EFFECT OF FROST ON THE GERMINATION OF CORN

THE EFFECT OF FROST ON THE GERMINATION OF CORN.

by

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INTRODUCTION.

The value of corn as a cereal crop in the warmer portions of North America has long been recognized, but its dependability in the cooler regions of the continent depends to a large extent upon the variety or strain grown. In localities where temperature is the limiting factor there exists the ever present danger of frost injury to that which is being matured for seed, and the larger part of Canada, outside of a portion of south-western Ontario, is included in this area. Taking the country as a whole, therefore, corn is more important as an ensilage than as a grain crop, and most of that grown for husking is of the earlier flint and dent types.

The great progress made in corn breeding during the past decade, particularly in the isolation and development of pure lines through self pollination, opens almost limitless possibilities for the adaptation of this crop to localities hitherto considered entirely unsuitable. It is generally conceded, however, that from a practical standpoint the most desirable varieties and strains are those which require for their development the major

portion of the available growing season. Hence we must always anticipate a certain amount of freezing injury in occasional years.

The purpose of the present study is to throw as much light as possible on the relations of frost to moisture, maturity and germination.

PREVIOUS INVESTIGATIONS.

Shepperd and Ten Eyck (1) state that dry corn is not injured by frost, but if stored in a damp place it may suffer injury.

Transeau (2) says of corn, "Unless its water content falls below 20 % before killing frosts come it is sure to be injured."

Cunningham (3) states, "Seed corn should be selected in the field after the corn is mature and before the first hard freeze occurs, and should be thoroughly dried before it is subjected to freezing temperature."

Russel (4) states in describing some experience in corn curing, "The corn cured in the furnace room

was practically kiln dried and produced almost a perfect stand of excellent vigor. While the corn cured in the tool house was not exposed to rains and snow, it was not protected from damp, foggy weather. This corn gave a good stand, but the plants were strikingly less vigorous than the furnace room corn. The corn which was hung from the eaves on the south side of the barn received no protection from the rains, snow or sun. This gave a poor stand, exceedingly deficient in vigor."

Fancher (5) states, "Hard frosts kill the germ in corn that contains a lot of moisture."

Kiesselbach and Ratcliffe (6) state in regard to autumn frosts, "Frosts sufficiently severe to kill the vegetative part of the corn plant are by no means necessarily severe enough to injure the germination of the kernels. The amount of moisture contained in the corn, and the duration and degree of cold are determining factors. In only very exceptional years is the germination injured by the first killing frost. More depends upon the kind of temperatures following."

The following table gives the results of

some experiments on the germinative ability of corn at different stages of maturity. The variety used by them was Hogues Yellow Dent. Immediately after harvest the seed was hung in a dry airy place and was tested for germination late in the winter.

TABLE 2. (Kiesselbach and Ratcliffe)

Germinative ability of corn harvested at various stages of maturity. Average for three years 1915-1917

Date of selec'n.	Condition of grain.	Days since fertiliz'n.	Germination %
Aug. 24	Milk stage	20	80
Aug. 31	Late Milk stage	27	92
Sept. 7	Roasting-ear	34	94
" 14	Late roasting-ear	41	97
" 21	Denting	48	97
" 28	Glazing	55	96
Oct. 5	Mature	62	96

They state further, " Dry corn containing 10-14 % of moisture will not be injured by any amount of winter freezing. Air dry corn with a moisture content of 10- 12 % will withstand the freezing temperature of liquid air or 190 degrees Fahrenheit below zero. On the other hand corn with 60 % of moisture may be killed by prolonged exposure to barely freezing temperature."

Kiesselbach and Ratcliffe (7) also report their observations on the physical and chemical effects of freezing seed corn. The readiness with which ice was formed in the kernels depended upon their moisture content. For seed containing 60- 80 % of moisture the freezing point was found to be only slightly below the freezing point of water. "On the other hand, no ice formation could be detected in air-dry kernels or in kernels containing less than 18 % of moisture, when subjected to the lowest temperature observed; namely 10 degrees F. below zero." They found further that the presence of ice around the embryo did not necessarily mean death. "The retention of life depends quite largely upon the duration of the frozen condition." And, "No rupture of cell walls or other cytological effect of freezing and ice formation within the kernels was apparent." From their experiments they were unable to determine definitely, exactly what caused the death from freezing, but they say, "Doubtless some chemical change has taken place, otherwise the tissues would not have darkened in color."

Kiesselbach (8) has endeavoured to establish a danger line of freezing injury or as he calls it

"An approximate safety zone." He says, " A slight lowering of the temperature or a longer duration of the exposure may initiate a reduction in the per cent germination at the moistures indicated but will not prove entirely fatal. Greater fatality will result as the adverse factors are extended. It will be noted that in general an extension of the time of exposure is comparatively as dangerous as is the lowering of the temperature, until the moisture content in the grain is reduced to 17 to 20 per cent where it manifests a decidedly greater resistance to the duration of exposure. When the moisture content is below 14 per cent corn will endure any natural low winter temperature for any length of time."

His chart indicates:-

(1) Corn containing 60 % moisture will withstand temperatures of 28 degrees F. and 20 degrees F. for periods of 8 and 4 hours, respectively.

(2) Corn having a water content of 50 % will withstand temperatures of 28 degrees, 24 degrees, and 20 degrees F. for periods of 12, 8, and 4 hours, respectively.

(3) Corn containing 40 % moisture will endure freezing temperatures of 28, 24, 20, 16 and 12 degrees F. for periods of 16, 12, 9, 6, and 4 hours respectively.

(4) Corn containing 30 % moisture will withstand freezing temperatures of 28, 24, 20, 16, 12, 8 and 4 degrees F. for periods of 24, 20, 14, 9, 6, 4, and 2 hours, respectively.

(5) Corn containing 25 % moisture will endure temperatures of 24, 20, 16, 12, 8, and 4 degrees F. for periods of 24, 18, 12, 8, 6, and 4 hours, respectively.

(6) Corn containing 20 % moisture will withstand temperatures of 16, 12, 8, 4, and 0 degrees F. for periods of 24, 16, 12, 8, and 5 hours, respectively.

(7) Corn containing 17 % moisture will endure temperatures of 4, 0, and -4 degrees F. for periods of 24, 16, and 6 hours, respectively.

(8) Air dry corn containing less than 14 % moisture will stand all natural low temperatures indefinitely.

"These data clearly suggest that corn is subject to freezing injury after it is ripe, whether in the field or in the crib until it is thououghly cured."

Duncan (9) reports germination experiments to show that while milk stage corn may germinate readily, it produces much less vigorous growth than that which is well matured.

A number of investigators have studied the relative germination of kernels from different parts of the ear. Halsted and Owen (10) cite experimental data to show that kernels from the centre of the ears were superior in viability to those at either extremity. They divided the ears into ten zones, beginning at the butt. The average germination of the fourth zone, which was the highest of all, was 94.44 %. The average germination of the first zone, the lowest of all, was 87.68 %. They state, "The ears were too well selected to yield any striking differences in viability as associated with place upon the cob."

Lacy (11) after reviewing the somewhat conflicting data and opinions of twenty-one investigators concludes that, "The tips and butts are certainly not inferior for seed purposes, and there seems little justification for the practice, prevalent in some sections, of discarding them for seed. " From the literature cited by Miss Lacy it would appear that any advantage possessed

by seed selected from the centres of the ears, is of a mechanical nature. The use of uniform sized seed in a corn planter tends to produce a more uniform stand of plants. The supposed value of uniformity of stand has, however, been somewhat discounted by Montgomery (12) and summing up the whole evidence, Miss Lacy comes to the conclusion quoted.

PLAN OF EXPERIMENT.

Three types of material were available for the work carried on. 1st. Ears from the variety plots of ensilage corn. 2nd. Ears from a multiplication field of North Western Dent. 3rd. Ears from a multiplication field of Quebec No. 28, flint corn.

The description of the work and the tabulation of the results naturally fall into three similar divisions. They will, therefore, be taken up one at a time.

All the corn used in these tests was grown during the summer of 1924. After the various

treatments mentioned, the corn for germination was placed in a dry basement room, some laid on wire racks, and the balance hung from suspended poles. The germination tests were made during the winter, and at no time did the temperature of the storage room approach that of freezing.

PART ONE.--ENSILAGE CORN.

The following is a list of the varieties used in this part of the experiment:-

Bailey (Check 1).
Leaming.
Bailey.
Golden Glow.
White Cap Yellow Dent.
Red Cob.
Bailey (Check 2).
North Western Dent.
Wisconsin No. 7.
Longfellow.
Comptons Early.
North Dakota.
Bailey (Check 3).
King Phillip.
Gold Nugget.
Stowells Evergreen.

List of varieties (continued):-

Minnesota No. 13.
Early Yellow Dent.
Bailey (Check 4).

In addition to these, samples of the first picking were also taken from a field of Golden Bantam sweet corn, grown by the Horticultural Department.

Methods Employed.

The first picking was made on October 14th., from which ten representative ears of each variety were selected. These were divided into five lots of two ears each. Two of these lots were analyzed for moisture content. The remaining three lots were frozen for ten hours at a temperature of 30 degrees F.,without husking.

A second picking was made on October 28th., divided and treated in the same manner, except that the temperature used was 28 degrees F..

A germination test was made of each frozen

lot by a modified "Rag Doll" method. A check, consisting of two untreated ears of each variety for each picking, was germinated in the same manner.

The freezing was done in a commercial cold storage plant where the temperatures were absolutely constant. In making the moisture determinations, each sample was husked and weighed as soon as picked. In bringing the entire lot to a constant air-dry weight, the excess moisture was driven off in a steam drier, after which the samples were left in wire trays for several weeks in a warm, dry, concrete basement. Ten lots were then selected at random, ground finely, and placed in glass jars. A preliminary experiment was then made to determine the most suitable length of drying period. An electric oven, operated at 90 degrees C., was used throughout. Porcelain crucubles, which had first been brought to a constant weight, were used.

