PERFORMANCE OF THREE HARD RED WINTER WHEAT VARIETIES SOWN IN DIFFERENT PLANTING ARRANGEMENTS

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CHAPTER I

INTRODUCTION

The importance of wheat as a leading food crop is incontestable. As the world population is getting larger and larger, increasing food production becomes a necessity. Plant breeding has been a major tool in the development of high yielding and high quality wheat varieties. However, for a new variety to be fully exploited, a proper environment should be offered to the plants. Thus, adequate cultural practices complete the task of the breeder and lead to a higher yield.

Seeding rate has long been thought to be a primary factor in the determination of the yield level. We now know, however, that grain yield increases with seeding rate up to a point beyond which a decline is obtained. Attention has now been shifted toward the repartition of the plants in the field. Broadcasting was an easy method of planting, but the unevenness of seed distribution and the difficulty of conducting adequate weed control led to the adoption of row planting. Departure from the use of the conventional 6-8 inch spacing has been suggested as a means for a better seed distribution and a minimal interplant competition.

Intraplant competition may occur at any time of the plant life during which the supply of the growth factors fails to satisfy the demand of the different part of the plant. Competition occurring between the components of yield may lead to a disequilibrium between the components and lower grain yields. It is now accepted that high grain yield is obtained at optimal values of the different components.

The primary objectives of this study are: (1) to investigate the effect of four different planting patterns on the performances of three hard red winter wheat varieties; and (2) to determine the relative importance and the interrelationships between the yield components in those varieties.

CHAPTER II

REVIEW OF LITERATURE

Increasing the grain yield has been the main objective of the cereal grower. Practice has taught him that increasing seeding rate would in general lead to a yield gain. Holliday (15) found that increasing plant density in various crops raised the yield up to a point where it became constant or declined depending on whether the yield is a product of the vegetative growth only, or also of the reproductive growth. Kirby (21) studied the effect of plant population in four barley varieties. Four seeding rates of 280, 140, 70, and 35 pounds per acre were used in such a way that mutual shading was a minimum. He observed that dry matter increased with density up to a point where it became constant. On the other hand, grain yield was highest at the seeding rate of 70 pounds per acre. Donald (11) reported a great deal of data showing the same relationship between yield and density.

With the development of physiological explanations for obtaining higher yields, much attention has been paid to the distribution of the plants in the field. The best spatial arrangement would be the one which would minimize the interplant competition.

Effect of Plant Distribution on Yield

The effect of plant distribution on yield has been investigated in various crops such as cereals. Porter, et al. (28) studied the effect of four row spacings on yield in grain sorghum. Yields at the 12-, 20-, and 30-inch row spacing were significantly greater than at the 40-inch spacing. Sauchelli (32) reported results on corn from Nebraska where a 10 percent yield increase was obtained when 30-inch rows were used instead of 40-inch rows. A 15 to 24 percent gain was noted when plantings were switched from 40- to 20-inch rows with the same number of plants per acre.

Recent work has been done on grasses. Black and Reitz (7) observed the influence of row spacing on three grasses grown in dry conditions at 76-, 107-, and 152-cm spacings. Seed production of green needlegrass (Agropyron intermedium [Host] Beauv.) decreased with increasing row width. Russian wildrye (Elymus junceus Fisch.) yielded best at the 107-cm spacing. Intermediate wheatgrass (Stipa viridula Trin.) gave its highest production at the 76-cm spacing.

Small grains have been the object of some investigations in different areas of the world. Pendleton and Dungan (27) compared the performances during a 7-year period of spring oats using two row directions and three spacings between rows. North-South rows were significantly superior to East-West rows. The magnitude of yield superiority depended on the spacing and was 12.7 percent in the 24-inch rows and only 3 percent in the 8-inch rows. Lashin and Schrimpf (23) found that of the three winter wheat varieties they used, one yielded consistently less at the wider spacing, another had its highest yield at intermediate spacings, and the third one behaved differently at different planting dates. Stoskopf (38) reported results from experiments with winter wheat where upright-leaved selections were tested against a tall, broad-leaved check. Although the narrow rows yielded on the average 9.8

percent more than the wide rows, the selections had a response different from that of the check. The selections and the check showed a 12.6 percent and a 6.9 percent increase, respectively. Furthermore the selections performed better at a higher seeding rate, whereas the check variety yielded more at a lower density. Baldwin (5) commented on trials carried out at the Norfolk Agricultural Station and which included barley, wheat and oats. Eight-inch spaced rows of barley resulted in a four percent yield increase above the 12-inch rows. The same percentage increase was obtained with winter and spring wheats when the spacing was reduced from eight inches to four inches. In spring oats, 3.5-inch spaced rows out-yielded the 8-inch rows by 2 percent. Baldwin concluded that narrower rows are worth adopting if cereals of higher yields are to be sought. Siemens (35) studied the effect of various row spacings on yield and other agronomic characters of wheat, barley, oat, and flax. He used five row spacings ranging from 6- through 30-inch spacings. Yield decreased whereas seed return per bushel seeded went up as the inter-row width increased. Siemen's experiment suffered from the fact that the same number of seeds were sown within a row so that spacing and seed rate were confounded. Holliday (16) reported an increase of 2 to 10 percent in wheat when row spacing was reduced from 7-8 inches to 3-4 inches. Out of 32 experiments reviewed only one showed an advantage for the wider rows. Kinra, et al. (20) reported results from experiments conducted at two locations in Southern Michigan which involved four row spacing distances. A general trend of yield decline was obtained when row spacing increased. Row spacing distances greater than 7 inches resulted in a smaller grain yield and in fewer culms per unit area. Rate of seeding x row width and row width x fertilizer rate interactions were found to be significant. Holliday (16) pointed out that an interaction between row spacing and seeding rate may exist. To obtain a reliable value of this interaction, a factorial experiment should be used which includes no less than three seeding rates and no less than three spacings. He stated that when the rows are too far apart, the seeding rate has a greater effect on yield than row spacing. He found that for the same seeding rate, grain yield decreases as row width gets wider and that this effect is more pronounced as seeding rate becomes very high or very low. Bleasdale (9) found that lower plant densities reduced the influence of spatial arrangement on crop yield. Stickler (37) planted a winter wheat variety at seeding rates of 0.5, 1.0, and 1.5 bu per acre and at three row widths. All nine possible combinations between the two factors were used to determine the effect on yield and components of yield for 'Pawnee' wheat. Grain yield was affected much more by row width than by seeding rate. The average yields corresponding to the 7-, 14-, and 20-inch rows were 25.9, 21.1, and 14.3 bu per acre. The between-row distance x seeding rate interaction was not significant for yield and yield components. It was concluded that it is unnecessary to carry out subsequent experiments involving the two factors simultaneously.

Plant Competition

The results reported above show a certain relationship between the yield of different crops and the plant arrangements used. Since the yield is governed to a great extent by external factors, the way in which the growth resources are distributed and then used by the plants should have been affected by the various planting patterns. Since it is irrational to talk about distribution of a single plant, it is rather impossible not to relate plant arrangement with plant community and then with plant competition. Black (7) stated that competition occurs when the needs of a plant population exceed the supply offered by the environment. Donald (11) noted that increasing the distance from a plant to its nearest neighbor will decrease the adverse effect of competition. Although hexagonal planting will be the ideal situation, experience has shown that square planting yielded consistently better than other planting types. Donald (11) reported Wiggan's data (1939) which showed that soybeans planted in 8 x 2 inch gave 39.8 bu/acre, those planted in 16 x 1 inch gave 36.5 bu/acre, and those planted in 32 x 0.5 inch yielded 32.0 bu/acre. He also reported data in which sorghum plants sown at a constant seeding rate per unit area gave 5880 pounds in 40-inch spaced rows and 6609 pounds in 20-inch spaced rows.

Holliday (16) indicated that square planting in cereals will delay the time at which overlapping occurs. However square arrangement would require rows which are so narrow that it is of no practical value. On the other hand, he suggested that extreme rectangularity will lead to a drastic yield decrease.

