YIELD COMPONENTS AND FLAG-LEAF AREA IN RELATION TO HEIGHT IN HARD RED WINTER WHEAT

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INTRODUCTION

The development of new high yielding semidwarf wheat cultivars in the United States was emphasized with the introduction of Norin 10 and other dwarf cultivars from Japanese wheat, in 1946 by S. C. Salmon. Since that time other short wheat cultivars have been introduced into the United States and used in crosses with locally adapted cultivars. Many semidwarf wheat cultivars have been produced and evaluated by Johnson, Schmidt and McKasha (1966b), McNeal, Berg, and Klages (1960), Porter et. al. (1964), and Vogel et al. (1956). Extensive reviews of the breeding and characteristics of semidwarf wheats have been reported by Briggle and Vogel (1968), Reitz (1968) and Reitz and Salmon (1968).

In 1949 a breeding program was initiated in Kansas to transfer the dwarf stature into locally adapted hard red winter wheats, to date no satisfactory types have been selected from this program which possess superior agronomic and quality characteristics when compared with adapted standard height cultivars.

This study was undertaken to examine possible areas of explanation for consistent yield increase failures with semidwarf hard red winter wheat grown under Kansas conditions. The material studied contained about 98% germplasm from hard red winter wheats.

Two areas of possible explanation were investigated. One was yield components and their relation to height. The second was flag-leaf area and its relation to height. These characters in three height classes were evaluated with respect to yield of semidwarf and standard hard red winter wheat selections. The knowledge of relationships between these characters and height in hard red winter wheat would be useful for making selections, planning crosses and evaluating breeding material under Kansas conditions.

LITERATURE REVIEW

Yield Components

Components of yield in wheat are: (1) number heads per unit area, (2) number of kernels per head, and (3) average weight per kernel, (Poehhman, 1949), (Quisenberry, 1928), Ramusson and Cannell, 1970), (Stickler and Pauli, 1961), (Woodworth, 1931).

Another component was suggested by Laude (1938), as number of plants per acre. Kronstad and Foote (1966) considered number of spikelets per spike and number of kernels per spikelet also to be components of yield. In this study components of yield studied were: spikes per unit area, kernels per spike, of which spikelets per spike and kernels per spikelet are directly related, and average weight per kernel with weight of kernels per spike and weight of 1000 kernels also being considered.

Correlation of plant height with yield and yield components and other agronomic characters has been reported by several workers. Shad and Ahmed (1967) reported plant height to be significantly correlated with yield, number of ears per plant, and 1000 kernel weight. Nonsignificant correlation coefficients were found for plant height with length of ear, number of kernels per ear, number of spikelets per ear, and date of earing (flowering). On the other hand, Stewart (1928) found significant correlation between height and spikelets per head.

Simple correlations for yield with kernels per unit area, heads per unit area, height, and heads per plant were all found to exceed 0.60 by Locke, Reuschwalde, and Mathews (1942). Grain yield was positively and highly correlated with ear number and 100-grain weight. Correlation values for grain yield with grain number per ear and ear length were positive and of lower magnitude in work by Gandhi et. al. (1964). Plant height was significantly (0.05 level) correlated with grain yield as was spikelets per ear. McNeal (1960) reported kernels per head and heads per plant to be more highly correlated with plant yield than kernel weight.

Nandpuri (1959) reported correlation coefficients to be significant between plant height and tillering in two of three years studied. However, values were low in magnitude and inconsistent with years. The author stated that from a plant breeder's viewpoint there was no relationship between characters studied. Stewart (1926) found rather high correlations between longest culm length and number of culms. But indicated correlations to be physiologic rather than genetic in their nature. In later studies, Steward and Bischopp (1931) and Stewart and Heywood (1929) showed correlation between number of culms and culm length to be nonsignificant. Arny and Garber

(1918) also found correlations between average height of culms and number of culms to be low.

Waldron (1933) found height to be nonsignificantly correlated with yield. The same was true for the correlation value between 100 kernel weight and kernels per spikelet. He did report positive significant correlation for yield with 1000 kernel weight, kernels per spikelet and weight of kernels per spike. Similar values were found for 1000 kernel weight correlations with test weight and weight of kernels per spike. Waldron (1929) reported significant correlation at one of two environments between yield and total kernels per head, and weight of 1000 kernels. Similar results were found at the second environment with the exception of negative but nonsignificant correlations between yield and number of kernels per head.

In work by Bridgeford and Hayes (1931) height was found to be correlated positively with kernels per spike and kernels per spikelet. Significant positive correlations were also reported between yield and plant height and 1000 kernel weight. One thousand kernel weights were found to be nonsignificantly correlated with height, kernels per spike and kernels per spikelet.

Sprague (1926) found positive correlations of intermediate values between grain yield per spike, grains per spike and weight per grain. He reported insignificant or very low correlation value between weight per kernel and grains per spike. Nebraska 60, one of the cultivars studied by Sprague, gave high positive correlations for grain yield per unit area with average number of spikes per unit area; intermediate correlation values with grain yield per spike and weight per kernel; and low positive correlation with culm length.

High positive correlation was reported by Roberts (1912) between number of culms per plant and weight of grain per spike and low positive correlations between culm length and number of grains per spike. He also found a high positive correlation between culm length and number of grains per spike.

Arny and Garber (1918) found yield to have a fairly consistent correlation with average weight of kernels and average height of culms and a somewhat higher correlation with number of culms. Moderately high correlations were reported between average height of culms and average weight of kernels in 3 of 4 years.

Borojevic (1968) in a study of spike and kernel characters of dwarf and semidwarf wheat lines found the length of spike, number and weight of kernels to have similar mean values. No correlation between stalk height and these characters were found. He did, however, find a positive correlation between stalk height and number of spikelets. A positive correlation for stalk height and kernel yield was found which according to the author demonstrates that semidwarf lines have more efficient compensation between yield components and are more suitable for production than dwarf lines. This is in agreement with Vogel et. al. (1956). In a similar study Borojevic and Mikic (1965) working with dwarf progenies from 30-50 cm. in plant height found little, if any, correlation between plant height and spike length, number of spikelets per spike, and number of kernels per spike. Those authors stated that considerable shortening of stalk need not lead to decrease in genetic capacity for yield in short or dwarf wheats.

In a study of two crosses of winter wheat in the F_3 and F_4 generation Reddi (1968) and Reddi, Heyne, and Liang (1969) found culm length and kernel weight to be positively and highly correlated in both crosses. Correlation between culm length and spike length was found to be low in both crosses; however, a positive significant correlation was reported in the F_4 generation of one of the crosses. The correlation between spike length and kernel weight was negative or low for both crosses. In one generation of each cross a positive and significant correlation was reported between culm length and tiller number. These authors stated lines with shorter culm length tended to have longer spikes and lower kernel weight characteristic of the Norin 10 germplasm.

From phenotypic correlation Johnson et. al. (1966a) found plant height to be highly correlated with kernel weight, grain yield, and spike length. Short plant height was associated with low kernel weight, short spike length, early maturity, low number of spikes per plant, low number of rachis internodes and low yield in Seu Seun 27. They stated that the significant correlation coefficients indicated that those characteristics tended to remain associated in the progeny from the cross of Seu Seun 27 with BlueJacket. In another study Johnson et. al. (1966b) found two short stature wheat cultivars CI 13678 (Norin 16 x Nebraska 60-Mediterranean-Hope) and CI 13677 (Seu Seun 27 x Nebraska 60-Mediterranean-Hope) to be more productive, on the average, than the two taller cultivars, Pawnee and Cheyenne. CI 13678, the consistently highest yielding cultivar, produced more kernels per spike, but the kernel weight and spike number per foot of row were less than other cultivars. CI 13677, the cultivar with the shortest straw, produced lighter weight kernels and fewer spikes than Pawnee and Cheyenne. The high number of kernels per spike of CI 13678 was associated with more spikelets per spike and more kernels per spikelet than others. CI 13677 had fewer spikelets but more kernels per spikelet than taller cultivars.

