EFFECT OF PHOSPHORUS SOURCES ON GERMINATION OF WHEAT, NITROGEN ON NITRATE ACCUMULATION IN SMALL GRAINS, AND DETERMINATION OF CRITICAL NUTRIENT LEVELS OF WHEAT

By

JOHN MILTON BAKER, JR.

Bachelor of Science
Texas College of Arts and Industries
Kingsville, Texas
1963

Master of Science
Oklahoma State University
Stillwater, Oklahoma
1966

Submitted to the Faculty of the Graduate College
of the Oklahoma State University
in partial fulfillment of the requirements
for the Degree of
DOCTOR OF PHILOSOPHY
May, 1970

EFFECT OF PHOSPHORUS SOURCES ON GERMINATION OF WHEAT, NITROGEN ON NITRATE ACCUMULATION IN SMALL GRAINS, AND DETERMINATION OF CRITICAL NUTRIENT LEVELS OF WHEAT

Thesis Approved:

Billy B. Tucker
Thesis Adviser

Laurence G. Morrill

Gene Guinn

D. Durham
Dean of the Graduate College

ACKNOWLEDGEMENTS

The author wishes to express his appreciation to the Agronomy Department, Agricultural Experiment Station and Oklahoma State University for the use of their facilities and their financial support which made these studies possible. Gratitude is also expressed to Phillips Petroleum Company for their financial support of one of the experiments.

Special appreciation is expressed to Dr. B. B. Tucker for his encouragement, guidance and advice throughout the course of this research. Also, special acknowledgement is due my other committee members, Dr. L. G. Morrill and Dr. G. Guinn.

Gratitude is also expressed to Mr. Bill Fuller and Mr. Harold Meyers for their assistance in carrying out the field laboratory work and to Mrs. Alice Heist for typing the manuscript.

TABLE OF CONTENTS

Chapter		Page
I.	INTRODUCTION	1
II.	EFFECTS OF RATES AND SOURCES OF PHOSPHORUS UNDER VARYING SOIL TEMPERATURE AND MOISTURE REGIMES ON THE EMERGENCE OF WINTER WHEAT [Paper submitted to Soil Science Society of America Proceedings for publication]	3
III.	THE EFFECTS OF RATES OF NITROGEN AND PHOSPHORUS ON THE ACCUMULATION OF NITRATE NITROGEN IN WHEAT, OATS, RYE AND BARLEY ON DIFFERENT SAMPLING DATES [Paper submitted to Agronomy Journal for publication]	20
IV.	CRITICAL N, P AND K LEVELS IN WINTER WHEAT [Paper to be submitted to Agronomy Journal for publication]	34
LITERATURE CITED		49

LIST OF TABLES

Table		Page
I.	Effect of Broadcast Versus Banding CSP with the Seed on Seedling Emergence and Yield of Wheat	17
II.	The Influence of Rates of Nitrogen Fertilizer on the Nitrate Nitrogen Accumulation of Wheat	27
III.	The Influence of Rates of Nitrogen Fertilizer on the Nitrate Nitrogen Accumulation of Oats	28
IV.	The Influence of Rates of Nitrogen Fertilizer on the Nitrate Nitrogen Accumulation of Barley	29
V.	The Influence of Rates of Nitrogen Fertilizer on the Nitrate Nitrogen Accumulation of Rye	30
VI.	Rainfall for Crop Year 1 July 1965 - 30 June 1966, Stillwater, Oklahoma	32
VII.	The Influence of Rates of Phosphorus on Nitrate Nitrogen Accumulation in Wheat Forage at Different Dates of Sampling	33
VIII.	The Effect of Fertilization and Date of Sampling on the Concentration of Nitrate Nitrogen, Organic Nitrogen, Phosphorus and Potassium of Wheat Forage and Yield of Grain	38
IX.	Critical NO_3-N, Organic N, P and K Concentrations at Different Dates of Sampling	39

LIST OF FIGURES

Figure		Page
1.	The Effect of DAP, MAP, OSP and CSP on the Emergence of Wheat Seedlings at Temperatures of 15, 20 and 25 C and Under 1 and 3 Bars Moisture Tension	9
2.	Effect of MAP on the Rate of Emergence of Wheat Seedlings at 15 C and 1 Bar Moisture Tension	11
3.	Effect of APP, DAP, and APS on the Emergence of Wheat Seedlings at Temperatures of 15 and 25 C and Under Moisture Tensions of 1 and 3 Bars on a Loam Soil	13
4.	Effect of APP, DAP and APS on the Emergence of Wheat Seedlings at Temperatures of 15 and 25 C and Under Moisture Tensions of 1 and 3 Bars on a Sandy Soil	14
5.	Effect of Rates of Nitrogen on Yield of Grain and Nitrate Nitrogen Content of Forage on Different Dates of Sampling	42
6.	Effect of Rates of Nitrogen on Yield of Grain and Organic Nitrogen Content of Forage on Different Dates of Sampling	43
7.	Effect of Rates of Phosphorus on Yield of Grain and Phosphorus Content of Forage on Different Dates of Sampling	45
8.	Effect of Rates of Potassium on Yield of Grain and Potassium Content of Forage on Different Dates of Sampling	47

CHAPTER I

INTRODUCTION

The research reported in this dissertation is divided into three chapters, each a manuscript prepared for publication in a professional journal. Except for minor modifications, the manuscripts appear just as they will be submitted to journals for publication.

The application of phosphorus in a band with the seed has been common practice in many wheat growing areas. This practice has been encouraged because phosphorus is often more efficiently utilized when placed in close proximity of the seeds. However, when some of the phosphorus sources that are available today are used, especially those with high N/P ratios, germination can be reduced. Severe reductions in germination have been observed on occasion when a particular source is used, but on other occasions the same source is used with no apparent harmful effects. The relative effects of several sources of phosphorus under varying temperature and moisture regimes are discussed in Chapter II.

The effects of nitrogen fertilization on nitrate accumulation of small grain forages are discussed in Chapter III. Small grain crops are frequently used for pasturing of livestock, and nitrate poisoning sometimes causes sickness or death of the livestock. It is a fairly common belief that nitrogen fertilization of these crops results in large enough accumulations of nitrates to cause nitrate poisoning of livestock consuming the forage. Four crops, wheat, oats, rye and barley, were studied under very high fertility conditions to determine the exact relationship between nitrogen fertilization and nitrate accumulation.

The establishment of critical nutrient levels in wheat was the objective of the research reported in Chapter IV. Plant analysis is playing an increasingly important role in diagnosing nutrient deficiencies and evaluating fertilization programs. Critical nutrient levels must be established before this diagnostic tool can be used on a particular crop. These values are established for some crops, mostly those of high cash value or those grown in areas with long histories of fertilization. These values have not previously been established for wheat. The objective of the work reported was to determine the critical nitrogen, phosphorus and potassium contents of winter wheat at several stages of growth.

CHAPTER II

EFFECTS OF SOURCES OF PHOSPHORUS UNDER VARYING SOIL TEMPERATURE AND MOISTURE REGIMES ON THE EMERGENCE OF WINTER WHEAT[1]

J. M. Baker, B. B. Tucker and L. G. Morrill[2]

Abstract

The effects of several sources of phosphorus on the emergence of winter wheat (*Triticum aestivum* L.) were compared when applied in a band with the seed under controlled temperature and moisture conditions. The detrimental effects of a given fertilizer treatment on emergence increased as temperature increased from 15 to 25 C. Increasing soil moisture stress from 1 to 3 bars also reduced emergence. The harmful effects of increasing the temperature from 15 to 25 C were greater than the harmful effects of increasing moisture tension from 1 to 3 bars. Emergence was reduced to a much greater extent on a sandy soil than on a medium textured soil for a given fertilizer treatment. The effects of temperature, moisture and soil texture appeared to be cumulative.

---

[1] Part of a thesis submitted by the senior author in partial fulfillment of the requirement for the Ph.D. Degree, Oklahoma State University, Stillwater, Oklahoma. Presented before Division S-8, Soil Science Society of America, November 1968.

[2] Extension Soil Specialist, Professor and Associate Professor, Agronomy, respectively, Oklahoma State University, Stillwater.

Ammonium polyphosphate, ordinary superphosphate and concentrated superphosphate had approximately equal effects on emergence and were much less detrimental than monoammonium and diammonium phosphate which were about equal. Ammonium phosphate sulfate decreased emergence to a much greater extent than any other source.

Banding of concentrated superphosphate with the seed reduced emergence as much as 40 per cent in the field. This reduced emergence, however, had no effect on yield of grain.

Additional Key Words for Indexing: fertilizer placement, seedling emergence, salt injury and phosphorus sources.

Introduction

Banding of phosphorus fertilizer in the drill row in contact with the seed of small grains is reported by Olsen and Drier (20) to increase the use efficiency of phosphorus. However, it is recognized that this method of application can inhibit or delay germination and resulting in stand reductions.

Several workers (1,3,5,13,20) have reported that the nitrogen and potassium fractions of fertilizers are the components most likely responsible for reduction in germination. On the other hand, Guttay (9) found that phosphorus could be just as deleterious as nitrogen and potassium. Kinra et al. (16) studied the effects of ordinary superphosphate and postulated that the water soluble fluorine in the material was responsible for reductions in germination.

Beaton et al. (2) found that the rate of dissolution of water soluble phosphorus fertilizers increased as temperatures increased.

However, Cummins and Parks (5) reported that temperature had no significant effect on the tolerance of corn and wheat to salt concentration. Chapin and Smith (3) stated that the probability of stand reduction resulting from fertilizer salts increases as the moisture content of the soil decreases. Hood and Ensminger (13) found that the detrimental effect of diammonium phosphate was not merely an osmotic effect since equivalent concentrations of other salts did not reduce germination as much as diammonium phosphate. They stated further that the detrimental effect was not due to ammonia alone since ammonium sulfate did not reduce germination as much as diammonium phosphate. Later, Hood et al. (14) studied the mechanism of ammonium phosphate injury to seeds and found that magnesium sulfate alleviated the harmful effect of ammonium phosphate, indicating that the injury is a result of Mg inactivation.

The objective of the work reported here was to define the effects of rates of several sources of phosphorus on the germination of winter wheat planted in soils of varying texture and under different soil temperature and moisture regimes. The study was divided into three specific experiments. Four phosphate fertilizer sources at three soil temperatures and two moisture levels were compared in the first experiment. In the second experiment, the influence of soil texture was studied as well as soil temperature, soil moisture and phosphate sources. The third experiment was conducted under field conditions to test the validity of conclusions drawn from the phosphate rate studies of Experiments 1 and 2.

