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Characters Connected With the Yield of the Corn Plant

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CHARACTERS CONNECTED WITH THE YIELD OF THE CORN PLANT

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In 1909 the Department of Agronomy of the Missouri Experiment Station began a study of the factors influencing the development of the corn plant. In 1914 this department was divided into the Departments of Soils and Field Crops, which thereafter separately carried on those phases of the study most appropriate for their respective attention. The study as a whole ended in 1920. That part of it directly concerned with the effect of nutrition upon growth has been reported by Duley and Miller.[1] That part concerned with the correlations between structure and function will be reported in this paper.*

I.—A Study of the Correlation Between Yield and Certain Characters of the Corn Plant.

The essential purpose of this study was to contribute to the solution of a problem then (1914) receiving much attention in the field of plant genetics—the correlation between yield and measurable variations in the visible characters of the corn plant. It is a familiar problem to all who have read closely the agronomic literature of the past 12 years. Likewise its conclusion, though never a real solution, is nearly conventional, for almost without exception its investigators have reported (1) that the correlations did not exist or (2) that those observed were not significant. The brief results reported in this paper are not exceptional to the ensemble of evidence from similar studies by other investigators. They are reported because (1) though brief, they contribute a clear case and (2) the great weight of concordant evidence now existing would seem almost to preclude a pos-

[1]This and subsequent numerical references are to the Bibliography.

*The writer had no connection with this project. He is merely a reporter of results secured in 1910, 1911 and 1914, from studies by C. B. Hutchison, C. E. Neff, S. B. Nuckols and others. His presentations and interpretations are therefore critical. Possibly the original investigators would have presented their data more accurately; possibly they would have interpreted it differently.

sibility that further study of the problem by the present conventional methods would prove fruitful.

REVIEW OF RELATED LITERATURE

To review in detail the evidence contributed by previous investigators would show to many readers a familiar picture. It seems unnecessary to do that. Therefore the following brief summary presents only the essential developments.

In 1909, Montgomery[2] reported that a long (large) ear, medi um depth of the kernel and stockiness of the stalk, were corre lated with relatively high yield. Variation in other characters of the plant and ear showed no relation to yielding ability. The correlation between size of the ear and yield is of course obvious —one is an expression of the other. In the same year Hartley[3] reached this very pointed conclusion—"No visible characters of apparently good seed ears are indicative of high yielding power." He had made more than 1,000 ear-rows tests of 4 varieties, over a period of 6 years.

In 1910, Pearl and Surface[4] said they found no evidence of close association between the conformation of the seed ear and the yield that it produced. They had studied two very different types of sweet corn, giving particular attention to the shape of the ear and the covering of the tip. Ewing[5] after a very thorough study of the variation in several dimensional characters, such as height, and leaf breadth, concluded that "No single character among those studied has shown itself so closely connected with yield as to stand out as a safe guide to the breeder."

In 1911, Love[6] concluded that no characters of the ear were highly correlated with earliness and that none could serve as an index of earliness. Sconce[7] an Illinois seed corn breeder, after a study of 6 years, stated his belief that the number of kernel-rows, the form of the kernel and the size of the germ were correlated with the yield of grain. Funk[8], another Illinois seedsman, while not denying the existence of correlations, concluded that the conventional corn score card does not emphasize the points that affect yield. When he maintained by selection the type which made the highest yields, he gradually produced an ear very different from that idealized by the score card.

In 1913 McCall and Wheeler[9] presented their interpretations of various statistical data of other investigators. They concluded that significant correlations between yield and length, weight, circumference and density of the ear, had not been shown.

In 1914 Williams and Welton[10] made an exhaustive report of studies through a period of 10 years. As an average, long ears showed an advantage in acre yield of 1.39 bushels over short ears; but tapering ears showed an advantage of 1.65 bushels over cylindrical ears; bare-tipped ears 0.34 bushels over full-tipped ears; smooth-dented kernels 1.76 bushels over rough-dented kernels; and ears of a high shelling percentage (88.16) were 0.52 bushels lower in acre yield than ears with a low shelling percentage (76.07).

