THE EFFECTS OF FOLIAR IRON, BANDED APPLICATIONS OF PHOSPHORUS AND IRON AND IRON-COATED SEED ON THE YIELD OF GRAIN SORGHUM

By

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TABLE OF CONTENTS

LIST OF TABLES

CHAPTER I

INTRODUCTION

Iron deficiencies are a rather common occurrence on many soils in Western Oklahoma. Economic losses resulting from iron deficiencies in Oklahoma are believed to be substantial, but are difficult to estimate. Efforts to correct iron deficiencies with inexpensive fertilizers have been disappointing. Only marginal success has been obtained with applications of soluble iron salts. Foliar applications of $FeSO_4$ have usually been recommended, however, more than one application is usually required and in many cases, several applications are required for complete correction. Soil applications of $FeSO_4$ are usually not effective in correcting iron deficiencies unless very high rates are used. These soluble iron salts apparently become fixed in the soil and are unavailable for plant use. The use of synthetic chelates have proven to be an effective method for correcting iron deficiencies, but they are expensive and their general use on low cash value crops, such as grain sorghum, is usually not economical.

Iron deficiency symptoms are generally more apparent early in the growing season and will usually diminish or in some cases completely disappear as the weather becomes more favorable for plant growth, especially on soils which are only mildly deficient in available iron. If a satisfactory method which was economical and convenient to use could be developed to correct early season deficiencies, early plant growth could be increased with a resulting increase in yields.

The objectives of this study were to (1) test the effectiveness of Fe-coated seed in alleviating early season deficiency symptoms, (2) determine the effect of Fe-coated seed on the yield of grain sorghum, (3) compare the effects of different sources of soil-applied iron on yields and (4) evaluate the effect of foliar applications of $FeSO_4$ on the yield of grain sorghum.

CHAPTER II

LITERATURE REVIEW

Approximately 5% of the earth's crust, by weight, is comprised of iron. It is the fourth most abundant element in the earth's crust and its total content in soils ranges from a low of 200 ppm to a high of 10% (58). Although total iron content in soils is usually high, there does not seem to be a suitable relationship between the total iron content in the soil and iron available for plant use. Iron deficiencies have been reported in numerous crops on approximately 4.86 million hectares of land in at least 22 western states. Oklahoma alone has an estimated 260,000 hectares of crop land which is affected by iron deficiencies to some degree (43).

Function of Iron

Iron functions in several mechanisms in the overall metabolism of plants. Iron has been identified as a component of various flavoproteins (metalloflavoproteins) active in biological oxidations (24). It is also present in iron-porphyrin protein complexes which include cytochromes, peroxidases and catalases (24, 32, 41). Iron has been shown to be capable of partly replacing molybdenum, a metal cofactor necessary for functioning of nitrate reductase (41, 58). It is believed that iron also functions in the synthesis of chloroplastic protein and

and in this way may impair the machinery for chlorophyll synthesis (24, 58). A malfunction or reduction in the supply of iron to the plants will cause a reduction of chlorophyll synthesis and result in a yellowing of the plant. This yellowing of the plant which is a direct result of an iron deficiency is referred to as "iron chlorosis".

Possible Causes of Iron Chlorosis

Iron deficiencies most generally occur on alkaline or calcareous soils and the resulting chlorosis is often referred to as "lime-induced" chlorosis (23, 32, 36, 56, 57, 60). It was once believed that "lime-induced" chlorosis was the result of a high calcium carbonate content and a raising of the soil pH to such an extent that it made iron unavailable for plant use, however, this reasoning is complicated by the fact that there is no consistent difference in the lime content of soils where plants are green and where they are chlorotic. This suggests that there is a combination of interacting factors which affect and limit the availability of iron for plant use in calcareous soils.

Calcareous soils which contain relatively large amounts of phosphorus can be particularly susceptible to iron deficiencies. Onken and Walker (49) found that an interaction between phosphorus and iron within the plant contributed to an inactivation of absorbed iron and subsequent chlorosis in grain sorghum grown on a calcareous soil in West Texas. Watanabe et al. (61) observed a depression in yield of corn grown in a calcareous solution with the addition of phosphorus. Decrease in yield was not followed by a decrease in iron concentration, but was related to high phosphorus concentration in plant tissue. DeKock (23) suggested that the high content of phosphorus in chlorotic plants probably results from an imbalance in the cell due to iron deficiency and that the phosphorus-iron ratio is an accurate assessment of iron status in plants. Brown et al. (15) also suggested that an excess of phosphorus which accumulates inside the plant may render the iron inactive.

The absorption of iron seems to be related to the ability of the root to reduce Fe^{+3} to Fe^{+2} (2, 3, 11, 16, 21, 56). Some researchers feel this reduction is essential before iron can be absorbed into the plant (2, 11, 16, 20, 21, 56). Ambler et al. (3) suggested that the area of greatest reducing capacity for ferric iron is located between the regions of root elongation and root maturation. This region of the root has shown to be more active in the upward translocation of iron than any other region.

The interference of metal ions plays an important role in the absorption or utilization of iron by plants. Ambler et al. (3) found that zinc interferes with the translocation of iron by inhibiting the reducing capacity of the root (Fe^{+3} to Fe^{+2}). Lingle et al. (38) found that with increasing concentrations of manganese, copper, calcium, magnesium, and potassium, iron concentration in stem exudate of soybeans was first increased then decreased to low levels. Small concentrations of zinc depressed iron levels in stem exudate over the entire range tested. Zinc strongly interfered with the uptake of iron by roots in decapitated plants but to a greater extent interfered with the translocation of iron to the tops of intact plants.

