U. of M.

THE UNIVERSITY OF MINNESOTA

GRADUATE SCHOOL

Report

of

Committee on Thesis

The undersigned, acting as a Committee of the Graduate School, have read the accompanying thesis submitted by Albert Cedric Arny for the degree of Master of Science. They approve it as a thesis meeting the requirements of the Graduate School of the University of Minnesota, and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science.

E M Freeman
Chairman

Andrew Boss

H.K. Hayes

__________1918

REPORT

of

COMMITTEE ON EXAMINATION

This is to certify that we the undersigned, as a Committee of the Graduate School, have given Albert Cedric Arny final oral examination for the degree of Master of Science. We recommend that the degree of Master of Science be conferred upon the candidate.

Minneapolis, Minnesota

..........191

E. M. Freeman
Chairman

Andrew Boss

H. K. Hayes.

Variation and Correlation in Wheat With Special Reference to Weight of Seed Planted

A THESIS

Presented to the Faculty of the Graduate School of the University of Minnesota in partial fulfillment of the requirements for the Degree of MASTER OF SCIENCE.

By

ALBERT CEDRIC ARNY

June, 1918.

MOM
A+6

CONTENTS

INTRODUCTION

Extensive work has been done to determine the relative value for planting of seeds of various sizes and weights selected by the use of the fanning mill and by hand. Some work along this line has been done by weighing the individual seeds planted. The evidence from some of these experiments is inconclusive and a study of them raises several questions regarding the seed used, the weather conditions and the character of the soil for the different seasons, and the technique followed.

1. Were the differences in weights or sizes of the individual seeds sown sufficiently great in any particular experiment so that a significant variation in yield could be expected?

2. Were the desired stands of plants usually secured and were they such that the various grades of seed could give expression to their particular value?

3. May not the rainfall and temperature conditions during any part or throughout the entire growing season have been such that differences in yield, which in all probability would have resulted under ordinary conditions, did not materialize?

4. What has been the role of degree of fertility of the soils on which these trials have been conducted?

5. Under the conditions which obtained for any particular year was the technique of the experiments such that the experimental error could be ascertained?

These factors, and in some cases others, are necessary considerations in arriving at conclusions from experiments regarding the relative value of various weights of seed for planting.

The data presented in this paper are the results of a four year preliminary study of size of individual seeds in their relation to the resultant plants to aid in interpreting more accurately trials of similar nature, which are now in progress, under field conditions.

A careful study of the reactions to environment over a period of years of plants grown from accurately weighed seeds of various sizes ought to give fundamental information of value in this connection.

In order to obtain the desired data in a form comparable for the four-year period and easily presented, the biometrical method was used. The formulae used may be found in Davenport's "Principles of Breeding (1907)".

The subject matter is arranged for presentation in two main divisions. In the first division, variability both of the seed used and of the resulting plants is studied. The means, standard deviations, and coefficients of variability are used to this end. In the second division, degree of relation (1) between weight of seed used and characters of the resultant plants, and (2) degree of interrelation between characters of the resultant plants is shown by correlation coefficients.

REVIEW OF LITERATURE

Love and Leighty (1914) working with a pure line of oats found that biometrical constants, i.e. means, standard deviations, coefficients of variability and correlation coefficients, vary more or less with environmental conditions such as degree of crowding of the plants and differences in the weather conditions. With conditions not so favorable for plant development, less variability was found in number of culms, total and average number of spikelets, and average number of kernels per spikelet. In average weight of kernels, greater variability was found under unfavorable conditions. When development was arrested by environmental conditions, yield was lowered, not by reduction in average weight per kernels or number of spikelets produced, but by a reduction of the number of kernels per plant, per culm and per spikelet. Correlations were broadly classified as (a) fluctuating, which vary considerably with environmental conditions and (b) stable, which vary less from year to year. Between yield of kernels per plant and their average weight, no correlation was found in one trial and in two others the coefficients were low but five and seven times their probable error, respectively. The interpretation is that, for the years when correlation between these two characters occurs, selecting the largest seeds would be securing them from the heaviest yielding plants. Average height of plants, as correlated with average weight per kernel, gave coefficients of .219±.029, -.023±.034, and .217±.032, respectively for three years. For one year there is no correlation. For the other two years the coefficient of correlation is seven times its probable error which is significant. For the two years the taller plants had a tendency to produce the larger kernels.

Leighty (1914) found practically the same correlation coefficients when determinations were made on single culms as when whole plants were used. There was a uniform tendency for the coefficients to be greater when single culms were used. In studying oats grown in hills as compared with that grown in drills, rather large differences occured in the correlation coefficients of the same variety for plants grown in the two ways. In any variety, when considerable differences occurred in the coefficients as obtained by the two methods, the lower was secured by using the plants grown in hills. From this it is concluded that differences due to spacing may amount to more than varietal differences.

Variability of yield, number of kernels, number of spikelets, and breaking strength of straw decreased with crowding while for height the least variability occurred in hills.

Hutchinson (1913) in a statistical study of oat plants grown from individually weighed seeds planted at definite distances apart, found medium high positive correlations between weight of seed planted and each of the following characters: yield of kernels, total weight of plant, number of kernels harvested, height before second leaf, height at four, six and ten weeks, at heading and at harvest. No correlation was found between weight of seed planted and average weight of seed harvested. In two trials medium to high positive correlation was found between yield of grain per plant and average weight of kernels harvested, while, in another trial no correlation was found between these two characters.

Atkinson (1912) using culms as the basis of determinations in a statistical study of eight spring wheat populations grown under field conditions, secured correlations as follows: between yield and average weight of kernel a range from .508±.022 to .837±.009; between average weight of kernel and length of culm a range of from .098±.030 to .523±.022; and between yield and length of culms, a range of from .217±.032 to .853±.008.

Meyers (1911) investigating the effect of soil fertility on variations and correlations in wheat, found that variability was decreased by increase in fertility and that all correlations were greatest on the poorer soil.

Roberts (1911), working with three pure lines of wheat, found that variability was reduced in favorable growing seasons and concludes that seasonal and soil factors are probably sufficient to overcome hereditary distinctions of yield in good seasons.

Waldron (1910), in a statistical study of oats grown under field conditions, found in correlating average weight of kernels with number of kernels per plant a negative correlation of -.595±.013. Between average weight of seed and length of head, and average weight of seed and length of culm, correlation coefficients of -.511±.005 and -.404±.017 respectively, were found. These correlations indicate that the large kernels are borne by the short plants having short heads and producing a small number of kernels per head.

Love (1912) on the other hand, shows positive correlation between height of plant and yield; between height and average weight of kernels; and between yield and average weight of kernels.

Montgomery (1912) sowed wheat and oats at different thicknesses and found that, when large and small seeds were planted together and the plants from them grew under competitive conditions, the highest mortality was among the plants from the small seeds. This indicated that the larger seeds produced the stronger plants. It was also found that, under field methods of seeding, there was a reduction of forty percent in the stand from planting time to harvest, even when large seeds only were used. The conclusion regarding size of seed is that, since under usual methods of thick seeding, a high mortality occurs, it does not seem that fanning mill selection can increase the efficiency of seed. In comparing two varieties of winter wheat, three grades of seed, lightest light, heaviest heavy, and the seed as it came from the thresher, no difference was found in quantity or quality of grain produced. A similar trial with one variety of oats gave like results.

Kiesselbach and Helm (1917) planted hand selected, large and small seeds alone and in competition with each other. The yield of grain was eleven percent lower when the small seeds were planted alone and twenty-four percent lower when planted in competition with the large seeds. In a two year trial of hand selected large and small seeds of two winter wheat varieties compared with unselected seed, the yield from the large seed was 2.3 percent greater than that from the unselected seed, and 5.4 percent greater than from the small seed. In a similar trial with two varieties of spring wheat, the yield of grain from the large seed, was 11.8 percent greater than that from the unselected seed and 19.5 percent greater than the yield from the small seed. In these two trials the seed was sown in equal numbers at a normal rate for the large seeds. In a one-year trial, plants from small seeds spaced six by ten inches produced seventy-two percent as large a yield of grain as plants from large seeds similarly spaced. As an average for a four-year trial of large, small and unselected seed of Turkey winter wheat, and similar trials of Kherson oats covering a five-year period, and Scotch Fife spring wheat covering a two-year period, the small seed yielded one-third of one percent less than the large seed when equal weights of seed were sown and eight percent less when equal numbers of seeds were sown. In a twelve-year trial of the heaviest one-fourth and lightest one-fourth of continuous fanning mill selected seed sown at the rate of five pecks per acre as compared for yield of grain with unselected seed of two varieties of winter wheat, considerable variation occurred but the average results show practically no difference. A similar trial of the same duration with Kherson oats gave somewhat higher yield for the lightest one-fourth as compared with the heaviest one-fourth six years out of twelve, but the average is slightly in favor of the heaviest one-fourth. In a similar trial with American Banner oats, covering a period of eight years, the lightest one-fourth yielded higher than the heaviest one-fourth in six out of eight years and averaged three and sixty-seven hundredths bushels more for the period of the trial.

Williams and Welton (1913) compared the yields for a period of five years from large and small seed oats separated by a fanning mill and sown at both a uniform rate in pounds per acre and at a varied rate, the aim of which was to secure the same number of plants per acre. The large seed exceeded the small in yield at both rates of seeding by approximately four bushels per acre. The experiment was continued by using large and small seed compared with seed as it came from the threshing machine. The four-year results show no advantage in favor of the heavy over the ungraded seed at either rate of seeding. At the uniform rate of seeding, the small seed was as efficient as either of the other two grades but at the varied rate it produced two bushels less per acre. A comparison was also made of hand selected primary and secondary kernels of oats definitely spaced. In three out of the five years the primary seeds proved more efficient.

In a more recent experiment Williams and Welton (1916) make a comparison in field trials for eight years of large, small, and unscreened seed of winter wheat with no advantage of large over either of the other two grades. A six year trial of hand selected large and small seeds from pure lines of wheat showed an advantage in yield of forty-eight percent in favor of the former.

Georgeson, Burtis and Otis (1897) in an eight-year trial of three grades of seed oats, heavy, light and unscreened, found the heavy seed more efficient than unscreened seed by one bushel and more efficient than the light seed by three bushels per acre.

In an earlier bulletin Georgeson, Burtis and Otis (1896) report the results of a six-year trial of heavy , light and unscreened wheat. The heavy and unscreened seed gave practically the same yields which were superior to the yields from the light seed by a bushel and a third, and a bushel and a half, respectively.

Zavitz (1915) reports the results of six trials with hand selected, large and small seeds of four varieties of oats grown at seven distances apart. In ninety percent of the trials the large seeds proved superior. In another trial covering a period of from three to nine years, hand selected,large, plump seed yielded in oats 15.4 bushels, in barley 10.6 bushels, in spring wheat 5.0 bushels, and in winter wheat 6.5 bushels per acre more than small,plump seed of the same variety. Large, plump seed in oats proved more efficient by 7.9 bushels per acre than medium sized plump seeds.

A part of the data for the year 1916 was turned over to Ralph J. Garber to work up for his masters thesis. This thesis was submitted in 1917.

METHODS

The soil on which the plants were grown is classified by the United States Soil Survey as Hempstead silt loam. The rotation followed on the field where the plants were grown in 1914 and 1915 was as follows: spring rye, clover, grain, corn with 14 tons of manure per acre, field peas, roots, and spring wheat. The soil is in a moderately high state of fertility. In 1916 and 1917 the plants were grown in a grain, clover, corn rotation, with 6 tons of manure applied preceding the corn. The soil is in a fair state of productivity.

Data on rainfall and temperature are given in Table I. It is necessary to keep in mind the weather conditions during the growing season for each of the four years in order to interpret correctly the results of the work.

1914. Seeds planted April 19th and some additional ones to make a more desirable number a few days later. Plants harvested August 4th. With a temperature above normal for May and a rainfall two inches below average, the plants made luxuriant growth as to height but produced only a moderate number of tillers. The high rainfall and approximately normal temperature of June was favorable for growth which was checked prematurely by the high temperature and drouth during early July. The latter part of July and early August was very wet and stem rust (P. graminis tritici) appeared on the plants when the kernels were in the milk stage. This resulted in a shriveling of practically all of the kernels.

1915. Seeds planted April 19th. Plants harvested August 17th. The approximately normal rainfall for April and May

Table I

Normal rainfall and temperature with montlly deviations for the growing seasons 1914-1917 inclusive. Minneapolis, Minnesota.