Materials and Methods

Experiment #1

Soil samples were collected from the surface of a Norge loam, air dried and passed through a 0.5 cm screen. The soil moisture tension was adjusted to either 1 or 3 bars by adding the required amount of water to the soil and allowing it to equilibrate for 1 week in an air tight container. The soil required 11.13 per cent moisture for 1 bar tension and 7.21 per cent for 3 bars tension.

A layer of soil, 3.75 cm thick, was packed into plastic boxes having inside dimensions of 12.7 x 30 cm and 11 cm deep. Three rows 28 cm long, were equally spaced in the boxes. Fertilizer was applied to each set of 3 rows at rates equivalent to 0, 20, 40 and 60 kg P/ha based on the assumption that each row represented a drill row width of 18 cm. Each set of 3 rows within a box received the same fertilizer treatment. The amount of nitrogen was incidental to the rate of phosphorus applied. Ordinary superphosphate (OSP, 0-9-0), concentrated superphosphate (CSP, 0-24-0), monoammonium phosphate (MAP, 15-25-0) and diammonium phosphate (DAP, 21-23-0) were the four sources applied. Each treatment was replicated three times in a randomized block design. Concentrated superphosphate, MAP and DAP were obtained from the Tennessee Valley Authority, while OSP was obtained from a commercial source. Sixteen seeds of winter wheat (Triticum L., Var. "Kaw") were planted in each row on top of the applied fertilizer. The seeds were then covered with a 1.5 cm layer of soil and packed. An air tight cover made of transparent plastic was placed on the box so the moisture level could be maintained.

The boxes were placed in a Shearer chest-type growth chamber where temperature was thermostatically controlled at either 15, 20 or 25 C. Total darkness was maintained throughout the experiment, except during short periods when plant counts were made.

Experiment #2

The methods and apparatus employed in this experiment were much the same as in Experiment #1.

The effects of rates of diammonium phosphate (DAP, 21-23-0), ammonium phosphate sulfate (APS, 16-9-0) and liquid ammonium polyphosphate (APP, 11-16-0) on the germination and emergence of winter wheat (Triticum aestivum L., Var. Triumph) were compared at 15 and 25 C with soil moisture adjusted to either 1 or 3 bars tension. These treatments were compared on two soil types, the Norge loam and Meno sand. The loam required 11.13 per cent and 7.21 per cent moisture whereas, the sand required 4.9 per cent and 2.4 per cent for the 1 and 3 bars tension, respectively. Ammonium phosphate sulfate was obtained from a commercial source while the other two materials were obtained from the Tennessee Valley Authority. Treatments were replicated four times in a randomized block design.

Experiment #3

A field experiment was established on Grant silt loam to compare concentrated superphosphate broadcasted prior to seeding and banding with the seed at planting time. The placement methods were evaluated by measuring seedling emergence and yield of winter wheat. Rates of 20, 40 and 80 kg P/ha were compared. The material was applied with a

John Deere LZB drill using 35 cm drill spacings. The broadcast treatment was applied to the surface, then disked into the surface 4 inches. The fertilizer was applied with the seed through the same spout and soil opening device.

Plant counts were made on all treatments 3 weeks after planting by counting a 1 meter length of drill row at random locations in each plot. Grain yields were estimated by harvesting 2.7 x 30 meters of each 6 x 30 meter plot.

The treatments were replicated four times in a randomized block design.

Results and Discussion

Experiment #1

The effects of sources of phosphorus on emergence under different temperature and moisture regimes, 21 days after planting, are illustrated in Figure 1. Results are expressed as percent of check, i.e., the percent of the treatment receiving no fertilizer under the same respective moisture and temperature conditions and on the same date of sampling. The absolute emergence of the check, 21 days after planting, was between 85 per cent and 87 per cent, depending on the moisture and temperature conditions. All main effects in this experiment were statistically different at 5 per cent probability level. In addition, all interactions except source X moisture, source X rate X temperature, source X rate X moisture and source X rate X moisture X temperature were also significantly different at the same probability level. The $LSD_{(.05)}$ for this experiment was 13.2 per cent of check,

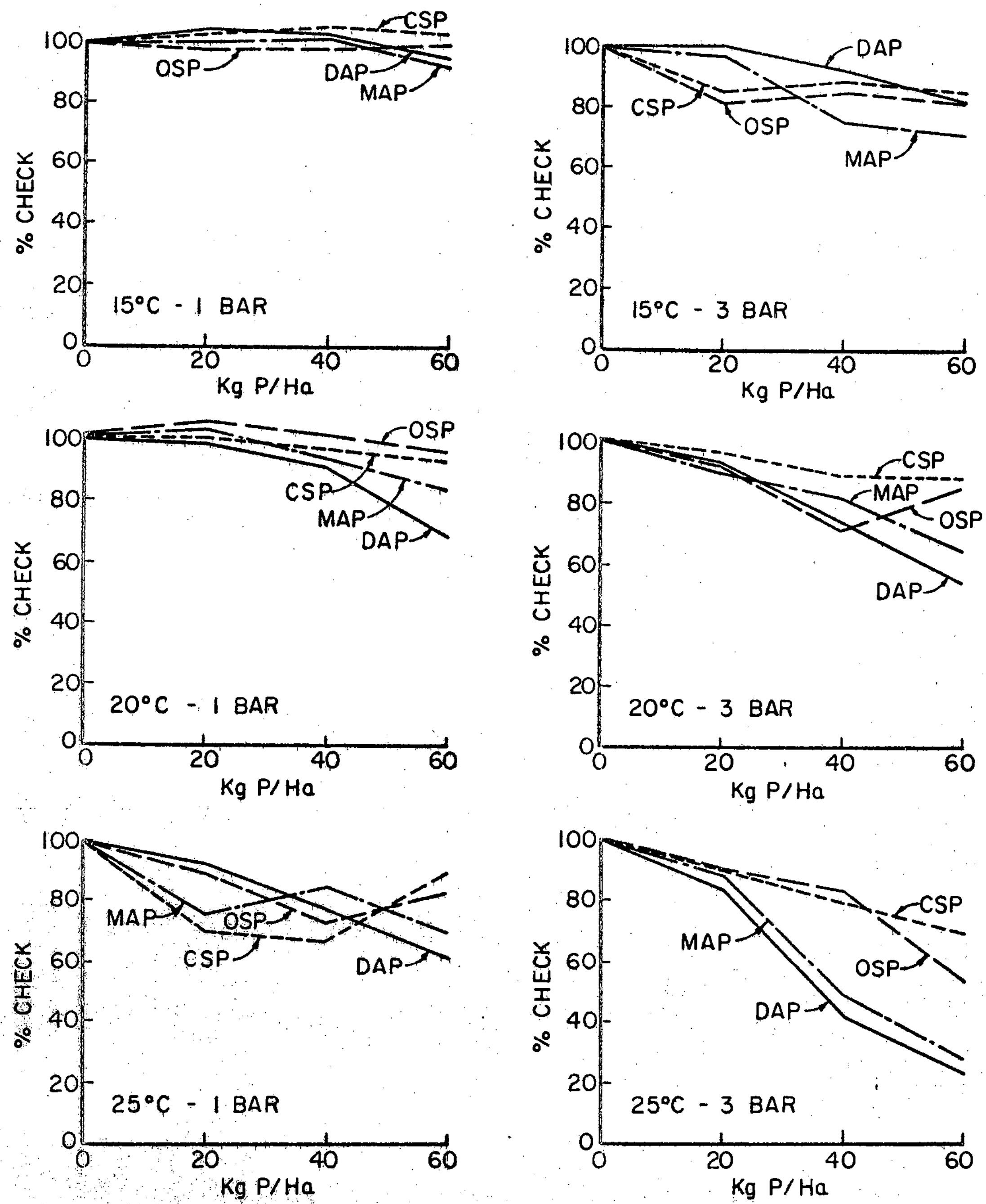

Figure 1. The Effect of DAP, MAP, OSP and CSP on the Emergence of Wheat Seedlings at Temperatures of 15, 20 and 25 C and Under 1 and 3 Bars Moisture Tension.

using the average emergence of all no fertilizer treatments as the basis for computing the LSD.

Emergence usually decreased as temperature increased when other variables were held constant. Little effect on emergence was noted at 15 C and 1 bar moisture tension. However, a general decrease in emergence was observed as the temperature was increased to 20 and 25 C, especially at the higher rates of application. The effects of sources of fertilizer on germination were not well delineated, but it appeared that the ammoniated phosphates reduced emergence to a larger degree than either of the superphosphates. The effects of increasing temperature at 3 bars moisture tension were much more marked. Only a general decrease in emergence, as rates of application increased, was observed at 15 C. The relative effects of sources became apparent as the temperature was increased to 20 and 25 C. The temperature increase resulted in much greater emergence reductions from MAP and DAP than from OSP and CSP. For instance, at 25 C and 3 bars moisture tension, emergence was reduced to only 80-85 per cent of check by OSP and CSP at 40 kg P/ha, while emergence was reduced to 40-50 per cent of check by MAP and DAP. The effects of OSP and CSP appeared to be similar for any given rate, temperature or moisture level, as were the effects of MAP and DAP, but the two groups were quite different from each other, especially under the most severe conditions.

Rate of emergence was often reduced when absolute emergence was relatively unaffected. For example, at 21 days after planting, the check (no fertilizer) and those treatments receiving 20 and 40 kg P/ha in the form of MAP all had about 95 per cent emergence (Fig. 2). At 7 days after planting, however, the treatment receiving no fertilizer

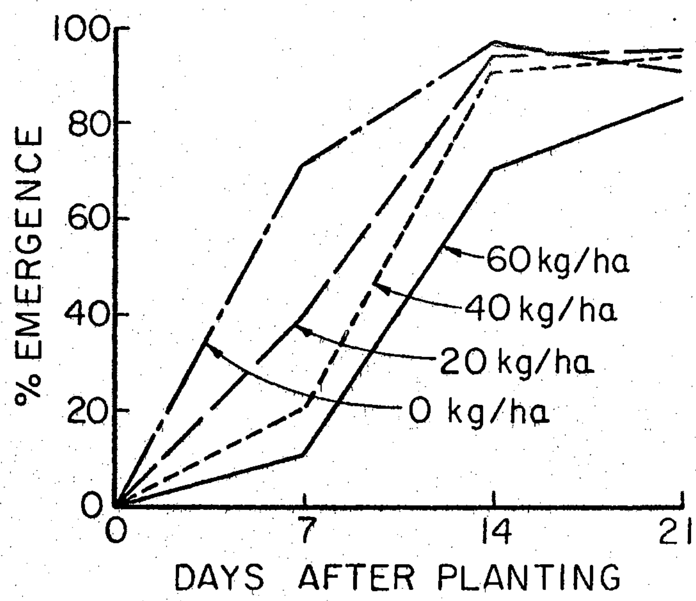

Figure 2. Effect of MAP on the Rate of Emergence of Wheat Seedlings at 15 C and 1 Bar Moisture Tension.

had 70 per cent emergence, whereas the treatment receiving 40 kg P/ha in the form of MAP had only 20 per cent emergence. At 14 days after planting, the check had only a slightly higher emergence than 40 kg P/ha rate. This reduction in the rate of emergence was typical of all sources. Those treatments which had the greatest effect on absolute emergence also had the greatest effect on rate of emergence.