Kannan and Joseph (35) found that manganese did not interfere with translocation of iron in germinating sorghum but did have an effect on the utilization of iron in chlorophyll synthesis. Twyman (59) stressed the importance of iron-manganese ratios in the metabolism of apparently normal plants, however, Morris and Pierre (42) found that the iron-manganese ratio was not a primary factor in the growth of lespedeza and that good growth was obtained over a wide range of iron-manganese concentrations. Carlson and Olson (19) found that ratios of iron to manganese in sorghum were not important when a high content (3 ppm) or a low content (.04 ppm) of iron is supplied but are important at the medium level (.5 ppm). They found that a ratio of one to one was superior at this level. They suggested that high manganese-iron ratios may aid in the development of iron chlorosis in plants but that other factors may determine whether or not chlorosis actually develops.

Sommers and Shive (55) suggested that manganese inactivates iron in the leaves by oxidizing it to the ferric state and precipitates it as ferric complexes. Hewitt (28) reported a chlorosis in sugar beets resembling iron deficiency from applied cobalt, copper, zinc, nickel chromium, and lead ions in purified sand culture. Similar results were also observed by DeKock (22) with mustard plants grown in acid-washed sand.

Brown et al. (14) believed that a high copper-manganese to iron ratio caused iron chlorosis to develop on certain calcareous western soils. Brown and Holmes (17) found that copper affected the absorption and utilization of iron in corn but not in sorghum or wheat. Adriano et al. (1) also observed copper and manganese antagonism on iron concentration in corn grown in high nutrient solutions. DeKock (22) suggested that active translocation of iron takes place in the phloem, which is where copper is mainly concentrated in the root and where it would thus exert maximum interference.

Brown et al. (12) found that rice grown in a flooded calcareous-organic mixture responded well and made good growth with additions of high levels of phosphorus, however, additions of copper severely limited absorption and utilization of iron. They concluded the probable cause was the additional metabolic processes in the plant. In an earlier study, Brown and Hendricks (13) proposed that the activity of copper-requiring systems most likely increased the amount of iron required and that since high phosphorus levels may retard iron uptake, this may explain the effect of a phosphorus-copper combination on iron deficiencies.

Berry and Reisenhauer (6) found that molybdenum strongly enhances iron accumulation in tomato plants at marginally adequate levels, however, at low or high levels, iron absorption is depressed. The observed effects of increased molybdate levels seem to be the result of an enhancement of the plant's ability to absorb and translocate iron and a reduction in the reactivity of iron compounds in the root media.

Considerable importance has been placed on the bicarbonate iron as a factor in iron chlorosis. In a split medium experiment using chlorosis susceptible soybeans, Brown et al. (18) observed that plants growing through a soil mix and into a solution containing no phosphorus or iron but 10 meq/l of $NaHCO_3$ did not become chlorotic nor was iron absorption reduced. However, soybeans grown in a complete solution of iron, phosphorus and 5 meq/l $NaHCO_3$ became severely chlorotic with a greater concentration of phosphorus being maintained in solution than with treatments containing no HCO_3. This suggests that chlorosis was more related to phosphorus concentration than to HCO_3. Lindsay and Thorne (37) have studied the effects of oxygen level and bicarbonate on chlorosis in bean plants grown in nutrient solutions at high pH. They found that aeration of the roots of bean plants with increasing oxygen concentration caused increased chlorosis in nutrient solutions containing sodium bicarbonate. This seems to indicate that the increase of plant chlorosis frequently associated with poorly aerated conditions cannot be primarily attributed to a reduced oxygen level in roots. Hale and Wallace (27), in studying the effects of phosphorus and bicarbonate on uptake of iron in soybeans, observed that HCO_3^- and CO_3^{-2} decrease accumulation of iron in roots but not always in leaves, however, neither impeded translocation of iron from the roots. Bicarbonate and $H_2PO_4^-$ each competitively inhibited iron accumulation suggesting an antagonistic effect between these anions in iron absorption. Porter and Thorne (50) found that varying amounts of $NaHCO_3$ in solution cultures in conjunction with different proportions of CO_2 brought about marked changes in growth and chlorophyll contents of beans and tomato plants and of iron content of leaves and stems of tomato plants. They suggested that the bicarbonate ion is a direct causitive factor of chlorosis in some plants, however, Brown (10) suggested that the effect of HCO_3^- in producing chlorosis is probably due to the interrelations between HCO_3^-, phosphorus, calcium, and iron and that the effect of HCO_3^- in producing chlorosis may be an indirect rather than a direct effect.

Often chlorotic plants on high lime soils will have a larger concentration of potassium and lower concentration of calcium than normal plants (5, 8, 36, 56). In earlier research, Lindner and Harley (36) suggested an antagonistic effect of potassium on iron which would indicate that if potassium is a cause of chlorosis, the potassium content of soils should be higher in areas of chlorotic plants than normal plants, however, work done by Bolle-Jones (8) with potatoes found no relationship between potassium-calcium ratio and chlorophyll content in the presence or absence of adequate potassium. Thorne et al. (57) and Brown et al. (15) have proposed that high potassium-calcium ratios are a result rather than a cause of chlorosis.

Plant species or varieties also play a significant role in whether or not iron chlorosis develops in some plants. The susceptibility to iron deficiency depends on the ability of the plant to respond to iron stress. This adaptive response is genetically controlled whereby H^+ ions and a reductant are released from the roots. These make iron available for uptake (2, 9, 11, 14, 16, 20). Examples of this were shown by Brown et al. (16) using chlorosis-susceptible PI-54619-5-1 (PI) and nonsusceptible Hawkeye (HA) soybeans. Iron-deficient HA roots showed much greater reduction of both iron and pH than iron-deficient PI roots or iron-sufficient PI and HA roots. As soybean plants developed chlorosis, their capacity to absorb iron increased. Iron-deficient HA roots showed this much more than iron-deficient PI roots.

