EVALUATION OF NITROGEN, PHOSPHORUS AND IRON SOURCES FOR WINTER WHEAT PRODUCTION

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WHEAT PRODUCTION

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CHAPTER I

INTRODUCTION

The research reported in this dissertation is divided into four chapters, each a manuscript prepared for publication in a professional journal. These manuscripts appear just as they will be submitted for publication, except for minor modifications.

Interest in the relative effectiveness of nitrogen sources is continually renewed by changes in the marketing structure of the various sources. In recent years interest in wheat forage production has increased because of low grain prices and high livestock prices, thus changing the trend of source, time and rate of N applications. Optimum N application dates depend on climatic factors, especially rainfall. In areas of high winter precipitation, spring applications are probably more efficient than fall applied. However, fall versus spring N applications, for grain production, is variable in the Southern Great Plains. A comparison of N sources, forms of N, rates of N and method of application on important wheat producing soils were the objectives of the study discussed in Chapter II.

The effect of adding carbonaceous materials and major fertilizers (N,P,K) to soils which are Fe deficient with small grains is discussed in Chapter III. Also changes in available soil Fe and Fe concentrations in plant tissue during the growing season is reported. Iron deficiencies in certain crops and shrubs are not uncommon on calcareous soils. Iron deficiency in sorghum is frequently observed in the Southern Great Plains and reduces yields in western Oklahoma. Small grains are less susceptible to Fe deficiency than sorghum, but Fe deficiency in small grains was observed in Oklahoma in the early 1950's. The amount of Fe chlorosis has increased rapidly since that time.

The effect of P and Fe source combinations on Fe deficiency in small grains is discussed in Chapter IV. Additions of inorganic Fe compounds to the soil are usually ineffective, since these compounds are rapidly converted by soil reaction to forms unavailable for plant uptake. Additions of chelated Fe materials to the soil is more effective, however the high cost is a deterrent to use on low value crops such as wheat. Phosphorus and Fe combinations have not previously been compared on small grains, since Fe deficiency in small grains are not observed in surrounding states.

A quantitative evaluation of the effect of N, P and K on the intricate relationships of the heavy metals is valuable in studying the Fe deficiency problem in small grains. Additional information is needed concerning the relationship of Fe, Zn and Mn on each other for uptake by wheat. The objectives of the study reported in Chapter V were: to study the effect of N, P, K fertilizers on Fe uptake and availability to winter wheat, and to determine the effect of Fe, Zn and Mn additions on the concentration of the heavy metal ions in the plant tissue.

CHAPTER II

A COMPARISON OF NITROGEN SOURCES FOR THE PRODUCTION OF WINTER WHEAT[1]

Abstract

Three sources of N (urea, ammonium sulfate, and ammonium nitrate) were compared at selected rates and application times for the production of winter wheat (*Triticum aestivum* L.). In one set of experiments, sources were compared at various rates with two application methods (broadcast on surface and drilled into the soil). In another experiment solid sources were compared with N solutions.

Differences in grain yields as affected by sources were small and non-significant in most studies with the exception of one study where ammonium sulfate was inferior to either urea or ammonium nitrate. Differences between fall preplant applications and spring topdressed nitrogen were small and of little practical significance. Summer N applications (post-harvest) resulted in less response than either fall or spring applications.

Additional Key Words for Indexing: fertilizer application, protein contents, Southern Great Plains.

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[1] Article co-authored with Billy B. Tucker and John M. Baker and to be submitted for publication in Soil Science Society of America Proceedings.

Introduction and Literature Review

Sources of fertilizer N for the production of various crops have been compared experimentally for years. However, as the economic factors and marketing structure of the various sources change, interest is renewed in the relative effectiveness of sources of nitrogen.

The effectiveness of N applications on winter wheat is influenced by a number of factors including the time of application. Numerous studies have been conducted in the winter wheat belt comparing fall preplant applications with spring topdressing (15, 16, 33, 35, 37, 44). Results from these studies vary depending primarily upon weather, especially rainfall and temperature. Optimum application dates varied between locations and between cropping seasons at specific locations due to the weather and other cultural practices. In areas with high winter precipitation and relatively warm soils, spring-applied N may be more efficient than fall applied. For example, Doll (15) suggested from experiments in Kentucky that if winter rainfall exceeded 10-12 inches, fall-applied N was less effective than spring-applied N. Researchers in Iowa (30) and Illinois (42) are in general agreement that spring applications of N are more effective than fall applications. Results of fall versus spring N applications for grain production in the Southern Great Plains have been more variable (16, 35, 37, 42).

In recent years, interest in wheat forage production for livestock grazing has increased because of low grain prices, and high livestock prices. This trend has aroused concern about previous conclusions drawn from time of N application experiments when grain yields were used as the criterion for effectivenss. Both timing of N applications and resources need to be re-evaluated as forage production becomes more important.

There seems to be general agreement among researchers as to effectiveness of N sources for wheat grain production. In general, N sources have proven to be equally effective when properly applied (21, 22, 25, 35, 37). However, research by Volk (39) and Ernst and Massey (17) show the potential for soil ammonia absorption is decreased when urea is applied under high temperatures, high moisture levels and high soil pH.

The objectives of these studies were to compare N sources, forms of N and rates of N, and method of application on winter wheat growing on "key" wheat soils.

Experimental Procedure

Experiment #1

Two experimental studies were conducted. Exp. 1 was a source, time and form of N study. This experiment was started in the summer of 1959 and continued through five crop years at the Wheatland Conservation Experiment Station, Cherokee, Oklahoma, on a Grant silt-loam (a Udic Argiustoll) with a 1% slope. The soil and climatic conditions at this location are typical of those in a large portion of the wheat belt of North Central Oklahoma and South Central Kansas. Stubble mulch tillage was used in this five-year study.

Two sources of N [ammonium nitrate (33% N) and urea (45% N)] were applied in granular and liquid forms in this study. The liquid materials were applied and evaluated because of increased use of N solutions in the wheat belt. Each source and form of N were applied at the rate of 45 kg N/ha at three dates: (1) summer, following harvest but prior to the initial tillage operation (approximately June 15), (2) fall, just after seedling emergence (approximately November 1), and (3) spring, prior to the initiation of spring growth (approximately March 1). The first application (pre-tillage) was chosen as "ideal" conditions for maximizing N losses.

Another phase of this experiment was initiated in 1964 and continued through three crop years. This portion of the experiment was conducted on the Agronomy Research Station at Perkins, Oklahoma, on a Teller loam (a Udic Argiustoll) with a 1% slope. Ammonium sulfate (21% N) was included, rates of N (37 and 67 kg N/ha) were added, and form of nitrogen deleted.

Experiment #2

We questioned how far the five-year data from Cherokee could be extended. Therefore, sources and rates of N were compared at 20 locations in Oklahoma in 1964 on "key" soils representing a large portion of the wheat belt. The location, soil phase, pH, and organic matter content of the soils are presented in Table 2.1. The soil texture ranged from sandy loams to clay loams. Soil reactions ranged from strongly acid (pH 4.6) to neutral (pH 7.3). Organic matter varied from 0.5% to 2.4% in the surface. Some locations were dry when the materials were applied; at other locations, the soil was moist.

In this study, two sources of N (ammonium nitrate and urea) were compared at five rates (0, 22, 45, 67, 90 kg N/ha) as a topdressing in February using two application methods: (1) broadcast on the surface, and (2) drilled into the ground. Drilling was used to determine if this method could be employed when conditions were conducive for losses of surface applied N. Since there was no difference in the zero N treatment for broadcast or drilling, they were averaged together in the Figs. 2.2 and 2.3.

At seven selected locations, forage yields and nitrogen contents were measured approximately one month after nitrogen application. These locations are indicated by an asterisk in Table 2.1.

Another phase of this experiment was initiated in 1965. Ammonium sulfate was included as a source of nitrogen and one method of application (drilling) deleted. These sources and rates of nitrogen were compared at 10 different locations on "key" wheat soils. The experimental sites in 1965 are reported in Table 2.1. The N content of the wheat grain was measured in all of the experiments to obtain the yield of N.

Results and Discussion

Experiment #1

The five-year averages of grain and N yields for source, form, and time of application of N from Cherokee are plotted in Fig. 2.1. It was evident throughout the study that climatic factors, particularly rainfall, influenced grain yields and N yields more than the differences in N treatments. There was a significant difference between years probably due primarily to amount and distribution of rainfall.

Ammonium nitrate and urea did not differ significantly in their influence on the grain or total N yields. Grain from the urea plots contained a higher percentage of N than grain from the plots fertilized with ammonium nitrate.

TABLE 2.1

Soil Characteristics of Experimental Locations (1964 and 1965)

Location	Soil Phase	pH	o.m.
1964			
Walters	Foard clay loam	5.1	1.19
Granite*	Miles sandy loam	5.5	0.52
Arapaho*	Carey silt loam	6.3	1.37
Mutual	Carey silt loam	6.9	0.87
Newkirk*	Tabler silt loam	4.8	1.31
Cherokee*	Grant silt loam	4.8	1.63
Sumner	Port silty clay loam	5.3	1.37
Snyder	Norwood loam	6.8	1.08
Dill City	St. Paul silt loam	5.4	1.40
Vinson*	Weymouth clay loam	5.8	1.13
Buffalo	Mansker clay loam	7.3	1.51
Carver*	Pond Creek silt loam	5.2	1.65
Hunter*	Bethany silt loam	4.6	1.50
Medford	Kirkland silt loam	4.9	1.69
Oklahoma City	Dale silt loam	5.3	2.37
Hess	Tipton loam	6.4	0.93
Hinton	Minco silt loam	5.3	1.23
Manitou	Tillman silt loam	6.0	0.75
El Reno	Norge loam	5.2	1.35
El Reno	Vanoss silt loam	4.9	1.49
1965			
Buffalo	Mansker clay loam	5.8	1.66
Orienta	St. Paul silt loam	6.1	1.18
Avard	Grant silt loam	7.1	0.91
Alva	Weymouth fine sandy loam	5.7	1.35
Wakita	Tabler clay loam	---	----
Wakita	Pratt sandy loam	4.0	0.38
Medford	Renfrow silt loam	4.8	1.59
Newkirk	Tabler clay loam	6.6	0.80
Sumner	Port silty clay loam	5.5	1.74
Cherokee	Grant silt loam	5.8	1.33

*Forage yields were determined at these locations.

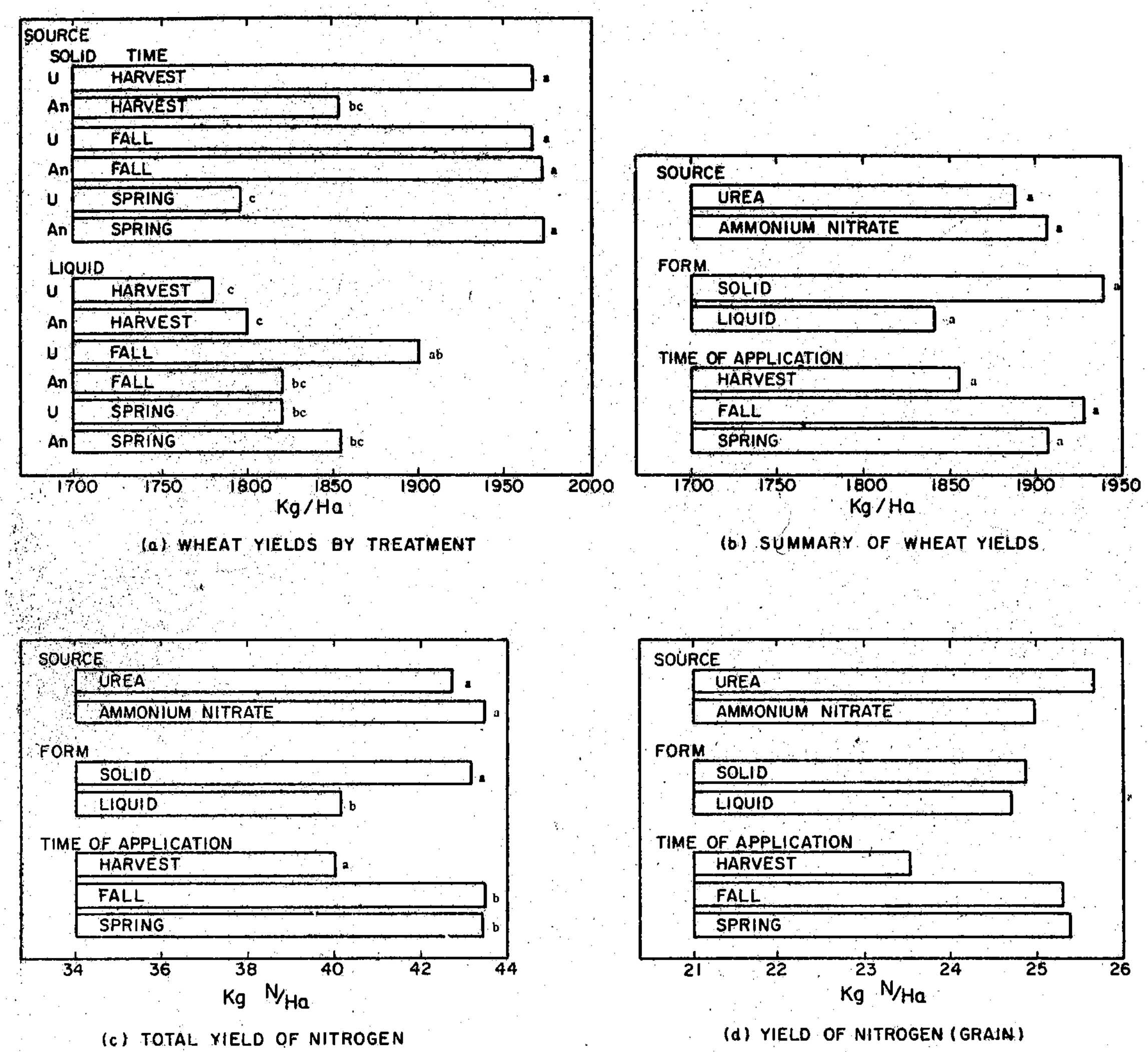


Fig. 2.1. Wheat Grain Yields, Total Yield of N, and Grain N as Affected by Source, Time of Application, and Form of Nitrogen. 1959-64. Cherokee. (Bars followed by the same letter are not significantly different at the 5% level.) U = $(NH_2)_2CO$; An = NH_4NO_3.

