A STUDY OF RESPIRATION IN POTATOES WITH SPECIAL REFERENCE TO STORAGE AND TRANSPORTATION.

by

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Thesis submitted to the Faculty of the Graduate School of the University of Maryland in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

1925.

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A STUDY OF RESPIRATION IN POTATOES WITH SPECIAL REFERENCE TO STORAGE AND TRANSPORTATION.

Introduction.

Considerable progress has been made concerning potato storage, but ideas still differ about the best storage conditions to prevent the losses due to shrinkage and to preserve the culinary value of the tubers. That specialized storage is necessary is now generally recognized, but specific recommendations that are best for all periods in the storage life of the tubers cannot be made. Before this can be done we must know more about the physiological life of the tuber while in storage.

When considering storage it should be remembered that the potato tuber is a living breathing organism and should be treated as such. Oxygen is taken up, solids are consumed, and carbon dioxide, water and heat are given off. The solids used are, of course, a total loss in food value. Carbon dioxide is given off by diffusing from the tissues. Metabolic water formed in respiration becomes a part of the water content of the tuber and may pass off as transpired water. If the respiration rate is high enough, heat will accumulate and is likely to become injurious unless dissipated by proper ventilation. Bailey and Gurjar (4)

and Bailey (5) found that high respiration was responsible for heating of grain which was stored in large quantities, and containing relatively high water content. Respiration rate varies with temperature. Within certain limits this process follows the Van't Hoff-Arrhenius generalization of a doubling or trebling with with each rise of 10°C. Gore (9) found this to be true in the case of many different kinds of fruits. Ziegenbein (18) found in the case of potatoes that the respiration rate fell to a very low mark when the temperature was changed from 45°C to 10°C. Until recently it was thought that the respiration rate at 0°C would be small indeed. However, recent data presented by Hopkins (11) and Bennett and Bartholomew (8) show that when the temperature is decreased below about 5°C the Van't Hoff generalization does not hold, the respiration rate being higher at 0°C than at 5°C in some instances.

Muller-Thurgau (14) and later Appleman (1 & 3) found that when potatoes which had been stored for a time at a temperature near 0°C were moved to higher temperatures there was a period of excessively high respiration. If kept at the higher temperature the rate gradually decreased until it came to equilibrium at the normal rate for this temperature. Hasselbring and Hawkins (10) found that in sweet potatoes which had

been stored at low temperature and changed to a higher temperature there was an excessively high rate of respiration.

The period of abnormally high respiration in potatoes after exposure to a low temperature is probably a very important factor in their keeping qualities, especially during late common storage and marketing. Gore (9) found that the more perishable fruits had the higher rates of respiration. High respiration of potatoes in large bulk will cause them to heat unless especial care is given to ventilation. This would not only further accelerate the rate of respiration but would also favor the growth of decay organisms.

Bartholomew (6&7) was able to produce blackheart in potato tubers by exposing them to a temperature of 38 to 45°C with free access of air, for 15 to 20 hours. He ascribed the production of the injury to a deficiency of oxygen in the injured regions of the tuber, brought about as a result of the increased rate of respiration in the tissues. The available supply of oxygen diffusing inward from the surface of the tuber was used up before it reached the interior tissues which died as a result of asphyxiation. Stewart and Mix (17) found that blackheart may be produced at temperatures as low as 40°F by restricting the supply of oxygen sufficiently. They also showed that the injury was caused by deficient

oxygen supply and not by the accumulation of carbon dioxide produced in respiration. They emphasize the importance of proper ventilation in storage of tubers, the higher the temperature the greater the need of proper ventilation. Bennett and Bartholomew (8) produced blackheart in tubers at temperatures as low as 0°C, by sealing them in air tight containers. They state that tubers exposed to low temperatures until they became sweet appeared to be more easily injured at high temperatures than non sweet potatoes. This they believe was due to the higher rate of respiration in the potatoes in which sugar had accumulated.

The respiration rate and not the temperature would seem to be the important factor in determining susceptibility to black heart. The initial high rate of respiration in potatoes after their removal from cold storage would be expected to make them more susceptible to blackheart at high temperatures.

The chief purpose of the investigators here reported was to determine at 17°C, 22°C, 30°C the respiratory response of potatoes after varying periods of storage at different degrees of constant and fluctuating low temperatures. An explanation of the high initial rate of respiration at higher temperatures after a period of cold storage was sought. Experiments were also planned to determine at a constant

storage temperature the respiratory intensity in potatoes during different periods in their storage life. The practical implication of this work was to discover a temperature that might be suitable for potato storage and at the same time would reduce to a minimum the intensity and duration of the initial high respiration when the tubers are exposed to the higher temperatures of transit and marketing as well as to the rise in temperature during late common storage.

General Methods and Materials.

