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A STUDY OF THE GERMINATING POWER OF SEEDS

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(WITH EIGHTEEN FIGURES)

Scattered throughout botanical literature are many statements regarding the length of time during which seeds may retain their germinating power or, as it is called, their viability. Some of these statements record the germination of seeds from old herbaria, others of seeds supposedly long buried in the earth, and still others of seeds which have been stored for known periods and under known conditions. Few of these records, however, bear critical examination.

Perhaps the earliest authentic records of tests of the continued vitality of air-dry seeds are those of ALPHONSE DE CANDOLLE.[1] In 1832 he first conceived the idea of testing seeds of different species which he had obtained in the harvest of 1831. He kept them all air-dry until May 1846, when he planted 20 seeds of each species. There were 368 species, representing 53 families. Of these but 5 out of 10 species of Malvaceae, 9 out of 45 species of Leguminosae, and 1 out of 30 species of Labiatae showed any power of germination.

Tests of the continued viability of buried seeds were made by DUVEL.[2] He used 109 species of 84 genera and 34 families, and,

[1] DE CANDOLLE, A., Sur la durée relative de la faculté de germer dans des graines appartenant à diverses familles. (Première expérience.) Ann. Sci. Nat. Bot. III. 6:373. 1846.

[2] DUVEL, J. W. T., The vitality of buried seeds. Bull. 83, Bur. Pl. Industry, U.S. Dept. Agric. 1905.

with the exception of two of his duplicate samples, they were all of the harvest of 1902. He mixed his seeds, in definite numbers, with dry clay soil in ordinary flower pots, and buried these in December 1902, to different depths, carefully covering each pot with an earthenware saucer to prevent the loss of seed and other accidents. The majority of the grains of wheat buried 6–8 inches and 36–42 inches had germinated and then decayed, while those at the medium depth of 18–22 inches were merely decayed, without indications of germination, when the pots were taken up in November 1903, eleven months after burial. Approximately all the barley at these three depths had germinated and afterward decayed during the same lapse of time. The majority of the commonly cultivated plants of field and garden could not withstand one year of burial, under the conditions which prevail in the soil outside of Washington, D.C. Many weed seeds, however, showed little deterioration within this length of time.

In 1907 BECQUEREL[3] reported the results of his examination into the germinating power of about 500 species of seeds, belonging to 30 of the more important families of the monocotyledons and dicotyledons, and varying in age from 25 to 135 years. These seeds came from the Muséum d'Histoire Naturelle in Paris. He used 10 seeds of each species, breaking off parts of the integuments of those which seemed impermeable, and, after washing them carefully in distilled water, placed them on damp cotton in crystallizing dishes and kept them at a temperature of 28° C. for more than a month. He obtained germinations in 50 species, all of which were included in four families, namely, the Leguminosae, Nelumbiaceae, Labiatae, and Malvaceae. The oldest seeds which germinated were 3 out of 10 of *Cassia bicapsularis*, one of the Leguminosae, which dated from 1819, and were therefore more than 85 years old at the time of the experiment.

In 1908 EWART[4] published the results of a similar set of tests of over 1000 species of seeds which he found locked in a cupboard in the botanical laboratory at Melbourne, Australia. They had been sent

[3] BECQUEREL, P., Recherches sur la vie latente des graines. Ann. Sci. Nat. Bot. IX. 5:193–311. 1907.

[4] EWART, A. J., On the longevity of seeds. Proc. Roy. Soc. Victoria 21:1–210. 1908.

from Kew in 1856 for the University Gardens, but these not being ready at the time expected, the seeds had been put away in a dark dry closet and had remained there unopened for upward of 50 years. In addition, he examined some ten-year-old seeds from Sydney and Adelaide, and more from the National Herbarium, making altogether nearly 3000 tests. He first tried germinating the seeds in soil, but finding this unsatisfactory, he soaked the seeds and then placed them on moist filter paper in glass dishes and set them in a germinator. Seeds which did not swell after one or two days in water were either filed or treated for 15–90 minutes with concentrated sulphuric acid, that is, until the cuticle was dissolved away. *Adansonia*, for example, required almost 6 hours' treatment of this sort. The seeds were then washed and thereupon swelled readily. EWART adds to his own long list by including some of the results of BECQUEREL, NOBBE, DE CANDOLLE, GIRARDIN, DARWIN, DUVEL, ROMANES, PETER, BERKELEY, and others, making a list, therefore, which comprises about 4000 species. He too found that the majority of those seeds which retain their germinating power for the longest term are members of the Leguminosae, and are generally hard-shelled.

As to the physical and chemical conditions prevailing in dormant seeds there is a diversity of opinion corresponding to the paucity of knowledge. EWART, for example, states that molecular changes and rearrangements continue until finally the seeds no longer retain the power to resume active life. Whatever these molecular changes may be called, whether respiratory or other, it is obviously important, for both theoretical and practical reasons, to determine the conditions in the seeds themselves and the means of maintaining and bettering these if possible. In this paper, however, we are concerned with the results of these conditions rather than with the conditions themselves.

Until recently, so far as we know, tests of the longevity or viability of seeds have depended upon the percentages of actual germinations in prepared beds. Such tests are simple enough in the case of seeds which germinate quickly, and in these cannot be improved upon. When, however, two weeks or more must elapse, even under the most favorable conditions, before one may know the

quality, that is, the germinating power, of the seeds in which one may be interested, a quicker method is desirable for every reason. Not only is the economy of time desirable, possibly for pecuniary reasons, as in the case of a seed-buyer, but also there is less danger, in briefer exposure, of injury or loss from fungous or other enemies of the seeds under examination. One of us has shown that, by using silvered Dewar flasks as calorimeters, one may quickly determine that heat is liberated in the germination of seeds, and has suggested that there may be such differences in the heats liberated by seeds of different ages that one may use these as indicators of age and germinating power or viability.[5] The following experiments were begun in order to test this idea, and they were continued with other and older seeds in order to prove its correctness.

The material used in our experiments came to us through the courtesy of Professor R. A. MOORE, of the University of Wisconsin, Professor E. J. WICKSON, of the University of California, and Professor L. H. PAMMELL, of the Agricultural College at Ames, Iowa, whom we take this opportunity of thanking for their prompt and generous response to our request for seeds of known and considerable age.

Method

The method has been described before. Some of the details, however, as applied to this particular investigation, should be described now. We used silvered Dewar flasks, some made by Burger of Berlin, others not so good, of about 250 cc. capacity. Most of the flasks were round-bottomed, but a few contained a small drainage tube opening into the bottom of the flask. There are differences in the efficiencies of the different flasks even of the same good make and pattern, but, as will appear later, there are great differences between good and bad flasks as insulators. These differences can be ascertained, without destroying the vacuum of the flask, only by using them under constant temperature.

We were fortunate enough to have a convenient constant temperature chamber. This has been sufficiently described before.[6] A maximum-minimum thermometer was taken into the room, but

[5] PEIRCE, G. J., A new respiration calorimeter. BOT. GAZ. 46:193–202. 1908; also The liberation of heat in respiration. BOT. GAZ. 53:89–112. 1912.

[6] See PEIRCE, BOT. GAZ. 53:90, 91. 1912.

the variations in the temperature were so slight that it was not thought to be worth while to continue to record the readings. The slight variations in room temperature shown in the record given below are due mainly to the opening of the room, the presence of one or more of the experimenters, and the heat liberated by a 32 candle-power incandescent light bulb. The light was turned on only as needed, but it is obvious that if the temperature of the room is moderately low, as it was, the heat liberated from a carbon filament lamp of considerable candle-power and radiated and exhaled from the body of an adult individual of average stature, during the 10–40 minutes required for work or observation, would be considerable, and in a smaller room would make a noticeable change in the temperature. In our case the fluctuations were slight.

The thermometers were of two sorts, short and long, the one requiring to be pulled part way out of the flasks to be read, the other long enough to make this unnecessary. Both read to 0°.1 C. The differences in the thermometers, flasks, and cotton plugs used to close the flasks and to hold the thermometers steadily in the necks, as well as the inevitable differences among the seeds themselves, are responsible for such lack as there may be of uniformity in the corresponding results.

The flasks were sterilized by being washed in corrosive sublimate solutions, generally saturated aqueous, and then thoroughly washed out with boiled and cooled distilled water. In many cases the seeds could not be sterilized, with the methods which we employed, without impairing their vitality. It is a matter of very considerable practical importance to find an agent which, at the same time that it is inexpensive, will effectively sterilize the surface of seeds without harming the germ within. We tried copper sulphate in various concentrations, but found it unreliable and often injurious. In most instances we used a saturated aqueous solution of corrosive sublimate. This is thoroughly efficient wherever it penetrates, but a considerable part of the surface of many, if not most, seeds is covered with a film of air, hard to dislodge, which prevents the sterilizing solution from reaching the spores or bacteria which may be adhering to the seed coats. SCHRÖDER[7] has discussed the

[7] SCHRÖDER, H., Die Wiederstandsfähigkeit des Weizen- und Gerstenkornes gegen Gifte und ihre Bedeutung für die Sterilization. Centralbl. f. Bakt. 28: 492. 1910.

difficulties in the way of sterilization, and suggests various methods and agents, but for our purposes the solutions of corrosive sublimate were the least objectionable. It is obviously desirable, if sterilization is to be generally practiced, to have a less powerful general poison than corrosive sublimate, at least in concentrated solutions; and experience has shown us that some seeds are so thin-walled or have walls so easily penetrated by the poison that it is only too easy to injure or even to kill them. Several of our experiments gave entirely negative results from this cause. Clover seemed to be particularly susceptible, presumably on account of the small size of the seed and its thin and permeable coat.

Experimental work

We made germination experiments, both in Dewar flasks and in seed beds, on barley, clover, corn (Cory sweet corn), hemp, oats, and wheat. The records of these are in the form of tables, graphs,

TABLE I

BARLEY

Date	Time	Hours elapsed	Room	Max.	Min.	1905	1911
March 8	11:00 A.M.	.....	19°.9 C.	.....	.....	17°.10 C.	17°.00 C.
9	10:00 A.M.	23	17.3	17°.21 C.	16°.22 C.	17.20	17.10
9	5:00 P.M.	30	17.2	.....	.....	17.30	17.35
10	9:00 A.M.	46	17.2	17.16*	16.17	17.50	17.77
10	6:00 P.M.	55	17.2	.....	.....	17.80	18.50
11	9:30 A.M.	70.5	17.1	17.16	16.17	18.30	19.44
11	5:00 P.M.	78	17.1	.....	.....	18.60	20.20
12	9:00 A.M.	94	17.2	17.16	16.06	19.20	22.20
12†	4:00 P.M.	101	17.2	.....	.....	19.50	22.50
12	4:05 P.M.	101	17.2	.....	.....	19.20	22.00
13	9:45 A.M.	118.75	17.1	17.21	16.39	20.20	22.25
13	4:30 P.M.	125	17.0	.....	.....	20.62	22.00
14	9:00 A.M.	142	17.0	.....	.....	21.40	21.40
14	3:00 P.M.	148	17.0	.....	.....	21.40	21.30

*This and other discrepancies between room and maximum temperatures are due to (1) the poor thermometer used to indicate the room temperature, and (2) the fact that the maximum temperatures were calculated from a Weather Bureau pattern thermometer with Fahrenheit scale.

† On the afternoon of March 12, the flasks were opened in order to determine whether any odor was present. None was detected and the contents of the flasks were not disturbed in any way. Nevertheless, the temperature in the flask containing 1911 seed fell steadily, from that time on, as the record shows.

and photographs. Our records will show that, other things being equal, a high temperature within a reasonable length of time is indicative of high germinating power and also of the ability to make

a rapid growth of root and shoot after germination, in other words, of vigor. The following experiments furnished the grounds for this statement.

EXPERIMENT I.—Barley from the University of Wisconsin; 15 grams of the crop of 1905 and a like amount from the crop of 1911, washed with a saturated solution of copper sulphate. Experiment set up March 8, 1912. The data are in table I.

On the eighth day the flasks were opened and emptied. No infection was visible and both lots of seed had germinated freely. It is to be noted, however, that the radicles from the 1911 seed were two or three times as long as those from the 1905 seed. The accompanying graph (fig. 1), constructed from the thermometer readings of table I, indicates the evolution of heat in these two sets of seeds.

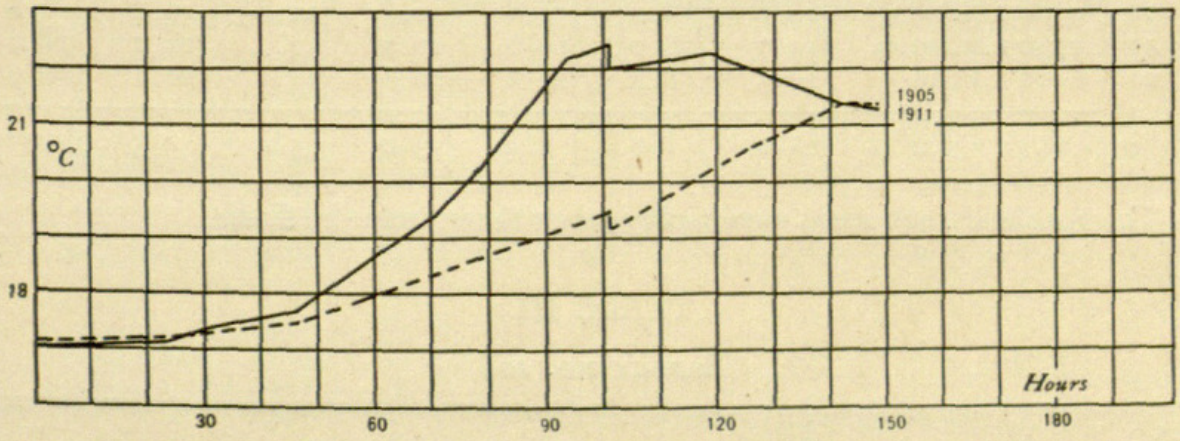


FIG. 1.—Barley (experiment I): 15 grams; broken line, 1905; solid line, 1911

EXPERIMENT II.—Barley from the University of Wisconsin and from Ames, Iowa; 10 grams of each year. On account of the hulls, no sterilization was attempted. Experiment set up as indicated in 1913. The data are in tables II and III.