Experiment #2

The results of Experiment 2 are illustrated in Figures 3 and 4. All main effects and interactions were significant at the 5 per cent level except rate X moisture X texture and source X rate X moisture X temperature. The $LSD_{(.05)}$ was 12.2 per cent of check based on the average of all no fertilizer treatments.

Loam Soil

At 20 kg P/ha, emergence was not materially affected on the Loam Soil (Fig. 3) when the temperature was 15 C and the moisture tension was 1 bar, but emergence was reduced slightly by the higher rates of DAP and APS under these conditions. Increasing the moisture tension to 3 bars did not increase the effect of APS and was only slightly reduced by DAP, but emergence was reduced to 83 per cent and 50 per cent of check at the rate of 40 and 60 kg P/ha, respectively, when APS was used as a source of phosphorus. Again, emergence was relatively unaffected by APS and DAP when the temperature was 25 C and moisture tension was 1 bar, but APS resulted in reductions to 83, 58 and 17 per cent of check by 20, 40 and 60 kg P/ha, respectively. The most detrimental environmental condition was 25 C and 3 bars moisture

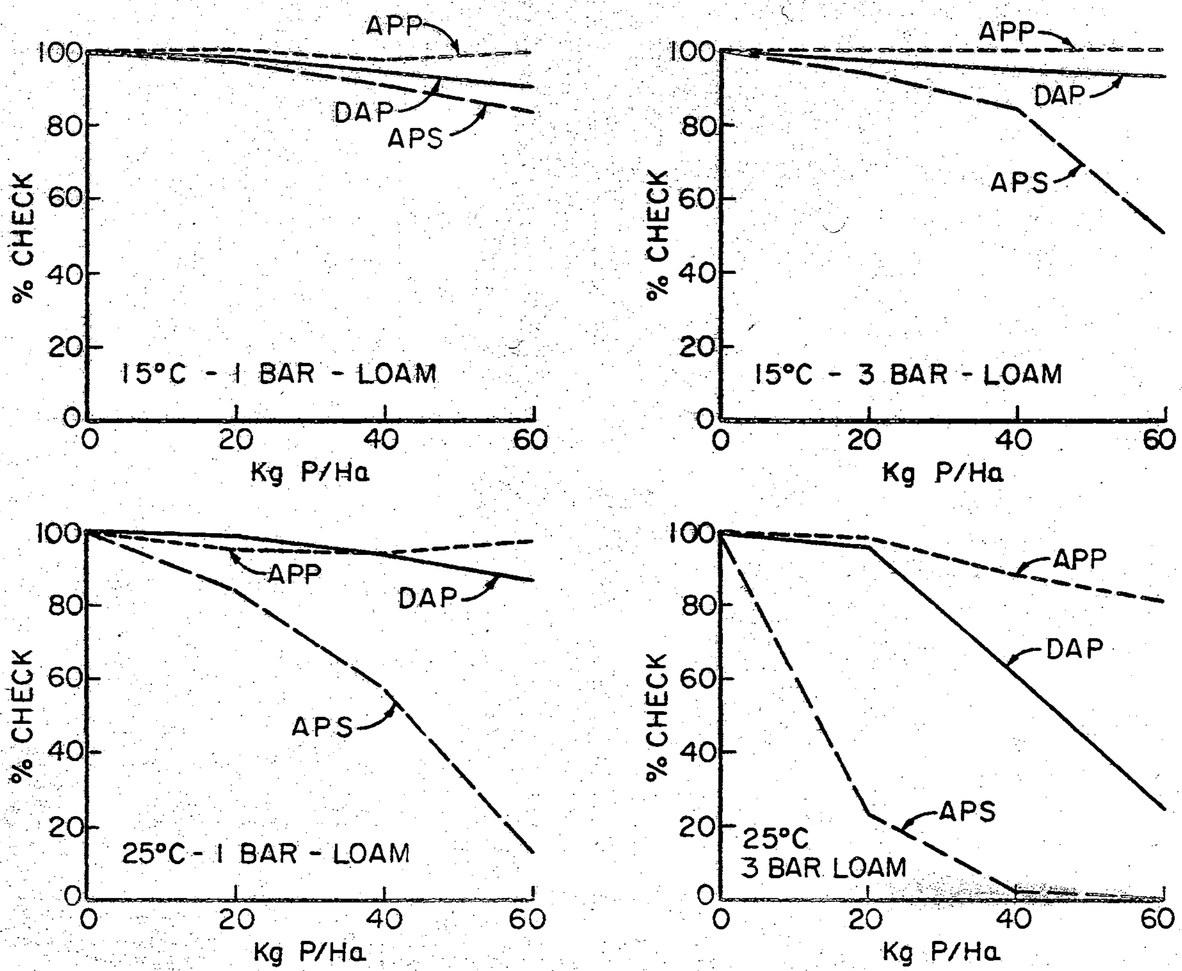

Figure 3. Effect of APP, DAP and APS on the Emergence of Wheat Seedlings at Temperatures of 15 and 25 C and Under Moisture Tensions of 1 and 3 Bars on a Loam Soil.

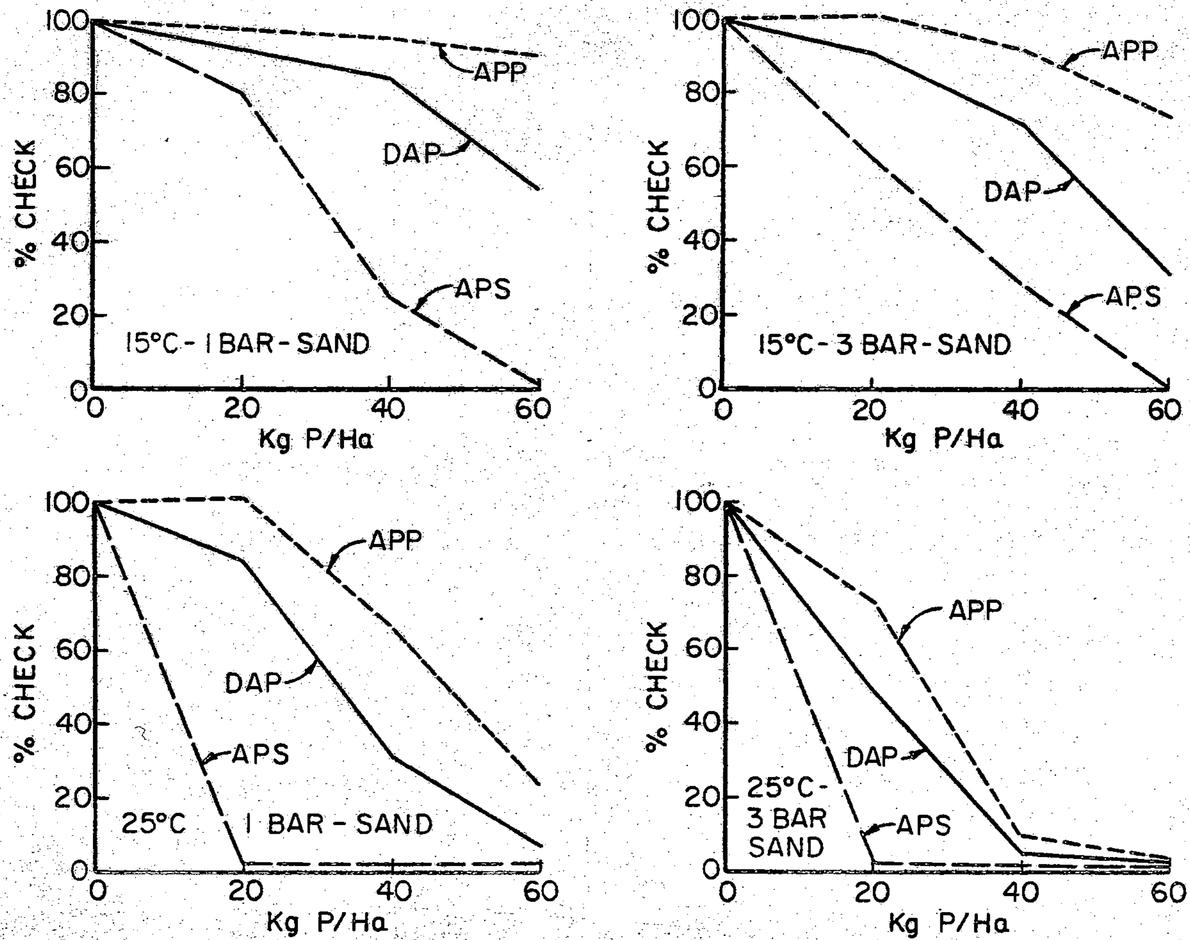

Figure 4. Effect of APP, DAP and APS on the Emergence of Wheat Seedlings at Temperatures of 15 and 25 C and Under Moisture Tensions of 1 and 3 Bars on a Sandy Soil.

tension. All sources reduced emergence under these conditions, although APP only reduced emergence to 92 per cent of check at 40 kg P/ha and 83 per cent of check at 60 kg P/ha. The effects of DAP were not severe at 20 kg P/ha under these conditions, but emergence was reduced to 58 per cent and 22 per cent of check by 40 and 60 kg P/ha. Ammonium phosphate sulfate was even more detrimental. Emergence was reduced to 22 per cent of check at the 20 kg rate, and essentially no emergence occurred at 40 and 60 kg P/ha.

Sandy Soil

For any given treatment, emergence was reduced to a much greater extent on the sandy soil (Fig. 4) than on the loam soil, probably due to the smaller buffering capacity and lower CEC of the sandy soil. Except for being much more drastic on the sandy soil, the effects of moisture and temperature appeared to be the same as on the loam soil.

Emergence was reduced by DAP and APS even under the relatively mild conditions of 15 C and 1 bar moisture tension. Little effect was observed from APP under these conditions. Diammonium phosphate reduced emergence to 96 per cent, 93 per cent and 56 per cent of check while APS reduced it to 81 per cent, 22 per cent and 3 per cent of check at the respective rates of 20, 40 and 60 kg P/ha.

