MOISTURE-NITROGEN RELATIONSHIPS IN WINTER WHEAT PRODUCTION

By

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CHAPTER I

INTRODUCTION

Efficient crop production in dryland regions depends on obtaining maximum yields with the limited supply of water available. Many attempts at predicting wheat yields based upon soil moisture at seeding were made long before nitrogen fertilization became an important production tool in the Great Plains. Attempts to predict wheat yields based upon soil moisture at seeding have met with varying degrees of success. In areas where dry conditions from seeding to harvest can be expected, yields can be predicted fairly well on the basis of subsoil moisture at seeding time. However, the reliability of the estimate is decreased as precipitation during the growing season increases.

Organic matter and nitrogen levels have declined materially in cultivated Great Plains soils since they were plowed from native sod. As a result, nitrogen is the nutrient that generally limits crop production in these soils when moisture supplies are adequate. Still, highly variable responses of winter wheat to applications of nitrogen fertilization have been demonstrated by many experiments. Soil moisture and available nitrogen supply in the soil are two factors that have contributed to these variable responses.

An important objective of this study was to evaluate the effects of available soil moisture at seeding and at topdressing, precipitation during the growing season, and levels of nitrogen fertilization on the yield of winter wheat in north central Oklahoma. It was a purpose of this study to develop multiple regression equations to aid in determining the rate of nitrogen to apply in the spring as a topdressing to obtain the optimum yield of winter wheat per pound of nitrogen applied, with available soil moisture at topdressing and probable rainfall during the growing season serving as indicators of the amount of nitrogen fertilizer required for a given yield level. Therefore, the overall objective of this study was to develop an effective means of calculating expected yields of winter wheat for a given year, thereby reducing the risk involved in nitrogen topdressing of winter wheat.

CHAPTER II

LITERATURE REVIEW

The amount of moisture in the soil at wheat seeding time is generally regarded as playing a vital role in wheat production. Finnell (6)[1] stated that stored moisture is the most important measurable factor affecting the success of the crop. From experience gained at Hays, Colby, and Garden City, Kansas, Hallsted and Mathews (7) made estimates of the probability of winter wheat failing or yielding in a specified range with a specified depth of soil moisture at planting time. They stated that when the soil was wet to a depth of 1 and 2 feet the chances of the yield exceeding 10 bushels per acre were 18 and 62 in 100, respectively. Compton (4) also derived a mathematical relationship between depth of moist soil and wheat yield for use in western Kansas. He indicated that yields would be increased an average of 4.25 bushels per acre for each foot-depth increment of moist soil.

In a generalized study of spring wheat yields at 15 Great Plains locations, Cole and Mathews (3) found that when the soil was wet to a depth of a foot or less at seeding, average yields ranged from 6.3 to 6.9 bushels per acre. With a 2-foot depth of moist soil, yields ranged from 11.7 to 12.6 bushels per acre and were only slightly higher for wheat on fallow than for continuous wheat. They estimated that with a

[1]Figures in parenthesis refer to Literature Cited.

2-foot depth of moist soil at seeding a yield of 10 bushels per acre would occur at least half of the time.

Pengra (16) investigated the feasibility of estimating spring wheat yields at seeding time in South Dakota from the amount of preseasonal precipitation (that occurring between harvest time of the preceding crop and seeding time in the spring, an interval of 8 or 9 months). He decided that this procedure would be useful in the drier part of the state within the boundaries of the Great Plains, where seasonal precipitation (that occurring during the 3½ months from seeding to harvest) is less than 11 inches. From regression analyses he estimated that yields of spring wheat increased from 1 to 2.5 bushels per acre per inch increment of preseasonal precipitation. Pengra also noted that above-normal seasonal precipitation seldom occurred in years when there was a marked deficiency in stored moisture, but that a majority of the years having good stored moisture had above-average seasonal rainfall. However, correlation coefficients for wheat yields and preseasonal precipitation in the areas receiving more than 11 inches of precipitation during the growing season were not significant.

From an analysis on yield and moisture data for winter wheat obtained at Garden City and Colby, Kansas, Mathews and Brown (12) concluded that each inch of water used by the crop above a threshold amount of 7 or 8 inches increased yield an average of about 2 bushels per acre. Their studies showed that an inch of stored moisture and an inch of precipitation during the growth of the crop made about the same contribution to yield. They estimated that in years when yield-reducing factors other than moisture were not pronounced the contribution of an inch of water to yield might be as much as 3½ bushels per acre.

Thomas et al. (24) made detailed statistical studies of yield-moisture relationships for spring wheat in the Dakotas and Montana. Linear regression analysis indicated that stored moisture accounted for only from 1.3 to 34% of the variability in yield, whereas seasonal precipitation accounted for from 11 to 73.7% of the yield variance. It was concluded that predicting yields on the basis of either of these criteria was so uncertain as to be impractical.

In a study of cultural practices and winter wheat production at Woodward, Oklahoma, Locke and Mathews (11) found that the correlation computed between stored soil moisture and yield on early plowed continuous wheat (plowed immediately after harvest) was below the level required for significance. Also, they compared yields of winter wheat or winter rye produced on pairs of plots that had different levels of stored soil moisture in the same year. In 118 of 123 comparisons, using data obtained over a period of 25 years, they found that the plot having more stored moisture yielded more. It appeared that the disturbing effect of extraneous factors, which tend to mask the relationship between stored moisture and yield, could be greatly reduced by comparing moisture levels and yield levels in the same year.

Staple and Lehane (23) summarized twelve years' data on the use of moisture by wheat crops at seven Experimental Substations in southern Saskatchewan. The linear regression of yield on evapo-transpiration showed an increase of 3.5 bushels per acre for each additional inch of water used by the crop. The estimate of yield was significantly improved when rainfall and stored moisture were used as separate variables. The regression coefficient for rainfall was 1.5 times that for stored moisture at seeding time.

Under dryland conditions the maximum yield potential for any given season will be determined largely by the amount of moisture available for the crop. This moisture is comprised of water stored in the soil during the winter and the rain which falls during the growing season. To use the available moisture efficiently, and, hence, obtain high yields, enough nitrogen and other nutrients must be available. Because of the decline in soil organic matter through the years of cropping, the amount of available nitrogen released by many soils in inadequate to support high wheat yields. The introduction of higher yielding varieties, as well as improved and more timely tillage, has increased the yield potential of the land. These practices have accentuated the nitrogen deficiency by increasing the demand for nitrogen by the crop. Consequently, to obtain maximum wheat yields under these conditions, additonal nitrogen must be applied.

The efficiency of nitrogen applications in increasing wheat yields is largely dependent upon the available soil moisture supply during the growing season (9, 13). Ramón and Laird (18) conducted a field study of the influence of soil moisture conditions and nitrogen fertilization on the yield and protein content of wheat produced on a heavy clay soil in central Mexico. Wheat was irrigated at the following available moisture percentages (just prior to irrigating): 67, 55, 40, and 1. Nitrogen was applied at the rate of 0, 45, 95, and 135 pounds per acre. Grain yields were increased from 10.2 to 66.5 bushels per acre in the optimum soil moisture treatment (irrigating at 55% available soil moisture) and from 9.7 to 35.9 bushels per acre in the driest treatment by the application of 135 pounds of nitrogen per acre. Grain yields were increased by 85% and straw yields by 187% due to soil moisture differences in the wheat fertilized with 135 pounds of nitrogen per acre. The protein content of the grain was lowest in the wettest treatment and highest in the driest treatment.

Leggett (10) analyzed the results of a large number of wheat fertility experiments in eastern Washington to determine the relationships which exist between available moisture and wheat yield and between available nitrogen and wheat yield. Analysis of the data using linear regression techniques gave a correlation coefficient of 0.87 between available soil moisture in the spring plus the rainfall during the growing season and wheat yields. Approximately 4 inches of water were required to produce the first bushel of wheat and 5.8 bushels of wheat per acre were produced for each additional inch of water available to the crop. When the available soil moisture and rainfall during the growing season were treated as separate variables, the reliability of the estimate was lowered. This indicates that soil moisture plus rainfall during the growing season is more closely related to yield than is either soil moisture or rainfall alone. The regression equation indicated that rainfall during the growing season was slightly more effective than was soil moisture in increasing wheat yields. In the anaylsis of the relationship between available nitrogen and the yield of wheat a correlation coefficient of 0.74 was obtained. The slope of the regression line indicated that approximately 3 pounds of nitrogen per acre were required to increase the wheat yield 1 bushel per acre over the range where nitrogen was limiting yield.

Ramig and Rhoades (17) undertook a 3-year field investigation at North Platte, Nebraska, to obtain information on the interrelationships of the effects of the preplanting soil moisture level and applications of nitrogen fertilizer on winter wheat production. Soil moisture levels of approximately 0, 3, 6, and 8 inches of available moisture in the 6-foot soil profile were established and nitrogen treatments of 0, 20, 40, and 80 pounds of nitrogen per acre were applied. Yield data were fitted with multiple linear regression equations with pounds of nitrogen applied per acre and inches of available soil moisture at seeding time as variables. From 70 to 85% of the variation in grain yield was accounted for by these 2 factors. In contrast, only 32 to 59.7% of the variation in wheat straw yield could be accounted for by preplanting soil moisture and rate of nitrogen fertilization. Percentage nitrogen in the grain increased as more nitrogen fertilizer was applied, but decreased as preplanting moisture level increased. Yield-of-nitrogen curves revealed greater nitrogen uptake as rate of nitrogen fertilization and preplanting soil moisture increased. Maximum yields of wheat resulted from the application of 20 pounds of nitrogen per acre for every 3 inches of available preplanting soil moisture. Water use and water-use efficiency increased as available soil moisture and rate of nitrogen fertilization increased.

Bauer et al. (1) conducted a series of fertility trials in North Dakota to evaluate effects of seasonal rainfall and stored available soil moisture at seeding on yield responses of spring-sown wheat and barley at varying rates of applied nitrogen. Average grain yields increased as rainfall increased, both without and with fertilizer. The magnitude of response, as well as the rate of nitrogen fertilizer needed for maximum yield, also increased as rainfall increased. With more stored available soil moisture at seeding, less seasonal rainfall was required to produce profitable responses to nitrogen. There were slightly higher correlations between yield and total moisture than with either precipitation or stored available soil moisture at seeding alone.

Olson et al. (15) found that when wheat yields were increased 6 bushels per acre because of fertilization, the plants were 12% more efficient in water usage. A precaution should be noted, however, when additional fertilizer applications are made because of increased quantities of water storage. In dryland conditions in semi-arid regions fertilization can cause wheat plants to grow rapidly during early stages and deplete soil moisture to critical levels (14). An early depletion of the soil water could result in reduced grain yields because of extensive vegetative growth early in the season and poor seed production late in the season. Olson and Rhoades (14) have referred to this phenomenon as "overstimulation".

CHAPTER III

CHEROKEE EXPERIMENT

The data analyzed in this experiment were taken from results of a continuous field experiment initiated in 1955 at the Wheatland Conservation Experiment Station, Cherokee, Oklahoma. The objective of this study was to determine the influence of available soil moisture at seeding and at topdressing time, rainfall during the growing season, and level of nitrogen fertilization on the yield and quality of hard red winter wheat at the same location over a period of nine years.

Materials and Methods

A completely randomized design was employed, consisting of a total of 24 plots. The size of each plot was determined by land slope and configuration. The experiment was located on a deep, medium-textured, moderately permeable Grant silt loam. Both stubble mulched and clean tilled continuous wheat (Kaw variety) were included in the experiment. Soluble phosphate was applied to all plots at the rate of 20 pounds of P_2O_5 (9 pounds of P) per acre at seeding. Half of the plots received 40 pounds of nitrogen applied as a topdressing at the beginning of spring growth, which is usually about the middle of March. The remaining 12 plots received no nitrogen fertilizer.

