COMPARATIVE AVAILABILITY OF PHOSPHORUS FROM SUPERPHOSPHATE AND AMMONIUM PHOSPHATE AT DIFFERENT SOIL MOISTURE LEVELS

By

NORMAN HOWARD WELCH

Bachelor of Science

Oklahoma Agricultural and Mechanical College

Stillwater, Oklahoma

1953

Submitted to the faculty of the Graduate School of
the Oklahoma Agricultural and Mechanical College
in partial fulfillment of the requirements
for the degree of
MASTER OF SCIENCE
August, 1956

COMPARATIVE AVAILABILITY OF PHOSPHORUS FROM
SUPERPHOSPHATE AND AMMONIUM PHOSPHATE
AT DIFFERENT SOIL MOISTURE LEVELS

Thesis Approved:

J. Q. Lynd
Thesis Adviser

Robert M. Reed

Robert MacVicar
Dean of the Graduate School

ACKNOWLEDGMENTS

The author feels indebted and wishes to express gratitude to the following persons:

Dr. J. Q. Lynd, thesis adviser, for supervision, advice and encouragement throughout the course of this study. Dr. U. S. Jones for helpful suggestions and information concerning this study. Mr. H. M. Galloway for furnishing the description of the soils used in this study. Dr. F. A. Graybill for advice on the statistical analysis of the data. Special gratitude is expressed for the financial assistance given by the Olin Mathison Chemical Corporation.

TABLE OF CONTENTS

	Page
INTRODUCTION	1
REVIEW OF LITERATURE	3
DESCRIPTION OF SOILS USED IN GREENHOUSE STUDY	8
EXPERIMENTAL PROCEDURE	10
Analysis of Soil	11
Analysis of Forage	11
Statistical Analysis	12
RESULTS AND DISCUSSIONS	14
Kirkland Silt Loam	14
Norge Fine Sandy Loam	17
Combined Yield Data	20
Nitrogen Composition	23
Phosphorus Composition	23
Potassium Composition	27
SUMMARY AND CONCLUSIONS	31
LITERATURE CITED	34
APPENDIX	38
VITA	43

LIST OF TABLES

Table		Page
1.	Distribution of fertilizer phosphorus one month after addition of a band of superphosphate to columns of Fayette silt loam of differing water content	5
2.	Some physical and chemical characteristics of soil materials used in the greenhouse experiment	13
3.	Effect of various soil treatments on Redlan sorghum forage grown at three soil moisture levels on Kirkland silt loam in the greenhouse	15
4.	Multiple range test showing the effect of fertilizer treatments on the yield of Redlan sorghum forage grown on Kirkland silt loam	16
5.	Effect of various soil treatments on Redlan sorghum forage yield grown at three soil moisture levels on Norge fine sandy loam in the greenhouse	18
6.	Multiple range test showing the effect of treatments on the yield of Redlan sorghum forage grown on Norge fine sandy loam.	19
7.	Effect of various soil treatments on Redlan sorghum forage vield grown at three soil moisture levels on Kirkland silt loam and Norge fine sandy loam in the greenhouse	21
8.	Multiple range test showing the effect of fertilizer treatments on yield of Redlan sorghum forage grown on Kirkland silt loam and Norge fine sandy loam in the greenhouse	22
9.	Effect of various soil treatments on the percent of nitrogen in Redlan sorghum forage grown at three soil moisture levels in the greenhouse	24
10.	Multiple range test showing the effect of various soil and moisture combinations on the percent of nitrogen in forage grown at three soil moisture levels in the greenhouse	25

Page

11. Effect of various soil treatments on the percent phosphorus in Redlan sorghum forage grown at three soil moisture levels in the greenhouse 26

12. Multiple range test showing the effect of various combinations of fertilizers and soil on the percent phosphorus in forage 28

13. Effect of various soil treatments on the percent potassium in Redlan sorghum forage grown at three moisture levels in the greenhouse 29

14. Multiple range test showing the effect of various soil treatments on the percent potassium in forage 30

15. Effect of various soil treatments on Redlan sorghum forage yield grown at three soil moisture levels in the greenhouse 39

LIST OF ILLUSTRATIONS

Figure		Page
1.	Effects of various soil treatments showing: 1. Am. Phos., 2. Super + Urea, 3. Super and 4. Check at .5 ME on Kirkland silt loam	40
2.	Effects of various soil treatments showing: 1. Am Phos., 2. Super + Urea, 3. Super and 4. Check at 1 ME on Kirkland silt loam	40
3.	Effects of various soil treatments showing: 1. Am. Phos. at .5 ME, 2. Super + Urea at .5 ME, 3. Am Phos. at 1 ME, 4. Super + Urea at 1 ME on Kirkland silt loam	41
4.	Effects of various soil treatments showing: 1. Am. Phos., 2. Super + Urea, 3. Super and 4. Check at .5 ME on Norge fine sandy loam	41
5.	Effects of various soil treatments showing: 1. Am. Phos., 2. Super + Urea, 3. Super and 4. Check at 1 ME on Norge fine sandy loam	42
6.	Effects of various soil treatments showing: 1. Am. Phos. at .5 ME, 2. Super + Urea at .5 ME, 3. Am. Phos. at 1 ME, 4. Super + Urea at 1 ME on Norge fine sandy loam	42

INTRODUCTION

The availability of soil phosphorus for plant growth is of major importance in Oklahoma (7)[1]. Oklahoma soils, in general, indicate deficiencies in phosphorus in forms that are available for plant use. Harper (18) reported results from soil tests of 6200 surface soil samples in Oklahoma and concluded that the soils of the eastern half of the state were more than 50 percent deficient in easily soluble phosphorus. These conclusions are complicated by the fact that a portion of the soil phosphorus is in an organic form and is not extractable with dilute acids.

In the complex soil system there are a number of chemical, physical and biological factors that can limit the availability of phosphorus for plant growth. These factors usually determine to a large extent the response that will be obtained from a particular phosphate fertilizer (37).

There has been considerable controversy over the relative availability of phosphorus from citrate soluble forms and from phosphate fertilizers that contain phosphorus in a water soluble form. There is evidence that the water soluble forms of phosphate may have advantages for stand establishment and seeding vigor with limited soil moisture (28).

The purpose of this study was to compare plant response from fertilizer phosphorus applied in ordinary granular super phosphate (0-20-0) with results obtained using ammonium phosphate at three moisture levels

---

[1]Figures in parenthesis refer to literature cited.

on two contrasting soil types. Urea (45-0-0) was used as a nitrogen source with the superphosphate treatments.

REVIEW OF LITERATURE

The problem of phosphorus fertilization is complicated by many factors. A large portion of the available phosphorus added to the soil in a phosphorus fertilizer may become unavailable to plants within a relatively short period of time. The problems of phosphorus fixation, release, immobilization and mineralization continue to be of major concern to soil and crop sciences. A comprehensive review of the extensive literature on the subject of soil and fertilizer phosphorus has been recently presented in Agronomy Monographs Vol. IV (37).

Volk (45) found that the availability of soil phosphorus and fertilizer phosphorus is related to the pH of the soil. At the more acid levels he concluded that the phosphorus was less available with the exception of rock phosphate which proved to be more available in acid rather than in neutral or alkaline soils.