Unless otherwise noted, the variety used for the experiments here reported was Rural New Yorkers No. 2. The potatoes were grown on the Experiment Station Farm at College Park. The original seed potatoes were obtained from the Ford Seed Co., Ontario County, N. Y.

The tubers selected were produced from apparently healthy plants and were free from scab or other injury. In the selection of samples care was taken to make each sample representative of the lot as to size of tuber. All samples used in an experiment were composed of the same number of tubers and weighed the same to within a few grams. Samples of different experiments varied in weight from about 1300 grams to about 2000 grams, most of them weighing 1500 grams or more. The samples were stored in small sacks made from regular potato sacks.

By courtesy of those in charge, the Arlington Cold Storage Plant of the United States Department of Agriculture was made available for the following storage temperatures: 32°F. 36°F, 40°F and 50°F.

An electric refrigerating machine was also employed to obtain constant low temperatures in a well insulated refrigerator. Two levels in the refrigerator were found where the temperature showed a constant difference of about 6°F. The mean temperature of the lower level was about 36°F while that of the upper level was about 42°F. The temperatures were not as constant as might be desired, but the fluctuations of about 5°F were usually regular over comparatively short periods of time, so the temperature of the tubers was more constant due to the lag in their response to short intervals of fluctuating external temperature.

A ventilated vegetable cellar and a brick vault were employed as types of common storage with fluctuating temperatures.

A well insulated box with fan to stir the air was used for storage at a constant high temperature. By means of electric heating and control a constant temperature of 22°C was maintained in this box. The maximum fluctuation was 0.2°C. This box also served for the respiration determinations which were all made

at a constant temperature of 22°C, unless otherwise noted. This temperature was chosen as it approximates the average temperature of transportation and marketing of the storage crop on Eastern markets.

The rate of respiration was determined, for the most part, by measuring the amount of carbon dioxide expired. The method and apparatus used were similar to those described by Gore (9).

The respiration rate was determined by drawing carbon dioxide free air over the respiring tubers and absorbing the expired carbon dioxide in sodium hydroxide. The air was drawn through the system by means of a water aspirator. The circuit of the air was as follows. It was drawn from the inside of the constant temperature chamber, through soda lime tubes, next through some baryta water, then it entered the respiratory chamber at the top, passed over the tubers and was removed from the bottom of the chamber. After leaving the respiratory chamber it bubbled through 100 c.c. of approximately normal sodium hydroxide in a Reiset tube and last of all through baryta water again. The soda lime removed the carbon dioxide from the air. The air was bubbled through baryta water to test its freedom from carbon dioxide. Large desiccators were used as respiratory chambers and the constant temperature chamber was large enough to hold

four of them at one time. Air was drawn through the system at a steady rate and fast enough to prevent accumulation of carbon dioxide in the respiratory chamber but slow enough to insure absorption by the sodium hydroxide in the Reiset absorption tubes. The flow of air was regulated by a stop cock on each line as well as by the flow of water through the aspirator. In the circuit rubber connections were made as short as possible to prevent absorption of carbon dioxide by the rubber..

The carbon dioxide absorbed by the sodium hydroxide was determined by the method described by Gore (9) with the modification recommended by Küster. Barium chloride was added in excess so that the carbonate was precipitated as barium carbonate. The precipitate was left in the beaker and a double titration made, using phenolphthalein and methyl orange as indicators and titrating with normal hydrochloric acid. When the end point of phenolphthalein was reached the excess hydroxide was neutralized. The number of cubic centimeters of N/1 HCl used in titrating from the end point of phenolphthalein to the end point of methyl orange was the equivalent of the carbonate present, or each cubic centimeter of N/1 HCl was equivalent to 0.022 grams of carbon dioxide expired by the tubers. Respiration rates are expressed in milligrams of carbon di-

oxide expired per kilogram of potatoes per hour. This was obtained by multiplying the number of hours of a determination by the number of kilograms of potatoes used and dividing the product into the total amount of carbon dioxide obtained during the period of determination. In making calculations the weight of the sample just before it was put into the constant temperature chamber was used. The decrease in weight while the samples were in the constant temperature chamber was negligible over a period of two or three weeks. The humidity within the respiratory chamber was relatively high.

When samples were first placed in the constant temperature chamber carbon dioxide free air was drawn over the tubers for a period of usually six hours, before respiration determinations were started. This was done in order to remove the carbon dioxide from the respiratory chamber and to allow the tubers to come to the temperature of the constant temperature chamber. Determinations were usually made every twenty-four hours.

In the determination of the respiratory quotient the method of Magness and Diehl (13) was used with the slight modification that instead of using a double siphon to maintain a constant water level, running water with an overflow at the desired level was used.

The whole apparatus was kept in the constant temperature chamber as slight changes in temperature interfere with the accuracy of this method.