Plant distribution involves the between-plant distances as well as the direction in which the rows are oriented. Sowing direction has been shown to have a consistent effect favoring the North-South over the East-West direction. Santhirasegaram, quoted by Donald (11), found that wheat plants yielded 11% more in the N-S than in the E-W planting direction. Pendleton and Dungan (27) found that oat plants in N-S rows received more light energy than those in E-W rows because of a higher light intensity between 10:00 a.m. and 2:00 p.m. Santhirasegaram (31) made a thorough investigation on the distribution of light intensity in wheat crops. He found a more uniform light distribution in the N-S rows which leads to a greater share of light received by the basal leaves. More light was measured at the ground surface in the 14-inch rows than in the 7-inch rows. Thus, the beneficial effect of a N-S row direction is greater with narrow rows. He concluded that there is an optimal row width which would give a maximum of total light energy during the day.

Donald (11) suggested that competition for light, water, and nutrients is a very complex phenomenon and may involve one or more factors at a time. Competition for light may start early after plant emergence if the plants are closely spaced. Black (7) reported a Japanese work done on a population of dent corn. The plants starting early in their development gave higher yield at the expense of their neighbors. This led to an alternation of vigorous and depressed plants. He drew attention to the fact that in broad-leaved plant populations the attenuation of light penetration was greater than in erect plant communities. However, he stressed that competition rarely is concerned with one single factor. Tanner, et al. (40) observed that upright-leaved small grains performed well under weed free conditions but were out-yielded by broad-leaved types when no weed control was made. They concluded that upright-leaf type small grains would be more efficient in narrow rows than the floppy-leaved types. Monteith (25) studied the microclimate in cereals and grasses and found that the profile of light absorption in grasses was more uniform than in clover. This was primarily due to the erect architecture of the grass which allowed light to be transmitted to the lower parts of the plant.

Donald (11) stated that competition between plants may involve the root system. Overlapping of the roots which occurs in narrow spacing enhances competition for water and nutrients. Root penetration was found greater between wide rows than within the rows where plants are closely spaced. Pendleton and Dungan (27) observed that soil moisture was higher between East-West rows than between North-South rows. However, soil moisture was in general higher in the wider spacings. Moisture content of the soil was lowest close to the row and highest midway between rows. In an experiment on grain sorghum, Brown, et al. (10) found that 40-inch spaced plant rows responded positively to an increase of moisture whereas the 20-inch spaced rows did not. Daily moisture use rate, however, was found to be unaffected by row spacing. Black and Reitz (7) found that the higher water efficiency of intermediate wheatgrass and Russian wildrye was due to a more proliferate root system in those species than in green needlegrass. Water use efficiency was increased by fertilization treatment in all cases. Fertilization, however, increased the water use efficiency of the intermediate wheatgrass and Russian wildrye more drastically at the narrower spacing. Siemens (35) found that moisture content between the rows of wheat or flax increased with row spacing. He concluded that the wider rows did not fully benefit from the higher soil moisture and did not use the available nitrogen efficiently. A relationship has been found between row width and the total root weight per acre by Foth, et al. (13). The narrower rows were associated with a higher root density in the upper 3-inch soil layer, below which it became constant. However, the N, P and K content of the plant tissue was independent of the spacing. They concluded that spacing in oats affects yield through a better utilization of sunlight rather than that of nutrients.

Yield and Components of Yield

To produce dry matter a plant needs a certain amount of water, light, carbon dioxide, and mineral nutrients. Discussing the elements influencing the photosynthesis process, Niciporovic (26) stressed the importance of leaf area as a critical determinant of yield. An optimal LAI (leaf area index) of 3.0-3.5 established early in the season and extending over a long period of the plant life would give a greater yield. Water shortage has an adverse effect on yield through its action on the LAI. In a thorough investigation of the effect of water on the development of cereals and grasses, Slavik (36) found that a high hydration level in the tissues was associated with an active growth. Although LAI *per se* is important on yield, Thorne (41) emphasized the value of the period after spike emergence. It is during that period that most of the carbohydrates of the grain are formed by the photosynthesizing parts of the plant situated above the flag leaf node. Langer (22) found that in wheat plants the flag leaf and other remaining green parts of the shoot accounted for 83% and the spike 17% of the grain carbohydrates. Saghir, *et al.* (30) studied the relative contribution of different parts of the wheat and barley plants. Shading the wheat spike resulted in a grain yield reduction of 59.7% and a shriveling of the grain at maturity. A 22.2% and an 11.5% yield decrease was obtained when shading affected upper and lower leaves, respectively. They concluded that varieties with large spikes and a greater leaf area in the upper part would give higher yields.

The yield of crops per unit area is determined by the number of fertile tillers per unit area, the number of florets per ear, and the seed size (14). In a study of yield in hybrid wheat, Shebeski (34) tried to predict the performances of the hybrid knowing those of the parents. He used the components of yield as a criterion. He found strong correlations between the yield and its three components but none of the components were transmitted in a consistent manner from parent to hybrid. The yield components of the parents had no predictive value of the hybrid yield. Fonseca and Patterson (12) used a seven parent diallel cross to investigate the heritability of the yield components and the interrelationships among the components. The heritability estimates for number of spikes per plot, and number of kernels per spike were high, whereas those for kernel weight and grain yield were medium or low. These findings show that the yield components may be influenced to a great extent by the environment.

Ryle (29) observed that in timothy plants, late arising tillers have a smaller potential to develop ears. The number of florets per ear is determined during the period between spikelet initiation and ear emergence. That number was found to be greater in early developed shoots and increased with nitrogen application. The seed weight is determined in the last developmental stage and is affected by intra- and interplant competition. Slavik (34) noted that water deficit in early development reduced the number of fertile tillers in spring wheat. A moisture stress occurring during spikelet or grain formation reduced the number of seeds per spike or the seed weight, respectively. Langer (22) discussed the internal and external factors which affect grain yield in wheat and barley. Shorter light period and higher moisture induced an increase of spikelet number. A relatively low temperature and a high light intensity were found to result in more spikelets per spike. Nitrogen fertilization had a similar effect. High or low temperature decreased grain weight in wheat, whereas a moisture stress occurring two weeks after anthesis had a very negative response.

Since plant arrangement changes the distribution of the external growth factors either directly or indirectly, it is expected that it would affect the components of yield. Lashin and Schrimpf (23) observed that yield per spike of winter wheat was highest at the widest spacing used. Foth, et al. (13) found no significant difference in the seed weight or in the number of oat panicles per unit area between the 7- and 11-inch spacing treatments. Siemens (35) indicated that 6-inch rows were associated with fewer tillers than 30-inch rows. This was due partly to a greater moisture available to the wider rows. An inconsistent response of the wheat 1000-kernel weight to spacing was obtained in three years and a significant increase in favor of the close-spaced rows in one year. Holliday (16) reported a larger number of spikes per unit area in narrow spacing in wheat and barley, a greater grain weight per spike in barley but a lower grain weight per spike in wheat. Stickler (37) stated that increasing row width resulted in a yield decrease mostly because of a greater within-row competition in the wider spacings. The competition resulted in a decline of the number of fertile tillers per unit area. This component was indeed affected most by spacing. Kernels per spike and kernel weight components were only slightly decreased in wider rows.

Interaction between components of yield has been thoroughly investigated by Fonseca and Patterson (12). They found negative correlations between components of yield. The correlation between number of fertile tillers and kernels per spike was highly significant and was greater than the correlation between kernels per spike and kernel weight which was more important than the correlation between number of fertile tillers and kernel weight. They concluded that the negative correlation between number of spikes and number of kernels per spike may constitute a hindrance to selection based on yield components. Johnson, et al. (18) observed that, in a study involving the yield components of four winter wheats, the variety CI 13678 had consistently a great number of kernels per spike and this component was not affected by changes in the two other components. Increasing this component would result in a yield gain.

In an attempt to define a universal variety, Grafius (14) proposed that yield can be represented by the volume (W) of a rectangular parallelipiped with the three edges (X,Y,Z) corresponding to the three yield components. A universal variety is one that has a good balance between the components with the longest edge representing the component most subject to variation and the shortest edge representing the component least subject to variation.