In 1916, Cunningham[11] reported that smooth and medium smooth kernels outyielded rough kernels by a considerable margin. Variation in several other characters showed no correlation with yield. He concluded that correlations were variable with the environment.

In 1917, Love and Wentz[6] found that "The characters of length, ratio of butt to tip, average circumference of cob, weight of ear, average weight of kernels, number of rows of kernels, and average length and width of kernels in seed ears do not show correlations significant enough to be of value in judging seed corn." They reached this conclusion after five years of study with one variety. Hughes[12] believed the first year's results of his experiment with seed corn indicated a close correlation between yield and the ear characters idealized by the score card.

In 1918 Hutcheson and Wolfe[13] believed they had found significant correlations between yield and the size and trueness to type of the ears. Many other characters, such as shelling percentage, number of rows, space between rows, and the filling of the butt, were not related to yield in a significant way. Olson, Bull and Hayes[14] from apparently the soundest and most comprehensive study yet conducted, failed to find a significant correlation between yield and any of a broad range of characters observed. They made the very practical statement that "Close selection for high scoring ears is of no practical value in increasing yield."

MATERIAL AND METHODS

Ten ears of each type in the following groups were selected from the variety Boone County White, as seed for the crop in which the correlation study was to be made.

A. Long, slim, smooth ears
B. Long, thick, smooth ears
C. Short, thick, smooth ears
D. Medium long, medium thick, medium rough
E. Long, slim, rough ears
F. Long, thick, rough ears
G. Short, thick, rough ears

Each of the 70 ears was planted in an ear-row, each type in a separate series. Thus there were 10 ear-rows of long, slim, smooth ears; 10 of long, thick, smooth ears; and so on. The series were contiguous and each fifth row was a check, planted with seed of one type. The hills were spaced 44 inches apart, each way, and two plants were left in each hill as the final stand. The crop received ordinary cultivation. Just before the tasseling stage 40 normal plants in each row were labeled, each plant standing among similar normal plants. There were labeled a total of 2800 plants and for each the following data were recorded:

1. Date of tasseling.
2. Date of silking.
3. Number of tillers at full growth.
4. Leaf area above the ear at full growth.
5. Leaf area below the ear at full growth.
6. Total leaf area at full growth.
7. Height of ear at full growth.
8. Relative position of the ear-shank.
9. Height of stalk at full growth.
10. Number of nodes in stalk.
11. Circumference of first internode above ground, at full growth.
12. Circumference of first internode above ear, at full growth.
13. Tassel length.

When two ears were borne by a plant, all measurements with reference to the ear were made by the upper ear only, although the total yield of both ears was determined. The leaf area was the sum of the areas of individual leaves measured by Montgomery's formula—Area=12x¾ (breadth x length). The tassel length was measured by finding the sum of the length of five average lateral branches, dividing this sum by five and multiplying the quotient by the number of laterals, then adding to the product the length of the central spike. Sound ears were gathered from 1,761 of the 2,800 plants measured, and stored under good drying conditions for six weeks. The weight of shelled grain produced by each plant was computed on the basis of a uniform content of moisture.

THE RESULTS

The mean yields of shelled grain produced by plants from the various types of seed-ears are shown here.

TABLE 1.—THE RELATIVE PRODUCTIVITY OF SEED FROM DIFFERENT TYPES OF EARS.