The fact that the 1909 seeds were very moldy when taken from the flask accounts for the high temperature in that flask. Two other experiments were set up at the same time, but as we were not able to sterilize, the seeds were found to be covered with mold and the unusually high temperatures were not thought worth recording.

It is not of course to be expected that such seeds will show a perfectly regular decrease in heat yield with increasing age. There are too many other factors which may influence their viability. In order correctly to interpret the variations from this regular decrease,

one should know the climatic conditions under which the seed was grown and harvested, and the conditions under which it was afterward stored. Immature seeds are open to the influence of

TABLE II

WISCONSIN BARLEY

Date	Time	1905	1906	1907	1908	1909	1910	1911	Room
April 13	1:00 P.M.	17°.4 C.	17°.5 C.	17°.4 C.	17°.4 C.	17°.6 C.	17°.6 C.	17°.6 C.	17°.0 C.
14	8:00 A.M.	17.6	17.6	17.5	17.6	18.6	18.4	18.2	16.9
14	6:00 P.M.	17.8	17.7	17.5	17.8	19.3	19.2	18.6	16.9
15	8:00 A.M.	17.9	17.8	17.5	18.0	21.1	21.0	19.1	16.9
15	5:15 P.M.	18.0	18.0	17.6	18.2	22.9	23.0	19.6	16.9
16	8:15 A.M.	18.3	18.3	17.6	18.6	23.6	24.0	20.8	16.9
16	5:30 P.M.	18.4	18.5	17.6	18.9	23.3	23.8	20.9	16.9
17	8:00 A.M.	18.7	19.0	17.7	19.4	22.4	23.3	21.0	16.9
18	8:30 A.M.	19.4	19.3	17.9	19.7	21.3	22.7	20.5	16.9
18	6:00 P.M.	19.5	19.4	17.9	19.7	21.0	22.6	20.3	16.9
19	9:00 A.M.	19.5	19.6	18.0	19.6	20.8	22.6	20.1	16.8
19	4:30 P.M.	19.6	19.7	18.05	19.6	20.7	22.7	20.1	16.9
21	8:00 A.M.	19.9	20.5	18.4	19.6	20.6	23.4	20.1	16.9
		2°.5	3°.0	1°.0	2°.2	3°.0	5°.8	2°.5	Increase

The 1910 and 1906 seeds were moldy when taken from the flasks.

TABLE III

BARLEY NO. 202

Date	Time	1909	1910	1911	Room
April 23.....	8:30 A.M.	17°.6 C.	17°.7 C.	17°.6 C.	17°.2 C.
23.....	4:30 P.M.	17.7	17.8	17.7	17.1
24.....	8:00 A.M.	18.0	18.2	18.0	17.2
24.....	4:30 P.M.	18.1	18.4	18.1	17.2
25.....	9:30 A.M.	18.6	19.1	18.6	17.2
25.....	5:00 P.M.	18.9	19.2	18.9	17.3
26.....	12:00 M.	19.7	19.2	19.7	17.3
27.....	10:00 A.M.	20.4	19.2	20.4	17.3
28.....	8:00 A.M.	21.7	19.4	21.7	17.3
28.....	6:00 P.M.	22.5	19.6	22.5	17.3
29.....	9:00 A.M.	24.9	20.1	24.9	17.3
		7°.3	2°.4	2°.1	Increase

environmental conditions to a far greater extent than the fully mature seed (EWART, *loc. cit.*). Even fully matured seeds, when stored under humid conditions, lose their vitality much more quickly than those stored in a dry atmosphere (DUVEL, *loc. cit.*).

The foregoing records have shown that there is a decrease in the amounts of heat liberated by germinating seeds of certain sorts as the seeds increase in age. In order to ascertain whether there is any proportional relationship between the respiratory activity, as indicated by the heat yield, and the germinating power, we still further tested some of the seeds used in the foregoing experiments by setting them out to germinate. Five lots of barley, those from Wisconsin and the no. 202 above, together with three more from Ames, Iowa,

TABLE IV

	Year	Number sprouting April				Percentage spr. 28	Lengths of plumules in cm. April 27–28			
		25	26	27	28		Shortest	Longest	Av.	Percentage growth
No. 364...	1909	17	25	38	.....	76	1.4	7.8	3.5	43
	1910	16	22	27	.....	54	1.0	8.1	5.5	67
	1911	31	37	46	.....	92	2.4	7.5	4.7	58
No. 294...	1909	19	27	43	.....	86	1.0	7.7	5.3	65
	1910	21	25	32	.....	64	1.0	8.7	6.9	8.5*
	1911	27	38	49	.....	98	1.0	8.9	6.1	75
No. 304...	1909	26	29	41	.....	82	1.3	8.5	6.0	74
	1910	24	24	28	.....	56	0.5	7.9	6.5	80
	1911	38	45	45	.....	90	1.0	9.5	6.6	81
Wisconsin.	1905	17	26	.....	40	80	0.5	8.9	5.3	65
	1906	3	23	.....	29	58	1.2	8.9	5.9	72
	1907	6	12	.....	18	36	1.0	7.6	4.2	51
	1908	26	38	.....	42	84	0.3	10.5	6.8	83†
	1909	41	46	.....	49	98	3.5	10.5	8.1	100
	1910	29	41	.....	47	94	2.0	9.7	6.7	82
	1911	28	39	.....	42	84	2.2	8.4	6.5	80
No. 202...	1909	12	29	.....	40	80	1.6	7.5	5.4	66
	1910	18	35	.....	40	80	3.5	8.1	6.5	80
	1911	18	41	.....	47	94	1.5	9.8	6.5	80

*Length of plumules April 27. †Lengths measured April 28.

were selected for the test. Fifty kernels of each year in each of the five lots were soaked for 24 hours in boiled distilled water. They were then planted in rows in shallow boxes of sand which had previously been steamed for three hours in an Arnold steam sterilizer and allowed to cool. The boxes were then set on the benches in the greenhouse awaiting germination. The date was April 22, 1913. The weather was very warm at this time. This partly accounts for the very quick response of these seeds. The data are in table IV.

The first counting was made three days from the time the seeds were planted; the last, six days from that time. In almost every case the 1911 seeds show the greatest number of seedlings at the

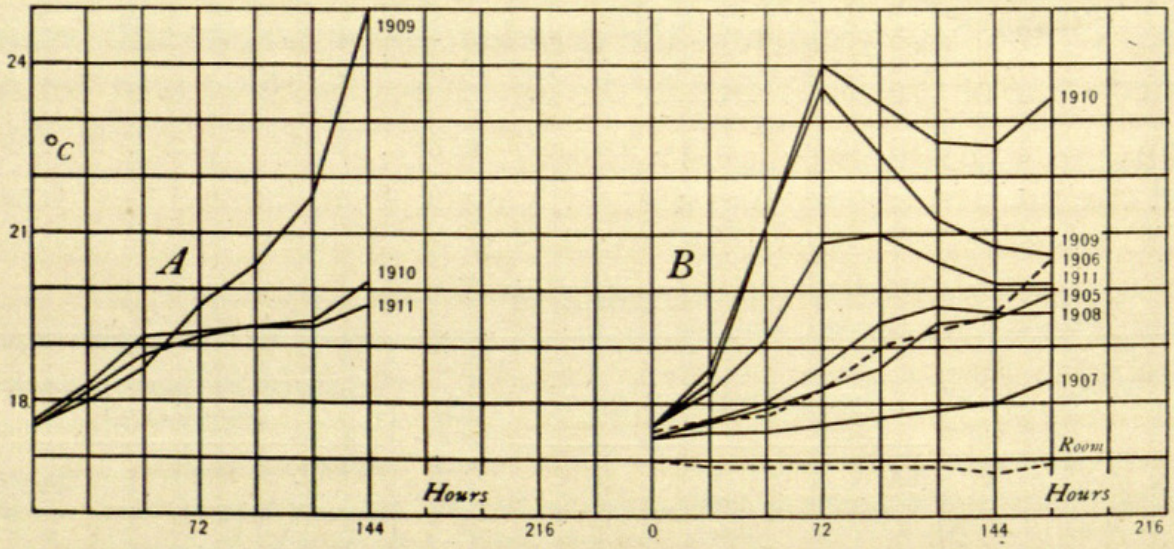


FIG. 2.—Barley in flasks (experiment II): *A*, no. 202; *B*, Wisconsin

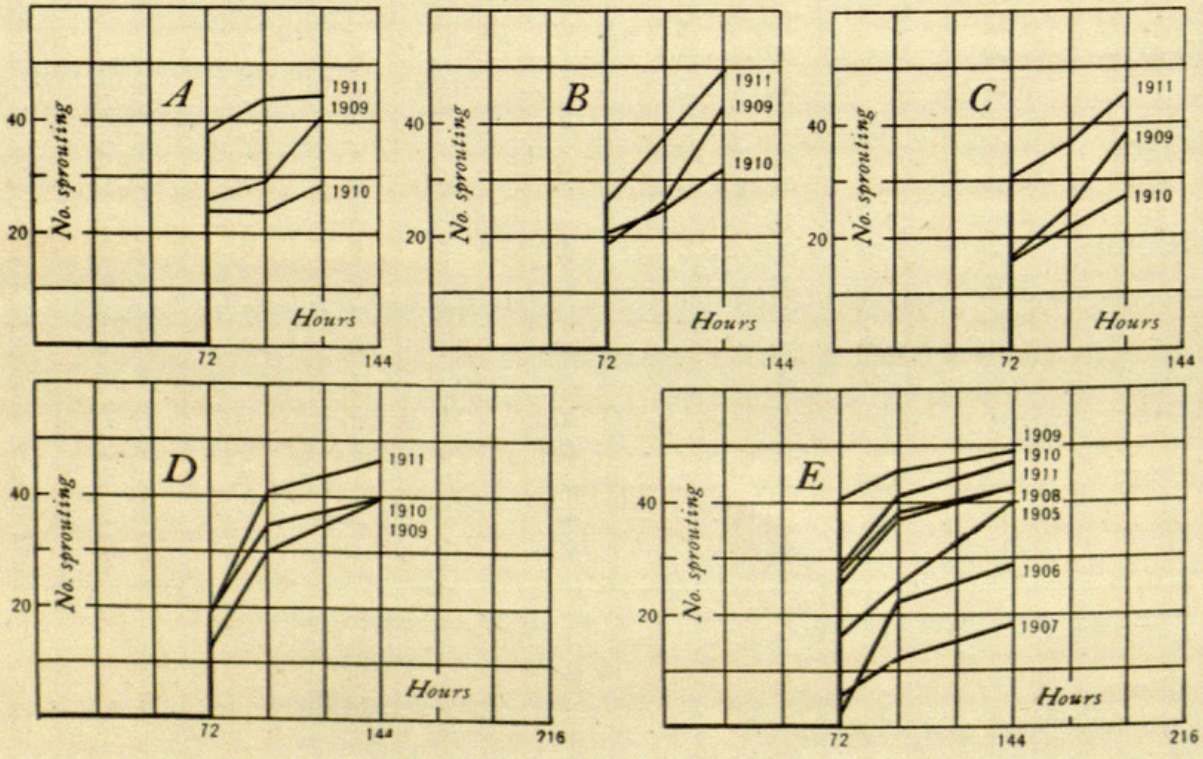


FIG. 3.—Barley in soil: *A*, no. 304; *B*, no. 294; *C*, no. 346; *D*, no. 202; *E*, Wisconsin.

first as well as at the last counting, and here also the 1910 seeds show lowered vitality, especially when compared with 1909. In the percentage of growth of the seedlings, the same decrease with age is evident.

For the sake of comparison, the accompanying curves are given (figs. 2, 3), but attention should be called again to the fact that, owing to the hulls, no attempt at sterilization was considered worth while, and hence there was very considerable molding in the Dewar flasks, with a corresponding rise in temperature independent of the heat yielded by the germinating barley. That this is the case will be more plainly shown in subsequent experiments and figures.

In spite of the various defects in this experiment, it is clear not only that the germinating power of seeds declines from year to year, but that this is indicated and can be tested by ascertaining the heat yield in such a good insulator as silvered Dewar flasks. Furthermore, inspection of the tables will show not only that the youngest seeds show the highest percentage of germination and the greatest heat yield, but they respond most quickly to the influence of conditions favorable to germination. They reach the maximum percentage of germination and maximum temperature sooner than older seed.

EXPERIMENT III.—Red clover (*Trifolium pratense*); 25 grams of seed from the crop of 1904 and the same amount from 1911; sterilized by washing with a concentrated aqueous solution of corrosive sublimate which was removed by repeated rinsings with boiled distilled water; placed in two sterile flasks and covered with boiled distilled water previously reduced to room temperature. At the end of 18 hours the water was poured off and the plugs carefully replaced in the necks of the flasks. The experiment was set up on February 20, 1912. The temperature record is given in table V.