The compensation phenomenon between the yield components was later stressed in a study by Adams (1) who noted negative correlations between X (number of pods/unit area) and Y (number of seeds/pod) and X and Z (seed weight) in navy beans (Phaseolus vulgaris L.). He stated that yield components in navy bean (and in crops in general) are genetically controlled. He found that when no stress conditions are present, i.e., in wide rows, the correlations between yield components are essentially very low. He concluded that the negative correlations among the components are not the result of linkage but rather that of competition of two or more plant organs for one common limited metabolite. An oscillatory variation of the growth factors was suggested which would lead to a limiting input at certain phases of the development of the different components. Whenever a component is in phase with the general input, that component is favored. This enhancement causes the creation of a repressor which would be unfavorable to one or both of the other components.

Adams and Grafius (2) discussed data presented by Rasmusson and Cannell who stated that negative correlations among yield components in barley were due to linkage. Adams and Grafius (2) suggested that yield components are independently controlled but are affected in an oscillatory manner in response to changes in the environment during critical developmental stages. Yield is thus a compromise between a genetic system and a developmental response. Higher yield is obtained when a high genetic ceiling is attained and a certain flexibility in response to growth factors is present.

Which of the components is the primary yield determinant is a matter of speculation. Bingham (6) proceeded to an artificial variation in grain number per spike in various varieties of winter wheat. He found that when the number of grain per spike decreased the grain size increased, but did not compensate for the grain number. He concluded that both characteristics are of similar importance. Jha and Ram (17) found a significant positive correlation between yield and number of seeds per spike in wheat. Siemens (35) found that competition between the number of seeds per spike and the seed weight differs in various species. Increasing growth factors by planting in wide rows led to an increase in seed size in barley and to more seeds per spike in wheat. He suggested that the indeterminate nature of floret formation in wheat led to an increase of the number of seeds but decreased the seed size. Barley, which has determinate floret formation, responded differently.

CHAPTER III

MATERIALS AND METHODS

Varieties and Arrangements

Three hard red winter wheat varieties (Triticum aestivum L.) were used in this experiment which was carried out in the 1969-70 season at the Agronomy Research Station in Stillwater. The growing season was marked by insufficient precipitation, particularly in November and May. Although April was wet, a 4.49 inch moisture deficit below the normal occurred during the period extending from September 1, 1969 through May 31, 1970 (3).

The choice of the varieties used was based on their contrasting individual characteristics (24). 'Triumph 64', which was released in 1964 by the Oklahoma Agricultural Experiment Station, is the leading hard red winter wheat variety in the State of Oklahoma. It grows well in a wide range of locations within the State and is grown to some extent in Texas and Kansas. It has good test weight, large kernel, and has the advantage of early maturity. 'Sturdy' was released by the Texas Agricultural Experiment Station in 1966. It is six to ten inches shorter than most of the hard red winter wheat varieties. It has stiff straw, withstands lodging and responds well to moisture and nutrients but is not recommended in dry areas. It has large spike, medium sized kernel, and excellent baking characteristics. The third variety, 'Parker', was developed and released by Kansas State University in 1966. It is a short to midtall variety with strong straw. Parker has an above average test weight but small kernel size. Its most important characteristic is its high tillering capacity.

These three wheat varieties were sown in four different plant arrangements which corresponded to: (1) six-inch spaced rows running East-West; (2) six-inch spaced rows running East-West and crossed at right angles by six-inch spaced rows; (3) 12-inch spaced rows running East-West; and (4) 12-inch spaced rows running East-West and crossed at right angles by 12-inch spaced rows. A common constant seeding rate of 1.2 bushel per acre was used for all planting patterns.

Field Layout and Characters Investigated

The experimental design was a split-plot with the varieties as main plots and the plant arrangements as subplots. The varieties were replicated four times. The plots were ten feet long and four feet wide. Planting date was October 22, 1969. The plots received a preplant application of 30 lbs/acre of N and 30 lbs/acre of P_2O_5. A supplement of 40 lbs/acre of N in the form of ammonium nitrate was applied in late February, 1970. A central area of 16 square feet was harvested from each subplot for the determination of grain yield.

Data were collected on grain yield, tiller count, kernel weight, number of kernels per spike, test weight, heading date, plant height, and protein content of the grain.

Yield determination was based on the weight of the threshed and cleaned grain harvested from each subplot and was expressed in grams per 16 square feet.

Tiller count was based on the number of fertile tillers in an area of two square feet. Two observations were made at random in each subplot.

Kernel weight was determined on two independent samples of 200 seeds each. The 200 kernels were taken at random from the grain harvested from each subplot. The kernel weight component was expressed in grams per 200 seeds.

The average number of kernels per spike was determined indirectly assuming that the yield per unit area (W) is the product of three components, namely: the number of fertile tillers per unit area (X); the number of kernels per spike (Y); and the kernel weight (Z). In those conditions, the formula giving the number of kernels per spike (Y) will be:

$$Y = \frac{25W}{XZ}$$

where: W is the grain yield expressed in grams per 16 square feet; X is the number of fertile tillers per two square feet; and Z is the 200-kernel weight, expressed in grams.

Test weight was determined on one sample taken randomly from each of the 48 subplot yields and was expressed in pounds per bushel.

Heading date corresponded to the date at which approximately 75 percent of the plants in the subplot have headed. Count of the days was done starting April 1 as one, i.e., "25" corresponded to April 25, etc. Heading date was taken as a measure of the relative earliness of the three varieties since all subplots were planted on the same day.

Height was determined at maturity and corresponded to the distance in inches separating the soil surface from the spike tips of the plants. Two or more measures were taken in each subplot.

Protein content of the grain was determined by the Kjeldahl method on one gram of ground whole grain. One sample was used from each subplot.

Statistical Analysis

Statistical analysis was carried out on the grain yield and the other characters using one sample per plot except for the tiller count where two separate readings were included in the analysis. Kernel weight analysis was made on the average of the two kernel weight samples from each subplot. Analyses of variance were performed to determine the effect of the varieties, the planting arrangements, and the variety x arrangement interaction on the characters under study. Planting arrangement factor has, however, been broken down into two components, namely spacing and drilling. Spacing involved a six-inch spacing distance and a 12-inch spacing distance. Drilling included two alternatives where the rows were either parallel (P) or crossed at right angles by other rows (C). As a consequence, the variety x arrangement interaction was broken down into a variety x spacing interaction, a variety x drilling interaction, and a variety x spacing x drilling interaction.

To evaluate the possible relationship between the grain yield and the remaining variables, bivariate analyses of variance were performed, as well as the simple correlations between those variables. The coefficient r_{XY} of simple correlation between two variables X and Y is given by the formula:

$$r_{XY} = \frac{\sum xy}{\sqrt{\sum x^2 \ \sum y^2}}$$

where $\sum x^2$ is the error sum of squares of the deviations of the variable X; $\sum y^2$ is the error sum of squares of the deviations of the variable Y; and $\sum xy$ is the error sum of products of the deviations of X and Y.

Partial correlations among the yield components were computed for each variety and then pooled over all varieties. In the case of three variables X, Y, and Z, the coefficient $r_{XY.Z}$ of partial correlation between X and Y when Z is maintained constant is given by the formula:

$$r_{XY.Z} = \frac{r_{XY}-r_{XZ}r_{YZ}}{\sqrt{(1-r_{XZ}^2)(1-r_{YZ}^2)}}$$

where the coefficients of simple correlation r_{XY}, r_{XZ} and r_{YZ} are computed using the formula given above.