Soil moisture was determined immediately following seeding of wheat in the fall and also at the time of topdressing in the spring. Samples were taken at soil depths as follows: 0 to 6 inches; 6 to 12 inches; and in foot layers thereafter to a depth of 4 feet. Soil moisture percentages were determined by drying to constant weight at 105°C. Precipitation was measured by ten recording rain gages and average values for rainfall were calculated. Precipitation during the growing season was taken to be that occurring from topdressing time to the end of May.

The soil samples collected for moisture determinations were used in further analyses. Fifteen-atmosphere percentages were determined by the pressure membrane method described by Richards (19). Available soil moisture was considered to be the moisture above the fifteen-atmosphere percentage. Fifteen-atmosphere percentage has been shown to approximate permanent wilting point (20) and is used for that purpose. Bulk densities of the various depths of the soil samples were determined by weighing dried samples of a fixed volume taken with a Veihmeyer sampling tube. Each bulk density value is based on weights of six replicates.

Soil pH was determined by use of a Beckman glass electrode pH meter on a 1:1 soil-water paste. The cation exchange capacity was determined by using ammonium acetate extractant (8). The Beckman DU spectrophotometer with flame attachment was used to determine the amounts of potassium, calcium, magnesium, and sodium in the filtrate obtained from the cation exchange capacity determination. Available soil phosphorus was extracted using Bray and Kurtz (2) No. 1 extracting solution. The organic matter content was determined by the potassium dichromate wet-oxidation method of Schollenberger (22). Results of the soil analyses are presented in Table X (Appendix).

The wheat was harvested with a combine, the grain carefully weighed, and yields calculated. Straw yields were determined for 8 of the 9 years at harvest time on each plot from three representative samples of two rod rows each. Total nitrogen content of the grain was determined for 6 of the 9 years of the experiment by the Kjeldahl method using the boric acid modification described by Scales and Harrison (21). Nitrogen recovery in the grain harvested from each plot was calculated for all years in which data was available.

Yield data were fitted with multiple regression equations of the general form: $Y = b_o + b_1x_1 + b_2x_2$, where: Y is the estimated yield in bushels per acre, b_o is the intercept, b_1 and b_2 are partial regression coefficients, and x_1 and x_2 are variables - pounds of nitrogen applied per acre, inches of available soil moisture at seeding or at topdressing time, precipitation from seeding to harvest or from topdressing time to harvest, and total moisture supply.

Results and Discussion

During the nine years for which data was available, a wide range of moisture conditions was encountered. Moisture in 1956 was very low and in 1959 and 1961 spring precipitation was above normal. The data for 1957 was omitted from this analysis because of severe lodging due to heavy rains at harvest, resulting in a very substantial reduction in yield. Yields in 1960 were also damaged due to heavy rains just prior to harvesting. A summary by months and years for precipitation is given in Table I.

Yields ranged from 18.6 bushels per acre without nitrogen in 1956 to 47.9 bushels per acre with 40 pounds of nitrogen in 1961. The yield data for all years is presented in Table II.

To establish different moisture levels, the data for all nine years

TABLE I

SUMMARY OF TOTAL PRECIPITATION AND DEPARTURES FROM NORMAL
CHEROKEE, OKLAHOMA

Month	1956 Total inches	1956 Departure inches	1958 Total inches	1958 Departure inches	1959 Total inches	1959 Departure inches
July	1.65	-0.47	2.19	+0.14	4.31	+2.21
August	1.27	-1.81	0.54	-2.46	3.04	+0.04
September	3.96	+1.42	6.22	+3.66	3.17	+0.57
October	2.09	-0.14	2.50	+0.29	0.39	-1.78
November	0.00	-1.40	1.44	+0.05	0.97	-0.41
December	0.00	-0.94	0.17	-0.77	0.31	-0.61
January	0.11	-0.69	0.73	-0.08	0.22	-0.79
February	0.11	-0.77	0.09	-0.79	0.12	-0.74
March	0.52	-0.92	2.28	+0.75	1.68	+0.15
April	0.33	-2.50	1.79	-1.14	3.05	+0.12
May	1.08	-2.69	1.75	-2.06	6.45	+2.58
June	2.20	-1.46	5.97	+2.10	1.34	-2.48
Yearly	13.32	-12.37	25.66	-0.39	25.05	-0.97

TABLE I (Continued)

Month	1960 Total inches	1960 Departure inches	1961 Total inches	1961 Departure inches	1962 Total inches	1962 Departure inches
July	0.66	-1.41	5.59	+3.44	1.66	-0.48
August	1.69	-1.28	2.80	-0.17	2.54	-0.42
September	6.22	+3.57	2.34	-0.31	3.16	+0.50
October	5.08	+2.85	3.60	+1.33	1.98	-0.28
November	0.13	-1.23	0.35	-0.98	2.19	+0.84
December	1.15	+0.22	1.36	+0.42	0.94	0.00
January	1.15	+0.35	0.08	-0.79	0.34	-0.45
February	1.67	+0.77	0.29	-0.57	0.10	-0.75
March	0.78	-0.74	4.16	+2.59	0.26	-1.28
April	0.90	-1.99	1.44	-1.42	2.36	-0.49
May	4.66	+0.77	5.26	+1.34	1.67	-2.20
June	3.35	-0.46	5.24	+1.40	5.32	+1.45
Yearly	27.44	+1.39	32.51	+6.30	22.53	-3.59

TABLE I (Continued)

Month	1963 Total inches	1963 Departure inches	1964 Total inches	1964 Departure inches	1965 Total inches	1965 Departure inches
July	4.57	+2.43	4.90	+2.66	0.15	-2.09
August	2.35	-2.61	1.69	-1.19	5.37	+2.49
September	3.32	+0.66	3.92	+1.22	0.86	-1.84
October	0.99	-1.27	0.73	-1.47	1.50	-0.70
November	1.02	-0.33	1.35	+0.01	5.84	+4.50
December	0.73	-0.21	0.13	-0.79	1.12	+0.20
January	0.38	-0.40	0.72	-0.05	0.01	-0.76
February	0.08	-0.77	0.89	+0.06	0.74	-0.09
March	1.31	-0.23	0.60	-0.92	0.85	-0.67
April	2.18	-0.67	2.10	-0.70	1.96	-0.84
May	2.07	-1.80	2.07	-1.73	2.07	-1.73
June	8.58	+4.71	3.30	-0.65	2.08	-1.87
Yearly	25.56	-0.56	22.41	-3.62	22.55	-3.40

TABLE II

GRAIN YIELDS, PERCENT GRAIN NITROGEN, YIELD OF GRAIN NITROGEN, AND STRAW YIELDS AT CHEROKEE, OKLAHOMA, 1956-1965

Year	Rate of Nitrogen	Grain Yield	Grain Nitrogen	Yield of Grain Nitrogen	Straw Yield
	lbs./acre	bu./acre	%	lbs./acre	tons/acre
1956	0	18.6	*M	M	1.51
	40	19.3	M	M	1.72
1958	0	33.3	M	M	2.07
	40	38.8	M	M	3.10
1959	0	27.0	M	M	1.40
	40	43.0	M	M	2.94
1960	0	17.8	2.04	21.8	M
	40	31.7	2.55	48.5	M
1961	0	36.2	1.39	30.2	1.77
	40	47.9	1.92	55.2	3.28
1962	0	19.7	1.82	21.5	0.86
	40	26.7	2.57	41.2	1.73
1963	0	20.9	1.88	23.6	0.94
	40	28.7	2.64	46.8	1.61
1964	0	24.0	1.79	25.8	1.10
	40	29.0	2.80	48.7	1.88
1965	0	25.4	1.71	26.1	1.12
	40	39.5	2.29	54.3	2.12

*M indicates missing data.

were combined for the regression analysis. Table III shows the soil moisture contents and total moisture supply available to the crop for each year of the study. At Cherokee precipitation from seeding to harvest plays a dominant role. Therefore, yield predictions based upon soil moisture at seeding time are difficult. However, as can be seen from Figure 1, yield of wheat at Cherokee followed total spring moisture available for plant growth rather closely.

Table IV presents the yield equations which were derived based upon the data available. When nitrogen was included as a variable, it accounted for a very large amount of the variation in grain yield. Rainfall follows nitrogen in significance in this analysis, and very little of the variation in yields can be accounted for by available soil moisture either at seeding time or at the date of topdressing application. Based upon the various regression equations which were developed, rainfall from topdressing to harvest appears to be the best indicator of the amount of nitrogen to apply as a topdressing in the spring. However, this figure is not available at the time that the wheat is topdressed. There was no improvement in the accuracy of the regression analysis by adding available soil moisture at topdressing to the inches of spring rainfall. Available soil moisture alone is a poor indicator of the yield potential, both at seeding and at topdressing time.

When nitrogen was eliminated as a variable and only the yields with 40 pounds of nitrogen fertilizer were considered, total moisture supply from topdressing to harvest was more highly correlated with yield than was total moisture supply from seeding time to harvest. Rainfall from topdressing to harvest accounted for nearly all of the variation in yield due to the total moisture supply.

TABLE III

SOIL MOISTURE CONTENTS AND TOTAL MOISTURE SUPPLY AT CHEROKEE, OKLAHOMA, 1956-1965

Year	ASM_1	$ASM_1 + R_1$	ASM_2	$ASM_2 + R_2$
	inches	inches	inches	inches
1956	2.10	6.34	2.10	4.16
1958	5.06	15.81	4.79	10.70
1959	2.50	15.69	2.02	13.32
1960	3.80	19.32	4.14	12.15
1961	3.33	19.87	2.27	13.46
1962	2.71	12.55	3.06	7.45
1963	3.10	11.86	2.57	8.21
1964	3.05	11.64	1.05	6.71
1965	1.24	15.33	3.08	8.70

ASM_1 = Available soil moisture at seeding (4-foot profile)

R_1 = Precipitation from seeding to harvest

ASM_2 = Available soil moisture at topdressing (4-foot profile)

R_2 = Precipitation from topdressing to harvest

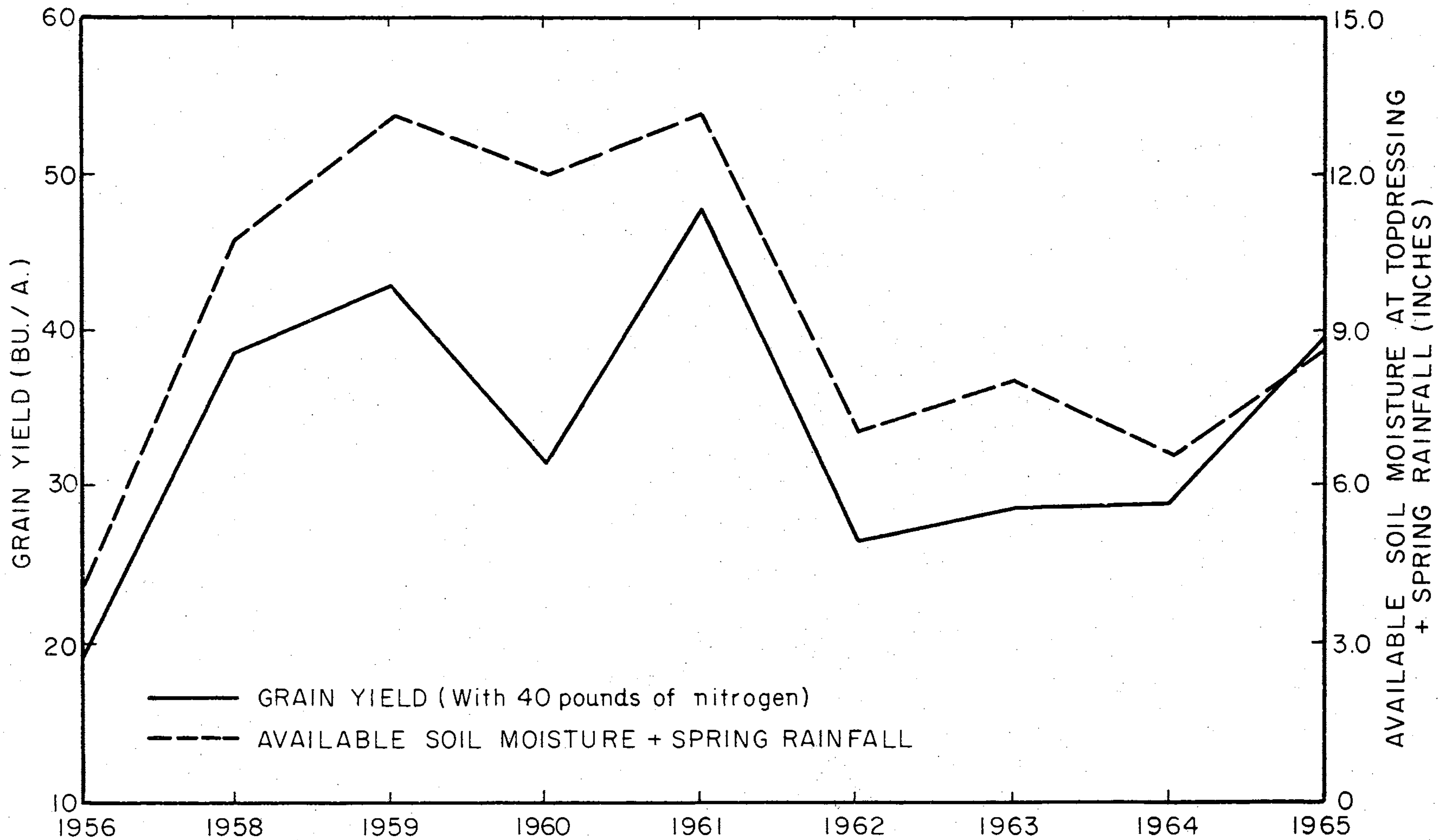

Figure 1. Relationship of Wheat Yields and Total Available Moisture Supply, Cherokee, Oklahoma

