + Mn + Zn + Cu + Mo	0	**	**	**	**
	19.6	**	**	**	**
	39.1	**	**	*	**
Fe + Mn + Zn + Cu + Mo + S	0	**	**	**	**
	19.6	**	**	**	**
	39.1	**	**	**	**

* Significant at 0.05
** Significant at 0.01
ns No Significance

TABLE XIV

STATISTICAL COMPARISON OF DTPA AND 0.01M $CaCl_2$ EXTRACTION PROCEDURES ON SPUR SOIL

Treatment	P kg/ha	Fe	Mn	Zn	Cu
Check	0	**	**	**	**
Fe	0	**	**	**	**
	19.6	**	**	**	**
	39.1	**	**	**	**
Mn	0	**	**	**	**
	19.6	**	**	*	**
	39.1	**	**	ns	**
Zn	0	**	**	**	**
	19.6	**	**	**	**
	39.1	**	**	**	**
Cu	0	**	**	**	**
	19.6	**	**	ns	**
	39.1	**	**	**	**
Mo	0	**	**	**	**
	19.6	**	**	*	**
	39.1	**	**	*	**
S	0	**	**	*	**
	19.6	**	**	**	**
	39.1	**	**	ns	**
Fe + Mn	0	**	**	**	**
	19.6	**	**	**	**
	39.1	**	**	ns	**
Fe + Mn + Zn	0	**	**	**	**
	19.6	**	**	**	**
	39.1	**	**	**	**
Fe + Mn + Zn + Cu	0	**	**	ns	**
	19.6	**	**	**	**
	39.1	**	**	ns	**
Fe + Mn + Zn + Cu + Mo	0	**	**	*	**
	19.6	**	**	**	**
	39.1	**	**	**	**
Fe + Mn + Zn + Cu + Mo + S	0	**	**	**	**
	19.6	**	**	**	**
	39.1	**	**	*	**

* Significant at 0.05
** Significant at 0.01
ns No Significance

TABLE XV

STATISTICAL COMPARISON OF MOLYBDENUM EXTRACTION PROCEDURES ON QUINLAN SOIL

Treatment	P kg/ha	DTPA vs $CaCl_2$	$(NH_4)_2C_2O_4$ vs DTPA	$(NH_4)_2C_2O_4$ vs $CaCl_2$
Check	0	ns	**	**
Fe	0	ns	ns	ns
	19.6	**	**	**
	39.1	ns	*	*
Mn	0	ns	*	ns
	19.6	**	ns	ns
	39.1	ns	*	*
Zn	0	ns	ns	ns
	19.6	ns	ns	ns
	39.1	ns	ns	ns
Cu	0	*	*	ns
	19.6	ns	ns	ns
	39.1	*	**	**
Mo	0	ns	**	**
	19.6	*	**	**
	39.1	*	**	**
S	0	ns	ns	ns
	19.6	ns	ns	ns
	39.1	ns	ns	ns
Fe + Mn	0	*	ns	ns
	19.6	ns	ns	ns
	39.1	ns	**	**
Fe + Mn + Zn	0	ns	**	*
	19.6	ns	*	*
	39.1	ns	ns	ns
Fe + Mn + Zn + Cu	0	ns	ns	ns
	19.6	ns	*	ns
	39.1	ns	*	*
Fe + Mn + Zn + Cu + Mo	0	*	**	**
	19.6	ns	**	**
	39.1	ns	*	**
Fe + Mn + Zn + Cu + Mo + S	0	ns	**	**
	19.6	ns	**	**
	39.1	**	**	**