In this preliminary experiment, four 5 gram samples were weighed out. These were dried for eight hours, cooled in a dessicator, weighed, dried for a second eight hours, again cooled, and finally weighed.

The following table shows the figures obtained:-

Table 1. Length of Drying Test. (Weight in grams)

Wt. of crucible	Wt. of sample.	Total weight.	Wt. at 8 hrs.	Wt. at 16 hrs.
32.8	5	37.8	37.49	37.485
35.21	5	40.21	39.906	37.893
34.55	5	39.55	39.33	39.226
35.066	5	40.066	39.747	39.745

It will be noted that in only one of the four samples was there any appreciable loss in weight after eight hours. Nevertheless it was deemed wise to carry all the oven samples for the full sixteen hours. The temperature, as previously indicated, was 90 degrees Centigrade.

Duplicate 5-gram samples were then taken from each jar and the loss in weight determined in the manner described. The following table gives the results of these analyses:-

Table 2. Moisture Determinations of ten Samples. (Weight in grams)

Original						Duplicate					
No.	Wt. of crucible	Wt. of sample	Total weight	Oven dry	Loss	No.	Wt. of crucible	Wt. of sample	Total weight	Oven dry	Loss
1	35.066	5	40.066	39.747	.319	1	34.55	5	39.55	39.226	.324
2	34.378	5	39.378	39.0699	.3081	2	34.36	5	39.36	39.047	.313
3	34.396	5	39.396	39.093	. 303	3	36.236	5	41.236	40.939	.297
4	33.22	5	38.22	37.9432	.2768	4	35.16	5	40.16	39.883	.297
5	34.720	5	39.720	39.3982	.3218	5	34.720	5	39.720	39.39	.33
6	34.49	5	39.49	39.18	.31	6	34.05	5	39.05	38.74	.31
7	32.8	5	37.8	37.4841	.3159	7	35.21	5	4o.21	39.895	.315
8	34.72	5	39.72	39.454	.266	8	32.142	5	37.142	36.876	.266
9	35.78	5	40.78	40.522	.258	9	34.217	5	39.217	38.959	.258
10	32.13	5	37.13	36.8741	.2559	10	32.71	5	37.71	36.4636	.2464
				Total	2.9345					Total	2.8564

Total moisture loss in 20 samples..... 5.7909 grams.

Average per cent of moisture..... 5.7909/

Average per cent of dry matter..... 94.2091.

It was then assumed that each air dry sample of corn contained 94.2091 % of dry matter. From this the total amount of dry matter in each lot was calculated, and finally the per cent of dry matter in each lot on the basis of the green weight. For example:-

The green weight of the original sample of Bailey (Check 1), as given in the first column of Table 3, is 679 grams. The air dry weight of the same sample is 337 grams. Multiplying 337 by 94.2091 gives 317.48 grams, the actual weight of dry matter. Dividing 317.48 by 679 gives .467, the amount of dry matter in each gram of the green material. Multiplying .467 by 100 gives 46.7, the amount of dry matter in 100 grams of the green material, or 46.7 %.

Table 3, shows the percentage of dry matter in each sample, determined by this method, for the first picking, and Table 4 shows the dry matter in each sample of the second picking.

Table 3. Percentage of Dry Matter in Ensilage Corn Picked October 14th.(Weight in Grams)

Variety	Original				Duplicate				
	Green Wt.	Air Dry Wt.	Dry Matter	% Dry Matter	Green Wt.	Dry Wt.	Dry Matter	% Dry Matter	Average % D.M.
Bailey(Check 1)	679	337	317.48	46.7	762	380	357.99	46.9	46.8
Early Leaming	505	214	201.6	39.9	733	357	336.32	45.8	42.9
Bailey	523	193	181.82	34.7	705	299	281.68	39.9	37.3
Golden Glow	622	257	242.11	38,9	674	300	282.62	41.9	40.4
White Cap Yellow Dent	475	192	180.88	38.0	836	374	352.37	42.1	40.0
Red Cob	928	229	215.73	23.2	615	130	122.47	19.9	21.5
Bailey (Check 2)	725	290	273.2	37.6	875	336	316.54	36.1	36.8
#North Western Dent(Var)	620	327	308.06	49.6	674	331	311.83	46.2	47.9
Wisconsin No. 7	458	102	96.09	20.9	787	331	311.83	39.6	30.7
Longfellow	490	219	206.31	42.1	573	251	236.46	41.3	41.7
Comptons Early	687	229	215.73	31.4	509	192	180.88	35.5	33.5
North Dakota	651	317	298.64	45.8	679	318	299.58	44.1	45.0
Bailey(Check 3)	699	266	250.59	35.8	593	280	263.78	44.4	40.1
King Phillip	680	298	280.74	41.2	490	259	244.00	49.7	45.4
Gold Nugget	654	276	260.01	39.7	457	157	147.90	32.3	36.0
Stowells Evergreen	1020	368	346.68	33.9	1000	331	311.83	31.1	32.5
Minnesota No. 13	670	343	323.13	48.2	769	412	388.14	50.4	49.3
Early Yellow Dent	552	305	287.33	52.0	657	344	324.07	49.3	50.7
Bailey (Check 4)	727	305	287.33	39.5	680	316	297.70	43.7	35.5
Golden Bantam	390	169	159.21	40.8	399	203	191.24	47.9	44.3

This North Western Dent is a variety row and a distinctly different lot from that mentioned in Part Two.

Table 4. Percentage of Dry Matter in Ensilage Corn Picked October 28th.
(Weight in grams)

Variety	Original				Duplicate				Average % D.M.
	Green Wt.	Air Dry Wt.	Dry Matter	% Dry Matter	Green Wt.	Air Dry Wt.	Dry Matter	% Dry Matter	
Bailey (Check 1)	525	246	231.75	44.1	728	335	315.60	43.3	43.7
Early Leaming	677	230	216.68	32.0	677	358	337.26	49.9	40.9
Bailey	689	289	272.26	39.5	662	339	319.36	48.2	43.8
Golden Glow	769	378	356.11	46.3	672	353	332.55	49.4	47.8
White Cap Yellow Dent	538	296	278.85	51.8	484	277	260.95	53.9	52.8
Red Cob	358	143	134.71	37.6	-	-	-	-	37.6
Bailey (Check 2)	589	304	286.39	48.6	470	241	227.04	48.3	48.4
North Western Dent(Var)	601	313	294.87	49.0	479	251	236.46	49.3	49.2
Wisconsin No. 7	443	267	251.53	56.7	483	243	228.89	47.3	52.0
Longfellow	328	157	147.90	45.0	469	221	208.20	50.9	48.0
Comptons Early	593	241	227.04	38.2	357	210	197.83	55.4	46.8
North Dakota	388	169	159.21	41.0	600	481	453.14	75.5	58.2
Bailey (Check 3)	625	314	295.81	47.3	613	312	293.93	47.9	47.6
King Phillip	703	391	368.35	52.3	549	317	298.64	54.3	53.3
Gold Nugget	664	357	336.32	50.6	710	428	403.21	56.7	53.6
Stowells Evergreen	758	297	279.80	36.9	727	242	227.93	31.3	34.1
Minnesota No. 13	537	290	273.20	50.8	658	352	331.61	50.3	50.6
Early Yellow Dent	448	277	260.95	58.2	625	384	361.76	57.8	59.0
Bailey (Check 4)	304	164	154.50	50.8	550	276	260.01	47.2	49.0
Golden Bantam	-	-	-	-	-	-	-	-	-

The rag dolls used for germination were made by spreading sheets of butter parchment about 24" by 30" upon a table. On each of these a piece of moist cotton of similar size was spread. Twenty-five kernels from each ear, representative of the butt, middle and tip, were picked off. These were placed on the cotton in rows 1 1/2" apart each way. The cloth and paper were then rolled up, tied, and placed in a moist part of the greenhouse for seven days, covered with damp sacking. The average temperature of the greenhouse was in the vicinity of 60 degrees F. At the end of the seven days the rolls were opened and the non- germinated kernels counted. It was noted that in practically every case the germination was weaker toward the centre of the roll; the germination seemed just as regular, but the shoots were seldom as long or stout. This was probably due to the limited amount of air in this part of the roll, and would suggest the possibility of reduced germination if the size of the rag doll were increased very much beyond that mentioned.

The results of the germination tests follow:-

Table 5. Percentage of Non-germinating Kernels in Ensilage Corn.

Variety	Picked October 14th.					Picked October 28th.				
	Frozen for 10 hrs. at 30 deg.				Check.	Frozen for 10 hrs. at 28 deg.				Check.
	1st.	2nd.	3rd.	Av.		1st.	2nd.	3rd.	Av.	
Bailey (Check 1)	0	0	6	2.0	6	8	4	0	4.0	2
Early Leaming	2	0	24	8.6	0	2	0	6	3.3	0
Bailey	0	8	0	2.6	6	2	0	2	.6	0
Golden Glow	4	0	18	7.1	2	4	12	24	13.3	0
White Cap Yellow Dent	4	0	0	1.3	0	2	0	0	.6	0
Red Cob	14	10	-	12.0	0	52	2	-	27.0	12
Bailey (Check 2)	2	0	0	.6	8	4	2	24	10.0	0
Wisconsin No. 7	0	0	0	0.0	6	12	16	4	10.6	0
Longfellow	1	2	0	1.0	0	0	2	10	4.0	4
Comptons Early	0	16	4	6.6	6	0	2	0	.6	6
North Dakota	4	0	0	1.3	2	2	8	2	4.0	2
Bailey (Check 3)	2	2	0	1.3	2	0	2	2	1.3	16
King Phillip	0	2	0	.6	0	0	4	2	2.0	4
Gold Nugget	0	2	2	1.3	0	2	4	0	2.0	2
Stowells Evergreen	5	2	0	2.3	0	2	0	18	6.3	0
Minnesota No. 13	2	0	0	.6	0	0	0	4	1.3	4
Early Yellow Dent	3	0	0	1.0	0	0	0	6	2.0	6
Bailey (Check 4)	6	0	4	3.3	2	16	8	16	13.3	0
Golden Bantam	6	6	2	4.6	1.3	-	-	-	-	-
North Western Dent(Var)	0	16	6	7.1	4	10	0	14	8.0	10

The extent of the frost injury to each of these pickings of ensilage corn has been calculated by Student's Method (13). The average number of non-germinated kernels in each frozen lot has been compared with the untreated check in each case. Odds of 30:1 are taken as significant (14). Table 6 gives the figures in detail for the first picking, and Table 7 for the second.