MacLean (30) conducted tests with alfalfa to find the soil pH at which the largest response was obtained from phosphorus fertilization. The greatest response was obtained at a pH of 7.5, but an optimum was usually reached at about a pH of 6.5 to 7.0.

Loscin (27) found that different forms of phosphorus compounds were fixed at different pH values. The citrate soluble phosphates were more available under acid soil conditions than were the water soluble phosphates. The water soluble phosphates were more available at a pH of 6.0 or above.

Cook (9) and other investigators (1), (29) found an increase in phosphorus availability as a result of lime applications.

Copeland (10) and Moser (33) have found that only one-tenth to one-half of the phosphorus added as available phosphate was used by the plant, while the remainder was "fixed" by the soil.

Stephenson (43) observed that the movement of phosphorus from the place of application was very slow. When large amounts of phosphorus and water were applied the phosphorus tended to move farther into the soil from the place of application. When organic phosphate was added in manure it moved farther and faster into the soil. This was believed to be due to the fact that the organic phosphates were not as soluble and they moved with the soil water.

Brown (5) and Midgley (32) found that phosphorus is fixed almost at the point of contact with the soil and that there was very little movement downward of the phosphorus. When the phosphorus was applied on the surface it was usually retained in the upper six inches of the soil.

Heck (19) found that soils low in phosphorus showed very little response to phosphate fertilization. This fact was attributed to the fixation of the phosphorus. Phosphorus fixation held the phosphorus in the surface soil and the plants were not able to obtain the phosphorus.

Brown (5) found that phosphorus was fixed more readily by clay soils than by sandy soils. Dalton (11) found that additions of organic matter were an effective way of increasing the availability of phosphorus. Hibbard (21) found that the additions of soluble organic matter increased the solubility and penetrating power of phosphorus.

The amount of moisture in the soil can affect the availability of phosphorus as was noted by Heslep (20). Tests were conducted to determine the rate of diffusion of phosphorus under different moisture conditions, Table 1. The rate of diffusion of phosphorus was directly proportional to the percent of water in the soil. It was found by comparing the rate of diffusion between the water soluble and the citrate soluble forms of phosphorus that the water soluble phosphorus diffused farther than the citrate soluble. It was assumed that the greater diffusion resulted in more soil area from which plant roots could absorb phosphorus.

TABLE 1

Distribution of fertilizer phosphorus one month after addition of a band of superphosphate to columns of Fayette silt loam of differing water content (20)

Water content of soil	Fertilizer P in soil at various distances in both directions from fertilizer band*				
	0.1-1 cm.	1-2 cm.	2-3 cm.	3-4 cm.	0.1-4 cm.
%	%	%	%	%	%
9.1	65	4	0	0	69
12.5	62	11	1	0	74
19.4	60	18	3	1	82
27.5	51	23	11	1	86

Applied at a rate to furnish 123.1 mg. of P_2O_5 per tube or 20 mg. per sq. cm. of cross-sectional area; 84.3 percent of the fertilizer P was in the water soluble form.

Heslep (20) found that practically all (88-98 percent) of the guaranteed phosphorus in ammonium phosphate was in the form of mono-ammonium phosphate, and that practically all the guaranteed phosphorus in superphosphate was in the form of mono-calcium and/or di-calcium phosphate.

The actual composition of ordinary superphosphate varies with the quality of materials used, the acid-rock ratio, the temperature and method of the mixture process and the length and conditions of the curing period (23).

Mono-ammonium phosphate was shown to have 37 parts per hundred solubility in cold water while mono-calcium phosphate showed 2 parts per hundred solubility in cold water (8).

Ammonium phosphate (11-48-0) contains 89 percent water soluble P_2O_5 and 9 percent citrate soluble P_2O_5, while ammonium phosphate (16-20-0), containing ammonium sulfate, contains 86 percent water soluble P_2O_5 and 12 percent citrate soluble P_2O_5. Normal superphosphate contains 78 percent water soluble P_2O_5 and 18 percent citrate soluble P_2O_5 (37).

Recent research (6) concerning the behavior of mono-calcium phosphate monohydrate in soil have shown complex dynamic reactions involving rapid conversions of that compound to a precipitation of dicalcium phosphate dihydrate.

Lewis (26) found that the phosphate fertilizers that had a large portion of their phosphorus in the water soluble form gave better response than those fertilizers that contained the citrate soluble form of phosphate.

Hinkle (22) found in comparing various fertilizers that there was very little significance in the difference in the yield between superphosphate and ammonium phosphate. Both increased the yield and percent of phosphorus in hay over the hay grown on soils with no phosphate added.

Olsen (34) working with wheat found that ammonium phosphate was slightly better in supplying phosphorus than was superphosphate, but the significance was not large. The greater uptake of phosphorus from ammonium phosphate was more pronounced in the early growth stage of the wheat. In an experiment with alfalfa he likewise found that superphosphate and calcium meta-phosphate supplied more phosphorus than ammonium phosphate. In another experiment by Olsen (34) it was found that superphosphate and ammonium phosphate were about equal in their ability to supply phosphorus.

Owen (35) used fertilizers with varying amounts of water solubility and found no significant difference in yield; however, the percent of phosphorus in the plant was higher from the fertilizer with the highest water solubility.

Fuller (15) found no significant difference between the response from super phosphate and ammonium phosphate.

Jones (24) and Speer (42) found that the highest yields were obtained from the fertilizers that contained their phosphates in the water soluble form.

Lawton (25) studied availability of phosphorus from the pellet form and from the pulverized form of fertilizers. The water soluble fertilizers were more available when in the pellet form, while the citrate soluble forms of phosphate were more available in the pulverized form.

Certain types of nitrogen fertilizer added with or mixed with phosphate fertilizers have been shown to affect the availability of the fertilizer phosphorus. Fudge (14) reported that the addition of acid forming nitrogen fertilizers tended to reduce the availability of fertilizer phosphorus. However, Green (16) believed that plants which utilize high amounts of phosphorus from soils low in available phosphorus was due to the root excretion of carbon dioxide resulting in carbonic acid formation that dissolved the phosphorus containing minerals in the soil.

There is no agreement among research workers as to the relative merits of fertilizers containing varying amounts of water soluble phosphorus. The relative effectiveness of these materials at various soil moisture levels is of particular interest to farming operations in subhumid agricultural areas.

DESCRIPTION OF SOILS USED IN GREENHOUSE STUDY

The soils used in this study were Kirkland silt loam and Norge fine sandy loam.

The soil classified as Kirkland silt loam was taken from the southeast corner of plot 6200 on the Agronomy farm at Stillwater, Oklahoma which is located one mile west of the campus of Oklahoma Agricultural and Mechanical College, north of Highway No. 51. The farm includes the S E ¼, section 16 and S W ¼ east of Cow Creek, of section 16, T 19N; R2E.

Kirkland silt loam (0 to 2 percent slopes) occupies the most level part of the farm, mostly in the northeastern portion. It has a grayish-brown surface and a claypan subsoil through which water moves very slowly. The soil occupies very gentle, plane to weak concave south-facing slope and is closely associated with Bethany silt loam. A detailed description of the soil characteristics of this soil type is presented in the detailed soil survey of the Agronomy Farm.