Even APP reduced emergence when the moisture tension was increased to 3 bars, though not nearly as much as DAP and APS. Emergence was reduced only by the 40 and 60 kg rates of APP, while all rates of DAP and APS materially reduced emergence. However, the effects on emergence were not nearly as great at 15 C with 3 bars of moisture tensions as they were at 25 C and 1 bar of tension. Emergence was reduced essentially to 0 by all rates of APS under the latter conditions. Twenty kg P from APP per hectare had no effect on emergence, but 40 and 60 kg/ha reduced emergence to 67 per cent and 28 per cent of check, respectively. The effects of DAP were intermediate to APS and APP under these conditions. All rates of all the sources tested reduced emergence substantially at 25 C and 3 bars moisture tension. Again, APS was the most detrimental and APP the least while DAP was intermediate. Emergence was completely inhibited by all rates of APS. Emergence was reduced to 46 per cent, 5 per cent and 3 per cent of check when 20, 40 and 60 kg P/ha was applied in the form of DAP while APP reduced emergence to 73 per cent, 10 per cent and 4 per cent of check by the same respective rates of application.

The same effects on rate of emergence that were noted in Experiment 1 were also observed in this experiment. Those sources of phosphorus having the greatest effect on absolute emergence also had the greatest effect on rate of emergence.

The combined observations of Experiments 1 and 2 indicate that a ranking of the fertilizer from least to the most detrimental for a given increment of phosphorus would be as follows: APP = OSP = CSP MAP = DAP - APS. Results of both experiments indicate that increasing the temperature from 15 to 25 C is more detrimental than increasing the moisture tension from 1 to 3 bars. Apparently the temperature effects are a result of the increased rate of dissolution of the fertilizer material and the increased activity of the salts in solution.

It should be noted that much better fertilizer-seed contact was established in these experiments than would be expected in the field using conventional equipment. Therefore, even though P rates are quoted on a kg/ha basis, they are probably not strictly comparable to the same rates applied in the field.

Experiment #3

The effects of two methods of applying P in the field on emergence and yields of grain were observed and the results recorded in Table I. Broadcasting and plowing down CSP prior to seeding had no effect on germination. While emergence was reduced substantially by the band application (Table I) yields were not affected by either method. This observation indicates that wheat has some mechanism, presumably increased tillering, to compensate for a 40 per cent reduction in initial stand when a seeding rate of 30 kg/ha was used.

TABLE I

EFFECT OF BROADCAST VERSUS BANDING CSP WITH THE SEED ON SEEDLING EMERGENCE AND YIELD OF WHEAT

	Broadcast		Band with Seed	
Rate kg P/ha	Emergence % Check	Yield kg/ha	Emergence % Check	Yield kg/ha
20	101.0	2900	97.0	3088
40	98.0	2996	83.0	2838
80	102.0	2798	60.0	2937

Check = 100% Emergence and 2963 kg grain/ha.

Yields: Not statistically different. Calculated F = 0.80.

Emergence: Statistically different at 1% probability level. Calculated F = 24.54.

Summary

The effects of any given fertilizer treatment on seedling emergence were dependent on temperature, moisture and soil texture. Emergence was usually reduced as temperature was increased from 15 to 25 C. A reduction in emergence was also observed when the soil moisture tension was increased from 1 to 3 bars. Soil texture was a very important factor, for emergence was consistently reduced to a greater extent on the sandy textured soil than on the medium textured soil. The effects of temperature, moisture and soil texture were cumulative.

All of the phosphate sources tested had some effect on emergence under the most severe conditions. Comparisons made on a loam soil indicated that APP, OSP and CSP affected emergence less than the other sources. The effect of these sources was relatively small except when the temperature was 25 C and moisture tension was 3 bars. Monoammonium phosphate and DAP were ranked next in severity, followed by APS which was extremely detrimental in almost all cases. Monoammonium phosphate and DAP resulted in a substantial reduction in emergence on the loam soil even at the lower rates of application, when the temperature was 25 C and water tension was 3 bars. Diammonium phosphate and APS reduced emergence even under the most favorable conditions when applied to a sandy soil. While APP was much less severe than DAP or APS, it too resulted in large reductions in emergence on the sandy soil.

Concentrated superphosphate resulted in a decrease in emergence when banded with the seed under field conditions. Broadcasting the material had no effect on emergence. Even though emergence was reduced 40 per cent by 80 kg P/ha, yields of grain were unaffected. This observation suggests that some reduction in emergence can be tolerated without any detrimental effects on grain yields when a seeding rate of 30 kg/ha is used and when good tillering conditions prevail.

CHAPTER III

THE EFFECTS OF RATES OF NITROGEN AND PHOSPHORUS ON THE ACCUMULATION OF NO_3-N IN WHEAT, OATS, RYE AND BARLEY ON DIFFERENT SAMPLING DATES[1/]

J. M. Baker and B. B. Tucker[2/]

Abstract

The NO_3-N concentration of wheat, oats, rye and barley forage was found to be a function of rate of nitrogen fertilization, phosphorus fertilization and date of sampling. The crops were not very different with respect to NO_3-N accumulation though barley and wheat appeared to accumulate more nitrates than rye or oats during periods of highest concentration. Nitrate-nitrogen concentrations were highest in samples collected 18 and 24 March when the plants were in the "joint" or "preboot" stage of growth. Concentrations greater than 3500 ppm were not uncommon in barley and wheat samples collected at these two stages of growth whereas, oat and rye samples never exceeded 3500 ppm. The NO_3-N concentrations rarely exceeded the potentially toxic level of 2100 ppm when 90 kg/ha or less nitrogen was applied, a rate that is

[1/]Part of a thesis submitted by the senior author in partial fulfillment of the requirement for the Ph.D. Degree, Oklahoma State University, Stillwater.

[2/]Extension Soil Specialist and Professor of Agronomy, respectively, Oklahoma State University, Stillwater.

as high as is typically applied to dryland winter wheat. Sub-lethal levels, 700 ppm or greater, were commonly found even at the lower rates of nitrogen application in samples collected 18 and 24 March. The NO_3-N concentration declined sharply after the 24 March sampling date and continued to decline through the 13 April sampling date. A slight increase in concentration appeared late in the season, especially in oats.

The tendency for NO_3-N accumulation was also found to be enhanced by a deficiency of phosphorus. The concentration in wheat forage was reduced from 1273 ppm to 284 ppm NO_3-N with the application of 15 kg/ha phosphorus. Phosphorus fertilization for maximum grain production appeared to be adequate for maintaining low NO_3-N levels in the forage.

Additional Key Words: nitrate toxicity, forage quality.

Introduction and Literature Review

The utilization of the forage of small grain crops is playing an increasingly important role in their production and management. The large number of annual livestock losses reportedly resulting from nitrate poisoning of animals grazing small grain pastures makes it imperative that the factors affecting nitrate accumulation in the forages of these crops be evaluated.

Oats, wheat, rye and barley are generally considered to be accumulators of nitrate (4,8,22). Several factors are known to affect the degree to which these crops will accumulate nitrates. One of the most obvious factors is the nitrogen level of the soil. Several researchers have shown that nitrogen fertilization increases the concentration of nitrates in plants that tend to accumulate nitrates (4,6,7,19). In addition, it has been shown that fewer nitrates accumulate when plants are supplied with ammonical nitrogen instead of nitrate nitrogen. Solid forms of nitrogen resulted in higher nitrate concentrations in ryegrass than liquid forms for a given rate and stage of growth. Deficiencies of nutrients other than nitrogen, particularly those involved in protein synthesis, often result in unusually high accumulations of nitrates due to limitations on assimilatory processes. As an example, high nitrates are often associated with deficiencies of phosphorus (22). Molybdenum, manganese, and sulfur deficiencies have been shown to cause accumulation of nitrates (9,22,24).

Stage of growth is recognized to be one of the most important factors affecting nitrate concentration in small grain crops. Some have reported that the nitrate level declines as the plant matures (4,7,8). It has been reported that nitrate concentration in oats tends to reach a peak in mid-January and declines as the plant matures. The plant parts also vary in their nitrate concentrates. Stems of small grain crops consistently contain higher nitrate levels than the leaves (4,24).

Another factor known to influence nitrate accumulation is light intensity. Marked increases in nitrates were demonstrated in oats when the plants were shaded (4). This is reported not to be as great when ammonical sources of fertilizers are used, presumably because of the energy requirement for nitrate reduction. Nitrate accumulations are also often associated with limited moisture conditions (24), especially when the plants are intermittently stressed for water.

Nitrate-nitrogen levels of 2100 ppm on a dry weight basis are considered potentially toxic with possible sub-lethal effects occurring with as little as 700 ppm nitrate-nitrogen (22). These values are not absolute since whether or not poisoning will occur depends, not only on the concentration of nitrates in theforage, but also, on the rate of intake and conditions within the animals' rumen that favor the reduction of nitrates to nitrites (10,22).

The objectives of the experiments reported in this paper were to establish the maximum amounts of nitrates that oats, wheat, rye, and barley would accumulate as a result of high nitrogen fertilization rates.

Rates of nitrogen fertilization much greater than ordinarily used were applied in order to establish the full nitrate accumulation response curve. The effects of phosphorus fertilization on the nitrate accumulation in wheat forage was also studied on a phosphorus deficient soil.

Materials and Methods

Four adjacent field experiments, each representing a different small grain crop, were conducted on a Kirkland silt loam soil at the Agronomy Research Station, Stillwater, Oklahoma. The plot size was 2.3 x 7 meters. The plots were arranged in a randomized block design with three replications.

The four small grain crops used were winter wheat (Triticum aestivum L., Var. Tascosa), winter oats (Avena sativa L., Var. Cimarron), rye (Secale cereale L., Var. Elbon) and barley (Hordeum vulgare L., Var. Will). Fertilizer treatments were applied on

15 August through the seed box of a 2.3 meter grain drill. The entire area was treated with 30 kg/ha phosphorus and 30 kg/ha potassium. Nitrogen rates of 0, 45, 90, 180, 360, 720 and 1440 kg/ha were compared. All fertilizer was applied on the surface and disked into the surface 7 cm of soil. All of the small grain crops were planted on 1 October, subsequent to a 10.0 cm rain.

A composite sample of three strips of drill row, 50 cm in length and selected at random, was collected from each plot at intervals throughout the growing season. The entire above ground portion of the plant was collected. Samples were collected on nine different dates, starting 3 December and ending 13 May. The length of the interval between sampling was not consistent due to occasional inclement weather conditions. Sampling dates were as follows: 3 December, 15 January, 4 February, 18 March, 24 March, 7 April, 13 April, 21 April and 13 May. Regrowth of plants previously sampled was not sampled again.