Table 6. Freezing Injury to Ensilage Corn Picked October 14th.

Variety	Non-germ. Checks	Non-germ. Frozen	Dif.	Dif.^{2}
Bailey (Check 1)	6	2.0	-4.0	16.00
Early Leaming	0	8.6	8.6	73.96
Bailey	6	2.6	-3.4	11.56
Golden Glow	2	7.1	5.1	26.01
W.C.Yellow Dent	0	1.3	1.3	1.69
Red Cob	0	12.0	12.0	144.00
Bailey (Check 2)	8	.6	-7.4	54.76
N.W.Dent.	4	7.1	3.1	9.61
Wisconsin No. 7	6	0.0	-6.0	36.00
Longfellow	0	1.0	1.0	1.00
Comptons Early	6	6.6	.6	.36
North Dakota	2	1.3	- .7	.49
Bailey (Check 3)	2	1.3	- .7	.49
King Phillip	0	.6	.6	.36
Gold Nugget	0	1.3	1.3	1.69
Stowells Evergreen	0	2.3	2.3	5.29
Minnesota No. 13	0	.6	.6	.36
Early Yellow Dent	0	1.0	1.0	1.00
Bailey (Check 4)	2	3.3	1.3	1.69
Golden Bantam	1.3	4.6	3.3	10.89
			19.9	397.21

Number = 20 Average dif.= .995 Average dif.^{2}=19.8605

$\sigma = \sqrt{19.8605-.9900} = 4.34$ $Z = .2292$

P = .8227 Odds = 4.6:1

Table 7. The Extent of Frost Injury to Ensilage Corn Picked October 28th.

Variety	Non-germ. Checks	Non-germ. Frozen	Dif.	Dif.^{2}
Bailey (Check 1)	2	4.0	2.0	4.00
Early Leaming	0	3.3	3.3	10.89
Bailey	0	.6	.6	.36
Golden Glow	0	13.3	13.3	176.89
W.C.Yellow Dent	0	.6	.6	.36
Red Cob	12	27.0	15.0	225.00
Bailey(Check 2)	0	10.0	10.0	100.00
N.W. Dent	10	8.0	-2.0	4.00
Wisconsin No. 7	0	10.6	10.6	112.36
Longfellow	4	4.0	0.0	0.00
Comptons Early	6	.6	-5.4	29.16
North Dakota	2	4.0	2.0	4.00
Bailey (Check 3)	4	1.3	-2.7	7.29
King Phillip	4	2.0	-2.0	4.00
Gold Nugget	2	2.0	0.0	0.00
Stowells Evergreen	0	6.3	6.3	39.69
Minnesota No. 13	4	1.3	-2.7	7.29
Early Yellow Dent	6	2.0	-4.0	16.00
Bailey (Check 4)	0	13.3	13.3	176.89
			58.2	918.18

Number = 19 Average dif.= 3.06 Average Dif.^{2}=48.3252

$\sigma = \sqrt{48.3252-9.3636} = 6.24$

Z= .4903 P = .97306 Odds = 36:1

Discussion.

While at first glance the percentage of dry matter, (Tables 3 and 4), of the duplicate samples, might appear to vary widely, yet when it is considered that only four ears are represented and very little was fully matured, the figures seem as close as could be expected.

The most outstanding variety from the standpoint of dry matter is the Red Cob. The average dry matter of this from the first picking was 21.5 % and from the second picking was 37.6 %. This being a particularly late variety, a low percentage of dry matter would be expected in comparison to lots that were more mature. The Stowells Evergreen and Wisconsin No. 7, two other late varieties, are also low in dry matter. It will be noted that these are among the ones showing the greatest increase in dry matter by the time of the second picking. It is probable that the extreme immaturity of some of the ears of Red Cob accounts for the irregularity in germination of the different ears,(Table 5), many of the kernels being scarcely formed.

It is regrettable that a more complete range of temperatures was not available. But from the

data presented it would appear that freezing for ten hours at a temperature of 30 degrees F. caused no appreciable injury, as shown by the odds of 4.6:1 (Table 6). It would seem that some injury had been caused to the Red Cob at this time, the average non-germinating kernels being 12.0%.

A temperature of 28 degrees for ten hours, two weeks later, apparently caused germination injury. Table 7 shows the odds of 36:1 that this was the case. It will be noted that the untreated ears of Bailey (Check 3) show a non-germination of 16 % (Table 5). In this case one of the ears was infected with one of the common disease organisms and so the figures from it were discarded, and the figure used, 4 %, was based on the sound ear only.

The figures obtained from this part of the experiment would seem to indicate the possibility of frost injury to immature ensilage corn if the temperature falls below 28 degrees for any length of time. This would agree in a general way with the findings of Kiesselbach (8) previously mentioned.

PART TWO. NORTH WESTERN DENT.

As a larger amount of this variety was available, it was possible to carry on more detailed work with it than was the case with the variety lots of Ensilage Corn, described in Part One. Two methods of applying frost injury suggested themselves. The one, a natural one, merely by leaving the corn in the field until certain low temperatures had occurred, and making pickings from time to time. The other, an artificial one, picking a group of ears and submitting them to a definite temperature for varying lengths of time. Both of these means were employed in this experiment.

Artificial Freezing For Different Periods

Corn from a multiplier field was gathered on the same dates as the ensilage corn, October 14th. and October 28th. Moisture and germination tests were made in the manner described for that, also.

Triplicate samples were placed in cold storage for 2, 4, 6, 8, 10 and 12 hours respectively, for the first picking. The temperature of the chamber was 30 degrees F.. In order to ascertain whether the temperature inside the husks was the same as the air

temperature, at the end of the two hour period a thermometer was inserted against the kernels. This registered the same as one hanging beside the ears.

The following table shows the resulting germination tests :-

Table 8. North Western Dent. Picked October 14.

Frozen at 30 Degrees. Average D.M., 46.2 %.

Time	1st.	2nd.	3rd.	Average % Non-germination
2 hrs.	0	2	1.6	1.2
4 "	2	0	0	.6
6 "	0	0	2	.6
8 "	6	10	14	10.0
10 "	6	0	0	2.0
12 "	2	0	4	2.0
	Check (No treatment)			0.

Duplicate samples of the second picking, October 28th, were carried for 2, 4, 6, 8, 10, and 12 hours at 28 degrees F. and a similar series at 4 degrees F.. The germination tests of these follow :-

Table 9. North Western Dent, Picked October 28.

Frozen at 28 Degrees F..Average Dry Matter 61.45 %.

Time	1st.	2nd.	Average % Non-germination
2 hrs.	2	0	1
4 "	12	0	6
6 "	0	2	1
8 "	2	8	5
10 "	8	0	4
12 "	0	2	1
Check (Untreated)			0

Table 10. North Western Dent, Picked October 28.

Frozen at 4 Degrees F.. Average Dry Matter 61.45 %

Time	1st.	2nd.	Average % Non-germination
2 hrs	6	2	4
4 "	22	24	23
6 "	84	50	67
8 "	66	67	67
10 "	52	74	63
12 "	66	70	68
Check (Untreated)			0

A study of Table 8 shows a very high percentage of germination. In only one freezing period, 8 hours, did the non-germination exceed 2 %, and in this the

figure is only 10 %. From the fact that each of the lots exposed for 10 and 12 hours gave very satisfactory germination it would seem probable that some other factor entered in.

The figures contained in Table 9 also show an average germination of well over 90 %, the lot which was frozen for 12 hours being as high as that which was in the freezing chamber for only 2 hours.

Table 10, however, shows decided frost injury to the corn exposed for 4 hours and longer. The average non-germination at 2 hours is only 4 %, increasing to 23 % at 4 hours, and 67 % at 6 hours. No greater injury was shown as the time of exposure was increased up to 12 hours, the figure of 68 % at that time being too close to consider it a definitely higher injury.

Natural Freezing Injury.

Pickings from the same multiplier field of North Western Dent were made on November 10th, November 18th, December 5th, and December 15th, following heavy frosts. A thermograph was kept in the corn patch from October 14th to December 16th and copies of the weekly temperature charts are given.

On three occasions prior to October 28th. the thermograph registered temperatures as low as 30 degrees F., and that this temperature was not injurious to germination is shown by the checks picked on that date (Tables 9 & 10). This is in harmony with the data on artificial freezing, given in Tables 8 and 9.