High nitrate nitrogen levels in the soil also appear to have a detrimental effect on the uptake and utilization of iron by plants. Aktas and Egmond (2) proposed that with high nitrate levels in the soil more OH^- ions are produced in the NO_3 assimilation process and more OH^- ions are excreted by the plant roots. Nitrate nitrogen has a pH increasing effect on the soil by increasing the OH^- and HCO_3^- ions in the vicinity of the plant roots and decreasing the solubility of the iron. Chlorosis in plants decreased with a decrease in NO_3^- levels in the soil. As NO_3^- levels decreased, the plants excreted more H^+ ions resulting in a lowering of pH in the rhizosphere which has been shown to stimulate the reduction of Fe^{+3} to Fe^{+2} (9, 11, 16, 20, 50, 58) which is believed essential for the uptake of iron (2, 11, 16, 20, 21, 56).

Other factors proposed by Wallace and Lunt (60) which may enhance iron deficiencies in plants include high light intensities, viruses, and root damage by nematodes or other organisms.

An important characteristic associated with iron deficiencies on calcareous soils is high moisture levels and poor aeration (10, 37, 43, 57, 60). Brown (10) suggested that moist soil conditions and decomposing organic matter provides an excellent condition for maximum HCO_3^- accumulation. Lindsay and Thorne (37) believe the higher concentration of CO_2 at root surface under high moisture conditions may account for the increase in HCO_3^-.

Iron deficiencies are usually most severe early in the growing season and can be directly associated with low temperatures (43, 51, 57, 60). Often these symptoms will disappear as the temperature becomes warmer, especially on soils which are only mildly deficient in available iron (29, 43, 63). This recovery may result from an increase in root growth which enables the plant to take up iron over a larger area or it is possible that iron availability increases in the soil as temperatures and microbial activity increase (63).

Low levels of total iron in soils is also a possible cause of iron chlorosis of plants, however, since iron is so widely distributed in most soils and is needed in relatively small amounts by plants, this type of chlorosis probably occurs very infrequently (36).

An interesting occurrence associated with iron chlorosis is that many researchers have found the iron content of chlorotic leaves to be as high as their normal counterparts (38, 55, 62), however, other researchers have found a good correlation between iron chlorosis and iron content in plants (5, 33, 54). Bennet (5) and Jacobson (33) propose that the apparent lack of correlation between iron in green leaves and chlorotic leaves in past experiments may have been due to surface contamination. They suggested that washing the leaves with distilled water did not effectively remove surface contamination. Bennet (5) concluded that complete removal of surface contamination requires washing with a dilute acid and subsequent rinsing.

Jacobson and Oertli (34) in a study of iron deficiencies in sunflowers suggested a correlation between iron and chlorophyll content of sunflower leaves exists if iron was supplied at a uniform rate but no relationship was observed with an interruption in supply of iron. A deficiency followed by an adequate supply of iron caused the plant to take up excess amounts of iron. They concluded that chlorosis was not completely reversible so chlorotic leaves may not turn green even when an adequate supply of iron is present, however, they are likely to accumulate as much or more iron than would be found under normal conditions.

Iron Deficiency Symptoms

The most easily observed symptom of iron deficiency is chlorosis of the leaves (4, 24, 32). Chlorosis of the interveinal portion of the leaves is usually the first deficiency symptom, the surface of the leaf usually showing a fine reticulate network of green veins setting off chlorotic areas (24). In more severe cases, the leaf may become completely chlorotic or even white, depending on the severity of the deficiency (32, 58). Generally the younger leaves are most affected.

This is primarily because iron is relatively immobile and cannot draw iron from the older leaves. The older leaves will become chlorotic as the severity of the chlorosis increases (24, 32, 58).

In the early stages of chlorosis there is a sharp distinction between green veins and light green (or yellow) tissue between the veins. This is in contrast with the chlorosis resulting from zinc or manganese deficiencies, in which there is a variance of green color in the leaves (4).

Correction of Iron Deficiencies

It is often more difficult to correct deficiencies of iron than those of other micronutrients. Applications of inorganic and organic sources have been extremely variable in their effectiveness due to the reactions that occur between the applied iron and the soil components (47). The most commonly used inorganic compound in correcting iron deficiencies is $FeSO_4$ while Fe-chelates are the most commonly used organic sources. Other organic sources of iron which have been used are iron polyflavonoids, iron ligninsulfonates and iron methoxyphenylpropane. Several compounds, as listed by Murphy and Walsh (47) which are used as sources of fertilizer iron, are given in Table I. Several sulfur products such as elemental sulfur, ammonium thiosulfate, sulfuric acid and ammonium polysulfide have also been effectively used to correct iron deficiencies. These compounds are effective in lowering soil pH and simultaneously acting as reducing agents (Fe^{+3} to Fe^{+2}) (58).

There has not been a great deal of work done in the past in the area of correcting iron deficiencies in field crops. Most of the work done with iron deficiencies has been directed toward high cash value

TABLE I

IRON CONTAINING FERTILIZERS

Source	Formula	% Fe (approx.)
Ferrous sulfate	$FeSO_4 \cdot 7H_2O$	19
Ferric sulfate	$Fe_2(SO_4) \cdot 4H_2O$	23
Ferrous oxide	FeO	77
Ferric oxide	Fe_2O_3	69
Ferrous ammonium phosphate	$Fe(NH_4)PO_4 \cdot H_2O$	29
Ferrous ammonium sulfate	$(NH_4)_2SO_4 \cdot FeSO_4 \cdot 6H_2O$	14
Iron frits	Varies	Varies
Iron ammonium polyphosphate	$Fe(NH_4)HP_2O_7$	22
Monosodium ferric ethylenediamine tetraacetate	NaFeEDTA	5-14
Monosodium ferric hydroxyethylene diaminetriacetate	NaFeHEDTA	5-9
Monosodium ferric ethylenediamine (d(o-hydroxyphenyl-) acetic acid)	NaFeEDDHA	6

TABLE I (Continued)

Source	Formula	% Fe (approx.)
Monosodium ferric diethylenetriamine pentaacetate	NaFeDTPA	10
Iron polyflavonoids	--------	9-10
Iron ligninsulfonates	--------	5-8
Iron methoxyphenylpropane	FeMPP	5

crops, such as fruit and vegetable production and ornamentals. In general, most of the work that has been done with field crops has included the use of soil applications of inorganic compounds such as ferrous iron salts, H_2SO_4 or iron oxides and foliar applications in which $FeSO_4$ is primarily used.