Series	Type of original seed ear	No. of ears harvested for yield test	Mean yield in ounces of shelled grain per plant	Probable error (±)
A	Long, slim, smooth	195	7.7400	.1409
B	Long, thick, smooth	228	7.7150	.1169
C	Short, thick, smooth	256	8.1836	.1209
D	Medium long, medium thick, medium rough	264	7.9924	.1100
E	Long, slim, rough	256	8.7740	.1182
F	Long, thick, rough	270	8.2741	.1190
G	Short, thick, rough	292	8.2363	.1111
	Composite	1761	8.1525	.0452

The mean yields range highest in Series E, F, and G, and lowest in Series A, B, C, and D. But between the highest yield, Series E, and the lowest, Series B, there is a difference of only 1.06 ounces of shelled grain per plant. This difference, though small, might be significant did not the yields of the check rows (Figure 1) show that Series E was favored by a variation in the fertility of the soil. Doubtless Series F and G were likewise favored.

There were then no significant differences between the yields of plants produced from the various seed-ears representing an extremely wide range of form and identation, in the variety Boone County White.

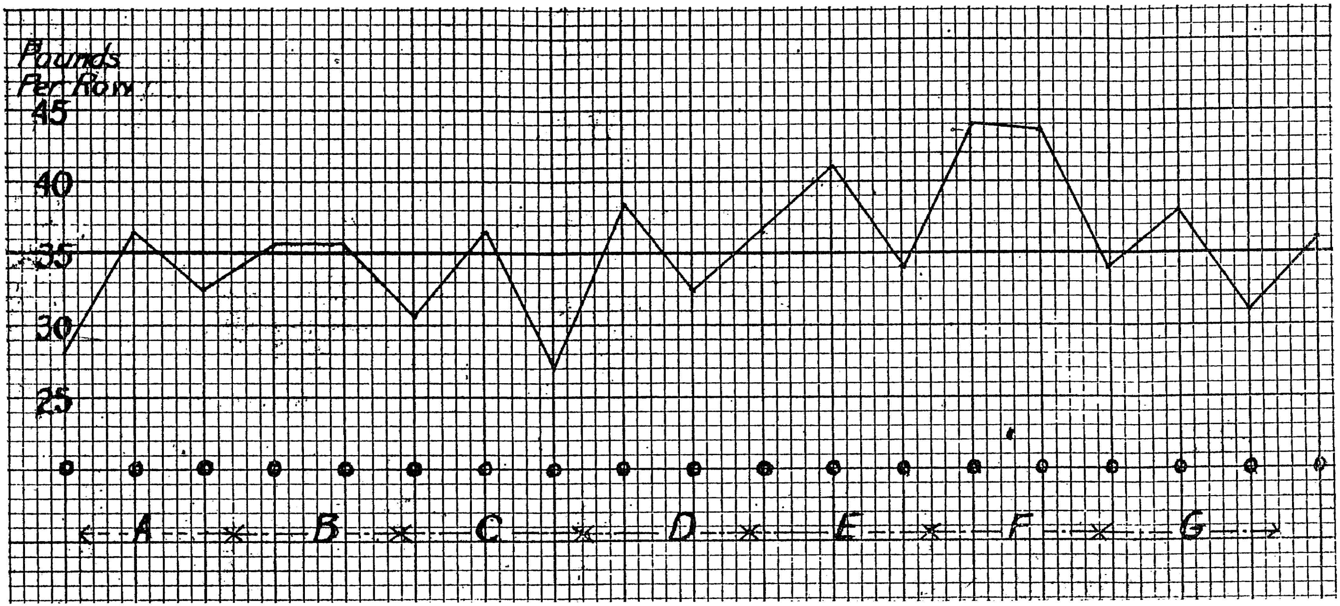

Fig. 1.—Showing the comparative location of Series A to G, and the location and yield in pounds of grain per row of the check rows marked O.

The correlation coefficients determined for the weight of shelled grain as the subject and various plant characters as the relatives are now shown.

TABLE II.—CORRELATIONS BETWEEN VARIATIONS IN PLANT CHARACTERS AND WEIGHT OF SHELLED GRAIN PER PLANT.