During the week ending November 4th. the temperature fell to 30 degrees F. on two occasions, and again to 28 degrees for a period of between three and four hours. On November 9th. 21 degrees was registered for about seven hours, and ears picked on the 10th. showed a non-germination of 16 %. During the week ending November 18th. the thermograph recorded a temperature of 10 degrees for three hours, and samples taken on this date averaged 82.6% of injury. The low point during the week ending the 25th. was 12 degrees. The week following, the low point was 20 degrees, and on December 4th. the temperature again fell to 10 degrees for two hours. A picking on December 5th. showed an average injury of 88 %. During the last forty-eight hours of the week ending December 16th. the thermograph varied from zero to 8 degrees, and a picking on December 15th., following approximately twenty hours at 0 degrees F., showed germination injury of 82.6 %.

The following gives in detail the germination tests at these dates:-

Table 11. Non-germination of North Western Dent at Various Dates.

Date	Min. Temp.	Av. % D.M.	Non-germination % 1st.	2nd.	3rd.	Average
Nov.10	21 deg.	65.5	38	8	2	16.0
" 18	10 "	72.1	100	100	48	82.6
Dec. 5	10 "	66.4	64	100	100	88.0
" 15	0 "	69.3	72	100	76	82.6

The percentage of dry matter seems to be as uniform as could be expected under the varying weather conditions obtaining at that time of the year. The difference in the germination injury of the various lots may have been due to different degrees of maturity, or there may have been some of the ears more fully protected by husks. In any case the trend of the injury is fairly evident. A temperature of 10 degrees F. rendered the corn practically unfit for seed, while appreciable injury was shown even at 21 degrees F..

Discussion.

While the data from these experiments with North Western Dent fail to establish a complete danger line of moisture and frost injury, no prospect of injury is apparent, for corn of this stage of maturity, as long as the thermometer stands at 28 degrees F. or higher. However, when the weather becomes so cool that temperatures around 20 degrees F. are recorded, injury may be expected. Temperatures of 10 degrees F. and lower render the field an unsafe place for seed corn. The desirability is also indicated of providing a curing room for corn, where it will not be subjected to low temperatures until the excess moisture is driven off. Further discussion of this phase of the problem follows the presentation of the experimental data concerning Quebec No. 28 corn.

PART THREE---QUEBEC NO. 28.

The Corn-crib As A Storage Place.

In this part of the experiment a small corn-crib, holding about two bushels of corn, was built and placed in a moderately exposed position near the college meteorological instruments. Corn from a multiplier field of this variety was husked and placed here on November 1st.. At this time the ears seemed well matured and hardened down.

Moisture and germination tests were made in the manner described for the ensilage corn. Ears were removed on February 2nd., February 20th., and on February 28th.

As indicated by the temperature charts, the early weather was comparatively mild. The first really severe frost occurred on the 17th. of November, when a minimum of 8 degrees and a maximum of 25 degrees F. were recorded. On the 18th. the range was from 9 to 20.5 degrees. December was characterized by fairly steady cold weather, a range of -9 degrees to -17 degrees on the 21st., and zero to -15 degrees on the 27th. being noted. During January the cold was also rather uniform. On the 1st. the temperature ranged from -6 to

-18 degrees. Still lower points were reached later in the month; on the 15th -19.5 degrees, on the 19th. -29 degrees, and finally the low point for the winter, -35 degrees on the 28th. No rain fell during the months of December or January.

During February the temperatures fluctuated greatly. As an example of the sudden changes at this period attention is drawn to maximum and minimum readings of 35 degrees on February 26th. followed by a record of -1 degrees on the 27th.

The first samples taken from the corn-crib, on February 2nd., showed an average germination injury of 17.3 % . The second sample, on February 20 th., showed an average injury of 60.6 %. The third sample, on February 28th., showed 86 % non-germination. Ears from the same field which had been stored in a dry basement room showed almost perfect germination. The following table shows this in more detail.

Table 12. Germination Injury in Corn-crib.

Date	Av.% D.M.	Germination 1st.	2nd.	3rd.	Average
Feb. 2	74.9	32	2	18	17.3
" 20	76.5	46	52	84	60.6
" 28	78.2	80	84	94	86.0
Check	90.6	0	0	1	.3

The greater percentage of dry matter (Table 12) in the later tests is believed to have been due to the removal of superficial ice. The weather during the latter part of February became mild enough for any ice and snow on the ears to melt and drain off, whereas a certain amount of congealed moisture probably adhered between the kernels at the time of the first sampling.

Discussion.

From these figures it would appear that less injury was caused to this material by steady cold than by broken weather with alternate freezing and thawing. Only slight, but none the less definite, injury, 17.3 %, was evident on February 2nd.. And although no temperature approaching the -35 degrees of January was experienced, -11 degrees on the 3rd. being the lowest, the non-germination on the February 20th. had increased to 60.6 %. Similarly the temperature of -1 degrees on the 27th. was followed by germination injury of 86 % on the 28th.

These conditions appear unavoidable in an average Quebec winter and therefore it is evident that a corn-crib is an unsuitable place in which to store seed corn. Complete protection from rain and snow seems desirable.

Butts, Middles and Tips.

In order to ascertain if any region of the ear were more susceptible to frost injury, ten ears were selected from the corn-crib on February 28th.. Sixteen kernels were shelled from the first and second rows at the butt, sixteen from the two rows near the middle, and sixteen from the two rows at the tip, of each ear. These were germinated in the same manner as in the previous tests. The following table gives the figures of the germination:-

Table No. 13. Frost Injury to Different Regions of the Ear. Quebec No. 28.

Ear No.	Butts	Middles	Tips
1	16	16	16
2	16	16	16
3	16	16	12
4	16	16	16
5	13	12	12
6	16	15	16
7	15	13	15
8	16	16	15
9	0	0	16
10	4	15	16
Average	12.8±1.18	13.5±1.0	15.0±.33

Superficially, these figures indicate that the least injury occurred to kernels at the butt and most

to kernels from the tip. However, when probable errors are taken into consideration, the differences, even between the butts and tips, are not significant.

Rate of Absorption of Air Moisture.

In an attempt to determine the rate at which air dry corn absorbed moisture, two tests were planned. In each case the material used was taken from a dry, concrete basement where it had been stored for upwards of three months. In the first test six lots of ten ears each were hung in a humid greenhouse. The various lots were removed after having remained there for 24, 48, 72 hours, 4, 10 and 24 days respectively. Of these lots, four ears from each were analyzed for moisture in duplicate samples of two ears each, as previously described, and six were submitted to whatever air temperature prevailed out of doors for 24 to 48 hours, and then tested for germination.

The relative humidity of the greenhouse was also determined by means of a sling hygrometer and the results of these observations are given in the following table:-

Table 14. Relative Humidity of Greenhouse.

Time	Relative Humidity in %.
10 a.m. (Before sprinkling)	54
10.15 " (After sprinkling)	69
2.p.m.	62
5. "	67
10.a.m. (Six days later)	67

Apparently the usual relative humidity varied around 60 %.

The following table gives the results of the moisture determinations:-

Table 15. Moisture in Corn Hung in Greenhouse.

Period	Dry Matter %		
	1st.	2nd.	Average
24 hours.	89.46	89.37	89.42
48 "	88.82	88.97	88.89
72 "	89.75	-	-
4 days	89.84	89.45	89.65
10 "	88.58	88.68	88.63
24 "	89.96	89.85	89.91
Check	90.21	90.56	90.38

It may be noted here that the temperature in the greenhouse varied considerably from day to day. When the sun shone brightly the thermometer went as high as 80 degrees F., while during the night it occasionally fell as low as 58 degrees.

The following table gives the germination tests for this material:-

Table 16. Germination Injury to Corn From Greenhouse. Quebec No. 28.

Period.	Av. Dry Matter %	Minn. Temp.	% Germination Injury 1st	2nd	3rd	Average
24 hrs.	89.42	-1 deg.	0	0	0	0
48 "	88.89	13 "	0	4	2	2
72 "	89.75	18.5 "	0	2	4	2
4 days	89.65	11. "	0	6	6	4
10 "	88.63	12.5 "	4	0	2	2
24 "	89.91	-1 "	0	2	0	.6

Discussion

The dry matter duplicates shown in Table 15 seem reasonably close, but apparently no regular increase in moisture content occurred. A definite increase seemed evident up to 48 hours, but after that considerable fluctuation in moisture was shown. It is suggested that the temperature differences previously mentioned had much to do with the indefinite nature of the results obtained.

Table 16 shows no appreciable injury to the germination of any of the lots, although temperatures as low as 1 degree below zero were recorded while the ears were hanging outside.

The Second Test

In the second test for the rate of absorption of moisture, the endeavour was made to keep the samples under as uniform conditions as possible throughout the entire period, and also to maintain a high degree of saturation of the air.

A simple apparatus was devised for the purpose. A wooden framework 24" high by 12" square was covered completely with two layers of cotton, the lower portion of this"skirt" being several inches longer than the frame. The entire arrangement was placed in a shallow copper pan which was filled with water, the cotton covering acting as a wick.

Seven pairs of Quebec No. 28 and a similar number of North Western Dent ears were hung from the inside of the framework. These were weighed carefully each day until they reached a constant weight.

The experiment was conducted in a basement room where the temperature was as uniform as it seemed possible to obtain. The relative humidity inside the apparatus was approximately 80 %, and that of the room in which the corn had been stored 52 %.

The actual weights of the ears from day to day are given in the following table:-

Table 17. Moisture Increases In Air Dry Corn.

(Weight in Grams)

N.W. Dent	Lot No.	Orig. Wt.	1st Day	2nd Day	3rd Day	4th Day	5th Day
	1	341	348	348	348	348	348
	2	253	256	258	258	258	258
	3	239	245	251	251	252	252
	4	228	232	232	233	233	233
	5	237	237	238	239	239	239
	6	230	232	232	232	232	232
	7	340	344	344	345	345	345
Que. No.28							
	1	316	320	325	326	326	326
	2	313	319	319	322	322	322
	3	330	332	332	334	334	334
	4	343	346	346	348	348	348
	5	404	408	413	420	420	420
	6	343	343	343	347	347	347
	7	318	322	322	323	323	323

The following table gives the relative weights of the ears from day to day:-

Table 18. The Relative Moisture Increases.