The soil classified as Norge fine sandy loam was taken from the post lot south of pasture III S at the Perkins, Oklahoma farm in Payne County and includes section 36, T 18N; R2E.

Norge fine sandy loam (1 to 3 percent slopes) is found in areas transitional between the Norge silt loam and the Norge silt loam deep phase areas, and the Dougherty very fine sandy loam. It occurs mostly on the horticulture section of the farm and is also found in the experimental pasture. The area has a convex surface and slopes to the east and west.

A detailed description of the soil profile characteristics of this soil type is presented in the detailed soil survey of the Perkins Experimental Farm.[1]

---

[1]Soil descriptions furnished by H. M. Galloway, Soil Scientist (Coop. S. C. S. and Ag. Exp. Sta.)

EXPERIMENTAL PROCEDURE

The soils used in the greenhouse experiment were screened in the field to pass a ¼ inch screen. They were brought into the greenhouse and the equivalent of 8 kilograms of dry soil were weighed into glazed, earthenware pots. The moisture equivalent for the soils was determined and the weights of each soil at its specific moisture equivalent plus the weight of the pot were recorded on each pot. The granulated 20 percent superphosphate and ammonium phosphate base fertilizer, 13-39-0, were both screened to obtain uniform granular materials ranging from .0500 to .0714 inches in diameter. The fertilizers were applied in a circular band one and one-half inches deep. The soil in each pot was then brought up to the specific designated moisture level and seeded to Redlan grain sorghum (Sorghum vulgare Pers.) (12), one inch above and one inch to the side of the fertilizer band. The pots were then arranged in a randomized block design within each soil group.

Individual pots were brought up to their respective moisture levels throughout the experiment by placing them on scales and bringing them up to weight with distilled water. Weighings were made at frequent intervals determined by the amount of plant growth and other conditions influencing the rate of water loss from the pots.

Four soil fertility treatments were used, at three soil moisture levels on the two soil types with three replications made of each individual treatment.

The soil fertility treatments were as follows:

Equivalent lbs. per acre
(1) 33.3-100-0 (Am. Phos. 13-39-0)
(2) 33.3-100-0 (Urea 45 % + Super 20%)
(3) 0-100-0 (Super 20%)
(4) Check (no fertilizer)

The soil moisture levels used were:

(1) .5 moisture equivalent
(2) 1 moisture equivalent
(3) 2 moisture equivalents

Analysis of Soil

Samples of each of the soils used in this study were taken into the laboratory and prepared for analysis by crushing with a metal roller and sieving through a twenty mesh screen. The results of the analyses are shown in Table 2.

The soil texture was determined by the method of Bouyoucos (2). pH determinations were made essentially by the method described by Peech (36), organic matter content was determined by the method of Schollenberger (39). The exchange capacity and total exchangeable bases were determined essentially as outlined by A. O. A. C. 1945 (31). Total nitrogen was determined by the Kjeldahl method (38). Total phosphorus was determined by the method of Shelton (40). Easily soluble phosphorus was determined by the method of Harper (17). The total potassium was determined by digestion by the method of Shelton (40) and reading on a model 18, Perkins Elymer flame photometer, exchangeable potassium was determined by the method of Toth (44). The moisture equivalent of the soils was determined by the method proposed by Briggs and McLane (3) and later modified by Briggs and Shantz (4).

Analysis of Forage

The forage samples were dried in an oven at 60.5^{o} C. and ground in a Wiley mill. Nitrogen analysis was conducted by the Kjeldahl method, Piper (38). The phosphorus analysis was determined by the method of Shelton (40). The potassium was digested by the method of Shelton (40) and read on a model 18 Perkins Elymer flame photometer. The results of the analysis for nitrogen, phosphorus and potassium are shown in Tables 6, 7 and 8, respectively.

Statistical Analysis

Forage yield and chemical composition data were subjected to analysis of variance according to the procedures of Snedecor (41). Multiple range tests and confidence limits were calculated according to Duncan (13). Coefficients of variation were determined according to Snedecor (41).

TABLE 2

Some physical and chemical characteristics of soil materials used in the greenhouse experiment

	Norge Fine Sandy Loam	Kirkland Silt Loam
Sand	77.25%	37.25%
Silt	20.00%	42.00%
Clay	2.75%	20.75%
pH	5.3	5.4
Organic Matter	.85%	1.43%
Total Exchange Capacity	3.21 meq./100 gms.	13.01 meq./100 gms.
Total Exchangeable Bases	1.27 meq./100 gms.	3.10 meq./100 gms.
Total N	.004%	.072%
Total P	117 lb/A	123 lb/A
Total K	40 lb/A	88 lb/A
Easily Soluble P	15.66 lb/A	44.16 lb/A
Exchangeable K	18 lb/A	31 lb/A
Moisture Equivalents		
.5 ME	2.67 %	7.235 %
1 ME	5.34 %	14.47 %
2 ME	10.68 %	28.94 %

RESULTS AND DISCUSSION

Results from the greenhouse study herein reported were primarily concerned with forage yields and nitrogen, phosphorus and potassium content of Redlan sorghum forage as affected by various soil and fertilizer treatments. Four fertilizer treatments at three soil moisture levels were compared on two contrasting soil types.

Kirkland silt loam:

Forage yields and analysis of variance data for results on Kirkland silt loam are shown in Tables 3 and 15. A multiple range test and confidence limits are presented in Table 4. Yields increased markedly with increases in soil moisture levels for all fertilizer treatments. Yield means for all fertilizer treatments were 4.51 gms. at .5 ME, 10.34 gms. at 1. ME and 18.08 gms. at 2 ME moisture levels, respectively and were significantly different at the 1 percent level. Confidence limits for these moisture yield data are shown in Table 4.

Average forage yield increases on Kirkland silt loam as affected by fertilizer treatments indicated Am. Phos. > Super > Super + Urea > Check (see Figures 1 and 2). This order was not consistent at all moisture levels, however. Mean yields for all soil moisture levels ranged from 9.56 gms. (check) to 12.08 gms. (Am. phos.) giving significant differences at the 5 percent level. The multiple range test indicates that the only significant difference between mean yields existed in comparing only the check (no fertilizer) treatment mean yield with average yields from each of the other three fertilizer treatments. There was no significant

TABLE 3

Effect of various soil treatments on Redlan sorghum forage yield grown at three soil moisture levels on Kirkland silt loam in the greenhouse

Treatments (lbs./A.)	Dry wt. yield (gms.) at three soil moisture levels .5 ME	1 ME	2 ME	$\bar{X}$
33.3-100-0 (Am. Phos. 13-39-0)	5.33	11.43	19.47	12.08
33.3-100-0 (Urea 45% + Super 20%)	4.03	10.63	18.73	11.13
0-100-0 (Super 20%)	4.87	10.80	17.77	11.14
Check (no fertilizer)	3.80	8.50	16.37	9.56
$\bar{X}$	4.51	10.34	18.08	10.98

All pots received the equivalent of 2000 lb./A of $CaCO_3$.
All yield figures represent the mean of three replications.