The solid forms of urea and ammonium nitrate were significantly better than the liquid forms in increasing grain and total N yields, but the form had no effect on per cent N in the grain.

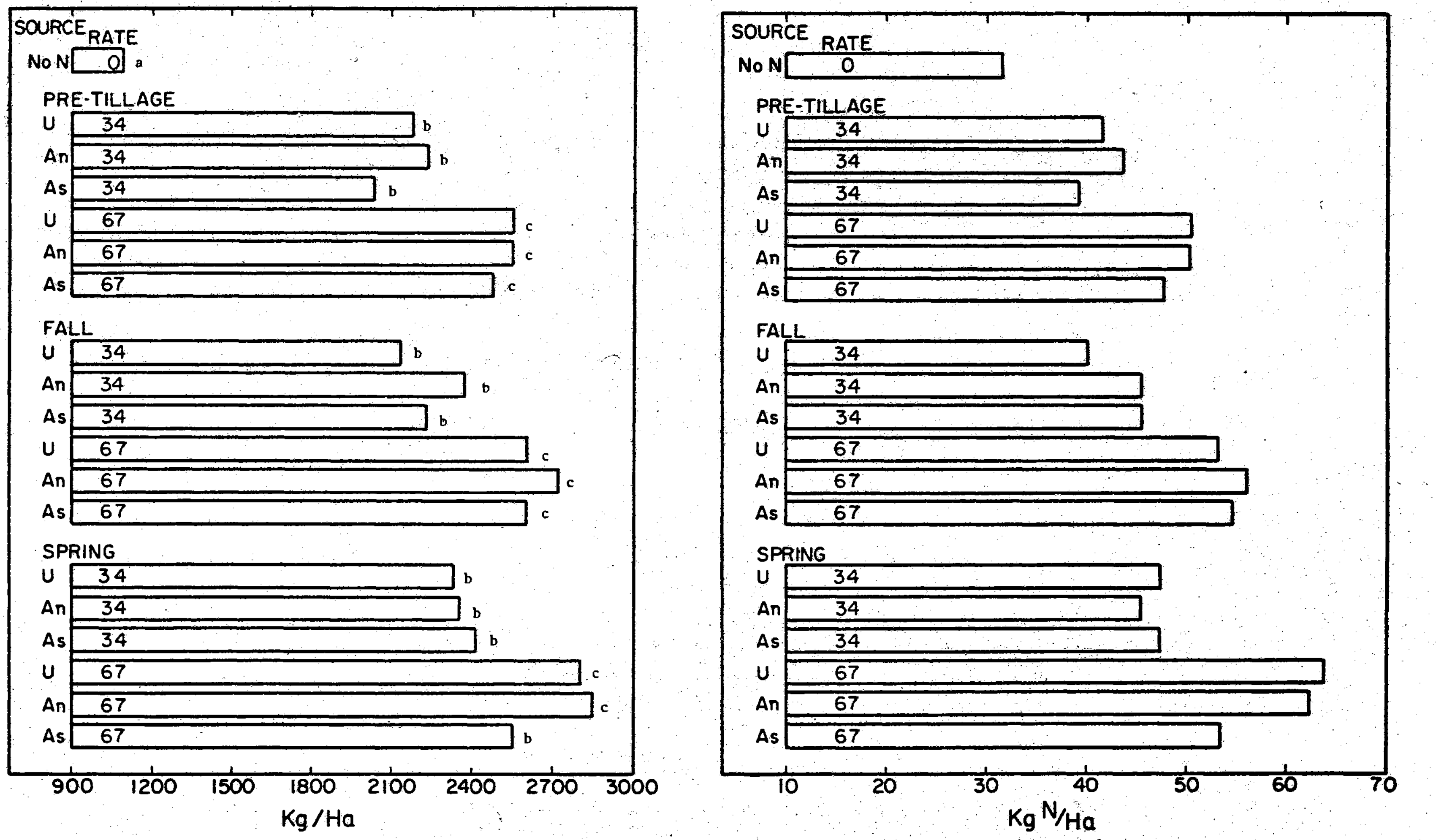
The fall applications of N were significantly better than the post-harvest applications in grain and straw production and total N yields. The time of application did not appreciably affect the per cent N in the grain. There was no difference between fall and spring applications.

The three-year averages of grain and N yields on source, rate, and time of application of N at the Perkins location are shown in Fig. 2.2. The three-year averages indicate that at any one rate or time of application there is no difference in grain yields or N yields between the sources of N. There was no difference in grain yield between dates of application when pooled over the three-year period. The 67 kg rate of N gave a higher grain yield regardless of source and time of application.

There was a significant difference between years, probably due to rainfall. Yield differences between years are not unusual in Oklahoma since rainfall and temperature patterns and other climatic factors are erratic, with variations between and within years.

Experiment #2

The average grain and N yields for source, rate, and method of application from the 20 locations in 1964 are shown in Fig. 2.3. The actual yield response to N was not as great as it had been in previous years when comparable yields were produced. This low response may be attributed to the extremely dry spring which prevailed at most locations. The results from the 20 locations are in general agreement with the



(a) GRAIN YIELD

(b) NITROGEN YIELD

Fig. 2.2. Wheat Yields and Yields of Nitrogen as Affected by Source, Rate, and Time of Application of Nitrogen. 1964-66. Perkins. (Bars followed by the same letter are not significantly different at 5% level.) U = $(NH_2)_2 CO$; An = NH_4NO_3; As = $(NH_4)_2 SO_4$.

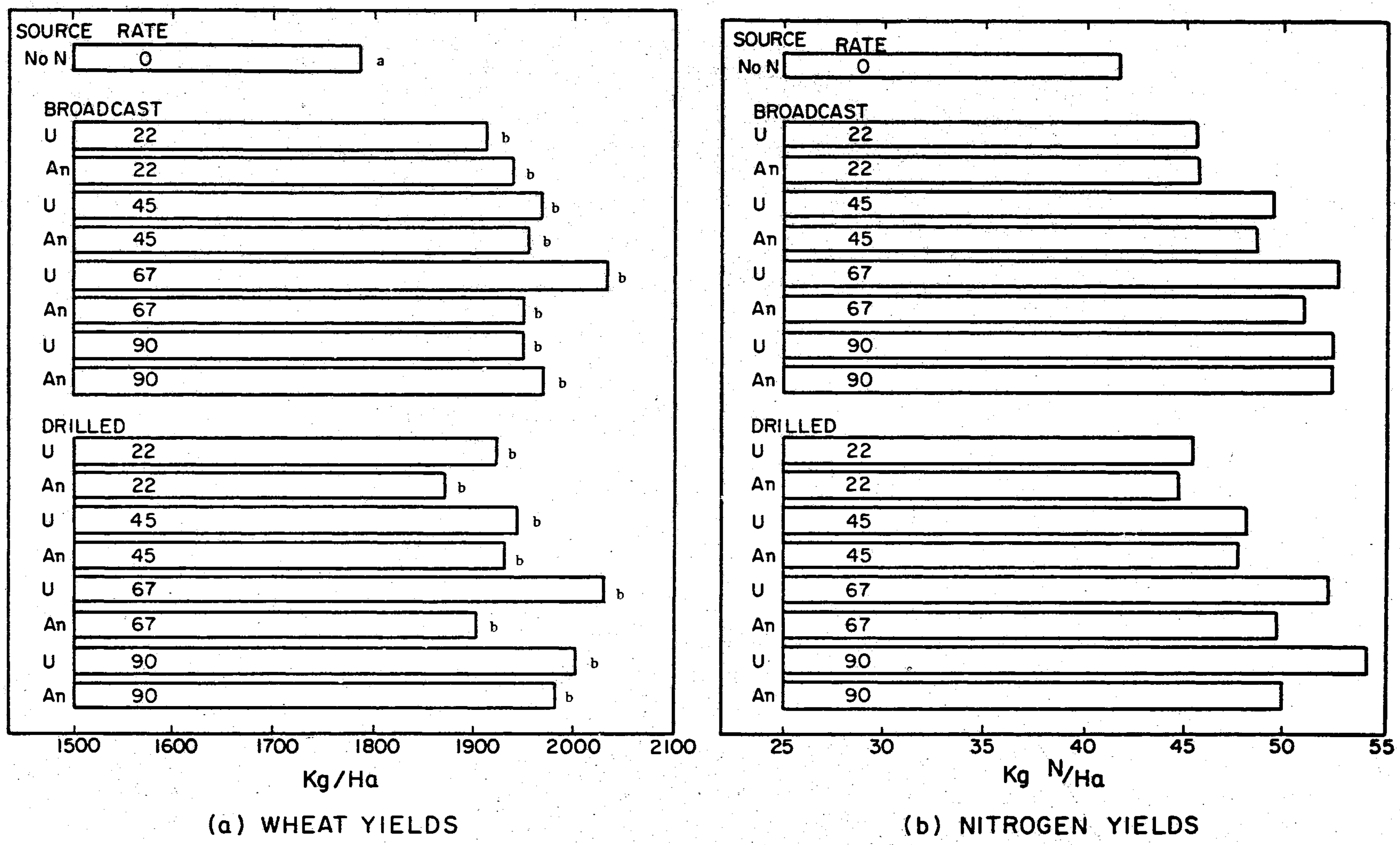


Fig. 2.3. Wheat Yields and Yields of Nitrogen as Affected by Source and Rate of Nitrogen. 1964. (Average of 20 locations.) (Bars followed by the same letter are not significantly different at 5% level.)

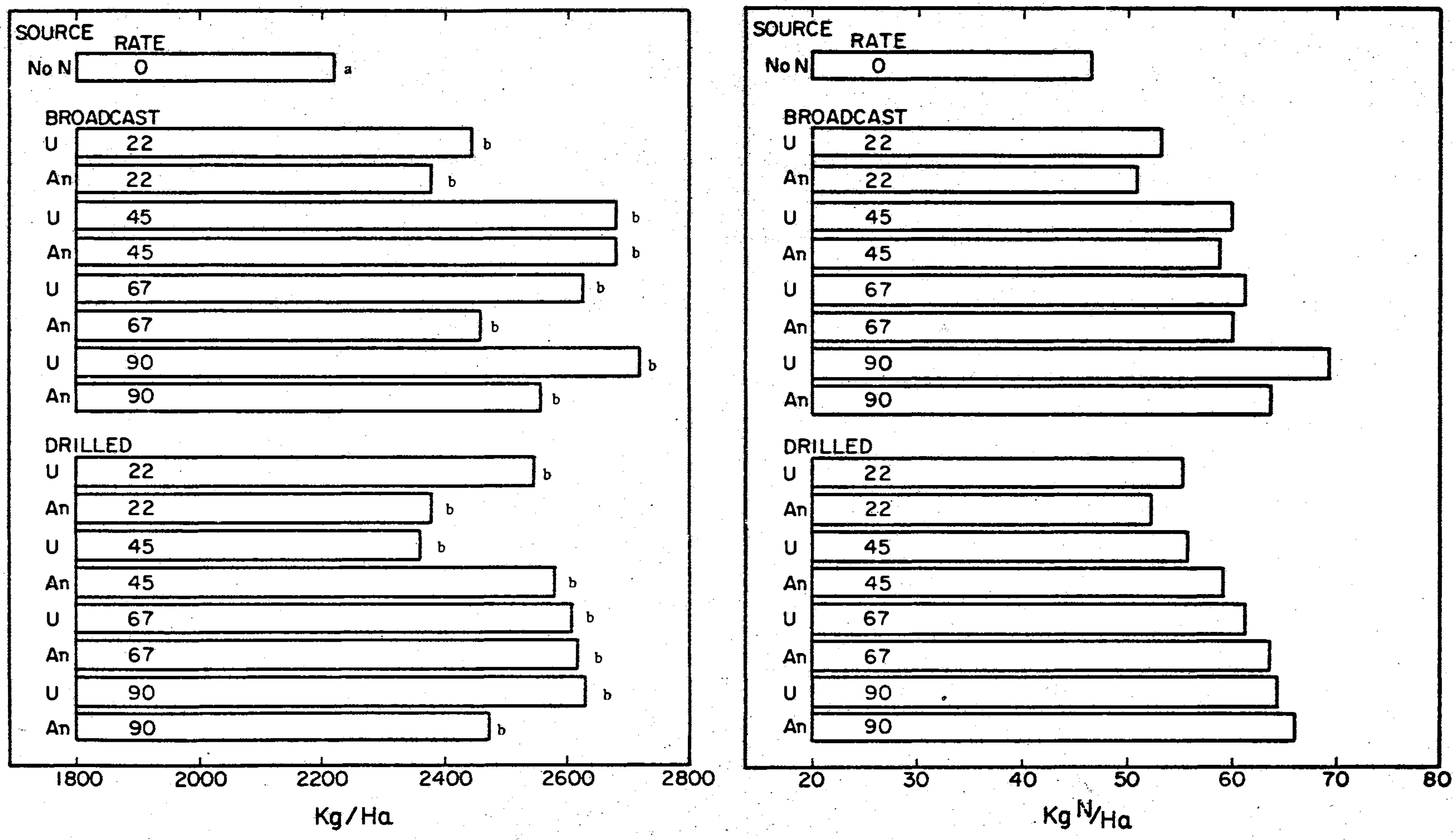
five-year study conducted at the Cherokee Station. Based on grain yields the differences between the sources of urea and ammonium nitrate are quite small. Again urea appears to give a slight advantage over ammonium nitrate in N yield. There was no difference in grain yields between rates of N. Yields from the 22 kg rate were as high as the 90 kg rate. There is, however, an increment increase of N yield through the 67 kg rate. Nitrogen drilled into the soil did not give significantly different results from that broadcast on the surface at any of the locations.

Yields were substantially increased by N applications at eight locations. At eleven of the locations, yields were unaltered by the application of N. Yields were decreased at one location which could probably be attributed to more soil moisture stress during flowering stage of growth on the plots receiving N. The nitrogen application caused greater growth of the wheat early and consequently, faster moisture use. The severe moisture stress during the critical flowering stage caused sterility to the tips of the spikes.

Only at three locations were yield differences between sources significant. At no location were yield differences between sources great enough to be of practical significance.

Per cent N in the grain increased with added N at all locations except two. Nitrogen content was extremely high at these two locations without added N.