* Significant at 0.05
** Significant at 0.01
ns No Significance

TABLE XVI

STATISTICAL COMPARISON OF MOLYBDENUM EXTRACTION PROCEDURES ON SPUR SOIL

Treatment	P kg/ha	DTPA vs $CaCl_2$	$(NH_4)_2C_2O_4$ vs DTPA	$(NH_4)_2C_2O_4$ vs $CaCl_2$
Check	0	**	ns	**
Fe	0	ns	**	**
	19.6	ns	*	**
	39.1	ns	**	**
Mn	0	ns	**	**
	19.6	*	**	**
	39.1	**	*	**
Zn	0	ns	**	**
	19.6	ns	**	**
	39.1	ns	**	**
Cu	0	ns	**	**
	19.6	ns	ns	*
	39.1	ns	*	*
Mo	0	**	**	**
	19.6	*	**	**
	39.1	**	**	**
S	0	ns	**	**
	19.6	ns	ns	*
	39.1	ns	*	**
Fe + Mn	0	ns	ns	*
	19.6	ns	ns	*
	39.1	ns	**	**
Fe + Mn + Zn	0	ns	**	**
	19.6	ns	**	*
	39.1	ns	ns	**
Fe + Mn + Zn + Cu	0	ns	**	*
	19.6	ns	**	**
	39.1	ns	*	**
Fe + Mn + Zn + Cu + Mo	0	*	**	**
	19.6	**	**	**
	39.1	*	**	**
Fe + Mn + Zn + Cu + Mo + S	0	*	**	**
	19.6	ns	**	**
	39.1	ns	**	**

* Significant at 0.05
** Significant at 0.01
ns No significance

TABLE XVII

STATISTICAL COMPARISON OF MOLYBDENUM EXTRACTION PROCEDURES ON QUINLAN AND SPUR SOILS

Treatment	P kg/ha	DTPA	$CaCl_2$	$(NH_4)_2C_2O_4$
Check	0	ns	ns	ns
Fe	0	ns	ns	ns
	19.6	ns	ns	ns
	39.1	ns	ns	ns
Mn	0	ns	ns	ns
	19.6	ns	ns	*
	39.1	**	ns	ns
Zn	0	ns	ns	ns
	19.6	ns	ns	ns
	39.1	ns	ns	ns
Cu	0	**	ns	ns
	19.6	ns	ns	ns
	39.1	ns	ns	ns
Mo	0	ns	ns	ns
	19.6	ns	ns	ns
	39.1	ns	ns	ns
S	0	ns	ns	ns
	19.6	ns	ns	ns
	39.1	ns	ns	ns
Fe + Mn	0	ns	ns	ns
	19.6	ns	ns	ns
	39.1	ns	ns	ns
Fe + Mn + Zn	0	ns	ns	*
	19.6	ns	ns	ns
	39.1	ns	ns	ns
Fe + Mn + Zn + Cu	0	ns	ns	ns
	19.6	ns	ns	ns
	39.1	ns	ns	ns
Fe + Mn + Zn + Cu + Mo	0	ns	ns	ns
	19.6	ns	ns	ns
	39.1	ns	*	ns
Fe + Mn + Zn + Cu + Mo + S	0	ns	*	ns
	19.6	ns	ns	*
	39.1	ns	ns	ns