In addition to the above, samples of winter wheat (*Triticum aestivum* L., Var. Tascosa) were collected from an existing soil fertility experiment on the Eastern Oklahoma Pasture Research Station, Muskogee, Oklahoma, where severe phosphorus deficiencies were known to occur. Samples collected from these plots were used to study the effects of rates of phosphorus on the accumulation of nitrate-nitrogen. Samples were collected 2 February, 6 March, 15 March and 21 March. Sampling techniques used in this experiment were the same as those used in the above experiments. Grain yields were also obtained by harvesting a 2.5 x 25 meter strip out of 7 x 25 meter plots using a self-propelled combine. All plots were treated with 35 kg/ha of potassium applied prior to planting and 90 kg/ha nitrogen applied 15 February, except one plot which received no fertilizer. Phosphorus rates of 15, 30 and 45 kg/ha were applied prior to planting. A randomized block design with four replications was used in this experiment.

Immediately after collection, forage samples from all experiments were dried in a forced air oven at 80 C. They were then processed in a macro-Wiley mill to pass through a 20 mesh sieve. The procedure for determining the nitrate-nitrogen content of theforage was that of Johnson and Ulrich (15), except that the steps in this procedure for eliminating the effects of chlorides were not included.

An analysis of variance was conducted on the data from each of the experiments.

Results and Discussion

The rate of germination and emergence was severely reduced by the higher rates of nitrogen, especially by the 360, 720 and 1440 kg/ha rates. In most cases, stand densities were not as high under these nitrogen treatments as with the lower rates. However, by 3 December, enough forage was produced under all treatments for sampling. The high nitrogen rates appeared to affect the stands of oats and wheat to a larger degree than rye and barley. Consequently, the effects of nitrogen on nitrate accumulation are confounded with any effects of stand density. This could possibly account for the higher coefficients of variability associated with comparisons of nitrogen on oats and wheat (65.0 and 30.0 per cent, respectively) than was found with the same comparisons on rye and barley (10.0 and 20.0 per cent, respectively).

The degree to which nitrates accumulated was a function of both time of sampling and rate of nitrogen applied with all of the crops. In general, all of the crops were affected in a very similar manner by both date of sampling and by rate of nitrogen. The effects of both of these variables were statistically significant at the 1 per cent level of probability except the effect of nitrogen on oats which was significant at the 5 per cent level of probability.

All four of the small grain crops had accumulated a higher level of NO_3-N in samples collected 3 December than the two subsequent sampling dates of 15 January and 4 February. Accumulations appeared to be greater in wheat (Table II), oats (Table III), barley (Table IV), and rye (Table V) during the early stages of growth. Levels as high as 1400 ppm NO_3-N were found in rye and barley in samples collected 3 December as opposed to levels no higher than 1000 ppm in oats and wheat. Accumulations generally increased as rate of nitrogen increased. While a general decline in NO_3-N was observed in all crops sampled 15 January as compared to the earlier date, rye and barley did not decline to the same level as oats and wheat. This decline continued through the 4 February date of sampling. The NO_3-N level never reached the potentially toxic level of 2100 ppm during the first three sampling dates even with the highest rates of nitrogen. However, sub-lethal levels of NO_3-N (700 ppm) were attained by all four of the crops on the December sampling date.

A sharp increase in NO_3-N concentration was observed in samples collected 18 and 24 March. The plants were in a "joint" or "pre-boot" stage of growth. All of the crops surpassed the potentially toxic levels of 2100 ppm. Concentrations appeared to be higher in wheat and

TABLE II

THE INFLUENCE OF RATES OF NITROGEN FERTILIZER ON THE NITRATE-NITROGEN ACCUMULATION IN WHEAT
(Results reported in ppm NO_3-N)

	Rates of Nitrogen Applied (kg/ha)						
Sampling Date	0	45	90	180	360	720	1440
3 Dec	210	362	198	962	408	688	467
15 Jan	35	52	12	12	52	47	156
4 Feb	58	35	35	58	82	35	140
18 Mar	1715	1482	2182	1447	3337	3628	3080
24 Mar	1202	1750	1015	2473	3582	3815	2800
7 Apr	70	82	105	350	712	653	1435
13 Apr	163	58	47	128	268	475	2345
21 Apr	58	70	93	152	233	455	1662
13 May	61	79	96	210	227	227	490

Dates: $F_{cal} = 29.1$**

Nitrogen: $F_{cal} = 8.0$**

CV = 30.0%

**Significant at 1% level.

TABLE III

THE INFLUENCE OF RATES OF NITROGEN FERTILIZER ON THE NITRATE-NITROGEN ACCUMULATION IN OATS (Results reported in ppm NO_3-N)

	Rates of Nitrogen Applied (kg/ha)						
Sampling Date	0	45	90	180	360	720	1440
3 Dec	373	128	782	700	665	1027	992
15 Jan	70	175	210	152	187	327	315
4 Feb	47	58	93	152	210	198	280
18 Mar	175	1505	922	2018	1412	1913	2523
24 Mar	513	1773	1540	898	2065	2648	4002
7 Apr	117	397	455	385	478	595	1458
13 Apr	245	408	490	292	537	607	2415
21 Apr	233	618	887	537	840	1108	2578
13 May	1143	735	315	280	1668	1097	1575

Dates: $F_{cal} = 11.5$**

Nitrogen: $F_{cal} = 3.37$*

CV = 65.0%

*Significant at 5% level.

**Significant at 1% level.

TABLE IV

THE INFLUENCE OF RATES OF NITROGEN FERTILIZER ON THE NITRATE-NITROGEN ACCUMULATION IN BARLEY (Results reported in ppm NO_3-N)

	Rates of Nitrogen Applied (kg/ha)						
Sampling Date	0	45	90	180	360	720	1440
3 Dec	628	840	513	572	782	992	1377
15 Jan	502	198	548	583	525	805	607
4 Feb	23	175	82	82	233	222	163
18 Mar	1470	502	1645	3162	3267	2065	1552
24 Mar	280	58	1295	3383	4492	5075	5833
7 Apr	23	58	373	560	1657	2310	2952
13 Apr	82	35	175	338	87	1598	1855
21 Apr	362	647	47	1143	782	910	1505
13 May	82	82	338	432	665	1517	2310

Dates: $F_{cal} = 52.3$**

Nitrogen: $F_{cal} = 36.5$**

CV = 10.0%

**Significant at 1% level.

TABLE V

THE INFLUENCE OF RATES OF NITROGEN FERTILIZER ON THE NITRATE-NITROGEN ACCUMULATION IN RYE
(Results reported in ppm NO_3-N)

	Rates of Nitrogen Applied (kg/ha)						
Sampling Date	0	45	90	180	360	720	1440
3 Dec	595	490	478	1015	1073	1342	1412
15 Jan	222	303	432	432	420	350	443
4 Feb	117	117	187	187	140	233	303
18 Mar	1668	1458	2053	1003	1225	2777	3150
24 Mar	1067	128	303	1178	1165	3442	4900
7 Apr	350	82	105	350	1027	980	1680
13 Apr	443	93	82	152	175	187	303
21 Apr	35	303	82	257	817	432	1738
13 May	58	82	23	443	513	1027	1563

Dates: $F_{cal} = 53.9$**

Nitrogen: $F_{cal} = 20.6$**

CV = 20.0%

**Significant at 1% level.

barley, where levels in excess of 3500 ppm were not uncommon, than in oats and rye where 3500 ppm was never exceeded. Sub-lethal levels of NO_3-N were noted at these stages of growth even at the lower levels of nitrogen application. Concentrations appeared to be the greatest in barley followed by wheat with no apparent differences between the concentrations found in oats and rye. In most cases, the potentially toxic level of 2100 ppm was exceeded only when nitrogen rates of 180 kg/ha or more was applied. Apparently, the plants were very active in their uptake of NO_3 at this stage of growth, but the NO_3 reduction processes were limited.

A notable decrease in NO_3-N concentrations was observed in samples collected 7 April. Seed formation had begun by this time and the NO_3-N obviously was converted to the amine form for assimilation into protein. The NO_3-N had declined to a point below the potentially lethal level in all cases though sub-lethal levels were still present in some cases where the higher rates of nitrogen were applied. The concentration in the oat forage never declined to the same extent as was observed in wheat, barley and rye at the lower rates of nitrogen application. The decline was greatest in wheat samples, especially at rates of nitrogen below 180 kg/ha. The decline continued through the 13 April sampling date, however, a slight increase in concentration was observed in samples collected 21 April and 13 May. This increase late in the growing season was especially apparent when rates of nitrogen greater than 180 kg/ha were applied.

The unusually high NO_3-N concentrations might partially be attributed to the plants being subjected to moisture stress during the growing season. Rainfall between 1 July and 1 April was 12.6 cm less than the long term average of 62.1 cm for the same period (Table VI). In addition, one very large rainstorm of 9.0 cm occurred during September, a major part of which was lost to runoff. Also, the high rates of nitrogen probably resulted in higher soil moisture tension because of a salt effect.

TABLE VI

RAINFALL FOR CROP YEAR 1 JULY 1965 - 30 JUNE 1966
STILLWATER, OKLAHOMA

Month	Rainfall (cm)	Deviation From Normal (cm)	Accumulated Deviation From Normal (cm)
Jul	4.4	-4.6	-4.6
Aug	6.8	-1.4	-6.0
Sep	16.5	7.9	1.9
Oct	1.3	-5.7	-3.8
Nov	0.1	-4.6	-8.4
Dec	5.7	2.3	-6.1
Jan	0.5	-2.5	-8.6
Feb	3.8	0.3	-8.3
Mar	0.4	-4.3	-12.6
Apr	6.1	-1.2	-13.8
May	8.8	-2.9	-16.7
Jun	9.5	-1.2	-17.9

Phosphorus was also found to be an important factor affecting NO_3-N accumulation in wheat forage (Table VII). Phosphorus had no substantial effect on the concentration of nitrates in samples collected 2 February, however, the addition of phosphorus greatly reduced the amount of NO_3-N in samples collected during March. Nitrates did not accumulate when both nitrogen and phosphorus were limited, but with the addition of 90 kg/ha nitrogen and no phosphorus the NO_3-N content of the forage became as high as 1273 ppm on 15 March. The concentration was decreased to 284 ppm NO_3-N with the addition of a mere 15 kg/ha phosphorus. The addition of 30 and 45 kg/ha of phosphorus had only a slight additional affect on samples collected 15 March. The nitrate concentrations in plants receiving 45 kg/ha phosphorus, on the other hand, were considerably lower, on the 21 March sampling date, than in those receiving 15 and 30 kg/ha phosphorus. Yields of grain were inversely related to the NO_3-N concentration of the forage. The highest yeild was obtained with the addition of 45 kg/ha phosphorus. This would indicate that the NO_3-N level of the forage would be minimized if the crop received enough phosphorus for maximum yield.