The use of soluble iron salts applied to the soil have usually not been effective unless very high rates are used. Withee and Carlson (63) found that applications of 560 kg/ha of $FeSO_4$ applied to the soil were somewhat effective in increasing yields in grain sorghum in Western Kansas, but were not economically practical. They concluded that spraying chlorotic grain sorghum with three sprays of 4% $FeSO_4$ solution at 280 l/ha per application was an effective method for improving yields in grain sorghum. They also observed that 2 foliar sprays produced more than 560 kg/ha of $FeSO_4$ applied to the soil. Mathers (39) found that an application rate of 560 kg/ha iron as $FeSO_4$ or 560 kg/ha H_2SO_4 was required for complete correction of iron chlorosis on irrigated grain sorghum in West Texas. He also observed that with increasing the rate of H_2SO_4 to 5600 kg/ha yields were reduced. This suggests that high rates of H_2SO_4 as a band application may leave a zone of soil with a high salt content that will reduce yields. Phosphorus did not affect yields when applied in combination with $FeSO_4$ or H_2SO_4, but yields decreased when phosphorus was applied alone. This agrees with Watanabe et al. (61) that when phosphorus is added to soil deficient in iron, the iron deficiency may become more severe. In greenhouse experiments, Olson (48) found that the use of iron oxides were not effective in correcting iron chlorosis in grain sorghum. Ferrous sulfate used at 1120 kg/ha failed to show a significant increase in yield, but did significantly increase chlorophyll content and total iron in leaves. Sulfuric acid added at 4480 kg/ha greatly increased growth which was believed to be because of the increased availability of phosphorus.

In greenhouse experiments, Mathers (39), using grain sorghum, found that effects of 250 ppm or more iron with 250 ppm or more H_2SO_4 were still significant on the third crop after soil treatments were made, suggesting that residual effects are possible from heavy applications of $FeSO_4$ and H_2SO_4. Hodgson et al. (30) reported a significant residual response to iron applied as $Fe_2(SO_4)_3$ in the greenhouse at rates above 186 ppm.

In field experiments conducted in the Rio Grande Plains of Texas, Fisher and Reyes (25) found that foliar sprays used at 2.5-5% $FeSO_4$ with a .01% wetting agent at 190 l/ha were much more effective in increasing yields in grain sorghum than as much as 1120 kg/ha of soil-applied $FeSO_4$.

From recent work conducted at the Southern Great Plains Field Station, Bushland, Texas, Mathers and Thomas (40) reported that applications of manure at rates of 22,000 kg/ha were effective in correcting iron deficiencies on calcareous soil. They also observed that application rates of up to 450 kg/ha of $FeSO_4$ applied alone to the soil had no effect on yields.

With difficulties encountered in the use of soil applications of inorganic salts, a considerable amount of attention has been given to soil applications of organic chelates. Holmes and Brown (31) found that of five Fe-chelates studies (EDTA, HEDTA, CDTA, DTPA, and EDDHA), only DTPA and EDDHA were effective in eliminating iron chlorosis in soybeans grown in 17 calcareous soils of the Western U.S.A. Mortvedt and Giordano (44) observed that soil applications of 16 ppm of iron as Fe-EDDHA significantly increased yields in grain sorghum. Salardini and Murphy (53) reported that of three sources of organic iron studied (Fe-polyflavonoid (Fe-PF), 9-10% Fe; Fe-lignosulfonate (Fe-LS), 11% Fe; and Fe-EDDHA, 6% Fe), Fe-LS produced the highest dry matter yields in grain sorghum followed by Fe-EDDHA and Fe-PF at rates of 20 ppm Fe, however, Fe-EDDHA was found to be most effective in correcting iron chlorosis.

These results seem to indicate that high rates of organic iron sources may be successfully used in certain cases, however, for low cash crops, such as grain sorghum, cost of application is a limiting factor and only low rates may be economically feasible.

Mortvedt and Giordano (44, 46) found that both $FeSO_4$ and $Fe_2(SO_4)_3$ may be effective for crops at reasonably low rates if they are applied with fluid polyphosphate fertilizers to the soil. They found that the maximum level of iron which could be dissolved in 11-16-0 solution (11-37-0 oxide form) is about 1%. This presents the possibility that enough iron for early crop growth could not be supplied at normal phosphorus application rates, e.g. 56 kg/ha of P_2O_5 would provide only 1.6 kg/ha iron. They suggested that the iron levels could be increased to about 3% iron if the fertilizer is first diluted with an equal volume of H_2O. Results also showed that 10-15-0 (10-34-0 oxide form) was about as effective as 11-16-0 as a carrier of ferric sulfate, but 8-11-0 (8-24-0 oxide form) was ineffective. In a greenhouse pot experiment, Mortvedt and Giordano (45) found that forage yields and uptake of grain sorghum from a band application of $FeSO_4$-ammonium polyphosphate suspension were doubled over those of polyphosphate alone. Inclusion of $(NH_4)_2S_2O_3$

resulted in a 15-25% increase in crop response.

The use of acid-treated mine tailings containing residual H_2SO_4 have been shown to encourage plant growth (7). Fuller and Lanspa (26) found that acid-treated tailings from a lead-zinc-copper mine effectively stimulated plant growth and iron uptake in grain sorghum when applied to a calcareous soil of the Southwestern United States.