Forage yields were taken on April 15 at seven locations. The results, including forage yield and yield of N, in the forage are shown in Fig. 2.4. The results were quite variable, but in general, forage yield increased with increasing rates of N. There was no



(a) FORAGE YIELDS (DRY MATTER)

(b) NITROGEN YIELDS (FORAGE)

Fig. 2.4. Forage Yields and Yields of Nitrogen as Affected by Source and Rate of Nitrogen. 1964. (Average of 7 locations.) (Bars followed by the same letter are not significantly different at 5% level.)

significant difference in forage yield to source, rate, or method, when pooled over locations. However, higher yields occurred with increasing rates of N at three of the seven locations.

The yield of N from the wheat forage was less variable. There was a significant increase in N yield with increasing rates of N over locations. Also, N yield was significantly greater in response to increasing rates of N at six of seven locations. There was no differences in N yield between sources and methods of application.

The effects of sources and rates of N on the averages of grain and N yields from 1965 are shown in Fig. 2.5. The grain yield response to nitrogen was better than in 1964 with good overall yields. Grain yield increased as a result of applied N at nine of the ten locations. At one location yields were unaltered by application of N due to the high natural fertility of the soil.

Statistical analysis indicated no significant difference between ammonium nitrate and urea over locations. There was a significant difference between these two sources and ammonium sulfate over locations. However, analysis by location revealed a significant difference between sources of N at only three locations. Ammonium nitrate and urea gave significantly higher wheat yields than ammonium sulfate at two of these locations. Ammonium sulfate gave significantly higher yields than ammonium nitrate at only one location, with no difference between urea and ammonium sulfate.

The wheat yields increased significantly with increasing rates of applied N through the 90 kg rate. The nitrogen yields also showed increment increases to rates of N. There was no significant difference in N yields between sources of N.

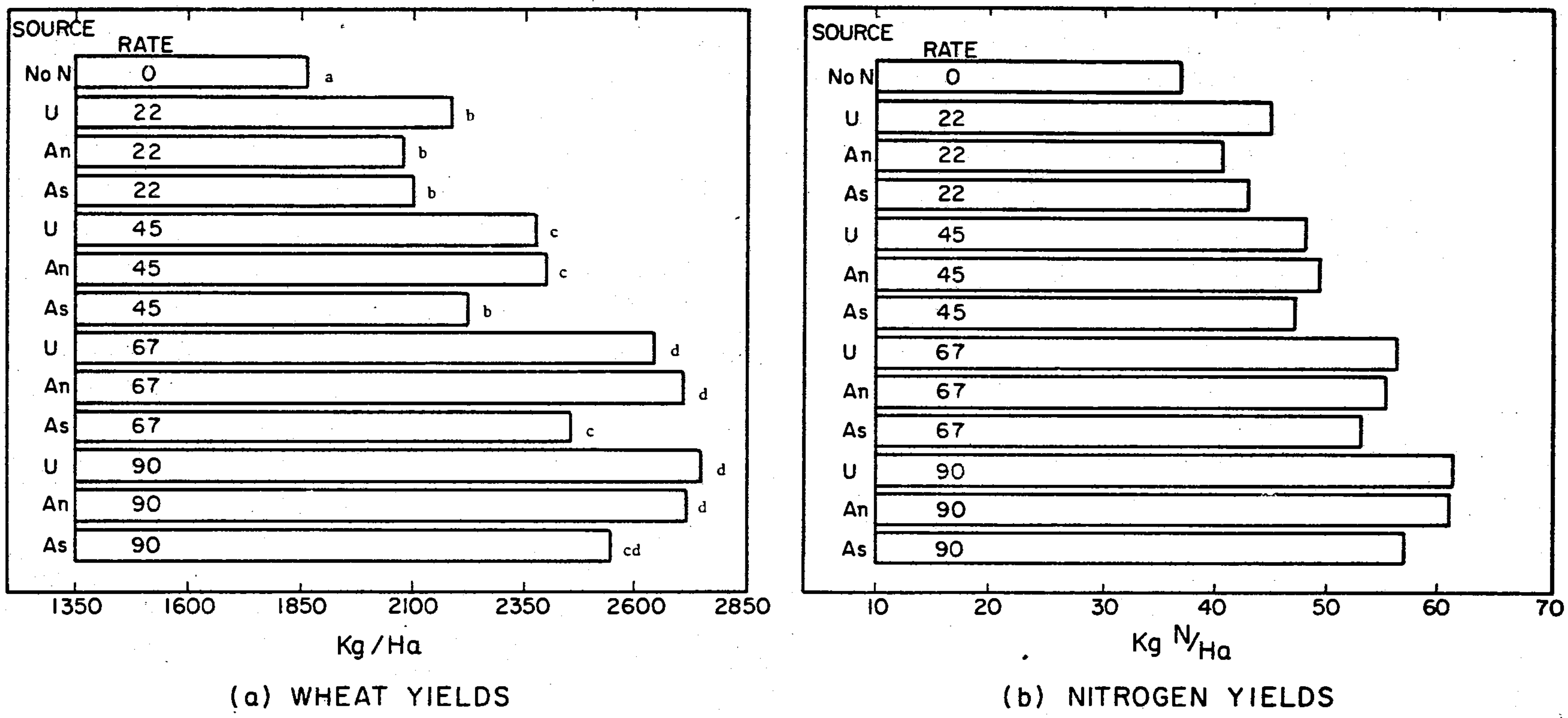


Fig. 2.5. Wheat Yields and Yields of Nitrogen as Affected by Source and Rate of Nitrogen. 1965. (Average of 10 locations.) (Bars followed by the same letter are not significantly different at the 5% level.) U = $(NH_2)_2\ CO$; An = NH_4NO_3; As = $(NH_4)_2\ SO_4$.

CHAPTER III

INFLUENCE OF FERTILIZER AND ORGANIC AMENDMENTS ON CORRECTING IRON DEFICIENCIES IN SMALL GRAINS[1/]

ABSTRACT

The influence of the major fertilizers (N, P, K) and carbonaceous materials on available soil Fe and changes in available soil Fe and Fe concentration in the plant tissue during the growing season was studied on soils which are Fe deficient for winter wheat (Triticum aestivum L.). These soils were moderately high in pH, low in o.m. content, and low in available Fe.

Wheat grain yields, visual observations, and soil test values indicated that additions of carbonaceous materials at the rate applied did not significantly change the available Fe status of these soils. The additions of manure show some promise for relieving the Fe deficiency symptoms. The major fertilizers (N, P, K) did not change the available Fe status of these soils under the experimental conditions tested. The DTPA soil test for available Fe appears to be correlated with Fe actually available for uptake by small grains. The concentration of Fe in plant tissue fluctuated during the growing season,

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1/Article co-authored with Billy B. Tucker and John M. Baker and to be submitted for publication in Agronomy Journal.

probably due to changes in rate of Fe uptake, growth rate of plants, soil temperature, and moisture.

Additional Key Words: available iron, chlorosis, calcareous soils, micronutrients.

Introduction

Iron deficiency of certain crops, shrubs, and trees are not uncommon on calcareous soils. Several investigators have reported a variation in susceptibility between plant species and even varieties within species (3, 5, 6, 7). Iron deficiency in sorghums is frequently observed in the Central and Southern Great Plains and has reduced yields in Western Oklahoma for years on some Entisols and Inceptisols. Since small grains were less susceptible to Fe deficiency than sorghums, the soils on which sorghums were chlorotic have traditionally been planted to small grains as an alternative crop. However, in the early 1950's Fe deficiencies were observed in small grains on some of these soils. The amount of Fe chlorosis observed in small grains has increased rapidly since that time, until approximately 50,000 acres are now affected. Iron deficiency of small grains has been noted in 10 counties in Oklahoma, but it is most severe in Custer, Washita, Beckham, Roger Mills, and Dewey counties.

Iron deficiency in small grains occurs on soils which are classified as Ustifluvents or Ustochrepts and in the fine or fine-silty, mixed (calcareous), thermic families. These Ustifluvents are young soils which in the past received sediments from calcareous parent materials deposited by the Washita River. Some of the soil series affected would be Clairemont, Mangum, and Spur (old classification). The Ustochrepts on which Fe deficiency of small grains occur are the Vernon, Weymouth, Woodward, and Quinlan series. Iron deficiencies are observed in small grains on these soils, especially in sloping areas where erosion is a problem.

The causative factors of Fe deficiency in various crops have been studied by several investigators (5, 7, 19, 40, 41).

Carbonaceous materials such as crude oil and natural gas have been reported to increase available Fe in soils when these were absorbed by soils as a result of accidental spillage and pipeline breaks (1, 8). The influence of carbonaceous materials on plant growth is probably the direct result of biological activity. Previous investigators (5, 7, 19, 41) have also indicated high P levels are a potential causative factor in Fe deficiency.

The objectives of the studies reported in this paper were: (1) to determine the effect of added carbonaceous materials on the yields of wheat grain, uptake of iron by the plants, and the soil-test Fe values of an Fe deficient soil, (2) to determine the influence of major fertilizers (N, P, K) on iron availability, and (3) to monitor changes in available soil Fe and Fe concentrations in plant tissue during the growing season.

Materials and Methods

Experiment #1

Four field experiments were initiated in the fall of 1969 on soils known to be Fe deficient. The soil at the Foss location was a Vernon silt loam (an Ustochrept) with a 4% slope. The soil at the Hammond and

Cheyenne locations was an Ustifluvent (Spur silt loam, old classification system) with a 1% slope. The soil at the Cordell location was a Vernon silt loam with a 2% slope. The experimental design was a randomized block with four replications. The treatments consisted of various carbonaceous materials and N and P fertilizers applied broadcast approximately 30 days prior to planting. The treatments and locations are reported in Table 3.1. Nitrogen was applied with the carbonaceous materials to give a 1:20 N:C ratio and then incorporated into the soil. The N and P treatments were also applied broadcast and incorporated preplant. Sixty-seven kg N/ha were applied as a topdress application to the carbonaceous and P treatments in February.

Additional information concerning the carbonaceous materials are: Nap 31 - a petroleum oil, unstable, breaks down easily, mostly unsaturated aromatics; Vis 50 - stable oil, breaks down slowly, mostly saturated, low in aromatics; Nap 600 - an intermediate oil between the other two; coal - contained 72% carbon; manure - dry, somewhat decomposed, from dairy lot and contained 1500 ppm Fe.

Winter wheat (*Triticum aestivum* L.) was seeded on all plots in late September of each year at rates from 67 to 84 kg/ha.

Experiment #2

Soil samples were periodically collected and analyzed for available Fe during the 1969-70 growing season at all 4 experimental locations. This experiment was continued during the 1970-71 crop year at three locations: $Foss_H$ (Huls Farm), $Hammond_B$ (Brown Farm), and $Hammond_H$ (Harding Farm). The analyses were expanded to include available Zn and and Mn in the soil. Also, the concentrations of Fe, Zn, Mn, and P was determined periodically in Fe deficient wheat plants growing on these soils (2 locations). These concentrations were compared with that in plants at the same location which received adequate Fe from a fertilizer application banded with the seed at planting time.

Laboratory

The Fe, Zn, Mn, and P concentrations and soil analysis were determined by the Oklahoma State Soil Test Laboratory. Available Fe, Zn, and Mn was determined using the DTPA (Diethylene triamine penta-acetic acid) method of extraction developed by Lindsay in Colorado (24).

Experiment #3

The effect of fertilizer materials on available Fe was determined in the laboratory. Soil from a Spur silt loam (an Ustifluvent) was brought into the laboratory and passed through a 0.5 cm screen. The soil was not dried, since preliminary investigations indicated that drying of these soils changed the available Fe status. The treatments consisted of N (alone), P (alone), [3 P sources: 18-20-0 (DAP), 0-20-0 (CSP), 15-26-0 (APP)], N + P (same 3 P sources), N + P + K (same 3 P sources), manure, H_2SO_4 (pH of soil adjusted to 7.0) and H_2SO_4 (pH of soil adjusted to 6.5) with 3 replications. The N, P, K and manure were applied at the rate of 40, 18, 33, and 5000 ppm, respectively. The fertilizer treatments were thoroughly mixed with the soil and the moisture status maintained at a constant level. The soil was sampled and analyzed periodically to determine available Fe, Zn, and Mn.

The treatments were statistically analyzed using a protected (Significant F) LSD (12).

Results and Discussion

Field Studies

Preliminary investigations of the Fe deficiency problem in small grains suggested the following three causative factors: (1) low organic matter (o.m.), (2) relatively high pH, (3) low available Fe. Since an economical means of decreasing the pH is not available, two major areas remained as possible solutions to the Fe deficiency problem: increase the o.m. content, subsequently increasing available Fe; and/or fertilization with Fe compounds.

Based on the observations of previous workers (1, 34), experiments with carbonaceous materials were initiated. High P additions were made to determine the effect on Fe deficiency in small grains. The treatments and yield results of the experiments are presented in Table 3.1. The relatively low yields and lack of response at Hammond and Cheyenne were the result of an extremely dry spring. Visual observations during the growing season suggested good forage growth response to the P and manure treatments. Thus, the lack of response could probably be attributed to higher moisture stress during the flowering and grain filling stages of growth, resulting in lower yields.

Yields from the Foss location were relatively low. However, good response was obtained from the P and manure treatments. The degree of Fe chlorosis indicated that these treatments relieved the Fe deficiency to a certain extent. The fact that Fe deficiency symptoms were not

TABLE 3.1

Carbonaceous Treatments and Wheat Grain Yield as Affected by Treatments (4 Locations), 1970

	Treatment	Rate (Kg/ha)	Yield Kgm/Ha: Wheat: Cordell	Wheat: Foss	Wheat: Hammond	Oats: Cheyenne
1	Manure	5600	1920[n]	1006[c]	912[n]	6110[s]
2	Manure	1120	1663[n]	682[c]	921[n]	5934[s]
3	NAP 31	1120	1426[n]	642[s]	685[c]	5667[s]
4	NAP 600	1120	1430[n]	553[s]	1142[c]	6196[s]
5	VIS 50	1120	1164[n]	827[s]	806[c]	6090[s]
6	Coal	2240	1759[n]	756[s]	790[c]	4554[s]
7	Coal	1120	1556[n]	731[s]	732[c]	5159[s]
8	Propane	1120	2145[n]	617[s]	790[c]	5287[s]
9	Propane	560	1384[n]	575[s]	717[c]	5124[s]
10	Diesel	1680	1446[n]	501[s]	721[c]	5625[s]
11	Diesel	840	1675[n]	491[s]	489[c]	5220[s]
12	P	55	2591[n]	1211[c]	1000[n]	5359[s]
13	P	110	2676[n]	1359[c]	1342[n]	6402[s]
14	N	67	1860[n]	504[s]	1181[c]	5032[s]
15	O	0	1776[n]	601[s]	1250[c]	5776[s]
		FLSD (5%)	605	480	NS	NS

[n]No Fe chlorosis observed

[c]Some Fe chlorosis observed

[s]Severe Fe chlorosis observed

completely relieved by high P additions suggests that the low P level in the soil is not the primary problem with these soils. Soil characteristics at each experimental location are given in Table 3.2.