	Year	April	May	June	July	Aug.
Rainfall inches						
Normal	1873-1903	2.50	3.20	3.70	4.20	3.70
Deviation from normal	1914	+1.25	-2.12	+4.62	-2.64	+5.01
	1915	-0.57	+0.06	+0.90	+2.11	-0.20
	1916	+0.63	+3.05	+0.53	-2.54	-2.03
	1917	-0.74	+0.32	-0.24	+0.25	-0.86
Temperature °F						
Normal	1873-1903	47	59	68	72	70
Deviation from normal	1914	-1.6	+2.9	-0.8	+3.3	-0.5
	1915	+9.3	+5.2	-4.9	-4.6	-4.1
	1916	-3.0	-0.4	-4.3	+6.9	+2.4
	1917	-1.5	-2.7	-3.8	+0.9	-2.1

with the exceptionally favorable temperature allowed the plants to make a luxuriant growth both as to height and tillering. Abundant rainfall during June and July with continued cool weather made conditions ideal for development in the late stages of growth. Stem rust was present in small amounts as the plants reached maturity but did no damage that could be detected.

1916. Seeds planted April 27th. Plants harvested August 4th. The rainfall was above normal for May and June with the temperature approximately average during May and considerably below normal for June. In July, the weather was dry and hot which hastened maturity and caused a moderate shriveling of some of the kernels.

1917. Seeds planted April 11th. Plants harvested July 31st. Normal rainfall with continued cool weather up to July and approximately normal for that month made this a favorable year for wheat.

Marquis wheat belonging to the group, Triticum vulgare, was used in the experiment throughout the four-year period. This wheat was originated at the Central Experiment Farms, Ottawa, Canada, in 1892, by crossing Red Fife and an early ripening wheat from India received in a sample of a commercial grade, Hard Red Calcutta, followed by a selection of individual plants in 1903. Marquis wheat is widely grown in the hard spring wheat district in Canada and in the United States. A supply of the seed of this variety was secured from Canada in 1913 and grown on University Farm that year. From the crop produced on University Farm in 1913, the individual seeds planted in 1914 and 1915 were selected. The seed planted in 1916 was selected from the 1915 crop. In 1917, the seed was taken from a Marquis line established by selecting individual plant number one-hundred thirty-five from the plants grown in 1914.

The seeds for planting were selected by hand and weighed to the fourth decimal place. If the fourth place was five or better the figure in the third decimal place was increased by one. As the seeds were weighed, they were placed in coin envelopes. The seeds were then arranged in classes according to weight and consecutive numbers entered on the envelopes and at the same time on three-inch wooden pot labels. The seeds were planted in four-inch rows and four inches apart in the row with the numbered pot label placed at the proper distance from each. One seed to each sixteen square inches made the rate of seeding approximately thirty pounds per acre. For the years 1914 and 1915, the seeds were planted at approximately the same depth. In 1916 and 1917 all seeds were planted at precisely the same depth. For all the years except 1914 when a few additional seeds were planted later to make up the desirable number, all the seeds were planted on the same day. Before using the plants from the seeds sown later in1914, comparison was made to ascertain whether they affected the results one way or another. Only where height at six weeks is involved was any effect found. Therefore, where height at six weeks is considered, the 219 plants from the first seeding are used. For all other characters, determinations were made on the full number of plants. In order to maintain uniform spacing for all plants, if a seed failed to grow, another plant of the same line was promptly taken from a reserve bed and substituted. These substitute plants were discarded at harvest. Border rows of the same variety were planted on all sides to obviate alley effect.

A few days before harvest, a dry-goods tag bearing the proper number was attached to each plant to identify it and to hold the culms together. All imperfect plants were discarded at this time. As each plant was pulled, the upper portion was wrapped securely in paper to obviate any shattering. The plants were then hung in the laboratory to dry.

Data were taken on the seedlings and on the mature plants as shown in Table II. The whole plant was the unit used in making the determination. Total weight of plant was determined after the root had been severed at the surface of the ground and discarded. The weight of the seed was subtracted from the total weight of the plant for the straw weight determination. Height of tallest culm was determined by measuring the stem from its attachment to the root to the tip of the apical spikelet. The average length of culms, including spikes, and of spikes only, per plant, was determined successively by laying them carefully end to end and taking their respective measurements. Then the total length divided by the number gave the average length of culms and spikes respectively. Determinations were made on a total of two thousand and forty-eight plants; three hundred in 1914, five hundred seventy-one in 1915, six hundred ninety-eight in 1916, and four hundred seventy-nine in 1917. All determinations have been checked.

THE EFFECT OF ENVIRONMENT DURING GROWTH

In Table II are given the means, standard deviations, and coefficients of variability with their respective probable errors for each of the characters studied. The seed for the 1914 and 1915 planting was selected from the 1913 crop and for the two years had approximately equal mean weights and standard deviations. The seed planted in 1916 and 1917 was selected from the crop grown in 1915 and 1916, respectively. The mean weight of the seed planted in 1916 was 7.254±.345 milligrams lower than and for 1917, 14.019±.352 milligrams lower than the mean weight of the seed used the two previous years.

The somewhat higher productivity of the soil on which the plants were grown in 1914 and 1915; the conditions favoring or retarding growth each season throughout the four years; and the mean weight of the seed planted are very pertinent to the consideration of the variability of the plant characters.

MEANS

The mean for number of days from planting to second leaf was determined for two years only. The greater number of days from planting to second leaf in 1917 as compared with 1916 was due to the lower temperature and dryer weather during the period between planting of the seed and emergence in the former year. The means for height in centimeters at appearance of second leaf are 5.286±.039 for 1915, 5.351±.024 for 1916, 6.247±.251 for 1917, and 6.401±.044 for 1914 with no significant difference between the first two or the last two. One of the highest and one of the lowest means for height at second leaf was for plants grown on the more productive soil; and likewise one of the highest and one of the lowest for plants grown from the greatest mean weight of seed. Temperature and moisture conditions appear to have had a large influence in rate of development at this early stage.

Table II

Means, standard deviations, and coefficients of variability for the characters studied

Characters studied	Means			
	1914	1915	1916	1917
Weight in milligrams of individual seeds planted	32.580±0.393	33.033±0.260	25.779±0.226	19.014±0.237
Number of days from planting to second leaf			13.769±0.049	26.373±0.041
Height in centimeters of plants at app. of 2nd leaf	6.401±0.044	5.286±0.039	5.351±0.024	6.247±0.251
Height in centimeters of plants at six weeks	22.525±0.150	23.277±0.110	18.515±0.076	15.638±0.641
Height in centimeters of tallest culm at maturity	87.021±0.389	113.663±0.173	91.043±0.149	98.763±0.193
Average height in centimeters of culms at maturity	68.833±0.460	98.419±0.272	84.693±0.159	94.483±0.208
Average length in centimeters of spikes per plant	7.638±0.039	8.337±0.029	7.985±0.018	8.032±0.020
Total length in centimeters of culms per plant	248.000±4.483	686.821±5.220	225.043±1.740	268.966±2.026
Total length in centimeters of spikes per plant	24.333±0.423	54.461±0.451	20.627±0.165	23.601±0.177
Number of culms per plant	3.606±0.063	6.977±0.053	2.651±0.019	2.847±0.020
Total yield in decigrams per plant	47.400±1.049	135.617±1.250	48.022±0.391	66.558±0.577
Yield in decigrams of straw per plant	39.600±0.894	94.603±0.832	30.644±0.245	41.299±0.357
Yield in decigrams of kernels per plant	8.153±0.209	40.512±0.466	17.305±0.144	26.007±0.227
Number of kernels per plant	55.860±1.081	142.629±1.428	69.183±0.549	75.087±0.648
Average weight in milligrams of kernels per plant	14.860±0.156	27.563±0.118	23.732±0.056	34.050±0.057

Table II continued

Standard Deviations				Coefficients of Variability			
1914	1915	1916	1917	1914	1915	1916	1917
10.079±0.278	9.199±0.184	8.834±0.160	7.695±0.167	30.940±0.930	27.850±0.597	34.27±0.69	40.47±1.02
		1.928±0.035	1.330±0.029			14.01±0.26	5.05±0.11
1.120±0.031	1.094±0.022	.956±0.017	.814±0.017	17.500±0.497	20.710±0.431	17.88±0.33	13.04±0.29
3.282±0.106	3.881±0.078	2.972±0.054	2.079±0.045	14.570±0.479	16.670±0.342	16.05±0.30	13.29±0.29
8.527±0.275	6.118±0.122	5.837±0.105	6.275±0.136	9.799±0.316	5.380±0.107	6.41±0.12	6.35±0.14
11.813±0.325	9.638±0.192	6.226±0.112	6.779±0.147	17.160±0.486	7.790±0.195	7.35±0.13	7.18±0.16
.996±0.027	1.008±0.021	.715±0.012	.658±0.014	13.050±0.366	12.090±0.245	8.96±0.16	8.19±0.18
115.127±3.170	185.019±3.693	68.139±1.230	65.755±0.143	46.420±1.529	26.940±0.575	30.28±0.59	24.45±0.56
10.861±0.299	15.968±0.319	6.473±0.116	5.768±0.125	44.640±1.450	29.320±0.634	31.38±0.62	24.44±0.56
1.628±0.044	1.862±0.037	.766±0.013	.652±0.014	45.150±1.475	26.690±0.569	28.92±0.56	22.91±0.52
26.93±0.742	44.137±0.881	15.320±0.276	18.748±0.408	56.810±2.007	32.550±0.715	31.90±0.63	28.17±0.66
22.957±0.632	29.466±0.588	9.601±0.173	11.584±0.252	57.970±2.064	31.150±0.679	31.33±0.62	28.05±0.66
5.378±0.148	16.498±0.329	5.674±0.102	7.383±0.160	65.950±2.484	40.720±0.938	32.79±0.65	28.39±0.67
27.753±0.764	50.584±1.001	21.514±0.388	21.041±0.458	49.680±1.672	35.470±0.792	31.10±0.61	28.02±0.66
3.999±0.110	4.185±0.084	2.211±0.039	1.874±0.040	37.160±1.156	15.180±0.310	9.32±0.17	5.50±0.12

The means in centimeters for height at six weeks are 22.525±.150 in 1914, 23.277±.110 in 1915, 18.515±.076 in 1916, and 15.638±.641 in 1917, with no significant difference between the first two. This is in the same order as the means for weight of seed planted and in practically the same ratio. The indications are that the influence of the weight of seed on the height of the plants at the six weeks period was greater than at second leaf.

The means for height of tallest culm at maturity in ascending order of magnitude are 87.021±.389 for 1914, 91.043±.149 for 1916, 98.763±.193 for 1917 and 113.663±.173 for 1915.

The means for average height of culms at maturity, average length of spikes, number of kernels, yield of kernels, and total yield per plant follow the same order as those for height of plant. The sequence for average height of culms and yield of kernels per plant representing the order for this group of characters is shown in the frequency distribution graphs, figures 1 and 2. For each of this group of characters the lowest mean occurs in 1914, the season least favorable to normal development during the latter part of the growing season, and the means for the other three years occur in ascending order according to the favorableness as a whole of the growing season for wheat, 1916, 1917, and 1915 respectively.

The means for number of culms per plant are 2.651±.019 in 1916, 2.847±.020 in 1917, 3.606±.063 in 1914, and 6.977±.053 in 1915. The means for yield of straw, total length of culms, and total length of spikes per plant are in practically the same order as those for number of culms.