In sampling potatoes for sugar analysis the following procedure was used. Five tenths of a gram of calcium carbonate was added to a Kohlrausch flask which was then counterpoised. The tubers were grated on a nut meg grater and the pulp thoroughly mixed. While the pulp was kept thoroughly mixed 50 grams were added to the counterpoised flask. 100 c.c. of boiling 95% alcohol was then added. The flask was then placed on a boiling water bath, brought to the boiling point and boiled five minutes. While boiling small funnels were placed in the flasks to act as condensers. After boiling, the flasks, while still hot, were filled to the mark with hot alcohol. They were then allowed to stand over night and then filled to the mark with cold 95% alcohol. The samples were kept until it was convenient to make the sugar determinations. Duplicate samples were always taken.

In making sugar determinations the Munson and Walker gravimetric method was used. In determining the total sugar content acid hydrolysis in the cold was employed.

Moisture content was obtained by drying a weighed amount of thoroughly mixed grated material in a vacuum oven at 80°C to constant weight.

Amino nitrogen in a water extract in which proteins had been precipitated was determined by the Van Slyke method, using the small size apparatus.

RESPIRATION IN POTATOES AT 22°C(71.6°F) AS INFLUENCED BY THE PERIOD IN THE STORAGE LIFE OF THE TUBERS.

It was first necessary to establish the normal respiration rate in potatoes stored continuously at the temperature chosen for the respiration tests. It was also necessary to know if the different periods in the storage life of the tubers would cause any fluctuations in the respiration rate at this constant storage temperature. In order to determine this, potatoes were stored at 22°C (71.6°F) November 7, 1922, about a week after they were dug, and kept at this temperature until January 25, 1923. Respiration rate was determined frequently for 24 hour intervals. The following year potatoes were placed at the constant temperature the day of digging, October 30, 1923, and removed February 7, 1924. Respiration rate was frequently determined during this period. Sprouts first started Jan. 6, 1923 and Dec. 28, 1923. They were not removed, but as the potatoes showed strong apical dominance there was only one sprout to a tuber in most cases.

Results are given in table No. 1. Fig. 1 shows graphically the results obtained in tubers stored at 22°C (71.6°F) from Oct. 30 to Feb. 7.

TABLE 1. Respiration of potatoes stored at constant temperature of 22°C (71.6°F).

Results are expressed in milligrams of CO_2 per kilogram per hour. The duration of each run was usually 24 hours.

Date		Date	
Nov. 8, 1922	11.77	Oct. 31, 1923	20.4
Nov. 9,	12.32	Nov. 1,	18.1
Nov. 10,	10.79	Nov. 2,	20.0
Nov. 11,	9.90	Nov. 3,	19.4
Nov. 12,	9.41	Nov. 4,	13.3
Nov. 13,	8.47	Nov. 5,	11.1
Nov. 14,	8.13	Nov. 6,	10.7
Dec. 7,	5.35	Nov. 16,	7.1
Dec. 8,	5.28	Nov. 17,	6.8
Dec. 9,	5.28	Nov. 20,	6.3
Dec. 10,	5.31	Nov. 21,	7.4
Dec. 11,	5.42	Nov. 22,	20.8
Dec. 12,	5.48	Nov. 23,	11.5
Dec. 13,	5.24	Nov. 24,	9.1
Dec. 14,	5.19	Nov. 25,	7.6
Dec. 15,	5.24	Nov. 26,	6.8
Dec. 16,	5.31	Nov. 27,	6.6.
Jan. 7, 1923	6.14	Dec. 4,	5.6
Jan. 8,	5.36	Dec. 5,	5.5
Jan. 9,	5.41	Dec. 6,	5.6
Jan. 10,	5.36	Dec. 11,	5.4
Jan. 11,	5.26	Dec. 12,	5.4
Jan. 12,	5.18	Dec. 13,	5.3
Jan. 13,	5.55	Dec. 18,	5.0
Jan. 15,	4.86	Dec. 19,	5.0
Jan. 16,	4.83	Dec. 20,	5.2
Jan. 17,	5.18	Dec. 25,	5.0
Jan. 19,	5.23	Dec. 26,	4.7
Jan. 21,	5.36	Dec. 27,	4.8
Jan. 23,	5.35	Jan. 1, 1924	5.5
Jan. 25,	5.76	Jan. 2,	5.5
		Jan. 3,	5.0
		Jan. 8,	4.9
		Jan. 9,	5.1
		Jan. 10,	5.8
		Jan. 11,	5.5
		Jan. 15,	5.0
		Jan. 16,	5.1
		Jan. 17,	5.6
		Jan. 22,	5.1
		Jan. 23,	5.2
		Jan. 24,	5.2
		Jan. 29,	5.6
		Jan. 30,	5.9
		Jan. 31,	6.0
		Feb. 5,	5.4
		Feb. 6,	5.4
		Feb. 7,	5.3

