EFFECTS OF DIFFERENT LEVELS OF MOISTURE STRESS ON YIELD AND YIELD COMPONENTS OF FOUR WINTER WHEAT VARIETIES

By

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure | Page

CHAPTER I

INTRODUCTION

Partial loss of the staple food crops is often incurred from moisture deficits which then affect the land, the grower, foreign trade, and the consumer. Parts of the Great Plains area of the United States often experience water deficits. Wheat is one of the leading crops in the Great Plains and is in primary consideration for physiologic and genetic investigations leading to the development of varieties which would be more tolerant to water stress.

Every process occurring in plants is affected in some way by the amount of available moisture. Water stress at different stages of plant growth affects different plant processes which in turn affect the quantity and/or quality of growth and production. A study of the effects of different moisture levels on wheat varieties could result in an understanding of how varieties differ in their ability to withstand varying degrees of moisture stress at different periods of growth. This type of a study could also determine how each variety adjusts to stress in terms of important yield components.

The primary objectives of this study are: 1) to determine the response of certain varieties to stress, and 2) to determine how these varieties behave with regard to yield and yield components.

CHAPTER II

LITERATURE REVIEW

Kramer (10) stated that the essential feature in plant-water relations is the internal water balance, water stress, or degree of turgidity which exists in the plants. Water deficits occur because the internal water balance and degree of water stress depend on the relative rates of water absorption and water loss. This water balance is affected by the complex combination of soil, plant, and atmospheric conditions.

In an experiment conducted under greenhouse conditions by Lehane and Staple (11) on several soil types, crops subjected to moisture stress at an early stage of growth yielded well on all soils tested. But crops with moisture stress late in the season yielded poorly on loam soils. In the same study, when wheat was subjected to moisture stress at an early stage of growth, the grain yield was superior to treatments in which moisture stress was applied late in the season. Similar results were reported by Mitchell (13) and Botkin (1).

Hallsted and Mathews (7), in an experiment conducted in Kansas, observed that the depth to which the soil was wet at seeding time had, on the average, a very close relationship to the yields obtained. A number of studies indicate that wheat yields in the Great Plains are roughly proportional to seasonal precipitation and the depth to which the soil is wetted at planting time (3, 6, 12).

In general, net photosynthesis is progressively reduced by water stress (10, 13, 21, 24). Water stress causes premature closure of stomata which reduces water loss, but stomatal closure also interferes with the uptake of carbon dioxide causing reduction of photosynthesis (10, 21). Stomata may, however, exert relatively greater control over water loss than over carbon dioxide uptake. Carbon dioxide has additional resistances to its transport and the stomatal resistance may be a smaller fraction of the total resistance for carbon dioxide (14).

Todd and Webster (24) working with cereal seedlings found that photosynthesis in most leaves ceases when they become wilted. The extent to which photosynthesis decreases as moisture stress increases seems to vary with the species of plant being tested and the environmental conditions encountered during the stress period. The ability of a plant to photosynthesize while under stress or to recover more quickly after rewatering might contribute to drought resistance.

Low temperatures enhance drought hardiness (13). Todd and Webster's (24) results indicate that some drought hardening may take place in the cereal plants in a manner similar to cold hardening of plants which can be achieved by exposure to low but nonfreezing temperatures.

After recovery from a period of drought, plants are usually much more resistant to the influences of further water stress. The hardened plants exhibit increased viscosity of the protoplasm, higher rates of photosynthesis, lower rates of respiration, greater root development, and less reduction in yield when further subjection to water stress (13). Photosynthesis in these hardened plants might decrease less during subsequent drought stresses which would be an important survival feature (24).

Earliness has been reported as a desirable feature in varieties grown in low rainfall areas (18), and provides some insurance against adverse effects of warm and dry weather. However, it has been pointed out that highest average yields tend to come from varieties with medium-early to late maturity (17).

Another means of minimizing losses from drought stress, as suggested by Sandhu and Laude (16), would be to develop cultural practices conducive to achieving a hardy condition in winter wheat plants and then to select strains that possess hardy germplasm.

Roots probably play an important role in drought tolerance. Growth pattern, depth of penetration, development, and amount of root material are important features leading to drought tolerance (8, 15). Hurd (8) suggested that root patterns could explain the varietal differences in resistance to drought and to damage by soil cracking. Late maturing varieties are thought to have a deeper and better developed root system which in turn should lead to greater drought resistance (17). Root systems that develop extensively before heading would be beneficial for the variety so that carbohydrates could be directed to the filling of the head and not toward developing new roots at the end of the growing season (18).

The deleterious effects of water deficits are usually most pronounced in tissues and organs which are in stages of most rapid growth and development. Consequently, there are certain stages in the growth cycle which are more susceptible to stress injury than others (13, 21). In wheat, the stages most susceptible to stress appear to be the growth periods of stem elongation, spikelet differentiation, and anthesis.

Wheat grain yields vary as a result of the combined effects of a) the number of spikes per unit area, b) the number of kernels per spike, and c) the average kernel weight (5, 9, 23). The expression of these yield components varies widely with moisture supply, soil fertility level, and other growth-limiting factors.

It has been reported (20) that drought during the period of rapid leaf development reduced the number of fertile tillers, drought during the period of spikelet formation decreased the number of spikelets per spike, drought during anthesis decreased the total number of grains, and drought during the period of grain formation decreased the weight of the grain. Campbell (2) noted that stress imposed at any particular stage of growth significantly decreased grain yield of wheat. Particularly severe effects occurred when stress was applied at the dough stage. Stress at times of floral initiation, anthesis, or grain filling tended to reduce the yield potential of a crop, although there were wide differences among the cereals in the effects of stress upon growth and development (24).

Slight water stress has been shown to reduce the rate of appearance of floral primordia (21). If the stress is mild and the period of stress is relatively brief, the rate of primordial initiation, upon relief of stress, is more rapid and the total number of spikelets formed may be unaffected. Yet, if the stress is severe or prolonged, total spikelet number may be substantially reduced (21).

Slayter (21) cited the work of Nichols and May with barley in a stress study. A control and two levels of moisture deficits were studied. The rate of initiation of floral primordia became progressively slower in the stressed plants but, upon rewatering, the rate in the 'mild' stress treatment increased rapidly so that by the time of stamen initiation, total spikelet number was almost the same as in the control. By comparison, in the 'severe' stress treatment, total spikelet number was at a much lower level at the time when development of the spike was concluded.

In a report by Schmidt (17), a citation was presented of work by Asana indicating that under moisture stress conditions in India, grain number per spike is an important and constant trait for yield stability. It was further suggested that under stress conditions the main spike contributes most to yield and therefore selection for large spike size (or larger number of grains per spike) would be beneficial. Donald (4) proposed a basic wheat ideotype having a 'large ear' with many florets which would contribute to a high grain yield in a crop community.

In the Great Plains of the central USA, tillering ability of winter wheat has been emphasized in many breeding programs. Plants which flower over an extended period are somewhat protected from isolated periods of stress. Many of these late tillers, however, will not produce fertile heads and whether these late tillers are beneficial or actually detrimental to yield is not known (17, 21).

Yield is the ultimate measurement of variety performance and represents the cumulative effects of the interactions of many factors of which moisture stress is only one, but an important one (17). Asana, as cited by Schmidt (17), asserted that high 1000-grain weight contributes heavily to stable varietal performance and high yield under high temperature and water stress conditions. In Nebraska yield tests, Schmidt (17) reported that 1000-grain weight has been highly variable from location to location and year to year, but variety rankings are relatively constant. Grain yield need not be related to kernel weight. Slayter (21) stated that weight per grain is influenced by pre- and post-flowering conditions with the latter case being the most important. In general, varieties with larger kernels are more responsive as conditions change from early drought stress to more favorable conditions during grain filling and thus can compensate for decreases in other yield components (17).

Production of high protein wheat is generally associated with conditions where soil moisture is the principle yield-limiting factor (1, 6). Fernandez g. and Laird (6) found that protein content of the grain was lowest in the wettest treatment and highest in the driest treatment. Botkin (1) noted that the same variety of wheat may vary in protein when grown under different seasonal conditions. Associations of increased protein content in the grain of wheat with hot, dry growing seasons were noted in reports by Shaw (18) and Shutte (19).

With regard to the efficiency of water use by crops, those grown under conditions of early stress used less moisture, but were equally as efficient in grain production as those grown under optimum conditions. Crops with moisture deficits during heading and grain filling periods were inefficient in moisture use (11). Some plants appear to conserve water or to use it more efficiently than others (25).

Water stress is known to decrease the shoot to root growth ratio (10, 13). Stress has also been found to decrease the proportion of lateral roots to total root length, and to decrease the ratio of leaf to stem (13). Mitchell (13) reported that during a period of soil water stress, the growth of organs was influenced in this order of decreasing severity: leaves-stems-roots.

A composite plant type of winter wheat for high yields in low rainfall areas was suggested by Schmidt (17). The plant should be intermediate in spike size with good spike fertility, above average in kernel weight, and well tillered with high tiller survival for spike production. It should also have a medium to small-sized leaf, a vigorous root system, and the ability to emerge rapidly from deep seeding.

CHAPTER III

MATERIALS AND METHODS

The study was conducted during the 1974-75 growing season at three locations in Oklahoma. These were the Agronomy Research Stations at Stillwater, Lahoma, and Altus. These locations were selected because of their contrast in environments in major wheat producing areas in the state.

Four hard red winter wheat varieties (*Triticum aestivum* L. em Thell) were selected for this study. They were 'Triumph 64', a variety traditionally considered as relatively drought hardy, 'Caprock', a semi-dwarf variety generally considered as being drought susceptible, 'Osage', a late maturing, standard height variety with good yield potential in Oklahoma, and 'Bezostaia 1', a Russian variety with relatively large spikes and large kernels. Triumph 64, Caprock, and Osage are grown commercially in Oklahoma. Bezostaia 1 is an important variety in Eastern Europe. All four varieties are currently being used as parent stock in the Oklahoma wheat breeding program.

Field Layout and Stress Levels

A split-plot design was used at each station for this study. The test at Lahoma, in the northcentral region of Oklahoma, was conducted on a Pond Creek silt loam soil, the test at Altus, in the southwest part of the state, was on a Hollister-Tillman clay loam soil, and the test at Stillwater was on a Norge loam soil. Fertilizer applications were as follows: Altus, 40#/A P_2O_5 pre-plant and 40#/A nitrogen top-dress; Lahoma, 100#/A 16-48-0 pre-plant and 40#/A nitrogen; and Stillwater, 200#/A 18-46-0 pre-plant and 150# ammonium nitrate top-dress. Planting was done on a tractor mounted four-row cone planter with planting dates of October 2, 1974, at Lahoma; October 7, 1974, at Stillwater; and October 8, 1974, at Altus.