Character	Coefficient of correlation	Probable error (±)
Days from planting to silking	-.4181	.0133
Leaf area above ear	.0885	.0167
Leaf area below ear	.0565	.0167
Total leaf area	.0702	.0161
Height of stalk	.1109	.0160
Number of nodes in stalk	.0843	.0161
Height of ear	-.0006	.0161
Relative position of the ear-node	.0340	.0161
Circumference of internode above ground	.1846	.0155
Circumference of internode above ear	.0893	.0160
Length of tassel	-.1251	.0170
Number of tillers	-.0160	.0160

Although some of these correlations are statistically significant, none of them are high enough to be valuable as an index of yield. The negative correlation between yield and the age of the plant at silking, the highest correlation found, would doubtless vary greatly with the season.

DISCUSSION

The results of this brief study are concordant with those of other studies herein cited, in finding no significant correlations between the yield of the corn plant and variations in its visible structures and characters. But these and all similar results make no proof that such correlations do not exist, although the total evidence has come from a very exhaustive analysis. To accept fully the negation of correlations would lead to the conclusion that the corn plant is exhibiting the phenomenon of no relationship between external structure and function. Of course the correlations exist.

Why then are they not found in a measure that would justify their use as an index of the relative ability of the progeny to yield? A very simple explanation may be suggested.

In all studies of such correlations yield has been treated, consciously or not, as a single character of the plant. Obviously, this conception of yield is fundamentally wrong. Yield is a performance, not a character. It is the ultimate performance of the whole complex relationship of functions and structures that make up the plant. No doubt each function and structure varies with the environment. No doubt each variation influences yield; but only as it contributes to the final complex result of all variations. And so the influence of a given variation upon yield cannot be finally measured, simply because it cannot be identified and separated from the combined influence of innumerable other variations.

But is there no visible index of yielding ability that may serve as a guide in the practical operation of selecting seed corn? It was to answer this question that all correlation studies of corn were begun. Certainly there is such an index. It is yield itself—almost the old and simple idea of selecting the biggest ears.

Taking as an example any common one-eared variety of the Middle West, the yield of grain from plant to plant must vary with the size of the ear, excluding of course the slight variation in shelling percentage and the losses from unsoundness. So far then as yield can be improved by seed selection, the most exhaustive studies have discovered no better method than field selection of the biggest, soundest ears, well matured and unfavored by apparent differences in their local environment—stand, fertility, and so forth. Or if the plant bears more than one ear, of course its total yield, rather than the size of the individual ear, should be considered. In a given environment the best adapted and best yielding strain will of course show some distinguishing characteristic. For example, under certain conditions the highest yielding strain may have smooth kernels. But it does not follow that continued close selection of smooth seed ears will increase or even maintain the yield of the strain. For by that operation a specialized strain not so well balanced with the environment might be produced.

CONCLUSION

Within the conventional limits of a variety of corn, no variation in the visible structures or characters of a normal, healthy plant is a reliable index of the relative ability of its progeny to yield. The relative yield of the mother plant is the only indication, uncertain as it may be, of the relative yield of the progeny.

This conclusion is based not wholly upon the brief evidence presented in this paper, but upon the total evidence contributed by all investigators of the problem.

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II.—A Study of the Relation of Certain Ear Characters to Shelling Percentage Shrinkage and Viability.

This study was made in 1910 and 1911. Its purpose was to find whether variations in certain characters commonly used in judging seed ears were indicative of the relative shelling percentage, shrinkage and germination.

MATERIAL AND GENERAL METHODS

In 1910, 660 sound ears of a rough, large-eared strain of Boone County White, grown on rich alluvial soil, harvested in December of 1909 and stored in a tightly boarded crib until March 1, were used as experimental material. They will be designated as *Lot A*.

In 1911, 500 sound ears of the same variety, but of a more variable strain, were used. They too had been grown on rich alluvial soil, but had been harvested early in October and air-dried on racks in a mouse-proof seed room for a period of 12 weeks. They will be designated as *Lot B*.