* Significant at 0.05
** Significant at 0.01
ns No significance

TABLE XVIII

STATISTICAL COMPARISON OF INITIAL GRAIN SORGHUM YIELDS AND MICRONUTRIENT CONCENTRATIONS IN QUINLAN AND SPUR SOILS

Treatment	P kg/ha	Fe	Mn	Zn	Cu	Mo	K	Yield
Check	0	ns	ns	ns	ns	ns	**	ns
Fe	0	ns	ns	ns	ns	ns	**	*
	19.6	**	*	ns	ns	ns	**	**
	39.1	ns	**	ns	ns	ns	**	**
Mn	0	ns	ns	ns	ns	ns	**	ns
	19.6	ns	**	ns	**	*	**	*
	39.1	nd	nd	nd	nd	nd	nd	ns
Zn	0	ns	ns	ns	ns	**	**	ns
	19.6	nd	nd	nd	nd	nd	nd	ns
	39.1	nd	nd	nd	nd	nd	nd	ns
Cu	0	ns	ns	ns	ns	ns	**	**
	19.6	ns	**	ns	ns	ns	**	ns
	39.1	ns	ns	ns	ns	ns	**	ns
Mo	0	ns	**	**	*	**	**	*
	19.6	nd	nd	nd	nd	nd	nd	ns
	39.1	ns	**	ns	ns	ns	**	ns
S	0	nd	nd	nd	nd	nd	nd	*
	19.6	ns	ns	*	*	**	**	ns
	39.1	**	*	**	ns	ns	**	ns
Fe + Mn	0	ns	ns	ns	ns	*	**	ns
	19.6	ns	*	ns	ns	*	**	ns
	39.1	ns	**	ns	ns	ns	**	ns
Fe + Mn + Zn	0	nd	nd	nd	nd	nd	nd	ns
	19.6	*	*	*	ns	ns	**	ns
	39.1	**	**	ns	ns	ns	**	*
Fe + Mn + Zn + Cu	0	nd	nd	nd	nd	nd	nd	ns
	19.6	nd	nd	nd	nd	nd	nd	ns
	39.1	*	ns	ns	ns	ns	**	ns
Fe + Mn + Zn + Cu + Mo	0	ns	ns	ns	ns	**	*	ns
	19.6	**	ns	**	*	ns	**	ns
	39.1	nd	nd	nd	nd	nd	nd	ns
Fe + Mn + Zn + Cu + Mo + S	0	**	ns	ns	ns	**	**	ns
	19.6	*	**	ns	ns	ns	**	**
	39.1	**	**	*	ns	**	**	ns

* Significant at 0.05
** Significant at 0.01
ns No significance
nd No data

TABLE XIX

STATISTICAL COMPARISON OF GRAIN SORGHUM REGROWTH YIELDS AND MICRONUTRIENT CONCENTRATIONS IN QUINLAN AND SPUR SOILS

Treatment	P kg/ha	Fe	Mn	Zn	Cu	Mo	K	Yield
Check	0	nd	nd	nd	nd	nd	nd	ns
Fe	0	nd	nd	nd	nd	nd	nd	ns
	19.6	ns	**	ns	*	**	**	ns
	39.1	ns	ns	ns	ns	**	**	**
Mn	0	ns	ns	ns	**	ns	*	*
	19.6	nd	nd	nd	nd	nd	nd	**
	39.1	nd	nd	nd	nd	nd	nd	ns
Zn	0	nd	nd	nd	nd	nd	nd	ns
	19.6	nd	nd	nd	nd	nd	nd	ns
	39.1	nd	nd	nd	nd	nd	nd	ns
Cu	0	nd	nd	nd	nd	nd	nd	ns
	19.6	nd	nd	nd	nd	nd	nd	**
	39.1	nd	nd	nd	nd	nd	nd	*
Mo	0	nd	nd	nd	nd	nd	nd	*
	19.6	nd	nd	nd	nd	nd	nd	ns
	39.1	nd	nd	nd	nd	nd	nd	**
S	0	nd	nd	nd	nd	nd	nd	ns
	19.6	nd	nd	nd	nd	nd	nd	ns
	39.1	nd	nd	nd	nd	nd	nd	ns
Fe + Mn	0	ns	ns	*	**	*	ns	ns
	19.6	ns	ns	ns	**	**	ns	**
	39.1	ns	ns	ns	ns	**	**	**
Fe + Mn + Zn	0	nd	nd	nd	nd	nd	nd	ns
	19.6	nd	nd	nd	nd	nd	nd	**
	39.1	ns	*	ns	ns	ns	**	*
Fe + Mn + Zn + Cu	0	nd	nd	nd	nd	nd	nd	ns
	19.6	nd	nd	nd	nd	nd	nd	ns
	39.1	ns	ns	ns	*	ns	ns	**
Fe + Mn + Zn + Cu + Mo	0	nd	nd	nd	nd	nd	nd	ns
	19.6	nd	nd	nd	nd	nd	nd	**
	39.1	nd	nd	nd	nd	nd	nd	ns
Fe + Mn + Zn + Cu + Mo + S	0	nd	nd	nd	nd	nd	nd	ns
	19.6	ns	*	ns	*	ns	ns	**
	39.1	nd	nd	nd	nd	nd	nd	**