Stickler and Pauli (1961) compared seven semidwarf winter wheats with Pawnee and Triumph for yield and individual components of yield (number of heads per unit, number of seeds per head and seed weight) in one year and with Pawnee and Quivira hybrid (Parker, CI 13285) in the second year of the study. Only one semidwarf line outyielded Pawnee and no semidwarf line outyielded Triumph in the first year of study. Yield component analysis revealed increased seed weight was responsible for yield superority of the semidwarf line and Triumph. A sister selection of the top yielding semidwarf the first year outyielded both Pawnee and Quivira hybrid (Parker, CI 13285) the second year the study was conducted. Yield superiority in the second year was attributed to a greater number of seeds per head and to greater seed weight.

Flag Leaf-Area

The relation of flag-leaf area to height was examined in the light of recent literature as reported by Carr and Wardlaw (1965), Drennan and Krishnamurthy (1964), Quinlaw and Sagar (1965), Stoy (1965), Thorne (1965) Simpson (1968) and Voldeng and Simpson (1967), relating the photosynthetic area above the flag-leaf node to yield in wheat plants. In those studies the entire area above the flag-leaf node was considered. The components of photosythetic area above the flag-leaf node are: flag-leaf sheath, flag-leaf lamina, peduncle, and spike. The above studies were conducted under greenhouse conditions which allowed more precise measurement of each component. However, in the field the only practical measurement was flag-leaf lamina area. A somewhat indirect measurement of the photosynthetic area of the spike was taken when total spikelets per spike were recorded. Since the glumes provide the major portion of the photosythetic area of the spike, it would seem logical to assume the more spikelets per spike the more photosynthetic area per spike.

The importance of flag-leaf lamina, flag-leaf sheath, and ear were shown by Thorne (1965) and Stoy (1965) to be significant in their contribution of photosynthates to final grain dry weight. The plant structures below the flag-leaf node apparently contribute only a small percentage to the final grain weight according to Voldeng and Simpson (1967). Estimates of 60-85% have been reported, Asana and Mani (1950), Enyi (1962), Quinlan and Sagar (1965) and Watson, Thorne, and French (1958) as the percentage of photosynthates contributed from plant structures above the flag-leaf node to final grain weight. The reasonable hypothesis from such reports would be that final yield of grain is proportional to the photosynthetic area above the flag-leaf node. The findings of Watson (1947) and Stoy (1965), that net assimilation rates appear to be closely comparable between cultivars, would add support to the hypothesis. If such a relationship exists it may help explain lower yields of semidwarf wheat cultivars in Kansas. If the hypothesis proves to be valid it would place a new selection tool in the hands of plant breeders. New high yielding cultivars may be selected with large photosynthetic area above the flag-leaf node.

This hypothesis was tested by Voldeng and Simpson (1967) using seven closely related lines of wheat. Because of limited number of lines and difficulty of measuring head area accurately only correlation coefficients between flag-leaf area and weight of grain for tillers within each cultivar were computed. They stated that contribution to grain weight from flag-leaf and ear to be 66-85% depending on line studied. High positive correlations between flag-leaf area and yield may provide a fair index for selection of high yielding plants under controlled environmental conditions. Results from their study also indicated that selection of plants with a large flag-leaf area and ear area is a valid criterion for selection of the higher yielding plants from a mixture of genotypes.

In a follow-up study Simpson (1968), examined this relationship more thoroughly by using 120 cultivars of wheat and measuring the correlation between grain weight per tiller and per plant, and the components of photosynthetic area above the flag-leaf node. He found high correlation coefficients between components of photosynthetic area above the flag-leaf node and grain yield on both a per plant and per tiller basis. The high correlation coefficients between components of photosynthetic area above the flag-leaf node and the number of kernels per head reported, indicated to Simpson that selection for a large photosynthetic area above the flag-leaf node, would also result in selection for a high grain number per tiller or plant. Correlations between flag-leaf lamina and grain weight or grain number were reported lower than other photosynthetic area components, particularly on a per tiller basis. His explanation for this was due to the floppiness of the lamina in comparison to the upright growth habit of the sheath and ear, which may have altered light interception. In this study Simpson divided the 120 cultivars into short, medium, and tall classifications on a height basis. He found short plants to be more productive on a per plant basis than tall plants. He attributed this to the increased tillering capacity of the short plants. He speculated that the photosynthates were used to increase height in tall plants were diverted to form more tillers in short plants. However on a per tiller basis short plants were found to be not much higher in photosynthetic area above the flag-leaf node than taller plants.

The contribution of photosynthates from the flag-leaf lamina to the developing grain was estimated to be 49% by Carr and Wardlaw (1965) from ^{14}C distribution studies. Thorne (1965) found that assimilation in the flag-leaf was equivalent to 110-120% of final grain weight, this high amount was due to respiration in the ear resulting in a net assimilation loss. He also found flag-leaves of wheat photosynthesized more than those of barley because they had more area and a slightly greater rate of photosynthesis.

In a study of two rice cultivars Enyi (1962) found the average contribution to final grain from each component to be; 60% from ear, 23% from flag-leaf lamina, sheath and peduncle and 17% from parts below the flag-leaf node.

Drennan and Krishmanurthy (1964) concluded that cereal yields depend more on assimilation in ears and flag-leaves than on compounds manufactured or stored in the green parts of the plants; with more assimilation occurring in the ear and peduncle than in the flag-leaf.

Stickler and Pauli (1961) in a study of agronomic characters of semidwarf winter wheats compared leaf area per culm of four semidwarf winter wheats with Pawnee and Triumph when grown in the greenhouse. They found two semidwarf lines to be significantly lower in leaf area per culm than Pawnee, and two not significantly different, while Triumph possessed the largest leaf area per culm. In a field trial conducted over two years, with seven semidwarf lines evaluated, only one was significantly greater in leaf area than Pawnee and one significantly less in first year. In second year of study no semidwarf lines were greater in leaf area than Pawnee.

From a study of Johnson et. al. (1966b), both CI 13678 and CI 13677, short stature cultivars, produced total flag-leaf area equal to or greater than Pawnee, due to increased leaf width in CI 13678 and CI 13677, although Pawnee produced longer leaves.

MATERIALS AND METHODS

The material in this study consisted of selections made from two wheat crosses, Norin 10/3*Pawnee//2*Kaw and Norin 10/5*Pawnee. Selections were made from over 1000 lines in 1968 on the basis of plant height. The materials studied were increases of F_3 plant selections made by M. V. Reddi (1968) in 1966. Approximately 50 selections were made from each cross. These selections were divided into four height classes. Four selections were randomly chosen from each height class within each cross and seeded in the fall of 1968. The parents of each cross were included resulting in 18 entries from each cross. In 1969 the plant height classes were changed to three. They were arranged as follows: Class I, the shortest class having nine selections; Class II, the intermediate class having thirteen selections; and Class III, the tallest class having fourteen selections.