CHAPTER IV

RESULTS AND DISCUSSION

Grain Yield

Two of the varieties, Parker and Sturdy, had similar grain yields, 379.81 gm/16 sq ft and 379.13 gm/16 sq ft, respectively. The third variety, Triumph 64, marked an average increase of 11.3% over the two other varieties. This difference was not enough to reach the 5% significance level of probability. The yield averages are presented in Table I. The superiority of Triumph 64 was not altered by the planting arrangements. However the three varieties responded differently to a change in spacing (Figure 1a). Yield was higher for Triumph 64 and lower for Sturdy at the 12-inch than at the 6-inch spacing, but the difference in both cases was small. Parker, on the other hand, yielded about 10% more at the wider spacing. This is probably due to the architecture of that variety which led to excessive shading between rows in the closer spacing. Sturdy, an erect, upright, and short-type variety, was the only variety which responded positively to a decreasing of row width. Tanner, *et al*. (40) stated that upright-leaf type small grains are more efficient in narrow rows than the floppy-leaved types. The higher yield at the wider spacing observed in Parker and Triumph 64 may also be attributed to the greater moisture available to the wide-spaced rows. Foth, *et al*. (13) found that narrower rows were associated with a higher root density. The latter would completely deplete the soil

TABLE I

AVERAGE EFFECT OF SPACING AND CROSSDRILLING ON YIELD AND YIELD COMPONENTS

Variety	Spacing (in)	Drilling	Yield (gms/16 sq ft)	No. Tillers/2 sq ft	Kernels/Spike	Kernel Weight (gms/200-kernels)
Parker	6	Parallel	372.75	161.75	12.10	4.79
	6	Cross	346.00	141.63	13.13	4.69
	6	Average	359.38	151.69	12.61	4.74
	12	Parallel	397.00	129.50	15.39	4.99
	12	Cross	403.50	128.75	15.13	5.24
	12	Average	400.25	129.13	15.26	5.11
	Average	Parallel	384.88	145.63	13.74	4.89
	Average	Cross	374.75	135.19	14.13	4.96
	Average		379.81	140.41	13.94	4.92
Sturdy	6	Parallel	398.75	109.38	16.77	5.47
	6	Cross	365.00	106.25	16.36	5.26
	6	Average	381.88	107.81	16.56	5.36
	12	Parallel	394.25	110.50	17.28	5.16
	12	Cross	358.50	91.75	18.84	5.24
	12	Average	376.38	101.13	18.06	5.20
	Average	Parallel	396.50	109.94	17.03	5.31
	Average	Cross	361.75	99.00	17.60	5.25
	Average		379.13	104.47	17.31	5.28

TABLE I (Continued)

Variety	Spacing (in)	Drilling	Yield (gms/16 sq ft)	No. Tillers/2 sq ft	Kernels/Spike	Kernel Weight (gms/200-kernels)
Triumph 64	6	Parallel	419.75	115.75	13.96	6.50
	6	Cross	437.25	113.75	15.48	6.28
	6	Average	428.50	114.75	14.72	6.39
	12	Parallel	455.50	111.25	16.27	6.33
	12	Cross	406.00	101.88	16.31	6.14
	12	Average	430.75	106.56	16.29	6.24
	Average	Parallel	437.63	113.50	15.12	6.41
	Average	Cross	421.63	107.81	15.89	6.21
	Average		429.63	110.66	15.51	6.31
Overall Average	6	Average	389.92	124.75	14.63	5.50
	12	Average	402.75	112.27	16.53	5.52
	Average	Parallel	406.33	123.02	15.29	5.54
	Average	Cross	386.04	114.00	15.87	5.47
Main Plot Error Mean Squares			3916.6	208.88	2.515	0.189
Subplot Error Mean Squares			1588.8	293.09	3.488	0.101

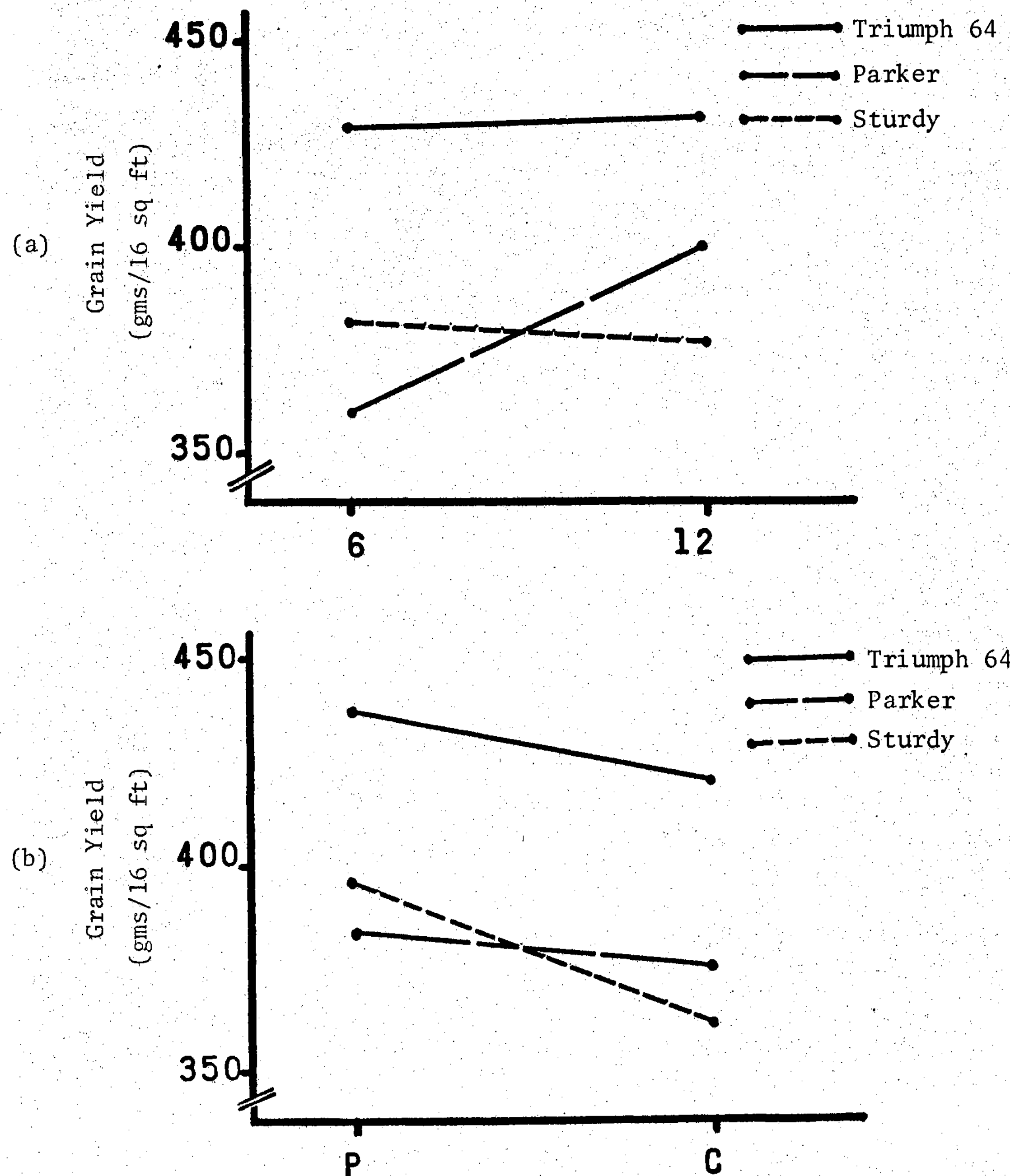

Figure 1. Average Grain Yields of the Three Wheat Varieties as Affected by (a) Spacing and (b) Crossdrilling. 6 and 12 refer to the 6- and 12-inch spacings. P and C refer to parallel and crossdrilled rows, respectively.

moisture in interplant spaces. Siemens (35), on the other hand, found a greater moisture content between wider rows.

When cross drilled, all three varieties responded similarly. Cross drilling resulted in a general yield decrease (Figure 1b). This may be due to a superposition of two or more seeds at the crossdrilling point and to a greater competition between plants near that point. Cross-drilling masked the row direction effect. This factor may have been determined if the experiment included North-South parallel rows. However, crossdrilled plots had more interplant shading since they included plants sown in both directions. This excessive shading may have contributed to the low performances of the three varieties in the cross-drilling treatment. Although having a consistent effect, crossdrilling did not result in a significant yield decrease; the F-value was 3.11, whereas a value of 4.21 was required for significance. Mean square values are presented in Table II.