Analysis of variance of yield data

Source	d f	s s	m s	F
Replications	2	1.00	.50	.22
Fertilizers	3	29.56	9.85	4.40*
Moisture	2	1112.97	556.48	248.43**
Fert. x Moist.	6	5.83	.97	.43
Error	22	49.24	2.24	
Total	35	1198.60		

*Denotes significance at the 5 percent probability level
**Denotes significance at the 1 percent probability level

C. V. = 13.63%

TABLE 4

Multiple range test showing the effect of fertilizer treatments on the yield of Redlan sorghum forage grown on Kirkland silt loam (see Table 3 for yield and A. O. V. data)

$s_m = .4989$ (5% p-level)

Check	Super + Urea	Super	Am. Phos.
9.50	11.13	11.14	12.08

(Super + Urea, Super and Am. Phos. are underscored by the same line.)

Note: Any two means not underscored by the same line are significantly different
Any two means underscored by the same line are not significantly different

Confidence limits for difference in treatment means

Fertilizer treatments (95%)

$s_m \times r_{.05} = 1.58$

Am. Phos. - Check,	.94 to 4.10
Super + Urea - Check,	-.01 to 3.15
Super - Check,	.0 to 3.16

Soil moisture treatments (99%) #

$s_m \times r_{.01} = 1.97$

2 ME - 1 ME,	5.77 to 9.71
2 ME - .5 ME,	11.60 to 15.54
1 ME - .5 ME,	3.86 to 7.80

Each moisture level was significantly different at the 1% probability level

interaction between soil moisture level and fertilizer treatment. Coefficient of variation for these data was 13.63% indicating a relatively low magnitude of standard error in relation to the overall yield mean obtained on this soil.

Norge fine sandy loam:

Forage yield and analysis of variance data for results of Norge fine sandy loam are shown in Tables 5 and 15. A multiple range test and confidence limits are presented in Table 6. There was a marked increase in yield with each increase in moisture level at all fertilizer treatments. Yield means for all fertilizer treatments were 6.13 gms. at .5 ME, 9.69 gms. at 1 ME and 12.69 gms. at 2 ME moisture levels, respectively and were significantly different at the 1 percent level. Confidence limits for these moisture yield data are shown in Table 6.

Average forage yield increases on Norge fine sandy loam as affected by fertilizer treatments indicated Am. Phos. > Super + Urea > Super > Check (see Figures 4 and 5). This order was consistent at all but 1 ME. Mean yields for all moisture levels ranged from 8.73 (Check) to 10.87 (Am. Phos.) giving significant differences at the 5 percent level. The multiple range test indicates that the only significant difference between mean yields existed in comparing only the Am. Phos. treatment mean yield with the mean yields from the other three fertilizer treatments. There was no significant interaction between soil moisture level and fertilizer treatments. The coefficient of variations for these data was 14.49 percent indicating a slightly higher magnitude of standard error in relation to the overall yield mean obtained on this soil as compared to yield data from the Kirkland silt loam.

TABLE 5

Effect of various soil treatments on Redlan sorghum forage yield grown at three soil moisture levels on Norge fine sandy loam in the greenhouse

Treatments (lbs./A.)	Dry wt. yield (gms.) at three soil moisture levels .5 ME	1 ME	2 ME	$\bar{X}$
33.3-100-0 (Am. Phos. 13-39-0)	7.00	11.37	14.23	10.87
33.3-100-0 (Urea 45% + Super 20%)	6.40	9.23	12.57	9.40
0-100-0 (Super 20%)	5.80	9.50	11.77	9.02
Check (no fertilizer)	5.33	8.67	12.20	8.73
$\bar{X}$	6.13	9.69	12.69	9.51

All pots received the equivalent of 2000 lb./A of $CaCO_3$.
All yield figures represent the mean of three replications.

Analysis of variance of yield data

Source	d f	s s	m s	F
Replications	2	.025	.0125	.007
Fertilizers	3	24.24	8.08	4.25*
Moisture	2	258.69	129.34	68.07**
Fert. x Moist.	6	3.26	.54	.28
Error	22	41.87	1.90	
Total	35	328.00		

*Denotes significance at the 5 percent probability level
**Denotes significance at the 1 percent probability level

C. V. = 14.49%

TABLE 6

Multiple range test showing the effect of treatments on the yield of Redlan sorghum forage grown on Norge fine sandy loam (see Table 5 for yield and A. O. V. data)

s_m + .4595 (5% p-level)

Check	Super	Super + Urea	Am. Phos.
8.73	9.02	9.40	10.87

Note: Any two means not underscored by the same line are significantly different
Any two means underscored by the same line are not significantly different

Confidence limits for difference in treatment means

Fertilizer treatments (95%)

$s_m \times r_{.05} = 1.46$

Am. Phos. - Super + Urea,	.01 to 2.93
Am. Phos. - Super,	.39 to 3.31
Am. Phos. - Check,	.68 to 3.60

Soil moisture treatments (99%) #

$s_m \times r_{.01} = 1.66$

2 ME - 1 ME,	1.34 to 4.66
2 ME - .5 ME,	4.90 to 8.22
1 ME - .5 ME,	1.90 to 5.22

Each moisture level was significantly different at the 1% probability level

Combined yield data:

The analysis of variance of conbined yield data from both soils and a multiple range test of these data are shown in Tables 7 and 8 respectively. Yield averages of the two soils at all soil treatments were 9.51 gms. on the Norge fine sandy loam and 10.98 on the Kirkland silt loam.

The Norge fine sandy loam, prior to greenhouse treatment contained 15.66 pounds per acre of soluble phosphorus and .004 percent total nitrogen, while the Kirkland silt loam contained 44.16 pounds per acre of soluble phosphorus and .072 percent total nitrogen. Significant difference in yield at the 1 percent level was present between the two soils.

Average forage yields on the two soils combined as affected by fertilizer treatments indicated Am. Phos. > Super + Urea > Super > Check. The multiple range test at the 1 percent level shows significant differences occur only in comparing Am. Phos. or Super + Urea with Check. The multiple range test at the 5 percent level indicates that significant differences occur when comparing Am. Phos. with Super + Urea, Am. Phos. with Super, Am. Phos. with Check and Super + Urea with Check.

The means of forage yields at all fertilizers treatments on both soils show 2 ME > 1 ME > .5 ME, with significant differences at the 1 percent level occurring between each moisture level. The magnitude of the standard error in relation to the overall mean gave a calculated coefficient of variation of 14.11 percent.