The addition of N at all locations except Cordell reduced yields below those receiving no treatment. Visual observations during the growing season indicated that N alone increased the severity of the Fe deficiency symptoms. This could be due to two factors or a combination of these factors: (1) additions of N reduces Fe uptake or metabolism in the plants, perhaps by enhanced uptake of other heavy metals; or (2) additions of N to soils low in P produces a metabolic imbalance in the plant.

Yield data and observations made during the growing season indicated that additions of carbonaceous materials did not change the available Fe status of the soil enough to correct the Fe deficiency. This could be due to increased microbiological activity with subsequent utilization of available soil Fe by the micro-organisms, thus reducing the amount of Fe actually available for plant uptake. Preliminary investigations found that decomposition of large amounts of wheat straw added to the soil increased the Fe deficiency. This is evidence for possible microbiological tie-up. It has been noted that wheat is more susceptible to Fe deficiency following a previous year's wheat crop which produced large amounts of wheat straw. The lack of increase in available soil Fe from additions of carbonaceous materials found in this study is in agreement with conclusions of Wiese (11). Wiese indicated that soils must be saturated with carbonaceous materials before measurable increases in o.m. and available Fe occurred.

TABLE 3.2

Soil Test Values at Experimental Locations

Location	Soil Type	pH	o.m.	P*	K**
$Foss_B$	Vernon Silt Loam	8.1	1.0	17	575
$Foss_H$	Vernon Silt Loam	8.2	0.1	7	280
$Hammond_B$	Spur Silt Loam	7.9	1.5	41	1180
$Hammond_H$	Spur Silt Loam	7.9	1.2	28	855
Cheyenne	Spur Silt Loam	7.9	1.2	19	430

*Bray 1 phosphorus

**Exchangeable potassium

It was postulated that the lack of response to the carbonaceous materials could have been due to insufficient time lapse from application to plant needs. Therefore, soil samples were taken at one location (Foss, at harvest) from all treatments to determine if any increase in soil test Fe had occurred. Analysis of these soil samples indicated that the additions of carbonaceous materials had no effect on available Fe, Zn, and Mn. The available Fe, Zn, and Mn (average of all treatments) was found to be 0.9, 0.8, and 10.5 ppm respectively.

Experiment #2

A study of changes in available Fe during the growing season should be valuable in elucidating the factors involved in Fe deficiency in small grains. These changes should help explain why Fe deficiency symptoms were observed at some experimental locations and not others. Soil samples were collected periodically during the growing season and analyzed for DTPA extractable Fe. The results of these analyses are shown in Fig. 3.1. The occurrence and severity of Fe deficiency symptoms for each treatment is indicated by a superscript in Table 3.1.

Iron deficiency symptoms were first observed at the Cheyenne location on January 7; at Foss, February 21; and at Hammond, March 6. No chlorosis was observed at the Cordell location. The deficiency symptoms dissipated at Hammond by March 26, and by April 15 plants at all locations had "recovered" from the chlorosis. The ability of sorghum plants to "recover" or grow out of Fe chlorosis at certain growth stages has been observed in Oklahoma and reported by other investigators (5, 45). The ability of small grains to "recover" during the spring may be due to warmer soil temperatures which could feasibly

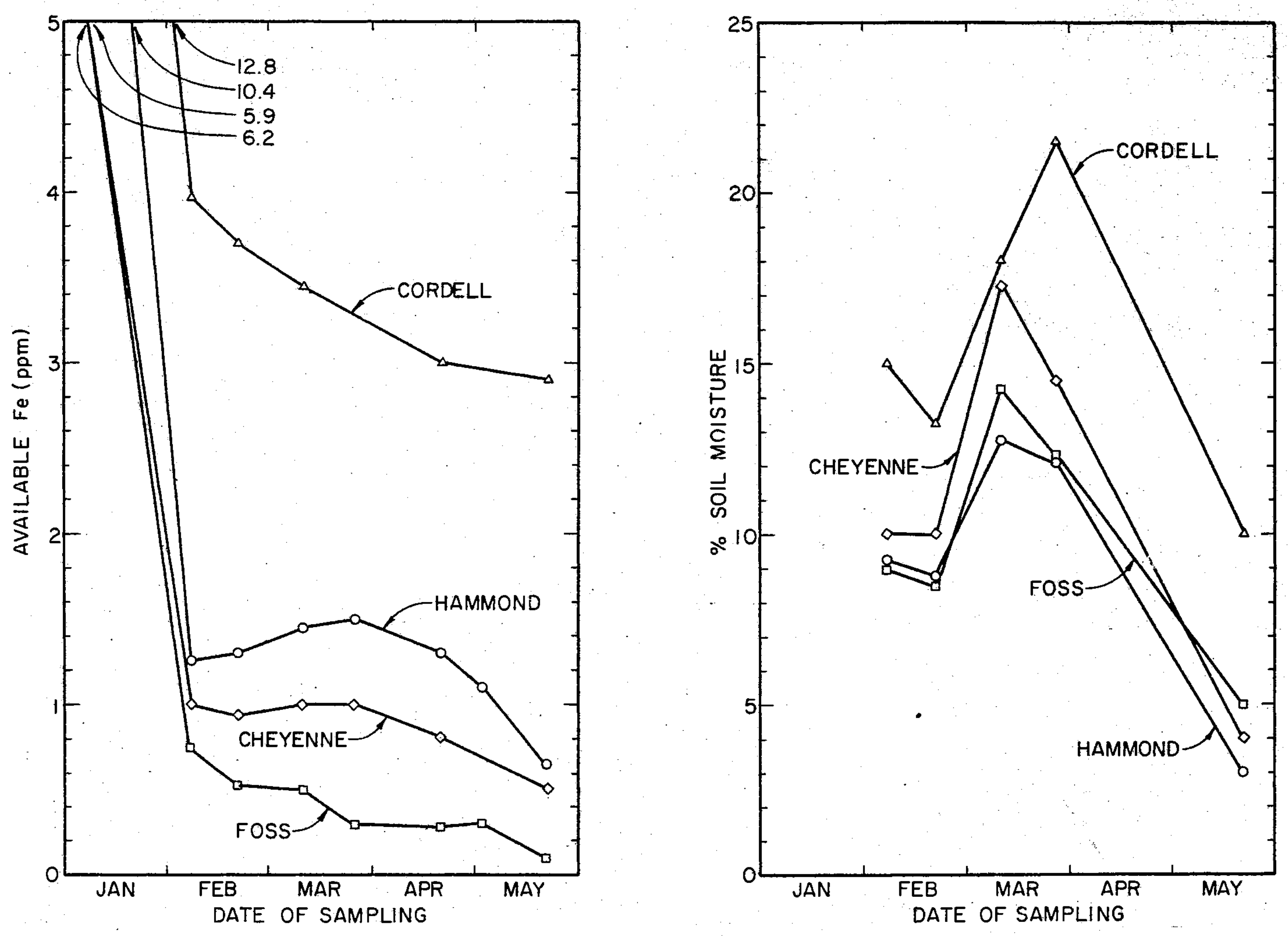


Fig. 3.1. DTPA Extractable Soil Fe and Per Cent Soil Moisture During the Growing Season at Four Locations. 1969-70 Crop Year.

increase the available Fe in the soil, or due to a larger root system which would come in contact with a larger portion of the available Fe. Also, it is possible that the Fe requirement of small grains could be lower during the latter stages of growth. On the other hand, changes in soil temperature and soil moisture could decrease the activity of other heavy metals which interfere with Fe uptake. DeLong et al (14) observed that available Mn in the soil increased following each rainfall.

Forage production of small grains was reduced considerably at the Foss and Cheyenne locations. A comparison of Fig. 3.1 and Table 3.1 suggests if DTPA extractable Fe in the soil is above 1.5 ppm during the "critical" growth stage of winter wheat (prior to March 26) that this is adequate for normal plant growth. This is suggested, since the two locations which exhibited the most severe Fe deficiency symptoms were below 1.0 ppm. The Hammond location appeared to be a borderline soil in that the deficiency symptoms were not severe and were present for only a short period of time. Also, visual observations indicated that growth of forage was not appreciably affected by Fe deficiency. No chlorosis was observed at Cordell suggesting adequate available Fe was present in this soil, with extractable Fe remaining above 3.0 ppm throughout the "critical period."

The change in DTPA extractable Fe during the season could probably be attributed to changes in soil temperature and moisture. The sharp decline in extractable Fe in Fig. 3.1 from 1-7 and 2-7 can probably be attributed to lower soil temperatures. The moisture content at each date of sampling was determined in an effort to correlate soil moisture and extractable Fe. The results are shown in Fig. 3.1. There appears to be little correlation with soil moisture alone and extractable Fe levels in the soil. However, the soil moisture levels do show the low moisture status of the soils during the latter growth stages of small grains, which accounted for the low yields obtained at some locations.

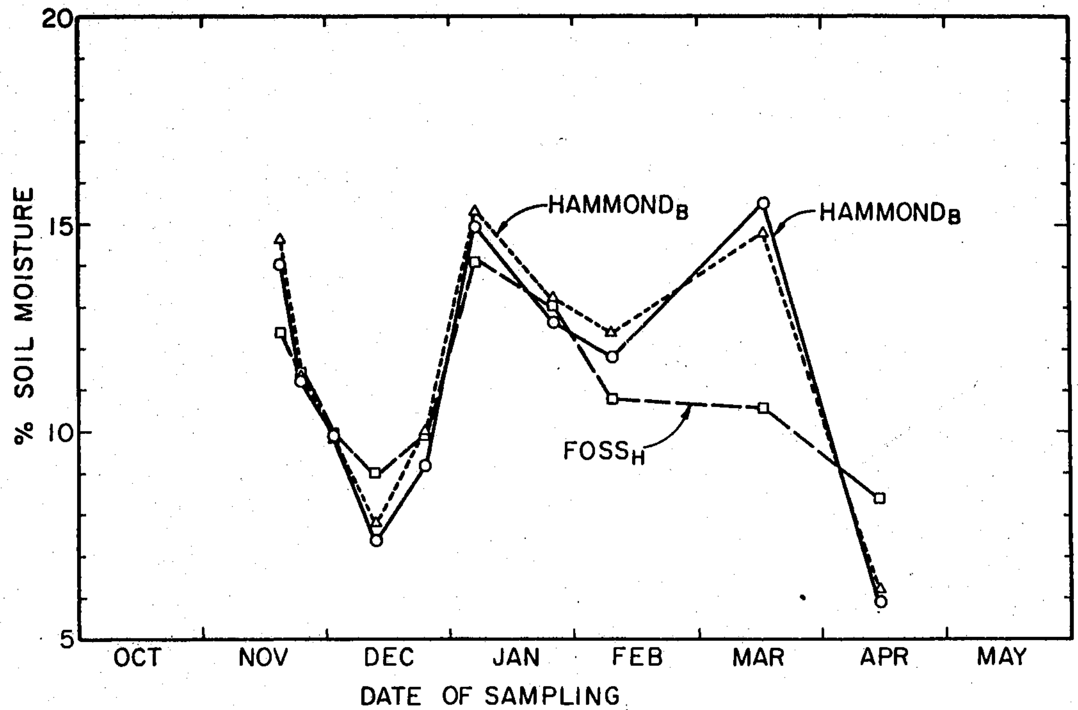
DTPA extractable Fe on moist soil (as collected at experimental locations) was found to be considerably lower than available Fe levels in the same soil when dried (normal laboratory procedure for analysis). Dry soil samples contained approximately 10 times as much extractable Fe as moist soils.