TABLE VII

THE INFLUENCE OF RATES OF PHOSPHORUS ON NO_3-N ACCUMULATION IN WHEAT FORAGE AT DIFFERENT DATES OF SAMPLING

Rate (kg/ha)	NO_3-N Concentration (ppm)				Yield
N P K	2 Feb	6 Mar	15 Mar	21 Mar	kg/ha
00-00-00	258	193	250	394	1693
90-00-35	311	752	1273	910	1478
90-15-35	455	236	284	648	3196
90-30-35	464	232	228	608	3427
90-45-35	315	202	223	354	3615

Effect of P application on yield: significant at 1% level.

Effect of P application on NO_3-N accumulation: significant at 1% level.

Effect of date of sampling on NO_3-N accumulation: significant at 1% level.

CHAPTER IV

CRITICAL N, P AND K LEVELS IN WINTER WHEAT[1/]

J. M. Baker, B. B. Tucker and L. G. Morrill[2/]

Abstract

Rates and combinations of N, P and K were applied to a soil known to be deficient in these nutrients in order to study the critical nutrient concentration at different stages of growth.

Samples of forage were collected 1 December, 17 January, 15 March and 27 March and were analyzed for nitrate-nitrogen, organic nitrogen, phosphorus and potassium. The forage content of the major nutrient elements was then related to yield of grain so that the critical concentrations could be estimated. The concentration of a given nutrient in the forage collected from the fertilizer treatment producing 90 to 100 per cent maximum yield was termed the critical level.

The NO_3-N content of the forage did not vary with nitrogen fertilizer applications in samples collected 1 December and 17 January, therefore, no critical concentration could be established for those dates. The nitrate-nitrogen level increased with nitrogen

[1/]Part of a thesis submitted by the senior author in partial fulfillment of the requirement for the Ph.D. Degree, Oklahoma State University, Stillwater, Oklahoma. Presented before Division S-8, Soil Science Society of America, November 1968.

[2/]Extension Soil Specialist, Professor and Associate Professor, Agronomy, respectively, Oklahoma State University, Stillwater.

application in samples collected 15 March and 27 March. The critical concentration for these dates was 350 ppm. Organic N, like NO_3-N, did not increase in samples collected 1 December and 17 January with the application of N, but did in samples collected 15 and 27 March. The critical concentration of organic N was 4.5 per cent.

The concentration of phosphorus in the forage throughout the sampling period was the most consistent of the nutrients tested. It did not change materially from one sampling date to another. A very good relationship between rate of P application and concentration of P in the forage and yeilds of grain was found. The critical concentration of P for all sampling dates was .45 per cent.

The critical concentration of K was the most difficult to establish since the effect of date of sampling was large. The critical concentration of K was 3.0 per cent on 1 December, 2.2 per cent on 17 January, 2.5 per cent on 15 March and 3.0 per cent on 27 March.

The effect of P application on NO_3-N accumulation was also observed to be large. Nitrate-nitrogen tended to accumulate to a much larger degree when P was deficient than when P fertilizer was applied.

Additional Index Words: threshold values, plant analysis, tissue analysis.

Introduction

The critical nutrient levels of several crops are fairly well established. For the most part, these crops are high value crops such as horticultural crops, corn, cotton, etc. For other crops, this information is often limited. The critical nutrient levels of wheat, for example, have not been very well established. The objective of this study was to define the critical N, P and K concentrations in winter wheat at several stages of growth.

Critical concentration has been defined several ways, but perhaps the most appropriate definition is that concentration of a given form of a specified nutrient within a specified plant part at which plant growth begins to decline (23).

It is well established that the concentration of a nutrient varies with the stage of growth of the plant and the plant part sampled (11, 12). Therefore, for proper interpretation of a plant analyses it is imperative that the critical concentration be established for a specified plant part at a specified stage of growth.

Small grain crops are generally considered to be accumulators of nitrate-nitrogen (4). The degree of accumulation is a function of the amount of nitrogen supplied and the time of sampling (18). However, nitrate accumulation is also known to be associated with a deficiency of phosphorus (22). The fact that the concentration does increase with increasing nitrogen fertility does indicate that it could possibly be used for diagnostic purposes.

The relationship of phosphorus and potassium fertility and their accumulation in wheat is not as well established as the relationship between nitrogen fertility and nitrate accumulation. In corn, however, both phosphorus and potassium concentrations increased in all plant parts as fertilization with these nutrients increased. In general, the concentration in all the plant parts was greatest at about the time of silking, except in the grain (11).

The critical concentration of nitrogen, phosphorus and potassium in wheat has recently been reported (17). The critical level of nitrogen was 2.6 per cent, phosphorus 0.30 per cent and potassium 1.8 per cent when the whole plant was sampled at the boot stage of growth.

Materials and Methods

Experimental field plots were established on a Parson clay loam soil in Eastern Oklahoma. The soil was selected because it was known to be very deficient in nitrogen and phosphorus and borderline in the case of potassium. It contained 5 ppm P, as indicated by extracting with a 20:1 ratio of Bray 1 extractant to soil, and 55 ppm exchangeable K.

The treatments (7x30 meters) were arranged in an incomplete factorial using a randomized block design with four replications. Rates and combinations of N, P and K (Table VIII) were applied prior to planting. The fertilizer was broadcast and disked into the soil immediately prior to the seeding of winter wheat (*Triticum aestivum* L.) on 17 October.

Plant samples were collected from each plot on four different sampling dates. Dates of sampling were 1 December, 17 January, 15 March and 27 March. The entire above ground portion of the plant was collected for analysis. The samples were dried immediately after collection at 80 C. The samples were then prepared for analysis by grinding in a macro-Wiley mill to pass through a 20 mesh sieve.

Nitrate-nitrogen determinations were made using the procedure described by Johnson and Ulrich (15) for samples containing low

TABLE VIII

THE EFFECTS OF FERTILIZATION AND DATE OF SAMPLING ON THE CONCENTRATION OF NO_3-N, ORGANIC N, PHOSPHORUS AND POTASSIUM OF WHEAT FORAGE AND A YIELD OF GRAIN[3]

Treat- ment #	Treatment kg/ha N P K	December 1				January 17				March 15				March 27				Yield kg/ha
		PPM NO_3-N	% N	% P	% K	PPM NO_3-N	% N	% P	% K	PPM NO_3-N	% N	% P	% K	PPM NO_3-N	% N	% P	% K	
1	00-30-40	372	4.9	.49	2.9	302	4.5	.40	2.1	122	4.5	.46	2.6	197	3.6	.48	3.0	2076
2	40-30-40	389	4.7	.39	2.6	337	4.8	.48	2.5	148	4.6	.43	2.7	180	3.8	.45	3.2	3111
3	80-30-40	464	4.7	.39	3.0	258	4.7	.45	2.3	228	4.8	.41	2.5	315	4.5	.43	3.0	3286
4	120-30-40	550	4.3	.31	2.7	363	4.1	.45	2.5	412	5.6	.44	2.9	411	5.0	.39	3.0	3427
5	80-00-40	311	3.6	.21	1.8	228	3.5	.24	1.8	1273	5.0	.28	2.6	810	4.8	.34	3.3	1478
6	80-15-40	455	4.4	.32	2.8	306	4.6	.38	2.4	284	5.1	.32	2.8	385	4.7	.37	3.2	3198
7	80-45-40	315	5.0	.46	2.7	298	4.8	.50	2.2	223	5.0	.50	2.4	188	4.2	.52	2.8	3615
8	80-30-00	332	4.6	.35	2.5	513	5.1	.48	2.1	276	5.1	.45	1.0	319	4.7	.47	2.4	3044
9	80-30-80	390	4.8	.38	3.3	411	4.9	.46	2.5	245	5.0	.42	1.7	228	4.3	.40	3.0	3433
10	00-00-00	258	4.0	.29	2.4	197	3.2	.27	1.7	250	5.4	.32	2.7	284	4.6	.34	3.2	1693
11	120-45-00	473	5.0	.42	3.0	311	4.7	.51	2.4	236	5.3	.47	2.7	416	4.9	.45	3.0	3454
12	120-45-00	415	5.1	.46	2.3	299	4.8	.51	2.3	412	5.3	.46	2.4	381	4.7	.45	2.6	3003
	$LSD_{(.05)}$	185	.53	.07	.56	150	.93	.09	.43	297	.68	.06	.35	279	.42	.06	.47	299
	F_{cal}	1.08	6.0	12.7	4.0	1.4	3.3	7.5	2.8	8.8	1.9	11.6	3.8	3.1	8.6	7.5	2.8	53.0

$F_{tab(.05)} = 2.12$

chloride levels. Kjeldahl nitrogen, exclusive of nitrate-nitrogen, was also determined. Phosphorus and potassium determinations were made on samples digested in nitro-perchloric acid. Phosphorus was determined colorimetrically using the hydrozine sulfate procedure described by Shelton and Harper (21). Potassium was quantized by flame emission. Yield of grain was obtained by harvesting a 3x30 meter strip from the middle of each plot with a self-propelled combine.

The critical concentration for each date of sampling is designated as the concentration in the plant resulting from the fertilizer treatment which gave 90 to 100 per cent maximum yield. The interactions of the nutrients, i.e., the effect of the application of one nutrient on the concentration of another in the plant tissue were also studied.

The main effects of N are illustrated by treatments 1, 2, 3 and 4 of Table IX. Main effects of phosphorus and potassium are illustrated in the same table by treatments 5, 6, 3 and 7 and by 8, 3 and 9, respectively.

TABLE IX

CRITICAL NO_3-N, ORGANIC N, P AND K CONCENTRATIONS AT DIFFERENT DATES OF SAMPLING

	Critical Nutrient Concentrations			
	1 Dec	17 Jan	15 Mar	27 Mar
NO_3-N (ppm)	425	No Value	350	350
Organic N (%)	No Value	No Value	4.5	4.5
Phosphorus (%)	.45	.45	.45	.45
Potassium (%)	3.0	2.2	2.5	3.0

A statistical analysis of variance was conducted on the concentration of each nutrient on each harvest date and on yields of grain.

Results and Discussion

Grain yields were increased by the addition of all three fertilizer elements: N, P and K. Also, in general, the concentration of a given nutrient increased in the plant tissue as the rate of application of that nutrient increased. Since both yield of grain and the concentration of a nutrient in plant tissue are related to the rate of application of that nutrient, it is logical to assume that yields are related to the concentration of the nutrient in the plant sample. Based on this assumption, it should then be possible to establish critical nutrient levels for grain production. However, since the concentration of the nutrients varied not only with rate of application but also with date of sampling, it is obviously necessary that either critical levels be established throughout the growing season or the plant samples must be collected at a specified stage of growth. The results also indicate that the concentration of a nutrient in the plant tissue can be a function of not only the application rate of the nutrient in question but also the application of other nutrients.