M. V. Reddi (1968) studied this material in 1966 and 1967, F_3 and F_4 lines of the 1140 lines he studied were seeded at the Agronomy Farm of the Kansas Agricultural Experiment Station, Manhattan, Kansas and at the South Central Kansas Experiment Field, Hutchinson, Kansas in the fall of 1967. Selections were seeded in a single row at the rate of 10 gm/13 ft. row (74 lbs. per acre) at Manhattan and at the rate of 8 gm/13 ft. row (59 lbs. per acre) at Hutchinson, with one replication per location. For the 1969 crop the selections were seeded in four-row plots, thirteen feet in length with 12-inch row spacings at both Manhattan and Hutchinson. The experimental design was a randomized complete block with four replications per location. Seeding rate in 1969 was same as in 1968.

Measurement Procedures

Yield components, kernels per spike and kernel weight, and flag-leaf lamina area measurements were taken in 1969 on five randomly selected culms per plot, which were tagged for later identification. Due to poor stands and winter damage no measurements were reported for the material grown at Manhattan in 1969.

Flag-Leaf Lamina Area. Flag-leaf lamina area measurements were taken approximately one week after anthesis. Maximum length X maximum width X a factor was used to determine flag-leaf lamina area. Maximum length was found by placing a ruler against leaf collar of flag-leaf and recording length of flag-leaf lamina. Maximum width was determined by moving the ruler along the lamina and recording point of maximum width. The factor was calculated by comparing the maximum length X maximum width of a selected flag-leaf lamina from each entry with area determined by a planimeter. The factor computed was 0.74. Factors of 0.79, 0.80 and 0.83 have been reported for wheat by Simpson (1968), Voldeng and Simpson (1967) and Stickler and Pauli (1961), respectively.

Spike Per Unit Area. Data for 1967 were taken from data compiled by Reddi (1968). He recorded the total number of tiller bearing heads per 18-inch of row. In 1968 the total number of spike bearing culms was counted from a uniform 24-inch section of row.

Kernels Per Spike. Kernels per spike were determined by counting the total number of kernels produced per spike. Spikes used for these counts were produced on culms used for flag-leaf lamina area measurements. The number of spikelets per spike were determined on these same spikes. From these two values the kernels per spikelet were computed.

Average Weight Per Kernel. Average weight per kernel was computed from the total number of kernels produced per spike and the total weight of kernels from each spike.

Plant Height. In 1967 plant height was taken from data compiled by Reddi (1968). Plant height in 1967 and 1968 was measured in the field as an average height in centimeters from the base of culm to tip of spike (awn excluded) of three or more randomly selected culms at each of three locations within the central portion of the row (one-foot on either end of row excluded). In 1969 plant height was recorded at two locations within the central portion of each of the two middle rows of a four row plot.

1000 Kernel Weight. The weight in grams of a 1000 kernels was based on a two-gram random sample taken from each row in 1967 and 1968. In 1969 it was based on a two-gram random sample from the first replication of each entry and three two-gram samples randomly drawn from a composite sample of each entry from replications two, three, and four.

Yield. Yield in 1968 was taken as the weight of grain produced from approximately a 9 foot row. In 1969 yield was the weight of grain produced from the middle two rows of a four-row plot each nine feet in length.

Test Weight. Test weight in pounds per bushel was taken on a composite sample of grain from each entry in replications two, three, and four.

Statistical Treatment of the Data

An unequal subclass analysis of variance was performed on data from 1969 on an IBM 360 Computer, at the Computing Center, Kansas State University. The program was supplied by the Statistical Laboratory Department of Statistics and Computer Science, Kansas State University. All correlation coefficients were calculated by the IBM 360 Computer from a program supplied by Dr. Richard L. Vanderlip, Department of Agronomy, Kansas State University.

Climatological Data

Precipitation and temperature data for the period September through June for years 1966-67 and 1967-68 are shown in Table 1. These data are for the City of Manhattan, but is comparable to data recorded on the Agronomy Farm.

Table 2 contains precipitation and temperature data for the period September through June for years 1967-68 and

Table 1.--Precipitation, and mean maximum, mean minimum and average air temperature from September through June for the years 1966-67 and 1967-68

		Precipitation (in.)		Temperature (°F)			
Month	Year	Total	Departure from Normal	Maximum Mean	Minimum Mean	Mean	Average Departure from Normal
September	1966	.60	-3.11	78.3	54.5	66.4	-4.2
	1967	7.97	4.26	77.0	53.4	65.2	-5.4
October	1966	.78	-1.54	72.4	42.8	57.6	-1.5
	1967	3.08	.76	68.0	45.3	56.7	-2.4
November	1966	.06	-1.18	58.5	33.5	46.2	2.5
	1967	.77	- .47	52.9	32.7	42.8	- .05
December	1966	.91	- .03	41.7	21.4	31.6	-2.0
	1967	1.24	.30	43.9	26.1	35.0	1.4
January	1967	.38	- .48	41.5	20.5	31.0	-1.4
	1968	.81	.05	39.1	17.8	28.5	-1.1
February	1967	.21	- .75	46.9	20.8	33.9	.1
	1968	.36	- .60	44.3	21.1	32.7	-1.1
March	1967	1.59	- .12	62.5	34.1	48.3	5.8
	1968	Trace	-1.71	63.7	35.3	49.5	7.0
April	1967	5.02	2.42	71.0	47.7	59.9	4.1
	1968	3.13	.53	68.3	42.5	55.4	.1
May	1967	2.95	-1.42	74.7	50.5	62.6	-2.4
	1968	3.52	- .85	71.8	49.6	60.7	-4.3
June	1967	9.86	4.75	83.0	62.4	72.7	-2.7
	1968	3.16	-1.95	85.8	62.9	74.7	-1.0

Data taken from climatological data for Manhattan, Kansas, U. S. Department of Commerce, Environmental Science Services Administration.

Table 2.--Precipitation, and mean maximum, mean minimum and average air temperature from September through June for the years 1967-68 and 1968-69

Month	Year	Precipitation (in) Total	Temperature (^{o}F) Maximum Mean	Minimum Mean	Mean
September	1967	4.19	78.4	56.0	67.2
	1968	2.78	82.5	54.6	68.6
October	1967	1.78	72.3	46.5	59.4
	1968	5.58	73.8	41.1	60.5
November	1967	1.06	54.7	32.1	43.4
	1968	2.58	50.1	32.7	41.4
December	1967	1.32	44.8	24.5	34.7
	1968	.88	39.6	20.2	29.9
January	1968	.10	42.4	21.3	31.9
	1969	.20	37.8	21.5	29.7
February	1968	.20	47.0	22.6	34.8
	1969	1.42	44.6	35.6	35.1
March	1968	.04	63.9	34.0	49.0
	1969	1.49	47.3	25.9	36.6
April	1968	2.76	68.6	41.2	54.9
	1969	4.25	68.1	43.9	56.0
May	1968	5.78	75.3	48.5	60.9
	1969	2.37	76.8	55.1	66.0
June	1968	2.35	89.0	63.8	76.4
	1969	4.40	85.3	59.4	72.4

Data taken from climatological data for Experiment Field, Hutchinson, Kansas, U. S. Department of Commerce, Environmental Sciences Services Administration.

1968-69 at the South Central Kansas Experiment Field, Hutchinson, Kansas. Departures from normal were not reported for Hutchinson.