In greenhouse experiments using a surplus by-product ("jarosite" 28% Fe, 35% S) of the copper refining industry, results of a 2:1 mixture of "jarosite"/H_2SO_4 compared favorably with conventional inorganic and chelated sources of iron in increasing yields in grain sorghum grown on a calcareous soil (52).

These results suggest a practical possibility of combining waste products from the copper mining-refining industry into usable agricultural products for correcting iron deficiencies on calcareous soils.

Some researchers believe that most iron chlorosis in the field today could be eliminated by using Fe-efficient plants as well as developing new crop varieties which are tolerant to low levels of available iron in the soil (9, 14). Mortvedt (43), however, suggested such selections could result in discarding germplasm which is superior in other traits and believes that research in improving methods of correcting chlorosis by soil and foliar applications should be continued.

CHAPTER III

METHODS AND MATERIALS

Three sites were selected in Western Oklahoma which had a history of iron deficiencies in plants. The areas were located near Berlin in Roger Mills County on a Dill fine sandy loam, near Orienta in Major County on a Treadway clay and near Rosston in Harper County on a St. Paul silt loam soil. The classification and analysis of the soils used are given in Table II.

All three experiments were initiated under non-irrigated conditions in the summer of 1979 using grain sorghum (Sorghum bicolor (L.) Moench.) as the test crop (variety SG-10). Planting date was June 14 at Orienta, June 18 at Rosston and June 20 at Berlin. Planting rate was 9 kg/ha with 100 cm row spacings, while the planting depth was approximately 2.5-4 cm. Preplant soil preparation at all sites consisted of two plowings with a tandom disk harrow at a depth of approximately 10 cm. No herbicide or insecticide applications were made at any of the locations. The Berlin and Orienta locations received one cultivation each during the season as the only method of weed control. The experiments were arranged in a randomized complete block design with four replications.

The fertilizer sources used included liquid 10-15-0 ammonium polyphosphate (10-34-0 oxide form), $FeSO_4 \cdot 7H_2O$ (20% Fe, 11% S), Iron-Sul* fertilizer from Duval Corp., which is a by-product of the copper

TABLE II

CLASSIFICATION AND ANALYSIS OF SOILS USED IN EXPERIMENTS

	pH	Kg/ha					PPM		
		NO_3-N	P	K	Ca	Mg	Fe	Zn	Mn
1. Dill fine Sandy Loam (Udic Ustochrepts: coarse-loamy, mixed, thermic) Berlin Location	6.7	12	16	202	1840	379	8.3	.38	10.4
2. Treadway Clay (Ustertic Camborthids: fine, mixed, thermic) Orienta Location	7.6	85	39	1120	5849	707	6.7	.64	13.8
3. St. Paul Silt Loam (Pachic Argiustolls: fine-silty, mixed, thermic) Rosston Location	7.9	40	43	661	9082	604	8.4	.41	11.6

refining industry. Sequestrene 138** (6% Fe) from Giegy Chemical Co., Inc. and Fe-coated seed. Seed coating consisted of Fe-Ke-Min*** from Georgia Pacific, Inc., which is an organic chelate derived from wood pulp and contained 11% iron. Coating on the seed was 16% of the seed, by weight. Iron coating of seed was done by Celpril Industries, Monteca, CA. Fertilizer treatments and rates are outlined in Table III.

All liquid fertilizer treatments which included APP, APP + $FeSO_4$ and APP + Sequestrene-138 were banded one-half with the seed and one-half 5 cm to the side and 5 cm below the seed at planting. Fertilizer treatments using APP and APP + $FeSO_4$ were made with Fe-coated and uncoated seed. Uncoated seed only was used with APP + Sequestrene-138. Iron-Sul fertilizer, used with uncoated seed only, was banded preplant approximately 10 cm directly below the seed. All foliar applications were made with $FeSO_4$ + a wetting agent with both Fe-coated and uncoated seed. Foliar applications were made at Berlin on July 18, 25 and August 20 and at Orienta on August 7, 21 and September 4. The Rosston location received only one foliar spray which was applied on August 7.

At each location, 45 kg/ha of nitrogen, as NH_4NO_3, was broadcast over the entire experimental area before planting.

Liquid 10-15-0 was applied by diluting to a 4/1 ratio of H_2O to fertilizer. Ferrous sulfate and Sequestrene-138 were mixed with liquid APP under constant agitation with a P.T.O. pump. Actual fertilizer application was made by the use of a squeeze pump.

Grain sorghum was harvested at Berlin on October 9 and at Orienta on October 20. The center two rows from each plot were harvested for yield data. Plot sizes were 4 X 12 and 4 X 15 meters at Berlin and

TABLE III

TREATMENTS USED IN EXPERIMENTS

Treatment	Soil Applied				Foliar*
	kg/ha				
	N	P	S	Fe	Fe
1. Check	0	0	0	0	0
2. Check + foliar-Fe	0	0	0	0	5.5
3. 10-34-0 banded with seed	13	20	0	0	0
4. 10-34-0 banded with seed + foliar-Fe	13	20	0	0	5.5
5. 10-34-0 + $FeSO_4$ banded with seed	13	20	5	9	0
6. 10-34-0 + $FeSO_4$ banded with seed + foliar-Fe	13	20	5	9	5.5
7. Iron-Sul (112 kg/ha) banded	0	0	34	18	0
8. Iron-Sul (112 kg/ha) banded + foliar-Fe	0	0	34	18	5.5
9. Iron Sul (224 kg/ha) banded	0	0	67	36	0
10. Iron-Sul (224 kg/ha) banded + foliar-Fe	0	0	67	36	5.5
11. Fe-coated seed	0	0	0	0	0
12. Fe-coated seed + foliar-Fe	0	0	0	0	5.5

TABLE III (Continued)

Treatment	Soil Applied				Foliar*
	kg/ha				
	N	P	S	Fe	Fe
13. Fe-coated seed + 10-34-0 banded	13	20	0	0	0
14. Fe-coated seed + 10-34-0 banded + foliar-Fe	13	20	0	0	5.5
15. Fe-coated seed + 10-34-0 + $FeSO_4$ banded	13	20	5	9	0
16. Fe-coated seed + 10-34-0 + $FeSO_4$ banded + foliar Fe	13	20	5	9	5.5
17. 10-34-0 + Sequestrene-138 banded with seed	13	20	0	2	0

* 3% Fe as $FeSO_4$ at 190 l/ha per application

Orienta, respectively. Due to extremely droughty conditions, no grain was harvested from the Rosston location.