N.W. Dent	Lot No.	Orig. Wt.	1st Day	2nd Day	3rd Day	4th Day	5th Day
	1	100	102.05	102.05	102.05	102.05	102.05
	2	100	101.18	101,97	101.97	101.97	101.97
	3	100	102.51	105.02	105102	105.43	105.43
	4	100	101.75	102.19	102.19	102.19	102.19
	5	100	100.00	100.42	100.84	100.84	100.84
	6	100	100.86	100.86	100.86	100.86	100.86
	7	100	101.17	101.17	101.47	101.47	101.47
	Average		101.36	101.89	102.05	102.11	102.11
Que. No.28	1	100	101.26	102.84	103.16	103.16	103.16
	2	100	101.91	101.91	102.87	102.87	102.87
	3	100	100.60	100.60	101.21	101.21	101.21
	4	100	100.87	100.87	101.45	101.45	101.45
	5	100	100.99	102.22	103.96	103.96	103.96
	6	100	100.00	101.16	101.16	101.16	101.16
	7	100	101.25	101.25	101.57	101.57	101.57
	Average		100.98	101.55	102.19	102.19	102.19

The figures in Tables 17 and 18 show the flint and dent corn to be very similar in water absorption. The average increase in moisture content of the North Western Dent was 2.11 %, and of the Quebec No. 28 , 2.19 %. The greatest increase occurred during the first two days, only one sample of the fourteen showing any increase after that time. All the samples were at constant weight at the end of the third day.

Dates of Critical Frosts

A study of the meteorological records at Macdonald College for a number of years back indicate the approximate dates at which critical frosts may be expected. In Table 19 are presented the earliest dates on which certain temperatures have been recorded for each of the ten years from 1914 to 1923. The table follows:-

Table 19. Earliest Dates of Critical Temperatures.

Years 1914-1923 Inclusive.

Year	32 deg.	28 deg.	21 deg.	10 deg.
1914	Oct. 6	Nov. 2	Nov. 9	Nov.17
1915	" 11	" 6	" 18	" 12
1916	" 1	Oct.23	" 12	" 26
1917	" 9	Nov. 4	" 12	" 24
1918	Sep.29	" 4	" 25	" 30
1919	" 14	Oct.20	" 15	" 28
1920	Oct.30	Nov. 7	" 13	Dec. 9
1921	" 9	Oct.26	" 6	Nov.23
1922	Sep.26	" 19	Oct.19	Dec. 6
1923	Oct. 6	" 22	Nov.19	" 18

The earliest frost in this period occurred in 1919, on September 14th.. A temperature of 28 degrees or lower was recorded earliest in 1922, when the thermometer registered as low as 21 degrees on October the 19th.. This was the only year of the ten in which as low a temperature was recorded in the month of October. In only one year, 1920, has the time between the first frost and a temperature of 21 degrees been as short as 14 days. In every other year there have been at least 24 days between the dates of these temperatures.

Discussion.

From these records it would appear that, in this locality, corn in the field is safe for at least a fortnight after the first light frost, and in most years no injury is likely for three or four weeks.

In three years of the ten, injurious frosts occurred prior to November 9th., and it is evident, therefore, that the first week in November is the very latest it is wise to leave seed corn in the field.

The usual late fall weather, however, is characterized by frequent cold rains, and on that account it is advisable to harvest all seed corn by the latter part of October, if possible.

SUMMARY

1. A temperature of 30 degrees F. for ten hours failed to cause significant injury to ears from the variety plots of ensilage corn, as evidenced by odds of 4.6:1.

2. A temperature of 28 degrees F. for ten hours caused slight injury to corn from the variety plots as shown by odds of 36:1. This injury was only serious in some of the more immature sorts.

3. North Western Dent containing 46.2 % of dry matter was not injured by a temperature of 30 degrees F. for any period up to twelve hours.

4. North Western Dent containing 61.45 % of dry matter was not injured by a temperature of 28 degrees F. for any period up to twelve hours.

5. North Western Dent containing 61.45 % of dry matter showed negligible injury after two hours of exposure to a temperature of 4 degrees F.. After four hours of exposure the injury was 23 %. This was increased to 67 % non-germination at the end of six hours, and 68 % at the end of twelve hours.

6. Germination injury of 16 % occurred to North Western Dent ,in the field, when the temperature fell to 21 degrees F..

7. Temperatures of 10 degrees F., in the field, rendered North Western Dent unfit for seed.

8. The combination of precipitation, frost and varying temperatures, common in Quebec during the winter months, render a corn-crib an unsuitable place in which to store seed corn. It seems possible that steady cold may be less injurious than weather in which low temperatures are interrupted by occasional thaws.

9. In the case of ears of Quebec No. 28, stored in the corn-crib from November 1st. to February 28th., the differences in germination injury to kernels from the butts, middles and tips were insignificant.

10. Well dried corn absorbs moisture from the air fairly rapidly, but the actual increase in the weight is small.

11. At Macdonald College injurious frosts have occasionally occurred toward the end of the third week in October, but in most years, from the standpoint of frost alone, corn has been safe in the field until the first week in November.

Literature Cited.

1. J.H.Shepperd and A.M.Ten Eyck. North Dakota Exp. Sta. Bull. 51. 1912.

2. Transeau's "General Botany", p. 168.

3. C.C.Cunningham. "Growing Corn in Kansas". Kansas Exp. Sta. Bull. 205. 1915.

4. H.L.Russel. "Seed Corn Curing".Wisconsin Exp. Sta. Bull. 240, p. 28-29. 1914.

5. P.L.Fancher. "Save Your Seed Corn". Ont. Dept. of Agr., Circular 14. 1918.

6. T.A.Kiesselbach and J.A.Ratcliff. "Freezing Injury of Seed Corn". Neb. Exp. Sta. Bull 163. 1918.

7. T.A.Kiesselbach and J.A.Ratcliff. "Freezing Injury of Seed Corn". Neb. Res. Bull. 16. 1920.

8. T.A.Kiesselbach. "Productive Seed Corn". Neb. Exp. Sta. Bull. 188.

9. G.H.Dungan. Article in A.S.A.,Vol. 16, No. 8, p. 473-481. 1924.

10. B.D.Halsted and E.J.Owen. Article in A.S.A., Vol. 9, p.267-274. 1917.

11. M.G.Lacy. Article in A.S.A., Vol. 7, p. 159-171. 1915.

12. E.G.Montgomery. "Experiments With Corn." Neb. Exp. Sta. Bull. 112, p.35-36. 1909.

13. H.H.Love and A.M.Brunson. Article in A.S.A., Vol. 16, No. 1. 1924.

14. T.B.Wood and F.J.M.Stratton. Article in J.A.S., Vol. 3, p. 417-440. 1910-11.

Plate 1. Variety Plots of Ensilage Corn.

Plate 2. Multiplier Field of Quebec No. 28 Corn.

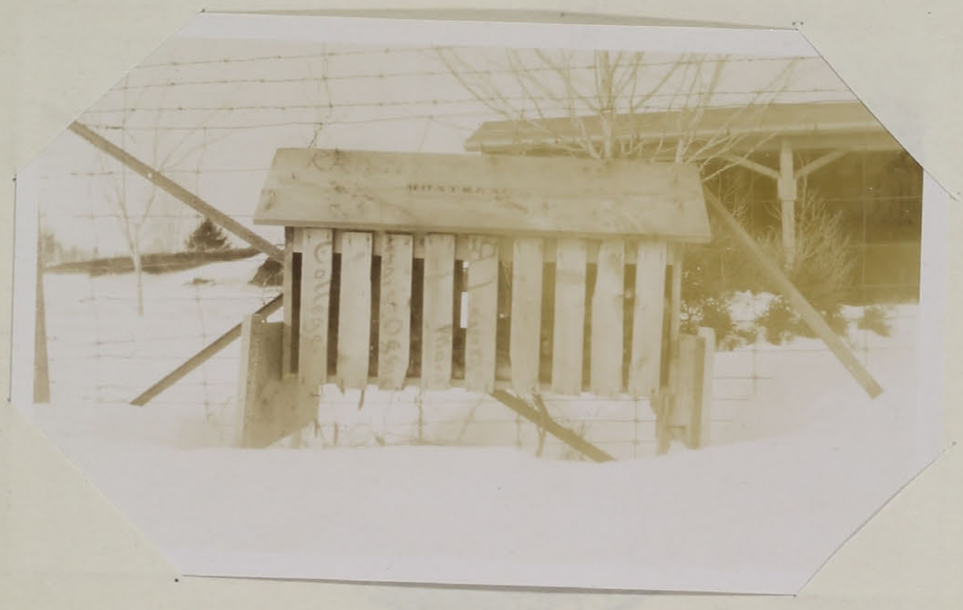

Plate 3. The Small Corn-crib Used.

Plate 4. Apparatus For Increasing Moisture Content.