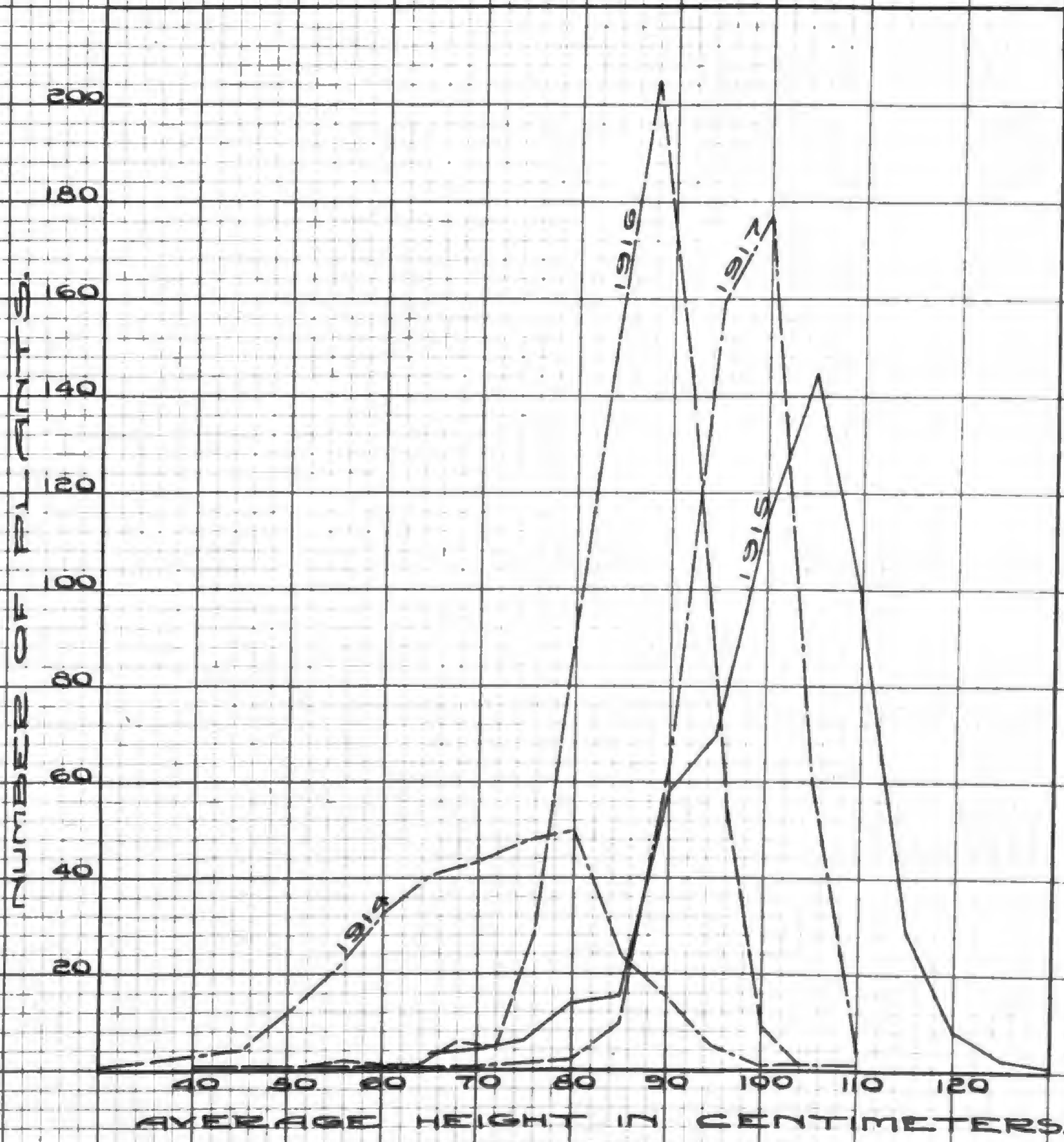

Figure 1. Graph showing the frequency distribution of the plants for average height. 1914-1917.

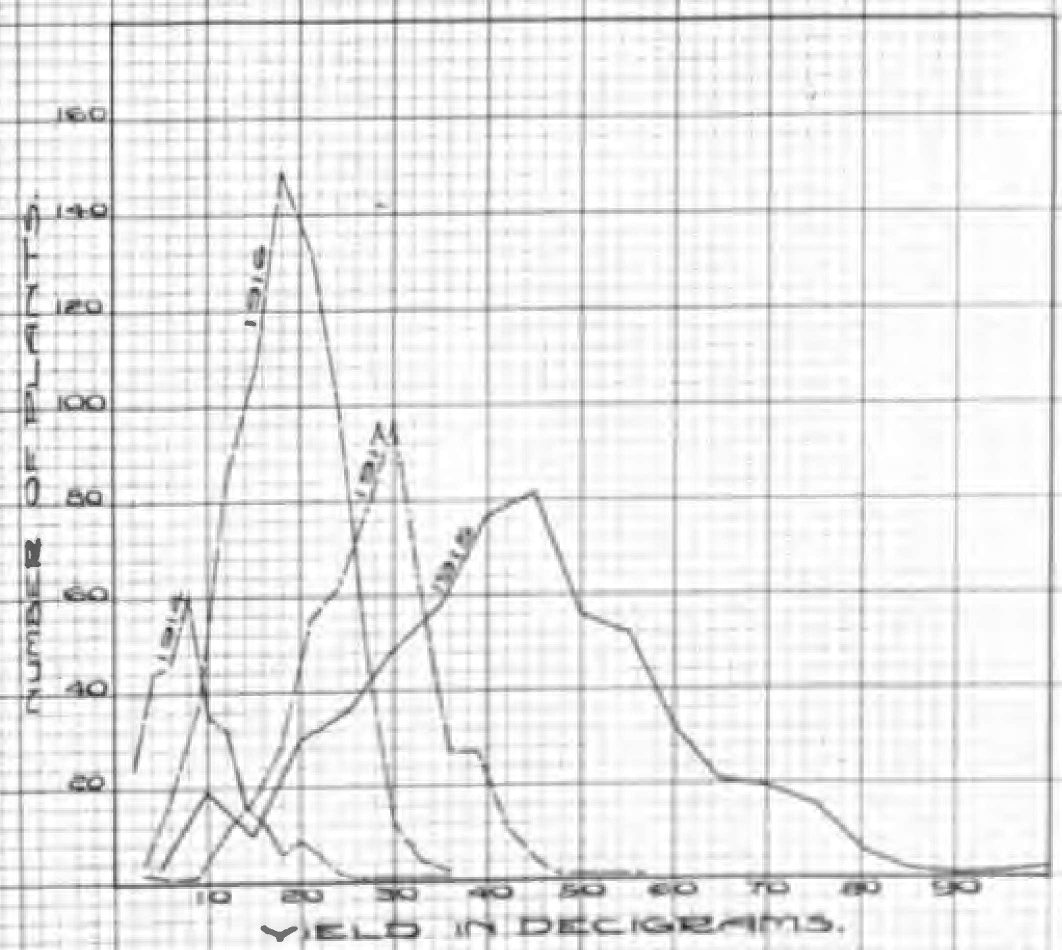

Figure 2. Graph showing the frequency distribution of the plants for yield of kernels. 1914-1917.

For number of culms per plant representing this group of characters, the order of the means is shown in the frequency distribution graph, figure 3. The magnitude of the means for this group of characters is largely dependent on the favorableness of conditions for growth during the early part of the season. This order is 1916, 1917, 1914, and 1915, respectively.

Comparison of the order of the means for the two groups of characters throughout the four-year period shows the means for the group of characters represented by height of tallest culm, which are dependent for their development upon conditions during the latter part of the growing season, follow the order of optimum conditions during that time; and that the means for the other group of characters represented by number of culms, which develop largely during the early part of the season, follow the order of the best conditions for early growth.

The means for average weight of kernel are 14.860±.156 in 1914, 23.732±.056 in 1916, 27.563±.118 in 1915 and 34.050±.057 in 1917. The frequency distribution graph, figure 4, shows this order. In 1914 and 1916, the sequence of the means for average weight of kernels is the same as yield of grain and number of kernels; but, in 1915 and 1917 in the reverse order. The kernels of the 1914 crop were shriveled as were also some of those of the 1916 crop. In 1915 and 1917 all kernels were well filled. Under the especially favorable conditions which prevailed throughout the entire growing season in 1915, a larger number and greater yield of kernels was produced but the average weight of the kernels was not as great as in 1916 when conditions favored a more normal development.

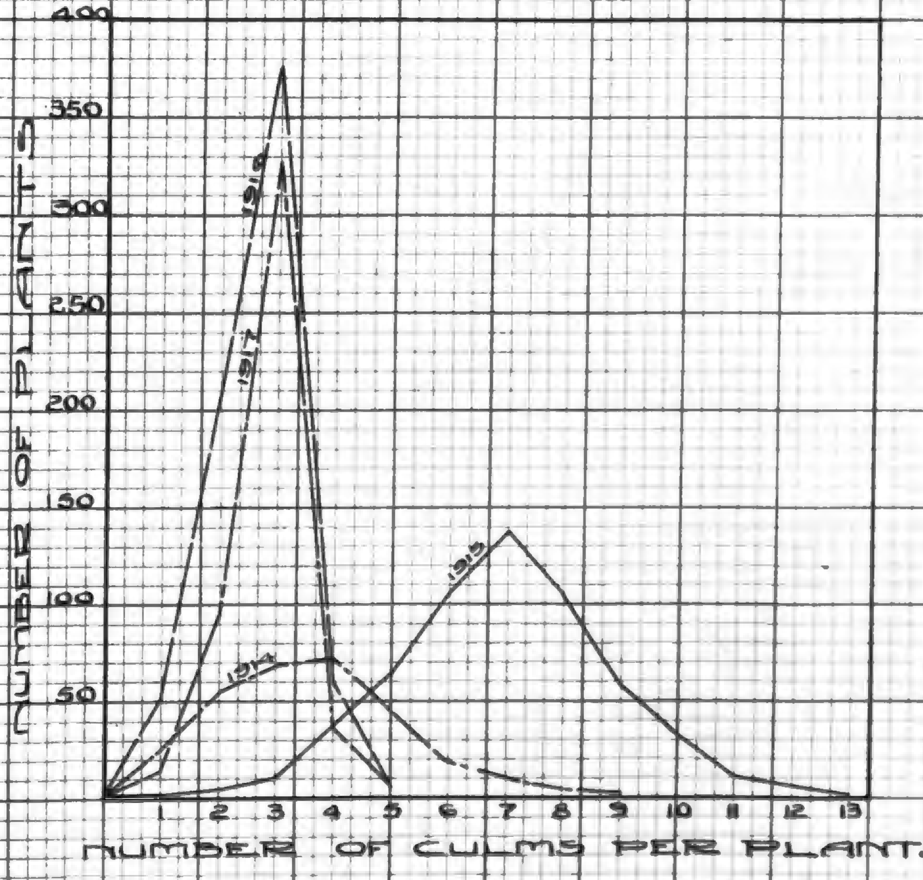

Figure 3. Graph showing the frequency distribution of the plants for number of culms. 1914-1917.

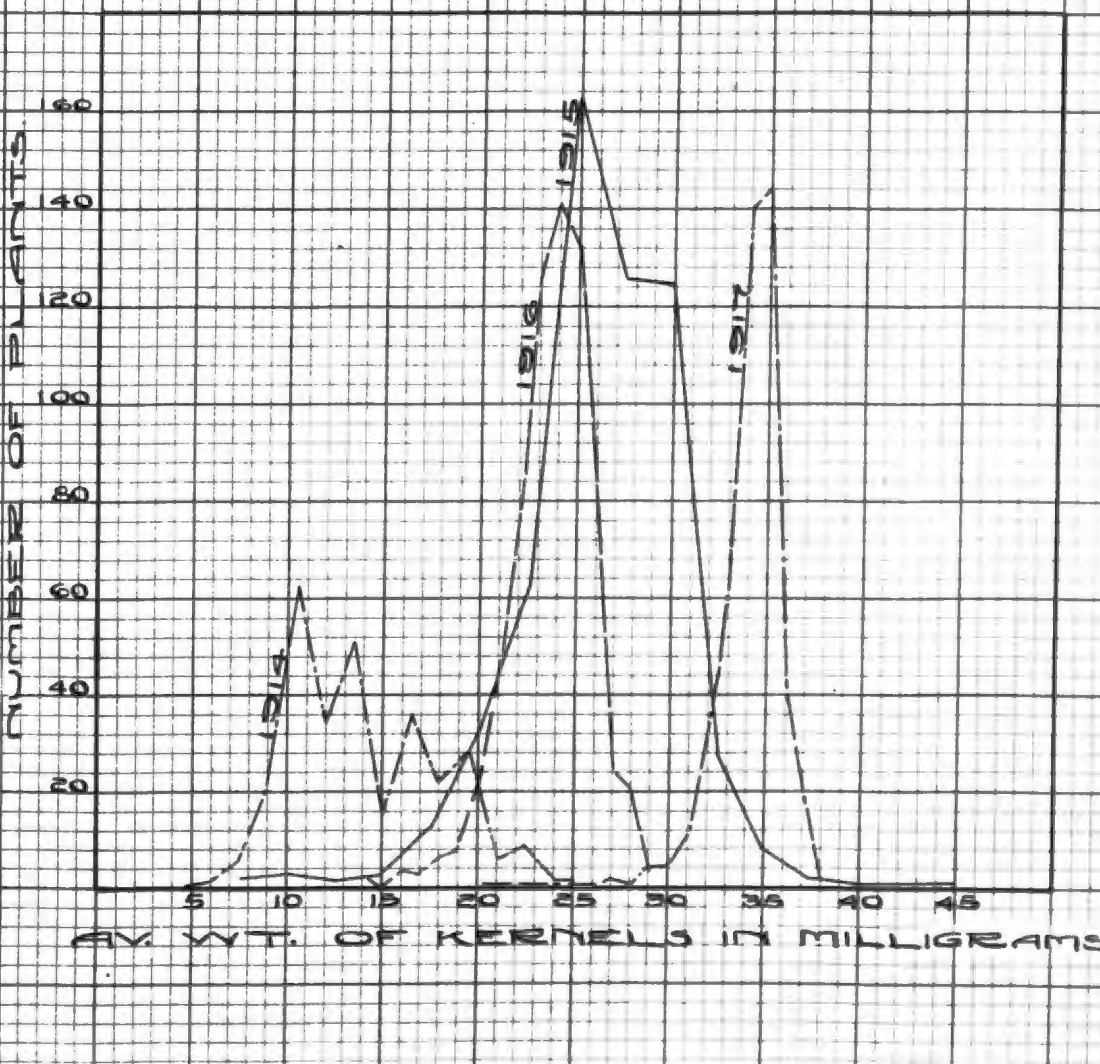

Figure 4. Graph showing the frequency distribution of the plants for average weight of kernels. 1914-1917.