Weather conditions for 1966-67 September through June were taken from Reddi (1968). The period started with a deficit precipitation and was worsened by above normal temperatures during March and April. However, normal and steady precipitation and mild temperatures during May and June helped insure a crop.

At Manhattan during the growing season of 1967-68 above normal precipitation and below normal temperatures occurred during the fall and winter. In early March a higher than average temperature initiated early spring growth followed by a hard freeze in the later part of March that damaged to varying degrees the individual lines. This was followed by a period of below average precipitation and temperatures, even under these conditions the wheat made satisfactory growth.

Weather conditions at Hutchinson for September 1967 through June 1968 were satisfactory with adequate precipitation and temperature for plant growth and development. For this same period the 1968-69 conditions were very good and wheat made excellent vegetative growth and produced good yields.

RESULTS

Means and Variability

Values for characteristics under study in 1967 were taken from data compiled by M. V. Reddi (1968). The data is for the specific selections made in 1968 and seeded for the 1969 crop for further study.

Means and variation, as expressed by standard deviation, for the components of yield (spikes per unit area and kernel weight as grams per 1000 kernels) and plant height are given in Table 3 for 1967 at Manhattan. Means for spikes per unit area were higher in Classes II and III, with Class II having highest mean value but showing more variability. Plant height classes used in 1969 appear to fit 1968 height data well, with highest variability found in Class I and highest mean value in Class III, which was expected. The highest mean and lowest variability was found in Class III for kernel weight, with Class I exhibiting lowest mean value and highest variability. In general Class III exhibited the least amount of variation in two of three characteristics studied in 1967 as measured by standard deviation. Class III also possessed highest mean values for plant height and kernel weight, while Class II had highest mean value for spikes per area.

Table 3.--Means and standard deviation for two components of yield and plant height in three height classes, Manhattan, Kansas, 1967[1]

	Height Class											
	I				II				III			
	Mean	Standard Deviation	Max.	Min.	Mean	Standard Deviation	Max.	Min.	Mean	Standard Deviation	Max.	Min.
Spikes per $Ft.^2$	46.8	5.3	58	39	59.5	12.2	83	44	57.6	8.8	67	42
Plant Height (cm)	53.2	29.7	71.9	45.0	63.4	27.8	83.2	49.2	71.0	19.1	86.6	60.4
Kernel Weight (gm/1000 kernels)	25.4	10.5	31.5	21.6	27.0	7.3	30.7	22.7	29.4	5.8	32.0	26.0

[1]From data collected by Reddi (1968)

In Table 4 means and variation expressed by standard deviation are shown for two components of yield (spikes per area and kernel weight as grams per 1000 kernels) and yield at Manhattan in 1968. No plant height measurements were recorded for selections at Manhattan in 1968. Therefore, data from 1968 were placed in height classes according to the height class the selection was placed in for 1969 season. A similar pattern of variability was shown in 1968 for spikes per area and kernel weight as occurred in 1967, with Class I having the lowest variability in spikes per area and highest variability in kernel weight. Class II had both the highest mean and variability for spikes per area. An identical trend was observed in 1968 for kernel weight, with tallest class having highest mean value and highest variability. Yields as computed were similar in both mean value and variability for all classes.

Values for means and variation expressed as standard deviation, of two components of yield (spikes per area and kernel weight measured as grams per 1000 kernels), yield and plant height are shown in Table 5 for Hutchinson in 1968. The means and variation for the two components of yield are similar in magnitude for all height classes with the exception of kernel weight variation which is somewhat larger in Class I. This same pattern was observed in both years at Manhattan. Plant height data fit 1969 classes nicely. However, Class III did show a higher variability in plant height when compared to 1967 data from Manhattan. Yield data exhibited similar mean

Table 4.--Means and standard deviation for two components of yield and yield in three height classes, Manhattan, Kansas, 1968

	Height Class											
	I				II				III			
	Mean	Standard Deviation	Max.	Min.	Mean	Standard Deviation	Max.	Min.	Mean	Standard Deviation	Max.	Min.
Spikes per $Ft.^2$	58.5	3.0	77	48	68.7	11.3	89	49	61.7	8.3	79	49
Kernel Weight (gm/1000 kernels)	32.8	14.4	33.3	16.8	26.3	12.2	30.8	15.7	27.6	10.0	31.7	21.3
Yield (gm/9$Ft.^2$)	244.9	46.1	310	167	250.9	51.6	311	177	250.9	51.6	332	168

Table 5.--Means and standard deviation for two components of yield, plant height and yield in three height classes, Hutchinson, Kansas, 1968

	Height Class											
	I				II				III			
	Mean	Standard Deviation	Max.	Min.	Mean	Standard Deviation	Max.	Min.	Mean	Standard Deviation	Max.	Min.
Spikes per Ft.^{2}	57.5	5.5	65	49	60.7	7.0	78	45	59.5	8.4	79	49
Kernel Weight (gm/1000 kernels)	28.2	12.5	34.5	21.9	28.7	6.4	31.3	24.7	29.9	8.7	36.4	24.1
Plant Height (cm)	56.4	9.9	61.0	51.6	84.3	9.1	88.1	78.0	95.2	14.7	101.6	88.1
Yield (gm/9Ft.^{2})	204.7	35.4	266	175	228.3	27.9	275	175	222.6	37.1	296	158

and variation values for all height classes, with height Class II showing a slightly higher mean value and lower variation than Classes I and III.

In 1969 a study of yield components and other agronomic characteristics was conducted. Means with their least significant difference values for data from these characters at Hutchinson, Kansas for 1969 are given in Table 6. Yield components studied were kernels per spike and kernel weight. Kernels per spike were expressed two ways as the total number of kernels produced per spike and the number of kernels per spikelet. Spikelets per spike was recorded to determine the second expression of kernels per spikelet. Kernel weight was also expressed in three ways as weight of kernels per spike, from which the average weight of the kernels was computed, and the weight of a 1000 kernels. Flag-leaf lamina area, yield, test weight were other characters evaluated to be related to plant height.

From Table 6 significant difference (.05 level) existed, for all but one character studied between Class I and both Class II and III. The only exception was kernels per spike in Class II which was significantly different from both Class I and II. Significant differences were found to exist between plant height, kernels per spike, average weight per kernel, 1000 kernel weight, and test weight in Class II and Class III.

Table 6.--Means for plant height, yield components, flag-leaf lamina area, yield and test weight in three height classes, Hutchinson, Kansas, 1969

Height Class	Plant Height (cm)	Kernels per Spike	Spikelets per Spike	Kernels per Spikelet	Weight of Kernels per Spike (gm)	Average Weight per Kernel (mg)	Kernel Weight gm/1000 kernels	Flag-leaf Lamina Area (cm^2)	Yield gm/ 18 Ft^2	Test Weight (lbs/bu)
I	68.0	20.3	13.7	1.5	.43	21.0	18.8	13.3	348.5	52.3
II	108.4	21.9	12.9	1.7	.57	26.5	24.4	15.6	498.1	58.0
III	129.0	20.3	12.8	1.6	.58	28.3	26.6	15.7	496.1	61.0
$LSD_{.05}$	9.5	.7	.2	.1	.02	.7	.5	.6	53.7	1.4
$LSD_{.01}$	12.6	.9	.3	.2	.03	.9	.4	.7	71.5	1.9

Correlations

Correlation coefficients for characters under study in 1967 at Manhattan are shown in Table 7. Plant height was found to be highly and positively correlated with kernel weight in all height classes. A significant correlation was found to exist between plant height and spikes per area in Classes II and III. A high positive correlation was shown between spikes per area and kernel weight but only occurred in Class II. All other correlation values were non-significant.