The soil analyses were expanded to include Zn and Mn in the 1970-71 crop year to determine if an interaction between these three elements could be found. The results are presented in Table 3.3 and Fig. 3.2 and 3.3. Iron deficiency symptoms were first observed on November 15 at the $Foss_H$ and $Hammond_H$ locations. The Fe deficiency symptoms appeared approximately 50 days earlier than the previous year. Observations made during several years indicate that the onset of Fe deficiency symptoms follow no obvious pattern but appears to be related to soil temperature and moisture. Fig. 3.2 indicates that the extractable Fe level at Foss was extremely low and remained low throughout the season. Iron deficiency symptoms on this soil were extremely severe and some of the deficient wheat plants died. The extractable Fe levels at the two Hammond locations fluctuated during the growing season. The wheat at the $Hammond_H$ location exhibited Fe deficiency symptoms, but the degree of chlorosis varied during the growing season and appeared to be directly related to the soil test levels. No Fe chlorosis was observed at the $Hammond_B$ location. Evidence given by Figs. 3.1 and 3.3 indicate the DTPA soil test for available Fe is correlated with the Fe

TABLE 3.3

Changes in Element Concentration in Wheat Tissue During the Growing Season

Date	Fe Def.	Fe Non-Def.	Zn Def.	Zn Non-Def.	Mn Def.	Mn Non-Def.	P Def.	P Non-Def.
	Concentrations (ppm)							
$Foss_H$								
11-20-70	488	248	86	43	174	147	3333	2677
12- 2-70	550	375	84	38	137	128	3703	2484
12-12-70	375	319	70	38	178	100	2568	2615
12-22-70	466	249	83	30	142	139	3794	2729
1-22-71	1044	448	78	38	126	83	4500	2516
3-11-71	675	463	82	38	179	108	5340	4005
3-24-71	800	650	85	48	170	78	4004	2340
4-12-71	444	218	107	53	138	48	3560	2296
4-29-71	1033	288	85	25	87	38	2779	1176
$Hammond_H$								
11-20-70	432	307	53	38	243	269	3557	2681
12- 2-70	650	531	54	49	275	234	3943	3609
12-12-70	625	300	62	38	262	261	3719	3041
12-22-70	382	270	61	52	310	275	3732	2964
1-22-71	900	594	66	38	228	235	4204	3284
3-11-71	736	738	64	53	318	290	3966	4572
3-24-71	907	875	46	53	213	161	3072	3288



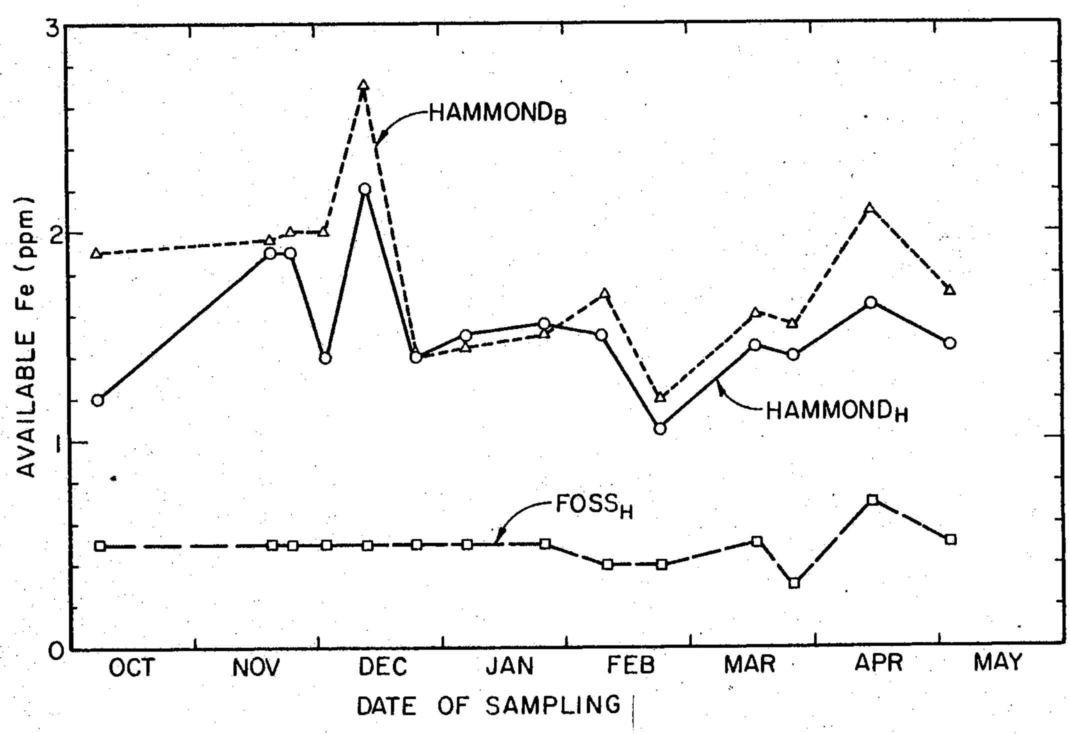


Fig. 3.2. Available Soil Fe and Per Cent Soil Moisture During the Growing Season at Three Locations. 1970-71 Crop Year.

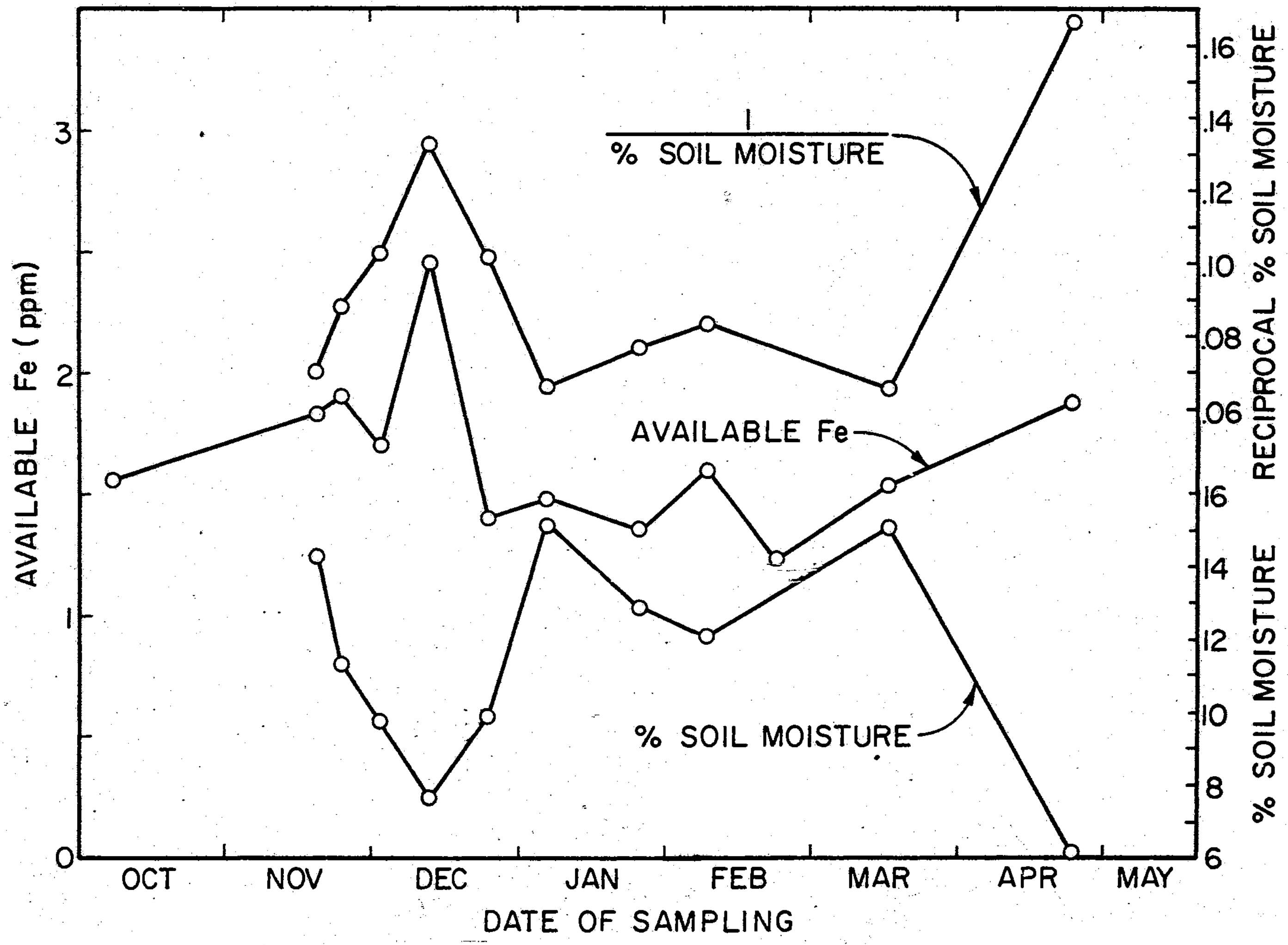


Fig. 3.3. Relationship of DTPA Extractable Soil Fe, Per Cent Soil Moisture, and Reciprocal Per Cent Soil Moisture During the Growing Season. (Average of Two Locations). 1970-71 Crop Year.

that is actually available for uptake by small grains. The soils with higher extractable Fe levels did not exhibit Fe deficiency symptoms over a two-year period.

The fluctuation of extractable Fe during the season could probably be correlated with soil temperature and moisture fluctuation. Also, plant uptake during periods of growth would affect the amount of extractable Fe in the soil. The data presented in Figs. 3.2 and 3.3 suggests an inverse relationship between extractable Fe and the per cent soil moisture--as soil moisture decreases extractable Fe increases. DTPA extractable Fe on moist soils (field conditions) was again found to be lower than extractable Fe levels in the same soil when dried (normal analysis procedure). Also, this difference was observed with available Zn and Mn. These differences in available Fe, Zn, and Mn with soil moisture content suggest that care should be used in soil preparation and handling prior to analysis.

A comparison was made of Fe, Zn, Mn, and P concentrations in Fe deficient wheat plants with plants receiving adequate Fe periodically during the growing season, and the results are presented in Table 3.3. The concentration of these elements fluctuated during the season, probably due to changes in growth and uptake rates as soil temperature and moisture changed. The fluctuations of Fe concentration in the Fe deficient and non-deficient plants were roughly the same; however, the Fe concentration in the chlorotic plants were higher than the non-chlorotic plants. The fluctuations of Zn were less than Fe and the Zn concentration was higher in the Fe deficient plants than those not showing Fe deficiency. Fluctuations occurred in Mn concentrations; however, the concentration appeared to depend more on experimental location than the Fe status of the plant. Phosphorus concentration varied and the Fe deficient plants were usually higher in P than the non-deficient plants.

Experiment #3

The effect of fertilizer materials on Fe availability was determined in the laboratory. A periodic sampling of the soil revealed there was no difference in the effect of the fertilizer materials used on extractable Fe, Zn, or Mn under these experimental conditions. The values obtained (average of all treatments) for Fe, Zn, and Mn were 0.2, 0.3, and 2.5 (moist) and 1.35, 0.75, and 8.00 (dry) ppm respectively.

CHAPTER IV

EVALUATION OF PHOSPHORUS AND IRON SOURCE COMBINATIONS FOR CORRECTING IRON DEFICIENCIES OF SMALL GRAINS[1]

Abstract

The effects of various Fe and P source combinations on Fe deficiencies of small grains were compared under field and growth chamber conditions.

Wheat grain yields and visual observations indicated that certain Fe-P combinations effectively corrected Fe chlorosis of small grains. Ferrous sulfate with fluid polyphosphate fertilizers appears to be an economical means of correcting iron deficiencies, especially when banded with the seed. Broadcast methods appear to require higher rates of Fe compounds to be effective. The poly-flavinoid materials and FeEDDHA were effective and have some carry over into the second crop year, however, the present high cost is a deterrent to widespread use on low value crops, such as small grains.

Additional Index Words: chlorosis, micronutrients, polyphosphates, iron chelates, fertilizer placement.

[1] Article co-authored with Billy B. Tucker and to be submitted for publication in Agronomy Journal.

Introduction

Iron deficiency in small grains has been observed in Western Oklahoma since the early 1950's. The amount of Fe chlorosis has increased rapidly since that time, until approximately 50,000 acres are now affected.

The ineffectiveness of soil-applied inorganic Fe compounds for correction has been well established (10, 18, 26). Various aspects of Fe, Zn, Mn relationships have been implicated by several writers (4, 20, 31, 36, 38, 41). Also, several investigators have indicated that high P levels in the soil increase the severity of Fe deficiency (4, 9, 31). However, recent investigations suggest advantages of applying Fe with polyphosphate fertilizers (28, 29). It has been suggested that this complimentary effect is the result of a sequestering action of the polyphosphates, holding the Fe available for uptake by plants or the formation of an Fe-P compound which is soluble, even at high soil pH values.

These studies were designed to compare various Fe and P source combinations under field and controlled conditions in the growth chamber using soils on which small grains show Fe deficiency.

Materials and Methods

Field Studies

Phosphorus and Fe sources were compared under field conditions at different locations for two years. Three soil locations were selected in the 1969-70 crop year on which small grains are known to be Fe deficient. The treatments and locations are given in Table 4.1. The soil at the Foss location was a Vernon silt loam (an Ustochrept) with a 4% slope. The soil at the Hammond and Cheyenne locations was an Ustifluvent (Spur silt loam, old classification system) with a 1% slope. Additional information concerning the fertilizer materials are: commerical blend - a P-Fe fertilizer marketed commercially; 18-20-0 (DAP) and 15-26-0 (TVA solid APP) coated - $FeSO_4$ was coated on the pellets of each source, also, FeDTPA was coated on pellets of 18-20-0; FeDTPA (ferric diethylenetriamine pentaacetate) - Sequestrene 330 Fe (10% Fe); $FeSO_4$ (21% Fe); FeKeMin (Georgia Pacific Inc., Bellingham, Washington) and Rayplex Fe (Rayonier Inc. of Canada) - lignin by-products of paper pulp to which Fe has been added, FeKeMin (11% Fe) Rayplex Fe (6.5% Fe); $ZnSO_4$ (36% Zn); Rayplex Zn (10.0% Zn); 0-20-0 (CSP). The P sources were applied at 44 kg P/ha. The micronutrient sources were applied on an elemental basis and the rates are given in Table 4.1. The treatments were applied broadcast prior to planting and incorporated into the soil.

Two other locations were selected in the 1970-71 crop year at $Foss_H$ (Huls farm) and $Hammond_B$ (Brown farm). Comparisons were made of various combinations of P and Fe sources. The P sources were: 0-20-0 (CSP), 18-20-0 (DAP), 0-32-0 (Super Phosphoric Acid), 15-26-0 (TVA solid APP), 10-15-0 (APP, fluid) and were applied at 29 kg P/ha. The Fe sources were: FeEDDHA [Fe ethylenediamine (di-(O-hydroxyphenyl-acetate))] - 6% Fe, $FeSO_4$ (21% Fe) and were applied with each source at 1 and 17 kg Fe/ha respectively. The Fe materials were placed in suspension with 10-15-0 and then were broadcast on surface of soil at the same time that the other P sources were applied, i.e., all treatments applied at the same time. The $FeSO_4$ was dissolved in H_2O and mixed with 10-15-0 on a 50-50 volume basis for convenience of application and applied at 2.7, 5.4, 8.1, and 16.2 kg Fe/ha with 29 kg P/ha. Ferrous sulfate was also mixed with manure, allowed to ferment, dried and applied at 34 kg Fe/ha and 11 MT manure/ha. Nitrogen was applied to each treatment to bring total N to 67 kg N/ha. All treatments were applied broadcast and incorporated approximately 1 week prior to planting.

Four P and Fe combinations were applied banded with the seed at 3 locations: $Foss_H$, $Hammond_B$, and $Hammond_H$ (Harding farm). The treatments were 15-26-0 coated with FeEDDHA, 15-26-0 coated with Fe_2O_3 and MnO, $FeSO_4$ was dissolved in H_2O and mixed with 10-15-0 on a 50-50 volume basis, and FeEDDHA was dissolved in H_2O and mixed with 10-15-0 volume basis. The P sources were applied at 29 kg P/ha and the Fe sources at 1, 1, 6, and 0.5 kg Fe/ha respectively.