Statistical analysis of yield data was done by partitioning the treatment sum of squares into single degree of freedom comparisons. The comparisons were meaningful but not always orthogonal.

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*, **, ***, Trade names and manufacturers are listed only to identify products. No endorsement of these products is intended.

CHAPTER IV

RESULTS AND DISCUSSION

The fertilizer sources used in these experiments were tested for their effectiveness in correcting iron deficiencies and increasing yields in grain sorghum. Iron-coated seed was used primarily to determine its effectiveness in reducing early season deficiency symptoms. Soil and foliar applications of $FeSO_4$ were used with Fe-coated and uncoated seed, while Iron-Sul fertilizer and Sequestrene-138 were used with uncoated seed only. Liquid 10-15-0 ammonium polyphosphate was used as a carrier for all soil applied $FeSO_4$ and Sequestrene-138.

Numerous problems were encountered with the experiments at the Orienta and Rosston locations. Because of late selection of both sites, planting was done in a poorly prepared seedbed. This resulted in erratic germination and a poor stand of sorghum. Normal plant growth was also severely hampered by a lack of adequate moisture during the growing season, particularly at the Rosston location. At the time of the first foliar application at Rosston on August 7, many of the plants had already died and the remaining plants were severely stunted in growth. Because of the extremely poor stand and severe lack of moisture it was concluded that further foliar applications would be of no benefit. None of the plants produced normal heads of grain. Consequently, the area was not harvested and no yield data from Rosston is presented.

The Orienta location was harvested, however, visual observations at harvest revealed that some of the plants had failed to produce normal heads of grain. Yields were also reduced by severe bird damage. Because of the abnormally low yields along with the erratic yields within treatments, it was apparent that the treatments used were not fairly evaluated. For these reasons, the yield data from the Orienta location will be discussed only in a general nature.

A good stand, however, was established at the Berlin location. Summer rainfall was unusually high for this area and good growth was obtained throughout the season with no sign of moisture stress in the plants at harvest time.

Visual signs of iron chlorosis early in the growing season were noted at both the Berlin and Orienta locations. Deficiency symptoms at Berlin were mild with only slight interveinal yellowing detected. There was significant variability among blocks at this location which suggested that the area was not uniformly deficient in iron although this was not visibly noticeable. Deficiency symptoms at the Orienta location varied from moderate to severe within the same treatment, but there was no significant variability among blocks.

The use of Fe-coated seed had no effect on early season deficiency symptoms at either the Berlin or the Orienta location. No difference in visual signs of deficiency was noted between the treatments receiving Fe-coated seed or the treatments with uncoated seed.

This apparent lack of effectiveness of Fe-coated seed may be explained in part by the fact that only a very small amount of iron is actually applied to the soil. Using coated seed (16% material by seed weight) containing 11% iron would effectively apply only about 160 g/ha of iron at a planting rate of 9 kg/ha. Apparently this does not supply the soil with enough iron to have any measurable effect on the amount of available iron within the rooting zone of the plant.

The ineffectiveness of Fe-coated seed was also reflected in yield of grain (Table IV). Yields from Fe-coated and uncoated seed without any additional fertilizer were not significantly different at either location. The addition of 13-20-0 fertilizer banded with the seed, however, did substantially increase yields at both locations although there was no significant difference between Fe-coated and uncoated seed with the exception of Fe-coated seed at Orienta. The significant decrease in yield at Orienta was probably not a valid indication of added fertilizer because of the problems encountered with moisture stress and bird damage. Banded applications of APP + $FeSO_4$ with Fe-coated seed were not effective in increasing yields over uncoated seed with APP + $FeSO_4$ at either location.

All treatments using soil-applied $FeSO_4$ were applied with APP used as a carrier. Previous work done by Mortvedt and Giordano (44, 45, 46) in greenhouse experiments at TVA had shown that mixing of $FeSO_4$ with fluid ammonium polyphosphate was effective and economical at low application rates. Their results showed forage yields and iron uptake from a band application of APP + $FeSO_4$ on a calcareous soil were twice those of APP alone. In past field experiments conducted in Western Oklahoma, Heizer (29) and Rogers (51) reported good success from low rates of banded APP + $FeSO_4$ in reducing iron deficiency symptoms and increasing yields in forage sorghum and wheat. Yield results from these field experiments, however, did not agree with those findings. Added $FeSO_4$ with APP was not effective in increasing yields with Fe-coated or uncoated seed at either location with the exception of APP + $FeSO_4$ with Fe-coated seed at Orienta (Table V). This increase in yield may have, in part, resulted from bird damage; however, iron deficiency symptoms were much more severe at this location, suggesting that a possible response to applied $FeSO_4$ might have been obtained. The apparent lack of effectiveness of APP + $FeSO_4$ at the Berlin location may be considered from two possible lines of reasoning. The first would be that there was simply not enough available iron within the vicinity of the roots for optimum iron uptake and utilization by the plant. This idea is proposed in light of the significant increase in yield which was obtained with banded applications of APP + Sequestrene-138 (Table VI). The other possible explanation for the lack of response from added APP + $FeSO_4$ might be in the possibility that since the area appeared to be only mildly deficient in available iron, applied phosphorus may have successfully corrected the iron deficiency. The use of APP may have sufficiently increased plant root growth allowing for a greater absorption and uptake of iron. The plots receiving banded applications of APP without $FeSO_4$ as well as treatments which included $FeSO_4$ showed no signs of obvious iron deficiencies at any time during the season. Heizer (29) also reported a reduction in deficiency symptoms in wheat with fluid APP applied alone. Rogers (51) suggested a complimentary effect of phosphorus on iron uptake on soils which show iron deficiencies in small grains.