The yields at all fertilizer treatments show Kirkland (2 ME) > Norge (2 ME) > Kirkland (1 ME) > Norge (1 ME) > Norge (.5 ME) > Kirkland

TABLE 7

Effect of various soil treatments on Redlan sorghum forage yield grown at three soil moisture levels on Kirkland silt loam and Norge fine sandy loam in the greenhouse

Source	d f	s s	m s	F
Soils	1	39.02	39.02	18.67**
Fertilizers	3	49.39	16.46	7.88**
Moisture	2	1217.88	608.94	291.36**
Soils x Fert.	3	4.41	1.47	.70
Soils x Moist.	2	153.78	76.89	36.79**
Fert. x Moist.	6	5.21	.87	.42
Soils x Moist. x Fert.	6	3.30	.55	.26
Reps. in soils	4	.58	.15	.07
Error	44	92.13	2.09	
Total	71	1565.70		

**Denotes significance at the 1 percent probability level

C. V. = 14.11%

TABLE 8

Multiple range test showing the effect of fertilizer treatments on yield of Redlan sorghum forage grown on Kirkland silt loam and Norge fine sandy loam in the greenhouse (see Table 7 for A. O. V. data)

$s_m = .3407$

Check	Super	Super + Urea	Am. Phos.
9.144	10.083	10.244	11.472

(5% p-level)

(1% p-level)

Multiple range test showing the effect of various soil and moisture combinations on the yield of Redlan sorghum forage grown on Kirkland silt loam and Norge fine sandy loam in the greenhouse

$s_m = .4082$ (1% p-level)

Kirk. (.5 ME)	Norge (.5 ME)	Norge (1 ME)	Kirk. (1 ME)	Norge (2 ME)	Kirk. (2 ME)
4.508	6.133	9.692	10.340	12.692	18.083

Note: Any two means not underscored by the same line are significantly different
Any two means underscored by the same line are not significantly different

Confidence limits for difference in treatment means

Fertilizer treatments (95%)

$s_m \times r_{.05} = 1.06$

Am. Phos. - Super + Urea,	.172 to 2.284
Am. Phos. - Super,	.333 to 2.445
Am. Phos. - Check,	1.272 to 3.384
Super + Urea - Check,	.044 to 2.156

Soil moisture treatments (99%) #

$s_m \times r_{.01} = 1.18$

2 ME - 1 ME,	4.20 to 6.55
2 ME - .5 ME,	8.89 to 11.24
1 ME - .5 ME,	3.51 to 5.87

Each moisture level was significantly different at the 1% probability level

(.5 ME) with a range of from 4.51 gms. on Kirkland silt loam at .5 ME to 18.08 on Kirkland silt loam at 2 ME (see Figures 3 and 6). The multiple range test shows the different soil and moisture combinations are not all significantly different (Table 8).

Nitrogen composition:

Percent nitrogen composition and analysis of variance data are shown in Table 9. A multiple range test of various soil and moisture combinations and confidence limits on various combinations of soil and moisture and moisture levels are shown in Table 10. Percent nitrogen decreased with each increase in soil moisture level at all fertilizer treatments. Percent nitrogen at each soil moisture level was significantly different at the 1 percent level.

Percent nitrogen means for all soil treatments were 1.466 for the Kirkland silt loam and 1.647 for Norge fine sandy loam. There was significant differences between composition of forage grown on the two soils at the 1 percent level. Significant differences in soils times moisture interactions were present at the 1 percent probability. Average percent nitrogen composition as affected by soils and moisture treatments indicated Norge (.5 ME) $>$ Kirkland (.5 ME) $>$ Norge (1 ME) $>$ Kirkland (1 ME) $>$ Norge (2 ME) $>$ Kirkland (2 ME). The multiple range test shows the difference between these are not all significant. Coefficient of variation for these data was 7.24 percent indicating low magnitude of standard error in relation to the overall percent nitrogen mean.

Phosphorus composition:

Percent phosphorus composition and analysis of variance data are shown in Table 11. A multiple range test and confidence limits for

TABLE 9

Effect of various soil treatments on the percent of nitrogen in Redlan sorghum forage grown at three soil moisture levels in the greenhouse

Treatments (lbs./A.)	Kirkland silt loam				Norge fine sandy loam			
	.5 ME	1 ME	2 ME	$\bar{X}$	.5 ME	1 ME	2 ME	$\bar{X}$
33.3-100-0 (Am. Phos. 13-39-0)	1.764	1.529	.949	1.414	1.865	1.865	1.579	1.770
33.3-100-0 (Urea 45% + Super 20%)	1.839	1.550	1.259	1.549	1.744	1.680	1.674	1.699
0-100-0 (Super 20%)	1.774	1.540	.850	1.388	1.669	1.375	1.445	1.496
Check (no fertilizer)	1.830	1.585	1.124	1.515	1.939	1.440	1.494	1.624
$\bar{X}$	1.802	1.551	1.046	1.466	1.804	1.590	1.584	1.647

The above percentage figures represent the mean of duplicate analyses obtained by combining plant materials grown on three replications

Analysis of variance of percent of nitrogen in forage

Source	d f	s s	m s	F
Fertilizers	3	.12109	.04036	3.29
Moisture	2	1.02742	.51371	44.24**
Soils	1	.19729	.19729	17.01**
Fert. x Moist.	6	.07887	.01314	1.23
Fert. x soils	3	.05573	.01858	1.79
Moist. x soils	2	.31078	.15539	13.39**
Error	6	.07631	.01272	
Total	23	1.86749		

**Denotes significance at the 1 percent probability level

C. V. = 7.24%

TABLE 10

Multiple range test showing the effect of various soil and moisture combinations on the percent of nitrogen in forage grown at three soil moisture levels in the greenhouse (see Table 9 for percent composition and A. O. V. data)

s_m = .0178 (5% p-level)

Kirk. (2 ME)	Norge (2 ME)	Kirk. (1 ME)	Norge (1 ME)	Kirk. (.5 ME)	Norge (.5 ME)
1.0455	1.5480	1.5510	1.5900	1.8017	1.8042

Note: Any two means not underscored by the same line are significantly different
Any two means underscored by the same line are not significantly different

Confidence limits for the difference in means of various soil and moisture combinations (only three of the eleven possible significant differences are presented)

$s_m \times r_{.05} = .0656$

Norge (2 ME) - Kirk. (2 ME),	.4369 to .5681
Kirk. (.5 ME) - Kirk (2 ME),	.6906 to .8218
Kirk. (.5 ME) - Norge (1 ME),	.1461 to .2773

Confidence limits for the difference in moisture level means

$s_m \times r_{.01} = .067$

.5 ME - 1 ME,	.166 to .300
.5 ME - 2 ME,	.439 to .573
1 ME - 2 ME,	.206 to .340

TABLE 11

Effect of various soil treatments on the percent phosphorus in Redlan sorghum forage grown at three soil moisture levels in the greenhouse

Treatments (lbs./A.)	Kirkland silt loam				Norge fine sandy loam			
	.5 ME	1 ME	2 ME	$\bar{X}$	.5 ME	1 ME	2 ME	$\bar{X}$
33.3-100-0 (Am. Phos. 13-39-0)	.0530	.0755	.0690	.0658	.0875	.0800	.0830	.0835
33.3-100-0 (Urea 45% + Super 20%)	.0630	.0725	.0695	.0683	.0860	.0890	.0770	.0840
0-100-0 (Super 20%)	.0665	.0710	.0770	.0715	.0860	.0815	.0785	.0820
Check (no fertilizer)	.0610	.0590	.0575	.0592	.0770	.0815	.0785	.0790
$\bar{X}$	.0609	.0695	.0682	.0662	.0841	.0830	.0792	.0821

The above percentage figures represent the mean of duplicate analysis on a composite sample obtained by combining three replications

Analysis of variance for percent phosphorus in forage

Source	d f	s s	m s	F
Fertilizers	3	.000220	.000073	1.97
Moisture	2	.000059	.000030	.81
Soils	1	.000536	.000536	14.49**
Fert. x Moist.	6	.000073	.000012	.32
Fert. x soils	3	.001075	.000358	9.68*
Moist. x soils	2	.000163	.000081	2.19
Error	6	.000220	.000037	
Total	23	.002346		

*Denotes significance at the 5 percent probability level
**Denotes significance at the 1 percent probability level

C. V. = 12.31%

soil and fertilizer combinations are shown in Table 12. Percent phosphorus composition means as affected by all soil treatments were .0662 for the Kirkland silt loam and .0821 for the Norge fine sandy loam. There was a significant difference at the 1 percent level between the phosphorus content of forage grown on the two soil types.