In the split-plot design, stress levels comprised the main-plots and the sub-plots consisted of the varieties. Main-plots were randomized within each replication and sub-plots were randomized within main-plots. There were four replications of each treatment. A plot consisted of four 3 m rows, with the two outside rows of each plot serving as guard rows. Stress levels were imposed by varying the seeding rate of the two outside guard rows of each plot.

Stress levels were imposed by the following seeding rates of the guard rows:

Stress Level 1	16.82 kg/ha	(15 lbs/A)
Stress Level 2	67.28 kg/ha	(60 lbs/A)
Stress Level 3	134.52 kg/ha	(120 lbs/A)
Stress Level 4	269.04 kg/ha	(240 lbs/A)

By varying the seeding rate of the guard rows, the intention was that different levels of soil moisture would be available to the two center test rows.

The two center rows served as test rows in all cases and were planted at the standard seeding rate of 67.28 kg/ha (60 lbs/A).

Characters Evaluated

Eight characters were evaluated in this study. Four of them consisted of grain yield and the three major yield components (tiller number, kernels/spike and kernel weight). The remaining four characters were grain protein content, test weight, plant height, and lodging. Measurements in all cases were made on the two center test rows of each plot.

Grain Yield

Grain yield was determined by harvesting a 2.4 m length of the two center test rows from each sub-plot. Plots were prepared for harvest by removing 0.3 m from each end of each test row. Test plots were harvested by a two-row plot harvester. Harvested bundles were threshed in a Vogel thresher and the threshed grain was recorded in grams per plot and then was converted to kilograms per hectare for statistical analysis.

Tiller Number

Fertile tillers within a representative 30 cm section of each test row were counted at the hard dough stage and recorded as the average of two samples per plot. This character was expressed as the number of tillers per 30 cm^2.

Kernels per Spike

A random selection was made of six spikes per test row. Kernels from the sampled spikes were counted, and the average number of kernels per spike was recorded for each plot.

Kernel Weight

Kernels from the spikes taken for kernels per spike measurements were weighed and expressed as grams per 1000 kernels.

Percent Protein

A 10 g sample of grain from each plot was used for protein determination by the Standard Kjeldahl method. This analysis was conducted in the wheat quality laboratory, Oklahoma State University.

Test Weight

Test weight on a per plot basis was determined by a small test weight apparatus in pounds per bushel and then converted to kilograms per hectoliter.

Plant Height

This trait was an average of four measurements in each plot (two measurements per test row) and was determined as the height of the plant in centimeters from the soil line to the tip of the spike, excluding awns.

Lodging

A visual estimation was made in each plot of the percentage of plants not standing erect.

Statistical Analysis

Computational analyses were made by the Statistical Analysis Systems (SAS) at the Oklahoma State University Computer Center. An analysis of variance for a split-plot design was conducted on all data collected. A separate analysis of variance was conducted for each location and an analysis of combined locations was also conducted. Stress by variety interaction mean squares were used to determine the effects of imposing stress on the varieties.

Phenotypic correlation coefficients were computed to determine the relationship between yield and each of the other traits. Correlation coefficients were obtained from the rep by variety (stress) entry line (Error b) in the analysis of variance computer printout for separate locations and from the entry line rep by variety (location by stress), (Error c), in the analysis of variance computer printout for locations combined.

CHAPTER IV

RESULTS AND DISCUSSION

In this study, an attempt to impose different levels of moisture stress was made by varying the seeding rates of the guard rows. However, at each of the three locations, above normal rainfall occurred and consequently the effectiveness of establishing differences in moisture stress was presumed to be reduced. Monthly rainfall data and deviations from the average for the three locations are presented in Tables I, II, and III. During the growing season, Lahoma (Enid weather station) received the highest rainfall, followed by Stillwater and Altus. It is of interest to note that average wheat yields were also highest at Lahoma, followed by Stillwater and Altus.

Mean squares from the analysis of variance of the data for eight traits for the combined locations are presented in Table IV. Differences among locations were significant at the .01 level of probability for all characters with the exception of lodging which was significant at the .05 level of probability. Mean squares for differences among varieties were significant at the .01 level of probability for all eight characters. Location by variety interactions were highly significant for all characters indicating that varieties performed differently in at least one of the locations with regard to the eight characters studied (Table IV).

TABLE I

RAINFALL RECEIVED AND DEVIATIONS FROM NORMAL FOR CROP YEAR 1974-75 AT STILLWATER, OKLAHOMA

		Received		Normal		Deviation from Normal	
Year	Month	mm	Inches	mm	Inches	mm	Inches
1974	July	16.0	0.6	92.5	3.6	- 76.5	- 3.0
	August	171.7	6.8	71.6	2.8	+100.1	+ 3.9
	September	153.2	6.0	101.9	4.0	+ 51.3	+ 2.0
	October	199.9	7.9	70.6	2.8	+129.3	+ 5.1
	November	155.2	6.1	38.4	1.5	+116.8	+ 4.6
	December	55.1	2.2	34.0	1.3	+ 21.1	+ 0.8
1975	January	77.0	3.0	24.1	1.0	+ 52.8	+ 2.1
	February	36.3	1.4	30.4	1.2	+ 5.8	+ 0.2
	March	78.0	3.1	45.5	1.8	+ 32.5	+ 1.3
	April	41.9	1.7	74.4	2.9	- 32.5	- 1.3
	May	333.5	13.1	124.2	4.9	+209.3	+ 8.2
	June	121.9	4.8	105.2	4.1	+ 16.8	+ 0.7
	TOTAL	1439.7	56.7	812.8	32.0	+626.9	+24.7

TABLE II

RAINFALL RECEIVED AND DEVIATIONS FROM NORMAL FOR CROP YEAR 1974-75 AT ENID, OKLAHOMA (FOR LAHOMA TEST)

		Received		Normal		Deviation from Normal	
Year	Month	mm	Inches	mm	Inches	mm	Inches
1974	July	23.6	0.9	83.3	3.3	- 59.7	- 2.4
	August	189.2	7.5	82.8	3.3	+106.4	+ 4.2
	September	103.1	4.1	83.8	3.3	+ 19.3	+ 0.8
	October	114.3	4.5	59.4	2.3	+ 54.9	+ 2.2
	November	105.4	4.2	39.9	1.6	+ 65.5	+ 2.6
	December	52.3	2.1	30.7	1.2	+ 21.6	+ 0.9
1975	January	77.5	3.1	20.3	0.8	+ 57.2	+ 2.3
	February	96.5	3.8	27.7	1.1	+ 68.8	+ 2.7
	March	53.9	2.1	42.2	1.7	+ 11.7	+ 0.5
	April	21.6	0.9	77.7	3.1	- 56.1	- 2.2
	May	177.6	7.0	113.3	4.5	+ 64.3	+ 2.5
	June	163.1	6.4	110.2	4.3	+ 52.8	+ 2.1
	TOTAL	1178.1	46.4	771.4	30.4	+406.7	+16.0

TABLE III

RAINFALL RECEIVED AND DEVIATIONS FROM NORMAL FOR CROP YEAR 1974-75 AT ALTUS, OKLAHOMA

		Received		Normal		Deviation from Normal	
Year	Month	mm	Inches	mm	Inches	mm	Inches
1974	July	4.8	0.2	52.6	2.1	- 47.8	- 1.9
	August	187.5	7.4	52.3	2.1	+135.1	+ 5.3
	September	214.6	8.5	62.2	2.5	+152.4	+ 6.0
	October	113.8	4.5	70.9	2.8	+ 42.9	+ 1.7
	November	16.8	0.7	22.6	0.9	- 5.8	- 0.2
	December	24.4	1.0	24.9	1.0	- 0.5	0.0
1975	January	40.1	1.6	21.3	0.8	+ 18.8	+ 0.7
	February	52.3	2.1	25.9	1.0	+ 26.4	+ 1.0
	March	22.9	0.9	32.0	1.3	- 9.1	- 0.4
	April	22.6	0.9	53.1	2.1	- 30.5	- 1.2
	May	117.1	4.6	109.2	4.3	+ 7.9	+ 0.3
	June	131.6	5.2	98.6	3.9	+ 33.0	+ 1.3
	TOTAL	948.4	37.3	625.6	24.6	+322.83	+12.7

TABLE IV

MEAN SQUARES FROM ANALYSIS OF VARIANCE OF DATA
COMBINED LOCATIONS

Sources of Variation	df	Grain Yield	Tiller Number	Kernels per Spike	Kernel Weight	Percent Protein	Test Weight	Plant Height	Lodging
Location	2	3510.25**	8357.35**	434.99**	365.26**	141.71**	397.49**	8149.27**	1318.15**
error a	9	26.34	183.41	4.66	3.74	2.19	2.71	28.79	227.79
Stress	3	159.24**	375.90*	27.79**	5.07	6.34*	4.63	51.89	750.67**
Loc x Stress	6	45.61	162.66	1.66	15.34	4.74*	8.73**	15.89	92.92
error b	27	28.39	89.19	1.68	6.77	1.83	2.31	20.82	84.47
Varieties	3	62.37**	4414.50**	854.95**	546.98**	0.86**	98.44**	2890.11**	2419.42**
Loc x Var	6	188.07**	277.80**	75.25**	13.72**	1.92**	8.03**	249.67**	1436.98**
Stress x Var	9	19.75	37.75	2.71	3.62	0.52*	2.23	11.30	115.95
Loc x Stress x Var	18	13.69	43.75	2.09	3.93	0.22	2.91	8.90	88.45
error c	108	11.66	41.53	1.72	2.70	0.21	1.16	7.20	62.51

*,** Significant at the .05 and .01 levels of probability, respectively.

Stress levels were highly significant (i.e. at the .01 level of probability) for grain yield, kernels per spike, and lodging, while significance at the .05 level was noted for tiller number and percent protein. Stress levels did not significantly affect kernel weight, test weight or height. The location by stress interaction was significant at the .01 level for test weight and at the .05 level for percent protein. There was also a significant stress by variety interaction for percent protein.

Mean squares from the analysis of variance of the data from individual locations are presented in Tables V, VI, and VII. Differences among varieties were significant at the .01 level of probability for all characters at all three locations with the exception of percent protein at Stillwater which was significant at the .05 level of probability. For certain traits, stress levels and/or stress by variety interactions were statistically significant. These will be discussed under the appropriate headings.