TABLE V

Date	Time	Hours elapsed	Room	Max.	Min.	1904	1911
February 20	4:00 P.M.	.....	17°.6 C.	.....	.....	18°.20 C.	18°.10 C.
21	9:30 A.M.	17.5	17.8	17°.16 C.	16°.39 C.	18.10	18.20
21	4:30 P.M.	24.5	.....	.....	.....	17.90	18.60
22	10:00 A.M.	42.0	17.6	17.05	16.50	17.80	20.20
22	5:30 P.M.	49.5	.....	.....	.....	17.70	21.70
23	9:30 A.M.	66.5	17.7	17.16	16.39	17.70	24.50
23	5:30 P.M.	74.5	18.0	.....	.....	17.70	25.40
24	9:30 A.M.	91.5	17.6	17.11	16.50	18.00	26.30
24	5:30 P.M.	99.5	17.7	.....	.....	18.40	26.45
25	9:30 A.M.	116.0	17.7	17.16	16.50	24.70	27.40
25	3:00 P.M.	122.0	17.7	.....	.....	25.80	27.50

As table V shows, and as graphically displayed in fig. 4, there was a very marked difference in the heat liberated by the two sets of seeds up to the fifth day. At this time the temperature in the 1904 flask rose very rapidly. Upon opening the flasks, the cause of this sudden rise was at once seen to be the active fermentation, the odor of which was evident, and the contents of the flask were found to be covered with *Penicillium*. The accuracy with which the heat yield indicates the germinating power of the seeds is shown by fig. 5, in which the contents of the two flasks are photographed in the Petri dishes into which they were emptied for this purpose. Not

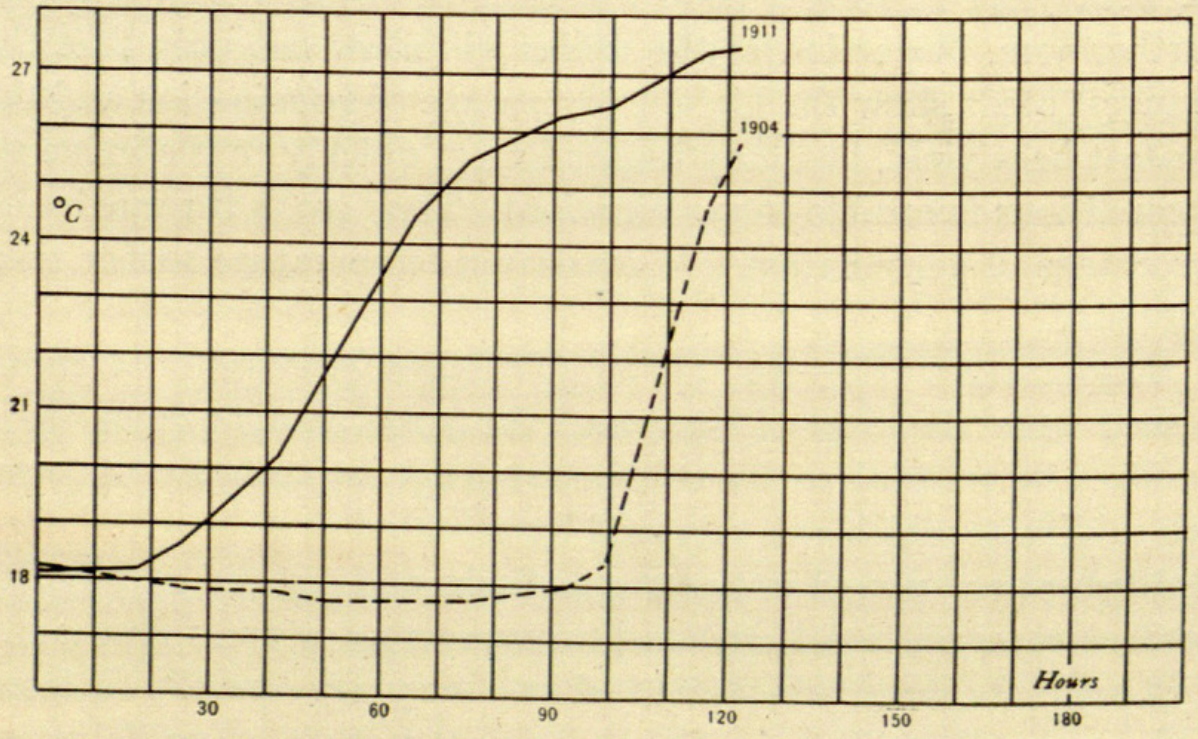
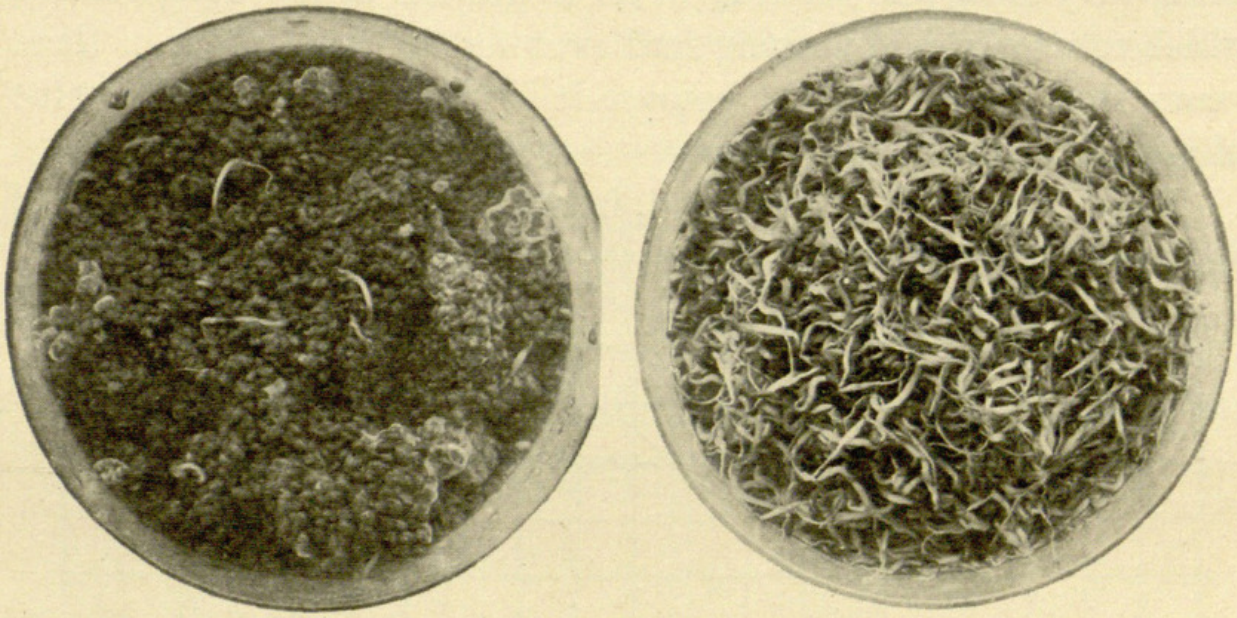


FIG. 4.—Red clover (experiment III): 25 grams; broken line, 1904; solid line, 1911.

more than 1 per cent of the whole quantity of 1904 seed showed any sign of germination. On the other hand, practically all of the 1911 seed had germinated and the seedlings were growing vigorously. In this flask merely a very slight trace of mold was present. I do not see that the inference that the faulty germination of the 1904 seed was due to the amount of mold and bacteria upon it is at all justified by the evidence, but rather that the sterilization had resulted in killing all but a few spores of the mold, and that some time had to elapse before these could produce any considerable amount of mycelium and liberate any considerable amount of heat.

EXPERIMENT IV.—Cory sweet corn, white cob, bought of C. C. Morse & Co., seedsmen, San Francisco, in 1908 or 1909 and 1911 or 1912, and purporting to be of the crops of 1908 and 1911, respectively; 30 grams of each, thoroughly washed in a 10 per cent aqueous solution of copper sulphate and then rinsed in boiled distilled



A *B*

FIG. 5.—Red clover: *A*, 1904; *B*, 1911

water at room temperature, were put in silvered Dewar flasks and soaked for 24 hours in boiled distilled water. This was poured off when the first temperature reading was taken. The experiment was set up on March 15, 1912. The data are given in table VI.

TABLE VI

Date	Time	Hours elapsed	Room	Max.	Min.	1908	1911
March 15	12:30 P.M.	.....	17°.6 C.	.....	.....	17°.00 C.	17°.10 C.
16	11:30 A.M.	23	16.9	17°.21 C.	16°.01 C.	17.00	17.15
17	10:30 A.M.	46	17.0	17.16	16.01	16.90	18.70
18	9:30 A.M.	69	17.0	17.16	16.06	16.90	20.75
18	5:00 P.M.	76.5	17.0	.....	.....	17.00	21.45
19	9:00 A.M.	92.5	17.0	17.16	16.06	17.75	23.00
19	5:00 P.M.	100.5	17.0	.....	.....	18.25	23.70
20	9:30 A.M.	117	17.2	17.16	16.06	18.75	24.45
20	4:30 P.M.	124	17.0	.....	.....	18.56	24.45
21	9:00 A.M.	140	17.0	17.16	16.01	18.40	24.30

On opening the flasks, both sets of seeds were found to be infected with mold, but with more on the older seeds than on the

younger ones; 24 per cent of the 1908 corn had germinated at the end of the experiment; the radicles were short as well as few. Practically 100 per cent of the 1911 corn germinated and the radicles were long and vigorous. In fig. 6 are given the curves made from the temperature data of table VI. This experiment, in addition to being very clear and striking in its indication of the deterioration which takes place on keeping seed even for the short space of three years, is of special interest because it furnishes a test of the value of commercial seed.

EXPERIMENT V.—Hemp seed, from Ames, Iowa, of the crops of 1907 and 1911, and of 1908 and 1910; 5.5 grams of each lot were

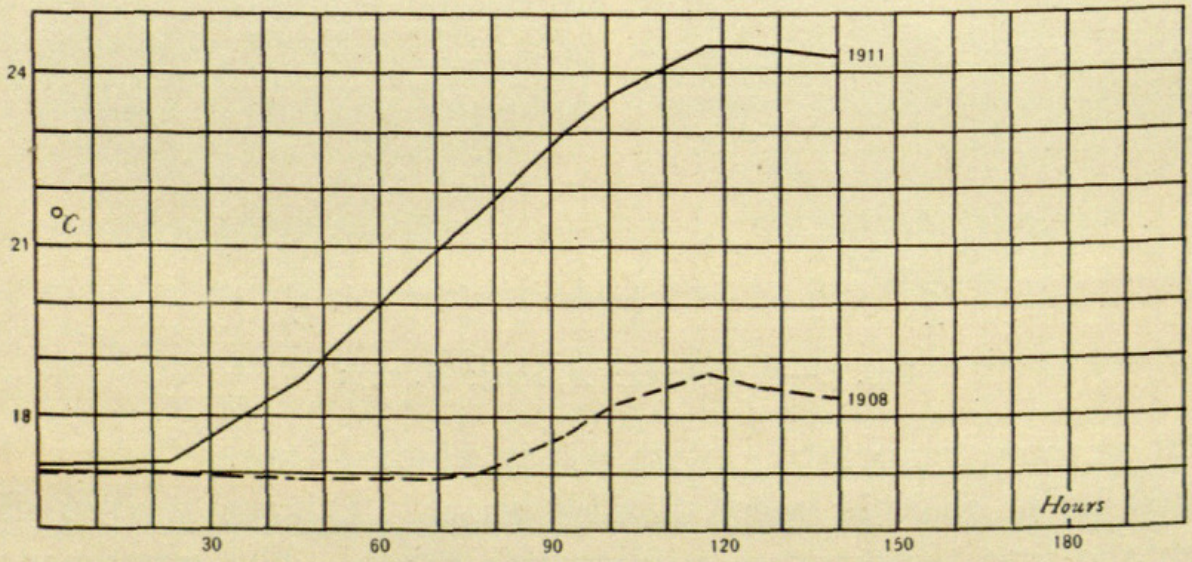


FIG. 6.—Cory corn (sweet) (experiment IV): 30 grams; broken line, 1908; solid line, 1911.

washed with concentrated aqueous solution of corrosive sublimate, thoroughly rinsed with boiled distilled water, and soaked for the usual length of time. The experiment with 1907 and 1911 seed was set up on May 1, that on the 1908 and 1910 seed on May 13, 1912. The data are given in table VII.

It is obvious that, because of the small amount of seed used, namely, 5.5 grams, the rise in temperature would be less than when larger quantities were used; but it is interesting and significant that only a small sample need be used to test the quality of seed, provided only that the insulator be a good one. Thus we have a rise of 5°.35 C. taking place in the flask containing 1911 seed, whereas the temperature in the flask containing 1907 seed merely fluctuated

with the temperature of the room. On opening the flasks a corresponding difference was revealed in the condition of the two sets of seeds. The 1911 lot had germinated very freely, and showed rather remarkable growth. Many radicles were 3–4 cm. long, and the cotyledons had emerged in nearly all the seedlings. On the other hand, only three of the 1907 seeds had germinated, less than 1 per cent. There was no mold in the 1911 seed, whereas the older seed