TABLE IV

MULTIPLE REGRESSION EQUATIONS FOR WHEAT GRAIN YIELDS AND MULTIPLE CORRELATION COEFFICIENTS

Regression Equations	R
1. $Y = 6.4420 + 0.2269(N) + 1.2844(ASM_1 + R_1)$	.78
2. $Y = 7.7399 + 0.2269(N) + 1.8059(ASM_2 + R_2)$	.81
3. $Y = 19.4132 + 0.2269(N) + 1.7921(ASM_1)$	.56
4. $Y = 22.4619 + 0.2269(N) + 0.8274(ASM_2)$	.53
5. $Y = 9.6479 + 0.2269(N) + 1.3404(R_1)$	.77
6. $Y = 12.3068 + 0.2269(N) + 1.8760(R_2)$	.81
7. $Y = 5.5550 + 0.4852(ASM_1) + 1.8916(R_1)$*	.83
8. $Y = 12.7002 + 1.4909(ASM_2) + 2.5578(R_2)$*	.87

N = Fertilizer nitrogen (pounds per acre)

ASM_1 = Available soil moisture at seeding (inches in 4-foot profile)

R_1 = Precipitation from seeding to harvest (inches)

ASM_2 = Available soil moisture at topdressing (inches in 4-foot profile)

R_2 = Precipitation from topdressing to harvest (inches)

*with 40 pounds of nitrogen per acre

Figure 2 shows the effect of available soil moisture at topdressing plus spring precipitation and nitrogen fertilization upon the grain yield of winter wheat. The greatest percentage increase in yield occurs at slightly more than 8 inches of total spring moisture supply. At this point nitrogen definitely becomes a limiting factor in the yield of winter wheat at this particular location, and nitrogen fertilization is essential as the moisture supply increases above this point, if maximum yields are to be realized.

The percentage of nitrogen increased with nitrogen fertilization, but decreased as total spring moisture supply (available soil moisture at topdressing plus spring rainfall) increased (Figure 3). Straw yields increased as both nitrogen level and total moisture supply increased, as illustrated by Figure 4.

The results of this study indicate that when nitrogen is adequate, each additional inch of total moisture supply will increase yields approximately 4 bushels per acre. Approximately 4 pounds of nitrogen are required to raise the yield one bushel per acre through the range where nitrogen is limiting yield. These results indicate that continuously cropped soils at Cherokee will produce maximum yields when approximately 20 pounds of nitrogen are applied per acre for every 3 to 4 inches of total moisture.

Yield-of-nitrogen curves reveal greater nitrogen uptake as rate of nitrogen fertilization and total moisture supply increased (Figure 5). Extrapolation of the linear portion of the yield-of-nitrogen curves to the abscissa indicated that this soil (Grant silt loam) had approximately 40 pounds of soil nitrogen per acre that was available in addition to the fertilizer nitrogen. Slopes of the lines indicate that

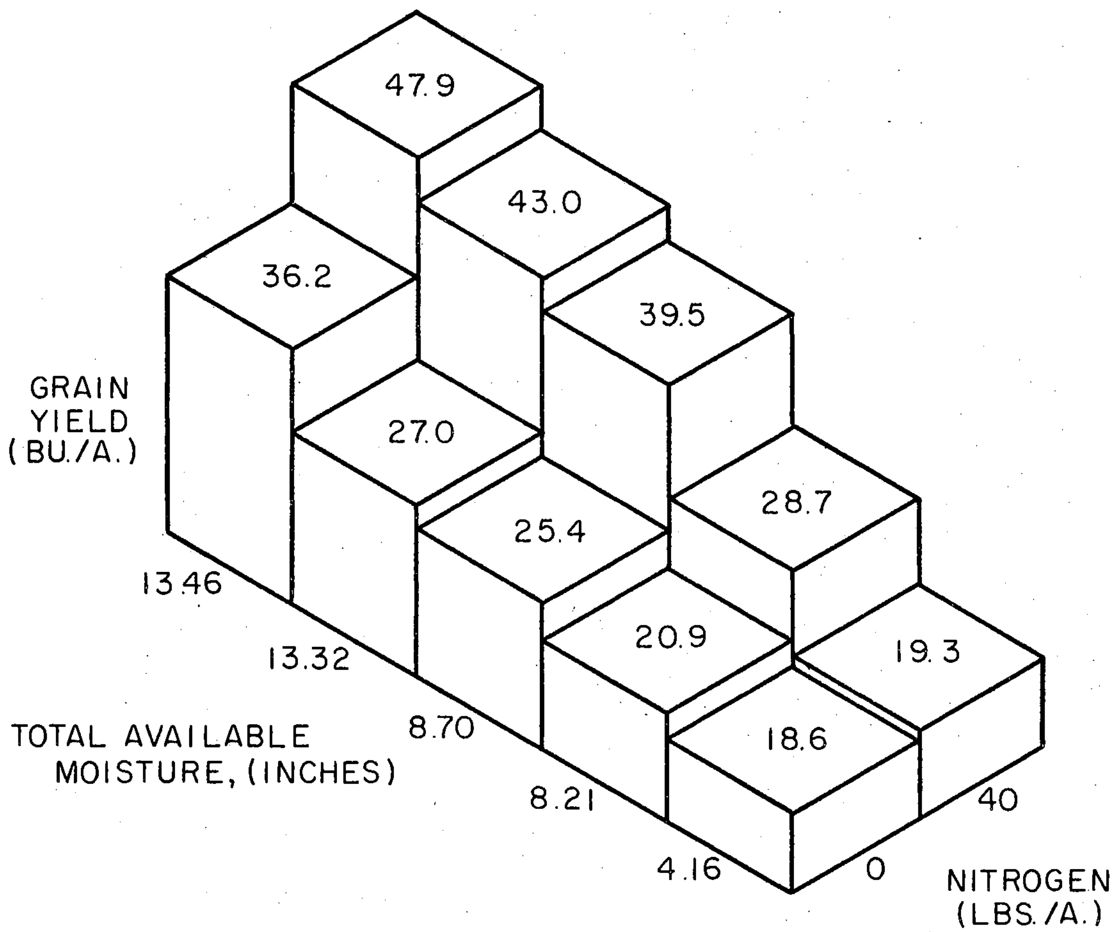

Figure 2. The Effect of Total Available Moisture Supply and Rate of Nitrogen Fertilization on the Yield of Winter Wheat, Cherokee, Oklahoma

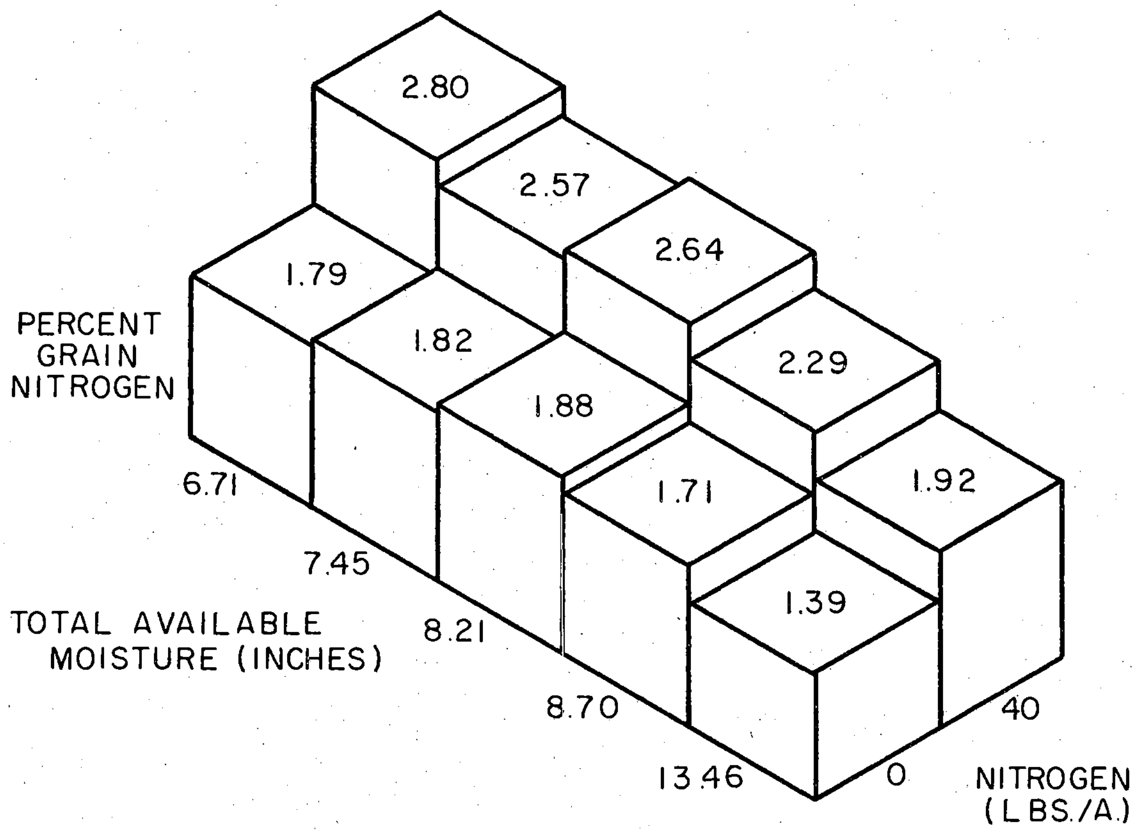

Figure 3. The Effect of Total Available Moisture Supply and Rate of Nitrogen Fertilization on the Total Nitrogen Percentage of Winter Wheat Grain at Cherokee, Oklahoma