Effects of Stress Levels

Stress level by variety response relationships for yield and yield components (i.e. tiller number, kernels per spike, and kernel weight) are presented as tables of means and also graphically, although some of these responses were not statistically significant. These are presented and discussed in order to try to understand which components were important in determining grain yield under the growing conditions encountered at three locations. Stress level by variety responses for the remaining characters which were statistically significant are also presented and discussed in this section.

TABLE V

MEAN SQUARES FROM ANALYSIS OF VARIANCE OF DATA
STILLWATER

Sources of Variation	df	Grain Yield	Tiller Number	Kernels per Spike	Kernel Weight	Percent Protein	Test Weight	Plant Height	Lodging
Replication	3	14.03	84.17	0.94	3.06	5.17	0.35	38.60	105.43
Stress	3	130.28*	524.77*	12.85*	7.95	14.17	3.46	48.49	320.64*
error a	9	26.51	121.12	1.79	5.22	4.57	1.13	24.42	60.84
Varieties	3	138.43**	1672.05**	152.11**	117.14**	0.95*	30.48**	1222.31**	43.14**
Stress x Var	9	15.44	39.64	4.48*	2.13	0.40	0.76	9.18	25.77**
error b	36	12.23	41.30	1.81	1.75	0.23	1.74	9.43	8.57

*, ** Significant at the .05 and .01 levels of probability, respectively.

TABLE VI

MEAN SQUARES FROM ANALYSIS OF VARIANCE OF DATA
LAHOMA

Sources of Variation	df	Grain Yield	Tiller Number	Kernels per Spike	Kernel Weight	Percent Protein	Test Weight	Plant Height	Lodging
Replication	3	34.28	443.88	3.32	1.10	0.18	3.14	38.75	185.77
Stress	3	63.06	163.78	7.34**	2.60	0.47	2.38	11.21	283.68*
error a	9	17.10	58.88	0.74	1.83	0.14	0.62	10.85	41.32
Varieties	3	136.17**	1465.60**	226.85**	263.73**	2.40**	53.73**	1340.29**	221.81**
Stress x Var	9	10.27	68.68	1.49	1.13	0.22	2.28**	12.50*	79.86
error b	36	14.35	55.77	0.97	2.04	0.13	0.68	5.70	38.68

*, ** Significant at the .05 and .01 levels of probability, respectively.

TABLE VII

MEAN SQUARES FROM ANALYSIS OF VARIANCE OF DATA
ALTUS

Sources of Variation	df	Grain Yield	Tiller Number	Kernels per Spike	Kernel Weight	Percent Protein	Test Weight	Plant Height	Lodging
Replication	3	30.70	22.18	9.70	7.06	1.24	4.66	9.02	392.18
Stress	3	57.13	12.68	10.92*	25.20	1.18	16.27	23.97	332.18
error a	9	41.55	87.56	2.51	13.24	0.78	5.16	27.21	151.25
Varieties	3	163.31**	1832.47**	626.49**	193.56**	1.36**	30.30**	826.85**	5028.43**
Stress x Var	9	21.41*	16.92	0.92	8.22	0.35	5.00**	7.43	187.22
error b	36	84.01	27.51	2.37	4.31	0.28	1.07	6.45	140.29

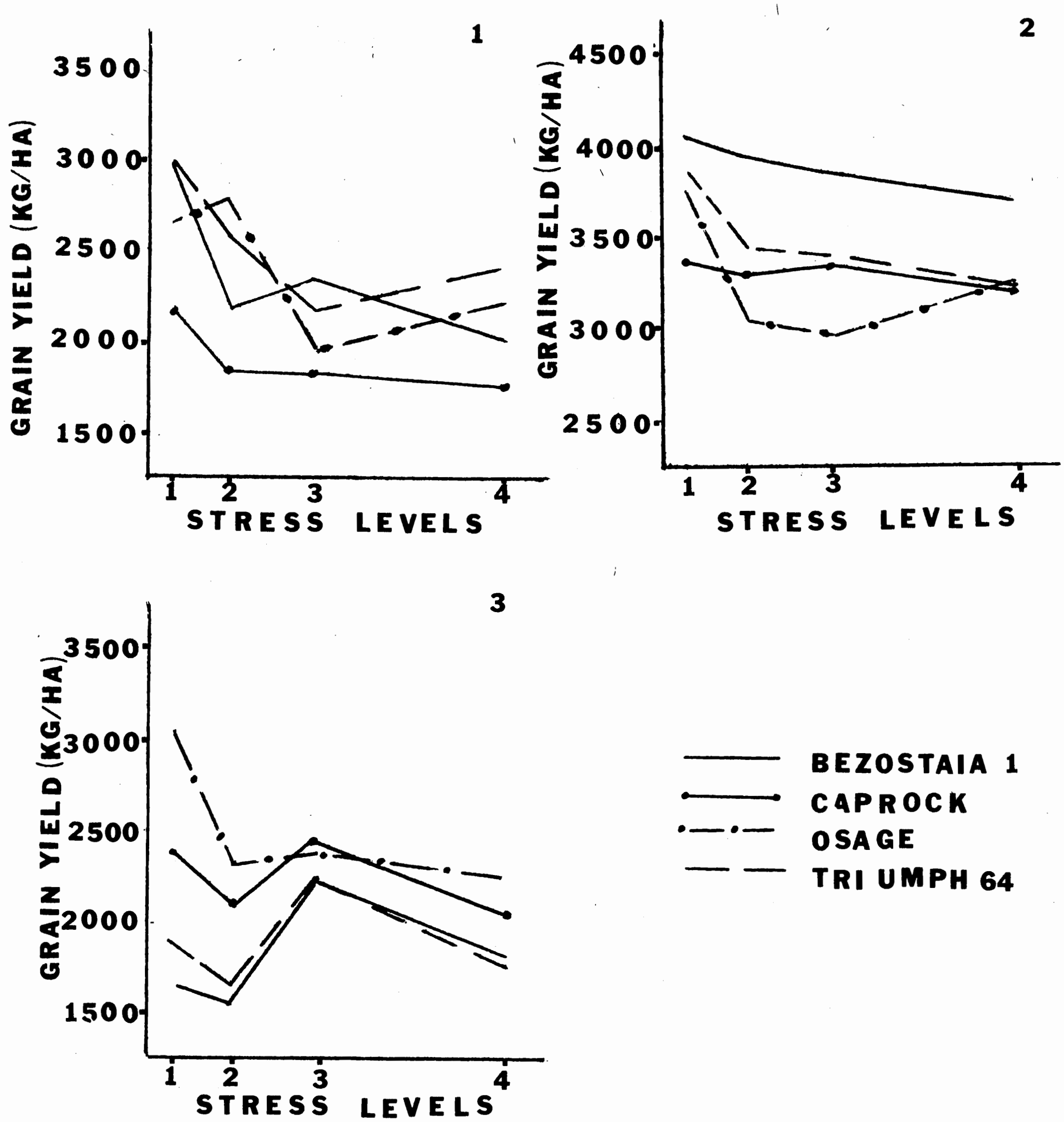
*, ** Significant at the .05 and .01 levels of probability, respectively.

Grain Yield

Significant differences among stress levels were observed for this trait only at Stillwater. And a significant stress by variety interaction was observed only at Altus (Tables V, VI, and VII).

At Stillwater, the highest yielding varieties under Stress Level 1 were Bezostaia 1 and Triumph 64, each with 2933 kg/ha (Table VIII). However, at Stress Level 2 Bezostaia 1 dropped more markedly than Triumph 64 (i.e. Bezostaia 1 yielded 700 kg/ha less at Stress Level 2 than at Stress Level 1, with the yield of Triumph 64 being reduced by 300 kg/ha in the same comparison). In Stress Level 3, Bezostaia 1 increased by 100 kg/ha over Stress Level 2 while Triumph 64 decreased by 400 kg/ha in the same comparison. Osage had an increase in yield from Stress Level 1 to Stress Level 2 of 100 kg/ha, a decrease in yield of approximately 830 kg/ha from Stress Level 2 to Stress Level 3, and then an increase of 300 kg/ha from Stress Level 3 to Stress Level 4. The yield of Caprock dropped by some 300 kg/ha from Stress Level 1 to Stress Level 2 and its yield at Stress Levels 3 and 4 was approximately the same as at Stress Level 2. At Stillwater, as shown in Figure 1, highest yields were generally produced at Stress Level 1. And there was little change from Stress Levels 3 to 4. However, the response was not the same for each variety.

The highest yields in this study were obtained at Lahoma (Table VIII). At this location, Bezostaia 1 had the highest average yield and also the highest single treatment yield which occurred at Stress Level 1. In all varieties at Lahoma, the highest yields were produced at Stress Level 1. The yield response to Stress Levels 2, 3,



Figures 1, 2, and 3. Grain Yield of the Four Wheat Varieties at the Four Stress Levels at Stillwater, Lahoma, and Altus, respectively.

TABLE VIII

MEANS FOR GRAIN YIELD (KG/HA)

Variety	Stress Level	Location: Stillwater[1/]	Lahoma	Altus[2/]	Average
Bezostaia 1	1	2933	4050	1658	2881
	2	2230	3956	1591	2592
	3	2328	3875	2237	2813
	4	2015	3677	1800	2497
	Avg	2377	3889	1821	2696
Caprock	1	2149	3394	2371	2638
	2	1796	3293	2176	2422
	3	1766	3300	2422	2496
	4	1759	3145	2025	2310
	Avg	1868	3283	2249	2466
Osage	1	2688	3751	3014	3151
	2	2762	3068	2277	2702
	3	1934	2960	2368	2421
	4	2230	3246	2331	2602
	Avg	2403	3256	2498	2719
Triumph 64	1	2933	3872	1850	2885
	2	2634	3421	1652	2596
	3	2235	3394	2244	2624
	4	2348	3226	1769	2448
	Avg	2537	3478	1879	2631
Average (All Varieties)	1	2676	3767	2223	2889
	2	2355	3434	1924	2571
	3	2065	3382	2318	2588
	4	2088	3323	1981	2464
	Overall Avg	2296	3477	2112	2628

1/ Differences among stress levels were statistically significant at Stillwater but not at Lahoma or Altus.

2/ Significant stress by variety interactions occurred at Altus but not at Stillwater or Lahoma.

and 4 tended to be rather similar within each variety (Figure 2).