Foliar applications of $FeSO_4$ were also ineffective in increasing yields. At both the Berlin and Orienta locations, foliar $FeSO_4$ applied as the only source of fertilizer resulted in no difference in yields from Fe-coated or uncoated seed (Table VII).

TABLE IV

EFFECT OF IRON-COATED SEED ON YIELD

Treatment	Yield, kg/ha	
	Berlin	Orienta
Check	2400	715
Fe-coated seed	2240	791
13-20-0	3177	1043
Fe-coated seed + 13-20-0	2857	402*
13-20-0 + $FeSO_4$	2926	755
Fe-coated seed + 13-20-0 + $FeSO_4$	2971	995

* Denotes significance at .10 level.

TABLE V

EFFECT OF SOIL-APPLIED $FeSO_4$ ON YIELD

Treatment	Yield, kg/ha	
	Berlin	Orienta
13-20-0	1377	1043
13-20-0 + $FeSO_4$	2926	755
Fe-coated seed + 13-20-0	2857	402
Fe-coated seed + 13-20-0 + $FeSO_4$	2971	995*

* Denotes significance at .10 level.

TABLE VI

EFFECT OF SEQUESTRENE-138 ON YIELD

Treatment	Yield, kg/ha	
	Berlin	Orienta
13-20-0	3177 AB	1043 A
13-20-0 + Foliar-Fe	2594 B	379 B
13-20-0 + $FeSO_4$	2926 B	755 AB
13-20-0 + $FeSO_4$ + Foliar-Fe	2743 B	452 B
13-20-0 + Sequestrene-138	3931 A	769 AB

Means with the same letter are not significantly different at the .10 level.

TABLE VII

EFFECT OF FOLIAR $FeSO_4$ ON YIELD

Treatment	Yield, kg/ha	
	Berlin	Orienta
Check	2400	715
Check + Foliar-Fe	2351	933
Fe-coated seed	2240	791
Fe-coated seed + Foliar-Fe	2550	459

NSD (.10)

Foliar $FeSO_4$ at 224 kg/ha applied to treatments receiving banded Iron-Sul fertilizer significantly decreased yields at the Berlin location. The significance of this decrease in yield is accentuated by the increase in yield from soil applied Iron-Sul fertilizer (Table VIII). Although yields at the Orienta location appeared to show a slight increase with applications of foliar $FeSO_4$ at both the 112 and 224 kg/ha rate of Iron-Sul fertilizer, the differences were not significant.

TABLE VIII

EFFECT OF FOLIAR $FeSO_4$ ON YIELD (WITH SOIL-APPLIED IRON-SUL FERTILIZER)

Treatment	Yield, kg/ha	
	Berlin	Orienta
Iron-Sul (112 kg/ha)	2629	671
Iron-Sul (112 kg/ha) + Foliar-Fe	2278	900
Iron-Sul (224 kg/ha)	3257	383
Iron-Sul (224 kg/ha) + Foliar-Fe	2480*	514

* Denotes significance at .10 level.

Foliar applications used as the only source of iron in combination with soil-applied APP were not effective in increasing yields with either Fe-coated or uncoated seed at Berlin (Table IX). Foliar applications with soil-applied APP significantly decreased yields at Orienta with uncoated seed, however, there was a significant increase in yields with Fe-coated seed.

TABLE IX

EFFECT OF FOLIAR $FeSO_4$ ON YIELD
(WITH SOIL-APPLIED APP)

Treatment	Yield, kg/ha	
	Berlin	Orienta
13-20-0	3177	1043
13-20-0 + Foliar-Fe	2594	379**
Fe-coated seed + 13-20-0	2857	402
Fe-coated seed + 13-20-0 + Foliar-Fe	2891	991*

* Denotes significance at .10 level
** Denotes significance at .05 level

Foliar application made to treatments receiving soil-applied APP + $FeSO_4$ were ineffective with either the Fe-coated or uncoated seed at both the Berlin and Orienta locations (Table X). In these experiments, and especially at the Berlin location, there seemed to be a general trend to a reduction in yields with the addition of foliar $FeSO_4$. A satisfactory explanation for this occurrence cannot be given. Visual observations of the plants did not reveal any noticeable leaf burn after foliar sprays were made. All foliar applications were made with a wetting agent at 5 ml/35 liters of solution. Withee and Carlson (63) encountered a problem with drying time in using foliar applications of $FeSO_4$ on grain sorghum in Western Kansas. They observed that effectiveness of sprays was best when temperatures were low and relative humidity high. Temperatures of 68 to 78° F, relative humidity of 65-80% and wind velocities of 1 to 7 miles per hour resulted in spray solutions drying on the leaves in 7 to 8 minutes. Under these conditions, the foliar sprays seemed to be most effective.

TABLE X

EFFECT OF FOLIAR $FeSO_4$ ON YIELD (WITH SOIL-APPLIED APP + $FeSO_4$)

Treatment	Yield, kg/ha	
	Berlin	Orienta
13-20-0 + $FeSO_4$	2926	755
13-20-0 + $FeSO_4$ + Foliar-Fe	2743	452
Fe-coated seed + 13-20-0 + $FeSO_4$	2971	995
Fe-coated seed + 13-20-0 + $FeSO_4$ + Foliar Fe	2605	547

NSD (.10)

All foliar sprays made at both Berlin and Orienta, however, were made under conditions of much higher temperature and quite possibly lower relative humidity. This may partly explain the lack of effectiveness of these foliar applications.