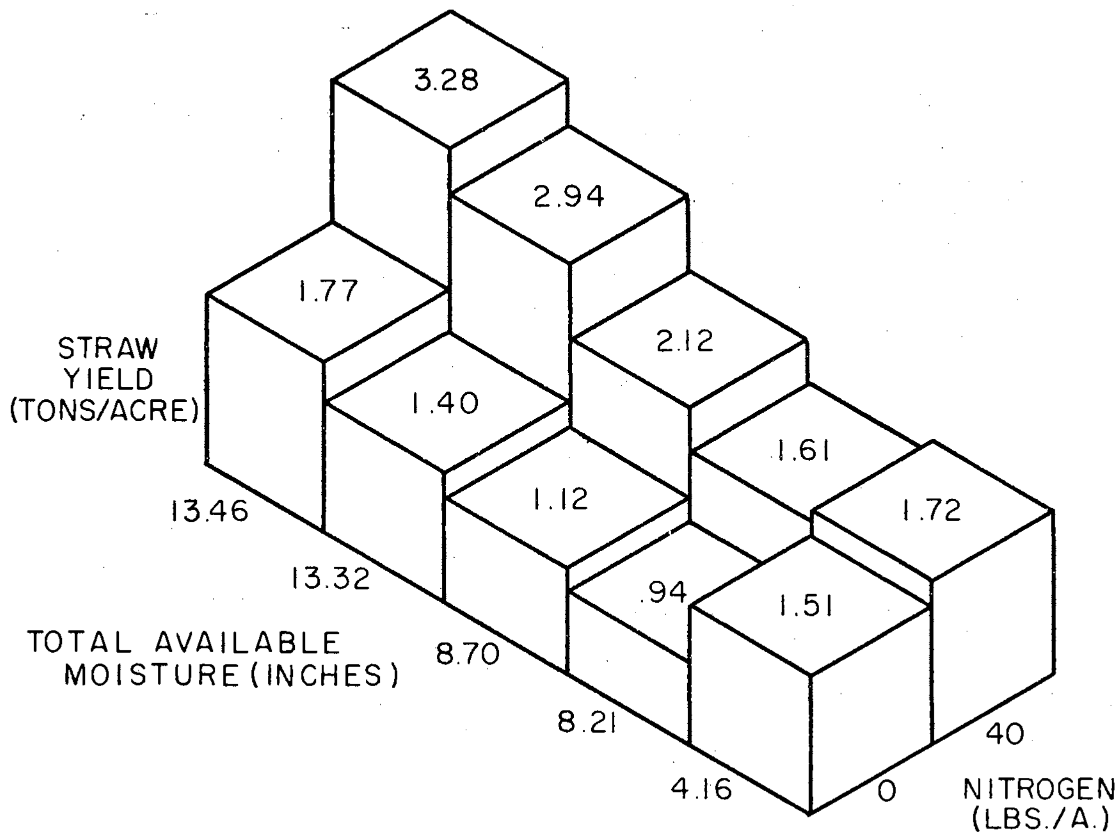

Figure 4. The Effect of Total Available Moisture Supply and Rate of Nitrogen Fertilization on the Straw Yields of Winter Wheat at Cherokee, Oklahoma

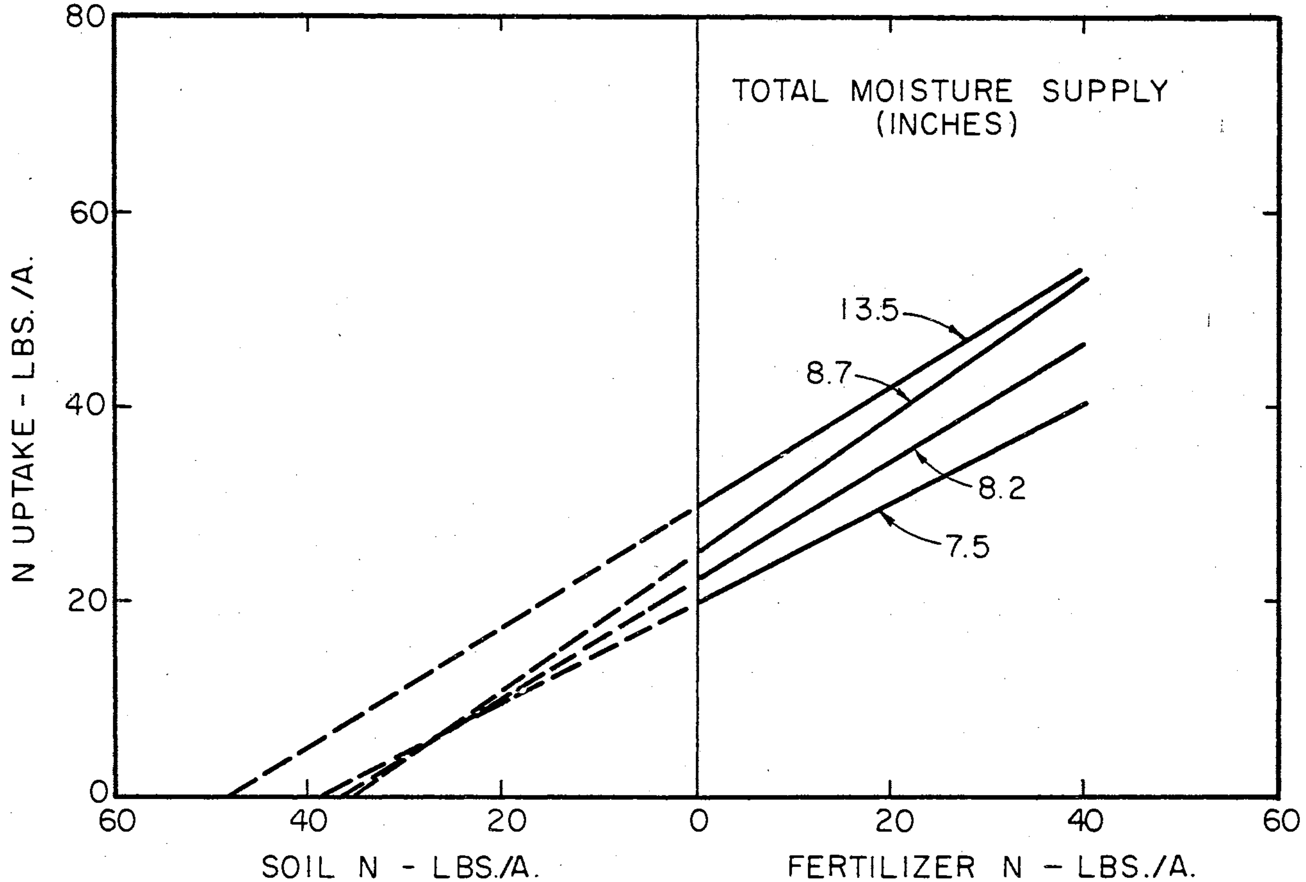

Figure 5. Yield-of-nitrogen Curves for Winter Wheat as Influenced by Total Available Moisture Supply, Cherokee, Oklahoma

approximately 0.6 pounds of nitrogen were absorbed per pound of fertilizer nitrogen applied. The intercepts on the Y axis show more soil nitrogen was used when greater quantities of total moisture were available.

Summary and Conclusions

Experimental data covering a period of nine cropping years were analyzed to determine the effects of available soil moisture at seeding and at topdressing, rainfall during the growing season, and level of nitrogen fertilization on the yield and quality of hard red winter wheat at Cherokee, Oklahoma. Regression analysis showed that spring rainfall is the best indicator of the yield potential of winter wheat at Cherokee. Grain yields and straw yields increased as total moisture supply and level of nitrogen fertilization increased, while the nitrogen percentage in the grain increased with level of nitrogen fertilization and decreased with increasing moisture supply. Approximately 66% of the variation in yield was accounted for by total moisture supply and level of nitrogen fertilization. The results indicate that continuously cropped Grant silt loam at Cherokee will produce maximum yields when approximately 20 pounds of nitrogen are applied per acre for every 3 to 4 inches of total moisture supply.

CHAPTER IV

OFF-STATION EXPERIMENTS

To determine how far the moisture-nitrogen relationships obtained at Cherokee could be extended, twelve experiments were conducted during 1964 and 1965 on "key" soils representative of a large portion of the wheat belt of north central Oklahoma (Figure 6). In addition, these experiments were established to introduce more levels of nitrogen fertilization, since only two rates (0 and 40 pounds) were included in the Cherokee study.

Materials and Methods

A randomized block design with three replications was employed for all of the experiments reported. Individual plot size was 20' x 100'. Five of the experimental locations received nitrogen treatments as follows: None, 20, 40, 60, and 80 pounds per acre of nitrogen topdressed in early March. The remaining seven locations had treatments of 0, 40, and 80 pounds of nitrogen per acre topdressed in the spring. Sources of nitrogen included ammonium nitrate, ammonium sulfate, and urea. All of the experiments were located on sites where a uniform soil type was available (Table V), a good stand of an adapted wheat variety existed, phosphorus and potassium levels were adequate for a high yield possibility, and where the sites were free from weeds, especially winter grasses.

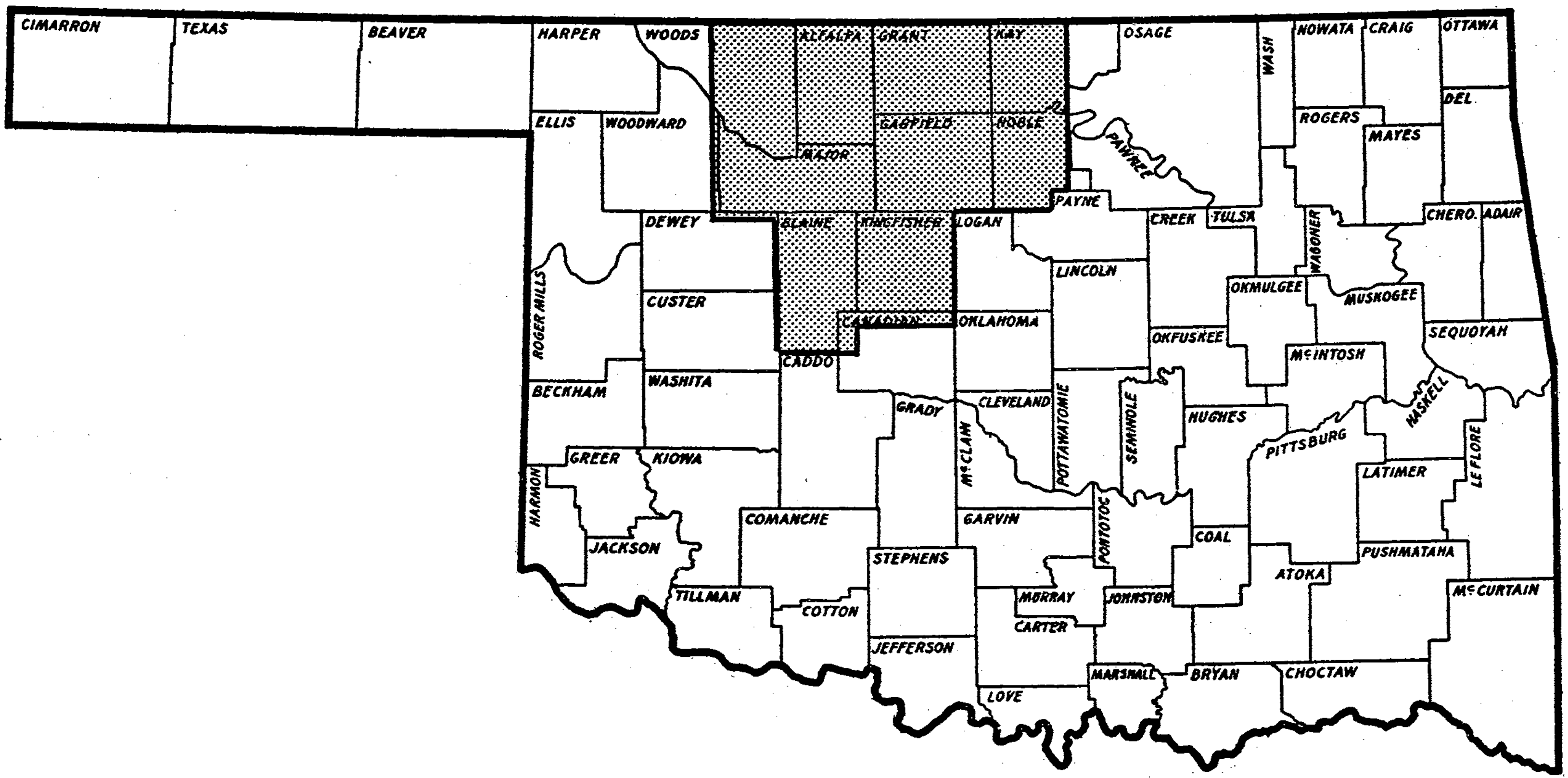

Figure 6. The Area in North Central Oklahoma Included in the Off-station Experiements

TABLE V

LOCATIONS AND SOIL SERIES OF OFF-STATION EXPERIMENTS

Year and Location Number	County	Town	Cooperator	Nearest Recording Weather Station	Soil Series
1964					
1.	Noble	Sumner	E. Shyrock	Perry	Port
2.	Caddo	Hinton	J. Helderman	Geary	Minco
1965					
3.	Woods	Alva	E. James	Alva	Weymouth
4.	Grant	Medford	L. Thrular	Renfrow	Renfrow
5.	Noble	Sumner	E. Shyrock	Perry	Port
6.	Blaine	Watonga	V. Dailey	Watonga	Shellabarger
7.	Blaine	Watonga	L. Scott	Watonga	Vanoss
8.	Blaine	Watonga	B. Powers	Watonga	Vanoss
9.	Blaine	Watonga	Rother Bros.	Watonga	Shellabarger
10.	Garfield	Drummond	R. Moyer	Fairview	Kingfisher
11.	Kay	Newkirk	L. Shick	Newkirk	Kirkland
12.	Kay	Ponca City	D. Jelsma	Ponca City	Tabler

Soil moisture was determined at the time of topdressing in the spring. Samples were taken at soil depths as follows: 0 to 6 inches; 6 to 12 inches; and in foot layers thereafter to a depth of 4 feet. Soil moisture percentages were determined by drying to constant weight at 105°C. Precipitation was assumed to be that amount measured at the nearest recording weather station, and rainfall during the growing season was taken to be that occurring from date of topdressing to the end of May.