Only two significant correlation coefficients occurred in the 1968 Manhattan data as shown in Table 8. Those two coefficients were high and positive and existed between kernel weight and yield in both Class II and III. Remaining correlation values were non-significant.

Correlation coefficients for data taken from Hutchinson in 1968 are shown in Table 9. Only one significant positive correlation occurred. It was between kernel weight and yield in Class I. While three highly negative correlations were shown. One existed in Class II between spikes per area and plant height. The other two occurred in Class III between kernel weight and plant height, and between kernel weight and yield. Other characters studied exhibited no significant correlation coefficients.

The relation of yield components, yield, flag-leaf lamina area, and test weight to plant height as measured by correlation coefficients are given in Table 10 for selections grown at Hutchinson, Kansas in 1969.

Table 7.--Correlation coefficients among two components of yield and plant height in three height classes, Manhattan, Kansas, 1967[1]

	Height Class					
	I		II		III	
	Plant Height	Kernel Weight	Plant Height	Kernel Weight	Plant Height	Kernel Weight
Spikes Per Area	-.230	.231	.330*	.645**	.308	.249
Plant Height		.625**		.493**		.407**

* Significant at .05 Level

** Significant at .01 Level

[1] From data collected by Reddi (1968)

Table 8.--Correlation coefficients among two components of yield and yield in three height classes, Manhattan, Kansas, 1968

	Height Class					
	I		II		III	
	Kernel Weight	Yield	Kernel Weight	Yield	Kernel Weight	Yield
Spikes Per Area	-.228	.052	-.060	.308	.218	.240
Kernel Weight		-.193		.654**		.565**

* Significant at .05 Level

** Significant at .01 Level

Table 9.--Correlation coefficients among two components of yield, plant height and yield in three height classes, Hutchinson, Kansas, 1968

	Height Class								
	I			II			III		
	Kernel Weight	Plant Height	Yield	Kernel Weight	Plant Height	Yield	Kernel Weight	Plant Height	Yield
Spikes Per Area	.104	.088	-.036	-.010	-.421**	.095	-.079	-.095	.114
Kernel Weight		.173	.639**		.088	-.306		-.527**	-.549**
Plant Height			.211			.025			.233

* Significant at .05 Level

** Significant at .01 Level

Table 10.--Correlation coefficients between plant height and yield components, flag-leaf lamina area, yield and test weight in three height classes, Hutchinson, Kansas, 1969

Height Class	Spikelets Per Spike	Kernels Per Spike	Weight of Kernels Per Spike	Kernel Weight	Average Weight Per Kernel	Kernels Per Spikelet	Flag-leaf Lamina Area	Yield	Test Weight
I	-.079	.319**	.279**	.056	.142	.382**	.006	.579**	-.047
II	.138	-.006	-.119	-.039	-.199*	-.132	.173	-.082	-.011
III	.265**	.038	-.093	-.163	-.201*	-.187	.260**	-.454**	-.012

* Significant at .05 Level

** Significant at .01 Level

Spikelets per spike was found to be significantly correlated to plant height in Class III (.265). A negative correlation was found for the same two characters in Class I (-.079), but was non-significant, as was the coefficient in Class II (.138). A significant correlation coefficient occurred between kernels per spike and plant height in Class I (.319), with non-significant values in Class II (-.006) and Class III (.028). There was a significant correlation between weight of kernels per spike and plant height in Class I (.279), while in Class II (-.119) and III (-.093) the correlation coefficients were non-significant. Significant negative correlations were found between plant height and average weight per kernel in Class II (-.199) and Class III (-.201), but was non-significant in Class I (.142). The relation of plant height to kernels per spikelet was significant in Class I (.382) with a significant negative value in Class III (-.187) and a non-significant value in Class II (-.132). A positive significant correlation coefficient was observed between plant height and flag-leaf lamina area in Class III (.260), but non-significant for the other two classes. Plant height correlation with yield was varied. In Class I it was high and positively significant, while Class II exhibited a non-significant coefficient. The correlation coefficients between plant height and test weight were all negative and low in magnitude.

Correlation coefficients for all the original variables, except plant height, for selections grown in 1969 at Hutchinson, Kansas, are given in Table 11.

Spikelets per spike correlation coefficients with kernels per spike and weight of kernels per spike were significant in all height classes. Significant correlation coefficients were also found between spikelets per spike and flag-leaf lamina area in Classes II and III, but the coefficient was non-significant in Class I. A negative significant correlation value occurred between spikelets per spike and yield in Class III, while they were non-significant in Classes I and II. Spikelets per spike were significantly correlated with test weight in Class I and II, but not in Class III. The same was true of correlation values between spikelets per spike and kernel weight.

The highest correlation coefficients found were between kernels per spike and weight of kernels. This was true of all height classes with values between classes being similar in magnitude. Significant correlation values were found between kernels per spike and flag-leaf lamina area in Classes II and III, with a non-significant value in Class I. Kernels per spike and yield were observed to be significantly correlated in Class I, but non-significant in the other two classes. All correlation values between kernels per spike and test weight were non-significant. The correlation coefficient in Class I was significant between kernels per spike and kernel weight,

Table 11.--Correlation coefficients among all pair of variables studied, except plant height, in three height classes, Hutchinson, Kansas, 1969

	Height Class	Kernel Per Spike	Weight of Kernels Per Spike	Flag-Leaf Lamina Area	Yield	Test Weight	Kernel Weight
Spikelets Per Spike	I	.426**	.415**	.117	.007	.238**	.190*
	II	.605**	.565**	.375**	.017	.311**	.254**
	III	.707**	.650**	.238**	-.219**	.099	-.029
Kernels Per Spike	I		.819**	.076	.532**	.161	.207*
	II		.853**	.352**	.099	.102	.087
	III		.842**	.245**	-.065	-.046	-.040
Weight of Kernels/ Spike	I			.057	.545**	.234**	.312**
	II			.243**	.155	.268**	.259**
	III			.188*	.083	.082	.050
Flag-Leaf Lamina Area	I				-.116	-.156	-.037
	II				-.134	-.024	.058
	III				-.156	-.114	.050
Yield	I					.428**	.446**
	II					.308**	.240**
	III					.393**	.066
Test Weight	I						.758**
	II						.670**
	III						.331**

* Significant at .05 Level
** Significant at .01 Level

with a non-significant positive value in Class II and a non-significant negative value in Class III.

Weight of kernels per spike exhibited significant correlation coefficients with flag-leaf lamina area in Classes II and III and was non-significant in Class I. The correlation value was significant in Class I between weight of kernels per spike and yield but non-significant in Classes II and III. When correlated with test weight and kernel weight, weight of kernels per spike showed significant correlation values in Classes I and II and non-significant values in Class III. All values were similar in magnitude.

Flag-leaf lamina area was found to be non-significantly correlated with yield, test weight and kernel weight in all height classes. Correlation coefficients for flag-leaf lamina area with yield and test weight were all negative, but non-significant. The correlations were non-significant between flag-leaf lamina area and kernel weight in all three classes.

Yield was significantly correlated with test weight in all height classes. Yield correlation coefficients with kernel weight was significant in Classes I and II and non-significant in Class III.

High significant correlation coefficients were found between test weight and kernel weight in all height classes.