Yield Components

The three varieties had different values for each yield component and responded differently to the planting patterns. The variety effect on fertile tiller count was highly significant ($P < 0.01$). Parker had a significantly ($P < 0.01$) greater number of fertile tiller per unit area than Triumph 64 or Sturdy. Triumph 64 was intermediate but not significantly different from Sturdy in tiller number. Averages for tiller count are presented in Table I. Six-inch spacing resulted in an average of 124.75 tillers per two square feet which was significantly greater ($P < 0.01$) than 112.27 obtained in the 12-inch spacing (Table I and Figure 2a). Holliday (16) found a greater number of spikes in

TABLE II

MEAN SQUARES FOR GRAIN YIELD AND OTHER CHARACTERS OF THREE HARD RED WINTER WHEAT VARIETIES

Source of Variation	d.f.	Grain Yield	Tiller Count	Kernels per Spike	Kernel Weight	Test Weight	Plant Height	Heading Date	Protein Content
Varieties	2	13418.7	11812.54**	45.694**	8.294**	57.766**	187.146**	149.771**	19.443**
Main Plot Error	6	3916.6	208.88	2.515	0.189	2.689	1.174	0.826	0.497
Spacing	1	1887.5	3737.51**	43.649**	0.005	0.005	1.333	0.021	0.060
Drilling	1	4941.0	1953.01*	4.025	0.051	0.255	1.333	0.188	0.317
Spacing x Drilling	1	426.0	8.76	0.220	0.150	0.005	1.333	0.021	0.060
Varieties x Spacing	2	2468.4	614.54	1.664	0.386*	2.880*	0.396	0.146	0.128
Varieties x Drilling	2	661.6	72.17	0.152	0.077	0.505	3.771*	0.438	0.264
Varieties x Spacing x Drilling	2	2586.3	669.54	3.765	0.027	0.412	2.021	0.146	0.188
Sub-plot Error	27	1588.8	293.09	3.488	0.101	0.549	0.782	0.280	0.199

*Significant at the 0.05 level of probability.

**Significant at the 0.01 level of probability.

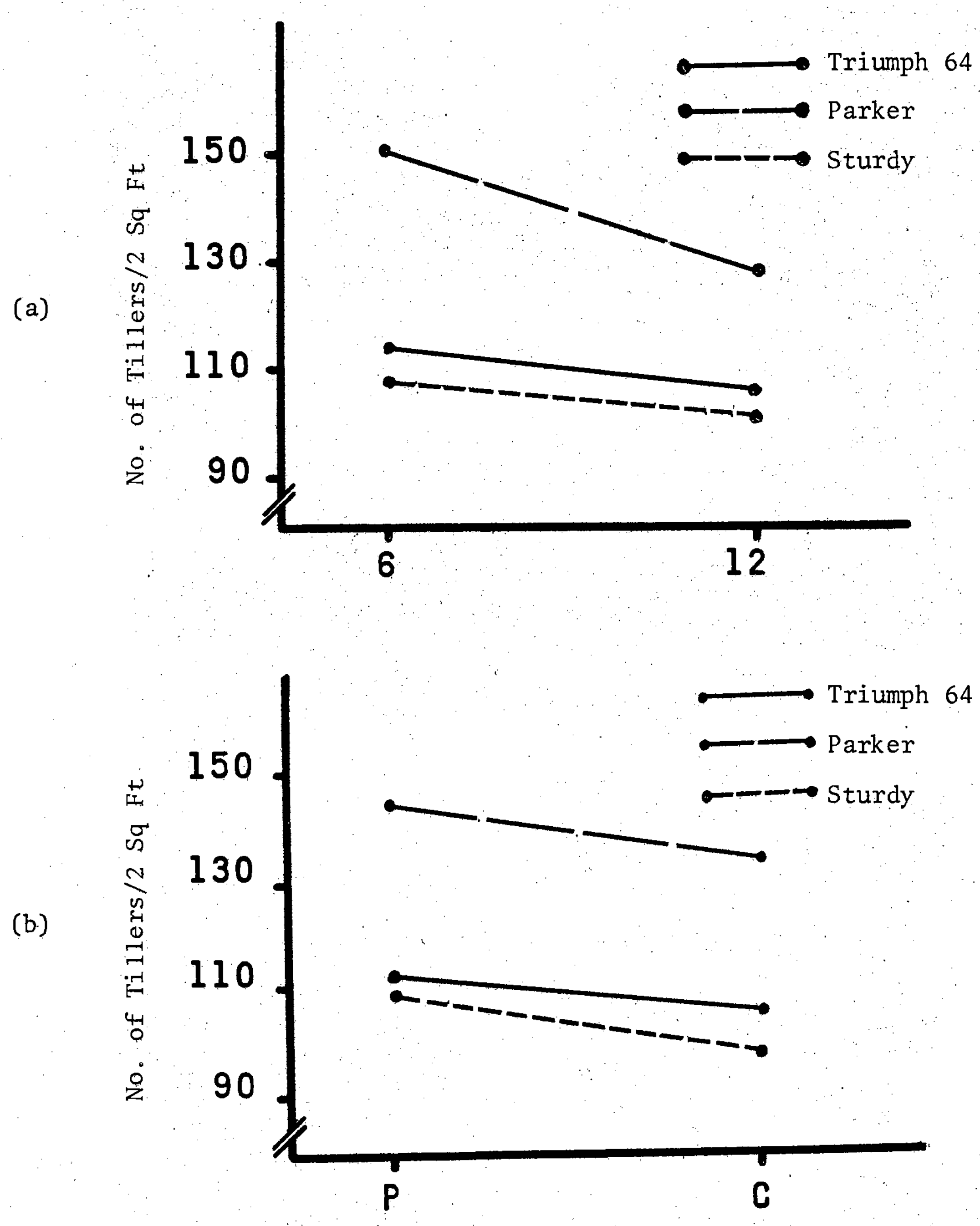

Figure 2. Average Tillering Capacities of the Three Wheat Varieties as Affected by (a) Spacing and (b) Crossdrilling. 6 and 12 refer to the 6- and 12-inch spacings. P and C refer to parallel and crossdrilled rows, respectively.

narrower rows of wheat and barley. Similar results have been obtained by Kinra, et al. (20). These findings suggest that tillering occurs at an early stage where competition between roots or between leaves of closely spaced plants has not become important. Stickler (27) stated that within-row competition in wider rows leads to fewer tillers. Crossdrilling resulted in a consistent decrease in the number of tillers per unit area (Figure 2b); this decrease could be attributed, as in the case of grain yield, to a greater crowding of the plants at and near the crossing point leading to excessive competition. No significant interaction was found between varieties and plant arrangements indicating that narrower spacing would in general be associated with more tillers and that crossdrilling would in general result in a decrease of fertile tillers per unit area.

The number of kernels per spike was different in the three varieties (Table I). Parker had the lowest value for this component, followed by Triumph 64 and then Sturdy. It is of practical value to notice that this order is the reverse of that for the tiller count. This fact can hardly be due to chance and may lead to the conclusion that if the two components are genetically controlled a negative correlation exists between tiller number and kernels per spike. It should be pointed out that the variety effect on kernels per spike was highly significant. The contrast "Sturdy-Parker" was significant at the 1% level of probability. The two other contrasts were significant at the 5% level of probability. Spacing effect on the kernels per spike component was highly significant (Table II); the six-inch treatment had an average value of 14.63 kernels per spike whereas the 12-inch treatment had an average of 16.53 (Table I). This effect was consistent over the three varieties (Figure 3). These results indicate that the number of kernels per spike was determined at a time where competition for growth resources has become rather important and shifted the balance in favor of the wide spaced plant rows. Crossdrilling resulted in a slight increase of the kernels per spike component. This increase, however, was not significant. These results indicate that the possible greater number of plants at the intersection of the rows did not affect the number of kernels per spike. Again the greater values of the kernels per spike at the 12-inch spacing and at the cross treatment corresponded to the smaller values of the tiller count at the same treatments (Table I). This shows a consistent interrelationship between the two components, which will be discussed in a later section of this chapter. Mean square values (Table II) showed no interaction between varieties and spacing or drilling. This indicates, if the varieties were randomly selected, that wider spacing would in general result in a greater number of seeds per spike.