The soil samples collected for moisture determinations were used in further analyses. Fifteen-atmosphere percentages were determined by the method of Richards (19). Available soil moisture was considered to be the moisture above the fifteen-atmosphere percentage. Bulk density values of the various soil types included in the study were obtained from the publication by Eck and Stewart (5). If the bulk density values of a soil were not included in this publication, then the values of a closely related soil were used to convert available moisture percentages to inches of available moisture.

Soil pH was determined by use of a Beckman glass electrode pH meter on a 1:1 soil-water paste. The cation exchange capacity was determined by using ammonium acetate extractant (8). The Beckman DU spectrophotometer with flame attachment was used to determine the amounts of potassium, calcium, magnesium, and sodium in the filtrate obtained from the cation exchange capacity determination. Available soil phosphorus was extracted using Bray and Kurtz (2) No. 1 extracting solution. The organic matter content was determined by the potassium dichromate wet-oxidation method of Schollenberger (22). Results of the soil analyses are presented in Tables XI to XXI (Appendix).

The wheat was harvested with a combine, and the area harvested ranged from 8' x 80' to 8' x 100'. The grain was carefully weighed, and yields were calculated. Total nitrogen content of the grain was determined by the Kjeldahl method, using the boric acid modification described by Scales and Harrison (21). Nitrogen recovery in the grain was calculated for all experimental plots.

Yield data were fitted with multiple regression equations of the general form: $Y = b_o + b_1x_1 + b_2x_2$, where: Y is the estimated yield in bushels per acre, b_o is the intercept, b_1 and b_2 are partial regression coefficients, and x_1 and x_2 are variables - pounds of nitrogen applied per acre, inches of available soil moisture at topdressing, precipitation from topdressing date to harvest, and total available moisture supply.

Results and Discussion

Good yield responses to nitrogen fertilization were obtained for both years of the study (1964 and 1965) at all twelve locations. Spring rainfall ranged from 4 inches in Blaine County in 1965 to slightly more than 10 inches in Kay County in 1965 (Table VI). Soil moisture supply varied from 3 inches of available moisture at Location No. 7 in 1965 to approximately 10 inches at Location No. 1 in 1964 (Table VII).

Yields ranged from 15.8 bushels per acre with no nitrogen at Location No. 9 to 47.3 bushels per acre with 80 pounds of nitrogen fertilizer at Location No. 11 (Table VIII). The yield data for all twelve locations were pooled in an attempt to arrive at some generalized conclusions concerning the effects of moisture supply and level of nitrogen fertilization on wheat production in north central Oklahoma. Table IX

TABLE VI

SUMMARY OF TOTAL PRECIPITATION AND DEPARTURES FROM NORMAL
AT OFF-STATION LOCATIONS

Month	Location 1 Total inches	Location 1 Departure inches	Location 2 Total inches	Location 2 Departure inches	Location 3 Total inches	Location 3 Departure inches
July	7.38	+4.41	3.89	+1.54	0.49	-1.53
August	3.66	+0.68	0.50	-2.05	4.28	+1.61
September	4.59	+1.30	6.08	+3.27	1.29	-1.29
October	1.77	-0.56	1.26	-1.27	1.16	-0.79
November	1.97	+0.17	1.57	+0.31	6.58	+5.36
December	0.56	-0.82	0.54	-0.73	1.61	+0.60
January	0.47	-0.68	0.58	-0.50	0.56	-0.40
February	1.89	+0.50	2.45	+1.28	0.60	-0.56
March	1.27	-0.79	0.67	-1.05	0.78	-0.79
April	1.15	-2.18	2.31	-0.47	3.56	+0.90
May	5.87	+0.92	6.88	+2.48	1.65	-2.58
June	1.68	-2.54	1.74	-2.12	4.56	+0.95
Yearly	32.26	+0.41	28.47	+0.69	27.12	+0.88

TABLE VI (Continued)

Month	Location 4 Total inches	Location 4 Departure inches	Location 5 Total inches	Location 5 Departure inches	Locations 6,7,8,9 Total inches	Locations 6,7,8,9 Departure inches
July	1.66		0.44	-2.53	0.98	-1.39
August	10.99		9.62	+6.64	3.73	+1.43
September	0.58		2.95	-0.34	2.24	-0.22
October	3.60		0.58	-1.75	1.34	-1.07
November	7.04		4.84	+3.04	5.37	+4.10
December	0.93	Data not available	0.97	-0.41	0.97	-0.46
January	0.47		0.61	-0.54	0.21	-0.81
February	0.94		0.79	-0.60	0.69	-0.44
March	1.33		1.99	-0.07	1.12	-0.45
April	1.20		1.62	-1.71	1.54	-1.07
May	5.17		4.45	-0.50	2.51	-1.96
June	3.54		3.49	-0.73	8.24	+4.45
Yearly	37.45		32.35	+0.50	28.94	+2.11

TABLE VI (Continued)

Month	Location 10 Total inches	Location 10 Departure inches	Location 11 Total inches	Location 11 Departure inches	Location 12 Total inches	Location 12 Departure inches
July	0.21		1.72	-1.44	0.40	-3.20
August	3.11		9.77	+6.50	10.49	+7.40
September	1.18		2.88	-0.37	4.72	+1.20
October	0.72		3.23	+0.86	3.53	+1.12
November	7.26		6.37	+4.84	6.60	+4.90
December	1.05	Data not available	1.01	-0.20	0.67	-0.66
January	0.28		0.84	-0.11	2.39	+1.35
February	1.43		0.56	-0.64	0.61	-0.62
March	1.36		0.94	-0.83	1.28	-0.64
April	1.43		2.47	-0.64	3.50	+0.37
May	2.88		7.10	+2.52	6.89	+2.18
June	4.27		4.21	+0.01	5.00	+0.57
Yearly	25.18		41.10	+10.50	46.08	+13.97

TABLE VII

SOIL MOISTURE CONTENTS AND TOTAL MOISTURE SUPPLY AT OFF-STATION LOCATIONS

Location Number	Year	ASM inches	ASM ≠ R inches
1.	1964	9.75	18.04
2.	1964	3.46	13.32
3.	1965	3.89	9.88
4.	1965	5.53	13.23
5.	1965	6.95	15.10
6.	1965	4.12	8.17
7.	1965	3.02	7.07
8.	1965	6.45	10.50
9.	1965	4.82	8.87
10.	1965	4.11	8.42
11.	1965	4.77	14.34
12.	1965	3.50	13.89

ASM = Available soil moisture at topdressing (4-foot profile)

R = Precipitation from topdressing to harvest

TABLE VIII

GRAIN YIELDS, PERCENT GRAIN NITROGEN, AND YIELD OF GRAIN NITROGEN AT OFF-STATION LOCATIONS

Year and Location Number	Rate of Nitrogen	Grain Yield	Grain Nitrogen	Yield of Grain Nitrogen
	lbs./acre	bu./acre	%	lbs./acre
1964				
1.	0	24.4	1.80	26.4
	20	30.1	1.80	32.5
	40	33.5	1.84	37.0
	60	36.8	1.90	42.0
	80	39.4	2.01	47.5
2.	0	22.5	1.87	25.2
	20	30.2	1.98	35.9
	40	32.8	2.10	41.3
	60	36.3	2.19	47.7
	80	39.0	2.36	55.2
1965				
3.	0	27.7	1.82	30.2
	20	26.4	1.91	30.3
	40	29.2	1.98	34.7
	60	33.4	2.08	41.7
	80	35.3	2.17	46.0
4.	0	24.8	1.88	28.0
	20	34.2	1.87	38.4
	40	38.7	1.89	43.9
	60	42.4	2.09	53.2
	80	43.8	2.15	56.5
5.	0	18.7	1.96	22.0
	20	26.1	1.87	29.3
	40	34.5	1.84	38.1
	60	40.3	1.86	45.0
	80	44.3	1.94	51.6
6.	0	18.2	1.71	18.7
	40	32.8	1.82	35.8
	80	36.6	2.11	46.3
7.	0	21.7	1.67	21.7
	40	33.2	1.96	39.0
	80	37.5	2.29	51.5

TABLE VIII (Continued)

Year and Location Number	Rate of Nitrogen	Grain Yield	Grain Nitrogen	Yield of Grain Nitrogen
	lbs./acre	bu./acre	%	lbs./acre
1965				
8.	0	18.6	1.81	20.2
	40	32.2	1.90	36.7
	80	38.6	2.29	53.0
9.	0	15.8	1.95	18.5
	40	30.0	2.08	37.4
	80	34.4	2.33	48.1
10.	0	26.3	1.75	27.6
	40	35.4	1.75	37.2
	80	36.0	2.25	48.6
11.	0	22.6	1.90	25.8
	40	41.0	1.94	47.7
	80	47.3	2.23	63.3
12.	0	30.3	1.84	33.5
	40	40.6	1.80	43.8
	80	45.2	1.93	52.3

presents the yield equations which were derived from an analysis of this data. When included as one of the variables, rate of nitrogen fertilization accounted for a very substantial amount of the variation in grain yields. Yields were more closely correlated with spring precipitation alone than with available soil moisture at topdressing plus spring rainfall. Only a very small amount of the variation in yields could be accounted for by available soil moisture at topdressing. Based upon the various linear regression equations which were developed, rainfall from date of topdressing to harvest appears to be the best indicator of the amount of nitrogen to apply as a topdressing in the spring.

Yields with a constant rate of 80 pounds of nitrogen per acre were used to consider the influence of available soil moisture at topdressing and spring rainfall under conditions where nitrogen supply was not limiting grain production. Under these conditions spring rainfall alone accounted for approximately 60% of the variation in yields. Available soil moisture at topdressing was a very poor indicator of the potential yield possibility. One inch of spring rainfall increased grain yield by 1.3 bushels per acre, while an inch of available soil moisture at topdressing was responsible for only 0.4 bushels per acre increase in grain yield.