As indicated by the means, the various characters studied responded more or less directly to external conditions which prevailed while each was making its most rapid development. Number of culms per plant and yield of straw were influenced most by environment during the early part of the growing season and number, yield and average weight of kernels by environment during the latter part of the growing season.

When growth was retarded or stopped by environmental conditions, lower yields of straw resulted from a reduction in the number, total or average length of culms per plant; and lower yields of grain, from a reduction in the number of kernels and for 1914 and 1916 only, a lower average weight of kernels. The kernels were more or less shriveled in 1914 and 1916. When the grain developed normally, as in 1915 and 1917, lower yield of kernels in 1917 was accompanied by a higher average weight per kernel.

STANDARD DEVIATIONS

The standard deviations for number of days from planting to second leaf are 1.928±.035 in 1916 and 1.330±.029 in 1917.

The height at second leaf, the two highest means are accompanied by the highest and lowest standard deviations. Better root development in 1917 during the prolonged cool period intervenihg between the time of planting the seed and emergence which may have permitted the plants to begin growth at the surface more nearly at the same time is a possible explanation of the lower standard deviation accompanying the higher mean.

The standard deviations for height at six weeks are in the same order as the means; with significant differences between any two except those in 1914 and 1916. The variability of average height at second leaf and at six weeks measured by the standard deviations is comparatively low during the four-year period.

For height of tallest culm, average height of culms and average length of spikes, the means in 1914 are lower but the standard deviations as high as or higher than the standard deviations for these characters in any of the other three years. The comparatively high variability in 1914 of average height of culms is indicated on the frequency distribution graph, figure 1. The differences in centimeters between the height of tallest culm and average length of culms are 18.188±.602 in 1914, 15.214±.322 in 1915, 6.350±.218 in 1916, and 4.280±.284 in 1917. The greater difference in height between the tallest culm and the average of the culms in 1914 indicates that the drouth in early July and the stem rust in late July and early August of that year, prevented the secondary culms from approaching in height the main culm as closely as they did the other three years. This would tend to increase the variability of these two characters as well as that of average length of spikes. Making due allowance for the abnormal conditions in 1914, it is of interest to note the comparatively low variability of height of tallest culm as indicated by the standard deviations.

For number and average weight of kernels and total yield of plants, the means were lowest in 1914 but the standard deviations for these characters in the same year were either next to the highest or equal to the highest.

The mean for yield of kernels in 1914 was reduced materially due to the drouth and black stem rust and the standard deviation is also low.

The mean for average weight of kernels per plant was highest in 1917 but it is accompanied by the lowest standard deviation in the four-year period. This is indicated on the frequency distribution graph, figure 4.

For number of culms, total length of culms, total length of spikes, and weight of straw per plant, the means for 1914 were either almost equalled or exceeded by those for 1915 and 1916, more favorable years; but the standard deviations are equalled or exceeded only by those for the 1915 crop.

In general, the standard deviations tend to follow the same order as the means, the variability being greatest where the means are the greatest, due in both instances, to favorable conditions for development. Exceptions to this tendency may be due in part to the frequent smaller differences between standard deviations as judged by their probable errors compared with the differences between means as judged by their prorable errors. Average weight of kernel had the highest mean in 1917 accompanied by the lowest standard deviation, which is an exception. A number of exceptions occurred in 1914 due to the very favorable condition for development during the first part and the opposite conditions during the latter part of the growing season.

COEFFICIENTS OF VARIABILITY

With few exceptions, the coefficients were higher in 1914 than in the other three years which corresponds to the generally lower means for that year.

As is indicated by the coefficients, number of days to second leaf and average weight of kernels in 1917 varied least but each character was highly variable from year to year. Height at six weeks, height at maturity, average height of culms, and average length of spikes were comparatively low in variability each year and from year to year. This confirms similar indications by the standard deviations.

As indicated by the coefficients of variability, the greatest variation in the four-year period occurred in 1914 for total weight per plant, yield of straw and yield of kernels.

CORRELATIONS

Correlation coefficients were determined for weight of seed used and each of the resultant plant characters listed in Table III. The assembled data also offered the opportunity to study the interrelation of plant characters for which the coefficients of correlation are presented in Table V. Since it was not considered feasible to present all the correlation tables, the selection for presentation was confined to those likely to be of most value and interest.

Table III.

Coefficients of correlation between weight of seed and characters of the resultant plants.

Characters studied	1914	1915	1916	1917
Weight in milligrams of kernels planted				
Number of days from planting to second leaf			-.484±.019	-.634±.018
Height in centimeters of plants at app. of 2nd leaf	.146±.038	.114±.027	.169±.024	.259±.028
Height in centimeters of plants at six weeks	.356±.040	.445±.022	.649±.014	.712±.015
Height in centimeters of tallest culm at maturity	.196±.037	-.037±.028	.311±.023	.074±.030
Average height in centimeters of culms at maturity	.093±.038	.099±.028	.192±.024	.118±.030
Average length in centimeters of spikes per plant	.007±.038	-.193±.027	.120±.025	.202±.029
Total length in centimeters of culms per plant	.251±.036	.066±.028	.460±.020	.395±.026
Total length in centimeters of spikes per plant	.259±.036	-.018±.028	.442±.020	.417±.025
Number of culms per plant	.232±.036	.116±.027	.480±.021	.398±.025
Total weight in decigrams per plant	.229±.036	.064±.028	.423±.021	.435±.024
Yield in decigrams of straw per plant	.226±.036	.046±.028	.407±.021	.401±.025
Yield in decigrams of kernels per plant	.143±.038	.088±.028	.445±.020	.478±.023
Number of kernels per plant	.246±.036	.076±.028	.458±.020	.465±.024
Average weight in milligrams of kernels per plant	-.062±.038	.086±.028	.055±.025	.141±.030

THE RELATION OF WEIGHT OF SEED USED TO THE RESULTANT PLANT CHARACTERS

Inspection of the coefficients given in Table III shows that, with certain exceptions, the correlation coefficients in 1914 and 1915 are lower than for the same characters in 1916 and 1917.

The relatively low correlation in 1914 and 1915 corresponds to the comparatively high variability in these two years, both of which are due in part to (a) the extreme climatological and pathological conditions, (b) the somewhat higher productivity of the soil and (c) the higher mean and greater range in weight of seed planted.

Correlation coefficients for number of days from planting to second leaf were determined in 1916 and 1917 only. The correlation coefficients are relatively high indicating that the plants from the heavier seeds reach the second leaf stage sooner than the plants from the lighter seeds. Correlation is highest in 1917, the year in which the mean weight of the seed was the lowest.

Weight of seed correlated with height of plants at second leaf gave coefficients varying from $.114 \pm .027$ in 1915 to $.259 \pm .028$ in 1917 and correlated with height at six weeks, a variation from $.356 \pm .040$ in 1914 to $.712 \pm .015$ in 1917. In each of the four years the coefficients as compared with their probable errors show a fair correlation for height at second leaf and a considerably higher correlation for height at six weeks. This indicates that, at the appearance of the second leaf, the greater food supply available to the plants from the larger seeds had not yet exerted its influence. An extreme difference of $.145 \pm .038$ in the coefficients for height

Figure 5. Weight in milligrams of individual seed planted correlated with height in centimeters of plant at six weeks. 1914.

	13	15	17	19	21	23	25	27	29	31	
18		1			3	1					5
20	1		2	4	3	2					12
22		2		4	4	4	1				15
24			2	5	5	5	2		1		20
26			1	1	7	5	5	1	1		21
28			3	2	4	4					13
30			1	1		2	2				6
32				1	1	2	2	1			7
34					2	4	2	1			9
36					2	9	2	1			14
38			1	1	3	2	2	1	4	1	15
40				3	6	6	3	2	3		23
42		1		2	1	9	4	1	1		19
44				3	4	2	6	4	1		20
46		1	1	1	1	6	1	1	2	1	15
48						1		1			2
50							1				1
52					1		1				2
	1	5	11	28	47	64	34	14	13	2	219

Correlation = .356±.040

Figure 6. Weight in milligrams of individual seed planted correlated with height in centimeters of plant at six weeks. 1915.

	9	11	13	15	17	19	21	23	25	27	29	31	33	35	
16				1	4		1	1							7
18			1	1	3	2	1								8
20				3	6	7	8	6	5						35
22	1		1	1	7	9	13	15	5						52
24			1		8	4	17	25	6	3					64
26						4	8	10	14	8	1				45
28				1		3	4		2	1					11
30			1			2	6	1	8	1	1				20
32					6	1	4	15	15	6					47
34				1	2	2	4	7	10	8	3	1			38
36						1	2	6	6	4	2				21
38					1			4	3		2				10
40				1		4	10	6	10	9	6				46
42			1		1	6	4	7	12	15	14	5			65
44					1	2		4	7	12	19	2		2	49
46			1		4	2	2	6	9	9	1	1			35
48						1	1	2	3	1	2				10
50				1	1	1	2			2	1				8
	1		6	10	44	51	87	115	115	79	52	9		2	571

Correlation = .445±.022

Figure 7. Weight in milligrams of individual seed planted correlated with height in centimeters of plant at six weeks. 1916.

	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	
8			1	2	1															4
10	1			2	4	2	4	2												15
12				1	7	9	6	2	3		1									29
14		1		1	5	5	13	11	7	3	2									48
16					4	5	8	16	7	9	6	3		1						59
18			1		1	1	4	8	4	6	9		1	1						36
20							2	2	7	4	6	2	1	1						25
22				1	2		2	6	5	11	6	2	3							38
24							3	7	5	9	21	6	13	2	2					68
26						1	3	6	6	11	20	17	7	5	1					77
28					1	2		3	4	5	11	13	9	9	4	1				62
30		1				3			3	2	12	9	9	2	2		1			44
32		1				1	1				1	4	3	1	2	2	1			17
34							1	2	3	4	3	7	5	3	1		2		1	32
36						1			1	3	3	5	10	8	9	4	1			45
38					1		2	1				11	11	8	13					47
40								1	2	1	2	4	7	6	4	3				30
42					1		1	1	1		1	2	3	3	3					16
44								1				1		2	1	1				6
	1	3	2	7	27	30	50	69	58	68	104	86	82	52	42	11	5		1	698

Correlation = .649 $\pm$ .014

Figure 8. Weight in milligrams of individual seed planted correlated with height in centimeters of plant at six weeks. 1917.

	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
6	1				2	4	8	8	2							25
8					1	1	8	10	9	3						32
10							8	6	14	9	2	2				41
12								2	11	14	5					32
14					1			2	7	8	15	1				34
16							1	2	3	8	21	4				39
18					1					9	15	7	1			33
20									2	8	13	11	5			39
22								2	4	4	8	9	9	1		37
24							1	2	1	4	10	2	12	4		36
26							1		1	3	4	11	12	6		38
28						1				1	7	11	12	3	1	36
30				1					1	2	5	9	6	7	1	32
32											3	6	10	5	1	25
	1			1	5	6	27	34	55	73	108	73	67	26	3	479

Correlation = .712±.015

at second leaf and .356±.042 for height at six weeks during the four-year period shows that correlation between weight of seed and both of the characters was influenced considerably by environment.

Between weight of seed and height of tallest culm at maturity, the correlation coefficients are -.037±.028 in 1915, .074±.030 in 1917, .196±.037 in 1914, and .311±.023 in 1916. As indicated by the coefficients in terms of their probable errors, there was practically no correlation between weight of seed and height of tallest culm at maturity in 1915 and 1917 and a good correlation in 1914 and 1916. The coefficients of correlation between weight of seed and average height at maturity are .093±.038 in 1914, -.099±.028 in 1915, .118±.030 in 1917, and .192±.024 in 1916. The coefficients of correlation of the two characters range from 2.45 times the probable error in 1914 to 8 times the probable error in 1916.

Between weight of seed planted and average weight of kernels harvested, the coefficients are -.062±.038 in 1914, .055±.025 in 1916, .086±.028 in 1915 and .141±.030 in 1917. While the coefficients are low in each of the four years, a slight correlation is indicated in 1914 and 1916, and in 1915 the coefficient is three times and in 1917 four and seven tenths times their respective probable errors. The most significant correlation between the two characters occurred in 1917 when the seeds planted were selected from a line established through the selection of individual plant number one hundred thirty-five of the 1914 crop. Since the results indicate that the Marquis wheat used in this experiment was not homozygous for weight of seed, it cannot be considered a pure line for this character.