The variety effect on the seed weight was highly significant (Table II). Triumph 64 had a 200-kernel weight of 6.31 grams, which was significantly greater than that of Sturdy. Parker had the lowest kernel weight which did not differ significantly from that of Sturdy (Table I). No difference for seed weight was statistically detected between the averages of the two spacings or between the parallel and cross treatments (Table I). This component was the only one not affected by plant distribution. Similar response of the seed weight to increasing environmental resources by the use of wide rows was reported by Holliday (16). Foth, _et al_. (13) found no significant differences in kernel weight between 7- and 11-inch spaced oat rows. A significant

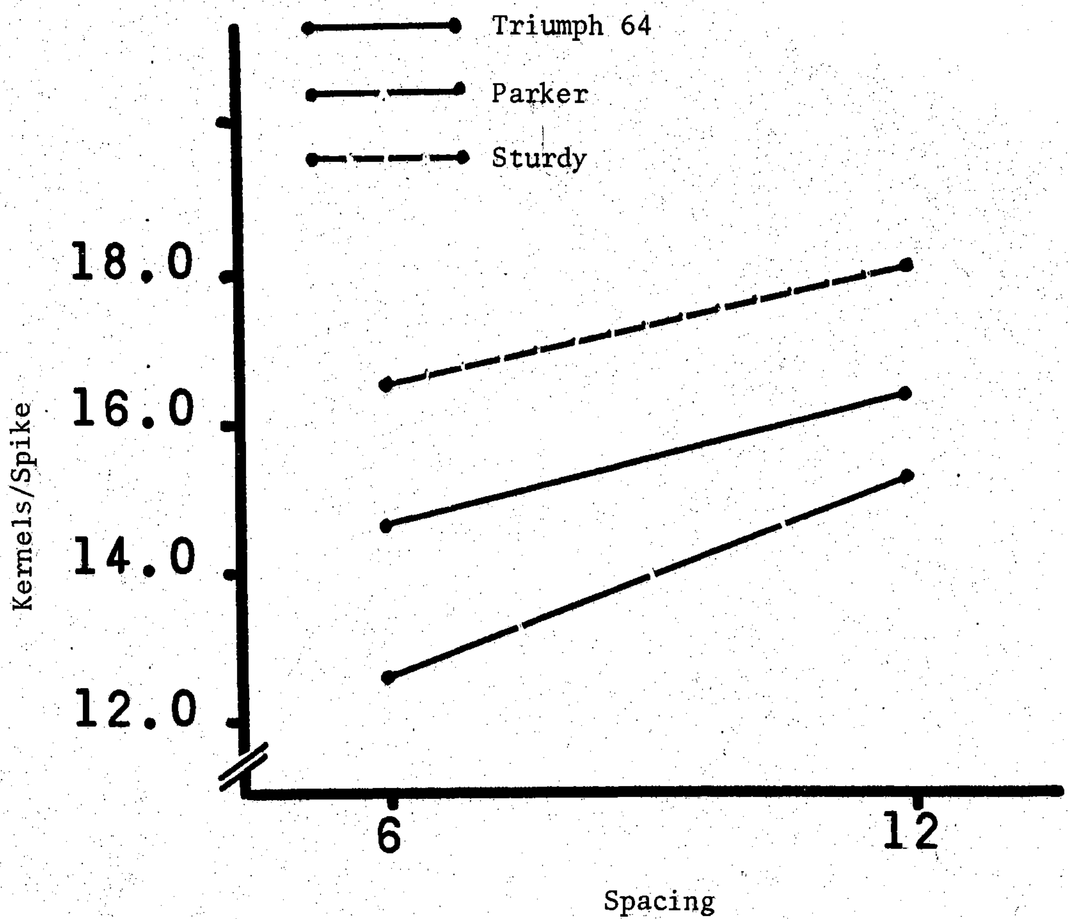

Figure 3. Average Number of Kernels per Spike of the Three Wheat Varieties at the 6- and 12-Inch Spacings No significant interaction was found between varieties and spacings.

variety x spacing interaction was detected which indicated that the varieties responded differently to the two spacings; Triumph 64 and Sturdy kernel weights decreased slightly with a widening of the spacing. Parker on the other hand showed a greater kernel weight for the wider row spacing. However the order of the three varieties was maintained irrespective of the spacing (Figure 4).

Other Characteristics

Analyses of variance showed highly significant variety effects on the test weight, the plant height, the heading date, and the protein content of the grain (Table II).

Triumph 64 had the highest test weight and was followed by Parker and then Sturdy (Table III, Figure 5). However the three varieties had different responses to the spacing treatment as shown by the significant variety x spacing interaction (Table II). Neither the spacing nor the drilling had a significant effect on the test weight. Similar results were obtained by Siemens (35). Kinra, et al. (20) found that row spacing was not consistent in its effect on test weight, but this component was positively correlated to grain yield. In the present experiment the test weight contributed a large part to the variation of the grain yield as will be shown in a later section of this chapter (Table IV).

The variety Parker had an average height of 35.81 inches and was taller than either of the other varieties; Sturdy was the shortest (Table III). A significant variety x drilling interaction (Table II) showed that the varieties responded differently to the cross treatment. The differences however were so small that the plant distribution effect

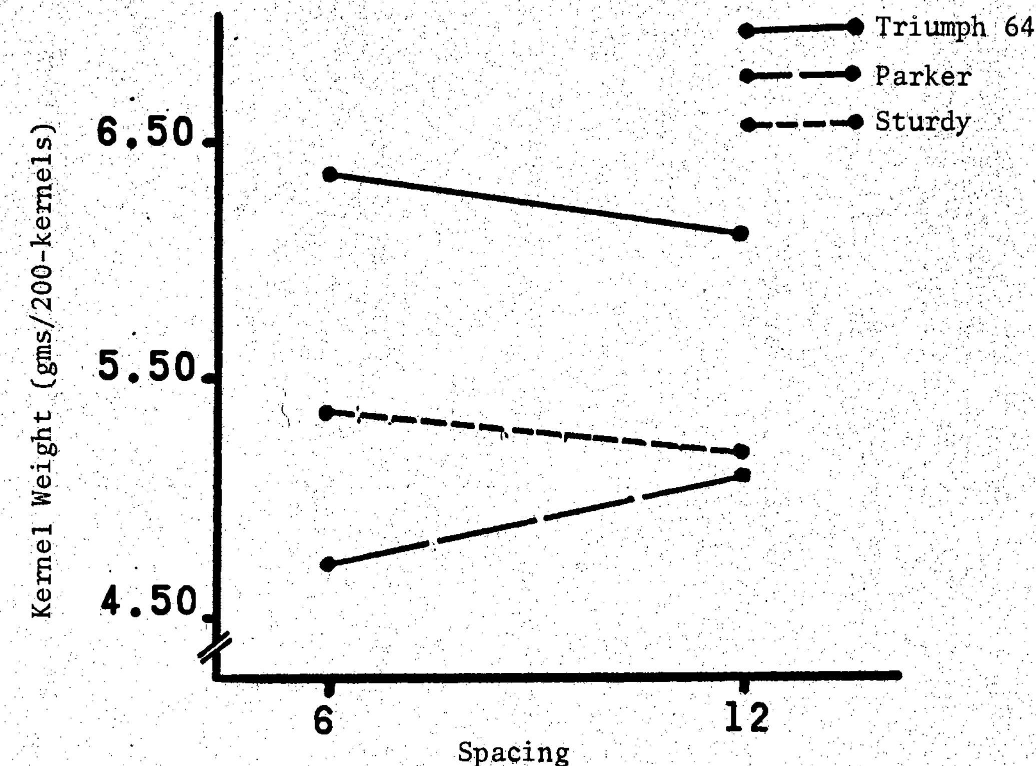

Figure 4. Average 200-Kernel Weights of the Three Wheat Varieties at the 6- and 12-Inch Spacings. The variety x spacing interaction was significant at the 0.05 level of probability.