DISCUSSION

The relation of yield components and flag-leaf lamina area to height in hard red winter wheat was studied in selections from two wheat crosses; Norin 10/3* Pawnee//2* and Kaw and Norin 10/5* Pawnee. The relation of those characters to plant height, with selections divided into three height classes was investigated.

Means and Variability

The mean values for spikes per area in 1967 (Table 3) at Manhattan indicated that Class II and III have a similar spike producing ability while Class I had a slightly lower spike producing ability. The means for spikes per area at Manhattan (Table 4) and at Hutchinson (Table 5) in 1968 are slightly higher than means for Manhattan, 1967. This may be due to the different planting rates used at the two locations. In 1967 a certain number of seeds per row was seeded, while in 1968 a measure of seed was used, which may account for the slight difference in mean values. In comparison of means in 1968 at the two locations, only Class II exhibited a somewhat larger difference between locations. This may be explained by the different seeding rates used at the two locations. The mean values for spikes per area are slightly lower than means reported by Johnson et al. (1966b). But are comparable to values reported by Stickler and Pauli (1961) and higher than means reported by Waldron (1929, 1933).

The variability in spikes per area was highest in Class II, for both years and locations, indicating this class possessed the widest range of values. The variability of Class III was nearly identical each year, with Class I having lowest variability. This would mean that selection of individuals from either Class II or III would tend to produce more spikes per area under similar seeding rates than selections from Class I.

The mean values for height in 1967 at Manhattan (Table 3) fit the classification established in 1969. The variability in plant height, especially Class I (±27.8 cm) indicate a wide range of plant heights within each of these classes. The value in Class III (±19.1) is not as high but does denote a range of plant heights within Class III. This may be due to segregation occurring in the height classes since the material was an increase of F_3 plants. This reason appears more valid, when variability in plant height at Hutchinson in 1968 (Table 5) is observed. The variability in plant height for Class I and II was one-third its value in 1967, in selections which are one generation older. The variability in Class III (±14.1) was still similar to its 1967 value. The genotype-environment interaction might also explain the expression of plant height and its variability.

The mean values for kernel weight at Manhattan in 1967 (Table 3) and 1968 (Table 4) and at Hutchinson in 1968 (Table 5) are similar in all height classes. The order of means was the same each year with Class III having the highest mean and Class I the lowest. This tendency of taller plants to produce heavier kernels, and shorter plants to produce lighter kernels is in agreement with Johnson et al. (1968b) but mean values are much lower than means for kernel weight reported by Borojevic (1968) for dwarf and semidwarf lines of wheat in Yugoslavia. However, they are in agreement with means reported by Stickler and Pauli (1961), Locke et al. (1942) and Waldron (1929, 1933).

The variability of kernel weight was highest each year and at each location in Class I indicating a wider range of means in this class. The variability in Class II for kernel weight was similar at Manhattan in 1967 and Hutchinson in 1968. But at Manhattan in 1968, was twice its value of the preceding year and its mean at Hutchinson. This may have been due to a genotype-environment interaction, resulting from below average precipitation during May and June, which may have effected kernel development. This may also explain the higher variability of kernel weight in Class I and III at Manhattan, when they are compared with values for Manhattan, 1967, and Hutchinson, 1968.

The comparison of mean yields at Manhattan (Table 4) and Hutchinson (Table 5) are comparable for location, year, and height class. This would indicate all height classes have similar yielding patterns at the two locations in 1968.

The variability of yield in all classes was higher at Manhattan in 1968 possibly due to the below average moisture in later part of growing period.

The mean values for plant height, yield components (kernels per spike and kernel weight), flag-leaf lamina area, yield and test weight at Hutchinson, 1969 (Table 6) were varied for the three height classes.

Plant height means were significantly different between each height class, which supported the division of plant height classes.

Mean values for kernels per spike were identical in Class I and Class III, while mean of Class II was significantly higher than both Class I and III. This was not due to more spikelets per spike, but due to a higher number of kernels per spikelet. Since Class II and III had nearly identical means for spikelets per spike and significantly lower means than Class I, the increased kernels per spike must be accounted for in the increased kernels per spikelet. As no date of bloom or weather conditions at time of bloom was recorded, it is difficult to determine whether the increased kernels per spikelet was due to environmental conditions or a genetic trait. The means for kernels per spike are considerably lower than values reported by Borojevic (1968) and Simpson (1968). This may be due to the different environments under which the studies were conducted. Stickler and Pauli (1961) reported similar mean values, and stated that their data indicated semidwarf wheats to have a slightly larger number of kernels per spike than standard height cultivars. Johnson et al. (1966b) also found short stature wheats to produce more kernels per spike.

The spikelets per spike mean value was largest in Class I and significantly different from Class II and III. This may be attributed to the presence of Norin 10 dwarfing genes in Class I selections. Norin 10 possesses longer spikes, which could carry more spikelets; therefore the largest number of spikelets per spike in Class I. Borogevic (1968) reported higher mean values for spikelets per spike, as did Waldron (1929, 1933) for spikelets per spike, with Locke et al. (1942) reporting lower values.

The highest mean value for kernels per spikelet was in Class II. The mean in Class II was significantly different from Class I, but non-significant from Class III. As previously mentioned it is not known whether the cause of higher number of kernels per spikelet was environmental or genetical. Borojevic (1968) and Waldron (1929, 1933) reported higher mean values, while Locke et al. (1942) reported similar means.

Mean values for weight of kernels per spike were highest in Class II and III. Class II and III produced more weight of grain per spike because of heavier kernels. The low weight of kernels per spike may be due to the Norin 10 dwarfing genes and their characteristic low kernel weight in selections within Class I. Borojevic (1968) and Simpson (1968) reported much higher values for weight of kernels per spike, while Waldron (1933) reported comparable values.

The means for average weight per kernel were significantly different in all three height classes, with Class III having the highest mean and Class I the lowest. Increased weight per kernel is another reason for higher weight of kernels per spike in Class II and III, when compared to Class I. The genes for shortness from Norin 10 may have been linked with low kernel weight, thus effecting means of selections in Class I.

The mean values for kernel weight, measured as weight of 1000 kernels were significantly different in all three height classes. The lower values in Class I, and the slightly lower values in Class II may be accounted for by the presences of either one or two genes for shortness in these classes. Means are comparable with those reported by Locke et al. (1942), but are lower, in most instances, in values reported by Borojevic (1968), Waldron (1929, 1933) and Simpson (1968).

The comparison of flag-leaf lamina area between the three height classes showed Class II and III to have identical leaf areas which were significantly different from the area of Class I. The production of larger flag-leaf lamina by taller plants may be related to the overall shortening effect of internodes and peduncle by Norin 10 dwarfing genes which may also shorten leaves resulting in smaller flag-leaf lamina area in selections of Class I. Johnson et al. (1966b) found larger flag-leaf areas to be associated with taller plants. Stickler and Pauli (1961) found this to be true for total leaf area per culm in a greenhouse study, but a field study produced opposite results. Simpson (1968) found higher flag-leaf lamina area means and medium height plants to have a larger flag-leaf lamina area, with tallest plants producing the least amount of flag-leaf lamina area. Simpson's study was conducted in the greenhouse which might explain differences in results.