The lowest average yields were produced at Altus (Table VIII). At this location, in which a significant stress by variety interaction occurred, three out of the four varieties produced their highest yields at Stress Level 3. The fourth variety, Osage, produced its second highest yield at Stress Level 3. The failure of Osage to follow the response pattern of the other three varieties at Altus is depicted in Figure 3. It is difficult to explain why high average yields occurred at Stress Level 3 (134.52 kg/ha seeding rate of guard rows) at Altus. It is possible that a certain amount of stress imposed by this stress level was effective during part of the growth cycle of the plants which, in turn, was favorable for the expression of one or more of the yield components. An examination of the stress level means at Altus (Tables VIII-XI) shows that Stress Level 3 resulted in the production of higher tillering and heavier kernels than any other stress level. Apparently the effects of stress imposed by Stress Level 3 operated to enhance these two yield components which, in turn, resulted in higher grain yield.

Tiller Number

The Stillwater location showed a significant difference among stress levels for this trait (Table V). Differences among stress levels were not statistically significant at the other two locations and there were no significant stress by variety interactions. At Stillwater, the highest tiller number was produced at Stress Level 1 for all varieties (Table IX). Varietal response to Stress Levels 2, 3, and 4 was somewhat inconsistent although tiller numbers at these

TABLE IX

MEANS FOR TILLER NUMBER (NO./30 CM^2)

Variety	Stress Level	Location: Stillwater[1/]	Lahoma	Altus	Average
Bezostaia 1	1	54.4	61.5	39.3	51.7
	2	47.3	55.3	37.4	46.6
	3	48.0	59.5	37.6	48.4
	4	46.1	57.8	37.0	47.0
	Avg	48.9	58.5	37.8	48.4
Caprock	1	65.9	75.9	49.3	63.7
	2	56.8	74.0	47.9	59.5
	3	53.9	70.8	51.6	58.8
	4	59.0	66.9	46.0	57.3
	Avg	58.9	71.9	48.7	59.8
Osage	1	82.8	89.1	61.5	77.8
	2	71.1	74.6	63.5	69.8
	3	64.3	74.4	63.9	67.5
	4	66.8	74.9	65.5	69.0
	Avg	71.2	78.3	63.6	71.0
Triumph 64	1	79.3	79.5	44.0	67.6
	2	63.6	73.5	49.6	62.3
	3	69.1	83.1	47.9	66.7
	4	63.8	81.1	45.1	63.3
	Avg	68.9	79.3	46.7	65.0
Average (All Varieties)	1	70.6	76.5	48.5	65.2
	2	59.7	69.3	49.6	59.5
	3	58.8	71.9	50.3	60.3
	4	58.9	70.2	48.4	59.2
	Overall Avg	62.0	72.0	49.2	61.1

[1/] Differences among stress levels were statistically significant at Stillwater but not at Lahoma or Altus. Stress by variety interactions were not significant at any of the locations.

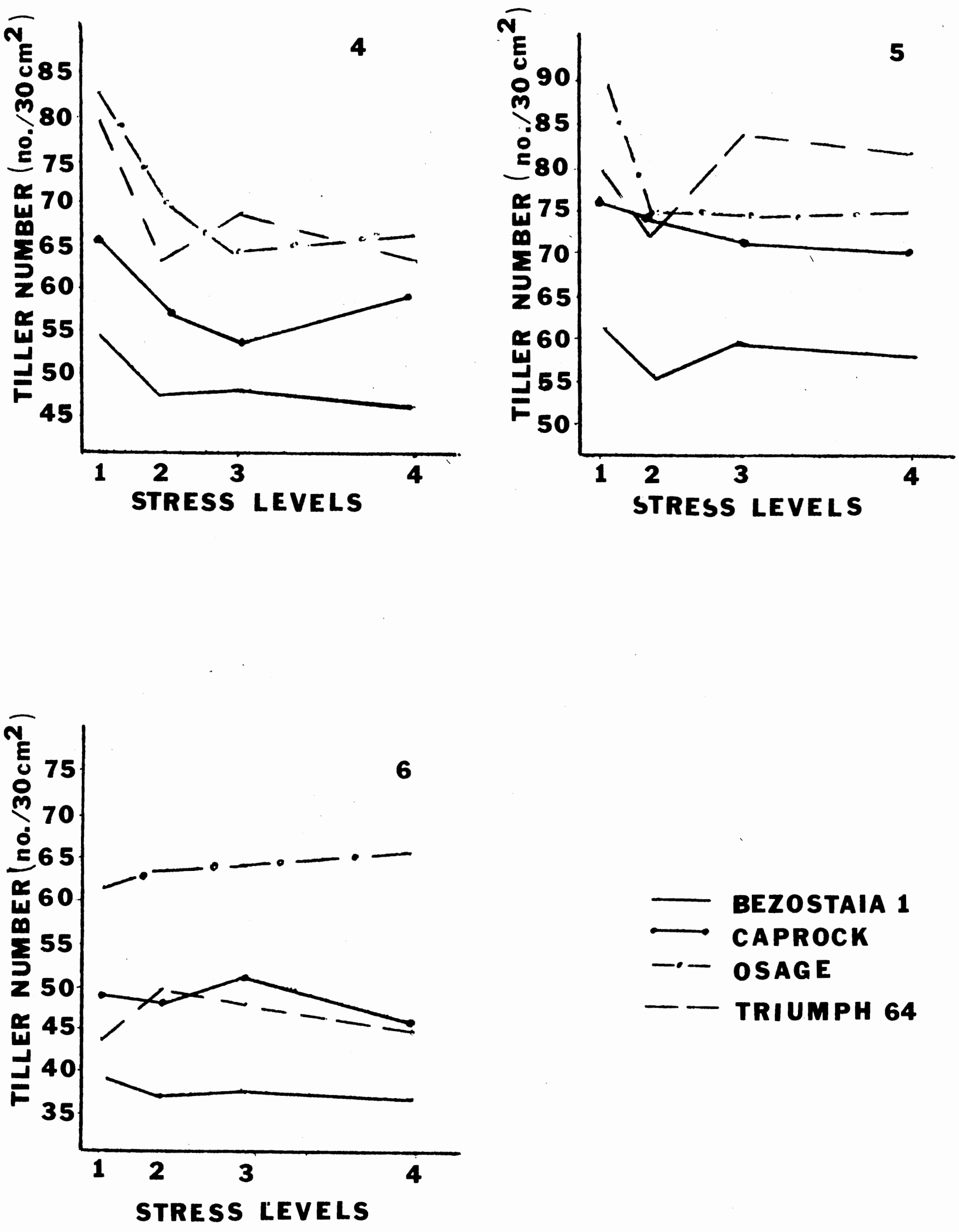
levels of stress did not differ greatly within each variety (Figure 4). At Stillwater, Osage produced the higher number of tillers (averaged across stress levels), followed by Triumph 64, Caprock, and Bezostaia 1.

When all three locations are considered, the highest average tiller production occurred at Lahoma and the lowest at Altus (Table IX). At all three locations, Bezostaia 1 had the lowest average tiller number. Osage had the highest average tiller number at Altus and Triumph 64 had the highest average number at Lahoma. The response of the four varieties to the four stress levels at Lahoma and Altus are shown in Figures 5 and 6, respectively.

Kernels per Spike

A highly significant difference among stress levels was observed for kernels per spike at Lahoma (Table VI). At Stillwater and Altus, differences among stress levels were significant at the .05 level of probability (Tables V and VII). Also, at Stillwater, a significant stress by variety interaction was observed for this trait. In nearly every case, when all varieties and locations are considered, the highest number of kernels per spike was produced at Stress Level 1. A notable exception occurred with Bezostaia 1 at the Stillwater test in which Stress Levels 2 and 3 were higher for this trait than Stress Level 1.

At Stillwater, Bezostaia 1 had the highest average value for kernels per spike and Osage the lowest (Table X). The four varieties in the test tended to respond similarly at Stress Levels 3 and 4 but not at Stress Levels 1 and 2 (Figure 7). This failure to respond



Figures 4, 5, and 6. Tiller Number of the Four Wheat Varieties at the Four Stress Levels at Stillwater, Lahoma, and Altus, respectively.