Figure 7 graphically depicts the relationship between grain yield on plots fertilized with 80 pounds of nitrogen per acre and total spring moisture supply available to the crop. The effect of total moisture supply (available soil moisture at topdressing plus spring rainfall) and level of nitrogen fertilization on the grain yield of winter wheat is shown in Figure 8. The most distinct increase in yield due to the effect of total moisture supply occurred at approximately 10 inches of available

TABLE IX

MULTIPLE REGRESSION EQUATIONS FOR WHEAT GRAIN YIELDS AND MULTIPLE CORRELATION COEFFICIENTS

Regression Equations	R
1. $Y = 17.6091 + 0.2141(N) + 0.5255(ASM + R)$	.87
2. $Y = 23.5825 + 0.2141(N) + 0.0809(ASM)$	.56
3. $Y = 17.1277 + 0.2141(N) + 0.9873(R)$	.89
4. $Y = 29.6635 + 0.3935(ASM) + 1.3079(R)$*	.68

N = Fertilizer nitrogen (pounds per acre)

ASM = Available soil moisture at topdressing (inches in 4-foot profile)

R = Precipitation from topdressing to harvest (inches)

*with 80 pounds of nitrogen per acre

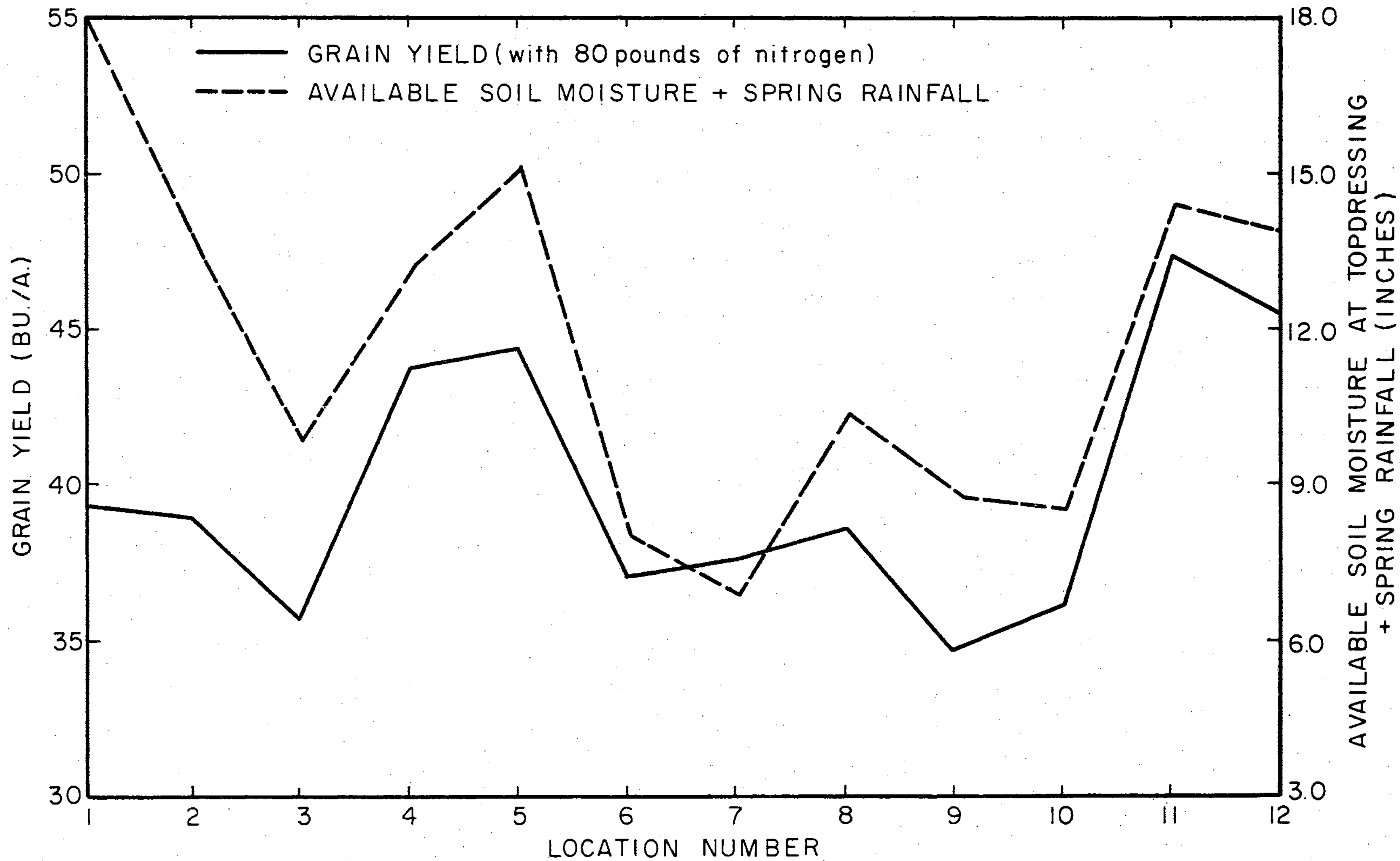

Figure 7. Relationship of Wheat Yields and Total Available Moisture Supply at Off-station Locations

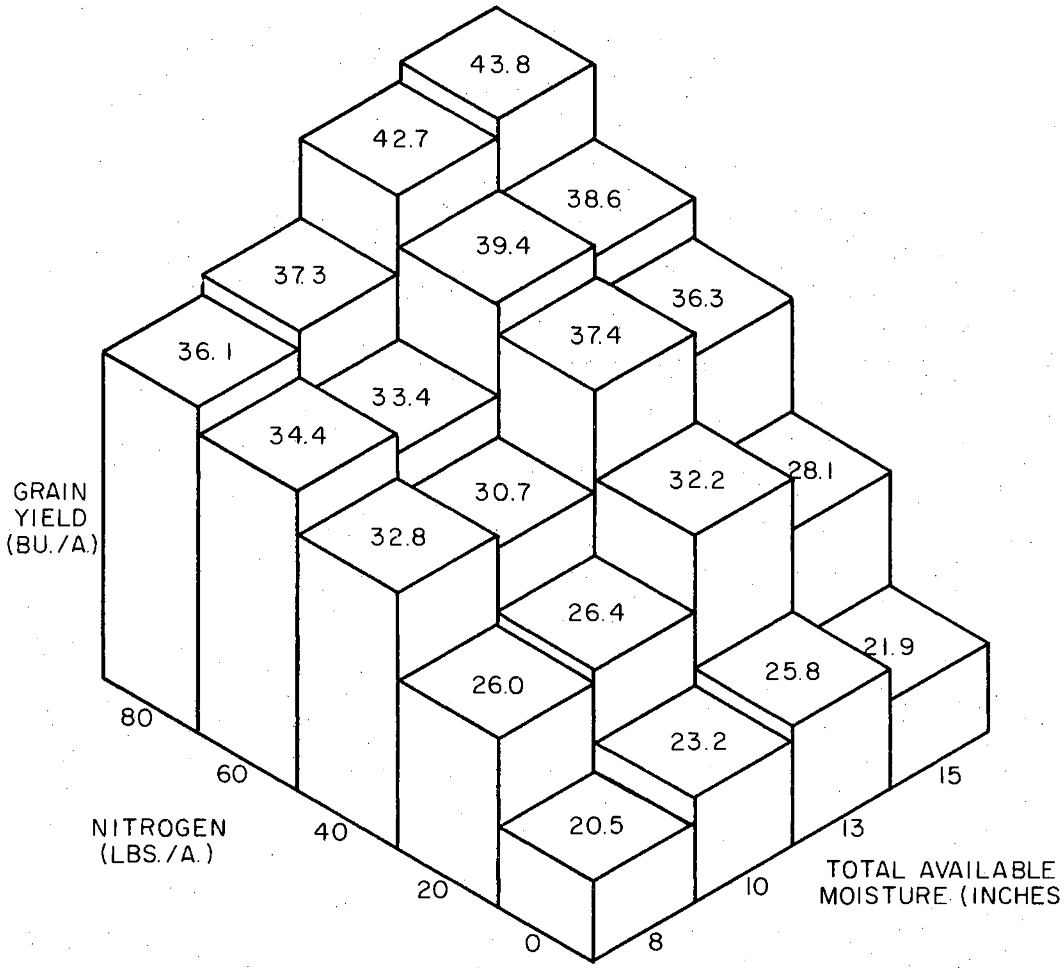

Figure 8. The Effect of Total Available Moisture Supply and Rate of Nitrogen Fertilization on the Yield of Winter Wheat at Off-station Locations

water. Yields with intermediate levels of nitrogen (20 and 40 pounds) were substantially increased with greater than 10 inches of total available water. Responses to nitrogen fertilization are evident at all moisture levels, with the greatest responses occurring at the higher moisture levels. Response to nitrogen fertilization was obtained at the lowest moisture level (approximately 8 inches of total water) up to the 40 pounds of nitrogen rate. This substantiates the data obtained at Cherokee, which indicated that approximately 40 pounds per acre of nitrogen should be applied for a total spring moisture supply of 8 inches. Results indicate that a fertilizer rate of 80 pounds of nitrogen per acre was feasible at the 15 inches of available water level.

The percentage of nitrogen in the grain increased as the rate of nitrogen fertilizer increased, but decreased as total moisture supply increased (Figure 9). This is in agreement with the results obtained at Cherokee and also with those of other workers (17, 18).

The results of this study indicate that when the supply of nitrogen is adequate, each additional inch of total moisture available to the crop will increase yields approximately 1.7 bushels per acre. Thus, the efficiency of total moisture supply for these locations is lower than the value obtained using the results of nine years of data at the Wheatland Conservation Experiment Station, Cherokee, Oklahoma. The Y intercept of the regression equations is more than twice the value of the Y intercept calculated from the Cherokee data. This is probably a result of favorable moisture conditions and soil nitrogen levels, which increased the base yields substantially over those obtained at Cherokee. Nitrogen responses were approximately the same as those obtained at Cherokee. The results indicate that 4 pounds of nitrogen are required

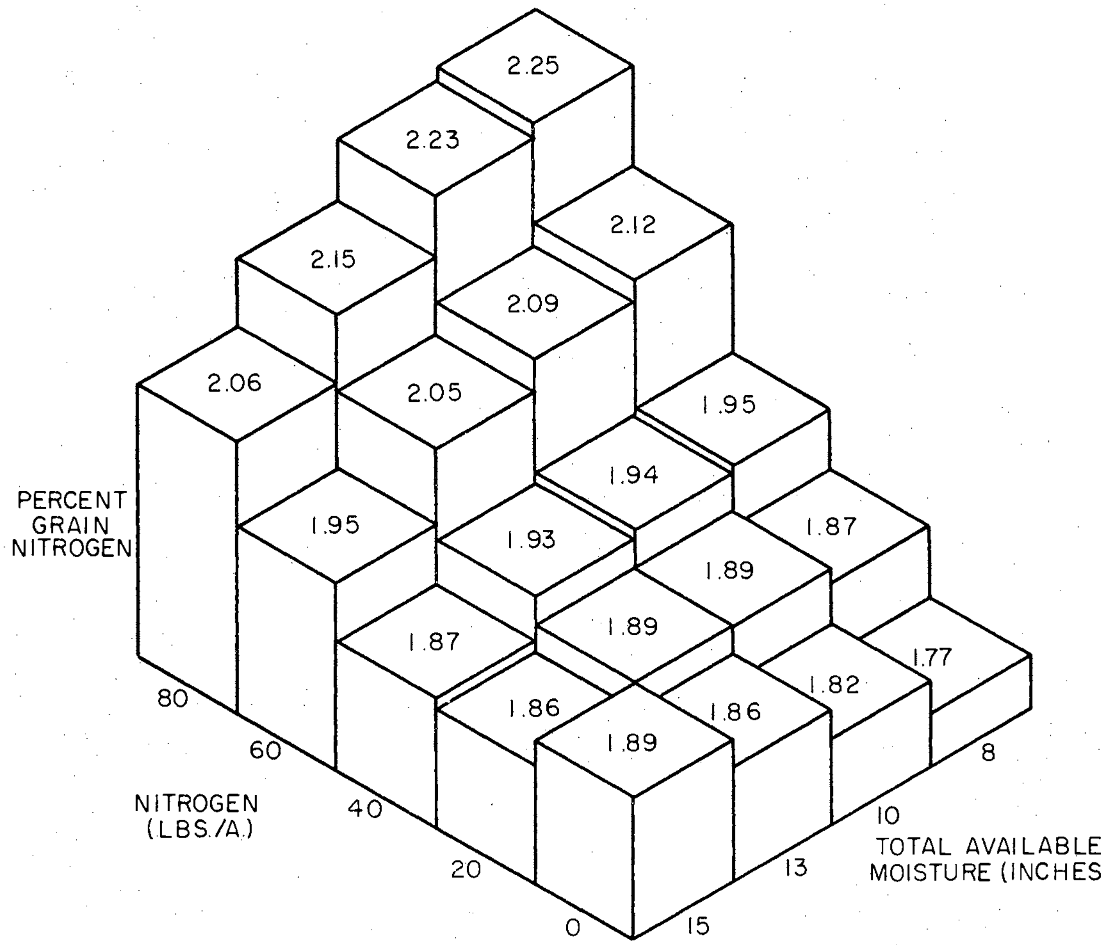

Figure 9. The Effect of Total Available Moisture Supply and Rate of Nitrogen Fertilization on the Total Nitrogen Percentage of Winter Wheat at Off-station Locations

to raise the yield one bushel per acre through the range where nitrogen is limiting yield.