* Significant at 0.05
** Significant at 0.01
ns No significance
nd No data

TABLE XX

STATISTICAL COMPARISONS OF INITIAL AND REGROWTH YIELDS AND MICRONUTRIENT CONCENTRATIONS IN GRAIN SORGHUM GROWN IN QUINLAN SOIL

Treatment	P kg/ha	Fe	Mn	Zn	Cu	Mo	Yield
Check	0	*	ns	ns	ns	ns	ns
Fe	0	ns	ns	ns	ns	ns	ns
	19.6	ns	**	ns	**	ns	**
	39.1	ns	**	ns	ns	ns	ns
Mn	0	ns	ns	ns	ns	ns	ns
	19.6	ns	ns	ns	**	ns	ns
	39.1	ns	ns	ns	ns	ns	ns
Zn	0	*	ns	ns	ns	ns	ns
	19.6	ns	ns	ns	**	ns	ns
	39.1	nd	nd	nd	nd	nd	ns
Cu	0	nd	nd	nd	nd	nd	ns
	19.6	ns	ns	ns	**	ns	ns
	39.1	nd	nd	nd	nd	nd	ns
Mo	0	ns	ns	*	ns	ns	ns
	19.6	ns	ns	ns	ns	ns	*
	39.1	ns	**	ns	ns	ns	ns
S	0	nd	nd	nd	nd	nd	ns
	19.6	nd	nd	nd	nd	nd	ns
	39.1	nd	nd	nd	nd	nd	*
Fe + Mn	0	ns	**	ns	ns	ns	ns
	19.6	ns	*	ns	*	ns	**
	39.1	ns	**	ns	ns	ns	**
Fe + Mn + Zn	0	**	ns	ns	**	ns	ns
	19.6	ns	**	ns	**	**	**
	39.1	ns	**	ns	*	ns	*
Fe + Mn + Zn + Cu	0	nd	nd	nd	nd	nd	ns
	19.6	ns	ns	ns	*	ns	*
	39.1	ns	*	ns	**	ns	**
Fe + Mn + Zn + Cu + Mo	0	nd	nd	nd	nd	nd	ns
	19.6	ns	**	*	*	ns	**
	39.1	ns	*	ns	*	ns	**
Fe + Mn + Zn + Cu + Mo + S	0	nd	nd	nd	nd	nd	*
	19.6	*	**	ns	ns	ns	**
	39.1	ns	**	ns	**	ns	**

* Significant at 0.05
** Significant at 0.01
ns No significance
nd No data

APPENDIX B

BRAY P-1 AND AMMONIUM OXALATE EXTRACTABLE MOLYBDENUM IN QUINLAN AND SPUR SOILS

TABLE XXI

BRAY P-1 PHOSPHORUS CONCENTRATIONS IN QUINLAN AND SPUR SOILS

Treatment	P applied kg/ha	P ---------ug/g--------- Quinlan	Spur
Check	0	18.0	7.7
Fe	0	16.9	22.7
	19.6	25.6	1.1
	39.1	87.1	77.9
Mn	0	23.0	49.6
	19.6	35.1	30.4
	39.1	39.8	6.1
Zn	0	17.1	11.5
	19.6	39.6	6.9
	39.1	80.8	29.3
Cu	0	16.2	24.5
	19.6	49.9	58.7
	39.1	57.6	98.1
Mo	0	18.1	55.5
	19.6	50.7	23.2
	39.1	44.6	46.4
S	0	20.0	23.2
	19.6	56.7	32.8
	39.1	80.5	14.9
Fe + Mn	0	25.9	27.3
	19.6	51.1	18.1
	39.1	100.8	34.7
Fe + Mn + Zn	0	23.1	49.6
	19.6	48.2	33.4
	39.1	53.2	43.7
Fe + Mn + Zn + Cu	0	12.2	27.7
	19.6	49.3	63.7
	39.1	54.0	71.2
Fe + Mn + Zn + Cu + Mo	0	19.4	1.6
	19.6	34.1	39.7
	39.1	75.6	10.4
Fe + Mn + Zn + Cu + Mo + S	0	18.8	28.0
	19.6	34.3	7.5
	39.1	81.1	13.5