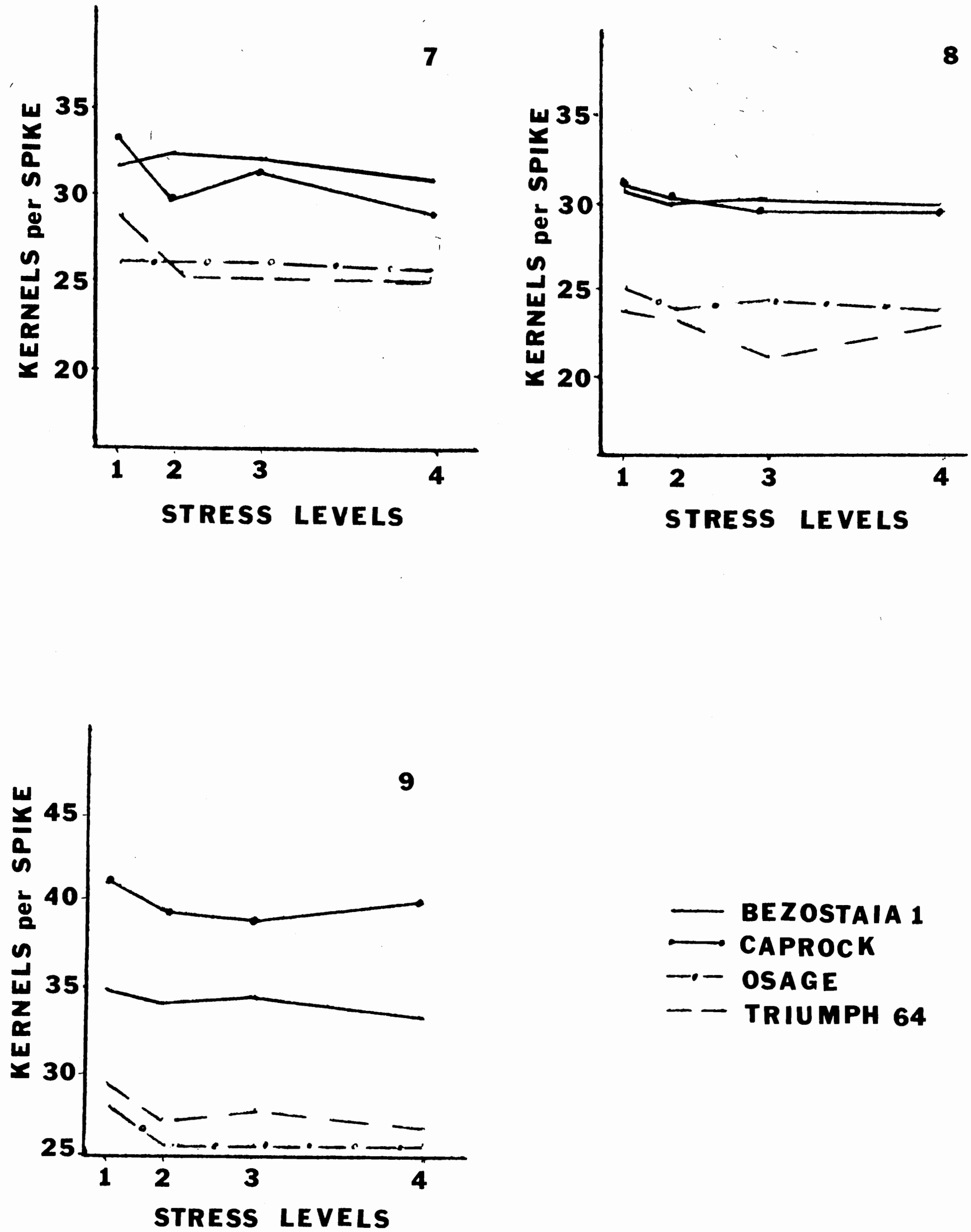
TABLE X

MEANS FOR KERNELS PER SPIKE

Variety	Stress Level	Location Stillwater[1,2]	Lahoma[1]	Altus[1]	Average
Bezostaia 1	1	31.9	31.3	34.9	32.7
	2	32.5	30.0	34.3	32.3
	3	32.2	30.4	34.7	32.5
	4	31.2	29.9	33.5	31.5
	Avg	32.0	30.4	34.3	32.2
Caprock	1	33.0	31.4	41.6	35.3
	2	29.4	30.3	39.4	33.0
	3	31.7	29.1	39.1	33.3
	4	28.9	29.8	39.9	32.8
	Avg	30.7	30.1	40.0	33.6
Osage	1	26.1	25.1	28.1	26.4
	2	26.1	24.1	25.9	25.4
	3	26.1	24.7	25.9	25.6
	4	25.7	24.1	25.9	25.2
	Avg	26.0	24.5	26.4	25.6
Triumph 64	1	28.5	24.3	29.0	27.3
	2	25.6	23.7	27.5	25.6
	3	25.3	21.5	27.7	24.8
	4	25.3	23.2	27.3	25.3
	Avg	26.2	23.1	27.9	25.7
Average (All Varieties)	1	29.9	28.0	33.4	30.4
	2	28.4	27.0	31.8	29.1
	3	28.8	26.4	31.8	29.0
	4	27.8	26.7	31.7	28.7
	Overall Avg	28.7	27.0	32.2	29.3

1/ Differences among stress levels were statistically significant at all three locations.

2/ Significant stress by variety interactions occurred at Stillwater but not at Lahoma or Altus.



Figures 7, 8, and 9. Kernels per Spike of the Four Wheat Varieties at the Four Stress Levels at Stillwater, Lahoma, and Altus, respectively.

similarly at all stress levels is reflected in the significant stress by variety interaction observed for this trait in the Stillwater test (Table V).

The highest average values for kernels per spike were obtained at Altus and the lowest at Lahoma (Table X). At these two locations, Bezostaia 1 and Caprock had relatively large values for this trait, while Osage and Triumph 64 had relatively low values. The response pattern of all four varieties across the four stress levels, however, was similar at these locations indicating an absence of interactions (Figures 8 and 9).

It is of interest to note that of the three yield components examined in this study, kernels per spike was the most sensitive to stress as evidenced by a significant response to stress levels at all three locations (Tables V, VI, and VII). Also, when stress levels are averaged over locations (Table X), there was a small but consistent decrease in the number of kernels per spike with each increase in stress level. These two findings, taken together, suggest that the type of stress imposed in this study by adjusting the seeding rate of the guard rows had a more consistent effect on this yield component than on the other two components or yield itself.

Kernel Weight

At none of the three locations were differences among stress levels statistically significant for this trait. Nor were there any significant stress by variety interactions (Tables V, VI, and VII). Kernel weight values were very similar when averaged across locations (Table XI). Average values for Stress Levels 1 through 4 were 33.2,

TABLE XI

MEANS FOR KERNEL WEIGHT (G/1000 KERNELS)

Variety	Stress Level	Location: Stillwater	Location: Lahoma	Location: Altus	Average
Bezostaia 1	1	37.4	40.8	32.9	37.0
	2	37.0	40.8	32.2	36.7
	3	37.6	41.0	38.4	39.0
	4	36.5	39.5	35.5	37.2
	Avg	37.1	40.5	34.7	37.5
Caprock	1	30.0	30.5	26.6	29.0
	2	31.7	30.2	25.2	29.0
	3	30.3	31.0	27.5	29.6
	4	30.5	30.9	26.1	29.2
	Avg	30.6	30.7	26.3	29.2
Osage	1	32.4	36.6	31.7	33.6
	2	35.5	36.2	29.8	33.8
	3	34.0	35.8	29.8	33.2
	4	34.6	34.9	29.9	33.2
	Avg	34.1	35.9	30.3	33.4
Triumph 64	1	31.9	35.5	32.1	33.2
	2	34.4	35.1	29.2	32.9
	3	32.6	34.2	33.0	33.3
	4	32.7	34.3	31.8	32.9
	Avg	32.9	34.8	31.6	33.1
Average (All Varieties)	1	32.9	35.8	30.8	33.2
	2	34.6	35.6	29.1	33.1
	3	33.6	35.5	32.2	33.8
	4	33.6	34.9	30.8	33.1
	Overall Avg	33.7	35.5	30.7	33.3

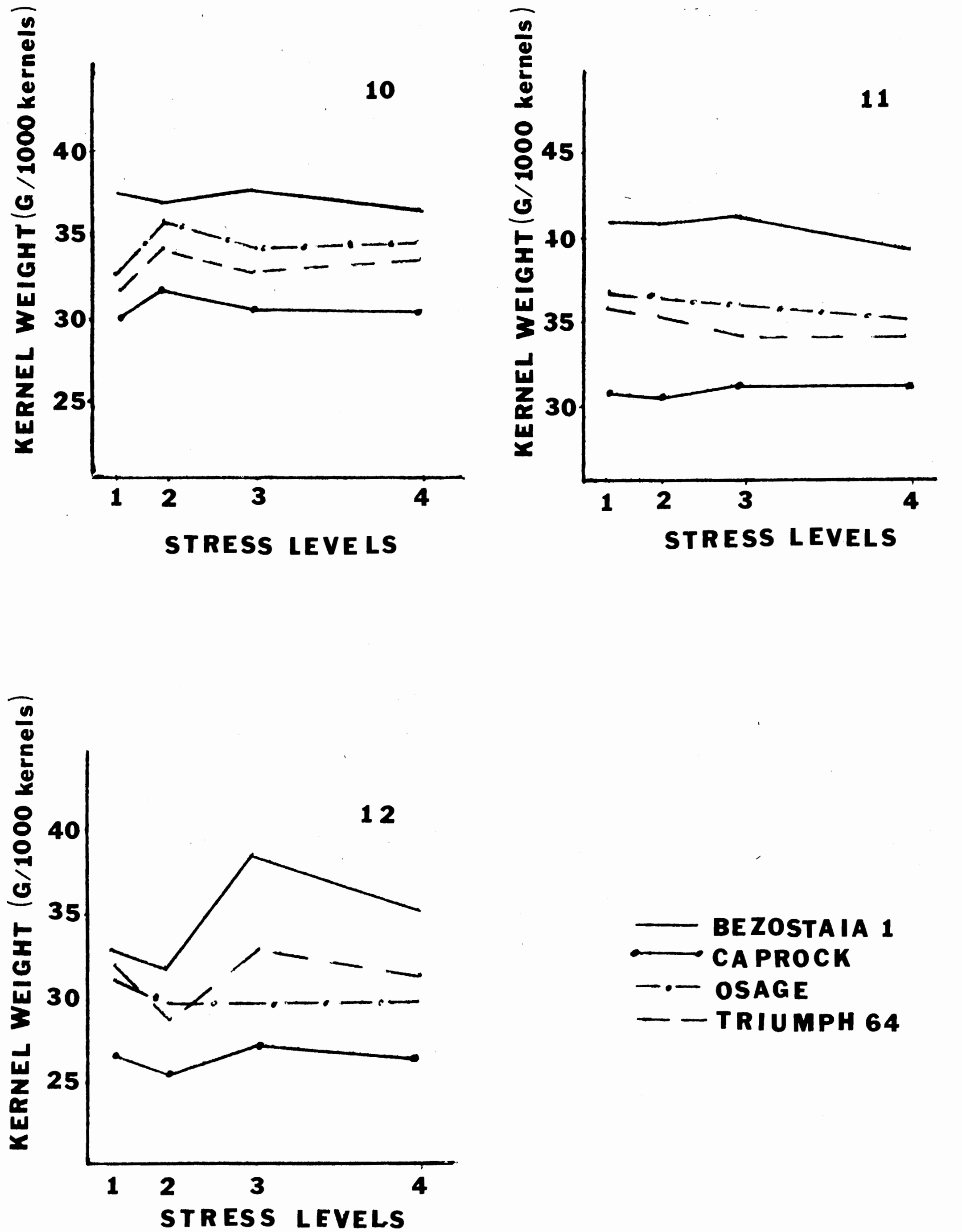
Note: Differences among stress were not statistically significant at any of the three locations, nor were there any significant stress by variety interactions.

33.1, 33.8, and 33.1, respectively. The response pattern of the four varieties across the four levels of stress is shown in Figures 10, 11, and 12 for Stillwater, Lahoma, and Altus, respectively. At all locations, Bezostaia 1 had the highest values for this trait and Caprock the lowest. Triumph 64 and Osage were intermediate in kernel weight. Only at Altus was there an indication of a differential response to stress. At this location Bezostaia 1, Triumph 64, and Caprock showed an increase from Stress Level 2 to Stress Level 3, while Osage did not. However, this response was not statistically significant.

The results discussed above indicate that kernel weight was the least sensitive of the three yield components to stress. At least it was less affected by the type of stress imposed in this study. This might have some implications in a breeding program where high grain yield is of major concern. Kernel weight is a primary component of grain yield and larger kernels may contribute substantially to higher yields. Also, it may be a stable character in terms of environmental influences as indicated by the results of this study.