TABLE VII

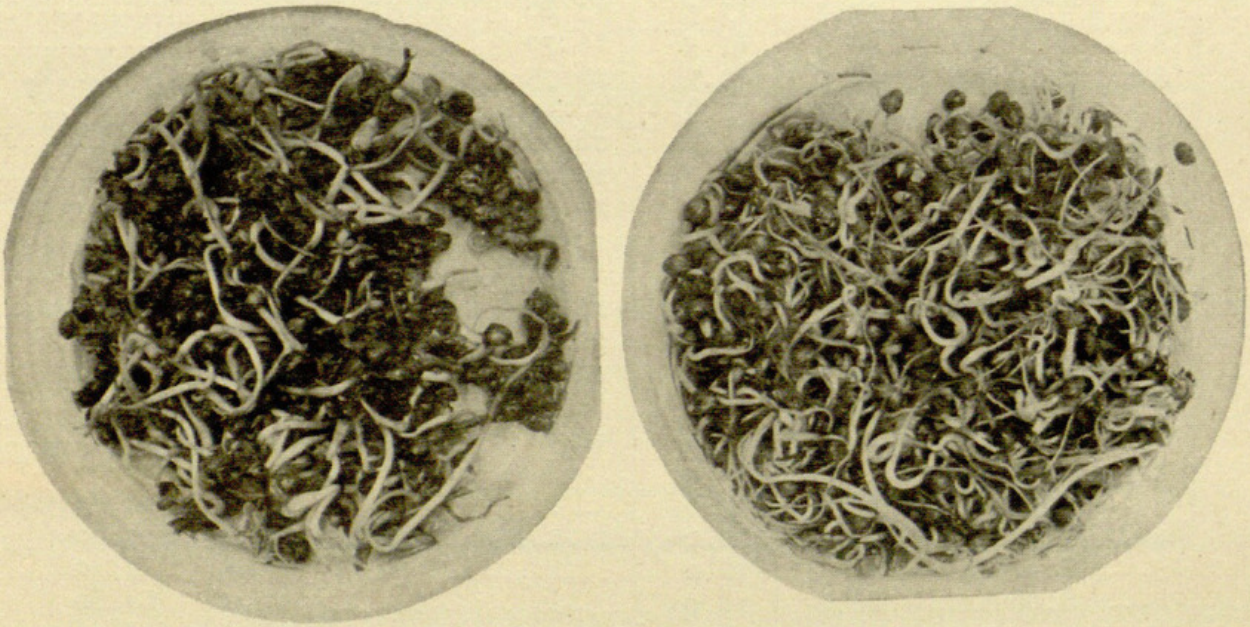
Date	Time	Hours elapsed	Room	1907	1911	1908	1910
May 1...	4:00 P.M.	.....	18°.0 C.	19°.80 C.	20°.55 C.	.....	.....
2...	2:30 P.M.	21.5	17.5	17.60	18.35	.....	.....
3...	9:30 A.M.	40.5	17.5	16.70	17.35	.....	.....
3...	5:30 P.M.	48.5	17.5	16.75	17.40	.....	.....
4...	8:00 A.M.	63.0	17.6	16.80	17.75	.....	.....
4...	5.30 P.M.	72.5	17.6	16.80	18.10	.....	.....
5...	9:30 A.M.	88.5	17.6	16.85	18.90	.....	.....
5...	4:30 P.M.	95.5	17.7	16.90	19.40	.....	.....
6...	9:30 A.M.	112.5	17.8	17.15	20.60	.....	.....
6...	3:30 P.M.	118.5	18.2	17.30	20.90	.....	.....
7...	8:30 A.M.	135.5	17.8	17.20	21.50	.....	.....
7...	4:30 P.M.	143.5	18.0	17.20	21.70	.....	.....
9...	10:00 A.M.	181.0	18.0	17.20	22.70	.....	.....
10...	9:30 A.M.	204.5	18.0	16.75	21.90	.....	.....
11...	9:30 A.M.	228.5	18.0	17.30	21.40	.....	.....
13...	12:00 M.	.....	18.0	.....	.....	27°.80 C.	28°.00 C.*
14...	9:30 A.M.	21.5	18.0	.....	.....	21.70	20.80
14...	3:30 P.M.	27.5	18.0	.....	.....	18.60	17.90
15...	8:30 A.M.	44.5	18.0	.....	.....	17.90	17.50
16...	8:00 A.M.	68.0	18.0	.....	.....	17.90	17.80
16...	4:00 P.M.	76.0	18.2	.....	.....	18.00	18.00
17...	9:30 A.M.	93.5	18.0	.....	.....	18.10	19.10
17...	3:30 P.M.	99.5	18.0	.....	.....	18.10	19.80
18...	9:30 A.M.	117.5	18.0	.....	.....	18.40	22.00
20...	5:30 P.M.	173.0	18.0	.....	.....	19.80	21.10
22...	9:30 A.M.	214.0	18.0	.....	.....	20.20	20.00

*In setting up this experiment, it was necessary to prepare a fresh supply of boiled distilled water. This did not have time to cool to room temperature, and hence the high initial temperatures and the immediate drop to room temperature.

had molded considerably. As table VII shows, the records of the 1910 and 1908 seeds are intermediate between those of the 1911 and 1907 seeds. About 95 per cent of the 1910 seeds germinated, but of the 1908 seed not over 40 per cent germinated. The seedlings of both of these latter sets were vigorous, as is shown by fig. 7. We believe that the high initial temperature to which the seeds of these two latter sets were exposed stimulated respiration in both lots, and

that the temperature record is somewhat higher than it would have been under perfectly normal and proper conditions.

From this experiment it is evident that a small sample of seed in a Dewar flask of good quality may be used with confidence to indicate the germinating power of a much larger quantity. At the same time that we are fortunate in knowing the ages of the seeds used in this experiment, we cannot know that the seeds were equally mature when they were harvested in the several seasons, and we can only believe that they were equally well kept. But be these things as they may, this experiment demonstrates the feasibility of ascertaining the germinating power of a given lot of seed, whatever



A *B*

FIG. 7.—Hemp: *A*, 1908; *B*, 1910

its age and experience may have been, and, furthermore, shows that this is possible in a short time and even with small quantities of material. But on the assumption that these four lots of seed differed from one another only in age, an assumption which we cannot make with any assurance, it is noticeable that the germinating power falls abruptly; thus the germinating power of the 1911 seed in 1912 was approximately 100 per cent, of the 1910 seed approximately 95 per cent, of the 1908 seed 40 per cent, and of the 1907 seed less than 1 per cent. We did not have any 1909 seed, and we regret this. The results recorded in table VII are graphically represented in fig. 8.

EXPERIMENT VI.—Oats from the University of Wisconsin, from the Experimental Farm at Davis, California, under the direction of the University of California, and from Ames, Iowa, were used in different quantities, as recorded below. In our early tests we attempted to sterilize the material, but experience showed this to be futile, at least under the ordinary conditions. It is to be noted, however, that in almost every instance, the amount of fungous infection increased with the age of the seeds. This is indicated in all of our experiments. In our first test, 20 grams of oats of the crops of 1904 and of 1911 from the University of Wisconsin were

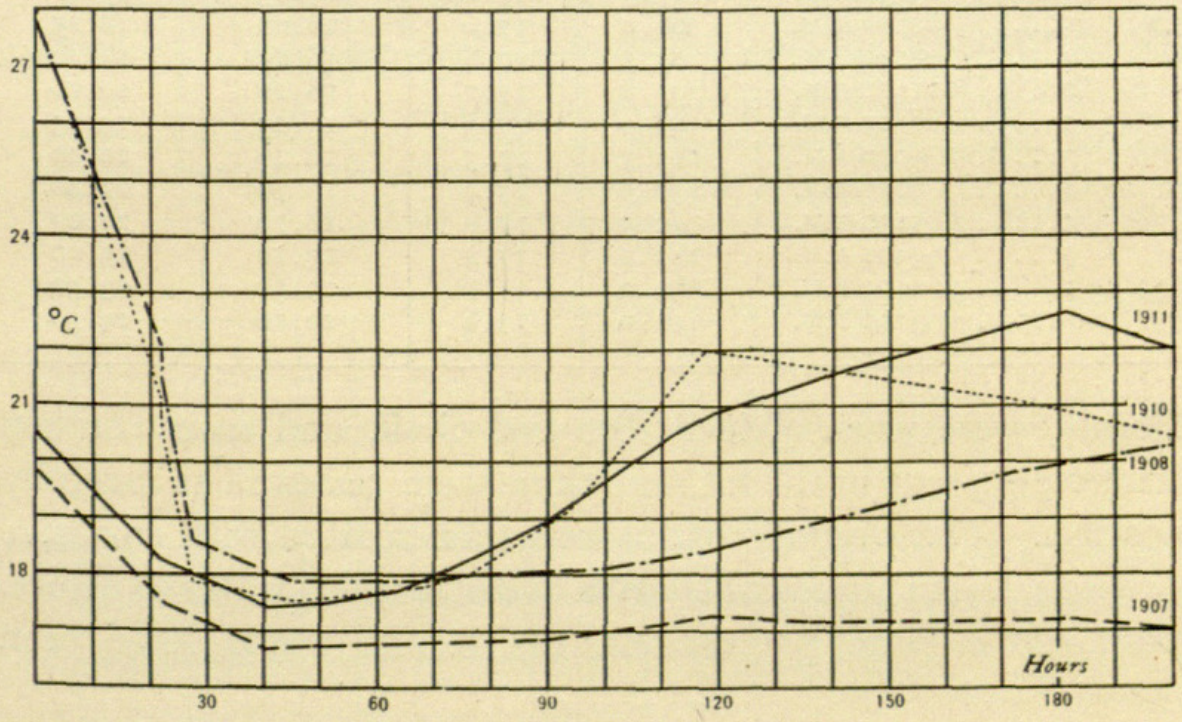


FIG. 8.—Hemp (experiment V): 5.5 grams; broken line, 1907; broken and dotted line, 1908; dotted line, 1910; solid line, 1911.

washed with a concentrated aqueous solution of corrosive sublimate, rinsed with boiled distilled water, and then soaked as before in the flasks and the water presently drawn off. The data are in table VIII.

On opening the flasks recorded in table VIII, one saw that 24.4 per cent of the 1904 seed had germinated, and of these seedlings not more than 2 or 3 per cent had radicles more than 3–4 mm. in length. A trace of blue mold was present. On the other hand, practically all of the 1911 seed had germinated, the radicles were long and vigorous, and there was no evidence of infection.

For purposes of contrast, and as indicating the direct connection between the quality of the seed and the amount of heat which it will liberate on germination, the following record is given in a separate table (IX), instead of being combined, as in some of the other cases, with others. Oats of the seasons of 1907 and 1911, from Davis

TABLE VIII

Date	Time	Hours elapsed	Room	1904	1911
February 27.....	4:00 P.M.	.....	17°.8 C.	18°.30 C.	18°.20 C.
28.....	4:00 P.M.	24.0	17.7	17.90	17.90
29.....	9:00 A.M.	41.0	17.6	17.85	17.80
29.....	3:30 P.M.	47.5	17.6	17.85	17.80
March 1.....	10:00 A.M.	66.0	17.6	18.00	18.15
1.....	6:30 P.M.	74.5	17.8	18.05	18.40
2.....	11:00 A.M.	91.0	17.7	18.20	19.00
2.....	6:00 P.M.	98.0	17.6	18.25	19.35
3.....	9:30 A.M.	113.5	17.5	18.40	20.10
4.....	9:30 A.M.	137.5	17.4	18.70	21.40
4.....	5:30 P.M.	145.5	17.6	18.70	22.00
5.....	9:00 A.M.	162.0	17.4	19.10	23.10
5.....	4:00 P.M.	169.0	.....	19.30	23.50
6.....	3:00 P.M.	192.0	17.6	20.10	24.38

California, were used. Much dirt and chaff, and many broken grains were present in the lot, but these were removed as carefully as possible. The cleaned residue was then treated with corrosive sublimate solution, and washed with boiled distilled water as before. Without these extra precautions, the results would have been

TABLE IX

Date	Time	Hours elapsed	Room	1907	1911
April 3.....	3:30 P.M.	.....	18°.2 C.	18°.30 C.	17°.50 C.
4.....	4:30 P.M.	25	17.5	17.70	17.60
6.....	11:30 A.M.	68	17.6	18.00	18.50
8.....	9:30 A.M.	114	.....	19.90	21.65
9.....	10:30 A.M.	139	17.6	20.70	24.75
9.....	4:30 P.M.	145	17.5	20.60	25.45
10.....	2:30 P.M.	167	17.5	20.90	27.50

entirely unreliable. The thoroughness with which one of us cleaned the material is indicated by the figures in table IX, the record of 30 grams of seed from each lot.

In figs. 9 and 10 are shown the curves constructed on the basis of the records of tables VIII and IX. Allowing for the difference in

the weights of the two samples and a correspondingly steeper curve, the difference in these two curves is indicative of the difference in the cleanliness, and the corresponding goodness of the two sets or lots of seeds. It is to be noted, also, that both sets of seeds in this

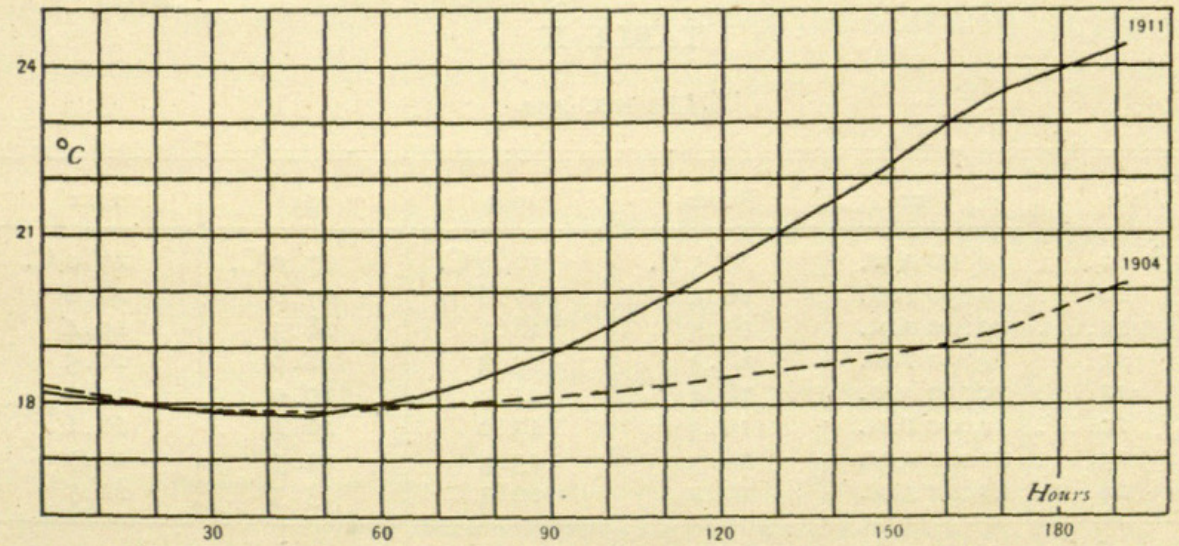


FIG. 9.—Oats (experiment VI): 20 grams; broken line, 1904; solid line, 1911

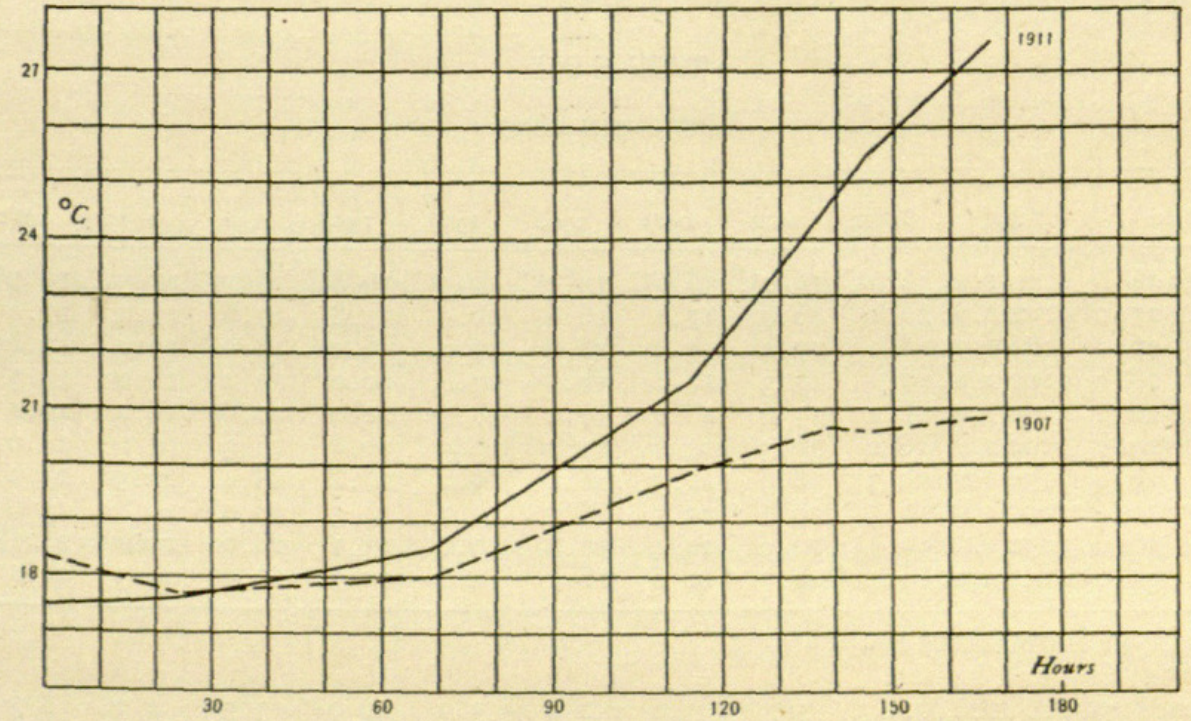


FIG. 10.—Oats (no. 339): 30 grams; broken line, 1907; solid line, 1911

latter test were badly infected with mold. Of the 1907 seeds less than half had germinated; but the 1911 seeds showed nearly 100 per cent germination.