Winter wheat (<u>Triticum</u> <u>aestivum</u> L.) was seeded on all plots in late September of each year at rates from 67 to 84 kg/ha.

Growth Chamber Studies

Soil from a Spur silt loam was collected and passed through a 0.5 cm screen to remove plant debris. The soil was not dried since preliminary investigations indicated that drying changed the available Fe status of this soil. Phosphorus and Fe source combinations were compared at three temperatures in the growth chamber. The P sources were: 0-20-0 (CSP), 18-20-0 (DAP), and 15-26-0 (APP, solid). The Fe sources were: FeEDDHA, $FeSO_4$, FeKeMin, and manure (1800 ppm Fe). The P-Fe combinations were thoroughly mixed with 750 gm (oven dry basis) of soil and placed in plastic pots. The Fe treatments: no Fe, FeEDDHA, $FeSO_4$, FeKeMin, and manure were applied with each P source at 0, 0.25, 2.5, 5.5, and 9 ppm Fe, respectively. Fifteen seeds of winter wheat were planted in each pot. The pots were placed in a Shearer reach-in-type growth chamber with controlled temperature and day length (10 hr. day). The experiment was repeated at each of 3 temperature settings: (1) 4^{o}-4^{o}, (2) 21^{o}-21^{o}, and (3) 21^{o}-4^{o} (day-night temperatures).

The seeds were germinated at 21^{o}C (day and night), and after emergence the night temperature was changed to 4^{o}C. The plants were clipped 3 weeks after emergence and the appropriate experimental temperatures applied.

Visual observations were made daily and forage yield and samples were collected from the second clipping of each temperature treatment. The period of growth for this clipping was 21 days at 21^{o}-21^{o}, 34 days at 21^{o}-4^{o}, and 78 days at 4^{o}-4^{o}. The clipping date depended upon growth rate. The Fe, Zn, Mn, and P concentrations in plant tissues were determined.

Results and Discussion

Field Studies

Grain yields were relatively low (Table 4.1); however, good response was obtained to certain P-Fe treatments at Foss. The yield data indicates that the highest yields were obtained with the Fe source, FeKeMin. Visual observations, plant color, and growth during the growing season indicated that this treatment relieved the Fe deficiency symptoms. Since Fe deficiency produces chlorotic (lack of chlorophyll)

TABLE 4.1

Fertilizer Treatments and Small Grain Yield as Affected by Treatments (3 Locations) 1970

		Micronutrient		Grain Yield (Kg/Ha)		
			Rate	Wheat		Oats
Trt.	P Source	Source	(Kg Fe/Ha)	Foss	Hammond	Cheyenne
1	Commercial Blend	Fe, Zn	0.6, 0.06	990[c]	1293[c]	5426[s]
2	18-46-0 (coated)	$FeSO_4$	11	1139[n]	734[n]	6030[s]
3	18-46-0 (coated)	FeDTPA	2	1436[n]	811[n]	5478[s]
4	15-62-0 (coated)	$FeSO_4$	11	1541[n]	850[n]	5677[s]
5	0-46-0	FeKeMin	13	1631[n]	652[n]	5300[s]
6	0-46-0	Rayplex Fe	7	1373[n]	823[n]	5655[s]
7	0-46-0	$FeSO_4$	11	1352[n]	941[n]	5195[s]
8	0-46-0	$ZnSO_4$	11	1045[s]	892[c]	5064[s]
9	0-46-0	Fe, $ZnSO_4$	11, 11	1179[s]	877[c]	5663[s]
10	0-46-0	Rayplex Zn	3	712[s]	1089[c]	5410[s]
11	0-46-0	Rayplex Zn, FeDTPA	2, 3	973[c]	884[c]	5334[s]
12	0	$FeSO_4$	11	904[s]	840[c]	6628[s]
13	0	FeDTPA	2	497[s]	768[c]	6248[s]
14	0-46-0	0	0	949[c]	1124[n]	5186[s]
15	0	0	0	418[s]	1080[c]	4743[s]
			FLSD	326	NS	NS

[n]No chlorotic plants observed

[c]Some chlorotic plants observed

[s]Severe chlorosis of all plants

plants, visual observations during the growing season are extremely important, especially since certain crops "recover" from the deficiency at later stages of growth. Visual observations may be more effective in comparing various Fe materials than yield data. However, increased yield is the ultimate economic "yardstick." The FeKeMin treatment looked good at the other two locations, but Fe deficiency symptoms developed on all treatments at Cheyenne. The chlorotic plants from the FeKeMin treatment recovered earlier in the spring than the other treatments.

The following treatments substantially increased yields at Foss: 18-20-0 and 15-26-0 (coated with $FeSO_4$), 18-20-0 (coated with FeDTPA), Rayplex Fe, and 0-20-0 with $FeSO_4$; and visual observations indicated that these treatments relieved the Fe deficiency symptoms. However, the FeKeMin treatment maintained a slightly darker color, more forage growth, and high grain yield. Forage growth and plant color were noticeably improved by all of the previously mentioned treatments with early spring growth at Cheyenne and Hammond.

Iron deficiency symptoms were first observed at the Cheyenne location January 7; at Foss, February 21; and Hammond, March 6. The deficiency symptoms dissipated at Hammond by March 26, and by April 15 the plants at all locations had "recovered" from the Fe chlorosis. The severity of Fe deficiency symptoms for each treatment is indicated by a superscript in Table 4.1.

The relatively low yields and lack of response at Hammond and Cheyenne was due to an extremely dry spring. However, visual observations during the growing season indicated good forage growth response to some of the treatments. Early growth responses producing good forage growth followed by grain yields could probably be attributed to more soil moisture stress during the flowering and grain filling stages of growth. Some of the treatments that produced the highest yields at the Foss location produced the lowest yields at Cheyenne and Hammond. These treatments gave good forage responses and were under more moisture stress during grain development, thus lower grain yields.

Yield data from Foss and visual observations at all locations indicated that the commercial blend treatment did not contain adequate Fe for normal plant growth or that the Fe was low in availability. The relatively high yield at Hammond for this treatment was probably due to lack of early growth response resulting in lower moisture use early in the season. The yield response from Zn applications at Foss was probably primarily due to P application, signified by comparing with P only (Trt. 14) Table 4.1. Iron deficiency symptoms were more severe on all plots that received Zn applications. Additions of Fe materials with Zn did not appreciably relieve the Fe deficiency symptoms, suggesting an antagonistic relationship between Fe and Zn for Fe uptake by plants.

The addition of Fe materials with N, where no P was added, enhanced the Fe deficiency throughout the "critical" growth stage of the wheat plants. Previous studies by the authors suggested a detrimental effect on Fe deficiency when N only was applied at other locations on these soils. Some evidence has been obtained suggesting enhanced Mn uptake by N additions as the causative factor. This effect of Zn and N-Fe combinations on Fe deficiencies was also observed at Cheyenne and Hammond, however, the differences were not as great.

The comparison of P and Fe sources, when applied broadcast, was continued at $Foss_H$ and $Hammond_H$ in the 1970-71 crop year. Iron deficiency symptoms were not observed at the $Hammond_H$ location, but severe chlorosis developed in certain plots at $Foss_H$. There was no difference at the Foss location in yield between P sources, Fe sources, or P-Fe combinations whenever the fertilizer material was applied broadcast. It was determined by visual observations that broadcast P-Fe combinations below 17 kg Fe/ha did not supply adequate Fe for normal wheat growth. Applications of P-Fe combinations increased forage growth above the check or treatments receiving only P. Due to an extremely dry winter the grain yields were relatively low at $Foss_H$ and resulted in loss of wheat stand at the $Hammond_H$ location.

Phosphorus and Fe combinations were applied banded with the seed at $Foss_H$, $Hammond_H$, and the $Hammond_B$ locations. No Fe deficiency symptoms were observed at the $Hammond_B$ location and no response was noted. Chlorosis did occur at both of the other locations. No response was obtained with 15-26-0 coated with Fe_2O_3 and MnO. This could be due to supplying Fe as Fe_2O_3 or the antagonistic effect of Mn on Fe uptake. Good response was obtained with 10-15-0 and $FeSO_4$ or FeEDDHA at the $Foss_H$ and $Hammond_H$ locations. It was determined by visual observations and yield data from $Foss_H$ that 10-15-0 plus 6 kg Fe/ha as $FeSO_4$ and 10-15-0 plus 0.5 kg Fe/ha as FeEDDHA supplied adequate Fe for normal plant growth and were equally effective in correcting Fe deficiency in small grains when banded with the seed. The 15-26-0 coated with FeEDDHA decreased Fe deficiency symptoms but was not as effective as the fluid P source. The 10-15-0 plus 6 kg Fe/ha as $FeSO_4$ treatment appears to be an effective, economical method of correcting Fe deficiencies in small grains. There appears to be a definite complimentary effect of P on Fe uptake on the soils which show Fe deficiency in small grains.

Soil applications of polyflavinoid and synthetic Fe chelates such as FeKeMin, Rayplex Fe, and FeEDDHA can correct Fe deficiencies in small grains. Visual observations and yield data indicated the beneficial effect of FeKeMin carried over into the second crop year. The present high costs of these chelating agents are a deterrent to widespread use in low valued field crops. However, these iron chelates could be economically feasible for ornamentals and high value crops.

Growth Chamber Studies

The appearance of Fe deficiency symptoms in small grains is erratic but appears to be correlated to some degree with soil temperature and moisture. For example, Fe deficiency symptoms were first observed in January of 1969-70 crop year, yet were observed in November of the 1970-71 crop year (50 days earlier). Also, when the soil temperatures increase during the spring, Fe deficiencies become less severe and may even dissipate. Therefore, phosphorus and Fe source combinations were compared in the growth chamber at three temperature settings: 4°-4°, 21°-21°, and 21°-4°C (day-night temperature), and the results are presented in Tables 4.2 and 4.3.

Wheat forage yields were not markedly affected by P or Fe source combinations (Table 4.2). However, forage yields were affected by temperature. Higher forage yields were produced at 21°-4° due to more favorable growing conditions for winter wheat.

The concentration of Fe in the plant tissue is closely related to the temperature treatments. The Fe concentration was highest at 4°-4°

TABLE 4.2

Forage Yields and Uptake of Fe, Zn, Mn, and P by Wheat as Affected by P and Fe Sources

Fe Source	P Source	Yield (mg/pot) 4°-4°	21°-21°	21°-4°	Fe 4°-4°	21°-21°	21°-4°	Zn 4°-4°	21°-21°	21°-4°	Mn 4°-4°	21°-21°	21°-4°	P 4°-4°	21°-21°	21°-4°
No Fe	CSP	9.0	10.7	17.2	317	127	54	137	115	76	410	416	241	3110	3306	2928
	DAP	8.8	10.0	19.0	338	86	45	167	94	71	398	369	229	3307	3459	3105
	APP	6.5	14.5	18.0	423	100	50	198	96	88	402	456	244	3633	3830	2928
Fe SO_4	CSP	9.0	14.0	19.8	405	107	74	136	79	61	362	291	182	3264	3094	3275
	DAP	9.8	13.8	17.3	498	111	63	106	92	58	322	295	157	3722	3115	3045
	APP	9.3	18.7	20.5	360	75	49	122	79	55	252	272	122	2434	3416	2950
Fe EDDHA	CSP	11.5	15.2	19.2	303	104	59	130	85	63	333	366	200	3244	3073	3035
	DAP	9.2	16.0	19.0	492	96	57	170	83	62	250	343	173	2807	3064	3063
	APP	8.8	17.3	20.0	385	88	62	125	88	81	287	382	217	3946	3572	3228
Fe Ke Min	CSP	7.3	16.3	21.0	375	103	60	165	74	47	520	249	137	4598	3155	2744
	DAP	9.5	16.7	18.7	400	98	60	155	122	76	267	275	139	3191	3062	3164
	APP	8.3	14.8	18.0	456	84	51	127	73	54	280	237	149	3580	3527	3347
Manure	CSP	9.3	12.0	18.3	365	89	65	168	111	72	227	449	228	3324	3940	3227
	DAP	5.7	19.5	19.0	565	77	72	165	83	81	522	414	264	5230	3872	4425
	APP	8.3	16.7	20.8	503	91	57	145	99	86	485	435	294	5014	4421	4616
FLSD	(5%)	NS	NS	NS	NS	NS	NS	52	NS	26	188	87	79	1681	876	912

TABLE 4.3

Total Concentration (Fe + Zn + Mn) and Concentration Ratios in Wheat Forage as Affected by P and Fe Sources