Both lots were selected at random, except with reference to soundness. In both lots the individual ears were described in the details hereafter stated in Tables I—IV. All descriptions were recorded by the same person. No mathematical correlations were determined, but all comparisons were made between two classes showing extreme variation of the character in question, each class constituting about 15 percent of the total number of ears in the lot. For example, in studying the relation of length of ear to shelling percentage in Lot A, the average shelling percentage of the 100 longest ears was compared with that of the 100 shortest ears in the same lot.

THE RELATION OF EAR CHARACTERS TO THE SHELLING PERCENTAGE OF THE EAR

In Table I is shown the relation of various ear characters to shelling percentage, as determined by this method. The differences are in most cases slight and inconsistent. Except the difference between light and heavy ears, which may be attributed to the higher moisture content of the latter (see Table II), the size and shape of the ear show no significant relation to shelling percentage; but ears marked by deep kernels, narrow kernels, and starchy kernels produced a slightly higher proportion of grain than ears marked by shallow, wide, and horny kernels.

TABLE I.—EAR CHARACTERS AND SHELLING PERCENTAGE.

	Lot A—1910		Lot B—1911	
Character of the ears	Shelling percentage	Ave. weight of grain (grams)	Shelling percentage	Ave. weight of grain (grams)
Long	84.1	451.4	84.4	393.3
Short	86.1	367.5	84.5	347.1
Large circumference	84.4	450.7	84.7	408.3
Small circumference	84.8	371.1	86.3	357.0
Heavy	83.8	464.0	86.0	422.0
Light	89.9	358.5	85.7	327.2
Many rows of kernels	85.0	441.2	85.5	411.6
Few rows of kernels	83.3	384.4	84.5	369.4
Cylindrical	84.1	412.4	85.2	326.5
Tapering	84.4	411.8	84.6	381.0
Rough indentation	84.1	421.7	83.9	396.8.
Smooth indentation	84.2	411.8	84.2	337.6.
Deep kernels	85.7	450.1	86.4	409.2
Shallow kernels	83.1	383.2	83.2	334.7
Wide kernels	83.8	415.8	84.1	382.2
Narrow kernels	85.2	419.0	85.7	393.0
Horny kernels	82.0	391.2	83.8	346.3
Starchy kernels	85.5	415.8	85.6	379.8

THE RELATION OF EAR CHARACTERS TO THE SHRINKAGE OF THE EAR

The relation of ear characters to shrinkage was studied in Lot B by comparing the length, circumference, and weight of the ears as first stored, with their length, circumference and weight at the close of the total drying period of 6 weeks. The results of this study are shown in Table II.

Little relation is shown between shrinkage and indentation or between shrinkage and the length and shape of the ear. Apparently, however, heavy ears, thick ears, deep-kerneled ears, and ears with a large number of rows, lost considerably more weight than ears of the opposite types.

TABLE II.—EAR CHARACTERS AND THE AVERAGE SHRINKAGE IN LENGTH, CIRCUMFERENCE AND WEIGHT OF EARS OF LOT B.

Character of the ears	Loss in Length		Loss in Circumference		Loss in Weight	
	Inches	Percent	Inches	Percent	Grams	Percent
Long	.4572	4.4	.3825	5.3	69.4	15.6
Short	.3520	4.0	.3843	5.2	61.6	16.5
Large circumference	.4250	4.6	.4624	5.9	75.4	17.0
Small circumference	.3354	3.4	.3329	4.9	49.9	12.6
Many rows	.3790	4.0	.3930	5.1	77.3	17.1
Few rows	.3612	3.7	.2295	3.4	59.8	14.5
Heavy	.5140	5.2	.4183	5.6	92.4	19.1
Light	.3412	3.3	.3300	4.7	44.5	12.8
Cylindrical	.4362	4.5	.4000	5.8	63.9	17.3
Tapering	.3710	3.9	.4000	5.5	65.8	15.6
Rough indentation	.3651	3.8	.3475	4.6	58.2	13.7
Smooth indentation	.4222	4.5	.4030	5.9	67.8	14.2
Deep kernels	.3849	4.0	.3520	4.6	89.7	18.3
Shallow kernels	.3108	3.2	.3700	5.5	59.8	15.7

In the same lot of ears the rapidity of shrinkage was determined by weighing at intervals of two weeks, 300 ears grouped in extreme classes as previously described.