With these records, which show the behavior of certain varieties of oats during the winter following the summer in which they grew,

we should compare others made a year later. Except where explicitly stated otherwise, the quantities used were 10 grams of seed. These were selected as well as possible to insure soundness, hulled, washed quickly in a saturated aqueous solution of corrosive

TABLE X

OATS NO. 444

Date	Time	Room	1909	1910	1911
March 20....	9:00 A.M.	16°.5 C.	16°.9 C.	17°.0 C.	17°.0 C.
20....	4:30 P.M.	16.4	17.8	17.6	18.0
21....	9:00 A.M.	16.4	18.7	18.3	19.4
21....	4:30 P.M.	16.4	19.3	18.6	20.5
22....	10:30 A.M.	16.4	21.9	19.9	25.0
22....	4:00 P.M.	16.3	23.0	20.4	26.1
23....	11:00 A.M.	16.3	23.3	22.5	24.7
24....	11:00 A.M.	16.2	20.3	23.3	20.7
Increase in temperature between first and highest readings.....			6°.4	6°.3	9°.1

TABLE XI

WISCONSIN OATS

Date	Time	Room	1904	1905	1906	1907	1908	1909	1910	1911
March 26..	6:00 P.M.	16°.2C.	16°.2C.	16°.6C.	16°.5C.	16°.5C.	16°.8C.	16°.7C.	16°.7C.	16°.7C.
27..	9:00 A.M.	16.1	16.9	17.1	16.8	16.9	17.8	17.6	17.2	17.5
27..	4:00 P.M.	16.1	17.0	17.2	16.8	17.0	18.2	18.0	17.4	17.85
28..	9:00 A.M.	16.1	17.3	17.8	17.1	17.4	20.2	19.4	18.0	19.3
28..	4:30 P.M.	16.1	17.6	18.2	17.2	17.7	21.9	20.6	18.4	20.4
29..	9:00 A.M.	16.2	18.3	19.6	17.7	18.5	26.8	14.9	19.6	24.0
29..	6:30 P.M.	16.3	18.9	20.5	18.0	19.2	26.8	28.4	20.5	25.0
30..	11:00 A.M.	16.3	19.8	20.5	18.7	19.7	24.3	30.0	20.8	23.9
30..	7:30 P.M.	16.4	19.9	20.4	18.9	19.7	23.1	28.6	20.6	23.1
31..	9:00 A.M.	16.4	19.7	20.0	18.9	19.6	21.7	26.3	20.3	22.1
Increase in temperature between first and highest readings.....			3°.3	3°.9	2°.4	3°.2	10°.0	13°.3	4°.2	8°.3

sublimate, and rinsed four times in sterile distilled water. They were then put into the Dewar flasks, which had been previously sterilized, together with the thermometers, and covered for 24 hours with sterile distilled water. At the end of this time the water was poured off. The data are given in tables X–XIV.

Inspection of table XI will show that the seeds of the crops of 1909 and of 1911 gave considerably higher temperatures than the older seeds of the four years preceding, but the results are not so regular as an average of similar experiments on similar seeds of this and other sorts might give. Not knowing the maturity of the seed when harvested, the manner of its curing and storage, and various other factors which might affect its vigor, we are dependent, in all of these cases, upon the facts of age and vigor as shown by Dewar flask and seed bed. We cannot further account for the differences.

TABLE XII

OATS NO. 293

Date	Time	Room	1907	1908	1909	1910	1911
April 2.....	3:00 P.M.	16°.7 C.	17°.2 C.	17°.3 C.	17°.3 C.	17°.2 C.	17°.3 C.
3.....	9:00 A.M.	16.7	17.6	17.7	17.6	17.8	18.4
3.....	3:00 P.M.	16.6	17.7	17.85	18.75	18.1	18.9
4.....	9:00 A.M.	16.7	18.4	18.75	18.5	19.2	21.8
4.....	5:00 P.M.	16.7	18.8	19.35	19.0	20.0	24.0
5.....	9:30 A.M.	16.6	20.2	20.5	19.4	21.2	27.8
5.....	5:00 P.M.	16.7	20.2	20.6	19.4	21.4	27.4
6.....	8:00 A.M.	16.7	20.1	20.3	19.15	20.9	24.4
6.....	5:00 P.M.	16.7	19.8	19.9	18.9	20.5	22.9
7.....	8:00 A.M.	16.6	19.2	19.3	18.6	19.8	21.6
7.....	5:00 P.M.	16.7	19.1	19.15	18.5	19.6	21.2
8.....	8:00 A.M.	16.9	18.7	18.6	18.3	18.8	20.1
Increase in temperature between first and highest readings				4°.7	5°.9	4°.2	3°.1

In this and some of the other tests, the first temperature reading in the Dewar flasks was 0°.5–0°.6 higher than the room temperature. This points to the fact that in the preliminary stages of germination, while the seeds were soaking in water, heat was also being liberated. The rate of heat liberation at different stages in germination is not uniform. This one of us will show elsewhere, for it has little to do with the special topic of this paper.

Table XIII shows irregularities which we are unable to account for, since we are unacquainted with the experience of the seeds before they came into our hands; but we include the table for the sake of completeness.

The record of the behavior of seeds of the same ages and varieties in a seed bed, that is, under the usual conditions for germination,

will show how well the viability of the seeds is indicated by their heat yields within a comparatively short time after germination is

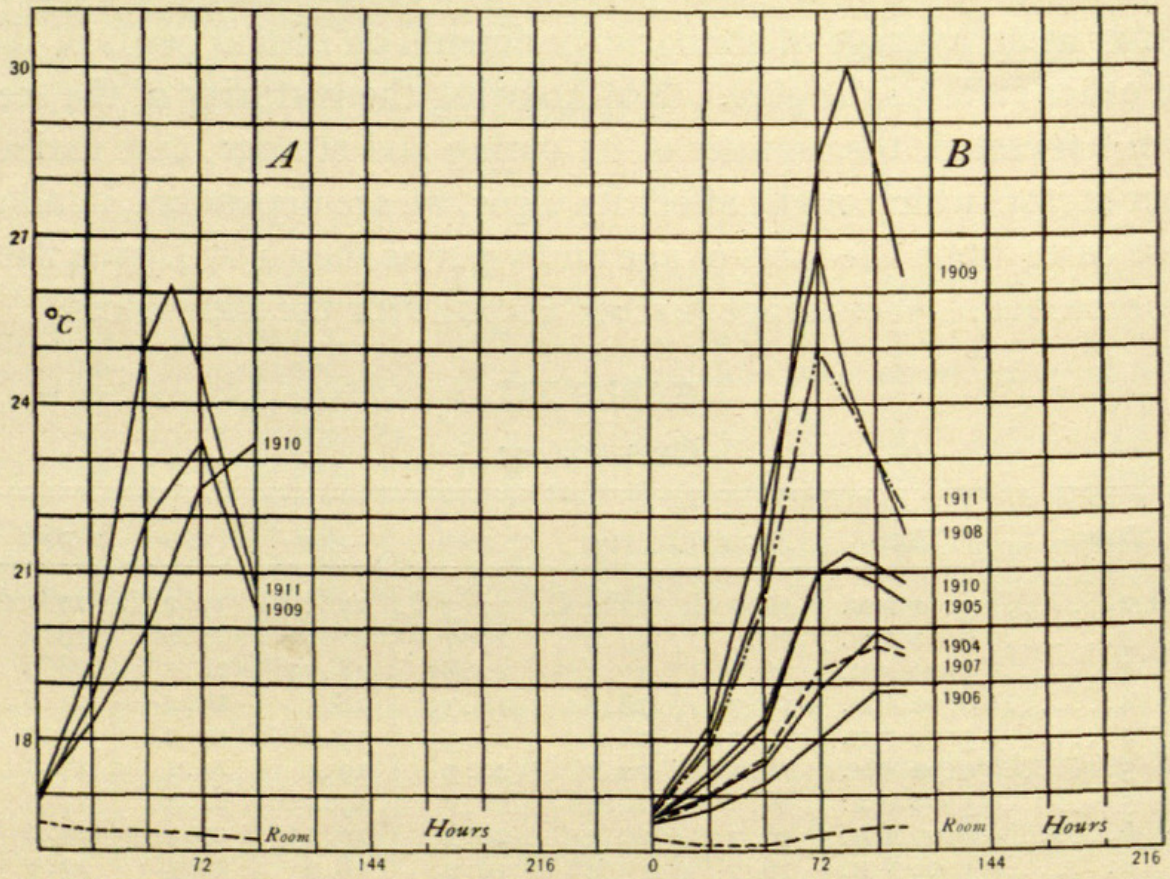


FIG. 11.—Oats in flasks: *A*, no. 444; *B*, Wisconsin

started in Dewar flasks. Fifty kernels were selected from each lot, but on account of the hulls, no attempt was made to sterilize them.

TABLE XIII

OATS NO. 339

Date	Time	Room	1907	1909	1910	1911
April 3....	3:00 P.M.	16°.6 C.	17°.2 C.	17°.2 C.	17°.3 C.	17°.2 C.
4....	9:00 A.M.	16.7	17.9	18.2	18.1	17.7
4....	5:00 P.M.	16.7	18.1	18.6	18.4	18.0
5....	9:30 A.M.	16.6	18.7	20.2	19.2	18.6
5....	5:00 P.M.	16.7	19.0	21.2	19.6	19.0
6....	8:00 A.M.	16.7	20.2	23.0	20.8	19.8
6....	5:00 P.M.	16.7	21.1	23.0	21.3	20.2
7....	8:00 A.M.	16.6	22.6	21.8	21.5	20.3
7....	5:00 P.M.	16.7	22.9	21.2	21.4	20.2
8....	8:00 A.M.	16.9	20.2	19.3	19.5	18.8
Increase in temperature between first and highest readings.....			4°.7	5°.9	4°.2	3°.1

TABLE XIV

Oats	Year	Number sprouting February				Percentage sprouting	Lengths of plumules Feb. 8–9 in cm.			Percentage of growth
		3	4	6	8		Shortest	Longest	Average	
White Probster...	1872	0	0	0	0	0	.....	.....	.....	.....
	1876	0	0	0	0	0	.....	.....	.....	.....
Wisconsin....	1877	0	0	0	0	0	.....	.....	.....	.....
	1904	24	38	44	48	96	2.2	12.1	9.12	75
	1905	31	39	42	42	84	1.0	11.8	8.10	67
	1906	5	27	41	46	92	3.1	11.1	7.96	66
	1907	19	27	35	39	78	1.6	11.3	8.44	70
	1908	37	49	49	49	98	8.2	11.9	10.50	87
	1909	30	43	47	48	96	3.7	12.4	9.22	76
	1910	8	25	44	44	88	3.0	12.2	8.03	66
	1911	34	46	50	50	100	7.4	13.3	11.33	94
No. 451.	1907	27	33	37	38	76	2.8	12.9	9.98	82
	1909	39	46	48	49	98	2.6	13.5	10.87	90
	1910	33	37	37	37	74	6.2	15.9	12.04	100
	1911	43	49	49	49	98	8.4	15.9	11.56	96
No. 286.	1907	25	27	28	28	56	7.6	14.6	11.29	93
	1909	34	44	45	46	92	3.9	13.5	11.08	92
	1910	30	40	40	47	82	4.7	14.5	9.60	79
	1911	38	46	47	47	94	5.8	16.0	10.55	39
No. 444.	1909	19	33	45	47	94	3.7	12.6	10.34	85
	1910	18	30	35	39	78	1.7	14.5	9.39	77
No. 293.	1907	27	40	42	44	88	3.8	13.6	9.05	75
	1911	18	37	44	50	100	2.9	14.2	10.13	84
	1908	20	33	42	43	86	5.2	16.2	11.51	95
	1909	14	36	48	49	98	6.4	15.0	10.88	90
	1910	21	40	47	47	94	5.4	16.8	10.92	90
	1911	19	40	50	50	100	6.7	16.3	11.42	94
No. 339.	1907	16	28	35	36	72	3.7	13.4	10.20	84
	1909	5	27	37	41	82	2.3	11.9	9.38	77
	1910	2	11	27	33	66	2.1	12.6	8.37	69
	1911	9	30	49	50	100	3.5	6.2	9.99	82

These were planted in boxes of sterilized sand in the greenhouse, on January 28 and 29, 1913.