TABLE XXII

AMMONIUM OXALATE EXTRACTABLE Mo MEANS AND STANDARD DEVIATIONS IN QUINLAN AND SPUR SOILS

Treatment	P kg/ha	Quinlan Soil Mo ug/g	Quinlan Soil $s_{\bar{d}}$	Spur Soil Mo ug/g	Spur Soil $s_{\bar{d}}$
Check	0	21.5	11.5	29.7	15.4
Fe	0	15.2	22.6	22.8	7.2
	19.6	50.7	15.6	28.2	13.2
	39.1	37.5	22.6	35.8	16.7
Mn	0	24.6	16.9	25.8	8.2
	19.6	7.2	7.1	22.0	5.9
	39.1	28.2	20.4	27.3	14.7
Zn	0	11.7	13.9	19.2	5.5
	19.6	42.2	47.6	26.0	7.6
	39.1	27.8	29.4	30.0	9.4
Cu	0	27.7	22.3	16.1	4.1
	19.6	18.4	23.3	32.0	19.0
	39.1	54.0	20.4	34.1	19.4
Mo	0	359.3	149.8	299.4	21.0
	19.6	348.8	162.4	308.8	44.2
	39.1	472.4	204.1	113.5	97.5
S	0	10.2	17.9	26.8	5.9
	19.6	28.2	20.9	28.2	17.4
	39.1	25.0	22.4	29.9	14.9
Fe + Mn	0	17.5	22.6	31.2	19.9
	19.6	21.2	18.1	31.5	22.5
	39.1	50.1	24.9	22.5	4.3
Fe + Mn + Zn	0	8.7	3.6	34.0	17.1
	19.6	39.7	25.3	22.8	12.1
	39.1	22.8	16.5	26.0	11.1
Fe + Mn + Zn + Cu	0	8.3	9.0	35.3	17.8
	19.6	12.0	7.7	39.2	11.0
	39.1	28.8	18.8	29.9	14.2
Fe + Mn + Zn + Cu + Mo	0	260.8	56.2	298.8	82.5
	19.6	446.7	220.1	372.1	124.3
	39.1	216.2	95.4	375.7	117.2
Fe + Mn + Zn + Cu + Mo + S	0	544.1	68.2	379.6	133.2
	19.6	598.4	31.7	446.0	92.2
	39.1	539.0	282.3	390.8	87.5