Fe Source	P Source	Total 4°-4°	Total 21°-21°	Total 21°-4°	Fe/Zn 4°-4°	Fe/Zn 21°-21°	Fe/Zn 21°-4°	Fe/Mn 4°-4°	Fe/Mn 21°-21°	Fe/Mn 21°-4°	Mn/Zn 4°-4°	Mn/Zn 21°-21°	Mn/Zn 21°-4°	P/Fe 4°-4°	P/Fe 21°-21°	P/Fe 21°-4°	P/Zn 4°-4°	P/Zn 21°-21°	P/Zn 21°-4°	P/Mn 4°-4°	P/Mn 21°-21°	P/Mn 21°-4°
No Fe	CSP	863	658	371	2.3	1.1	0.7	0.8	0.3	0.2	3.0	3.7	3.2	9.9	27	58	23	29	39	7.6	8.3	12
	DAP	203	549	346	2.3	0.9	0.7	0.9	0.2	0.2	2.7	3.9	3.4	9.9	41	69	21	38	46	8.4	9.8	14
	APP	1023	651	382	2.1	1.0	0.6	1.1	0.2	0.2	2.0	4.8	2.8	8.7	39	61	19	40	34	9.2	8.4	12
$FeSO_4$	CSP	903	477	317	3.0	1.3	1.2	1.3	0.4	0.4	2.5	3.8	3.1	7.8	36	49	23	41	56	9.2	10.7	18
	DAP	926	497	278	4.5	1.2	1.1	1.6	0.4	0.4	3.0	3.6	2.8	8.0	29	51	34	35	54	12.0	11.5	19
	APP	734	426	227	3.0	0.9	0.9	1.4	0.3	0.5	2.1	3.4	2.3	6.9	46	60	20	43	56	9.7	12.5	29
Fe EDDHA	CSP	767	555	322	2.3	1.2	0.9	1.3	0.3	0.3	2.4	4.4	3.2	10.6	32	54	24	37	48	11.0	8.4	16
	DAP	912	522	292	3.0	1.2	1.0	2.0	0.3	0.3	1.5	4.2	3.0	7.4	32	54	17	38	53	11.3	8.9	17
	APP	796	557	360	3.2	1.0	0.8	1.3	0.2	0.3	2.3	4.3	2.8	11.2	45	55	32	41	41	13.7	9.5	15
Fe Ke Min	CSP	1440	426	244	4.8	1.4	1.3	1.5	0.4	0.4	3.2	3.5	3.0	6.1	34	47	27	43	59	8.6	13.9	20
	DAP	822	495	275	2.6	1.0	0.9	1.6	0.4	0.4	1.7	2.8	2.3	8.7	34	57	21	30	51	11.4	11.0	23
	APP	863	394	255	3.6	1.2	1.0	1.7	0.4	0.3	2.2	3.4	2.9	8.0	43	66	28	49	64	12.7	15.4	22
Manure	CSP	760	649	364	2.2	0.9	0.9	1.6	0.2	0.4	1.4	4.1	3.3	9.1	46	54	21	37	45	15.4	8.9	28
	DAP	1287	573	417	3.9	0.9	0.9	1.4	0.2	0.3	3.1	5.1	3.4	9.1	55	64	32	48	59	10.3	9.8	17
	APP	1133	625	437	3.6	0.9	0.7	1.0	0.2	0.2	3.4	4.5	3.7	11.2	51	80	34	47	59	11.2	10.6	16

and lowest at 21^{o}-4^{o}. Comparison of yield and Fe concentrations indicate that under favorable growing conditions for winter wheat (21^{o}-4^{o}) higher yields and lower concentrations of Fe occur. Under adverse growing conditions (4^{o}-4^{o}) accumulation of Fe occurred. The accumulation at 4^{o}-4^{o} could be due to uptake rate exceeding growth rate, while under more favorable growing conditions (21^{o}-4^{o}) growth rate exceeds uptake and the "dilution" effect occurs. The P and Fe source combinations did not significantly affect the Fe concentrations.

The Zn concentrations were also affected by the temperature treatments, however, the accumulation effect was less than with Fe. Ferrous sulfate, FeEDDHA, and FeKeMin reduced the Zn concentrations below that without Fe and with the manure treatment, regardless of P source. Apparently the antagonistic effect of Fe on Zn uptake reduced the Zn concentration. The Fe present in the manure was probably tied up by micro-organisms decomposing the manure, thus preventing Fe interference with Zn uptake.

Manganese concentration was affected by temperature treatments, with a consistently lower Mn concentration at 21^{o}-4^{o}. The antagonistic effect of Fe on Mn uptake is indicated by lower Mn concentration with the Fe sources: $FeSO_4$, FeEDDHA, and FeKeMin.

The P concentrations were not appreciably affected by temperature or P source. The P concentrations were higher with the manure treatments, probably due to P in the manure or possibly enhanced P availability with increased microbiological activity.

Additional information concerning the heavy metal relationship can be obtained from the total concentration (Fe + Zn + Mn) and various ratios presented in Table 4.3. The total concentration of heavy metals was affected by the temperature treatments. Lower total concentration under more favorable growing conditions (21^{o}-4^{o}) would be indicative of a "dilution" effect or uptake rate-growth rate relationship. The decrease in total concentration by $FeSO_4$, FeEDDHA, and FeKeMin was probably due to antagonism of Fe on Zn and Mn uptake when a supply of readily available Fe is present.

The Zn/Fe and Mn/Fe ratios are lower for the $FeSO_4$, FeEDDHA, and FeKeMin treatments due to the adverse effect of Fe on Zn and Mn uptake. The Mn/Zn ratios are decreased by $FeSO_4$ and FeKeMin, probably because Mn appeared to be decreased more by Fe additions than Zn. The reason FeEDDHA does not have the effect on Zn and Mn concentrations that $FeSO_4$ or FeKeMin does is that a lower amount of Fe is added as FeEDDHA.

There did not appear to be any significant difference between the P sources on Fe uptake or relationships with the other heavy metals.

CHAPTER V

EFFECT OF FERTILIZER ELEMENTS ON IRON DEFICIENCIES OF WINTER WHEAT[1/]

Abstract

Rates and combinations of the three major fertilizer elements and treatments of Fe, Zn, and Mn were applied to soil samples from a Spur silt loam soil (a Fluventic Haplustoll), on which winter wheat consistently exhibits iron deficiency symptoms. Winter wheat (*Triticum aestivum* L.) forage yields and nutrient uptake were obtained on two successive crops in the growth chamber with three different temperature regimes ($4^{\circ}C - 4^{\circ}C$, $21^{\circ}C - 21^{\circ}C$, $21^{\circ}C - 4^{\circ}C$; day-night temperatures). Forage yields were increased by N, P, and Fe when temperatures were favorable. Highest yields were obtained at 21°-4°. Total concentrations (Fe + Zn + Mn) were high at low temperatures (unfavorable growth), especially Fe. The decreases in concentrations at other temperatures is probably the "dilution effect" from increased growth. Additions of Zn and Mn decreased the Fe concentration, suggesting the concentration of Fe, Zn, or Mn in the plant depends upon the level of the other two in the soil. Nitrogen increased Mn and decreased Fe concentrations in the plant and significantly affected the concentration ratios. Some

[1/]Article co-authored with Billy B. Tucker and to be submitted for publication in Agronomy Journal.

evidence was accumulated, suggesting low Fe/Mn ratios as partially responsible for the Fe deficiency.

Additional Key Words: nutrient uptake, chlorosis, temperature, nutrient interaction.

Introduction

Iron deficiency of plants on calcareous soils is widespread and is frequently observed on sorghums in the Central and Southern Great Plains. Iron deficiency in small grains was first observed on certain soils in Oklahoma in the early 1950's but has spread rapidly since that time, until approximately 50,000 acres are now affected.

It has been observed that plants or varieties within species will vary in their ability to absorb nutrients. Considerable research information on the subject has been accumulated with corn and soybeans (6, 8). The available Fe in the soil and Fe uptake is affected by proper nutrient balance. Various aspects of Fe, Zn, Mn relationships have been implicated by several writers (2, 11, 20, 23, 31, 36, 38, 41). Several investigators (4, 23, 38, 41) have reported that the optimum level of Fe, Zn, and Mn depends on the levels of the other two. An example is the low levels of Mn in the leaf tissue results in low Fe or Zn requirements, while high levels of Mn result in high Fe or Zn levels.

The importance of available Fe, Zn, Mn ratios on the Fe status of plants has been established (11, 38, 40). As the amount of available Fe, Zn, or Mn becomes excessive in the soil, the uptake of the others will be suppressed. A detrimental effect of high P levels on Fe deficiency has been implied (5, 8, 19, 41).

The purpose of these two experiments was to study the effect of N, P, K fertilizers on Fe uptake and availability in winter wheat. Also, the effect of Fe, Zn, and Mn additions on the concentrations of these heavy metal ions in the plant were investigated. It was believed that a quantitative evaluation of the effect of N, P, and K on the intricate relationships of the heavy metals and P would be valuable in studying the Fe deficiency problem in small grains.

Materials and Methods

Soil samples were collected from a Spur silt loam soil on which winter wheat was exhibiting an Fe deficiency. The soil was screened through a 0.5 cm screen to remove plant debris. The soil was not dried, since preliminary work indicated that drying changed the available Fe, preventing characteristic symptoms from developing. The N-P-K and Fe-Zn-Mn treatments were applied as a 2^3 factorial arrangement of treatments with three replications. The N, P, K, Fe, Zn, and Mn treatments were thoroughly mixed with 750 gm (treatments applied on an oven dry basis) of soil at 40, 17, 25, 5, 5, 5 ppm respectively and placed in plastic pots. The N, P, K, Fe, Zn, and Mn materials used were 33-0-0 (NH_4NO_3), 0-20-0 (CSP), 0-0-50 (KCL), $FeSO_4$, and $MnSO_4$ respectively. Fifteen seeds of winter wheat (Triticum aestivum L. Var. "Wichita") were planted in each pot.

The pots were placed in a Shearer reach-in-type growth chamber with controlled temperature and day-length (10 hr. day). The experiment was repeated at each of three temperature settings: (1) 4°-4°, (2) 21°-21°, (3) 21°-4°C (day-night temperature).

The seeds were germinated at 21°C and after emergence the night temperature was changed to 4°C. The plants were clipped three weeks after emergence and the appropriate experimental temperatures applied.

Visual observations were made daily with forage yield and samples collected from the second clipping at each temperature treatment. The period of growth for this clipping was: 21 days at 21°-21°, 34 days at 21°-4°, and 78 days at 4°-4°. The clipping date depended on growth rate. The Fe, Zn, Mn, and P concentrations in plant tissue were determined.

In order to simplify reporting, the results from the N-P-K fertilizers (Experiment 1) and the Fe-Zn-Mn additions (Experiment 2), are reported separately.

A statistical analysis of the data was made using FLSD (Preliminary significant F with LSD) (7).

Results and Discussion

Experiment 1

Element uptake and plant growth are closely related under normal growing conditions. However, element concentration in plant tissues may vary depending on rate of uptake, mobility, plant growth, and stage of growth. Since essential elements do not enter the plant at a constant rate, concentration or accumulation of certain elements may occur if normal plant growth is interrupted by limiting factors such as adverse temperatures or nutrient deficiencies. Accumulation of some elements may also occur if the rate of uptake exceeds the growth rate. Dilution of certain elements may occur if rate of plant growth exceeds nutrient uptake or if one limiting nutrient is supplied and as increased growth rate occurs.

The effects of N, P, K additions on yield and Fe, Zn, Mn, and P concentrations are recorded in Table 5.1. The addition of N increased the yield of dry matter at each temperature treatment. Phosphorus increased the yield slightly at 21^{o}-21^{o} and 21^{o}-4^{o}, while K appeared to depress yields.

The Fe concentration in the forage at 4^{o}-4^{o} was higher than at the other temperature treatments. This was probably due to reduced growth rate caused by low temperature, allowing Fe accumulation during this period of time. The addition of N decreased Fe levels at 21^{o}-21^{o} and 21^{o}-4^{o}. The decrease could probably be attributed to a dilution effect of increased growth or to enhanced uptake of the other heavy metals coupled with a corresponding decrease in Fe uptake. The Zn concentrations at 4^{o}-4^{o} follow the Fe accumulation patterns at this low temperature. Addition of N or P appeared to depress Zn concentration.

The differences in Mn concentrations between temperatures were lower than for Fe and Zn. Nitrogen increased the Mn concentration at each temperature treatment. The decrease in Fe and increase in Mn with N additions is an indication of an antagonistic relationship between Fe and Mn, similar to that found by Twyman (38). According to Bennett (4) Mn may produce Fe deficiency by depressing absorption of Fe, because of the antagonism existing between these two elements. Observations and yield data from field studies of iron deficiency in small grains indicated when N was applied without P, that Fe deficiency symptoms were more severe. The increased uptake of Mn and corresponding decrease in Fe uptake could explain the phenomenon observed in the field studies.

TABLE 5.1

Influence of N, P, K, and Temperature on Forage Yield
and Nutrient Composition

Trt.	Dry Matter (mg/pot)			Fe (ppm)			Zn (ppm)			Mn (ppm)			P (ppm)		
	4°-4°	21°-21°	21°-4°	4°-4°	21°-21°	21°-4°	4°-4°	21°-21°	21°-4°	4°-4°	21°-21°	21°-4°	4°-4°	21°-21°	21°-4°
000	55	82	77	548	229	162	325	97	96	233	300	151	2337	3569	3566
00K	52	78	67	426	125	139	141	112	118	292	349	140	2887	3528	3564
0P0	57	95	92	416	166	86	112	97	78	215	276	133	3070	4664	5284
0PK	45	68	57	828	150	117	191	96	125	323	280	145	4195	5472	5191
N00	90	140	247	346	104	43	120	90	61	407	408	252	2521	2286	1674
N0K	75	150	273	308	84	59	152	96	132	415	351	252	3235	3291	2991
NP0	101	142	250	346	117	42	133	93	62	357	362	228	2903	3134	3083
NPK	90	107	172	316	127	54	136	115	76	410	415	241	3110	3306	2928
Sig. Effect	N	N	N	N	N	N, P	NPK	NS	NPK	N, K	N	N	P, K	N, P	N, P
Calc. F	20**	25**	75**	18**	12**	40**, 45*	6.9*		5.7*	27*, 5.2*	7.6*	45*	13**, 16**	24**, 14**	64**, 30**

*Significant at 5% level   **Significant at 1% level   NS - Non-significant at 5% level

The difference in P levels of the forage were not large and appeared to depend more on N-P-K treatments than on temperature. The P concentrations were increased by P additions and decreased by N with or without P at each temperature. This decrease or dilution effect was probably due to increased growth and forage production from added N plus P.

Additional information on the relationship between the heavy metals was obtained by an interpretation of the total Fe, Zn, and Mn concentration, heavy metal ratios, and their ratios with P. This data is presented in Table 5.2.

The high total concentration at 4^{o}-4^{o} is additional evidence of nutrient accumulation during periods of stress, in this case, low temperature. Dilution of the total concentration occurred with increased growth, under more favorable growing conditions (21^{o}-21^{o} and 21^{o}-4^{o}). Nitrogen did not appreciably affect the total concentration. However, the total concentration was decreased by P and increased when K was added with P. This increase could be due to the slight depression in yield when K was added with P.

Nitrogen appeared to decrease the Fe/Zn and Fe/Mn ratios, and increased the Mn/Zn ratios at each temperature treatment. This would be expected since N depressed Fe and enhanced Mn uptake. Also Zn uptake was depressed but not to the extent of Fe.