Figure 9. Weight in milligrams of individual seeds planted correlated with yield in decigrams of kernels per plant. 1914.

	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35	
14		1	1		1														3
16		1		1	2														4
18	7	3	5	3	1		1												20
20	4	5	3	5		1	2	2		1									23
22		3	9	6	3	5	1					1							28
24	2	5	2	8		5	1	1	1	1	1								27
26		4	2	2	2	1	3	1											15
28	1	1	2	2					1										7
30		1		2	3	1			1										8
32				3	1		1			1									6
34	1	1	2	1		4		1	1										11
36			2	2	2	4		1	1	2									14
38	1	3	1	4		2	1	2			3		1						18
40		7	2	6	4	2	2	1	1	2	1	1			1			1	31
42	3	2	4	6	6	3	3	2		1									30
44	2	4	8	5	4		2				1								26
46	1	3	2	3	4	4		2		1									20
48	2				2		1												5
50		1	1	2															4
	24	45	46	61	35	32	18	13	6	9	6	2	1		1			1	300

Correlation = .143±.038

Figure 10. Weight in milligrams of individual seeds planted correlated with yield in decigrams of kernels per plant. 1915.

	2.5	7.5	12.5	17.5	22.5	27.5	32.5	37.5	42.5	47.5	52.5	57.5	62.5	67.5	72.5	77.5	82.5	87.5	92.5	97.5	
16	1	1				1		1	2			1									7
18		1			1	1	2		2		1										8
20		2	1	1	3	6	4	4	2	2	7		2		1						35
22	2		1	1	4	2	5	7	4	7	6	7	2	2	1	1					52
24		4	1	2	3	8	8	5	8	10	7	2	4	2							64
26			1			3	5	7	9	4	7	3		3	1		1		1		45
28			1	1	1	1	2	3	1					1							11
30		1		1	3	3	2	1	2	2	3		1				1				20
32		1	2	3		2	5	13	8	5	3	3	1	1							47
34		1		3	4	6	5	4	7	5	1		1	1							38
36					2	4	2	2	5	1	2	2	1								21
38		1			1		1	3	1			1			1	1					10
40		1		5	3	4	4	7	11	1	3	1	2	3	1						46
42		4	1	6	7	6	4	9	6	4	7	3	2	2	3					1	65
44		1	1	1	1		5	7	9	7	3	4	5	3	1	1					49
46		1	1	5	3	2	2	2	5	7	1	3			3						35
48							1	1		1	1	1			2	2		1			10
50				1			1	1				1		1	1	1				1	8
	3	19	10	30	36	49	58	77	82	56	52	32	21	19	15	6	2	1	1	2	571

Correlation = .088±.028

Figure 11. Weight in milligrams of individual seeds planted correlated with yield in decigrams of kernels per plant. 1916.

	2.25	3.75	5.25	6.75	8.25	9.75	11.25	12.75	14.25	15.75	17.25	18.75	20.25	21.75	23.25	24.75	26.25	27.75	29.25	30.75	32.25	33.75	
8			1		1	1		1															4
10	1				4	2	1	2	2	2	1												15
12			3	1	2	7	3	4	5	1		1	1	1									29
14			1	1	5	4	12	7	5	6	2	3	1		1								48
16		1	2	2	1	6	5	4	6	8	8	8	4	1	2			1					59
18				1	1	3	2	2	7	4	4	4	6		1			1					36
20					1			4	2	6	6	2	3	1									25
22		1		2	1	1	4	3	4	3	5	3	6	1	2	2							38
24				1			2	5	9	6	7	10	4	6	5	7	3	2	1				68
26			1	1	1	6	3	3	5	7	11	6	8	12	4	7	1	1					77
28	1	1			1	1	4	2	4	7	5	2	10	12	2	8		2					62
30	1		1		2	1	1	5	4	3	7	10	2	1	5	1							44
32	1			1		1				2	3	3	2	1	1	2							17
34							2	1		2	2	6	3	5	3	3	2			1	1	1	32
36						1	2	2	3	2	2	9	2	7	6	4	1	4					45
38			1		1		1			2	6	8	7	3	6	2	6	2	1		1		47
40		1				2	1		1	1	3	2	1	4	5	1	5		1	1		1	30
42		1		2			1	1			1		1	3		3	1	1		1			16
44												1	2	1	1					1			6
	4	5	10	12	21	36	44	46	57	62	73	78	63	59	44	40	19	14	3	4	2	2	698

Correlation = .445±.020

Figure 12. Weight in milligrams of individual seeds planted correlated with yield in decigrams of kernels per plant. 1917.

	1.5	4.5	7.5	10.5	13.5	16.5	19.5	22.5	25.5	28.5	31.5	34.5	37.5	40.5	43.5	46.5	49.5	52.5	55.5	
6	1			3	7	4	6	2	1	1										25
8	1		1	6	2	2	8	6	3	3										32
10					3	8	9	7	7	4	3									41
12						7	4	4	10	2	2	2	1							32
14				1	1	2	2	6	5	9	5		1	2						34
16				1	1		4	3	8	5	8	5	3	1						39
18							4	2	5	13	4	1	4							33
20						1	6	4	9	9	8	1	1							39
22							1	8	10	9	4	1	1	2	1					37
24					2	1	3	8	4	9	6	1	2							36
26					2	1	3	6	4	11	7	2	1	1						38
28						2	4	3	3	8	6	5	3	1			1			36
30		1					1	3	4	5	4	6	4	2	1				1	32
32						1			5	5	1	3	6	2	1	1				25
	2	1	1	11	18	29	55	62	78	93	58	27	27	11	3	1	1		1	479

Correlation = .478±.023

The coefficients for weight of seeds planted correlated with yield of kernels per plant are .088±.028 in 1915, .143±.038 in 1914, .445±.020 in 1916 and .478±.023 in 1917. In 1914 and 1915 the coefficients of correlation are low, 3.1 times and 3.8 times their probable errors, respectively, with no significant difference between them. The coefficients in 1916 and 1917 are considerably greater than those in 1914 and 1915.

The weight classes for the individual seeds planted, number of plants in each class harvested, and the average yield in decigrams of kernels per plant are given in Table IV. This gives the same data with respect to yield from kernels of different weights as is given in the correlation tables but in more direct form. That increase in weight of seed planted was not consistently followed by increased yield of kernels is evident.

Regression for yield of kernels in each of the four years is shown in figures 5, 6, 7 and 8. Regression for yield was consistently greater in 1916 (figure 7) for the seeds up to twenty-four milligrams than for the larger seeds. Apparently increase in amount of endosperm in 1916 and 1917 up to the weights of seeds indicated gave more uniformly proportionate increases in yield than were given by increases in endosperm beyond these amounts.

Very similar to the correlations between weight of seeds and yield of kernels in each of the four years are those between weight of seed and total length of culms, total length of spikes, number of culms, total yield, yield of straw and number of kernels per plant.

Correlation between weight of seed and plant characters at maturity in 1916 and 1917 was, for height of tallest culm, low

Table IV.

Weight classes of seeds planted and average yield of kernels per plant.

Weight classes of ind. seeds planted, mg.	1914 Number of plants harvested	1914 Avg. yield per plant dg.	1915 Number of plants harvested	1915 Avg. yield per plant dg.	1916 Number of plants harvested	1916 Avg. yield per plant dg.	1917 Number of plants harvested	1917 Avg. yield per plant dg.
6							25	16.38
8					4	9.00	32	18.28
10					15	11.25	41	21.77
12					29	11.72	32	23.91
14	3	5.67			48	12.84	34	26.21
16	4	7.00	7	31.07	59	14.89	39	28.01
18	20	4.20	8	32.50	36	15.88	33	28.23
20	23	6.74	35	37.21	25	16.23	39	26.50
22	28	7.64	52	42.98	38	15.91	37	27.93
24	27	8.26	64	38.98	68	18.95	36	26.08
26	15	7.93	45	46.28	77	17.89	38	26.84
28	7	6.43	11	33.36	62	18.52	36	29.08
30	8	9.00	20	38.00	44	16.47	32	31.22
32	6	10.33	47	38.88	17	17.25	25	33.70
34	11	8.82	38	35.39	32	21.14		
36	14	11.14	21	39.88	45	20.08		
38	18	10.89	10	42.50	47	20.86		
40	31	10.81	46	39.02	30	20.90		
42	30	8.20	65	38.42	16	18.94		
44	26	6.62	49	45.97	6	22.50		
46	20	8.50	35	38.79				
48	5	6.60	10	61.50				
50	4	5.50	8	57.50				

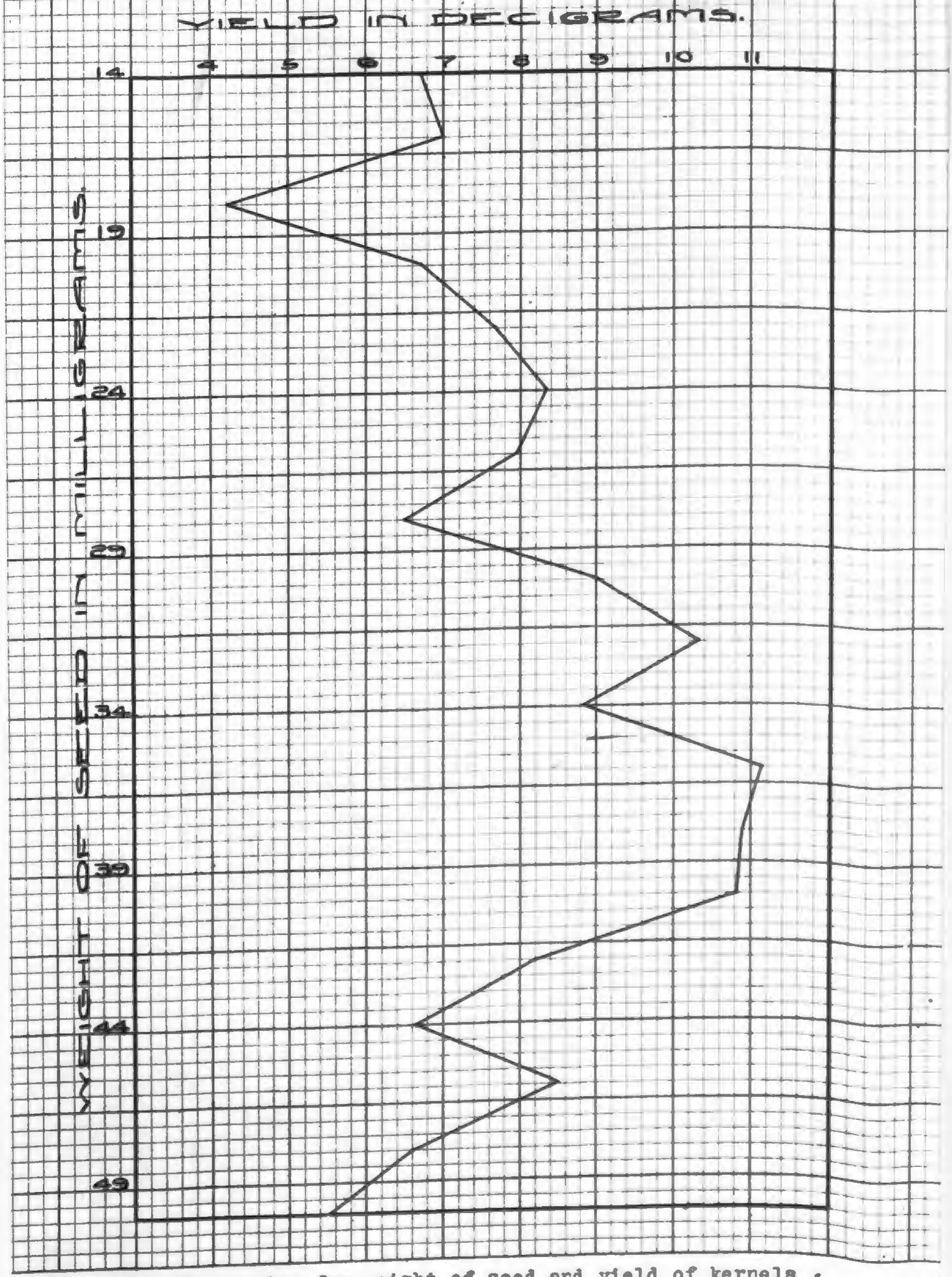

Figure 13. Regression for weight of seed and yield of kernels per plant in 1914.