Percent phosphorus composition means as affected by soils and fertilizers show Norge (Super + Urea > Am. phos. > Super > Check) > Kirkland (Super > Super + Urea > Am. phos. > Check). However, the multiple range test shows these differences are not all significant, Table 12. The coefficient of variation for these data was 12.31% indicating a relatively low standard error in relation to the overall percent phosphorus mean.

Potassium composition:

Percent potassium composition and analysis of variance data are recorded in Table 13. Multiple range test and confidence intervals for soil treatments are shown in Table 14. Percent potassium means for all fertilizer treatments decreased with increases in soil moisture level. Percent potassium means at all fertilizer treatments show .5 ME > 1 ME > 2 ME with significant differences between moisture levels.

The average percent potassium for all soil treatments were 2.05 for the Kirkland silt loam and 2.22 for the Norge fine sandy loam, with a significant difference between results from the soils at the 1 percent level.

Percent potassium means as affected by fertilizer treatments indicated Check > Super + Urea > Am. Phos. > Super and ranged from 1.988 (Super) to 2.262 (Check). However, the multiple range test indicates significant differences exist only in comparing Check or Super + Urea with Super. The magnitude of the standard error in relation to the overall mean results in a comparatively low coefficient of variation of 5.11%.

TABLE 12

Multiple range test showing the effect of various combinations of fertilizers and soil on the percent phosphorus in forage (see Table 11 for percent composition and A. O. V. data)

s_m = .0035 (5% p-level)

Kirk. Check	Kirk. Am. Phos.	Kirk. Super + Urea	Kirk. Super	Norge Check	Norge Super	Norge Am. Phos.	Norge Super + Urea
.0592	.0658	.0683	.0715	.0790	.0820	.0835	.0840

Note: Any two means not underscored by the same line are significantly different
Any two means underscored by the same line are not significantly different

Confidence limits for difference in means of various combinations of soil and fertilizers (only four of eleven possible significant differences are presented)

$s_m \times r_{.05}$ = .0129 (5% p-level)

Norge(Super) - Kirk.(Super + Urea),	.0007 to .0266
Norge(Check) - Kirk.(Check),	.0068 to .0327
Norge (Am. Phos.) - Kirk.(Am. Phos.),	.0051 to .0390
Norge (Super + Urea) - Kirk.(Check),	.0118 to .0377

TABLE 13

Effect of various soil treatments on the percent potassium in Redlan sorghum forage grown at three soil moisture levels in the greenhouse

	Kirkland silt loam				Norge fine sandy loam			
Treatments (lbs./A.)	.5 ME	1 ME	2 ME	$\bar{X}$	.5 ME	1 ME	2 ME	$\bar{X}$
33.3-100-0 (Am. Phos. 13-39-0)	2.46	1.94	1.58	1.99	2.74	1.96	1.92	2.21
33.3-100-0 (Urea 45% + Super 20%)	2.52	1.94	1.64	2.03	2.82	2.30	1.90	2.34
0-100-0 (Super 20%)	2.34	1.80	1.72	1.95	2.46	1.92	1.69	2.02
Check (no fertilizer)	2.43	2.36	1.84	2.21	2.60	2.20	2.14	2.31
$\bar{X}$	2.44	2.01	1.69	2.05	2.65	2.09	1.91	2.22

The above percentage figures represent the mean of duplicate analysis on a composite sample obtained by combining three replications

Analysis of variance of percent potassium in forage

Source	d f	s s	m s	F
Fertilizers	3	.2487	.0829	7.025*
Moisture	2	2.2852	1.1426	96.010**
Soil	1	.1800	.8000	15.120**
Fert. x Moist.	6	.1372	.0228	1.910
Fert. x soils	3	.0527	.0175	1.47
Moist. x soils	2	.0237	.0118	.99
Error	6	.0715	.0119	
Total	23	2.2999		

*Denotes significance at the 5 percent probability level
**Denotes significance at the 1 percent probability level

C. V. = 5.11%

TABLE 14

Multiple range test showing the effect of various soil treatments on the percent potassium in forage (see Table 13 for percent composition and A. O. V. data)

$s_m = .045$ (5% p-level)

Super	Am. Phos	Super + Urea	Check
1.988	2.100	2.183	2.262

Note: Any two means not underscored by the same line are significantly different
Any two means underscored by the same line are not significantly different

Confidence limits for difference in various soil treatments

Fertilizer treatments (95%)

$s_m \times r_{.05} = .1621$

Check - Super,	.1112 to .4354
Super + Urea - Super,	.0329 to .3571

Soil moisture treatments (99%) #

$s_m \times r_{.01} = .2125$

.5 ME - 1 ME,	.2810 to .7060
.5 ME - 2 ME,	.5298 to .9548
1 ME - 2 ME,	.0363 to .4613

Each moisture level was significantly different at the 1% probability level

SUMMARY AND CONCLUSIONS

The objective of this study was to compare the plant response from four fertilizers treatments including superphosphate and ammonium phosphate as sources of fertilizer phosphorus. Each fertilizer treatment was maintained at three soil moisture levels on two contrasting soil types in a greenhouse experiment. The soils used in this experiment were classified as Kirkland silt loam and Norge fine sandy loam. The fertilizer treatments used included: 33.3-100-0 as Ammonium Phosphate (13-39-0), 33.3-100-0 as Superphosphate 20% + Urea 45%, 0-100-0 as Superphosphate 20% and Check (no fertilizer). The soil moisture treatments used were: .5 Moisture Equivalent, 1 Moisture Equivalent and 2 Moisture Equivalents. Redlan sorghum (Sorghum vulgare Pers.) was used as an indicator crop. The conclusions made from this study were based on the yield and nitrogen, phosphorus and potassium composition of the forage harvested from the greenhouse pots.

The following conclusions were based on results and statistical analyses of the data obtained from this experiment.

1. On the Kirkland silt loam, Ammonium Phosphate, Superphosphate and Superphosphate + Urea treatments gave similar yields. However, all three gave significantly higher yields than the Check treatment.
2. On the Norge fine sandy loam, Superphosphate + Urea, Superphosphate and Check treatments gave similar yields. Ammonium Phosphate gave significantly higher yields than all the other fertilizer treatments.

3. On both the Norge fine sandy loam and the Kirkland silt loam, highly significant differences in yields were obtained at the three soil moisture levels.

4. Yields on both soils showed the Ammonium Phosphate treatment produced significantly higher yields (5 percent level) than the other fertilizer treatments. The Ammonium Phosphate treatment gave consistently higher forage yields at three moisture levels on both soils.