Nitrogen

Yields of grain were maximized at the 80 kg N/ha in this experiment since the yields from the 120 kg application were not statistically different at the 5 per cent level. Two nitrogen fractions, NO_3-N and organic nitrogen, in the plant samples were related to yields to determine which fraction could best be used for predicting the nitrogen status of the plants.

The effects of nitrogen application on the NO_3-N and organic N content of the forage samples and on yields of grain are illustrated by treatments 1-4 of Table VIII or by Figures 5 and 6. In general, the NO_3-N content of the forage decreased as the season progressed. This was not as apparent with organic N except at the 0 and 40 kg N application rates in samples collected 27 March.

The NO_3-N content of the forage samples collected 1 December increased as the rate of nitrogen application increased (Figure 5). This was not evident in samples collected 17 January. The NO_3-N analysis reflected the rate of nitrogen application best in samples collected 15 March and 27 March, a period when the nitrogen demand by plants is greatest. The latter two dates of sampling would then be superior to the earlier dates of sampling. The slopes of the curves representing NO_3-N versus rate of nitrogen application were greater on these dates than earlier dates.

The organic N content of the forage samples collected 1 December and 17 January did not increase as the rate of nitrogen application increased, but samples collected 15 March and, especially, 27 March did reflect the rate of nitrogen application (Fig. 6). The NO_3-N content of the samples collected 27 March increased almost linearly as the rate of nitrogen increased. This would then be the best date of sampling that could be used for predictive purposes, whereas, the samples collected 1 December and 17 January would have no value for prediction.

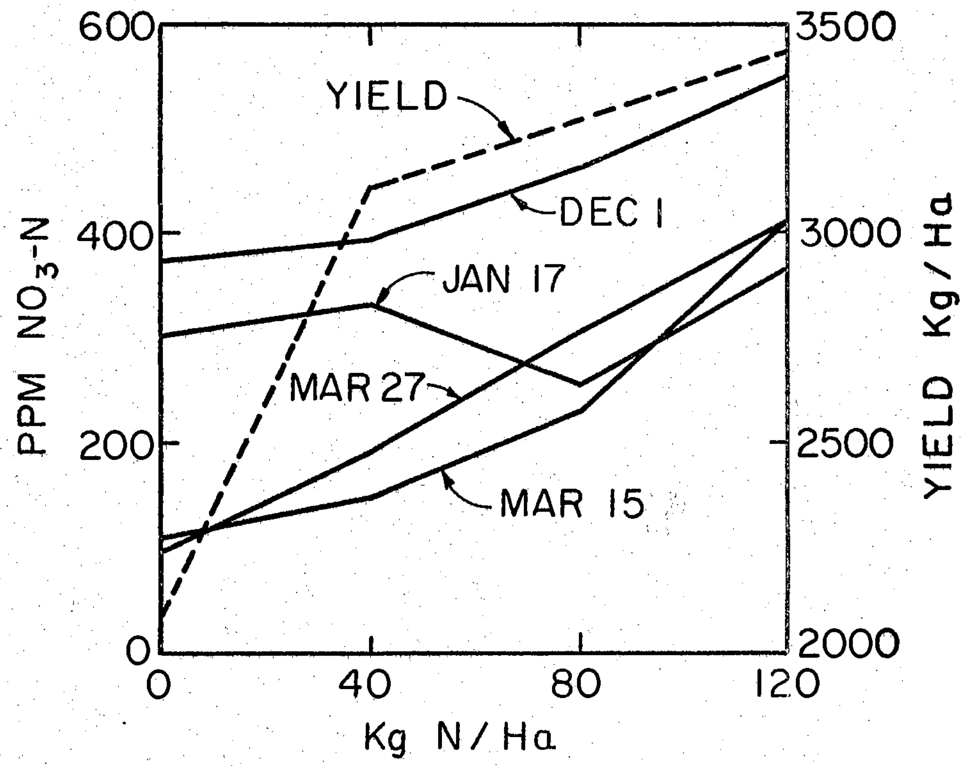

Figure 5. Effect of Rates of Nitrogen on Yield of Grain and Nitrate-Nitrogen Content of Forage on Different Dates of Sampling.

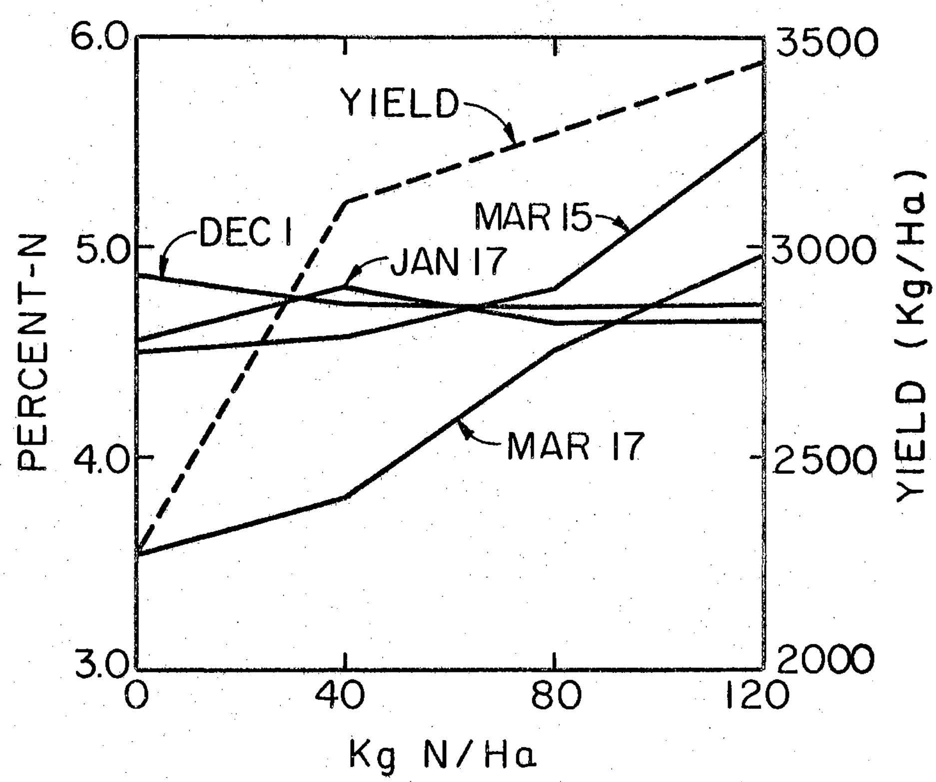

Figure 6. Effect of Rates of Nitrogen on Yield of Grain and Organic Nitrogen Content of Forage on Different Dates of Sampling.

Since the yields of grain were maximized with 80 kg N, the critical concentration of NO_3-N and organic N would be the concentrations found with this rate of application. These values are given in Table IX. It should be remembered that these values cannot be considered absolute, but should represent the middle of a range that represents "optimum" nitrogen conditions.

The calculated F values were consistently higher for organic N determinations than for NO_3-N analysis. This would indicate that the NO_3-N concentration was either not affected to the same degree by nitrogen applications or that experimental error associated with the analysis of NO_3-N was greater.

Phosphorus

Yields of grain were highest when 45 kg P/ha was applied. The concentration of P in the plant samples collected from this treatment is the critical concentration for the respective date of sampling.

The P content of the plant samples did not vary with stage of growth as did N, NO_3-N and K (Fig. 7). This, of course, simplifies the interpretation of the analysis since the stage of growth at time of sampling need not be considered. In addition, the slope of the curve representing applied P versus concentration of P in the tissue was greater with P than with N or K and was almost linear. This too makes interpretation easier.

The concentration of plant tissue from all sampling dates fell within the range of .45 to .50 per cent at the optimum rate of fertilization of 45 kg/ha. The critical concentration is then termed .45 per cent P regardless of stage of growth at sampling time (Table IX).

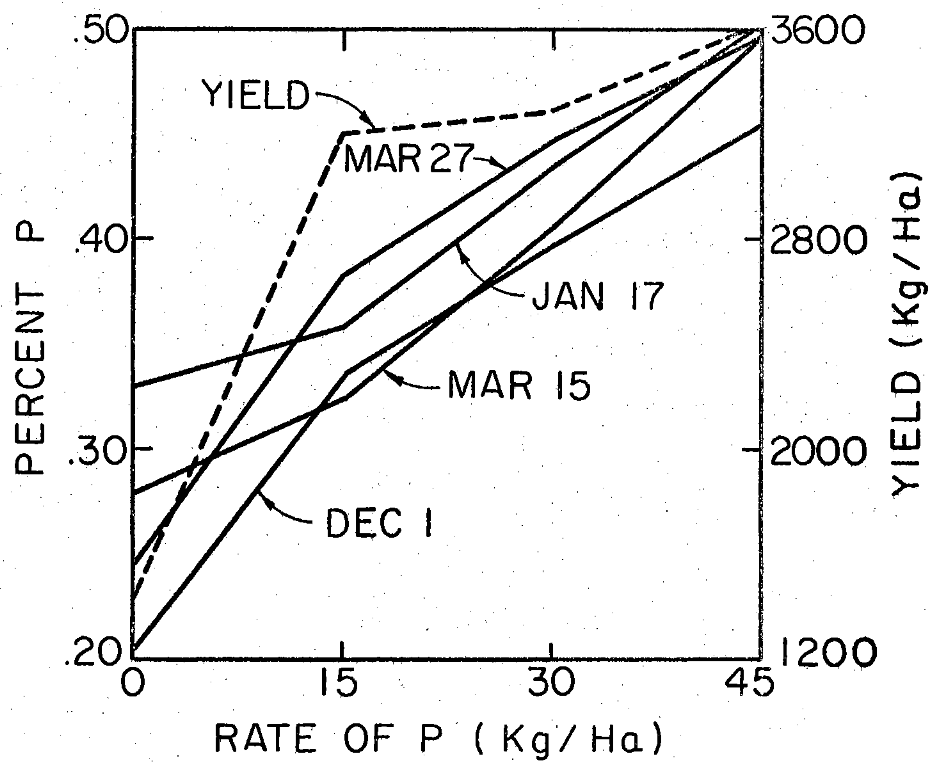

Figure 7. Effect of Rates of Phosphorus on Yield of Grain and Phosphorus Content of Forage on Different Dates of Sampling.

The calculated F values for phosphorus determinations were higher than for the other chemical analyses.

Potassium

Yields of grain did not increase with K applications as they did with the application of N and P. The 40 kg K/ha rate appeared to be the optimum rate of potassium fertilization and, therefore, the fertility level at which critical K concentrations are established.