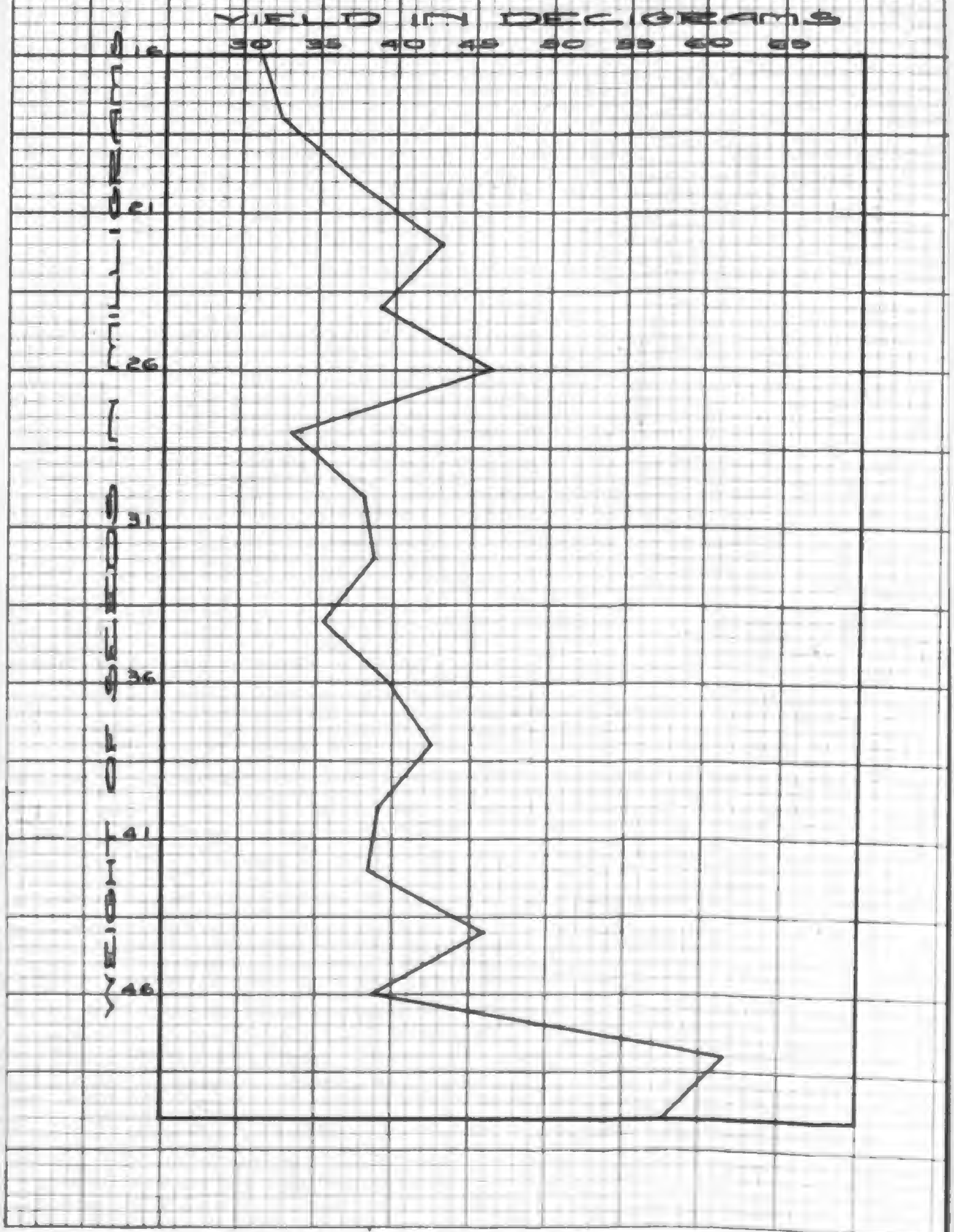

Figure 14. Regression for weight of seed and yield of kernels per plant in 1915.

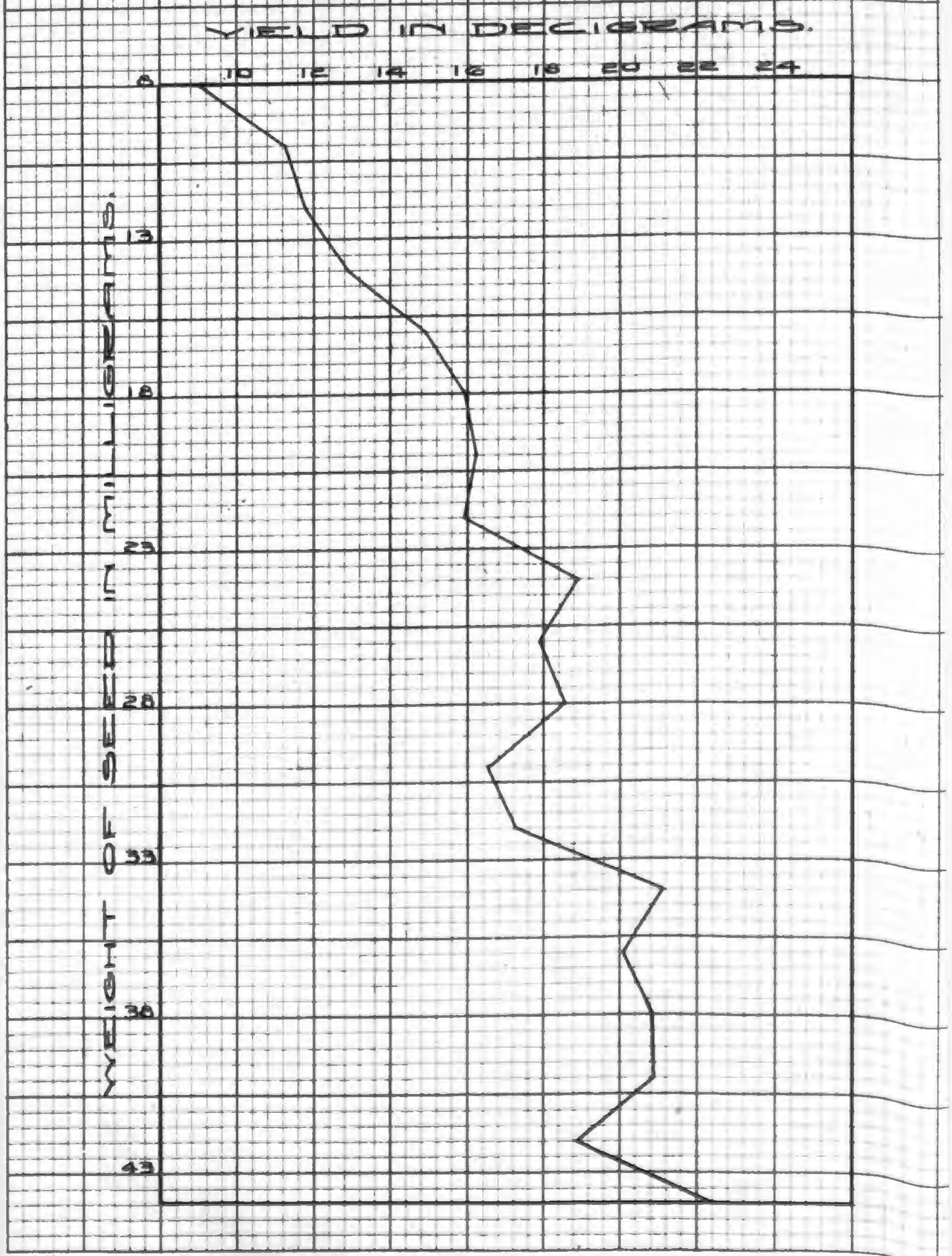

Figure 15. Regression for weight of seed and yield of kernels per plant in 1916.

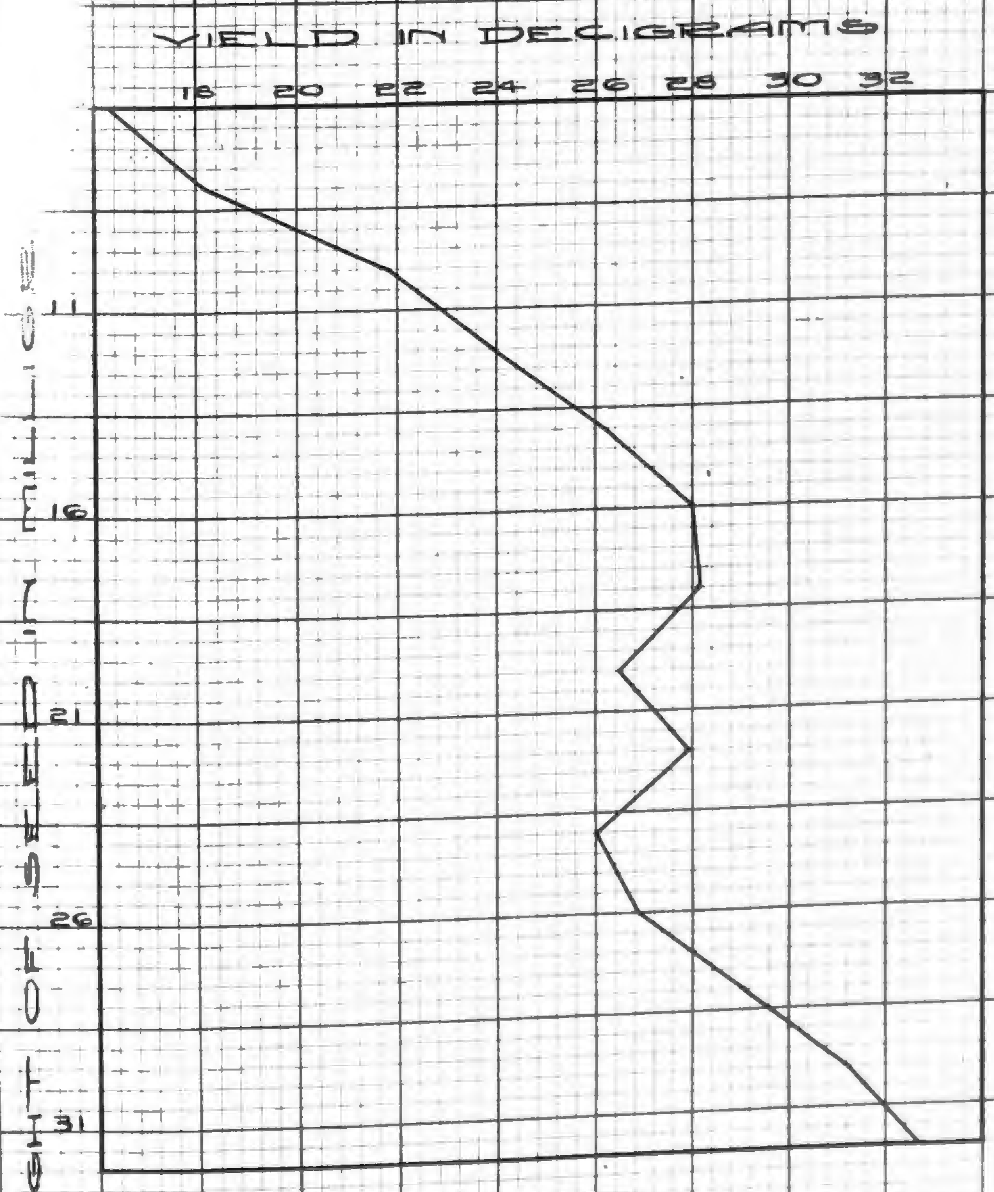

Figure 16. Regression for weight of seed and yield of kernels per plant in 1917.

and variable; for average height of culms and average length of spikes, low but less variable; and for total length of culms, total length of spikes, number of culms, total weight, and yield of grain and straw, medium with little fluctuation. The only significant difference in 1916 and 1917 between coefficients for weight of seed planted and characters at maturity is that between those for height of tallest culm. Therefore, it is evident that on soil of medium productivity, the more favorable weather conditions in 1917 as compared with that in 1916 did not influence correlation to any marked extent.

In 1914 and 1915, the coefficients for all plant characters at maturity are comparatively low; and, with the exception of those for number of culms, yield of kernels, and average weight of kernels, they are significantly lower in 1915 than in 1914. This difference is due to the highly favorable environmental conditions in 1915.

Considered as a whole, there is a distinct tendency toward correlation between weight of seed sown and the characters of the resultant plants. However, the correlation, even under average conditions, is not high in any instance, and is subject to the influence of environmental conditions to so marked an extent that, with some characters, the relation may be obliterated entirely; and, with other characters including yield, may be made so slight that under ordinary conditions of experiment no relation could be detected.

Correlation between weight of seed planted and average weight of kernels harvested indicates that the Marquis wheat used was not homozygous for weight of seed and, therefore, cannot be considered a pure line for this character.

Table V.

Coefficients of correlations between plant characters.