The yield means were nearly alike for Class II and III, and were significantly different from the lower mean of Class I. This may be due to the characteristic of low yields from wheat containing Norin 10 dwarfing genes under Kansas conditions. The lower yields from short-stature wheats was not in agreement with results reported by Johnson et al. (1966b) and Vogel et al. (1956), while Porter et al. (1964) reported short-stature wheats to outyield taller wheats under high rainfall conditions. Stickler and Pauli (1961) reported a semidwarf selection to outyield one of two standard height cultivars in two years of study.

The main reason for lower yield of Class I selections is related to kernel weight. In three measurements of kernel weight; weight of kernels per spike, average weight per kernel and weignt of a 1000 kernels, Class I exhibited the lowest mean in each measurement. It appears that the shorter wheats have the potential, as they were shown to have a significantly greater number of spikelets per spike in which kernels may develop. But due to lower kernel weights and a slightly lower number of kernels per spikelet they do not produce the yields of taller wheats. When short wheats outyielded taller wheats it was due to either a greater kernel weight or a greater number of kernels per spike (Johnson et al., 1966b), (Stickler and Pauli, 1961).

The differences in mean values for test weight were significant between each height class. Class III having the highest mean and Class I the lowest. The reason for this may be related to the effect of dwarfing. Test weight differences, reported by Johnson et al. (1966b) and Porter et al. (1964), between plants differing in plant height were in favor of taller plants but only by a slight margin.

Correlations

The correlation coefficients between plant height and spikes per area for Manhattan in 1967 (Table 7) and Hutchinson in 1968 (Table 9) were significant only in Class II. The values were just opposite. At Manhattan in 1967, the value was .330, indicating that the taller selections in Class II tended to produce more spikes per area at this location than selections in the other two classes. While at Hutchinson the coefficient was -.421 in Class II, indicating that as plant height went down spikes per area went up and vice versa. Reason for this difference in coefficients was not apparent. Nandpuri (1959) reported plant height and tillering (spikes per area) to be significantly correlated but values were low in magnitude and inconsistent with years. Stewart (1926) found large coefficients between culm length and number of culms, but considered the cause to be physiologic rather than genetic. Stewart (1929), Stewart and Bischopp (1931) and Stewart and Heywood (1929) reported correlations to be non-significant.

The correlation coefficient of plant height with kernel weight, measured as weight of 1000 kernels, for Manhattan, 1967 (Table 7) and Hutchinson, 1968 (Table 9), 1969 (Table 10), differed widely in their value. At Manhattan in 1967 the coefficients were highly significant for all height classes. This may be due to the planting rate in this year and also to favorable weather conditions during kernel development. In 1968 at Hutchinson correlation coefficients were non-significant in Class I and II. But in Class III, a highly significant negative correlation was found. No reason or explanation was apparent, only speculation that more photosynthates went to maintain plant height than to kernel development.

M. V. Reddi (1968) reported a highly significant correlation between culm length and kernel weight in his studies of material from which selections were made for this present study. The comparison of this correlation by Reddi and the correlation coefficient between plant height and kernel weight found in Class III (-.454) at Hutchinson in 1969 are opposite. This reversal may be explained by the fact that one would not expect any correlation between plant height and kernel weight within a height class, as the selections were expected to be similar because of backcrossing. Therefore any correlation would be the result of environmental rather than genetic within a height class. Since Reddi determined correlation coefficients between plant height and kernel weight from the entire 1140 lines, with no distinction between plant heights, the correlation could have been due to either genetic traits or environmental factors. Non-significant correlation coefficient between plant height and kernel weight were reported by Locke et al. (1942), Gandhi et al. (1964) and Bridgeford and Hayes (1931). While Shad and Ahmed (1967) reported significant coefficients.

In 1969 at Hutchinson (Table 10) significant correlations were found between plant height and yield in Class I and III. The significant value in Class I (.579) may indicate that shorter plants in Class I having at least two genes for dwarfing resulted in yields lower than taller plants in Class I. The significant coefficient in Class III (-.454) was unexpected and unexplainable. Plant height was found to be significantly correlated with yield by Shad and Ahmed (1967), Locke et al. (1942), Bridgeford and Hayes (1931) and Johnson et al. (1968a). Non-significant correlations were reported by Waldron (1933) and Sprague (1926).

The correlation coefficient between spikes per area and kernel weight was significant in Class II at Manhattan in 1967 (Table 7). This may indicate that selections in Class II possessed physiological processes to maintain both a large number of spikes and at the same time produced photosynthates for full kernel development.

The correlation coefficients between kernel weight and yield were significant in Class II and III at Manhattan in 1968

(Table 8). This seems reasonable since an increase in kernel weight would result in an increase in yield since kernel weight is an important component of yield. It appears to be even more critical with short wheats, especially those containing Norin 10 dwarfing genes. This was seen in correlation coefficients at Hutchinson in 1969 (Table 11). The significant values in Class I demonstrated that the increase in kernel weight was accompanied by an increase in yield. The coefficient in Class II was also significant but of lower magnitude than the coefficient in Class I. Bridgeford and Hayes (1931) and Waldron (1933) reported significant correlation between kernel weight and yield.

The correlation between plant height and spikelets per spike, kernels per spike, average weight per kernel, kernels per spikelet, flag-leaf lamina area and test weight at Hutchinson in 1969 (Table 10) differed widely among the three height classes.

Class III was the only height class where a significant correlation was found between plant height and spikelets per spike. This may have resulted from either longer spikes with more spikelets or a greater spike density, no measure of these two characters were recorded so no definite reason was proposed. Stewart (1928) reported significant correlation coefficients between plant height and spikelets per spike as did Bridgeford and Hayes (1931), and Locke et al. (1942). While non-significant values were shown by Shad and Ahmed (1967), Gandhi et al. (1964), Borojevic (1968) and Borojevic and Mikic (1965).

Kernels per spike were found to be significantly correlated with plant height in Class I. The significant correlation between kernels per spikelet and plant height in Class I was directly related to kernels per spike. Since both correlations were found to be significant it may be reasoned that Class I selections set seed better under weather conditions present at time of pollination and fertilization than did other selections in Class II and III; therefore, the two significant correlations of kernels per spike, and kernel per spikelet with plant height. Significant correlations between plant height and kernels per spike were reported by Locke et al. (1942) reporting significant correlation between plant height and kernels per spike and kernels per spikelet. While Shad and Ahmed (1967) and Borojevic (1968) and Borojevic and Mikic (1965) reported non-significant values for correlation between plant height and kernels per spike.

The correlation coefficient between plant height and weight of kernels per spike was significant in Class I. This may be due to the low kernel weight characteristic of short stature wheats. Borojevic (1968) and Borojevic and Mikic (1965) reported non-significant correlations for those two characters.

A significant negative correlation coefficient was found between plant height and average weight per kernel in Class II and III. This may be related to more photosynthates going to substain the taller plants and less to developing kernels when compared to shorter plants within the respective height class.

Sprague (1926) reported a non-significant correlation coefficient between culm length and weight per grain.

The correlation of flag-leaf lamina area with plant height was found to be significant in Class III. The occurrence of this may be related to the expression of larger plant structures as plants become taller. Simpson (1968) reported similar results as did Johnson et al. (1968b) and Stickler and Pauli (1961).

The correlation coefficients, among all variables at Hutchinson in 1969 (Table 11) varied among height groups.

The correlation coefficient between spikelets per spike and kernels per spike were significant in all height classes. This most likely was related to favorable conditions for pollination and fertilization rather than a character associated with selections in the respective height classes.