Percent Protein

Mean squares for differences among varieties were highly significant at two locations, Lahoma (Table VI) and Altus (Table VII), and were significant at the .05 level of probability at Stillwater (Table V). Differences among stress levels were significant at the .05 level of probability for this trait from the combined location analysis (Table IV).



Figures 10, 11, and 12. Kernel Weight of the Four Wheat Varieties at the Four Stress Levels at Stillwater, Lahoma, and Altus, respectively.

The highest percentage of protein was analyzed from the grain yield at the Altus study (Table XII). When averaged across locations (Table XII), Stress Level 1 resulted in somewhat higher percent protein than the other stress levels.

Test Weight

Highly significant differences were observed in the mean squares analyses of data for test weight among varieties at all locations. Mean squares were highly significant for stress by variety interaction at Lahoma (Table VI) and at Altus (Table VII).

Bezostaia 1 was consistent in test weights over stress levels for Stillwater and Lahoma, and showed a marked increase in test weight from Stress Level 2 to Stress Level 3 for the Altus study (Table XIII). Osage and Triumph 64 were consistent over stress levels for all locations. Caprock was less consistent in the Stillwater and Lahoma tests, but showed less variation in the Altus study.

Caprock's response to stress levels was quite dissimilar to the other varieties at Lahoma (Figure 13), and probably was the cause of the significant stress by variety interaction observed at this location. At the Altus location, Bezostaia 1 responded differently than the other varieties as shown in Figure 14.

Plant Height

Mean square differences among varieties were highly significant for height at all locations and a significant stress by variety interaction was observed at Lahoma (Table VI).

TABLE XII

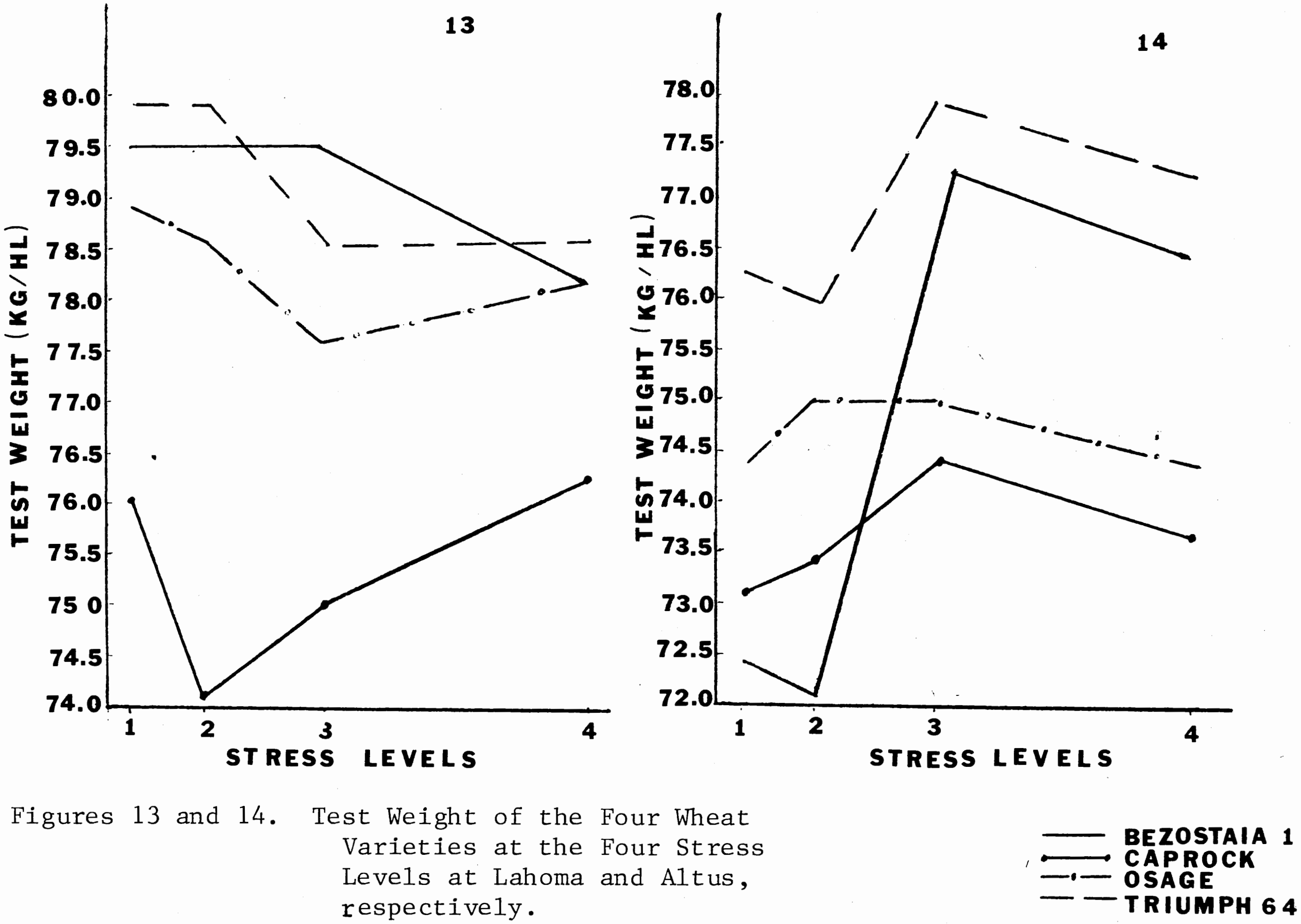
MEANS FOR PERCENT PROTEIN

Variety	Stress Level	Location Stillwater	Lahoma	Altus	Average
Bezostaia 1	1	14.1	13.5	15.9	14.5
	2	12.3	13.3	15.9	13.8
	3	12.8	13.2	15.1	13.7
	4	12.0	13.3	15.2	13.5
	Avg	12.8	13.3	15.5	13.9
Caprock	1	13.5	14.2	15.3	14.3
	2	12.2	14.3	15.7	14.1
	3	12.5	14.1	15.2	13.9
	4	12.2	14.1	15.6	13.9
	Avg	12.6	14.2	15.4	14.1
Osage	1	13.9	13.9	14.8	14.2
	2	11.6	14.0	14.5	13.7
	3	12.4	14.2	15.2	13.9
	4	11.3	13.6	14.8	13.2
	Avg	12.3	13.9	15.1	13.7
Triumph 64	1	14.0	14.1	15.8	14.6
	2	11.5	13.5	16.2	13.8
	3	11.9	13.3	15.2	13.5
	4	11.8	13.0	15.9	13.6
	Avg	12.3	13.5	15.8	13.8
Average (All Varieties)	1	13.8	13.9	15.4	14.4
	2	11.9	13.8	15.8	13.8
	3	12.4	13.7	15.2	13.7
	4	11.8	13.5	15.4	13.6
	Overall Avg	12.5	13.7	15.4	13.9

TABLE XIII

MEANS FOR TEST WEIGHT (KG/HL)

Variety	Stress Level	Location Stillwater	Lahoma	Altus	Average
Bezostaia 1	1	73.1	79.5	72.4	75.0
	2	73.1	79.5	72.1	74.9
	3	73.1	79.5	77.3	76.6
	4	74.4	78.2	76.0	76.2
	Avg	73.4	79.2	74.5	75.7
Caprock	1	70.2	76.0	73.1	73.1
	2	72.1	74.1	73.4	73.2
	3	71.5	75.0	74.4	73.6
	4	72.1	76.3	73.7	74.1
	Avg	71.5	75.3	73.7	73.5
Osage	1	72.4	78.9	74.4	75.2
	2	72.4	78.6	75.0	75.3
	3	72.8	77.6	75.0	75.1
	4	73.1	78.2	74.4	75.2
	Avg	72.7	78.3	74.7	75.2
Triumph 64	1	74.4	79.8	76.3	76.8
	2	75.0	79.8	76.0	77.0
	3	74.7	78.6	77.9	77.1
	4	75.0	78.6	77.3	77.0
	Avg	74.8	79.2	76.9	77.0
Average (All Varieties)	1	72.5	78.6	74.1	75.0
	2	73.2	78.0	74.1	75.1
	3	73.0	77.7	76.1	75.6
	4	73.7	77.8	75.3	75.6
	Overall Avg	73.1	78.0	74.9	75.3



Figures 13 and 14. Test Weight of the Four Wheat Varieties at the Four Stress Levels at Lahoma and Altus, respectively.

Considerable variation across stress levels at Lahoma was noted for Bezostaia 1 and Osage (Table XIV). Bezostaia 1 varied from 103.8 cm at Stress Level 3 to 96.8 cm at Stress Level 4. Osage varied from 112.0 cm at Stress Level 4 to 108.5 cm at Stress Level 2. The least amount of variation in height at Lahoma was observed for Caprock which had a range of only 1.3 cm across all stress levels. The response pattern of the four varieties to stress levels at Lahoma is shown in Figure 15.

Lodging

Mean square differences among varieties were highly significant at all locations for lodging. Also, the stress by variety interaction was observed to be highly significant at Stillwater (Table V). Stress levels were significant at Stillwater (Table V) and at Lahoma (Table VI).

At both Stillwater and Lahoma, the largest amount of lodging was at Stress Level 1 for each variety (Table XV). Triumph 64 was the variety most lodged at each location and had the widest range of variation across stress levels (Table XV). Caprock and Bezostaia 1 had the lowest lodging values and Osage was intermediate. Response patterns at Stillwater and Lahoma are shown in Figures 16 and 17, respectively.