These results indicate that the soils included in this study will produce maximum yields when approximately 20 pounds of nitrogen per acre are applied for every 4 to 5 inches of total moisture.

Yield-of-nitrogen curves reveal slightly greater nitrogen uptake as rate of nitrogen fertilization and total moisture supply increased up to the 13 inches of total moisture level (Figure 10). Then a slight decrease in nitrogen uptake occurred with 15 inches of total moisture supply. Extrapolation of the linear portion of the yield-of-nitrogen curves to the abscissa indicated that these soils had an average of 50 to 60 pounds of available soil nitrogen per acre which could be utilized in addition to the fertilizer nitrogen. Slopes of the lines indicate that approximately 0.4 pounds of nitrogen were absorbed per pound of fertilizer nitrogen applied, which is somewhat less than the corresponding value obtained at Cherokee.

Summary and Conclusions

Experimental data covering an area of eight counties in north central Oklahoma and conducted over a period of two years were analyzed to determine the effects of available soil moisture at topdressing, precipitation from topdressing to harvest, and level of nitrogen fertilization on the yield and quality of hard red winter wheat. Regression analysis showed that spring rainfall is the best indicator of the yield potential of winter wheat in north central Oklahoma. Grain yields increased as total moisture supply and level of nitrogen fertilization increased, while the nitrogen percentage in the grain increased with

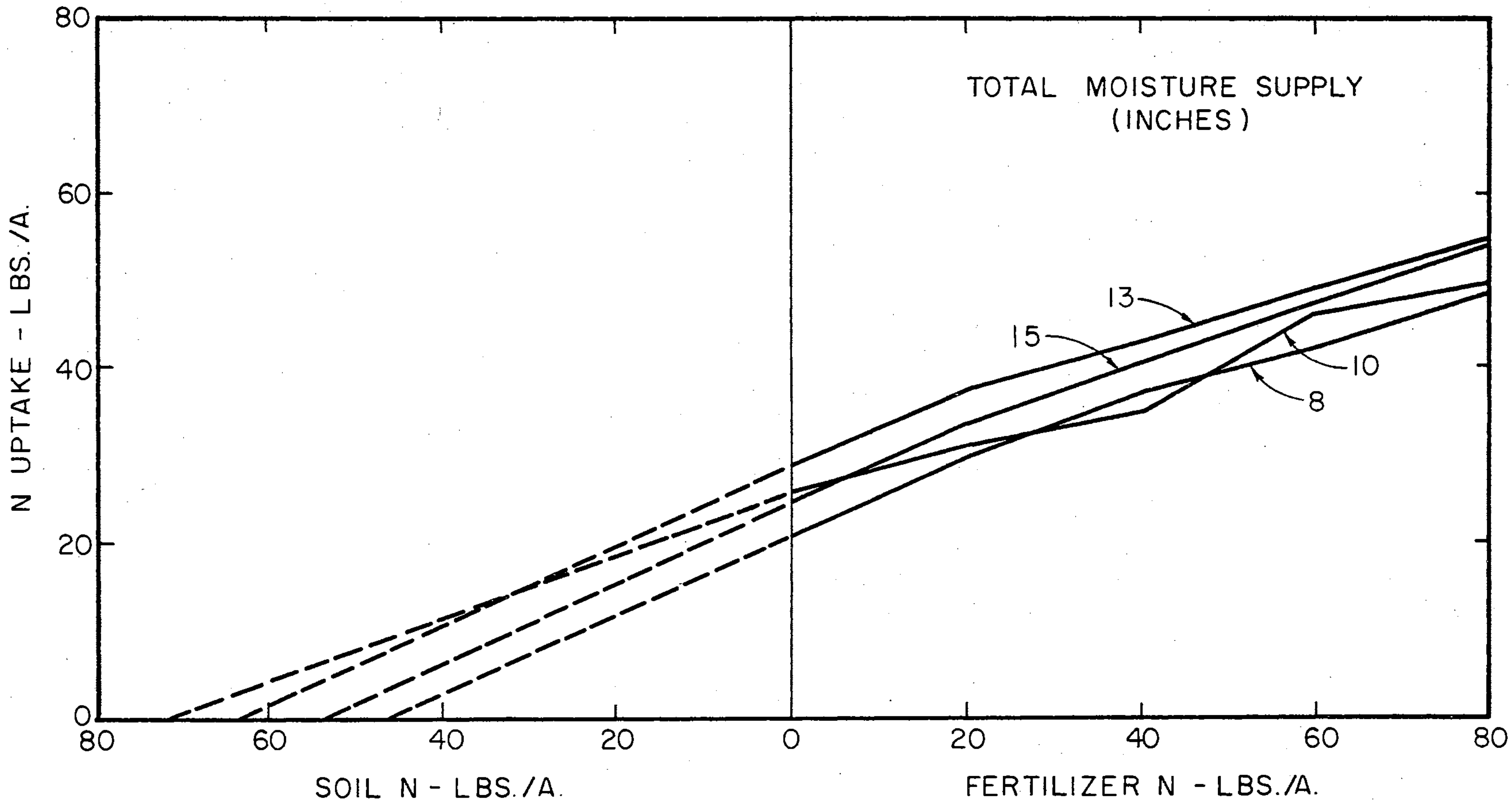

Figure 10. Yield-of-nitrogen Curves for Winter Wheat at Off-station Locations as Influenced by Total Available Moisture Supply

level of nitrogen fertilization and decreased with increasing moisture supply. Approximately 75% of the variation in grain yield was accounted for by total moisture supply and level of nitrogen fertilization. The results indicate that the wheatland soils of north central Oklahoma will produce maximum yields when approximately 20 pounds of nitrogen are applied per acre for every 4 to 5 inches of total moisture supply.

CHAPTER V

GENERAL SUMMARY AND CONCLUSIONS

Experimental data from the Wheatland Conservation Experiment Station, Cherokee, Oklahoma, and from twelve locations throughout the wheat belt of north central Oklahoma show that precipitation from spring topdressing time to harvest plays a very dominant role in determining the yield potential for a given year. Yield predictions based only upon either seeding time moisture or soil moisture at topdressing time are generally unreliable for this area. Therefore, prediction of the growing season precipitation is necessary if wheat yields, and consequently rate of nitrogen fertilizer to apply, are to be predicted with a high level of confidence.

For the nine years of data from Cherokee, below normal rainfall occurred seven years and above normal rainfall two years. When sixty to ninety-day rainfall forecasts become reliable, then soil moisture contents of samples taken at topdressing time can be added to expected spring precipitation to predict yields, and thus determine the optimum rate of nitrogen to apply as a topdressing at the beginning of spring growth. Until long-range weather forecasts become a reality, nitrogen needs of winter wheat in north central Oklahoma will have to be assessed by determining stored soil moisture and then assuming that spring rainfall will be below, above, or near normal for a particular location.

The results of these experiments indicate that the wheatland soils of north central Oklahoma will produce maximum yields when approximately 20 pounds of nitrogen per acre are applied for every 4 inches of total spring moisture supply available to the crop. More moisture-nitrogen experiments on winter wheat need to be conducted using more elaborate experimental designs and more refined techniques so that the level of nitrogen fertilizer to apply can be established with greater precision. Once the mathematical relationships of moisture, nitrogen, and yield are determined for a given area, the risk involved in nitrogen fertilization of winter wheat in Oklahoma will be greatly reduced.

LITERATURE CITED

1. Bauer, A., R. A. Young, and J. L. Ozburn. 1965. Effects of moisture and fertilizer on yields of spring wheat and barley. Agron. J. 57: 354-356.

2. Bray, R. H. and L. T. Kurtz. 1945. Determination of total, organic, and available forms of phosphorus in soils. Soil Sci. 32: 329-341.

3. Cole, John S. and O. R. Mathews. Relation of the depth to which soil is wet at seeding time to the yield of spring wheat on the Great Plains. U.S.D.A. Circ. 563. 1940.

4. Compton, L. L. Relationship of moisture to wheat yields on western Kansas farms. Kansas Ext. Bull. 168. 1943.

5. Eck, H. V. and B. A. Stewart. Water-retention properties of seventeen Oklahoma soils. Okla. Agr. Exp. Sta. Bull. B-526. 1959.

6. Finnell, H. H. Soil moisture and wheat yields on the High Plains. U.S.D.A. Leaflet No. 247. 1948.

7. Hallsted, A. L. and O. R. Mathews. Soil moisture and winter wheat with suggestions on abandonment. Kansas Agr. Exp. Sta. Bull. 273. 1936.

8. Jackson, M. L. Soil Chemical Analysis. Prentice Hall, Englewood Cliffs, N. J., 1958. Chap. 4.

9. Jackson, T. L., H. M. Reisenauer, and G. M. Horner. Nitrogen recommendations for wheat production in eastern Washington. Wash. Agr. Exp. Sta. Circ. 179. 1952.

10. Leggett, G. E. Relationships between wheat yield, available moisture, and available nitrogen in eastern Washington dry land areas. Wash. Agr. Exp. Sta. Bull. 609. 1959.

11. Locke, L. F. and O. R. Mathews. Relation of cultural practices to winter wheat production, Southern Great Plains Field Station, Woodward, Oklahoma. U.S.D.A. Circ. 917. 1953.

12. Mathews, O. R. and Brown, L. A. Winter wheat and sorghum production in the Southern Great Plains under limited rainfall. U.S.D.A. Circ. 477. 1938.

13. Neidig, R. E. and R. S. Snyder. 1924. The relation of moisture and available nitrogen to the yield and protein content of wheat. Soil Sci. 18: 173-179.

14. Olson, R. A. and H. F. Rhoades. Commercial fertilizer for winter wheat in relation to the properties of Nebraska soils. Neb. Agr. Exp. Sta. Res. Bull. No. 172. 1953.

15. Olson, R. A., C. A. Thompson, P. H. Grabouski, D. D. Stukenholtz, K. D. Frank, and A. F. Dreier. 1964. Water requirement of grain crops as modified by fertilizer use. Agron. J. 56: 427-432.

16. Pengra, R. F. 1952. Estimating crop yields at seeding time in the Great Plains. Agron. J. 44: 271-274.

17. Ramig, R. E. and H. F. Rhoades. 1963. Interrelationships of soil moisture level at planting time and nitrogen fertilization on winter wheat production. Agron. J. 55: 123-127.

18. Ramón, F. G. and R. J. Laird. 1959. Yield and protein content of wheat in central Mexico as affected by available soil moisture and nitrogen fertilization. Agron. J. 51: 33-36.

19. Richards, L. A. 1941. A pressure membrane extraction appartus for soil solution. Soil Sci. 51: 377-386.

20. Richards, L. A. and L. R. Weaver. 1943. Fifteen atmosphere percentage as related to the permanent wilting percentage. Soil Sci. 56: 331.

21. Scales, F. M. and A. P. Harrison. 1920. Boric acid modification of the Kjeldahl method for crops and soil analysis. Ind. and Eng. Chem. 12: 350-352.