Comparison of the behavior of oats of different ages as recorded in tables X–XIV is rendered somewhat easier by figs. 11–14. In

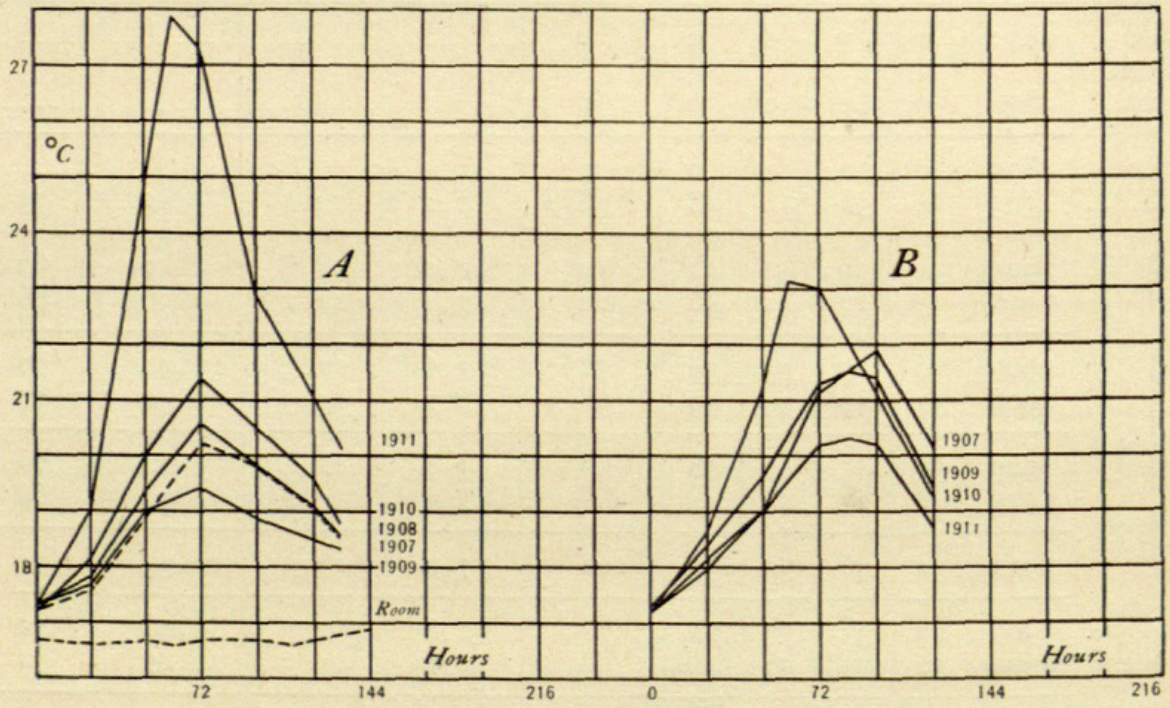


FIG. 12.—Oats in flasks: *A*, no. 293; *B*, no. 339

these it is plainly shown that the vitality and viability of these seeds is indicated more promptly by the temperatures yielded in Dewar flasks than in seed beds, and that what may properly be called the "normal" temperature for the species is developed, other things

TABLE XV

Date	Time	Hours elapsed	Room	1907 (no. 1746)	1911
April 3.....	3:30 P.M.	.....	18°.2 C.	16°.80 C.	17°.10 C.
4.....	4:30 P.M.	25	17.5	16.90	17.50
6.....	11:30 A.M.	68	17.6	18.60	20.50
8.....	9:30 A.M.	114	.....	23.80	28.15
9.....	10:30 A.M.	139	17.6	26.50	28.00
9.....	4:30 P.M.	145	17.5	26.35	27.70
10.....	2:30 P.M.	167	17.5	25.15	27.15

being equal, by the youngest and freshest seed. This will come out still more plainly in the following experiment with wheat.

EXPERIMENT VII.—Wheat, from the University of California, the University of Wisconsin, and the College of Agriculture at Ames

Iowa, was used in the various quantities recorded below and treated in the various ways there indicated. Our first test was made in April 1912, with 30 grams of seed from the Experimental

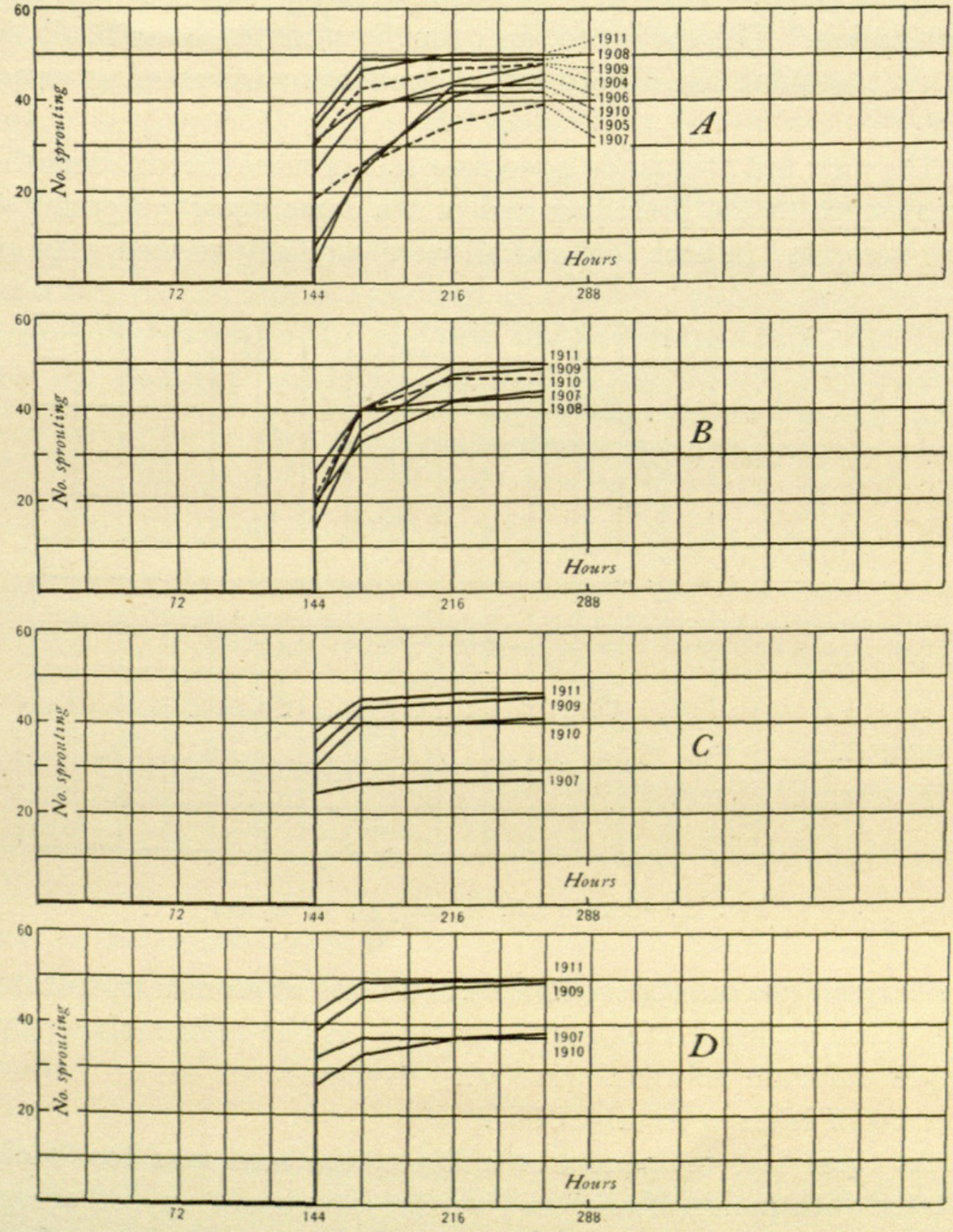


FIG. 13.—Oats in soil: *A*, Wisconsin; *B*, no. 293; *C*, no. 286; *D*, no. 451

Farm of the University of California, at Davis, California. The seed was not as clean and whole as one could wish, and there was too much chaff with it. The material was treated with a concen-

trated aqueous solution of corrosive sublimate and then duly washed in sterile distilled water. The record is given in table XV. Upon opening the flasks, the wheat was found to be quite sweet and free from mold. The 1911 seed showed practically 100 per cent germination. The 1907 seed, on a rough estimate, showed only 60 per cent germination. Both lots of seedlings were growing vigorously.

The next test was made upon four sets of wheat seeds, from the same source as the preceding and of the same ages; 30 grams of seed were used in each lot, and all were carefully washed with an

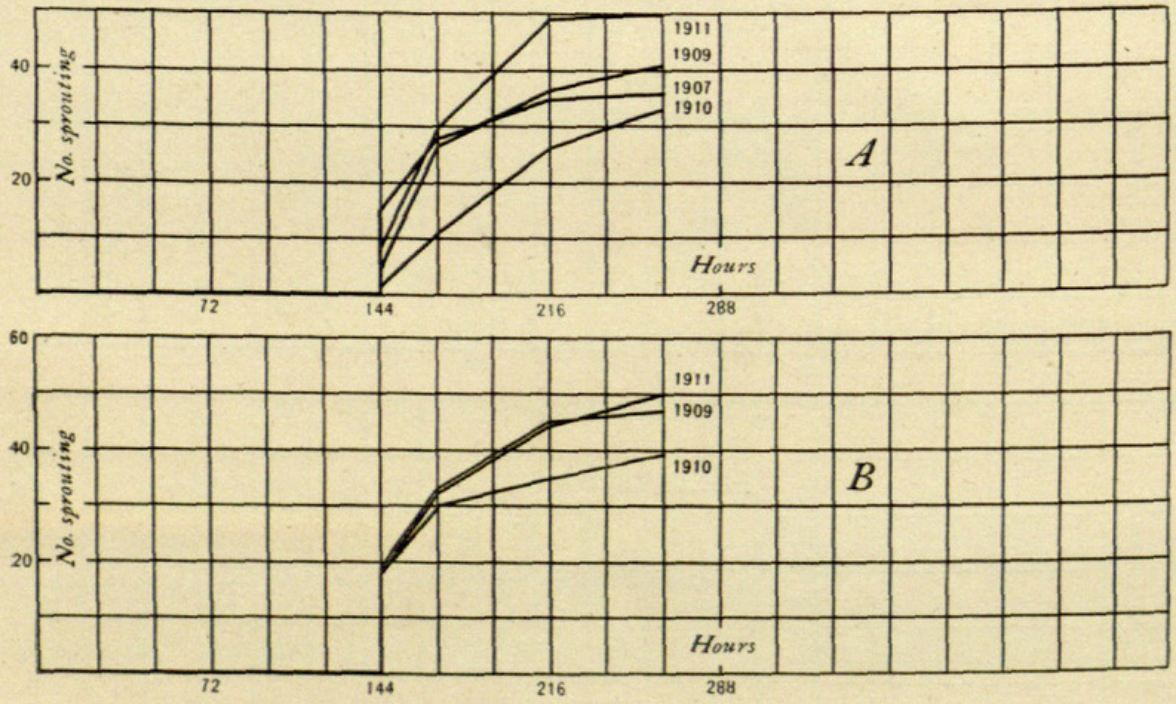


FIG. 14.—Oats in soil: *A*, no. 339; *B*, no. 444

aqueous solution of copper sulphate, saturated at room temperature, and rinsed as usual with sterile water. As the results show, the copper sulphate solution was quite ineffective as an antiseptic. The record is given in table XVI.

As these last temperatures indicate, the seed was too badly infected with mold (*Mucor*) to give the experiment any other significance than this, namely, that germinating seeds, as well as the higher animals, have temperatures which may be considered "normal" or characteristic; and if the seed under test does not show this temperature, or one not far removed from it, one is justified in concluding that there is something wrong with it. If the

temperature is abnormally high, this is due to other organisms also liberating heat in the insulator; if abnormally low, the seed itself is weak. In many cases, at least, this weakness is due to age.

Through the courtesy of Professor PAMMEL, of Ames, Iowa, we had a number of seeds of quite considerable age. We made preliminary germination tests of these while our Dewar flasks were in use, and found that none of the seeds which we had from the crops of 1871 to 1887, inclusive, would germinate under the conditions of our germination boxes. We cannot say that no preservative had been applied to them, but their behavior is entirely consistent with that reported by BECQUEREL and by EWART. BECQUEREL (*loc. cit.*) found that wheat only 34 years old could no longer germinate. EWART (*loc. cit.*) found that out of 750 seeds of wheat 16 years old

TABLE XVI

Date	Time	Hours elapsed	Room	1907 (no. 114)	1911	1907 (no. 639)	1911
April 16.....	3:00 P.M.	.....	18°.0 C.	.....	.....	.....	.....
17.....	3:00 P.M.	24	18.0	19°.10 C.	19°.45 C.	20°.00 C.	18°.60 C.
18.....	2:30 P.M.	47.5	18.0	18.00	19.20	19.90	19.15
19.....	12:00 M.	69.5	18.0	18.40	21.00	21.35	21.20
20.....	10:30 A.M.	92	17.5	19.00	24.25	23.40	24.60
21.....	10:30 A.M.	116	17.5	21.40	31.00	27.00	26.95
23.....	2:00 P.M.	167.5	.....	38.80	44.20	37.00	42.90

only 8 per cent could sprout, while in other experiments wheat 12–13 years old showed no vitality. We tested, therefore, only two lots of these oldest seeds in Dewar flasks and, owing to the age and corresponding value of the material, used only small quantities; 5 grams of each of these two lots were carefully selected, cleaned, washed with a sterilizing solution, and then rinsed thoroughly with sterile water. The record is given in table XVII.

From these figures it is apparent that one can ascertain whether seeds will germinate under ordinary conditions by moistening them duly and keeping them for a time under known conditions of temperature in Dewar flasks. If, within a reasonable length of time there is no rise in temperature or a rise which does not indicate a "normal" temperature for the species concerned, one may conclude that the seed will not germinate. It goes almost without

saying that the time which must elapse before such a conclusion is justified varies with the species, as does the "normal" temperature.