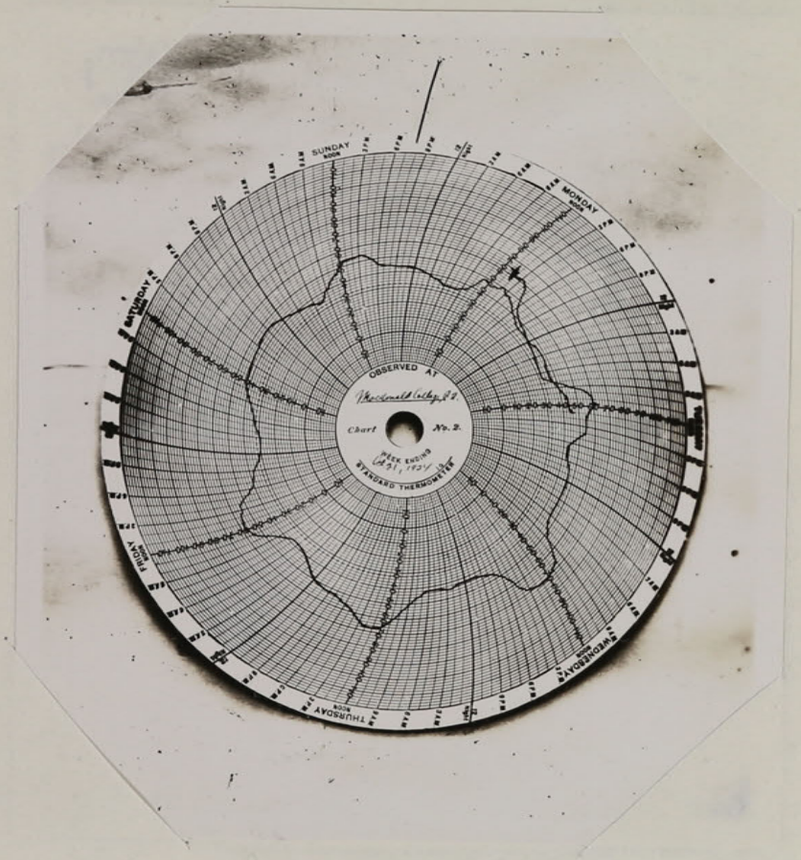

Plate 5. Thermograph Record.

October 14-21, 1924.

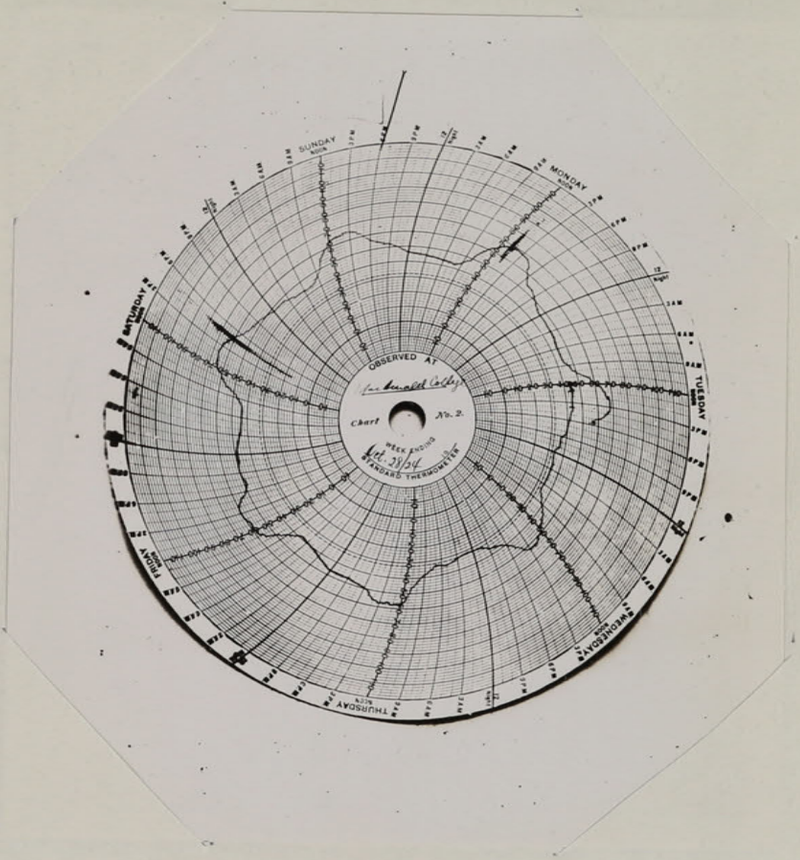

Plate 6. Thermograph Record.

October 21-28, 1924.

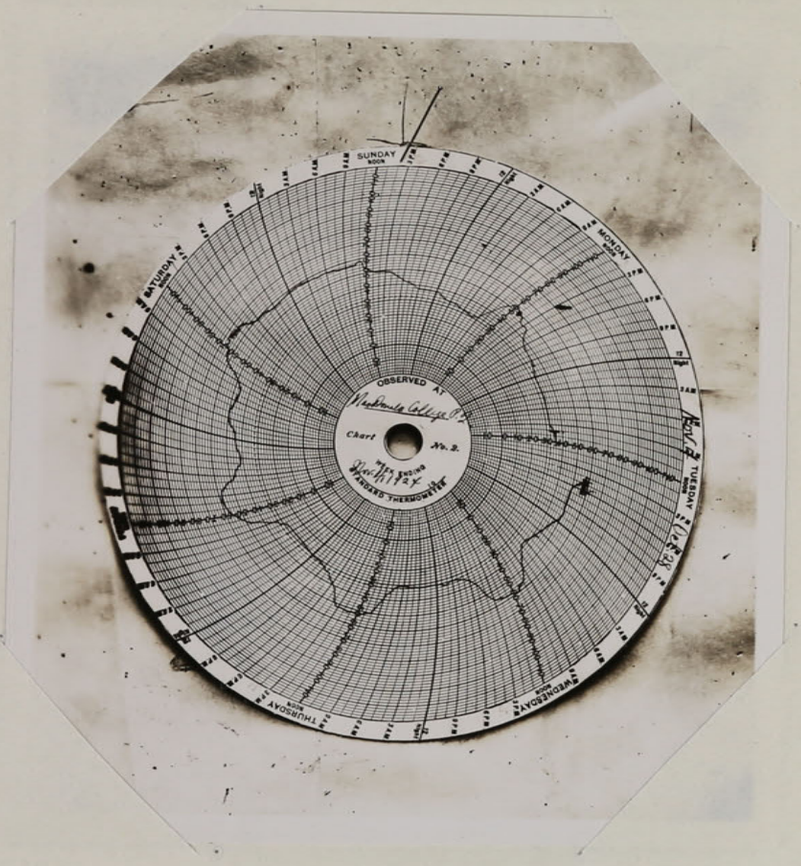

Plate 7. Thermograph Record.

October 28 to November 4, 1924.

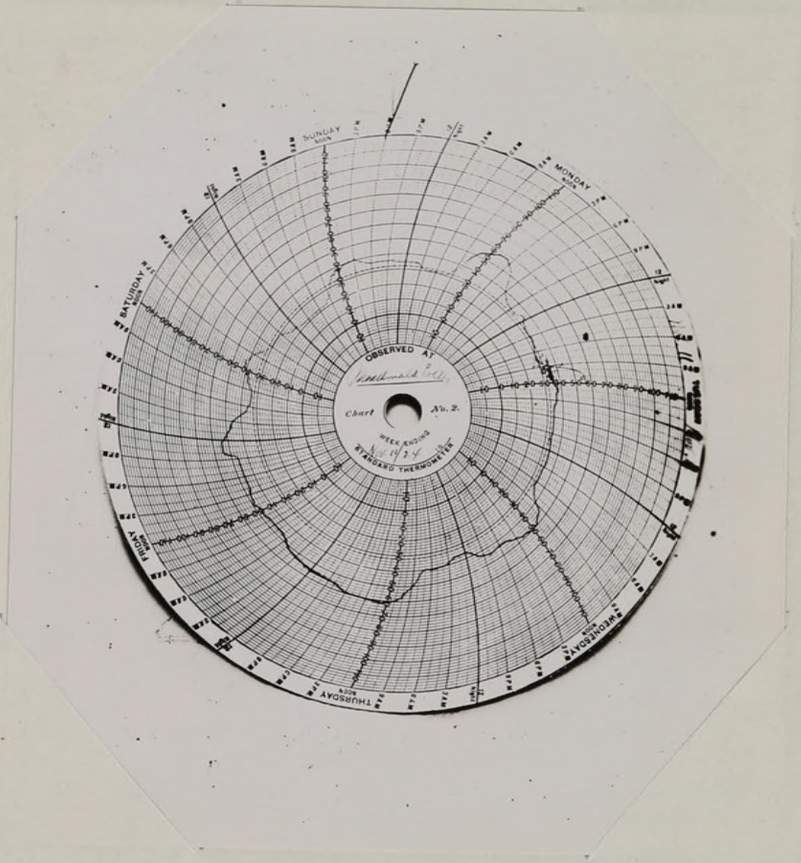

Plate 8. Thermograph Record.

November 4-11, 1924.

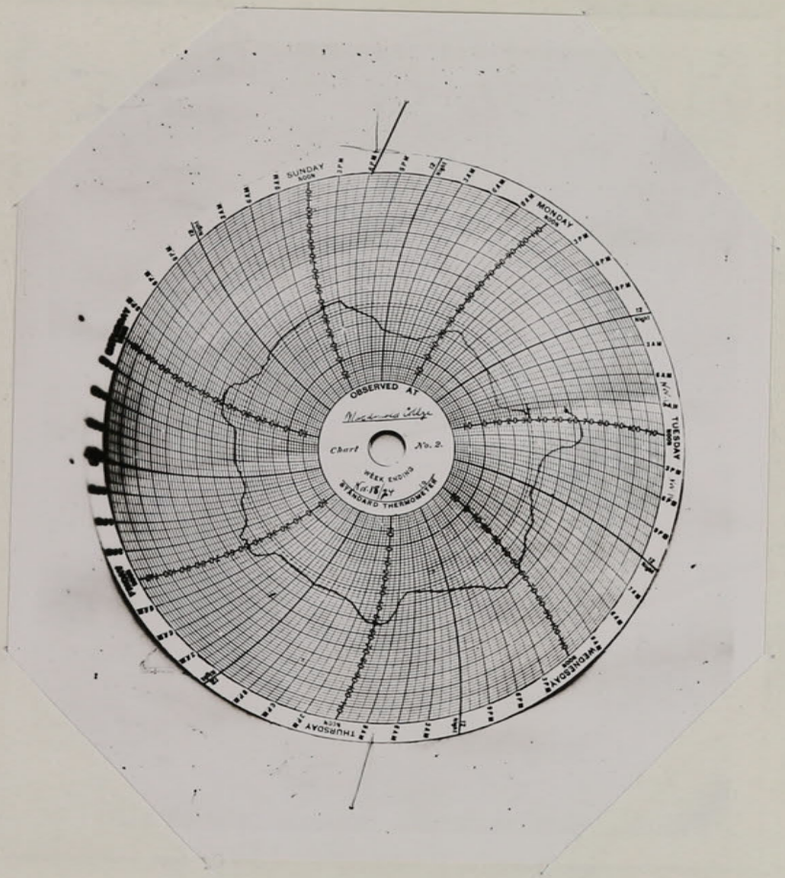

Plate 9. Thermograph Record.
November 11-18, 1924.