22. Schollenberger, C. J. 1931. Determination of organic matter. Soil Sci. 31: 483-496.

23. Staple, W. J. and J. J. Lehane. 1954. Wheat yield and use of moisture on substations in southern Saskatchewan. Can. Journ. of Agr. Sci. 34: 460-468.

24. Thomas, J. R., T. J. Army, and E. J. Cox. Relationship of soil moisture and precipitation to spring wheat yields in the Northern Great Plains. U.S.D.A. Prod. Res. Rpt. 56. 1962.

APPENDIX

TABLE X

PROPERTIES OF GRANT SILT LOAM

Location: Wheatland Conservation Experiment Station, Cherokee, Oklahoma.

Depth	Bulk Density	Moisture Retention at 15 atm.	1:1 pH	Organic Matter	Avail. P	Cation Exchange Capacity	Exchangeable Cations Ca	Mg	K	Na
inches	g./cm.^{3}	%		%	ppm	-----------m.e./100g. of soil-----------				
0-6	1.51	5.3	5.7	1.16	13	10.9	3.0	1.8	.56	.07
6-12	1.50	7.4	5.8	1.09	12	15.9	3.0	2.9	.36	.04
12-24	1.40	7.5	6.1	0.98	6	12.0	6.3	2.5	.33	.08
24-36	1.46	9.6	6.3	0.52	3	13.9	6.6	3.3	.30	.12
36-48	1.40	7.5	6.4	0.29	7	10.4	9.0	4.3	.21	.17

TABLE XI

PROPERTIES OF PORT SILTY CLAY LOAM

Locations 1 and 5: E. Shyrock Farm, Sumner, Oklahoma.

Depth	* Bulk Density	Moisture Retention at 15 atm.	1:1 pH	Organic Matter	Avail. P	Cation Exchange Capacity	Exchangeable Cations			
							Ca	Mg	K	Na
inches	g./cm.^{3}	%		%	ppm	-----------m.e./100g. of soil-----------				
0-6	1.24	12.1	6.1	1.74	44	19.0	8.2	16.2	.62	.17
6-12	1.43	14.4	5.7	1.67	42	20.7	8.8	16.7	.67	.26
12-24	1.49	15.5	6.1	1.21	15	24.9	9.2	19.7	.51	.26
24-36	1.42	12.7	6.1	0.92	21	16.2	10.2	19.2	.36	.17
36-48	1.47	15.4	6.2	1.13	25	23.0	12.6	22.4	.46	.26

* Bulk density values are those of Minco loam.

TABLE XII

PROPERTIES OF MINCO LOAM

Location 2: J. Helderman Farm, Hinton, Oklahoma.

Depth	Bulk Density	Moisture Retention at 15 atm.	1:1 pH	Organic Matter	Avail. P	Cation Exchange Capacity	Exchangeable Cations Ca	Mg	K	Na
inches	g./cm.^{3}	%		%	ppm	-----------m.e./100g. of soil-----------				
0-6	1.24	6.6	6.4	1.62	38	11.9	5.8	12.0	.97	.09
6-12	1.43	7.8	6.4	1.47	30	13.8	6.4	12.5	.72	.09
12-24	1.49	7.9	6.6	1.08	17	17.6	7.4	15.5	.87	.09
24-36	1.42	7.8	7.0	0.69	12	17.6	7.2	16.7	.77	.09
36-48	1.47	9.2	7.7	0.41	10	17.9	23.6	19.0	.72	.09

TABLE XIII

PROPERTIES OF WEYMOUTH VERY FINE SANDY LOAM

Location 3: E. James Farm, Alva, Oklahoma.

Depth	* Bulk Density	Moisture Retention at 15 atm.	1:1 pH	Organic Matter	Avail. P	Cation Exchange Capacity	Exchangeable Cations Ca	Mg	K	Na
inches	g./cm.^{3}	%		%	ppm	-----------m.e./100g. of soil-----------				
0-6	1.45	5.0	6.4	1.35	4	8.7	3.6	10.5	.46	.09
6-12	1.40	6.6	6.4	1.11	19	10.4	4.5	13.4	.21	.09
12-24	1.41	6.7	6.6	0.91	13	10.6	5.1	12.2	.26	.09
24-36	1.45	4.9	6.7	0.55	27	8.6	11.0	10.0	.15	.09
36-48	1.46	3.9	7.4	0.31	12	5.0	15.1	9.5	.21	.09

* Bulk density values are those of Carey silt loam.

TABLE XIV

PROPERTIES OF RENFROW SILT LOAM

Location 4: L. Thrular Farm, Medford, Oklahoma.

Depth	Bulk Density	Moisture Retention at 15 atm.	1:1 pH	Organic Matter	Avail. P	Cation Exchange Capacity	Exchangeable Cations Ca	Mg	K	Na
inches	g./cm.^{3}	%		%	ppm	----------m.e./100g. of soil----------				
0-6	1.36	7.2	5.4	1.59	44	10.3	5.1	10.9	.36	.17
6-12	1.41	9.2	6.1	1.52	15	11.9	6.8	14.2	.27	.26
12-24	1.50	16.1	6.8	1.11	8	19.7	9.0	20.2	.46	1.22
24-36	1.65	18.7	7.4	0.65	4	22.1	11.0	24.5	.46	1.74
36-48	1.62	17.9	7.6	0.43	6	25.0	19.0	25.0	.62	2.35

TABLE XV

PROPERTIES OF SHELLABARGER FINE SANDY-LOAM

Location 6: V. Dailey Farm, Watonga, Oklahoma.

Depth	* Bulk Density	Moisture Retention at 15 atm.	1:1 pH	Organic Matter	Avail. P	Cation Exchange Capacity	Exchangeable Cations Ca	Mg	K	Na
inches	g./cm.^{3}	%		%	ppm	m.e./100g. of soil				
0-6	1.46	7.7	5.8	0.62	17	10.0	4.8	11.0	.41	.09
6-12	1.56	7.2	6.2	0.59	8	12.7	6.4	10.9	.21	.09
12-24	1.57	6.8	6.6	0.46	6	11.3	6.4	10.2	.21	.09
24-36	1.44	6.8	7.5	0.23	8	11.4	12.0	10.9	.21	.09
36-48	1.50	5.3	7.8	0.18	6	7.3	19.2	9.7	.15	.09

* Bulk density values are those of Pratt loamy fine sand.

TABLE XVI

PROPERTIES OF VANOSS LOAM

Location 7: L. Scott Farm, Watonga, Oklahoma.

Depth	Bulk Density	Moisture Retention at 15 atm.	1:1 pH	Organic Matter	Avail. P	Cation Exchange Capacity	Exchangeable Cations Ca	Mg	K	Na
inches	g./cm.^{3}	%		%	ppm	-----------m.e./100g. of soil-----------				
0-6	1.53	4.9	5.9	1.21	15	9.1	4.6	7.9	.36	.09
6-12	1.55	7.0	6.8	1.15	10	11.9	6.2	12.5	.21	.26
12-24	1.60	15.0	7.4	0.95	8	22.1	7.5	22.0	.46	1.91
24-36	1.66	17.6	7.7	0.67	6	26.1	15.9	33.4	.46	3.13
36-48	1.61	14.3	7.8	0.44	6	25.6	24.8	31.7	.56	3.91

TABLE XVII

PROPERTIES OF VANOSS LOAM

Location 8: B. Powers Farm, Watonga, Oklahoma.

Depth	Bulk Density	Moisture Retention at 15 atm.	1:1 pH	Organic Matter	Avail. P	Cation Exchange Capacity	Exchangeable Cations Ca	Mg	K	Na
inches	g./cm.^{3}	%		%	ppm	------------m.e./100g. of soil----------				
0-6	1.53	2.9	6.0	0.62	10	3.6	2.8	6.7	.26	.09
6-12	1.55	4.0	6.0	0.77	8	5.7	3.0	7.4	.26	.09
12-24	1.60	6.6	5.7	0.93	6	9.0	5.1	7.9	.36	.09
24-36	1.66	8.3	5.7	0.85	23	12.9	6.4	6.2	.36	.09
36-48	1.61	8.1	5.9	0.54	6	12.0	6.2	13.4	.36	.09

TABLE XVIII

PROPERTIES OF SHELLABARGER FINE SANDY LOAM

Location 9: Rother Bros. Farm, Watonga, Oklahoma.

Depth	* Bulk Density	Moisture Retention at 15 atm.	1:1 pH	Organic Matter	Avail. P	Cation Exchange Capacity	Exchangeable Cations Ca	Mg	K	Na
inches	g./cm.^{3}	%		%	ppm	-----------m.e./100g. of soil-----------				
0-6	1.46	3.1	5.8	0.54	13	4.7	2.8	12.5	.15	.09
6-12	1.56	3.6	5.6	0.59	10	5.4	4.0	7.9	.15	.09
12-24	1.57	7.7	5.5	0.75	6	11.3	5.5	7.4	.26	.09
24-36	1.44	8.8	5.7	0.54	6	12.9	6.8	10.9	.36	.09
36-48	1.50	10.1	5.9	0.26	2	15.9	7.2	13.4	.36	.09

* Bulk density values are those of Pratt loamy fine sand.

TABLE XIX

PROPERTIES OF KINGFISHER SILT LOAM

Location 10: R. Moyer Farm, Drummond, Oklahoma.

Depth	* Bulk Density	Moisture Retention at 15 atm.	1:1 pH	Organic Matter	Avail. P	Cation Exchange Capacity	Exchangeable Cations Ca	Exchangeable Cations Mg	Exchangeable Cations K	Exchangeable Cations Na
inches	g./cm.^{3}	%		%	ppm	------------m.e./100g. of soil-----------				
0-6	1.45	7.0	6.3	1.50	15	12.4	7.0	15.5	.46	.17
6-12	1.48	9.0	6.6	1.50	15	13.7	8.4	19.0	.46	.26
12-24	1.41	11.5	7.0	1.10	6	17.3	9.2	21.5	.51	.26
24-36	1.47	8.6	7.9	0.82	2	12.7	30.2	27.6	.26	.26
36-48	1.54	8.2	8.0	0.49	8	9.6	26.6	25.7	.26	.26

* Bulk density values are those of Grant silt loam.

TABLE XX

PROPERTIES OF KIRKLAND SILT LOAM

Location 11: L. Schick Farm, Newkirk, Oklahoma.

Depth	Bulk Density	Moisture Retention at 15 atm.	1:1 pH	Organic Matter	Avail. P	Cation Exchange Capacity	Exchangeable Cations			
							Ca	Mg	K	Na
inches	g./cm.^{3}	%		%	ppm	-----------m.e./100g. of soil-----------				
0-6	1.35	8.9	6.3	2.23	34	17.4	15.4	8.5	.56	.26
6-12	1.45	9.6	6.0	2.28	21	18.2	12.9	11.5	.46	.44
12-24	1.52	14.0	6.2	1.49	10	21.6	12.7	18.4	.51	1.04
24-36	1.65	13.5	7.0	0.72	8	19.8	19.5	20.2	.46	1.74
36-48	1.62	13.3	6.6	0.90	8	17.2	11.7	19.0	.51	2.18

TABLE XXI

PROPERTIES OF TABLER SILT LOAM

Location 12: D. Jelsma Farm, Ponca City, Oklahoma.

Depth	Bulk Density	Moisture Retention at 15 atm.	1:1 pH	Organic Matter	Avail. P	Cation Exchange Capacity	Exchangeable Cations Ca	Mg	K	Na
inches	g./cm.^{3}	%		%	ppm	-----------m.e./100g. of soil----------				
0-6	1.44	7.3	6.9	1.97	36	15.0	12.6	22.9	.46	.17
6-12	1.35	14.3	6.1	1.80	15	23.3	7.0	23.4	.26	.61
12-24	1.49	18.7	7.1	0.97	6	49.6	14.7	31.7	.56	1.48
24-36	1.62	15.9	7.5	0.49	4	25.4	18.0	30.2	.51	1.65
36-48	1.61	16.6	7.4	0.28	15	25.4	13.8	27.1	.56	1.91

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