5. Combining yield data from both soils, the soil times moisture interaction significantly affected the yield. Ranked in the order of decreasing yields with significance at the 1 percent level they are as follows: Kirkland (2 ME), > Norge (2 ME), > Kirkland (1 ME), Norge (1 ME), > Norge (.5 ME), > Kirkland (.5 ME).

6. Percentages of nitrogen and potassium in the forage were significantly greater at the 1 percent level from forage grown at .5 ME than from the forage grown at 1 ME or 2 ME. The percent nitrogen and potassium was also significantly greater from the forage grown at 1 ME than from the forage grown at 2 ME moisture level.

7. The greatest percentages of nitrogen, phosphorus and potassium was obtained in the forage grown on Norge fine sandy loam.

8. Moisture times soil interaction affected the percent of nitrogen in the forage. Ranked in the order of decreasing percentages with significance at the 5 percent level they are as follows: Norge (.5 ME) and Kirkland (.5 ME), > Norge (1 ME), Kirkland (1 ME) and Norge (2 ME), > Kirkland (2 ME).

9. The percent phosphorus in the forage increased with all phosphorus fertilizer treatments on both soils. There was significant differences at the 5 percent level between phosphorus content as affected

by fertilizer treatment and soil interaction. The increase in phosphorus content was as follows: Kirkland silt loam, Super > Super + Urea > Am. Phos. > Check; Norge fine sand loam, Super + Urea > Am. Phos. > Super > Check.

10. The fertilizer treatments showed a significant effect on the percent potassium in the forage at the 5 percent level. Ranked in the order of decreasing percentages they were as follows: Check > Superphosphate + Urea > Ammonium Phosphate > and Superphosphate.

LITERATURE CITED

1. Beater, B. E. The value of preliming, primarily as a means of improving the absorption of phosphorus by plants. Soil Sci., 60:337-352. 1945.

2. Bouyoucos, G. J. Directions for making the mechanical analyses of soils by the hydrometer method. Soil Sci., 42:225-228. 1936.

3. Briggs, L. J. and McLane, H. L. The moisture equivalent of soils. U. S. Dept. Agri. Bur. Soils Bull., 45:1-23. 1907.

4. Briggs, L. J. and Shantz, H. L. The wilting coefficient for different plants and its indirect determination. U. S. Dept. Agri. Bur. Soils Bull., 230:1-83. 1912.

5. Brown, Lindsey A. A study of phosphorus penetration and availability in soils. Soil Sci., 39:227-287.

6. Brown, W. E. Unpublished manuscript to be presented at the November, 1956 meetings of the Soil Science Society of America, Cincinnati, Ohio.

7. Chaffin, W. A soil improvement program for Oklahoma. Okla. Ext. Cir., No. 412. 1945.

8. Chemistry and Physics Hand Book 1945. Ind. and Eng. Chem. Anal. Ed. 1935.

9. Cook, R. L. Divergent influence of degree of base saturation of soils on the availability of native, soluble, and rock phosphate. Jour. Amer. Soc. Agron., 27:297-317. 1935.

10. Copeland, O. L. and Merkle, F. G. The influence of certain soil treatments upon the fixation and availability of applied phosphates. Soil Sci. Soc. Amer. Proc., 6:321-327. 1941.

11. Dalton, Joseph D., Russel, Glenn C. and Siebling, Dale H. Effect of organic matter on phosphate availability. Soil Sci., 73:173-180. 1952.

12. Davies, F. F. and Sieglinger, J. Dwarf kafir 44-14 and Redlan two new combine-type grain sorghums. Okla. Agri. Exp. Sta., Bull. 384.

13. Duncan, D. B. Multiple range and multiple F test. Biometrics II., No. 1:1-42. March 1955.

14. Fudge, Franklin J. Influence of various nitrogenous fertilizers on phosphorus availability. Jour. Amer. Soc. Agron., 20:280-293. 1928.

15. Fuller, W. H. Effect of kind of phosphate fertilizer and method of placement on phosphorus absorption by crops grown on Arizona calcareous soils. Ariz. Agri. Exp. Sta. Tech., Bull. 128. 1953.

16. Green, Jesse. The response of individual plants and of individual crops to phosphate fertilizers. Amer. Fert. 102:11. 1945.

17. Harper, H. J. Determination of the easily soluble phosphorus in Soils. Science., 76:415-416. 1932.

18. Harper, Horace J. Easily soluble phosphorus in Oklahoma soils. Okla. Agri. Exp. Sta., Bull. 205. 1932.

19. Heck, Floyd A. Phosphate fixation and penetration in soils. Soil Sci., 37:343-355. 1934.

20. Heslep, J. M. and Black, C. A. Diffusion of fertilizer phosphorus in soils. Soil Sci., 78:389-410. 1954.

21. Hibbard, P. L. Factors influencing phosphate fixation in soils. Soil Sci., 39:337-358. 1935.

22. Hinkle, D. A. Efficiency of various phosphate fertilizers on calcareous soils for alfalfa and sweet clover. Jour. Amer. Soc. Agron., 34:913-918. 1942.

23. Jacob, K. D. Editor. "Fertilizer Technology and Resources in the United States." Agronomy Monographs, Vol. III, Academic Press Inc. N. Y., 1953.

24. Jones, U. S. Phosphate fertilizers. Miss. Agri. Exp. Sta. Bull., 503. 1953.

25. Lawton, K. and Cook, R. L. Interaction between particle size and water solubility of phosphorus in mixed fertilizers as factors affecting plant availability. Farm Chem., 118:44-46. 1955.

26. Lewis, Glenn C., Baker, G. O. and Snyder, R. S. Phosphate fixation in calcareous soils. Soil Sci., 69:55-62. 1950.

27. Loscin, C. L. and Guillermo, R. J. The fertilization effects of various forms of phosphorus compounds on sugar cane grown in the Victorios-Monopla-Cadiz district. Soil Sci. Soc. Phill. Proc., 7:6-19. 1955.

28. Lynd, J. Q. Grass-legume band seeding with a shoe type drill. Agron. Jour., 47:195-196. 1955.

29. McIntire, W. H. A new explanation of what happens to superphosphate in limed soils. Jour. Amer. Soc. Agron., 33:1093-1099. 1941.

30. MacLean, A. J. and Cook, R. L. The effect of soil reaction on the availability of phosphorus for alfalfa in some eastern Ontario soils. Soil. Sci. Soc. Amer. Proc., 19:311-314. 1955.

31. Methods of Analyses, Assoc. Official Agri. Chem. 6th Edition, page 14-16. 1945.

32. Midgley, A. R. The movement and fixation of phosphate in relation to permanent pasture fertilization. Jour. Amer. Soc. Agron., 23:778-799. 1931.

33. Moser, F. Fixation and recovery of phosphate from some lateritic soils. Soil Sci. Soc. Amer. Proc., 6:328-334. 1941.

34. Olsen, Sterling R., Schmehl, Franks., Watanabe, Franke S., Scott, C. O., Fuller, W. H., Jordan, J. V. and Kunkel, Robert. Utilization of phosphorus by various crops as affected by source of material and placement. Colo. Agri. Exp. Sta. Tech., Bull. 42. 1950.