The K content of the samples varied considerably with stage of growth, indicating that the critical concentration varies with stage of growth (Fig. 8). In general, the concentrations were relatively high early in the season (1 December) and decreased markedly before the 17 January sampling date. The concentrations then increased during the next two sampling periods. The concentrations of the samples collected 1 December and 27 March were highest and very similar. The samples collected 17 January had the lowest concentration and those collected 15 March were intermediate.

The critical concentration for 1 December and 27 March date of sampling is 3.0 per cent, for 17 January it is 2.7 per cent and 2.5 per cent for 15 March.

Other Observations

In many cases, the concentration of a nutrient in the plant samples was affected not only by the application of the nutrient in question, but also by other nutrients. The most striking evidence of this is the effect of P applications on NO_3-N concentration. When no P was applied, the NO_3-N concentration of the forage reached 1275 ppm

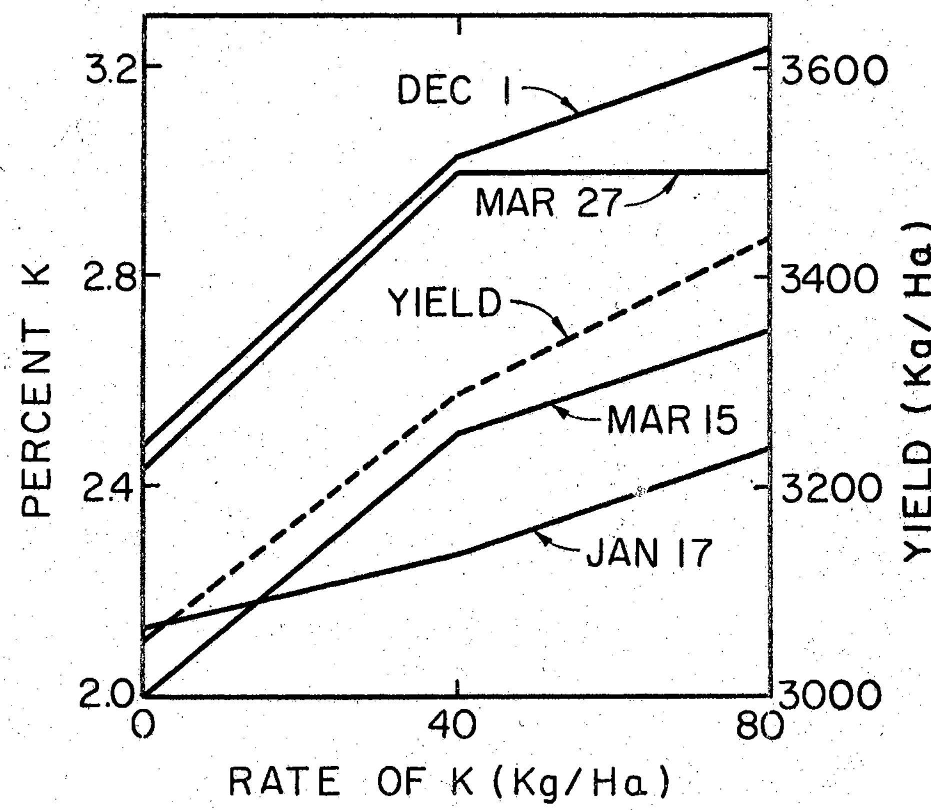

Figure 8. Effect of Rates of Potassium on Yield of Grain and Potassium Content of Forage on Different Dates of Sampling.

(Treatment 5, 1 December, Table VIII). However, with the application of only 15 kg/ha of P, the NO_3-N content dropped to 284 ppm. This supports earlier evidence that phosphorus deficient plants have a tendency to accumulate NO_3-N.

In addition, a severe P deficiency apparently affected the potassium concentration in the plant. The K content of forage receiving no P was lower than treatments receiving P in samples collected 1 December and 17 January. This observation was not confirmed in samples collected 15 and 27 March.

The application of N did not have any apparent effect on the concentration of P and K except in samples collected 1 December. In this case, the P content of the forage tended to decrease with increasing rates of N application, apparently due to a dilution effect at a time when phosphorus demands by winter wheat are greatest.

The application of potassium did not appear to affect the concentration of any of the other nutrients but would not be expected to in this case because the deficiency of K was not severe.

LITERATURE CITED

1. Allred, S. E. and A. J. Chlrogge. 1964. Principles of Nutrient Uptake from Fertilizer Bands. VI Germination and Emergence of Corn as Affected by Ammonia and Ammonium Phosphate. Agron. J. 56:309-313.

2. Beaton, J. D., R. C. Speer and A. Brown. 1965. Effect of Soil Temperature and Length of Reaction Period on Water Solubility of Phosphorus in Soil-Fertilizer Reaction Zones. Soil Sci. Soc. Amer. Proc. 29:194-198.

3. Chapin, J. S. and F. W. Smith. 1960. Germination of Wheat at Various Levels of Soil Moisture as Affected by Applications of Ammonium Nitrate and Muriate of Potash. Soil Sci. 89:322-327.

4. Crawford, R. F., W. K. Kennedy and W. C. Johnson. 1961. Some Factors that Affect Nitrate Accumulation in Forages. Agron. J. 53:159-162.

5. Cummins, D. G. and W. L. Parks. 1961. The Germination of Corn and Wheat as Affected by Various Fertilizer Salts at Different Temperatures. Soil Sci. Soc. Amer. Proc. 25:47-49.

6. Flynn, L. M., C. W. Gehorke, M. E. Muhrer, G. E. Smith and M. S. Zuber. 1957. Effects of Temperature, Rainfall and Fertilizer on Yields and Composition of Corn Plants. Mo. Agr. Exp. Sta. Bull. 620.

7. Gordon, C. H., A. M. Decker and H. G. Wiseman. 1962. Some Effects of Nitrogen Fertilizer, Maturity and Light on the Composition of Orchardgrass. Agron. J. 54:376-378.

8. Gul, Ajam and B. J. Kolp. 1960. Accumulation of Nitrates in Several Oat Varieties at Various Stages of Growth. Agron. J. 52:504-506.

9. Guttay, J. R. 1957. The Effects of Fertilizer on the Germination and Emergence of Wheat and Oats. Mich. Agr. Exp. Sta. Quart. Bull. 40:193-202.

10. Hanway, J. J., J. B. Herrick, T. L. Willrech, P. C. Bennett and J. T. McCall. 1963. The Nitrate Problem. Iowa St. Univ. Coop. Ext. Special Report No. 34.

11. Hanway, J. J. 1962. Corn Growth and Composition in Relation to Soil Fertility: II. Uptake of N, P and K and Their Distribution in Different Plant Parts During the Growing Season. Agron. J. 54:217-222.

12. ________. 1962. Corn Growth and Composition in Relation to Soil Fertility: III. Percentages of N, P and K in Different Plant Parts in Relation to Stage of Growth. Agron. J. 54:222-229.

13. Hood, J. T. and L. E. Ensminger. 1964. The Effect of Ammonium Phosphate and Other Chemicals on the Germination of Cotton and Wheat Seeds. Soil Sci. Soc. Amer. Proc. 28:251-253.

14. ________ and ________. 1965. The Mechanism of Ammonium Phosphate Injury to Seeds. Soil Sci. Soc. Amer. Proc. 29:320-322.

15. Johnson, C. M. and A. Ulrich. 1950. Determination of Nitrate in Plant Material. Anal. Chem. 22:1526-1529.

16. Kinra, K. L., H. D. Foth and J. F. Davis. 1962. Effect of Ordinary Superphosphate on Emergence of Oats and Wheat. Agron. J. 54:180-181.

17. Milsted, S. W., H. L. Motto and T. R. Peck. 1969. Critical Plant Nutrient Composition Values Useful in Interpreting Plant Analysis Data. Agron. J. 61:17-20.

18. Moeller, W. J. and R. L. Thurman. 1966. Nitrate Content of Fall-Sown Rye, Wheat and Oat Forages. Agron. J. 58:627-628.

19. Nowakowski, T. Z. 1961. The Effect of Different Nitrogenous Fertilizers, Applied as Solids or Solutions, on the Yield and Nitrate-N Content of Established Grass and Newly Sown Ryegrass. J. Agr. Sci. 56:287-292.

20. Olson, R. A. and A. F. Drier. 1956. Fertilizer Placement for Small Grains in Relation to Crop Stand and Nutrient Efficiency in Nebraska. Soil Sci. Soc. Amer. Proc. 20:19-24.

21. Shelton, W. R. and H. J. Harper. 1941. A Rapid Method for the Determination of Total Phosphorus in Soil and Plant Material. Iowa St. College J. of Sci. 15:402-413.

22. Tucker, J. M., D. R. Cordy, L. J. Berry, W. A. Harvey and T. C. Fuller. 1961. Nitrate Poisoning in Livestock. Calif. Agr. Exp. Sta. and Ext. Ser. Cir. 506.

23. Ulrich, A. and F. J. Hills. 1967. Principles and Practices of Plant Analysis. Soil Sci. Soc. Amer. Spec. Pub. 2:11-24.

24. Wright, M. J. and K. L. Davison. 1964. Nitrate Accumulation in Crops and Nitrate Poisoning in Animals. Adv. in Agron. 14:197-217.

VITA

3

John Milton Baker, Jr.

Candidate for the Degree of

Doctor of Philosophy

Thesis: EFFECT OF PHOSPHORUS SOURCES ON GERMINATION OF WHEAT, NITROGEN ON NITRATE ACCUMULATION IN SMALL GRAINS, AND DETERMINATION OF CRITICAL NUTRIENT LEVELS OF WHEAT

Major Field: Soil Science

Biographical:

Personal Data: Born 4 January 1940 at Temple, Texas, son of Milton and Edna Baker.

Education: Graduated from Academy High School, Temple, Texas, 1957. Undergraduate work at Temple Junior College, 1957-1959, and Texas College of Arts and Industries, 1960-1963. Master of Science Degree from Oklahoma State University, 1963-1966. Completed requirements for the Doctor of Philosophy Degree at Oklahoma State University, May 1970.

Experience: Reared on a farm and performed farm chores, 1953-1957, while attending high school. Employed, part time, as clothing salesman and as advertising assistant for newspaper while attending junior college, 1957-1959. Student trainee of Soil Conservation Service during the summers of 1961 and 1962. Graduate Research Assistant, Oklahoma State University, 1963-1964. Instructor performing responsibilities in wheat fertility research, Oklahoma State University, 1964-1969. Extension Soil Specialist, Oklahoma State University, 1969 to present.

Member: Alpha Tau Alpha, Alpha Chi, Society of Sigma Xi, American Society of Agronomy, and Soil Science Society of America.