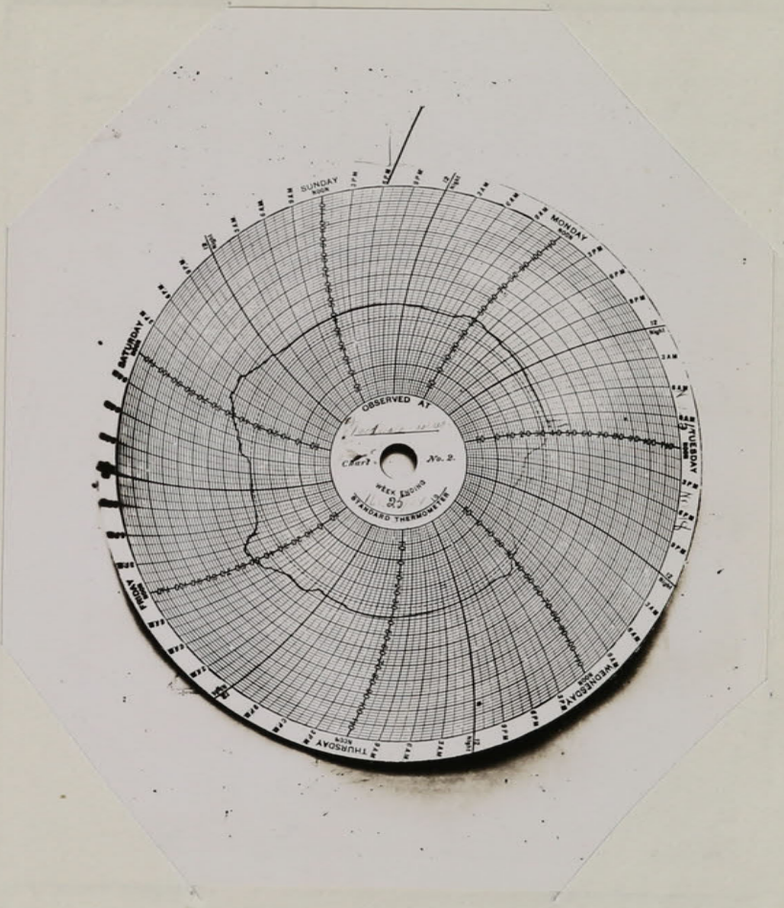

Plate 10. Thermograph Record.
November 18-25, 1924.

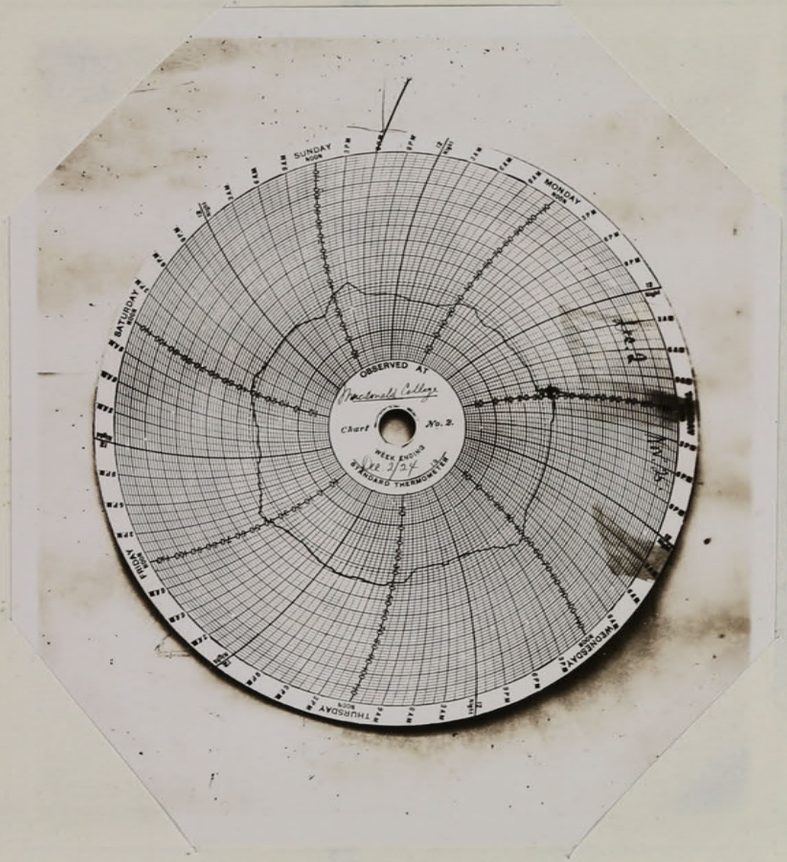

Plate 11. Thermograph Record.

November 25 to December 2, 1924.

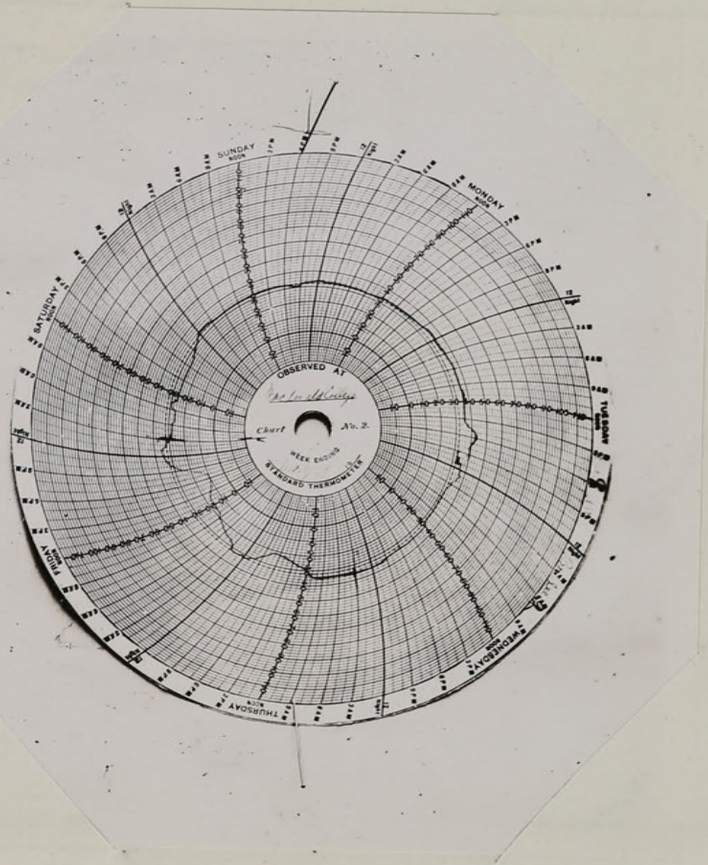

Plate 12. Thermograph Record.

December 2-9, 1924

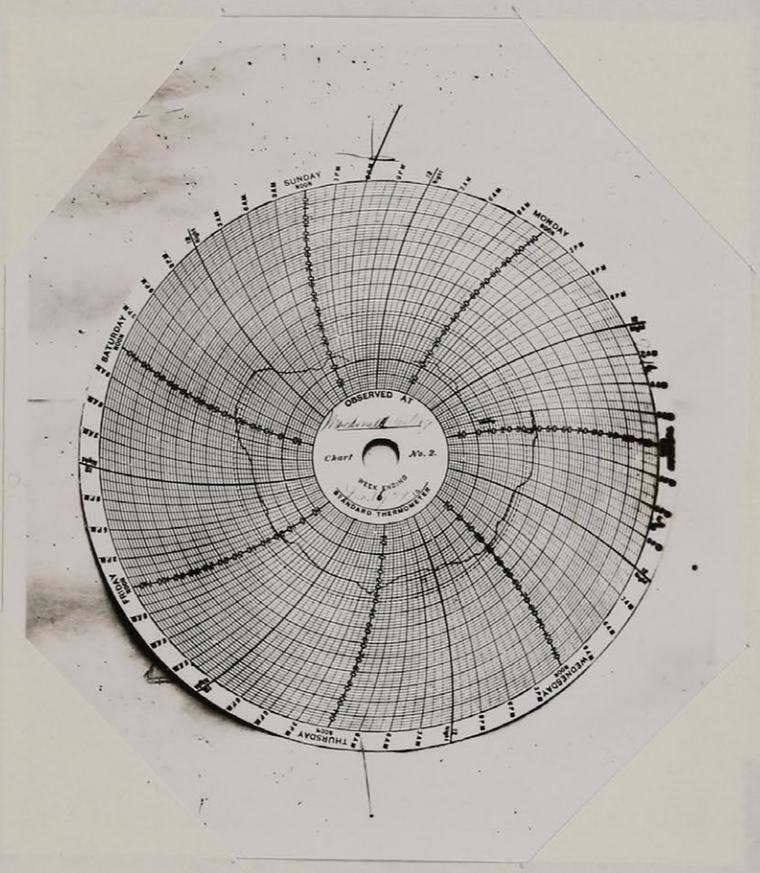

Plate 13. Thermograph Record. December 9-16, 1924.