Yield Component Relationships

In an attempt to find some pattern of yield component contribution to total grain yield, the variety with the highest average yield of each location was examined with regard to its yield components. In these comparisons, the average values (across stress levels) for

TABLE XIV

MEANS FOR PLANT HEIGHT (CM)

Variety	Stress Level	Location Stillwater	Lahoma	Altus	Average
Bezostaia 1	1	80.8	101.0	75.8	85.8
	2	78.3	99.5	76.5	84.8
	3	79.0	103.8	78.0	86.9
	4	75.3	96.8	76.0	82.7
	Avg	78.3	100.3	76.6	85.0
Caprock	1	78.8	89.8	76.0	81.5
	2	75.1	89.0	73.5	79.2
	3	75.0	89.3	73.0	79.0
	4	74.0	88.5	71.0	77.8
	Avg	75.7	89.1	73.4	79.4
Osage	1	95.0	109.0	84.0	96.0
	2	97.3	108.5	82.0	95.9
	3	93.8	109.3	81.3	94.8
	4	93.8	112.0	80.5	95.4
	Avg	94.9	109.7	81.9	95.5
Triumph 64	1	90.8	107.3	89.8	95.9
	2	86.0	105.8	91.5	94.4
	3	85.0	108.0	91.0	94.7
	4	86.0	106.8	87.0	93.3
	Avg	86.9	106.9	89.8	94.6
Average (All Varieties)	1	86.3	101.8	81.4	89.8
	2	84.2	100.7	80.9	88.6
	3	83.2	102.6	80.8	88.9
	4	82.3	101.0	78.6	87.3
	Overall Avg	84.0	101.5	80.4	88.6

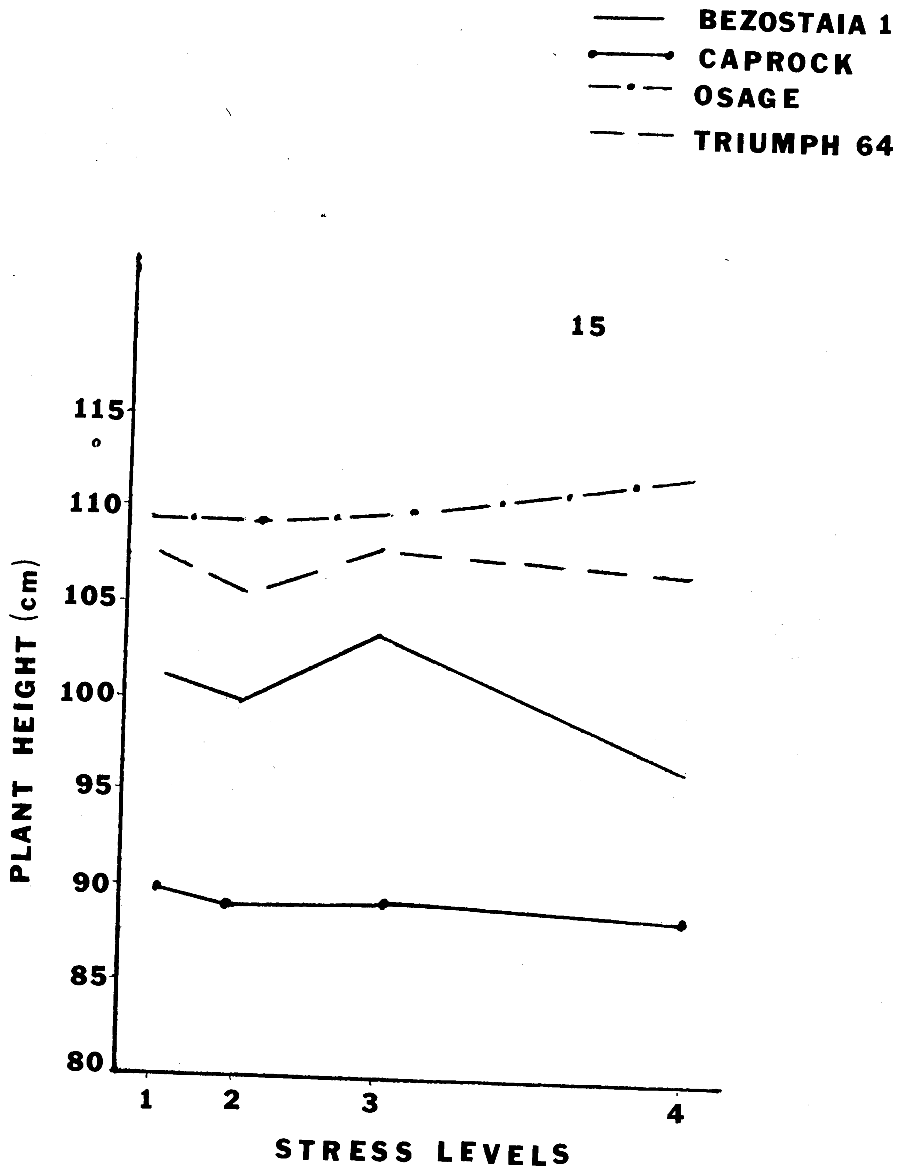
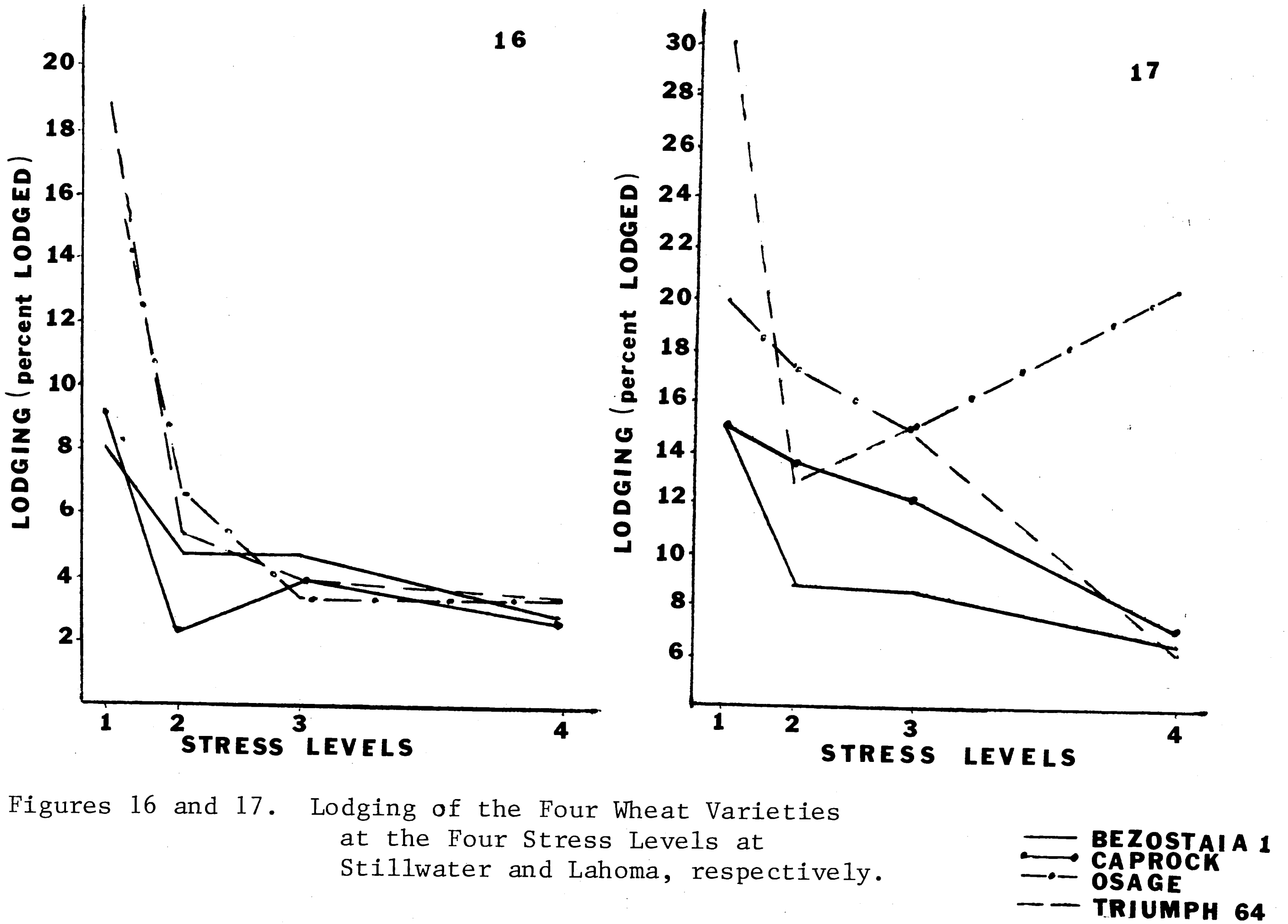


Figure 15. Plant Height of the Four Wheat Varieties at the Four Stress Levels at Lahoma.

TABLE XV

MEANS FOR LODGING (PERCENT LODGED)

Variety	Stress Level	Location: Stillwater	Lahoma	Altus	Average
Bezostaia 1	1	8.0	15.0	5.5	9.5
	2	4.8	8.8	4.3	5.9
	3	4.8	8.8	3.5	5.7
	4	3.0	6.8	2.0	3.9
	Avg	5.1	9.8	3.8	6.3
Caprock	1	9.3	15.0	4.8	9.7
	2	2.3	13.8	2.0	6.0
	3	4.0	12.5	1.5	6.0
	4	2.8	7.5	2.0	4.1
	Avg	4.6	12.2	2.6	6.4
Osage	1	15.5	20.0	15.0	16.8
	2	6.8	17.5	10.0	11.4
	3	3.5	15.0	7.5	8.7
	4	3.5	20.0	7.5	10.3
	Avg	7.3	18.1	10.0	11.8
Triumph 64	1	18.8	30.0	45.0	31.3
	2	5.5	12.5	57.5	25.2
	3	4.0	15.0	23.8	14.3
	4	3.5	6.3	35.0	14.9
	Avg	7.9	15.9	40.3	21.4
Average (All Varieties)	1	12.9	20.0	17.6	16.8
	2	4.8	13.1	18.4	12.1
	3	4.1	12.8	9.1	8.6
	4	3.2	10.1	11.6	8.3
	Overall Avg	6.2	14.0	14.2	11.5



Figures 16 and 17. Lodging of the Four Wheat Varieties at the Four Stress Levels at Stillwater and Lahoma, respectively.

yield and yield components are considered (Tables VIII, IX, X, and XI).

Triumph 64 had the highest average yield at Stillwater. It ranked second in tiller number, third in kernels per spike and third in kernel weight. The high yield of Triumph 64 was apparently made by a balance of yield components since none of them could be singled out as being of prime importance.

Bezostaia 1 was the highest yielding variety at Lahoma. Its average yield was nearly 500 kg/ha above the second-ranked variety, Triumph 64. Bezostaia 1 ranked last in tiller number and first in kernels per spike and kernel weight. Apparently, the general environmental conditions that prevailed at Lahoma favored types with a high number of kernels per spike and high kernel weight. Tillering seemed to be of minor importance at this location.

Osage had the highest average yield at Altus. It ranked first in tiller number, last in kernels per spike, and third in kernel weight. Tiller number was apparently of major importance in contributing to grain yield at this location. For all four varieties at this location, there was a one-to-one relationship between ranking for grain yield and ranking for tiller number. The average tiller number of all varieties was much lower than at the other two locations. The varieties apparently compensated for low tillering to some extent by producing more kernels per spike (Table X), but environmental conditions prevented the development of large kernels. Altus had the lowest average kernel weight of all three locations.