35. Owen, L., Lawton, K., Robertson, L. S. and Apostolakis, C. Laboratory, greenhouse and field studies with mixed fertilizers varying in water soluble content and particle size. Soil Sci. Soc. Amer. Proc., 19:315-319. 1955.

36. Peech. M. and English, L. Rapid microchemical soil tests. Soil Sci., 57:167-195. 1944.

37. Pierre, W. H. and Norman, A. G. Editors. Soil and Fertilizer Phosphorus in Crop Nutrition. Agronomy Monographs, Vol. IV. Academic Press Inc. New York, N. Y. 1953.

38. Piper, C. S. Soil and plant analysis. Interscience publishers, Inc. New York, N. Y. 1950.

39. Schollenberger, C. J. A rapid approximate method for determining soil organic matter. Soil Sci., 24:65-68. 1927.

40. Shelton, W. R. and Harper, H. J. A rapid method for the determination of total phosphorus in soil and plant material. Iowa State College Jour. of Sci., 15:403-408. 1951.

41. Snedecor, G. W. Statistical methods, 4th Edition. The Iowa College Press. Ames, Iowa. 1946.

42. Speer, Robert J., Allen, Seward E., Maloney, Margaret and Roberts, Ammarette. Phosphate fertilizers for the Texas blackland: Relative availability of various phosphate fertilizers. Soil Sci., 72:454-469. 1951.

43. Stephenson, R. E. and Chapman, H. D. Phosphate penetration in field soils. Jour. Amer. Soc. Agron., 23:759-770. 1931.

44. Toth, S. J. Estimation of cation-exchange capacity and exchangeable Ca, K and Na contents of soils by the flame photometer techniques. Soil Sci., 67:439-445. 1949.

45. Volk, Garth W. Availability of rock and other phosphate fertilizers as influenced by lime and form of nitrogen fertilizer. Jour. Amer. Soc. Agron., 36:46-56. 1944.

A P P E N D I X

TABLE 15

Effect of various soil treatments on Redlan sorghum forage yield grown at three soil moisture levels in the greenhouse

	Dry wt. yields (gms) at three soil moisture levels							
	Kirkland silt loam				Norge fine sandy loam			
Treatments (lbs./A.)	.5 ME	1 ME	2 ME	X̄	.5 ME	1 ME	2 ME	X̄
33.3-100-0	5.5	10.6	18.0		7.7	10.8	17.1	
(Am. Phos. 13-39-0)	5.5	13.3	19.0		7.6	12.1	12.2	
	5.0	10.4	21.4	12.08	5.7	11.2	13.4	10.87
33.3-100-0	4.1	10.0	22.7		7.0	10.4	10.7	
(Urea 45% + Super 20%)	3.3	11.8	17.8		6.9	8.8	13.4	
	4.7	10.1	15.7	11.13	5.3	8.5	13.6	9.40
0-100-0	5.7	11.3	16.5		6.7	9.8	11.3	
(Super 20%)	4.1	10.5	19.4		4.9	10.1	11.1	
	4.8	10.6	17.4	11.14	5.8	8.6	12.9	9.02
Check	3.3	8.8	16.7		4.5	8.7	9.8	
(no fertilizer)	4.1	9.1	15.2		5.8	8.4	12.5	
	4.0	7.6	17.2	9.56	5.7	8.9	14.3	8.73
X̄	4.51	10.34	18.08	10.98	6.13	9.69	12.69	9.51

All pots received the equivalent of 2000 lbs./A. $CaCO_3$

Figure 1. Effects of various soil treatments showing: 1. Am. Phos., 2. Super. + Urea, 3. Super. and 4. Check at .5 ME on Kirkland silt loam

Figure 2. Effects of various soil treatments showing: 1. Am. Phos., 2. Super. + Urea, 3. Super. and 4. Check at 1 ME on Kirkland silt loam

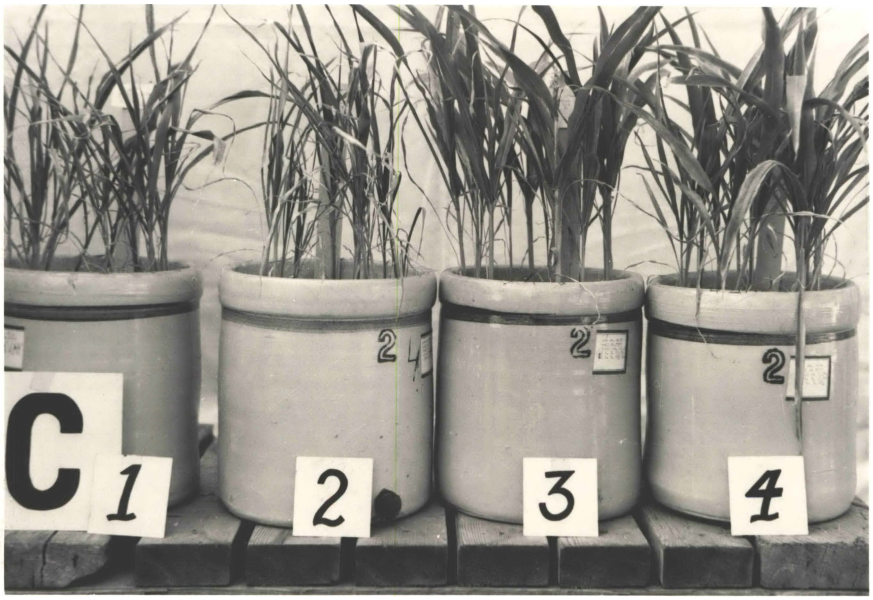

Figure 3. Effects of various soil treatments showing: 1. Am. Phos. at .5 ME, 2. Super + Urea at .5 ME, 3. Am. Phos. at 1 ME, 4, Super + Urea at 1 ME on Kirkland silt loam

Figure 4. Effects of various soil treatments showing: 1. Am. Phos., 2. Super + Urea, 3. Super and 4. Check at .5 ME on Norge fine sandy loam

Figure 5. Effects of various soil treatments showing: 1. Am. Phos., 2. Super + Urea, 3. Super and 4. Check at 1 ME on Norge fine sandy loam

Figure 6. Effects of various soil treatments showing: 1. Am. Phos. at .5 ME, 2. Super + Urea at .5 ME, 3. Am. Phos. at 1 ME, 4. Super + Urea at 1 ME on Norge fine sandy loam

VITA

Norman Howard Welch

candidate for the Degree of

Master of Science

Thesis: COMPARATIVE AVAILABILITY OF PHOSPHORUS FROM SUPERPHOSPHATE AND AMMONIUM PHOSPHATE AT DIFFERENT SOIL MOISTURE LEVELS

Major: Soils

Biographical:

Personal data: Born at Checotah, Oklahoma, December 30, 1931, the son of Richard Lee and Ada Mae Welch.

Education: Attended elementary school at Onapa, Oklahoma and was graduated from Onapa High School in 1949; undergraduate study at Oklahoma Agricultural and Mechanical College, Stillwater, Oklahoma, 1949-1953. Graduate study completed at Oklahoma Agricultural and Mechanical College, 1955-1956.

Experiences: Reared on a farm. Employed by Bureau of Indian Affairs, summer of 1952. Served in the United States Army 1953-1955.

Member of Agronomy Club.

Date of Final Examination: July, 1956.