APPENDIX C

CONCENTRATIONS OF N AND K IN GRAIN SORGHUM GROWN IN QUINLAN AND SPUR SOILS

TABLE XXIII

CONCENTRATIONS OF N AND K IN GRAIN SORGHUM GROWN IN QUINLAN SOIL

Treatment	P kg/ha	Initial Growth N %	Initial Growth K ug/g	Regrowth N %	Regrowth K ug/g
Check	0	1.7	11625	3.0	5625
Fe	0	2.0	9883	2.7	9350
	19.6	2.1	11508	2.0	5417
	39.1	2.6	12842	1.9	8050
Mn	0	2.0	9867	3.2	9317
	19.6	2.3	11767	3.2	9600
	39.1	3.0	11733	3.3	6475
Zn	0	2.0	8883	3.0	8662
	19.6	2.4	11517	3.3	4351
	39.1	2.2	11717	3.2	6650
Cu	0	2.1	10792	3.6	4150
	19.6	2.5	11767	3.2	9575
	39.1	2.9	11400	3.2	6175
Mo	0	1.9	8817	2.9	7525
	19.6	2.5	11783	3.4	8175
	39.1	2.7	12150	3.5	10767
S	0	2.0	-----	3.6	10075
	19.6	2.5	13012	3.3	6725
	39.1	3.0	12142	3.8	9450
Fe + Mn	0	2.0	10450	2.6	7975
	19.6	2.2	11892	2.1	8192
	39.1	2.5	12300	1.9	6575
Fe + Mn + Zn	0	1.9	10267	2.8	4983
	19.6	2.2	12383	2.1	5325
	39.1	2.4	11117	2.0	5458
Fe + Mn + Zn + Cu	0	2.1	10875	2.8	6275
	19.6	4.6	11775	2.4	7133
	39.1	2.4	11858	2.1	8258
Fe + Mn + Zn + Cu + Mo	0	2.0	7475	3.4	5475
	19.6	2.1	11258	2.2	9242
	39.1	2.3	11550	2.2	6000
Fe + Mn + Zn + Cu + Mo + S	0	2.2	9800	3.4	-----
	19.6	2.4	11642	2.6	9717
	39.1	2.2	11700	2.1	6517

TABLE XXIV

CONCENTRATIONS OF N AND K IN GRAIN SORGHUM
GROWN IN SPUR SOIL

Treatment	P kg/ha	Initial Growth N %	Initial Growth K ug/g	Regrowth N %	Regrowth K ug/g
Check	0	2.5	254	2.9	12500
Fe	0	2.9	231	3.5	16375
	19.6	2.1	260	1.9	14275
	39.1	2.9	258	1.9	13675
Mn	0	3.3	254	3.0	13675
	19.6	3.3	258	---	-----
	39.1	2.9	272	3.6	12900
Zn	0	3.6	257	2.7	-----
	19.6	3.8	258	---	-----
	39.1	3.7	188	3.1	-----
Cu	0	3.2	251	3.1	-----
	19.6	2.6	252	---	-----
	39.1	3.6	205	---	-----
Mo	0	2.8	225	---	-----
	19.6	3.1	235	---	-----
	39.1	3.7	253	---	-----
S	0	1.9	246	3.0	13600
	19.6	3.2	242	---	12650
	39.1	3.2	262	2.8	14225
Fe + Mn	0	2.2	246	---	12375
	19.6	2.8	221	2.8	12642
	39.1	1.7	243	3.6	12550
Fe + Mn + Zn	0	3.3	242	3.1	-----
	19.6	2.6	241	---	14600
	39.1	3.1	244	2.7	12638
Fe + Mn + Zn + Cu	0	3.7	238	---	-----
	19.6	2.1	222	2.9	10500
	39.1	---	235	2.8	13025
Fe + Mn + Zn + Cu + Mo	0	---	258	2.7	-----
	19.6	2.0	254	---	-----
	39.1	3.4	250	0.4	12575
Fe + Mn + Zn + Cu + Mo + S	0	3.6	260	2.6	-----
	19.6	3.1	252	2.8	15075
	39.1	3.1	228	2.4	9200

APPENDIX D

STATISTICAL DATA FOR ORTHOGONAL COMPARISONS
OF EXPERIMENTAL DATA

TABLE XXV

ERROR MEAN SQUARES AND DEGREES OF FREEDOM IN ERROR TERM USED IN SINGLE DEGREE OF FREEDOM ORTHOGONAL COMPARISONS OF EXPERIMENTAL DATA

Comparison	df in error term	EMS
Quinlan Soil		
DTPA Extractable Fe	66	7.03×10^{-2}
Initial Yield	65	2.23×10^{-4}
Regrowth Yield	65	3.25×10^{-3}
Spur Soil		
Initial Yield	47	7.56×10^{-3}
Regrowth Yield	46	1.73×10^{-3}

VITA[2]

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