It is apparent from the foregoing discussion that the wheat plant makes its yield through differential contribution of its yield components depending on prevailing environmental influences. At Lahoma, where relatively high tillering occurred for all varieties, this component did not appear to be limiting. In this situation, kernels per spike and kernel weight were more important for high yields. At Altus on the other hand, where tillering was relatively low for all varieties, sufficient yield compensation was not made through kernels per spike or kernel weight, and those varieties with above average tillering ability produced the highest yields.

Phenotypic Correlation Coefficients

The correlation coefficient is a measure of the mutual relationship between two variables (22). The association between grain yield and the other characters involved in this study was examined by computing phenotypic correlation coefficients for each location (Table XVI) and for combined locations (Table XVII). Correlation coefficients were taken from the rep by variety entry line from the analysis of data printout.

Inverse relationships were found between grain yield and percent protein at each location. The coefficients at Stillwater and Altus were highly significant for this correlation and the Lahoma study was significant at the .05 level of probability. Lodging was inversely associated with grain yield at Lahoma (Table XVI).

The Stillwater study had a highly significant positive correlation between yield and test weight and the correlation between yield and test weight at Lahoma was also significant. At Lahoma, significant positive correlations were also between yield and tiller number and between yield and kernel weight.

TABLE XVI

PHENOTYPIC CORRELATION COEFFICIENTS OF GRAIN YIELD VS SEVEN OTHER CHARACTERS

	Location		
	Stillwater	Lahoma	Altus
Tiller Number	0.291	0.394*	0.391*
Kernels per Spike	0.146	0.188	-0.127
Kernel Weight	0.203	0.390*	0.354*
Percent Protein	-0.587**	-0.388*	-0.478**
Test Weight	0.477**	0.725**	0.302
Plant Height	0.009	0.011	0.569**
Lodging	0.080	-0.423**	-0.076

r values

Degrees of Freedom (n-2 = 35) .05 = .325 *
.01 = .418 **

TABLE XVII

PHENOTYPIC CORRELATION COEFFICIENTS OF GRAIN YIELD VS SEVEN OTHER CHARACTERS

	Combined Locations
Tiller Number	0.358**
Kernels per Spike	0.061
Kernel Weight	0.308**
Percent Protein	-0.475**
Test Weight	0.486**
Plant Height	0.160
Lodging	-0.145

r values

Degrees of Freedom (n-2 = 108, read as 100)
.05 = .195 *
.01 = .254 **

The positive correlation between yield and plant height was highly significant at Altus. At this location there were also significant positive correlations between yield and tiller number and between yield and kernel weight (Table XVI).

In the combined location analysis for correlation coefficients (Table XVII), there was an inverse relationship between yield and percent protein, which was highly significant. Highly significant positive relationships were also noted between yield and tiller number, between yield and kernel weight, and between yield and test weight.

CHAPTER V

SUMMARY AND CONCLUSIONS

This study, dealing with the responses of four wheat varieties at four different stress levels was conducted to provide information which might be used as a guide in developing varieties with certain high or low potential for yield components which in turn might result in more tolerance to stress. The study was conducted during the 1974-75 growing season at three locations in Oklahoma. Stress levels were imposed by varying the seeding rate of the two outside rows of each four-row plot. In all cases, the two center test rows of each plot were seeded at the standard seeding rate of 67.28 kg/ha.

Yield is the ultimate measurement of varietal performance and represents the cumulative effects of many genetic and environmental factors of which moisture stress is one.

Every variety produced its highest yield, when averaged across the three locations, at Stress Level 1 (minimum stress). Osage, on the average, was less affected by stress and Caprock was the most affected in terms of grain yield performance.

The locations experienced higher than normal rainfall which, no doubt, reduced the effects of stress as they were imposed in this study. The response of the varieties to stress was less than expected. There was a near absence of stress by variety interactions. Each variety tended to exhibit a similar pattern of response in regard to yield and yield components at all locations and under all stress levels.

Of all the yield components, kernels per spike was the most sensitive to stress as evidenced by significant differences among stress levels at each location. Perhaps kernels per spike was more sensitive to the type or the timing of stress that resulted by the procedure used in this study in imposing stress. This finding disagrees with work conducted by Asana in India as reported by Schmidt (17) in which grain number per spike appeared to be an important and constant trait providing yield stability.

The yield component least sensitive to the type of stress imposed in this study was kernel weight. There were no significant differences among stress levels nor were there any significant stress by variety interactions for this trait. Kernel weight is a major component of grain yield and if, as indicated in this study, it is stable with regard to environmental influences (moisture stress), this could have important implications in variety development programs. Evidence would seem to indicate that breeders should try to develop genotypes with larger kernels which should tend to result in higher yields under varying stress conditions. This would be true if there were a positive cause and effect relationship between kernel weight and grain yield. And it is generally accepted that this is the case. This agrees with Schmidt (17) in that varieties with larger kernels are more responsive as conditions change from early drought stress to more favorable conditions during grain filling and produce higher yields.

An examination of the highest yielding variety at each location revealed that different components were operating to make yield at the different locations. At Lahoma, Bezostaia 1 was the highest yielding variety. It had the lowest tiller number, the highest number of kernels per spike and the highest kernel weight. Osage was the highest yielding variety at Altus. It also had the highest tiller number. Tillering appeared to be the most important component at Altus where the general level of tillering was rather low. Comparative tillering patterns between the Lahoma and Altus tests suggested that these two locations may have represented an optimum minimum condition (Altus) and an optimum maximum condition (Lahoma) for this component. At or near the lower limit, extra tillering appeared to be very important to yield, as was the case at Altus. At or near the upper limit, extra tillering did not appear to be important and in fact may have reduced yields, as was the case at Lahoma. In the Stillwater study, a balance of yield components appeared to be important in terms of grain yield. Triumph 64 was the highest yielding variety in this test and, relative to the other varieties, was intermediate in expression of yield components.

A negative correlation between yield and percent protein was absent in this study. This finding is consistent with studies conducted by Botkin (1), Fernandez g. (6), Shaw (18), and Shutte (19). Positive correlations were observed between grain yield and tiller number and also between grain yield and kernel weight.

Pertinent conclusions to be drawn from this study are as follows:

1. Of the four varieties tested, Osage was least affected by stress and Caprock was the most affected.
2. Of the yield components, kernel weight was the least sensitive to stress while number of kernels per spike was the most sensitive. This could have important

implications in a breeding program. The data suggest that selection for higher kernel weight should be emphasized.

3. Different components were important to grain yield at different test locations (tiller number at Altus, kernels/spike and kernel weight at Lahoma, and a balance of the three components at Stillwater).
4. Under minimum tillering situations (as at Altus), extra tillering was important to grain yield. Under maximum tillering situations (as at Lahoma), reduced tillering was associated with high grain yield.

LITERATURE CITED

1. Botkin, C. W. 1955. The protein and moisture content of wheat grown in New Mexico. New Mexico Agr. Exp. Sta. Bul. 230.

2. Campbell, C. A. 1968. Influence of soil moisture stress applied at various stages of growth on the yield components of Chinook wheat. Can. J. Plant Sci. 48:313-320.

3. Cole, John S. 1938. Correlations between annual precipitation and the yield of spring wheat in the Great Plains. USDA Tech. Bul. 636.

4. Donald, C. M. 1968. The breeding of crop ideotypes. Euphytica 17:385-403.

5. Engledon, F. L. and S. M. Wadham. 1923. Investigations on yield in the cereals. J. Agr. Sci. 13:390-439.

6. Fernandez g., Ramon and R. J. Laird. 1959. Yield and protein content of wheat in Central Mexico as affected by available moisture and nitrogen fertilization. Agron J. 51:33-36.

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

8. Hurd, E. A. 1968. Growth of roots of seven varieties of spring wheat at high and low moisture levels. Agron. J. 16:201-205.

9. Kiesselbach, T. A. and H. B. Sprague. 1926. Relation of the development of the wheat spike to environmental factors. J. Am. Soc. Agron. 18:40-60.

10. Kramer, P. J. 1963. Water stress and plant growth. Agron J. 55:31-35.

11. Lehane, J. J. and W. J. Staple. 1962. Effects of soil moisture tension on growth of wheat. Can. J. Soil Sci. 42:180-188.

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

13. Mitchell, R. L. 1970. Winter and drought survival of crop plants. In: Crop Growth and Culture. Iowa State University Press, Ames, Iowa. pp. 254-259.

14. Moss, D. N., J. T. Woolley, and J. F. Stone. 1974. Plant modification for more efficient water use: The challenge. Agric. Meteorol. 14:311-320.

15. Russell, M. B. 1957. Water and Its Relation to Soils and Crops. Academic Press, New York. pp. 43-77.

16. Sandhu, A. S. and H. H. Laude. 1958. Tests of drought and heat hardiness of winter wheat. Agron. J. 50:78-81.

17. Schmidt, J. W. 1975. Development of winter varieties for low rainfall, non-irrigated areas. Proc. Second Int. Winter Wheat Conf., Yugoslavia. pp. 65-73.

18. Shaw, G. W. 1913. Studies upon influences affecting the protein content of wheat. Univ. Calif. Pub. in Agr. Sci. 1.

19. Shutte, F. T. 1925. Influence of environment on protein content of wheat. Canadian Chemical Metallurgy 9:195.

20. Slavik, B. 1966. Response of grasses and cereals to water. In: The Growth of Cereals and Grasses. Butterworths, London. pp. 227-240.

21. Slayter, R. O. 1971. Physiological significance of interim water relations to crop yield. In: Physiologic Aspects of Crop Yield. Eastin, J. D., F. A. Hoskins, C. Y. Sullivan, and C. H. M. van Bavel. Am. Soc. Agron. pp. 53-83.

22. Snedecor, G. W. and W. G. Cochran. 1969. Correlation. In: Statistical Methods. pp. 172-198.

23. Terman, G. L., R. E. Ramig, A. F. Dreier, and R. A. Olson. 1969. Yield-protein relationships in wheat grain as affected by nitrogen and water. Agron. J. 61:755-759.

24. Todd, G. W. and D. L. Webster. 1965. Effects of repeated drought periods on photosynthesis and survival of cereal seedlings. Agron. J. 57:399-404.

25. ________________, F. W. Ingram, and C. A. Stutte. 1962. Relative turgidity as an indication of drought stress in cereal plants. Proc. Okla. Acad. Sci. 42:55-60.

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