It may be mentioned that at both the Berlin and Orienta locations the last foliar spray was made as heads were in the flowering stage. This is not believed, however, to have been detrimental to the plant. Fisher and Reyes (25) found that spraying chlorotic plants as late as early head formation increased grain production in sorghum.

The use of soil + foliar applications of $FeSO_4$ were also ineffective in increasing yields (Table XI). Yields at the Berlin location showed an apparent slight decrease for both the Fe-coated and uncoated seed, but the differences were not great enough to be significant. There was a significant decrease in yield with added soil + foliar-Fe at the Orienta location with uncoated seed, however, there was an increase in yield with Fe-coated seed.

TABLE XI

EFFECT OF SOIL + FOLIAR $FeSO_4$ ON YIELD

Treatment	Yield, kg/ha	
	Berlin	Orienta
13-20-0	3177	1043
13-20-0 + $FeSO_4$ + Foliar-Fe	2743	452*
Fe-coates seed + 13-20-0	2357	402
Fe-coated seed + 13-20-0 + $FeSO_4$ + Foliar-Fe	2605	547

* Denotes significance at .10 level.

The use of band applications of Iron-Sul fertilizer produced a favorable response in yield at the Berlin location as can be seen in Table XII. Iron-Sul at the 224 kg/ha rate showed a significant increase in yield over the unfertilized treatment. This increase in yield may be explained by the enhanced solubility of iron within the rooting zone and an increased phosphorus availability to the plant. These results agree with work by others who have successfully used industrial waste products in correcting iron deficiencies (26, 52). There was, however, a gradual decrease in yield at the Orienta location with increasing rates of Iron-Sul. This may be explained in part by the adverse environmental factors encountered at the location, particularly the lack of moisture. Excess amounts of soluble salts within the rooting zone combined with a lack of moisture may have substantially restricted root growth of the plant.

TABLE XII

EFFECT OF IRON-SUL ON YIELD

Treatment	Yield, kg/ha	
	Berlin	Orienta
Check	2400 A	715 A
Iron-Sul (112 kg/ha)	2629 AB	671 A
Iron-Sul (224 kg/ha)	3257 B	383 A

Means with the same letter are not significantly different at the .10 level.

This study, as well as past research show that by-products from the copper mining industry are potentially commercial sources of iron in calcareous soils. A waste product which has a high fertilizing efficiency should be economically competitive with existing inorganic materials presently used. It is felt by this author that further research in this area may be warranted.

Sequestrene-138 applied at a rate of 2 kg Fe/ha as a band application to the soil with fluid APP was effective in increasing yields at the Berlin location (Table VI). The apparent success of Sequestrene-138, at this low rate, in correcting iron deficiencies may be due to the area being only mildly deficient in available iron and the increased mobility of iron in chelated form. At the Orienta location, where iron deficiencies were more severe, there was no response from applied Sequestrene-138.

TABLE XIII

EFFECT OF AMMONIUM POLYPHOSPHATE ON YIELD

Treatment	Yield, kg/ha	
	Berlin	Orienta
Check	2400	715
13-20-0	3177*	1043
Fe-coated seed	2240	791
Fe-coated seed + 13-20-0	2857	402

* Denotes significance at .10 level.

Phosphorus response was very evident in yields at the Berlin location (Table XIII). There was a significant increase in yield with banded applications of APP with the uncoated seed, but differences were not large enough to be significant with Fe-coated seed. At the Orienta location, there did not appear to be a consistent response to APP. Yield differences were not significant with either the Fe-coated or uncoated seed. This lack of response, however, can be primarily attributed to insufficient moisture for normal nutrient uptake and plant growth.

CHAPTER V

SUMMARY AND CONCLUSIONS

Three field experiments were established in Western Oklahoma using grain sorghum as the test crop. The experiments were primarily designed to test the effectiveness of using seed coated with an organic iron chelate (Fe-Ke-Min, 11% Fe) in alleviating early season iron deficiencies and to determine whether Fe-coating of seed used with moderate rates of soil and foliar-applied $FeSO_4$ could effectively reduce iron deficiencies and increase yields.

Other iron sources evaluated in this study were Iron-Sul fertilizer which is a by-product of the copper refining industry and contains 30% sulfur and 16% iron and Sequestrene-138 (6% Fe).

The use of Fe-coated seed was ineffective in reducing early season iron deficiency symptoms and had no effect on yield of grain. Ferrous sulfate applied in a band with ammonium polyphosphate (10-34-0 oxide form) as a carrier at 9 kg Fe/ha did not increase yields over those of APP alone with either Fe-coated or uncoated seed. Band applications of APP (13-20-0 kg/ha) substantially increased yields of grain with both Fe-coated and uncoated seed. Three foliar applications of 3% Fe as $FeSO_4$ at 190 l/ha were not effective in increasing yields with either Fe-coated or uncoated seed. Iron-Sul fertilizer applied as a band application with uncoated seed at a rate of 224 kg/ha (67 kg S, 36 kg

Fe/ha) was effective in increasing yields. Yield from band-applied APP + Sequestrene-138 with uncoated seed at 2 kg Fe/ha was significantly higher than all soil or foliar applications of $FeSO_4$. Highest yields in this study were obtained from band applications of APP + Sequestrene-138. Increased yields were obtained with applied APP + Sequestrene-138 although no apparent symptoms of iron deficiency were detected at any time during the growing season on either the plots receiving APP alone or APP + Sequestrene-138.

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TABLE XIV

ANALYSIS OF VARIANCE OF GRAIN YIELDS USED IN SINGLE DEGREE OF FREEDOM COMPARISONS

Source	df	Mean Squares
Berlin Location		
Replications	3	9186014*
Treatments	16	720857
Error	48	405045
Corrected Total	67	873640
Orienta Location		
Replications	3	200176
Treatments	16	218728
Error	48	214374
Corrected Total	67	214778

* Significant at .05 level.

2

VITA

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Master of Science

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