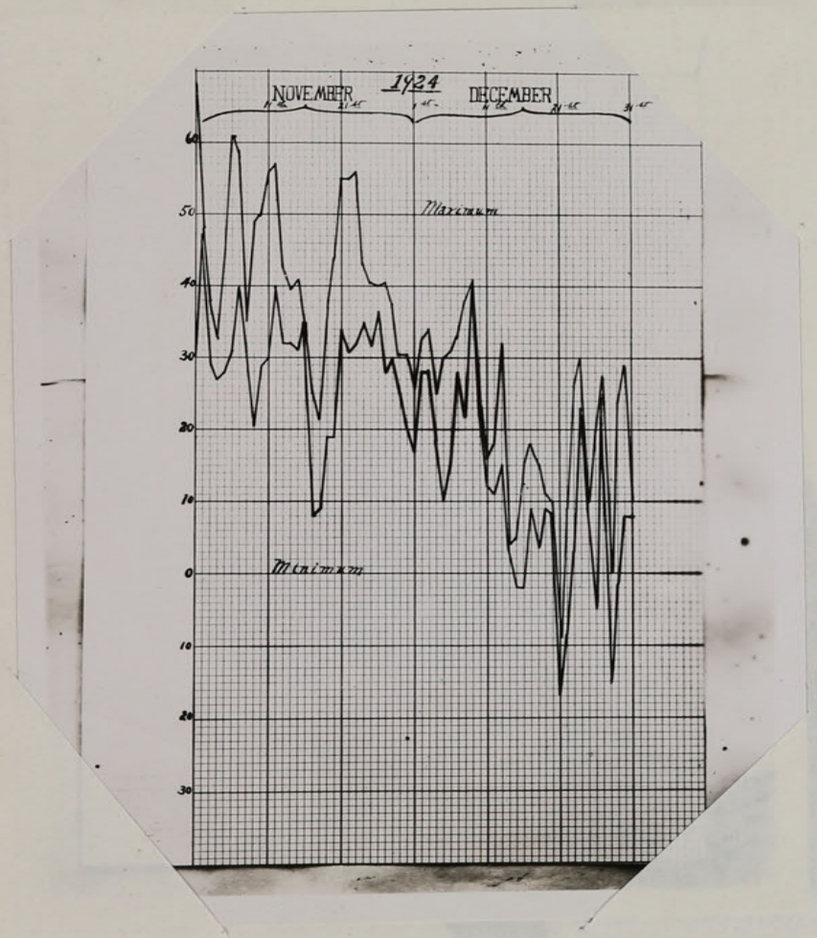

Plate 14. Temperature Chart.

November and December 1924.

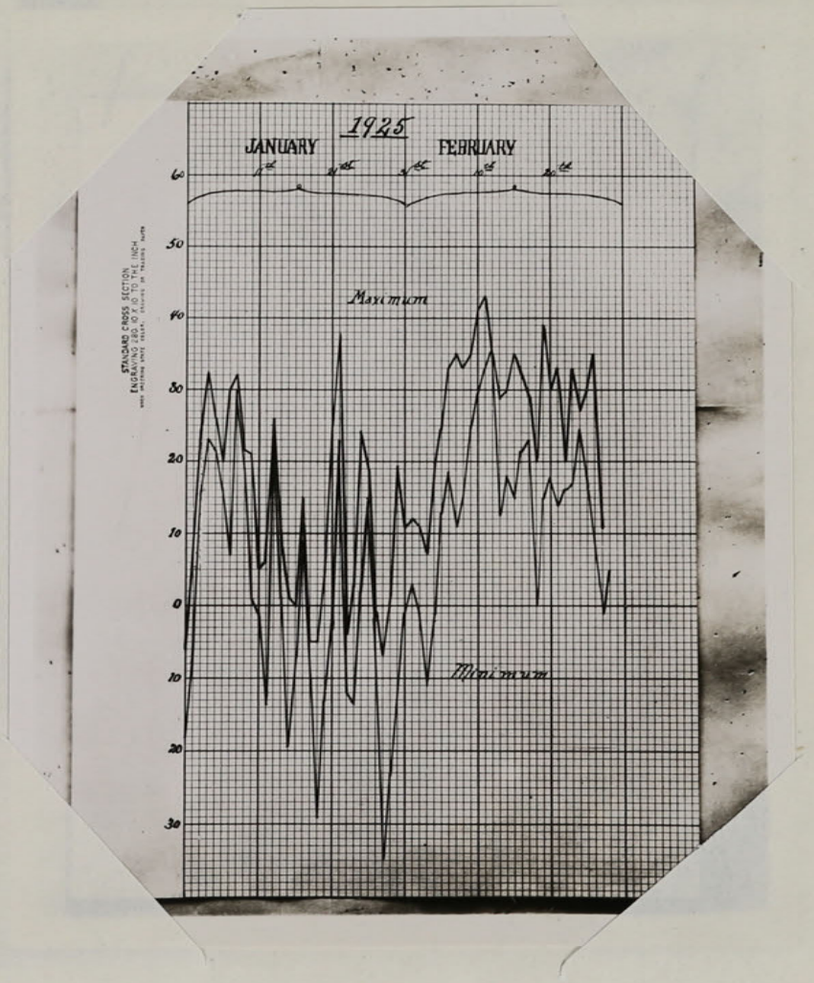

Plate 15. Temperature Chart.

January and February 1925.

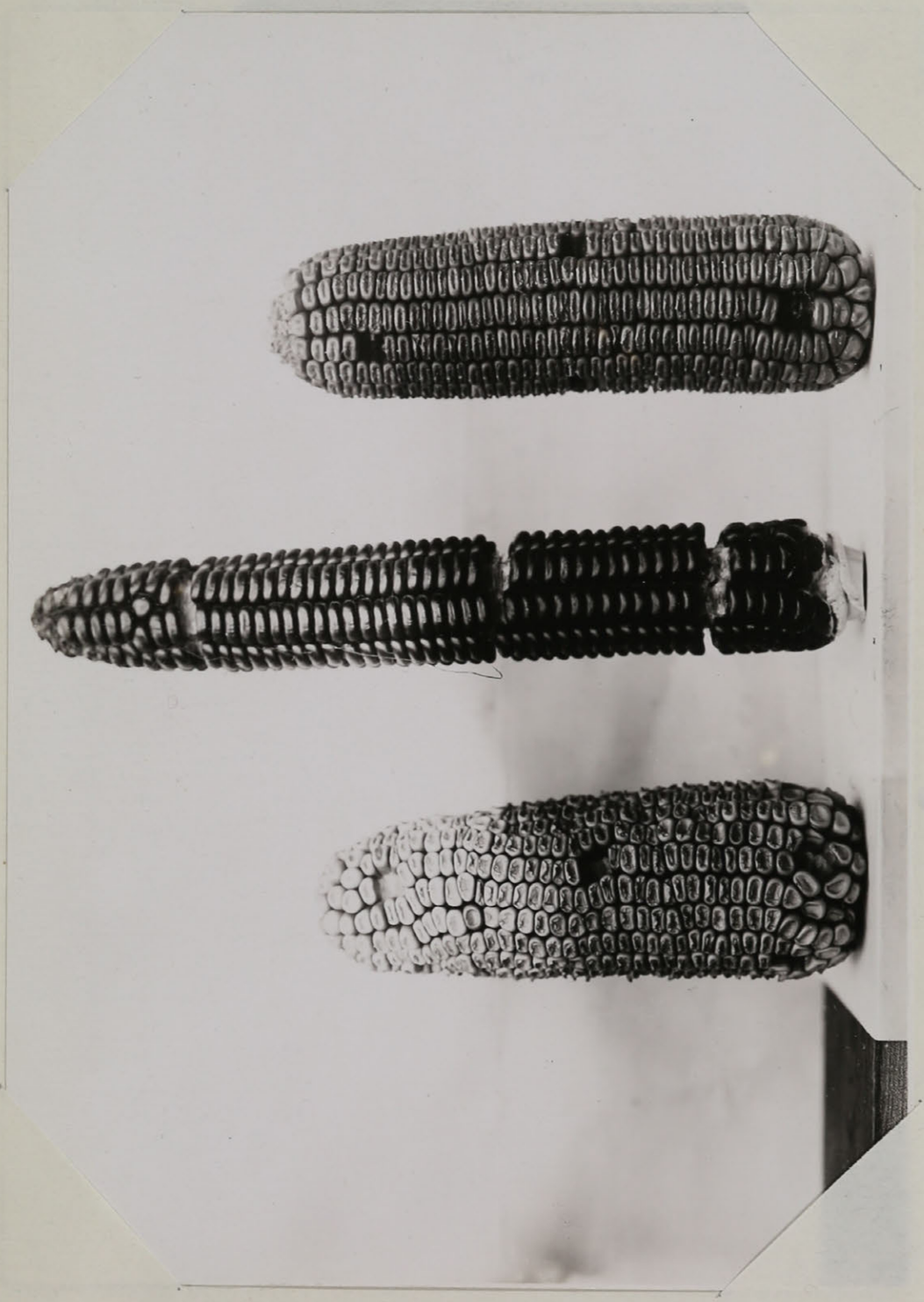

Plate 16. Method of Sampling Ears.

Plate 17. Construction of Rag Dolls. Note the Combination of Butter Parchment and Cloth.

Plate 18. The Rag Dolls Ready for Germination.