The results are shown in Table III.

TABLE III.—EAR CHARACTERS AND THE PROGRESSIVE RATE OF SHRINKAGE.

Character of the ears	Percentage of Loss in weight						
	2-wks	4-wks	6-wks	8-wks	10-wks	12-wks	Total
Large circumerence	8.6	5.6	1.7	1.1	0.7	0.5	18.2
Small circumference	6.6	5.3	1.6	1.2	0.4	0.4	15.5
Heavy	9.6	6.2	1.6	1.1	0.5	0.5	19.5
Light	6.9	4.5	1.8	0.8	0.3	0.6	14.9
Many rows	8.6	6.2	1.5	1.0	0.6	0.3	18.2
Few rows	7.8	5.2	1.9	1.0	0.8	0.4	17.1
Rough indentation	7.8	5.5	1.7	0.9	0.4	0.5	16.8
Smooth indentation	8.2	5.9	1.8	0.9	0.8	0.6	18.2
Deep kernels	10.5	5.9	1.9	0.9	0.6	0.2	20.0
Shallow kernels	7.9	5.3	1.5	1.2	0.5	0.2	16.6
Horny kernels	8.4	5.7	1.6	1.1	0.2	0.4	17.4
Starchy kernels	8.9	5.7	1.8	1.0	0.4	0.5	18.3

It may be noted first that in all classes of ears more than 75 percent of the total shrinkage occurred during the first four weeks, and that thereafter the shrinkage in all classes of ears was very slight from one two-week interval to another. Weather conditions were about the average for October, November and December in this section. These results then may indicate the probable time required to air-dry seed corn under good conditions of farm storage. Apparently it would not be necessary to keep the seed ears on racks or various other drying devices for longer than a month. They could then be stored in a more convenient bulk without damage because of the moisture they contained. Their remaining moisture would be given off very slowly and uniformly over a long period.

There seems little significance in the relative rates of shinkage by ears of the different types. Large ears and heavy ears lost moisture more rapidly during the first two weeks than ears of the opposite types, due probably to their large, heavy cobs. The comparatively rapid drying of deep-kerneled ears may indicate the desirability of this type for seed, provided they are also large, sound, and well matured.

THE RELATIONS OF EAR CHARACTERS TO VIABILITY

At the time of this study the ears (Lot A) were two years old. They had been harvested in December 1909 and stored for nearly 3 months under rather poor conditions before they were sent to the Experiment Station. Their shelling percentage had been determined (Table I) and the grain of individual ears, stored separately in bottles, had been fumigated several times with hydrocyanic acid gas. In November, 1911 this seed was tested for germination.

To make the tests, kernels were planted at a depth of 1 inch in sand which was kept at a temperature of about 80°F during the day and about 60°F during the night, and in a fairly uniform condition of moisture. A composite hundred kernels from each ear of the 660-ear lot—a total of 66,000 kernels—were planted in two equal series, one 12 days later than the other. Ten days after planting, the numbers of strong sprouts, weak sprouts, and sprouts not appearing above the ground, were counted. The results are given in the following table.

TABLE IV.—EAR CHARACTERS AND GERMINATION.