Characters studied	1914	1915	1916	1917
Yield in decigrams of kernels per plant				
Number of kernels per plant	.851±.010	.881±.006	.952±.002	.973±.001
Average weight in milligrams of kernels per plant	.550±.027	.504±.021	.370±.022	.306±.027
Number of culms per plant	.500±.029	.669±.015	.818±.008	.824±.009
Average height in centimeters of culms per plant	.384±.033	.303±.025	.478±.019	.452±.024
Average length in centimeters of spikes per plant	.357±.034	.344±.024	.459±.020	.591±.020
Total length in centimeters of spikes per plant	.636±.023	.838±.009	.910±.004	.911±.005
Number of culms per plant				
Average length in centimeters of spikes per plant	.061±.038	.024±.028	.039±.025	.236±.029
Total length in centimeters of spikes per plant	.872±.009	.839±.008	.958±.002	.946±.003
Average weight in milligrams of kernels per plant				
Number of kernels per plant	.137±.038	.192±.027	.160±.024	.160±.030
Number of culms per plant	-.071±.038	.137±.027	-.054±.025	-.009±.030
Average length in centimeters of spikes per plant	.153±.030	.120±.027	.552±.017	.411±.025
Total length in centimeters of spikes per plant	.001±.038	.159±.027	.079±.025	.091±.030
Average height in centimeters of culms per plant				
Number of kernels per plant	.257±.036	.339±.025	.364±.022	.431±.025
Average weight in milligrams of kernels per plant	.458±.030	.071±.028	.648±.014	.426±.025
Number of culms per plant	.195±.037	.092±.028	.046±.025	.205±.029
Average length in centimeters of spikes per plant	.315±.035	.419±.023	.775±.010	.668±.017
Total length in centimeters of spikes per plant	.036±.038	.260±.026	.235±.024	.351±.027
Height in centimeters of plants at app. of 2nd leaf				
Height in centimeters of plants at six weeks	.406±.038	.467±.022	.470±.019	.466±.024
Height in centimeters of tallest culm at maturity	.380±.033	.270±.026	.272±.023	.211±.029
Height in centimeters of plants at six weeks				
Height in centimeters of tallest culm at maturity	.359±.038	.236±.026	.523±.018	.314±.027

THE INTERRELATION OF PLANT CHARACTERS

The coefficients given in Table V show that only in the group where yield of kernels is correlated with other characters is there a general tendency toward less correlation in 1914 and 1915 than in 1916 and 1917. This condition, altho much less marked, is similar to that found when weight of seed was correlated with plant characters at maturity and is due to the differences in environment between the first two and last two years.

YIELD OF KERNELS CORRELATED WITH OTHER PLANT CHARACTERS

The coefficients for yield of kernels per plant correlated with number of kernels per plant are .851±.010 in 1914, .881±.006 in 1915, .952±.002 in 1916, and .975±.001 in 1917. In contrast with the coefficients when weight of seed was correlated with plant characters, the correlation is consistently high in each of the four years. With a fair uniformity in the average weight of kernels, high correlation between yield of kernels and number of kernels is to be expected.

Yield of kernels correlated with average weight of kernels gave coefficients of .550±.027 in 1914, .504±.021 in 1915, .370±.022 in 1916, and .308±.027 in 1917. This order is the opposite of the general tendency for the coefficients in this group to be lower in the first two than in the last two years. The correlation between the two characters is substantial and fairly consistent. This indicates that the higher yielding plants have a tendency to produce kernels of greater average weight.

Figure 17. Yield in decigrams of kernels per plant correlated with average weight in milligrams of kernels per plant. 1914.

	5.25	6.75	8.25	9.75	11.25	12.75	14.25	15.75	17.25	18.75	20.25	21.75	23.25	24.75	26.25	
1		2	1	2	8		7		2	1	1					24
3	1		1	7	18	5	5	1	5	1	1					45
5			3	4	11	8	10	2	3	1	4					46
7			1	6	10	9	12	6	7	4	3		2		1	61
9				2	10	7	5	1	5	1	4					35
11					4	2	6	3	6	3	5	1	2			32
13					1	2	3	2	4	4		2				18
15							2		2	2	5	1		1		13
17						1			1	1		1	2			6
19					1		1		1	1	2		2	1		9
21									1	2	1	1	1			6
23										1	1					2
25											1					1
27																
29											1					1
31																
33															1	1
35																
	1	2	6	21	63	34	51	15	37	22	29	6	9	2	2	300

Correlation = $.550 \pm .027$

Figure 18. Yield in decigrams of kernels per plant correlated with average weight in milligrams of kernels per plant. 1915.

	8.75	11.25	13.75	16.25	18.75	21.25	23.75	26.25	28.75	31.25	33.75	36.25	38.75	41.25	43.75	46.25	
2.5				1		1	1										3
7.5		1			1	4	2	6	2	1	1	1					19
12.5			1		1	3		2	2	1							10
17.5	2	1		1	2	1	5	10	5	2	1						30
22.5		1	1	1	2	7	6	10	3	5							36
27.5					3	4	12	17	7	4	1		1				49
32.5					2	1	14	17	14	8	2						58
37.5					1	6	13	27	16	11	2	1					77
42.5						4	5	31	22	18	1	1					82
47.5						1	3	24	13	12	2	1					56
52.5							1	10	20	15	5	1					52
57.5								2	12	13	3		1	1			32
62.5								4	4	12						1	21
67.5								4	3	9	2	1					19
72.5									3	7	5						15
77.5										2	2	2					6
82.5										2							2
87.5										1							1
92.5											1						1
97.5										2							2
	2	3	2	3	12	32	62	164	126	125	28	8	2	1		1	571

Correlation = .504±.021

Figure 19. Yield in decigrams of kernels per plant correlated with average weight in milligrams of kernels per plant. 1916.

	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	
1.5	3			1													4
4.5			2	2	1	3	2	2	1	2	2	1					18
7.5					1	1	3	4	2	3	4	4	7	4	3	1	37
10.5		1	1		1	2	5	8	20	19	18	2	2	2	3		84
13.5						2	9	12	8	11	22	28	10	2	3		107
16.5			1		2		2	12	30	46	16	11	18	6	4	1	149
19.5					1			2	5	27	49	35	10		4		133
22.5								1	6	8	19	35	26	2	1	1	99
25.5								1	3	8	8	11	9	7	2		49
28.5								2	1	1	3	2		2	1		12
31.5												2	2				4
34.5											1	1					2
	3	1	4	3	6	8	21	44	76	125	142	132	84	25	21	3	698

Correlation = .370 ± .022

Figure 20. Yield in decigrams of kernels per plant correlated with average weight in milligrams of kernels per plant. 1917.

	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	
1.5	1							1														2
4.5													1									1
7.5																	1					1
10.5										1		1	1			1	4	3				11
13.5										1	2	3	1	4	3	2	1	1				18
16.5							1					3	2	4	11	6	2					29
19.5						1		1				2	7	5	17	13	7	2				55
22.5										1	1	1	11	21	13	8	4	2				62
25.5			1						1	1	2	1	3	16	30	20	2	1				78
28.5										1		1	3	4	38	37	8	1				93
31.5													1	3	19	29	5				1	58
34.5													1	2	2	13	4	4	1			27
37.5													2	3	3	13	3	2	1			27
40.5													1	2	3	3	1	1				11
43.5														1	1			1				3
46.5															1							1
49.5																	1					1
52.5																						
55.5																	1					1
	1		1			1	1	2	1	5	5	12	34	65	141	145	44	18	2		1	479

Correlation = .306±.027

The coefficients for yield of kernels correlated with the number of culms are .500±.029 in 1914, .669±.015 in 1915, .818±.008 in 1916, and .824±.009 in 1917. Correlation between the two characters is relatively high but not as consistent as that between yield of kernels and number of kerneds. Plants with the greater number of culms are usually the higher yielders.

For yield of kernels correlated with average height of culms, the coefficients are .303±.025 in 1915, .384±.033 in 1914, .452±.024 in 1917, and .478±.019 in 1916. This is a substantial and fairly consistent correlation. For yield of kernels and average length of spikes, the coefficients are very similar to those between yield of kernels and average height of culms. There is a distinct tendency for the plants producing the higher yields of grain to have the greater average height of culms and greater average length of spikes. Stated in another way, the plants having the greater average height of culms and average length of spikes have a tendency toward being the highest yielders.

The coefficients for yield of kernels correlated with total length of spikes per plant are .636±.023 in 1914, .808±.009 in 1915, .910±.004 in 1916, and .911±.005 in 1917. Correlation between these two characters is high and relatively consistent approaching that between yield of kernels and number of kernels. Stated directly, the plants with the greatest total length of spikes were generally the highest yielders.

The results for yield of kernels correlated with the several characters may be summarized as follows: Increased yield of kernels is very closely accompanied by increase in number of kernels, number of culms, and total length of spikes and somewhat less closely accompanied by increase in average weight of kernels per plant, average height of culms and average length of spikes.

NUMBER OF CULMS CORRELATED WITH OTHER PLANT CHARACTERS

For number of culms correlated with average length of spikes per plant, the coefficients are .061±.038 in 1914, .024±.028 in 1915, .039±.025 in 1916, and .236±.029 in 1917. In the first three years, there is practically none and in the last year a low correlation. The conclusion is that these two characters move practically independent of each other.

The coefficients for number of culms correlated with total length of spikes per plant are .872±.009, .839±.008, .958±.002, and .946±.003, respectively for the four-year period. The correlation between the two characters is somewhat more close and consistent than that between yield of kernels and total length of spikes. Increase in number of culms is followed by increase in total length of spikes per plant but not by greater average length of spikes.

AVERAGE WEIGHT OF KERNELS CORRELATED WITH OTHER PLANT CHARACTERS

The coefficients for average weight of kernels as correlated with number of kernels per plant are .137±.038, .192±.027, .160±.024 and .160±.030, respectively, for the four years. The coefficients are uniformly low but positive in each instance with the lowest 3.6 times its probable error. To a limited extent, increase in number of kernels is accompanied by greater average weight of the kernels.

Average weight of kernels correlated with number of culms per plant gave coefficients of -.071±.038 in 1914, .137±.027 in 1915, -.054±.025 in 1916, and -.009±.030 in 1917. The low coefficients as judged by their probable errors and the variation from year shows slight or no correlation between these characters.

The coefficients for average weight of kernels correlated with average length of spikes are .153±.038, .120±.027, .552±.017, and .411±.025, respectively, for the four years. The relatively low correlation in the first two and the substantial correlation in the last two years indicates that, under the conditions of environment which prevailed in 1916 and 1917, there is a strong tendency for the two characters to move together ; and that, under extreme environmental conditions, such as prevailed in 1914 and 1915, the relation is considerably reduced.

For average weight of kernels correlated with total length of spikes, the coefficients range from .001±.038 in 1914 to .159±.027 in 1915. There is no correlation in 1914 and for the other three years the relation is low. Therefore, the conclusion must be that the two characters move practically independent of each other.

When average weight of kernels is correlated with number of kernels, number of culms, average length of spikes and total length of spikes, no consistently high relationship is found. Subject to radical change by environment, there is a moderate correlation with average length of spikes. With number of kernels, the correlation is rather low but consistent. Average weight of kernels is practically independent of total length of spikes.

Figure 21. Average height in centimeters of culms per plant correlated with average weight in milligrams of kernels per plant. 1914.

	5.25	6.75	8.25	9.75	11.25	12.75	14.25	15.75	17.25	18.75	20.25	21.75	23.25	24.75	26.25	
27.5					1											1
32.5																
37.5																
42.5				1	3											4
47.5		1		2	5	3	1									12
52.5			1	5	6	2	4		2	1						21
57.5		1	2	5	7	6	6		3	1	1		1			33
62.5	1		1	2	13	8	6	2	4	2	2					41
67.5			2		7	7	8	5	3	5	3	1	2			43
72.5				1	8	4	9	1	8	5	10	1	1			48
77.5				4	9	3	9	2	9	5	4	2	3			50
82.5				1	4		7	1	3	2	4		1		1	24
8715						1		2	3	1	3	1	1	2	1	15
92.5							1	1	1		2					5
97.5								1								1
102.5												1				1
107.5									1							1
	1	2	6	21	63	34	51	15	37	22	29	6	9	2	2	300

Correlation = .458±.030

Figure 22. Average height in centimeters of culms per plant correlated with average weight in milligrams of kernels per plant. 1915.

	8.75	11.25	13.75	16.25	18.75	21.25	23.75	26.25	28.75	31.25	33.75	36.25	38.75	41.25	43.75	46.25	
62.5						1			1		1						3
67.5								1	3								4
72.5		1			1		1	1	1			1					6
77.5	1					2	3	3	2	1	2						14
82.5						3	3	4	3	4	1						18
87.5	1		1		3	4	5	16	13	10	4	1					58
92.5				1		5	7	21	15	15	5	1					70
97.5				1	2	6	8	29	32	27	6	2		1		1	115
102.5		1	1		5	6	19	46	25	36	1	3	2				145
107.5				1	1	5	12	31	22	21	5						98
112.5		1					3	7	7	8	3						29
117.5								5	1	2							8
122.5							1			1							2
127.5									1								1
	2	3	2	3	12	32	62	164	126	125	28	8	2	1		1	571

Correlation = .071±.028

Figure 23. Average height in centimeters of culms per plant correlated with average weight in milligrams of kernels per plant. 1916.