TABLE XVII

Date	Time	Room	Talaverra spring wheat, 1871	California white spring wheat, 1872
December 12....	11:30 A.M.	19°.0 C.	18°.1 C.	17°.6 C.
13....	1:30 P.M.	19.0	18.1	17.6
14....	9:00 A.M.	18.75	18.1	17.6
14....	4:30 P.M.	18.75	18.1	17.6
15....	4:00 P.M.	18.5	18.1	17.6
16....	1:00 P.M.	18.5	18.0	17.6
17....	2:00 P.M.	18.5	18.0	17.5
18....	12:00 M.	18.5	17.95	17.5
20....	3:00 P.M.	19.0	17.9	17.4

Table XVIII records the temperatures developed in silvered Dewar flasks by three lots of wheat of the same variety, marked no. 791, of the crops of 1909, 1910, 1911; 10 grams of each lot were

TABLE XVIII

Date	Time	Room	1909	1910	1911
February 5..	1:30 P.M.	17°.5 C.	16°.7 C.	16°.7 C.	16°.8 C.
6..	10:00 A.M.	17.0	16.7	16.8	17.3
6..	1:30 P.M.	17.0	16.8	16.9	17.4
6..	4:30 P.M.	17.0	16.9	17.0	17.4
7..	8:30 A.M.	17.0	17.0	17.2	17.7
7..	5:30 P.M.	17.25	17.1	17.3	18.3
8..	9:30 A.M.	17.0	17.3	17.6	19.2
8..	1:30 P.M.	17.25	17.3	17.7	19.4
8..	4:30 P.M.	17.0	17.4	17.7	19.5
9..	2:00 P.M.	17.25	17.7	18.1	20.0
10..	8:30 A.M.	17.0	18.1	18.6	19.7
10..	4:00 P.M.	17.0	18.2	18.7	19.6
11..	8:30 A.M.	17.0	18.3	18.9	19.3
11..	4:30 P.M.	17.0	18.3	19.0	19.2
12..	8:30 A.M.	17.0	18.3	19.0	18.9
12..	4:30 P.M.	17.0	18.2	19.0	18.8
13..	8:30 A.M.	17.0	18.1	18.8	18.7
Increase in temperature between first and highest readings.....			1°.6	2°.3	3°.2

used, being washed and soaked in the usual ways. As the table shows, the rise in temperature of the 1911 seed was much more prompt and rapid than in the other lots, and more rapid in the seed of 1910 than in that of 1909. The maximum temperatures

increased correspondingly regularly from 1909 to 1911, and the maximum is reached more than 42 hours earlier in the 1911 seed than in the other two. In this connection it should be stated that, as will be shown later, the comparative viability of the different lots of seed is indicated in the Dewar flasks within 24–48 hours, whereas the seed planted in soil showed nothing within 72 hours. Had there been older seed than that of 1909, the delay in soil would have been still greater in proportion. The data of the flask test are given in table XVIII.

The increasing heat yield, indicated in the last line of table XVIII, is quite as striking in regularity as the increasing percentage of germination for the crops of the years 1909, 1910, 1911, as recorded in the table of germinations following. This is shown again, and for another variety of wheat, in table XIX.

TABLE XIX

Date	Time	Room	1909	1910	1911
February 6..	1:30 P.M.	17°.0 C.	16°.6 C.	16°.3 C.	16°.7 C.
6..	4:30 P.M.	17	16.8	16.4	16.9
7..	8:30 A.M.	17	17.1	16.5	17.3
7..	5:30 P.M.	17.25	17.2	16.65	17.5
8..	9:30 A.M.	17	17.5	16.8	17.9
8..	1:30 P.M.	17.25	17.5	16.8	18.0
8..	4:30 P.M.	17	17.6	16.9	18.0
9..	2:00 P.M.	17.25	17.8	17.0	18.5
10..	8:30 A.M.	17	18.2	17.2	19.1
10..	4:00 P.M.	17	18.3	17.3	19.3
11..	8:30 A.M.	17	18.5	17.4	19.8
11..	4:30 P.M.	17	18.6	17.5	19.9
12..	8:30 A.M.	17	18.7	17.6	19.9
12..	4:30 P.M.	17	18.8	17.7	19.9
13..	8:30 A.M.	17	18.8	17.75	19.8
Increase in temperature between first and highest readings.....			2°.2	1°.45	3°.2

Ten grams of each harvest, 1909 to 1911, inclusive, of wheat no. 98, were treated in the usual way and placed in Dewar flasks. The figures are given in table XIX.

For some unknown reason, the seeds of the 1910 lot started at a disadvantage, the temperature in the flask in which they were contained (flask no. 5) being 0°.3–0°.4 lower than in the other two. Nevertheless, the temperatures behave as in the preceding experi-

ments, rising more rapidly and to a higher point in the flask containing the freshest seed, and the rise beginning more promptly among the freshest seed, the other seeds lagging more and more according to their ages. In 24 and 48 hours marked differences in viablility are indicated in the flasks which did not appear in the seed beds until 72 hours had elapsed.

In order to test the quality of flask no. 5, which had been used in the preceding experiment with seed not the freshest, we set up another experiment in the same way as the preceding, using another variety of wheat, no. 1746, of which we had material from 1907 to 1911, inclusive, and putting the freshest and therefore presumably the best in this flask. As before, the temperature in the flask was lower throughout this experiment than in the others. From this we can only infer the inferior quality of this particular flask. The data are given in table XX. Except for the behavior of this particular flask, this experiment conforms to the rule which the preceding tests have indicated, namely that the freshest seeds are also the most vigorous. This is confirmed still further by the germinations in the seed bed.

TABLE XX

Date	Time	Room	1907	1908	1909	1910	1911
February 15..	12:00 P.M.	17°.5 C.	16°.8 C.	16°.8 C.	16°.8 C.	16°.8 C.	16°.4 C.
15..	4:00 P.M.	17.1	16.9	16.9	16.9	17.0	16.5
16..	9:00 A.M.	17.1	17.0	17.1	17.2	17.3	16.7
16..	5:00 P.M.	17.1	17.1	17.2	17.3	17.5	16.8
17..	8:30 A.M.	17.1	17.3	17.3	17.6	17.9	17.0
17..	12:00 M.	17.1	17.3	17.3	17.65	18.0	17.05
17..	4:30 P.M.	17.1	17.4	17.4	17.7	18.1	17.1
18..	8:30 A.M.	17.1	17.5	17.5	18.1	18.7	17.4
18..	4:00 P.M.	17.1	17.6	17.55	18.3	19.0	17.6
19..	8:30 A.M.	17.1	17.7	17.7	18.8	19.7	18.0
19..	4:30 P.M.	17.1	17.7	17.8	19.0	20.0	18.2
20..	9:00 A.M.	17.1	17.75	18.0	19.5	20.4	18.7
20..	6:30 P.M.	17.1	17.8	18.2	19.7	20.4	18.8
21..	8:30 A.M.	17.1	17.8	18.4	19.8	20.4	18.8
21..	4:30 P.M.	17.8	18.4	18.4	19.8	20.4	18.8
22..	9:45 A.M.	17.1	17.7	18.5	19.8	20.2	18.8
Increase in temperature between first and highest readings			1°.0	1°.7	3°.0	3°.6	2°.4

A series of seeds, no. 639, also including the crops of 5 years, but in flasks of uniformly better quality, is reported upon in table XXI,

the quantities and the preliminary treatment of the seed being the same as before.

TABLE XXI

Date	Time	Room	1907	1908	1909	1910	1911
March 11.....	8:30 A.M.	17°.0 C.	17°.2 C.	17°.2 C.	17°.1 C.	17°.1 C.	17°.4 C.
11.....	3:00 P.M.	16.7	17.3	17.4	17.4	17.4	17.4
12.....	8:30 A.M.	16.5	17.4	17.5	17.7	18.1	18.2
12.....	4:30 P.M.	16.55	17.5	17.6	17.9	18.5	18.6
13.....	8:15 A.M.	16.5	17.7	17.8	18.3	19.85	19.9
13.....	4:30 P.M.	16.5	17.9	18.1	18.6	20.8	20.9
14.....	8:30 A.M.	16.5	18.2	18.8	19.6	21.3	22.5
14.....	4:30 P.M.	16.5	18.4	19.0	20.0	21.1	22.7
16.....	9:00 A.M.	16.5	18.6	19.7	20.3	20.3	21.2
17.....	9:00 A.M.	16.5	18.6	20.1	20.2	20.5	21.0
Increase in temperature between first and highest readings.....			1°.4	2°.9	3°.2	4°.2	5°.1

The high room temperature at the beginning of this test was undoubtedly due to the presence of the experimenter and to the electric light (32 candle-power, carbon filament) which was in use for some little time.

For the sake of completeness, we include also table XXII, showing the behavior of wheat no. 114, of the crops of 1907, 1909, 1910, 1911, under conditions similar to those of the foregoing tests.

TABLE XXII

Date	Time	Room	1907	1909	1910	1911
March 18.....	11:00 A.M.	17°.2 C.	17°.05C.	17°.1 C.	17°.1 C.	17°.1 C.
18.....	4:30 P.M.	16.5	17.1	17.1	17.2	17.1
19.....	9:00 A.M.	16.5	17.2	17.2	17.7	17.4
19.....	6:00 P.M.	16.5	17.3	17.3	18.0	17.6
20.....	9:00 A.M.	16.5	17.5	17.6	18.3	17.95
20.....	4:30 P.M.	16.4	17.6	17.7	18.4	18.2
21.....	9:00 A.M.	16.4	17.9	17.7	18.5	18.5
21.....	4:30 P.M.	16.4	17.9	17.7	18.5	18.5
22.....	10:30 A.M.	16.4	18.1	17.8	18.35	18.4
22.....	4:00 P.M.	16.3	18.2	17.8	18.3	18.4
23.....	11:00 A.M.	16.3	18.3	17.8	18.2	18.2
24.....	10:00 A.M.	16.2	18.5	17.6	17.9	17.9
Increase in temperature between first and highest readings.....			1°.45	0°.7	1°.4	1°.4

For a comparison of these respiration temperatures with the actual percentages of germination under the usual conditions, we

selected 50 good kernels of the crop of each year, from 1907 to 1911, inclusive, of the different varieties which had been tested in Dewar flasks, as the preceding records show. These seeds were quickly washed in a saturated aqueous solution of corrosive sublimate and rinsed four times in boiled distilled water. They were then soaked for 24 hours in distilled water and planted, on January 16 and 17, 1913, in shallow boxes of sand. These boxes contained sand and had previously been steamed for three hours in an Arnold steam sterilizer and thereupon allowed to cool. Pending the germination of the seeds, these boxes stood on the benches in the greenhouse. In the last four columns to the right, in table XXIII, will be found the measurements and the percentage of growth of the plumules of the seedlings from the seeds of different ages. These percentages were obtained by using the longest plumules as an arbitrary standard for comparison. In addition, therefore, to the information regarding actual germination which this table gives, we have also a record of the amounts of growth in length of these seedlings. These figures show that the older seed is not only slower in germinating and that there are fewer germinating seeds the older the seed is, but also that the seedlings, when the seed does germinate, are inferior in size to those from fresher seed, even when grown under the same conditions. The temperatures developed, therefore, within a short time in such an excellent insulator as a silvered Dewar flask, indicate plainly the values of the lots of seeds sampled. It would have been interesting for us to follow the later development of these seedlings of different ages, and to compare the harvests from the different lots, but the conditions of our experiments were such that this was not at the time possible. Table XXIII, supplementing the figures of previous tables showing the results of our Dewar flask experiments, shows the percentages of germination and also the percentages of growth immediately following germination.

Inspection of table XXIII shows an almost surprisingly regular decrease in the number of seeds sprouting as the age of the seed increases. This is plainest in the varieties numbered 791 and 98. The reasons for the less regularity in the other three varieties are not known to us. We have already pointed out that the different

flasks are not equally perfect insulators, and that the various conditions of harvesting and storage would also affect the results. Nevertheless, it is plain that the evidence of Dewar flask and of seed bed are quite consistent. Germination is increasingly tardy

TABLE XXIII

Wheat	Year	No. of kernels	No. sprouting January		Per cent-age spr. Jan. 27	Lengths of plumules in cm. January 27–28			
			25	27		Short-est	Long-est	Average	Percent-age of growth
Talaverra spring..	1871	50	.....	.....	0	.....	.....	.....	.....
California white spring.....	1872	50	.....	.....	0	.....	.....	.....	.....
No. 791.....	1909	50	45	46	92	0.4	7.0	4.75	74
	1910	50	47	47	94	1.0	8.1	5.67	88
	1911	50	47	49	98	1.1	8.5	5.95	92
No. 98.....	1909	50	28	35	70	0.3	6.8	3.73	58
	1910	50	33	36	72	0.2	7.8	4.28	66
	1911	50	34	41	82	1.0	7.1	4.63	72
					Jan. 30				
	1876	50	.....	.....	0	.....	.....	.....	.....
No. 1746.....	1907	50	27	29	58	0.7	7.3	3.62	56
	1908	50	6	6	12	1.4	8.8	6.41	100
	1909	50	36	45	90	0.3	8.5	3.46	53
	1910	50	36	38	76	0.3	8.1	2.81	43
	1911	50	39	43	86	1.3	8.5	5.35	83
No. 639.....	1907	50	26	26	52	0.2	6.2	2.66	32
	1908	50	15	18	36	0.2	3.4	1.20	18
	1909	50	26	29	58	0.3	6.5	2.49	38
	1910	50	41	42	84	0.4	7.3	2.71	42
	1911	50	50	50	100	0.2	7.4	2.41	37
No. 114.....	1907	50	34	36	72	0.2	6.2	2.75	42
	1909	50	43	44	88	0.6	6.9	3.84	59
	1910	50	42	44	88	1.0	6.0	2.94	45
	1911	50	44	44	88	0.3	8.2	3.32	51
	1876	50	.....	.....	0	.....	.....	.....	.....
	1876	50	.....	.....	0	.....	.....	.....	.....
	1876	50	.....	.....	0	.....	.....	.....	.....
Central Kansas I	1877	50	0	0	0	0	0	0	0
Central Kansas II	1877	50	0	0	0	0	0	0	0
Iowa white winter	1887	50	.....	.....	0	.....	.....	.....	.....

the older the seed. Furthermore, the percentages of growth, as shown by the lengths of the plumule, accord perfectly with the percentages of germination and correspond with the temperatures attained in the flasks. In varieties numbered 791 and 98, for example, there is the same regular decrease in growth as in

germination with the increasing age of the seed. The younger and more viable seeds sprout more promptly and produce a greater