In all height classes the correlation coefficient between spikelets per spike and weight of kernels per spike were significant. This may be accounted for in having favorable growing conditions allowing sufficient photosynthate production for kernel development. These values agree with results reported by Simpson (1968).

Spikelets per spike was found to be significantly correlated with flag-leaf lamina area in Class II and III. This may be related to the expression of taller plants resulting in longer spikes and large lfag-leaf lamina area. Simpson (1968) reported significant correlation between these two characters.

A significant negative correlation was found between spikelets per spike and yield in Class III. The reason for this may be that the fewer kernels produced the heavier they became and vice versa. It is the kernels per spikelet which determines this rather than spikelets per spike.

Spikelets per spike correlations with test weight and kernel weight were significant in Class I and II. As test weight and kernel weight are both a measure of the same component, they are considered together. The increase in spikelet per spike must be accompanied by favorable conditions for the development of heavier kernels, which prevail in this year, resulting in this significant correlation of spikelets per spike with test weight and kernel weight.

A high significant correlation was found between kernels per spike and weight of kernels per spike in all three height classes. An explanation of this may be due to favorable growing conditions during the period of kernel development allowing all kernels produced by a plant to develop fully.

The correlation coefficients between kernels per spike and flag-leaf lamina area were significant in Class II and III. This may have resulted from favorable growing conditions and an adequate supply of photosynthates, which were partially produced by an increased flag-leaf lamina area.

Kernels per spike were found to be significantly correlated with yield in Class I. The appearance of this significant correlation in Class I shows that any increase in one of the components of yield appears readily in the shortest material, since it is the lowest yielding height class.

The correlation coefficient between kernels per spike and kernel weight was significant in Class I. This may be related back to the significant correlation between kernels per spike and yield which may be accounted for by the increase in kernel weight when kernels per spike increase in Class I selections.

Weight of kernels per spike correlation coefficients with flag-leaf lamina area were significant in Class II and III. The most apparent reason for this would be an increase of photosynthates to the developing kernels from the larger flag-leaf lamina area. This reason appears invalid when the correlation coefficients between flag-leaf lamina area and yield are observed. The values are non-significant in all height classes indicating no relation of yield with flag-leaf lamina area. Which does not agree with results reported by Simpson (1968).

The correlation coefficient between weight of kernels per spike and yield was significant in Class I. Since weight of kernels per spike is one of the measurements for the kernel weight component of yield. One would expect an increase in yield from an increase in one of the components of yield. This is especially true of short selections in Class I.

Weight of kernels per spike was found to be significantly correlated with both test weight and kernel weight in Class I and Class II. The reason for this is that they are all the measurements of the same component of yield and should be related.

Yield was found to be significantly correlated with test weight in all height classes. Since test weight is an indirect measure of the kernel weight component of yield one would expect a positive relation between the two characters.

The correlation between test weight and kernel weight is significant in all three height classes. Because the two measurements are of the same component, this type of relation would be expected.

SUMMARY AND CONCLUSION

The relation of yield components and flag-leaf lamina area to height was investigated in three height classes of hard red winter wheat. Selections used for study were made from two wheat crosses: Norin 10/3* Pawnee//2* Kaw and Norin 10/5* Pawnee.

Of the three components of yield studied, spikes per area exhibited the lowest variability among the three height classes. However, the correlation coefficient of spikes per area with plant height was only significant in Class II. The coefficient was positive at Manhattan in 1967 and negative at Hutchinson in 1968. No apparent reason for this reversal was evident. Possibly a genotype-environment interaction occurred between the two locations in the two years.

The kernel weight component of yield showed the most variability in the three years studied. The correlation coefficients between kernel weight and plant height were significant in all height classes at Manhattan in 1967. In 1969 at Hutchinson a significant negative correlation was found between plant height and kernel weight in Class II. The difference in results might be due to the different planting rates employed in 1967 and 1968.

The kernels per spike component of yield was found to be significantly correlated with plant height in Class I at Hutchinson in 1969. This significant correlation and the significant correlation of plant height with kernels per spikelet would indicate that the increased kernels per spike in Class I resulted from an increased seed set and a higher mean for spikelets per spike in Class I selections.

A significant correlation coefficient between flag-leaf lamina area and plant height was found in Class III. This with the higher means for flag-leaf lamina area in Class II and III indicated flag-leaf lamina area to be associated with taller plants.

The most apparent reason for the yield increase failure of short wheats in this study was due to low kernel weights. When kernel weights were high, (Manhattan and Hutchinson (1968), the yields of short wheats were near the levels of taller wheat. Therefore, the kernel weight component of yield appeared to be the limiting component of yield in short wheats grown under Kansas conditions.

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YIELD COMPONENTS AND FLAG-LEAF AREA IN RELATION TO HEIGHT IN HARD RED WINTER WHEAT

by

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The relation of yield components and flag-leaf lamina area to height was investigated in three height classes of hard red winter wheat. This was to examine possible areas of explanation for differences in yield among various plant heights in semidwarf and standard height hard red winter wheat lines grown under Kansas conditions. The material studied consisted of 32 increases of F_3 plants selected from two wheat crosses; Norin 10/3* Pawnee//2* Kaw and Norin 10/5* Pawnee.

The components of yield studied were spikes per unit area, kernels per spike and average weight per kernel. Measurements for spikes per unit area were taken at Manhattan, Kansas in 1967 and 1968, and at Hutchinson, Kansas in 1968. Kernels per spike measurements were taken at Hutchinson, Kansas in 1969. Measurements for average weight per kernel, determined as weight of 1000 kernels, were taken at Hutchinson in 1967, 1968 and 1969, and at Manhattan in 1967 and 1968. Flag-leaf lamina area was determined at Hutchinson, Kansas in 1969.

Data for 1967 measurements at Manhattan were taken from works compiled by M. V. Reddi (1968). Measurements for 1968 were taken from a single row of each line grown at Manhattan and Hutchinson. Measurements at Hutchinson in 1969 were taken from replicated four-row plots.

Spikes per area showed similar means and the least variability among the three height classes. This would indicate spike producing ability to be comparable between height classes. However, the correlation coefficient of spikes per area and plant height was only significant in Class II. The correlation coefficient was positive at Manhattan in 1967 and negative at Hutchinson in 1968. No apparent reason was evident, except a possible genotype-environment interaction between the different locations in the two years.

The kernel weight component of yield exhibited the highest means in Class III. It also showed the most variability of components studied among height classes. The positive correlation coefficient between kernel weight and plant height was significant in all height classes at Manhattan in 1967. In 1969 at Hutchinson a significant negative correlation was found between plant height and kernel weight in Class II. The differences in results might be due to different planting rates employed in 1967 and 1969.

The kernels per spike component of yield was found to be significantly correlated with plant height in Class I at Hutchinson in 1969. This significant correlation and the significant correlation of plant height with kernels per spikelet would indicate that the increased kernels per spike in Class I associated with increased plant height resulted from an increased seed set and a higher mean for spikelets per spike in Class I selections.

A significant correlation coefficient between flag-leaf lamina area and plant height was found in Class III. This with the higher means for flag-leaf lamina area in Class II and

Class III indicated flag-leaf lamina area to be associated with taller plants.

The most apparent reason for the yield increase failure of short wheats in this study was due to low kernel weights. When kernel weights were high (Manhattan and Hutchinson, 1968) the yields of short wheats were near the level of taller wheats. Therefore the kernel weight component of yield appeared to be the limiting component of yield in short wheats grown under Kansas conditions.