TABLE III

AVERAGE EFFECT OF SPACING AND DRILLING ON TEST WEIGHT, PLANT HEIGHT, HEADING DATE AND GRAIN PROTEIN CONTENT

Variety	Spacing	Drilling	Test Weight (lb/bu)	Plant Height (in)	Heading Date (Days After April 1st)	Protein Content
Parker	6	Parallel	59.00	36.25	31.00	14.95
	6	Cross	59.00	35.75	30.75	15.63
	6	Average	59.00	36.00	30.88	15.29
	12	Parallel	60.25	34.75	30.75	15.13
	12	Cross	59.75	36.50	31.00	14.95
	12	Average	60.00	35.63	30.88	15.04
	Average	Parallel	59.63	35.50	30.88	15.04
	Average	Cross	59.38	36.13	30.88	15.29
	Average		59.50	35.81	30.88	15.16
Sturdy	6	Parallel	58.25	29.75	29.50	15.35
	6	Cross	58.13	29.25	30.00	15.23
	6	Average	58.19	29.50	29.75	15.29
	12	Parallel	57.38	30.00	29.25	15.25
	12	Cross	58.00	29.00	29.75	15.33
	12	Average	57.69	29.50	29.50	15.29
	Average	Parallel	57.81	29.88	29.38	15.30
	Average	Cross	58.06	29.13	29.88	15.28
	Average		57.94	29.50	29.63	15.29
Triumph 64	6	Parallel	62.13	34.75	25.00	13.23
	6	Cross	61.75	35.75	25.00	13.38
	6	Average	61.94	35.25	25.00	13.30
	12	Parallel	61.75	34.00	25.25	13.15
	12	Cross	61.25	35.25	25.00	13.53
	12	Average	61.50	34.63	25.13	13.34
	Average	Parallel	61.94	34.38	25.13	13.19
	Average	Cross	61.50	35.50	25.00	13.45
	Average		61.72	34.94	25.06	13.32
Overall Average	6	Average	59.71	33.58	28.54	14.63
	12	Average	59.81	33.25	28.50	14.55
	Average	Parallel	59.79	33.25	28.46	14.51
	Average	Cross	59.73	33.58	28.58	14.67
Main Plot Error Mean Squares			2.689	1.174	0.826	0.497
Sub-Plot Error Mean Squares			0.549	0.782	0.280	0.199

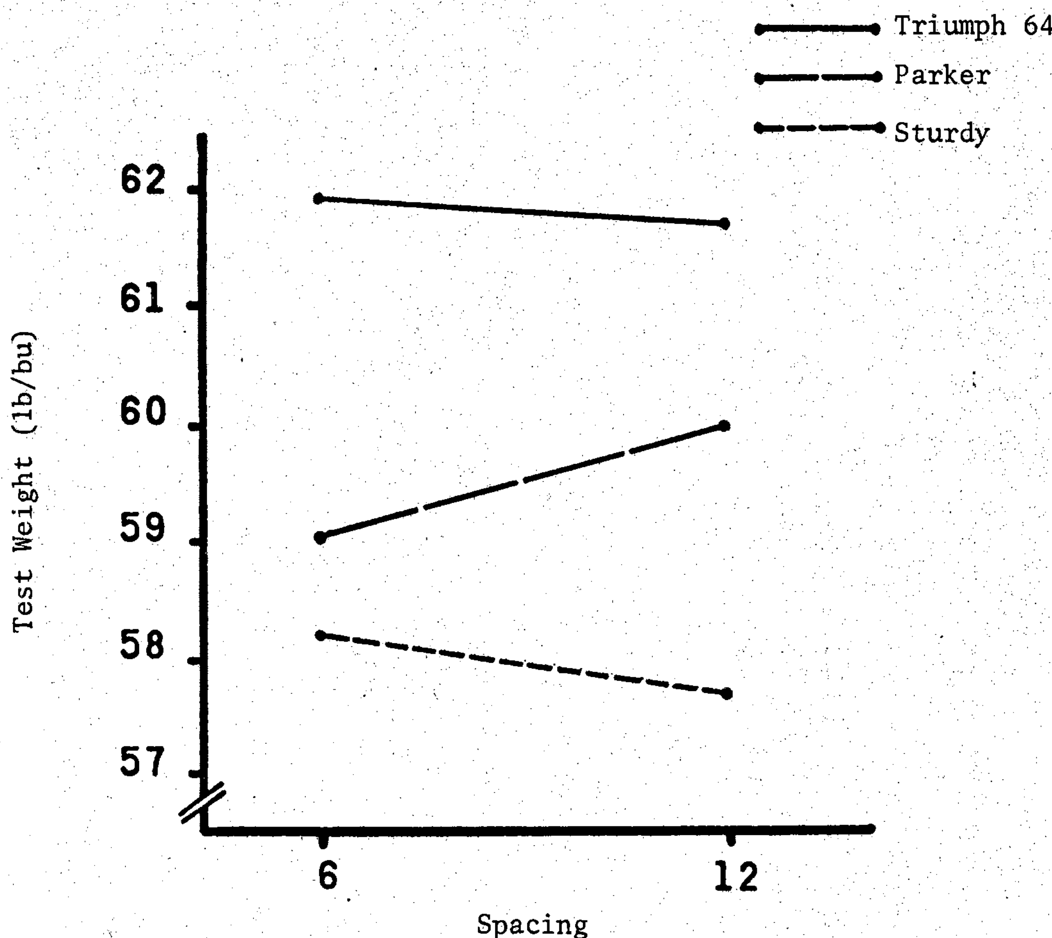

Figure 5. Average Values of the Test Weight of the Three Wheat Varieties at the 6- and 12-Inch Spacings. The variety x spacing interaction was significant at the 0.05 level of probability.

TABLE IV

RELATIVE IMPORTANCE OF DIFFERENT CHARACTERS ON GRAIN YIELD OF THREE HARD RED WINTER WHEAT VARIETIES

	Regression Coefficient[1]	Coefficient of Determination[2] r^2
Tiller Count	0.047	0.0009
Kernels/Spike	10.473	0.240
Kernel Weight	83.621	0.440
Test Weight	26.373	0.240
Heading Date	-8.694	0.013
Plant Height	19.879	0.192
Protein Content	-39.50	0.200

[1]Coefficient of simple regression of grain yield on each character.

[2]The coefficient of determination r^2 represents the fraction of the sum of squares of the deviations of yield that is due to variation of each character.

on height seemed negligible. The experiment, in contrast, showed that plant height is positively correlated with the number of kernels per spike and that it contributed 19.2% to the variation of yield (Tables IV and V).

Heading date figures (Table III) showed that Triumph 64 matured approximately five and six days earlier than Sturdy and Parker, respectively. Maturity was not affected by the plant arrangements (Table II). A significant negative correlation was found between height and heading date (Table V); taller plants tended to mature earlier in this experiment. Schlehuber, et al. (33) found that shorter plant families were earlier maturing than taller plant families.

The protein content of the grain was affected by the variety treatment ($P < 0.01$). Sturdy had the highest and Triumph 64 the lowest grain protein content (Table III). These two varieties had respectively the lowest and the highest grain yield per unit area. This behavior was further confirmed by a significant negative correlation between grain yield and protein content ($r = -0.447$). The latter characteristic was not significantly affected by the plant distribution (Table II). Kinra, et al. (20) found percent protein values of 12.1, 12.3, 12.4, and 12.5 which corresponded to 55.0, 54.9, 53.4 and 48.4 bu/acre of grain and to 7-, 9-, 11-, and 14-inch spacings. The present experiment showed values of 14.63 and 14.55 percent protein content which corresponded to 39.2 and 40.5 bu/acre of grain and to 6- and 12-inch spacings, respectively. It seems that the slight variations of protein content in both studies are not a direct result of the spacing but rather that of a negative correlation between yield and protein content, such correlation being found in both experiments. The impact of this correlation on a

TABLE V

COEFFICIENTS OF SIMPLE CORRELATIONS AMONG YIELD COMPONENTS AND OTHER CHARACTERS

	Tiller Count	Kernels/ Spike	Kernel Weight	Test Weight	Plant Height	Heading Date
Tiller Count	1	-0.758**	-0.179	-0.159	-0.200	0.008
Kernels/Spike		1	0.245	0.281	0.465*	-0.347
Kernel Weight			1	0.667**	0.152	0.300
Test Weight				1	-0.048	0.245
Plant Height					1	-0.450*
Heading Date						1

*Significant at the 0.05 level of probability. Twenty-four degrees of freedom were associated with the coefficient of simple correlation between two characters. The significant value for 24 degrees of freedom is 0.388.

**Significant at the 0.01 level of probability. The significant value for 24 degrees of freedom is 0.496.

selection program is of primary importance. Baker, et al. (4) suggested that this interrelationship between grain yield and nitrogen content results in a tremendous difficulty to improve both characters at the same time. Stuber, et al. (39) on the other hand found that the correlation coefficient is too low to constitute a hindrance to simultaneous improvement of both traits.

Relative Importance of the Yield Components

Assuming a constant linear relationship between the grain yield and its three components over the four replications, it is possible to compute the simple regression coefficients of yield on each component (Table IV). The coefficient of regression of yield on seed weight was the highest. Thorne (41) emphasized the importance of the seed weight in the determination of grain yield in winter wheat. The regression coefficient of yield on tiller count was essentially null; that of yield on kernels per spike was intermediate.