	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	
50												1					1
54				1							1						2
58													1				1
62			1														1
66	1			1		3	1										6
70	1				1	1	1	1									5
74		1	1		1	1	7	6	3	7	1		1				29
78			1	1	1	3	8	21	21	20	11	3	2				92
82			1		1		2	9	42	44	39	12	1				151
86					1		1	6	8	43	61	61	19	4	1		205
90					1		1		2	10	26	39	42	10	8	1	140
94	1							1		1	3	13	15	10	9	1	54
98												3	3	1	2	1	10
102															1		1
	3	1	4	3	6	8	21	44	76	125	142	132	84	25	21	3	698

Correlation = $.648 \pm .014$

Figure 24. Average height in centimeters of culms per plant correlated with average weight in milligrams of kernels per plant. 1917.

	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	
37.5	1																					1
42.5																						
47.5								1														1
52.5																						
57.5																						
62.5																						
67.5																1						1
72.5																						
77.5												1	1									2
82.5							1			1	1	1	2	1	2		1					10
87.5								1		1	1	4	10	19	15	9	3	2				65
92.5			1						1	1	2	4	16	24	58	38	10	3			1	159
97.5						1				1	1	2	5	14	55	71	20	5	2			177
102.5										1				7	11	26	9	6				60
107.5																	1	2				3
	1		1			1	1	2	1	5	5	12	34	65	141	145	44	18	2		1	479

Correlation = .426 ± .025

AVERAGE HEIGHT OF CULMS CORRELATED WITH OTHER PLANT CHARACTERS

The coefficients for average length of culms correlated with number of kernels per plant are .257±.036, .339±.025, .364±.022 and .431±.025, respectively, for the four years. This is a substantial and fairly consistent relation very similar to that found between yield of kernels and average height of culms. There is a tendency for increase or decrease in average height of culms to result in the production of a larger or smaller number of kernels per plant.

When average height of culms is correlated with average weight of kernels, the coefficients are .458±.030 in 1914, .071±.028 in 1915, .548±.014 in 1916 and .426±.026 in 1917. With the exception of the very low correlation in 1915 due to extremely favorable environmental conditions, the relation is substantial. The indications are that under ordinary conditions there is a tendency for increase or decrease in average height of culms to be accompanied by a raising or lowering of average kernel weight.

For average height of culms correlated with number of culms per plant the coefficients are -.195±.037 in 1914, -.092±.028 in 1915, .046±.025 in 1916 and .205±.029 in 1917. The correlation varies considerably from year to year and is low in each instance. Therefore, the conclusion may be drawn that the slight tendency for the two characters to vary together is highly modified by the influences of environment.

The coefficients for average height of culms correlated with average length of spikes per plant are .316±.035 in 1914, .419±.023 in 1915, .775±.010 in 1916, and .568±.017 in 1917.

Similar to the correlation between yield of kernels and average length of spikes, the relation of these two characters has a tendency to be high but is strongly modified by environmental conditions.

When average height of culms is correlated with total length of spikes per plant, the coefficients are .036±.038, .260±.026, .235±.024, and .351±.027. This is a variation from no correlation to a fairly substantial one. The influence of environment may entirely overcome the tendency of the two characters to move together.

Considering as a whole the relation of average height of culms to other plant characters there is a tendency for an increase or decrease in average height of culms to be accompanied by an increase or decrease in number of kernels and average length of spikes. Between average height of culms and average weight of kernels there is a substantial correlation and between average height of culms and total length of spikes there is a moderate correlation three years out of four. The correlation between average height of culms and number of culms is always low.

CORRELATION OF HEIGHT OF PLANTS AT DIFFERENT STAGES OF DEVELOPMENT

When height in centimeters at appearance of second leaf is correlated with height of the same plants at six weeks from seeding, the coefficients are .406±.038 in 1914, .467±.022 in 1915, .470±.019 in 1916, and .466±.024 in 1917. The correlation between the two characters is substantial and consistent.

For height of plants at appearance of second leaf correlated with height of tallest culm at maturity, the coefficients are .380±.033 in 1914, .270±.026 in 1915, .272±.023 in 1916, and

.211±.029 in 1917. This is a medium correlation modified considerably by environmental influences.

The coefficients for height in centimeters at six weeks correlated with height of the tallest culms of the same plants at maturity are .399±.038, .236±.026, .523±.018, .314±.027. The correlation between the two characters varies from rather low to moderatly high depending upon the environment.

Cohsidering as a whole the correlations between height of plants at different stages of development, there is a distinct tendency for plants of varying heights at second leaf to maintain the same relative heights at six weeks but there is a lesser tendency for this relation to be maintained at maturity. Some of the shorter plants at second leaf approach closely or equal in height the taller ones at maturity. There is a tendency, considerably modified by environment, for differences in height of plants at six weeks to be maintained in the tallest culm at maturity.

Considering the interrelation of plant characters as a whole, there is a range from practically none to a high correlation. Correlation is modified by environment, the degree of modification due to this cause varying with the characters considered.

Increased yield of kernels is very closely accompanied by increase in number of kernels, number of culms and total length of spikes; and somewhat less closely accompanied by increase in average weight of kernels per plant, average height of culms and average length of spikes.

A larger number of culms per plant is accompanied by a greater total length of spikes but not by a greater average length of spikes.

Average weight of kernels is substantially and fairly consistently correlated with yield of kernels; and, subject to radical change due to environment, moderately correlated with average length of spikes. With number of kernels, the correlation is rather low but always consistent. Average weight of kernels is practically independent of average length of spikes.

There is a distinct tendency for greater average height of culms to be accompanied by a greater average length of spikes, number of kernels and a higher yield of kernels. Average height of culms is substantially correlated with average weight of kernels and moderately correlated with total length of spikes in three years out of four. The correlation between average height of culms and number of culms is always low.

There is a distinct tendency for plants of varying heights at second leaf to maintain the same relative heights at six weeks; but there is a lesser tendency for this relation to be maintained at maturity.

GENERAL DISCUSSION

During early growth in 1914 and 1915, the means for height of the plants are greater than those in 1916 and 1917 due to the somewhat more productive soil on which the plants were grown, to the more favorable weather conditions and a higher average weight of seed planted. In 1915 the favorable growing conditions continued throughout the season and the mean for each plant character at maturity, except average weight of seed, is the highest in the four-year period. In 1914, during July, drouth followed by an epidemic of black-stem-rust lowered materially the means for all plant characters at maturity.

For each of the characters studied, except yield of kernels, the variability as indicated by the standard deviations, is as high as or higher in 1914 and 1915 than in 1916 and 1917. The generally higher variability in the former two as compared with that in the latter two years is accompanied by generally lower correlation coefficients (1) when weight of seed sown is correlated with resultant plant characters and (2) when yield of kernels is correlated with other plant characters.

When weight of seed sown is correlated with plant characters at maturity, it is noticeable that in 1915 there are four coefficients with the minus sign and that there is a tendency for the coefficients to be lower than in 1914.

In contrast with the low and varying relation in 1914 and 1915 is the generally moderate and consistent correlation between weight of seed sown and plant characters in 1916 and 1917 when the plants were grown on the poorer soil and from somewhat lower mean weight of seed.

From this study, conclusive evidence is given that for the conditions under which the work was done, environment reduced radically or obliterated entirely the correlationbetween weight of seed sown and plant characters among which is yield.

This information answers, in part at least, the questions raised in the introduction to this article regarding the role of weather and soil in comparisons of heavy and light seed for planting.

If these results were applicable to the wheat crop in general during the four year period, it is clear that, on soils of moderately high productivity with favorable weather conditions, heavy kernels as compared with light kernels used for planting may be expected to give very moderate or no increase in yield.

In the study of the interrelation of plant characters, a substantial and fairly consistent correlation was found between yield of kernels and average weight of kernels, average height of culms, and a somewhat higher correlation with number of culms. Between average height of culms and average weight of kernels there is a moderately high correlation each year except in 1915 when the coefficient is very low.

If these relations held for the wheat crop during the four year period, separating from the crop eadh year seed of higher average weight would be selecting seed from plants which had a decided tendency toward higher yield; and, with the exception of the year 1915, from plants which were taller and at the same time higher yielding. In 1915 there was practically no relation between average weight of kernels and average height of culms and separating the larger seeds from this crop would be selecting seed from both high and low yielding plants.

The tendency of the tallest plants and the plants having the greatest number of culms to be the highest yielders is a valuable index in making individual plant selections from mixed populations.

SUMMARY OF CONCLUSIONS

Subject to the environmental conditions under which the work was done, the following conclusions may be drawn:

The magnitude of the means for any of the characters studied varied in response to environmental conditions. Lower yields of straw resulted from a reduction in number, total length, or average length of culms per plant; and lower yields of grain from a reduction in the number of kernels. When the kernels developed normally, lower yield was accompanied by a higher average weight per kernel.

In general, a reduction in the magnitude of the means is accompanied by less variability. A number of exceptions to this general tendency occurred.

Correlation between weight of seed sown and resultant plant characters at maturity is not high in any instance and may be so modified by environmental conditions that the relation may be slight or obliterated entirely.

Correlation between plant characters is modified by environment, the degree of modification from this cause varying with the characters considered.

Increased yield of kernels is very closely accompanied by increase in number of kernels, number of culms and total length of spikes; and somewhat less closely accompanied by increase in average weight of kernels per plant, average height of culms and average length of spikes.

A larger number of culms per plant is accompanied by a greater total length of spikes but not by a greater average length of spikes.

Average weight of kernels is substantially and fairly consistently correlated with yield of kernels, and, subject to radical change due to environment, moderately correlated with average length of spikes. With number of kernels the correlation is rather low but always consistent. Average weight of kernels is practically independent of average length of spikes.

There is a distinct tendency for greater average height of culms to be accompanied by greater average length of spikes, number of kernels and higher yield of kernels. Average length of spikes is moderately correlated with average weight of kernels three years out of four. The correlation between average height of culms and number of culms is always low.

There is a distinct tendency for plants of varying height at second leaf to maintain the same relative heights at six weeks; but there is a lesser tendency for this relation to be maintained at maturity.

ACKNOWLEDGEMENTS

The writer wishes to acknowledge his appreciation of the helpful suggestions given by Dean E. M. Freeman, Professor H. K. Hayes and Professor Andrew Boss. The assistance of Professor R. J. Garber in the biometrical work is very highly valued.

BIBLIOGRAPHY

Atkinson, Alfred
1912. A study of the correlation of characters of wheat. Presented as a thesis for the degree of M.S. in Agriculture, Cornell University, 1912. (not published)

Davenport, Eugene
1907. Principles of breeding. 1-727.

Georgeson, C. C.; Burtis, F.C; and Otis, D.H.
1897. Experiments with oats. Kan. Agr. Expt. Sta. Bulletin 74:199-200.

1896. Experiments with wheat. Kan. Agr. Expt. Sta. Bulletin 59:89-105.

Kiesselbach, T.A. and Helm, C.A.
1917. Relation of size of seed and sprout value to the yield of small grain crops. Nebr. Agr. Exp. Station Research Bulletin 11:1-73.

Leighty, C. E.
1914. Variation and correlation of oats (Avena sativa) Cornell University Agr.Expt.Sta. Memoir 4:77-216.

Love, H. H. and Leighty, C.E.
1914. Variation and correlation of oats (Avena sativa) Cornell University Agr.Expt.Sta. Memoir 3:1-70.

Love, H. H.
1912. A study of the large and small grain question. Amer. Breeders' Assoc. Ann. Rept. 7:109-118.

Meyers, C. H.
1912. Effect of fertility on variation and correlation in wheat. Amer. Breeders' Assoc. Ann.Rept. 7:61-74.

Montgomery, E. G.
1908. Cultivation of small grains. Use of the fanning mill for selecting wheat and seed oats. Nebr. Agr. Exp. Sta. Bulletin 104:1-34.

1912. Competition in cereals. Amer. Breeders' Assoc. Ann. Rept. 7:118-127.

Roberts, H. F.
1912. Variation and correlation in wheat. Amer. Breeders' Assoc. Ann. Rept. 7:80-109.

Waldron, L. R.
1910. A suggestion regarding heavy and light seed grain. Amer. Nat. 44:48-56.

Williams, C.G. and Welton, F.A.
1913. Oats. Ohio Agr. Expt. Sta. Bulletin 257:255-283.

1916. Wheat experiments. Ohio Agr. Expt. Sta. Bulletin 298:447-484.

Zavitz, C. A.
1915. Inflnence of seed selection. Ont. Agr. College Bulletin 228:10-12.