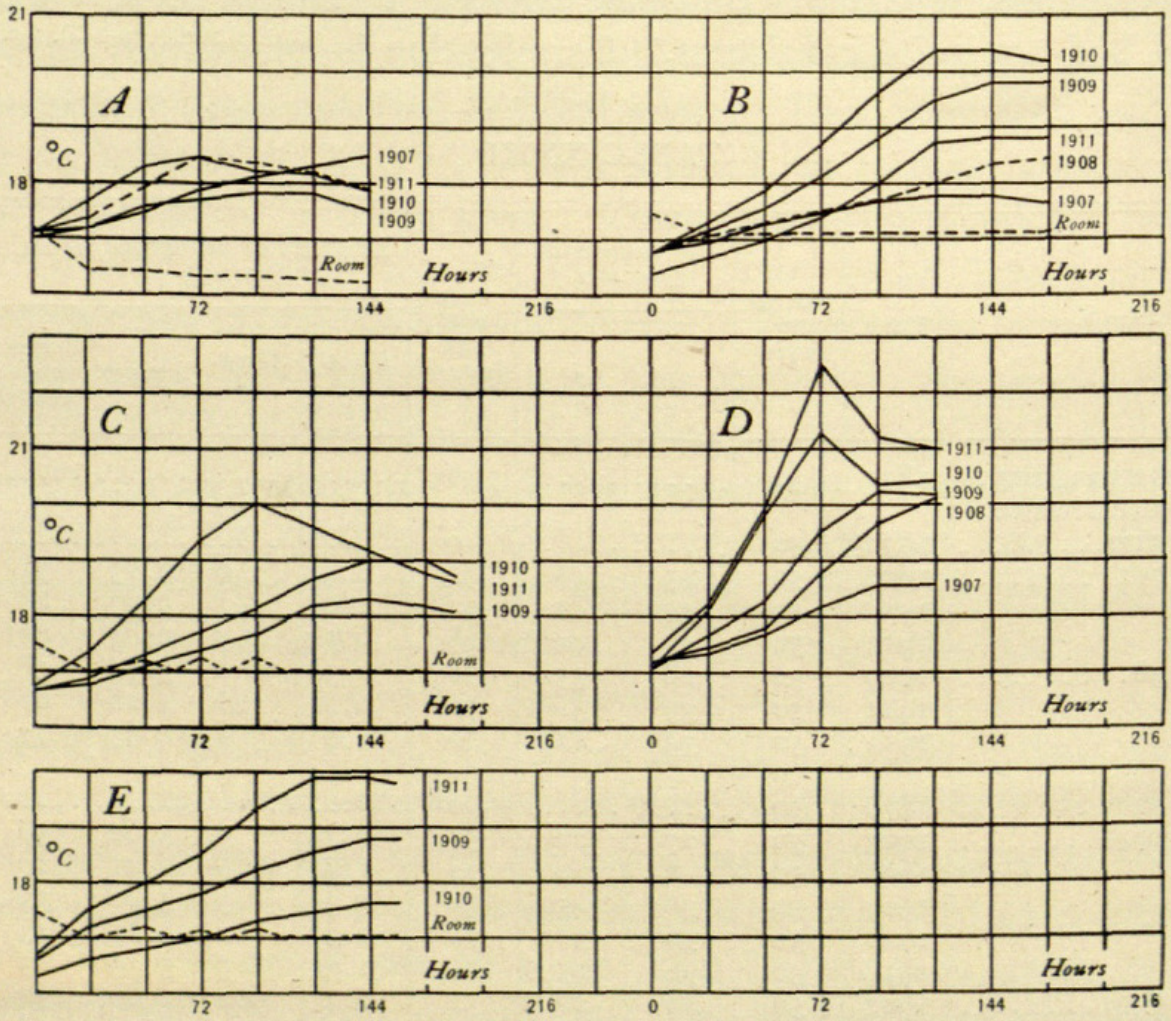


FIG. 15.—Wheat in flasks: *A*, no. 114; *B*, no. 1746; *C*, no. 791; *D*, no. 639; *E*, no. 98.

early growth than the older ones. The accompanying graphs (figs. 15–17) facilitate a comparison of the results as indicated in the foregoing tables.

Summary

Our experiments with seeds of different known ages indicate that one may readily ascertain the quality of these seeds, that is, their germinating power or viability, and the vigor of their growth immediately following germination, by determining the temperatures which they will develop in silvered Dewar flasks under conditions suitable for germination.

Each species of plant which we have studied appears to have, like the higher animals, a "normal" temperature, departures from

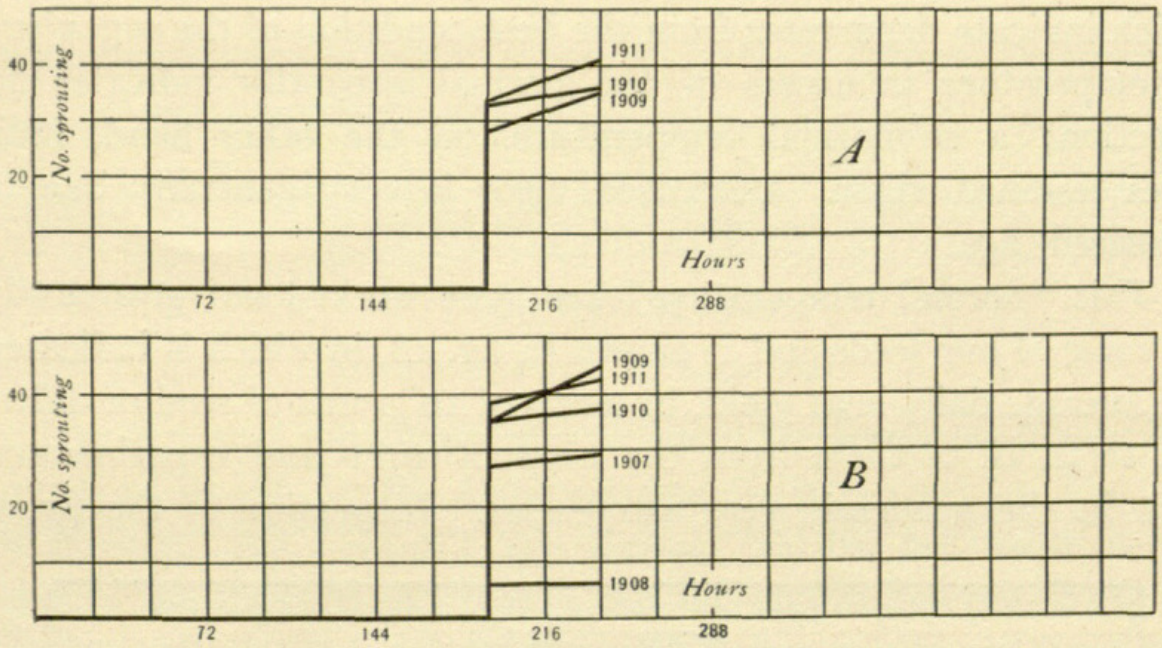


FIG. 16.—Wheat in soil: *A*, no. 98; *B*, no. 1746

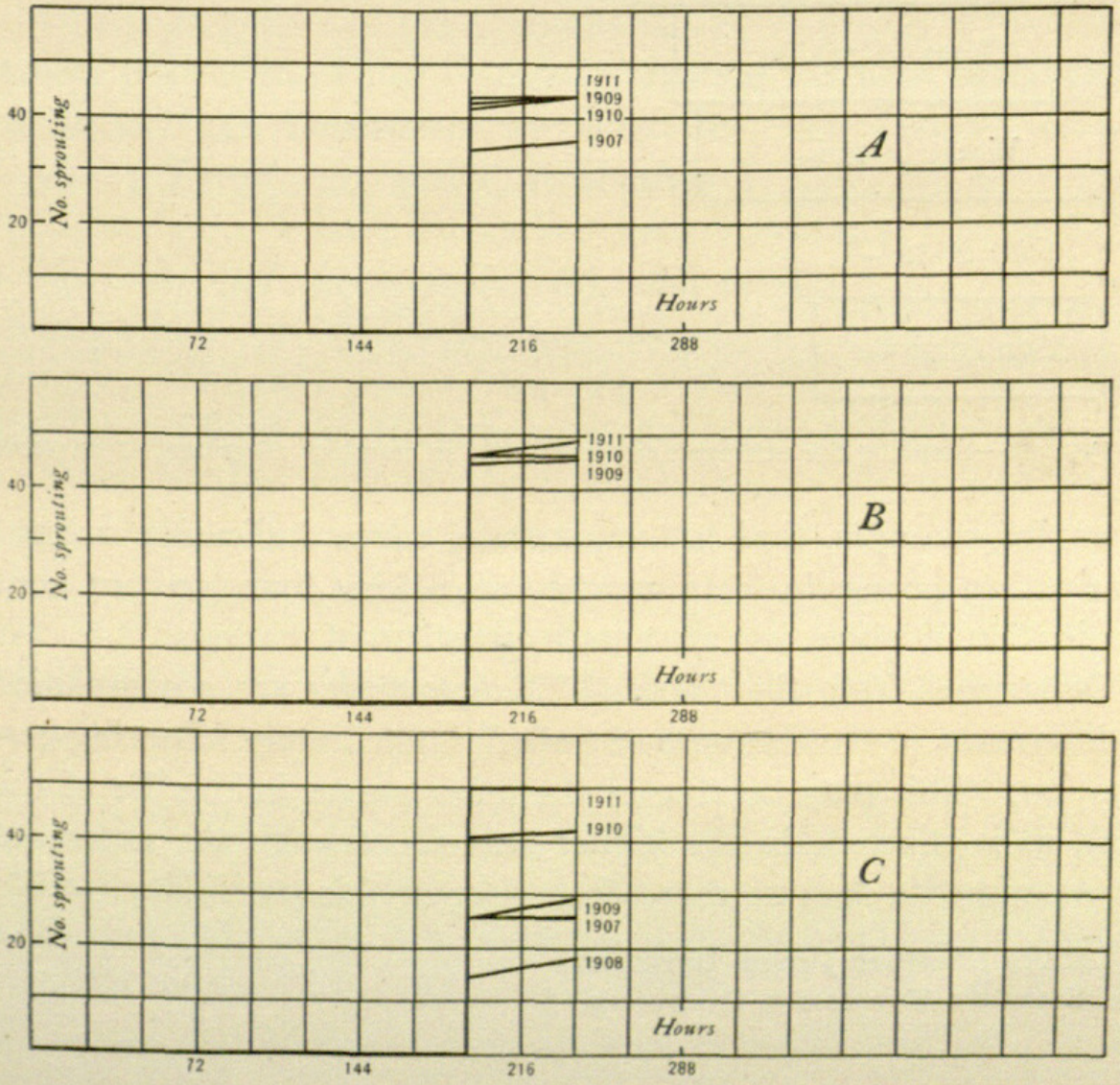


FIG. 17.—Wheat in soil: *A*, no. 114; *B*, no. 791; *C*, no. 639

which indicate departures from the best condition of the organism. A temperature in excess of the normal generally indicates an infection; a subnormal temperature, on the other hand, indicates lessened vigor. Decreased vigor is very generally due to increased age.

This "normal temperature" has been worked out graphically for some of our seeds and is shown in fig. 18, in which is indicated the average daily heat yield, in terms of 10 grams of seed of different sorts, all of them from the crop of 1911 and experimented with in the academic year 1911–1912. Inspection of the figure

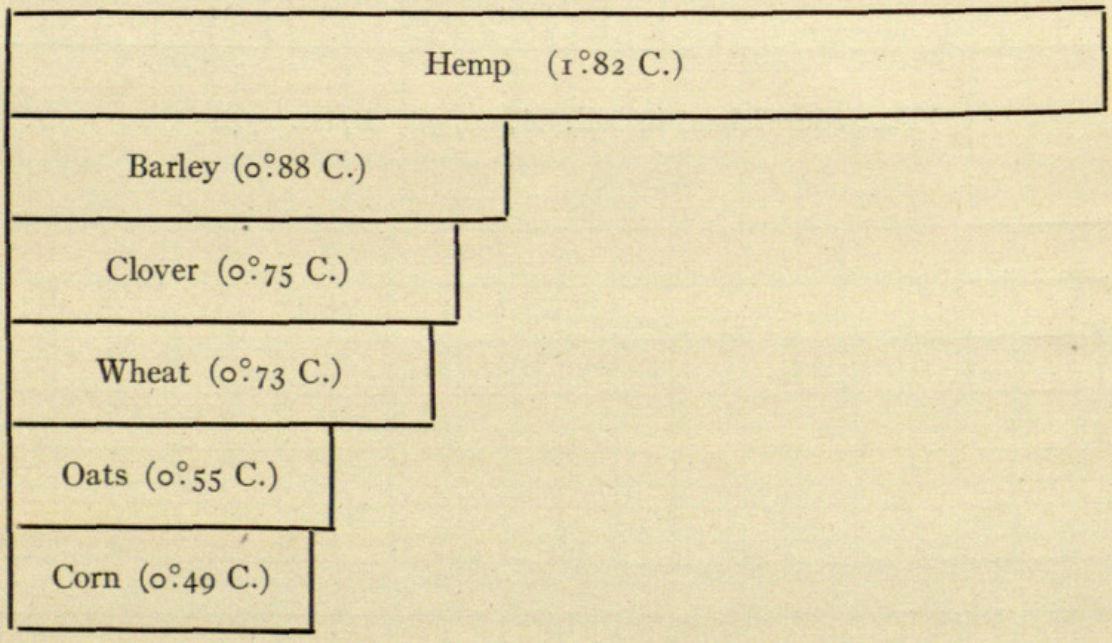


FIG. 18.—Showing the average daily heat yield in terms of 10 grams; 1911 seed

shows, for example, that a temperature curve indicating normal germinating power in oats would mean less than 50 per cent germination if given by an equal quantity of barley.

Departures from the "normal" temperatures are accompanied by differences in the amounts of growth immediately following germination. This may be true of the other stages in the life of the plant, as is the case in the higher animals, though the nature of our experiments does no more than suggest this possibility.

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