These findings were paralleled by the values of the coefficient of determination r^2 which represents the fraction of the sum of squares of the deviations of yield that is due to variations in each of the components (Table IV). About 44% of the variation of yield was due to a variation in kernel weight.

These results suggest that the seed weight is the most closely related to the grain yield. Furthermore it was the only component not affected by the plant arrangements, indicating its stability. On the other hand the number of tillers was the least related to the yield and the most subject to the influence of the environmental changes since it was affected by spacing and drilling. The number of kernels per spike was intermediate.

When the relationships between yield and components of yield for each variety were investigated the results indicated the same pattern for Parker and Sturdy. Kernel weight had a coefficient of determination of 66.26% for Parker and 56.55% for Sturdy; kernels per spike was less important and contributed only 27.1% and 29.2% to the variation of yield in Parker and Sturdy (Table VI). The influence of tiller count on yield was trivial in both varieties. On the other hand, kernel weight in Triumph 64 contributed only about 5.7% to the variation of yield, whereas the two other components had a greater influence. This indicates that the high yield of this variety is not the result of a high kernel weight _per se_ but also of a better balance between the yield components. Triumph 64 had the highest seed weight, demonstrating again the importance of that component. However this did not result in a drastic decrease of the other components as would be expected from a pure compensatory mechanism. Triumph 64 had in fact intermediate values for tiller count and kernels per spike. Parker, on the other hand, had the greatest tiller number and corresponding low values for the other components. Sturdy had the highest number of kernels per spike with corresponding low tiller count and kernel weight (Table I). Thus a good balance between the components led to the high yield of Triumph 64. Adams and Grafius (2) stressed the importance of such a phenomenon and concluded that a high yielding variety has a high genetic potential for each component accompanied by a certain flexibility which leads to a good balance of the components in different environments and thus to a maximal use of the growth resources.

TABLE VI

PERCENT OF THE VARIATION OF GRAIN YIELD DUE TO VARIATION IN OTHER CHARACTERS[1]

	Tiller Count[2]		Kernels/ Spike	Kernel Weight	Test Weight	Plant Height	Heading Date
	r_1	r_2					
Parker	3.36	8.24	27.14	66.26	23.43	45.97	2.63
Sturdy	18.40	5.57	29.16	56.55	77.62	1.15	6.30
Triumph 64	13.69	15.37	12.96	5.71	2.47	23.14	3.06

[1]The protein content was not included in this analysis.

[2]r_1 and r_2 refer to the two independent samples made in the determination of tiller count.

Competition Between the Components of Yield

The relative variation of a component in response to that of another component can be described by the correlations among the components. Both simple and partial correlation coefficients have been computed and showed approximately the same pattern (Table VII). The nonsignificance of the partial correlation $r_{XY.Z}$ in Parker and Sturdy is attributed to a small number of degrees of freedom. It indicates that the variation of kernels per spike is due to a simultaneous effect of tiller count and kernel weight. The pooled correlation between tiller count and kernel weight was negative when simple and positive when partial. This is probably due to the positive correlation between kernels per spike and kernel weight on one hand and the strongly negative correlation between kernels per spike and tiller count. This result indicates that the variation of tiller number was associated with little change in the kernel weight. Only the kernels per spike and the tiller count were strongly correlated; the negative coefficient of correlation between these two components $r_{XY.Z} = -0.749$ indicates that competition occurs between the number of tillers established and the number of seeds per spike. Fonseca and Patterson (12) found a highly significant negative correlation between the number of spikes per unit area and the number of kernels per spike and concluded that such relationship may constitute a hindrance to selection based on yield components. The correlations among components for each variety showed the importance of the correlation between tiller count and kernels per spike. It can be seen, however, that in the case of Triumph 64 neither the simple nor the partial correlation, although both important in magnitude, reached the significance level of probability.

TABLE VII

SIMPLE AND PARTIAL CORRELATION COEFFICIENTS AMONG THE YIELD COMPONENTS OF THREE HARD RED WINTER WHEAT VARIETIES

Variety[1]	Tiller Count vs Kernels/Spike[2]		Tiller Count vs Kernel Weight[3]		Kernels/Spike vs Kernel Weight	
	Simple (r_{XY})	Partial ($r_{XY.Z}$)	Simple (r_{XZ})	Partial ($r_{XZ.Y}$)	Simple (r_{YZ})	Partial ($r_{YZ.X}$)
Parker	-0.652*	-0.593	-0.413	-0.260	0.350	0.117
Sturdy	-0.790**	-0.778	-0.231	0.080	0.350	0.282
Triumph 64	-0.437	-0.436	-0.023	-0.004	0.044	0.038
Pooled Correlations	-0.758**	-0.749**	-0.179	0.010	0.245	0.170

[1]Significant values for simple and partial correlations are 0.632 and 0.811 at the 5% level of probability, corresponding to 8 and 4 degrees of freedom, respectively. The significant values at the 1% level of probability for the same numbers of degrees of freedom are 0.765 and 0.917, respectively.

[2]X, Y and Z refer to tiller count, kernels per spike and kernel weight, respectively.

[3]Only one sample of tiller count was included in the analysis.

[4]Significant values for simple and partial correlations are 0.388 and 0.532 at the 5% level of probability, corresponding to 24 and 12 degrees of freedom, respectively. The significant values at the 1% level of probability for the same numbers of degrees of freedom are 0.496 and 0.661, respectively.

The formation of tillers and the production of kernels within a spike probably overlap at a certain stage, particularly in early spring, when the spikelet initiation starts and the tiller number has not yet been fixed. If this assumption is accepted, the two components will be drawing upon the same available growth resources at the same time. This condition is characterized by Donald (11) as conducive to competition. In this study, the tiller number and the kernel weight are suggested to be determined at different periods and so are the kernel weight and the kernels per spike components. Thorne (41) stated that the ear number is affected by environmental factors occurring during early developmental stages, whereas the seed weight is influenced by changes occurring after pollination. This is confirmed by Ryle's results (29).

According to Adam's findings (1), the existence of strongly negative correlations such as the r_{XY} found in this study implies that the plants were not in optimal growth conditions during the establishment of tillers and the initiation of kernels.

CHAPTER V

SUMMARY AND CONCLUSIONS

Three hard red winter wheat varieties were planted in four different arrangements which permitted the study of the effect of spacing and crossdrilling on certain characteristics. Data have been collected on grain yield, yield components, test weight, height, heading date and protein content.

Although not statistically significant, differences in yield were in favor of Triumph 64. Parker and Sturdy produced about the same amount of grain per acre. The three varieties behaved differently in the two spacings. Only the erect, short type variety responded by a slight yield increase to a narrow spacing. All three varieties marked a consistent decrease with crossdrilling.

The number of tillers per unit area was significantly affected by the genotype and the spatial arrangements. Parker had the highest and Sturdy the lowest tillering capacities. The number of tillers per unit area was increased by a narrowing of the rows and decreased by the crossdrilling treatment.

The highest number of kernels per spike was found in the variety Sturdy. This component was significantly increased in wider rows but was not affected by the crossdrilling.

The three varieties had different kernel weights and responded differently to the two spacings. However the planting patterns did not significantly affect this component. Triumph 64 had the greatest kernel weight.

Test weight, plant height, heading date, and grain protein content were not influenced by the spatial arrangements. Parker was the tallest and the latest maturing variety. Sturdy was the shortest and had the highest protein content. Triumph 64 was the earliest maturing variety, had the highest test weight but the lowest protein content. A negative correlation was found between yield and grain protein content.

The data showed the importance of the seed weight as the primary determinant of grain yield. This component was the least affected by the planting patterns.

Strongly negative correlation was found between the number of tillers per unit area and that of kernels per spike, indicating that these two components have drawn differentially upon the same growth resources. The two other correlations among the yield components were not significant, showing the relative independence of the kernel development from that of the other components.

The results of this one-year experiment are of preliminary importance. They indicated however that there was no advantage in cross-drilling wheat rows. The findings showed that the high kernel weight of Triumph 64 was not associated with small values of the other two components. Selecting varieties with a high genetic potential for each yield component but with a good balance between the components will lead to higher grain yields.

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