(Percentage of Germination in 10 Days)

Character of the ears	Strong plants	Weak plants	Plants not above ground	Total germination
Long	34.8	12.1	7.2	54.1
Short	37.3	13.3	9.6	60.1
Large circumference	30.5	11.0	7.3	48.8
Small circumference	45.4	12.9	6.8	65.1
Heavy	28.3	11.8	7.1	47.2
Light	42.2	12.6	7.0	61.8
Many rows (22 and more)	30.9	11.5	6.4	48.8
Few rows (16 and less)	44.7	13.2	7.0	64.9
Twisted rows	39.6	12.6	6.8	59.0
Straight rows	38.1	12.0	6.6	56.7
Cylindrical	38.2	11.8	6.2	56.2
Tapering	39.0	12.4	7.2	58.6
Close spaced rows	42.4	13.7	7.5	63.6
Open spaced rows	37.2	11.6	8.3	57.1
Rough indentation	35.3	12.6	7.5	55.4
Smooth indentation	46.4	11.8	5.4	63.6
Wide kernels	33.4	12.5	7.8	53.7
Narrow kernels	35.5	12.1	5.8	53.4
Deep kernels	27.0	11.4	6.7	46.6
Shallow kernels	44.2	12.9	5.5	62.0
Horny kernels	54.4	8.0	4.4	66.8
Medium horny kernels	39.4	11.8	6.1	57.3
Starchy kernels	36.0	10.1	7.2	53.3
Large germs	34.1	10.9	6.4	51.4
Small germs	41.6	12.4	6.1	60.1
High shelling percentage	30.2	11.5	6.5	48.2
Low shelling percentage	43.6	11.3	5.8	60.7
Heavy grains	32.3	12.6	7.4	52.3
Light grains	37.1	11.9	5.5	54.5
Heavy cobs	33.4	12.2	7.0	52.5
Light cobs	39.3	12.5	6.3	58.1

A brief inspection of the data will show that seed from short ears, light ears, ears with few rows, and ears of small circumference, germinated better than seed from ears of the opposite extreme types. However, it can hardly be assumed that these various characteristics of size bear a direct relation to the viability of the seed. Each of them is in some degree merely an expression of the circumference or weight of the cob; and one might expect a comparatively low germination in seed borne on a large, sappy cob, because of the unfavorable effect of a higher moisture content. Some verification of this is found in the fact that seed from light cobs germinated 58 percent, while seed from heavy cobs germinated 52 percent.

The data do not show a material difference in the germination of seed from ears extremely variable in shape and in the form and spacing of the kernel rows. However, smooth, shallow, horny kernels, germinated better than rough, deep, and starchy kernels, respectively. Small germs sprouted better than large germs.

It is possible that the treatment of the seed previous to the germination tests—late harvesting, 3 months storage in a crib, and several fumigations with hydrocyanic acid gas—may have affected differently the viability of the various types. Certainly the viability of all types was very low as a result of this treatment.

SUMMARY

1. Ears extremely characterized by deep kernels, narrow kernels or starchy kernels, had a slightly higher shelling percentage than ears of the opposite extremes. No other characteristics of the ear showed a significant relation to the proportion of grain.

2. Heavy ears, thick ears, deep-kerneled ears, and ears with a large number of rows, lost considerably more weight than ears of the opposite extremes, during a total drying period of 6 weeks. These characteristics are of course closely related to the size of the cob. Other characteristics of the ear showed no relation to the total loss of moisture.

3. In all types of ears more than 75 percent of the total shrinkage occurred during the first 4 weeks of a drying period of 12 weeks. Additional shrinkage was very slow over the following 8 weeks period. This indicates that when seed corn has been air-dried on racks or other devices for about a month, under climatic conditions similar to those of this experiment, it may safely be stored in a more convenient bulk.

4. Smooth kernels, shallow kernels, horny kernels, and kernels with small germs, showed a higher viability than kernels of the opposite extremes. No characteristic of the ear as a whole showed a relation to viability which may not be traced to the moisure content of the cob. Possibly the previous treatment of the seed influenced the relative viability of the different types.