Since N depressed Fe and Zn concentrations and enhanced Mn uptake, the P-heavy metal ratios were affected accordingly. The P-heavy metal ratios increased by P additions. DeKock (13) and Orken and Walker (32) indicated the P/Fe ratio to be an accurate assessment of the Fe status in plant leaves. DeKock suggested that a ratio > 50 resulted in

TABLE 5.2

Influence of N, P, K, and Temperature on Total (Fe + Zn + Mn) Concentration and Nutrient Composition Ratios

	Total Conc.			Fe/Zn			Fe/Mn			Mn/Zn		
	4°-4°	21°-21°	21°-4°	4°-4°	21°-21°	21°-4°	4°-4°	21°-21°	21°-4°	4°-4°	21°-21°	21°-4°
000	1107	626	408	2.1	2.4	1.7	2.7	0.8	1.1	1.0	3.1	1.6
00K	860	587	397	3.4	1.1	1.2	1.4	0.4	1.0	2.3	3.1	1.2
0P0	744	540	298	3.8	1.7	1.1	2.0	0.6	0.6	1.9	2.9	1.7
0PK	1343	527	387	4.4	1.6	1.0	2.7	0.6	0.8	1.7	2.9	1.2
N00	873	604	355	2.9	1.2	0.7	0.9	0.3	0.2	3.4	4.5	4.1
N0K	875	532	444	2.0	0.9	0.5	0.8	0.3	0.2	2.7	3.7	2.0
NP0	837	572	332	2.6	1.3	0.7	1.0	0.3	0.2	2.7	3.9	3.7
NPK	863	657	371	2.3	1.1	0.7	0.8	0.3	0.2	3.0	3.7	3.2
Sig. Effect	NPK	NP	P, K	N	N, K	NP	N	N	N	NPK	N	NPK
Calc. F	9.4	5.4*	6.3*, 5.7*	6.1*	13**, 7.5*	4.7*	17**	11**	43**	9.2	6.6*	5.9*

	P/Fe			P/Zn			P/Mn		
	4°-4°	21°-21°	21°-4°	4°-4°	21°-21°	21°-4°	4°-4°	21°-21°	21°-4°
000	5	16	23	10	38	37	11	12	24
00K	7	28	27	22	31	31	10	10	26
0P0	8	33	64	28	48	71	15	17	40
0PK	5	42	46	22	57	44	13	20	36
N00	7	24	40	21	25	27	6	5	6
N0K	11	39	54	21	34	24	8	10	13
NP0	9	29	75	22	34	50	8	9	14
NPK	10	27	58	23	29	39	8	8	12
Sig. Effect	PK, N	K, NP	N, PK	NPK	NPK	N, P, K	N, P	NPK	NP
Calc. F	6.9*, 16**	4.7*, 6.3**	9, 6	6.1*	7.0*	5, 19, 6	26*, 6.0*	9.0**	6.1*

*, **, NS - Significance level at 5%, 1%, and Non-significant respectively.

chlorotic plants and that the high P content probably resulted in a metabolic imbalance in plants due to Fe deficiency. The P/Fe ratios in this data were generally less than 50, excpet for certain treatments at 21^{o}-4^{o}. Ratios above 50 did not result in chlorotic wheat plants suggesting the detrimental effect of P on Fe reported by some writers does not exist for wheat or possibly that wheat is more tolerant to high P/Fe ratios than other crops such as sorghum, corn, or soybeans.

Experiment 2

The balance or relationship between the heavy metals has been studied extensively in nutrient solutions; however, this balance depends to a certain extent on stage of growth, crop, or even variety within a species. The balance which must be maintained in a nutrient solution for normal plant growth may be significantly different from normal growth in field situations.

Experiment 2 was designed to determine the effect of Fe, Zn, Mn, and interactions on heavy metal uptake and concentration in the plant. The results are presented in Table 5.3. The production of dry matter at 4^{o}-4^{o} was not affected by any treatment. The low yield and lack of response was probably due to low growth rate at these adverse temperatures. The addition of Fe increased the dry matter production at 21^{o}-21^{o}. This was probably due to lack of interference to Fe uptake and utilization at these high temperatures. Field studies indicate that as soil temperatures increase in the spring, Fe deficiency becomes less severe and deficiency symptoms disappear. The addition of Zn and Mn appeared to depress yield at 21^{o}-21^{o}. This depression agrees with information obtained by Watanabe et al (41) and Twyman (38) where

TABLE 5.3

Influence of Fe, Zn, Mn, and Temperature on Forage Yield and Nutrient Composition

Trt.[1]	Dry Matter (mg/pot)			Fe (ppm)			Zn (ppm)			Mn (ppm)			P (ppm)		
	4°-4°	21°-21°	21°-4°	4°-4°	21°-21°	21°-4°	4°-4°	21°-21°	21°-4°	4°-4°	21°-21°	21°-4°	4°-4°	21°-21°	21°-4°
000	90	107	172	317	127	54	137	115	76	410	416	241	3110	3306	2928
00M	82	143	225	510	84	68	347	92	81	340	420	245	4792	3490	2729
0Z0	83	125	178	443	84	54	287	109	73	290	343	234	3809	3367	2809
0ZM	65	83	170	540	98	107	148	131	69	407	374	229	4527	3159	2942
F00	90	140	198	405	107	74	137	79	61	362	291	182	3264	3095	3275
F0M	80	172	213	362	79	56	122	70	50	363	292	149	3609	2927	2757
FZ0	103	153	202	310	90	61	140	99	57	300	266	139	3098	2790	2901
FZM	81	177	182	473	81	73	137	76	69	202	258	153	3555	2483	2498
Sig. Effect	NS	Fe	NS	NS	NS	NS	FZM	Fe, Zn	NS	NS	Fe	Fe, Zn	Mn	Fe	NS
Calc. F		9*					11**	22**, 5*			18**	146**, 5*	5*	14**	

[1]F=Fe, Z=Zn, M=Mn for simplification in this table

* Significant at 5% level

** Significant at 1% level

additions of Zn and Mn decreased yield at low concentrations of Fe. The addition of Fe increased yield at 21°-4°. The lack of yield response when Zn and/or Mn were added with Fe suggests that, at this temperature, interference of iron uptake or utilization may have occurred.

Evaluation of Fe, Zn, Mn, and P concentrations in the plant tissue as affected by these heavy metal additions showed that Fe concentrations were strongly affected by temperature. The high Fe levels at 4°-4° could probably be correlated with rate of uptake exceeding growth rate. The lower Fe concentrations at 21°-21° and 21°-4° could be attributed to dilution caused by increased growth rate under more favorable growing conditions. Thus the concentrations of Fe depend more on temperature or essentially growth rate than on treatment.

The Zn concentrations were also affected by the temperature treatments; however, the accumulation effect was less than Fe. The Zn level at 4°-4° was increased by Zn and Mn additions alone but decreased when Zn and Mn were both applied. Application of Fe decreased Zn concentrations in the plants at 21°-21°. Heavy metal additions did not appreciably affect the Zn level at 21°-4°. The Mn concentrations were affected by the temperature treatments, but not as drastically as Zn and Fe. The lower Mn levels at 21°-4° were probably due to higher growth rate resulting in dilution of Mn in plant tissues. The addition of Fe decreased Mn levels for each temperature, especially at 21°-4°. Zinc also appeared to depress Mn levels. The fact that concentrations of each heavy metal depends to a certain extent on the availability of the other two, further confirms a definite relationship between these nutrients.

The P concentration was not affected appreciably by temperature. Iron decreased P concentrations and was probably the result of dilution with increased growth by Fe additions. Additional information on the relationship of heavy metals and P can be obtained by looking at the ratios reported in Table 5.4. The P/Fe and P/Zn ratios were not affected by heavy metal treatments. These ratios varied depending on temperatures and followed closely the pattern set by Fe and Zn concentrations, since P concentration varies little at different temperatures. The P/Mn ratios were significantly increased by Fe except at the low temperature. This was probably primarily due to the effect of Fe additions reducing Mn concentrations.

The results of total (Fe, Zn, Mn) concentrations and the ratios are given in Table 5.4. The high total concentrations are probably the result of accumulation by the plants due to an imbalance or Fe deficiency present in this Spur soil. The addition of Fe decreased the total concentration at all temperatures. This lower concentration could be due to dilution from increased growth when Fe was supplied.

There was no consistent difference in Mn/Zn ratios at the different temperatures and there appeared to be little relationship between heavy metal additions and Mn/Zn ratios.

The higher Fe/Zn ratios at 4^{o}-4^{o}, than the other temperatures suggested that Fe accumulates faster in plant tissue during a period of low growth rate on Fe deficient soils. However, Twyman (38) found that the concentration of Fe within the plant tissue had little relation to the incidence of chlorosis in Fe deficient plants. Watanabe,

TABLE 5.4

Influence of Fe, Zn, Mn, and Temperature on Total Concentration and Nutrient Composition Ratios

Trt.[1]	Total Conc.			Fe/Zn			Fe/Mn			Mn/Zn		
	4°-4°	21°-21°	21°-4°	4°-4°	21°-21°	21°-4°	4°-4°	21°-21°	21°-4°	4°-4°	21°-21°	21°-4°
000	863	658	371	2.3	1.1	0.7	0.8	0.3	0.2	3.0	3.7	3.2
00M	1197	596	393	1.4	0.9	0.8	1.5	0.2	0.3	1.0	4.6	3.0
0Z0	1023	537	361	1.9	0.8	0.7	2.1	0.3	0.2	1.2	3.3	3.2
0ZM	1095	603	405	3.6	0.7	1.6	1.3	0.3	0.5	2.7	2.8	3.4
F00	903	477	317	3.0	1.3	1.2	1.3	0.4	0.4	2.5	3.8	3.1
F0M	847	441	356	3.0	1.1	0.8	1.1	0.3	0.4	2.9	4.2	2.2
FZ0	750	454	257	2.5	0.9	1.1	1.1	0.4	0.4	2.2	2.8	2.5
FZM	812	414	294	3.5	1.1	1.1	2.5	0.3	0.3	1.6	3.4	2.2
Sig. Effect Calc. F	Fe 4*	Fe 34*	Fe 6*	NS	Fe, Zn 8*, 11**	NS	NS	NS	Fe 6*	FZM 16**	Zn 7*	Fe 8*

Trt.	P/Fe			P/Zn			P/Mn		
	4°-4°	21°-21°	21°-4°	4°-4°	21°-21°	21°-4°	4°-4°	21°-21°	21°-4°
000	10	27	58	23	29	39	8	8	12
00M	10	42	41	13	38	35	14	8	12
0Z0	9	40	56	15	31	39	18	10	12
0ZM	8	33	33	30	24	43	11	9	13
F00	8	36	49	23	41	56	9	11	18
F0M	10	39	51	29	43	42	11	10	19
FZ0	10	34	48	23	30	52	10	11	21
FZM	10	32	35	26	33	37	26	10	17
Sig. Effect Calc. F	NS	NS	NS	FZM 9*	Fe, Zn 6*, 10**	NS	NS	Fe 5*	Fe 46**

[1] F=Fe, Z=Zn, M=Mn for simplification in this table
NS - Non-significant at 5% level

*Significant at 5% level
**Significant at 1% level

et al (41)found that an Fe/Zn ratio of 0.2 appears to have a detrimental effect on yield in corn. The heavy metal treatments in this study appeared to have little effect on the Fe/Zn ratio. The Fe/Mn ratios were also higher at 4^{o}-4^{o}, and again there appeared to be little relationship between the ratio and heavy metal treatments. However, Twyman (38) found that when Fe/Mn ratios in plant tissues of oat plants was <0.2, Fe chlorosis was observed. Somers, et al (36) found that normal growth of soybeans did not occur unless the Fe/Mn ratio of the nutrient solution was between 1.5 and 2.5. Soil test values for available Fe, Zn, and Mn using the DTPA extractant method, were obtained for the Spur soil used in these experiments. The Fe/Mn, Fe/Zn, and Mn/Zn ratios were found to be 0.2, 1.8, and 8.3 respectively. If the ratio limits observed by Somers, et al (36) can be used as a guage of the relationship in the soil. then the low Fe/Mn ratio could be the causative factor of Fe deficiency in this young Mollisol. Also, according to Morris and Pierre (27) an increase in Fe to a nutrient solution containing an Fe deficient plant resulted in a decrease in Mn absorbed rather than an increase in Fe absorbed.

Chlorosis symptoms characteristic of Fe deficiency were not obtained for any of the Fe, Zn, and Mn treatments. Preliminary research indicated that once soils which exhibit Fe deficiency in small grains are disturbed by bringing to greenhouse or growth chamber, characteristic Fe deficiency symptoms did not develop. This is probably related to changes in the chemical processes of the soil associated with pot culture.

CHAPTER VI

SUMMARY AND CONCLUSIONS

Differences in wheat grain yields as affected by ammonium nitrate, urea, and ammonium sulfate were small and nonsignificant. However, ammonium sulfate was inferior to either urea or ammonium nitrate in one study. Differences between fall preplant applications and spring top-dressed N were small. Summer N (post harvest) applications were inferior to fall and spring applications.

Additions of carbonaceous materials to Fe deficient soils at the rates applied had little effect on the available Fe status of the soil. The DTPA soil test for available Fe appears to be correlated with Fe available for uptake by small grains. Fluctuations of available soil Fe occurred during the growing season, probably the result of soil moisture and temperature changes. Available soil Fe appears to be inversely related to the soil moisture. Concentrations of Fe, Zn, Mn, and P in wheat tissue fluctuated during the growing season, probably due to changes in soil Fe availability, growth rate, and uptake rate by the wheat plants. Manure treatments hold some promise in correction of Fe deficiency in wheat; however, large rates are necessary resulting in high treatment costs.

Iron deficiency in small grains was effectively corrected by certain P-Fe combinations. Ferrous sulfate with fluid polyphosphates appear to be an economical means of correcting Fe deficiencies of small grains, especially when banded with the seed. Synthetic chelates and polyflavinoid complexes to which Fe has been added are effective, but the present high cost prevents widespread use on low value crops. These Fe sources could be used for treating Fe deficiencies of high valued crops and ornamentals, however.

The concentration of the heavy metals in wheat tissue was influenced by temperature and N, P, K fertilization. The heavy metals accumulated at low temperatures (unfavorable growth) and the "dilution effect" was observed with higher forage yields under more favorable growing conditions. Forage yields were increased by N, P, and Fe additions. Additions of Zn and Mn decreased the Fe concentration, suggesting an antagonistic relationship between these heavy metals. Nitrogen increased Mn and decreased Fe concentration in the plant tissue. Some evidence was accumulated, suggesting low Fe/Mn ratios to be responsible for the Fe deficiency of small grains growing on Spur silt loam soil.

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