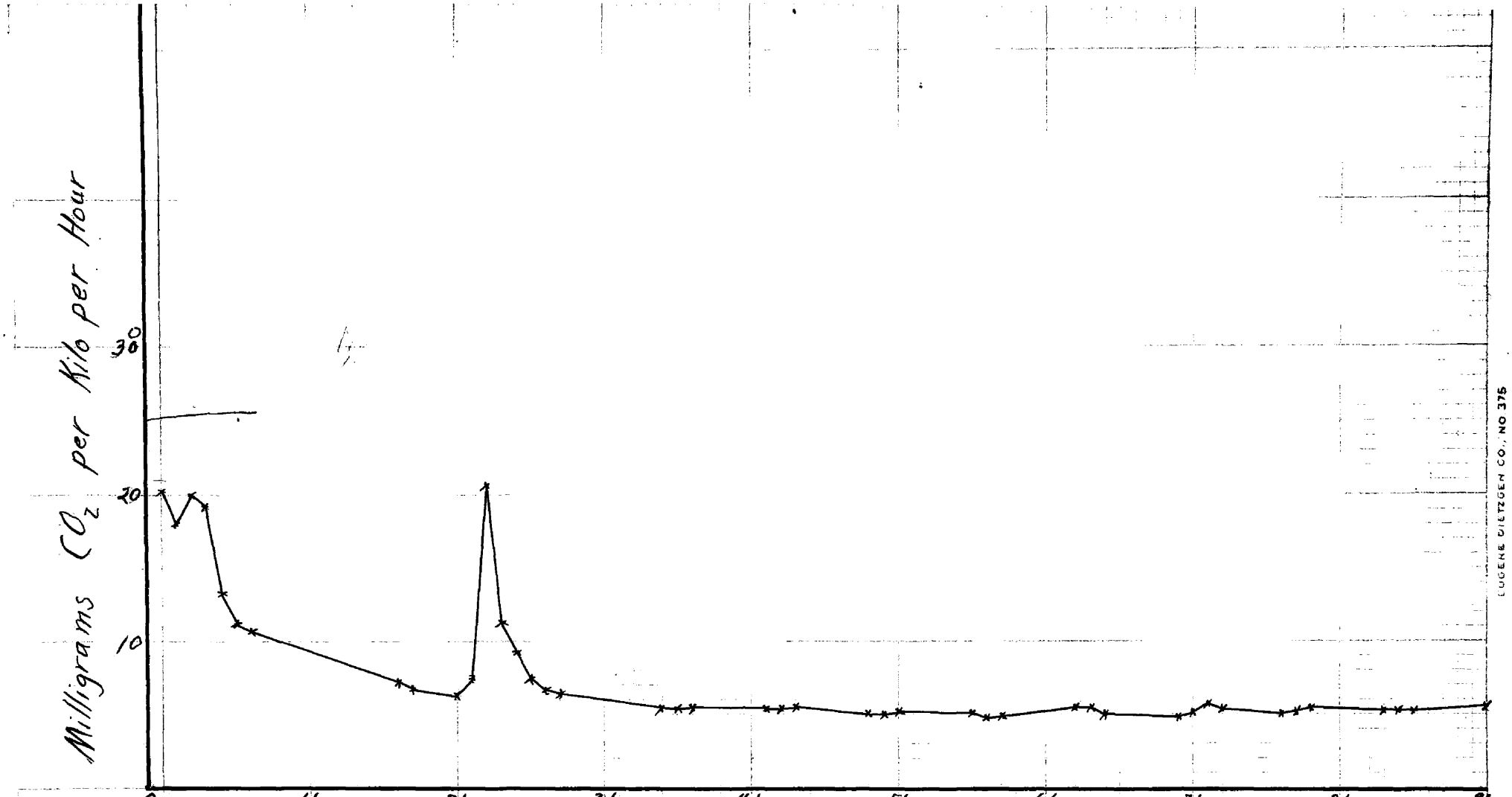


Fig. 1.

Respiration in Potatoes Placed at 22°C (71.6°F) the Day of Digging

There was a period of high respiration immediately after digging, and the rate did not become constant until after about a month in storage. After the respiration rate had come to equilibrium it remained practically constant during the rest of the period of storage. The starting of sprouts caused no apparent increase in respiration rate. The rate of respiration after coming to equilibrium is considered the normal rate and a check with which to compare respiration rates in tubers which had previously been stored at different temperatures.

RESPIRATORY RESPONSE IN POTATOES AT HIGHER TEMPERATURES AFTER STORAGE AT DIFFERENT CONSTANT LOW TEMPERATURES.

Experiment 1:- Samples of potatoes were stored, soon after digging in the Arlington cold storage plant of the United States Department of Agriculture at temperatures of 50, 40, and 36°F.

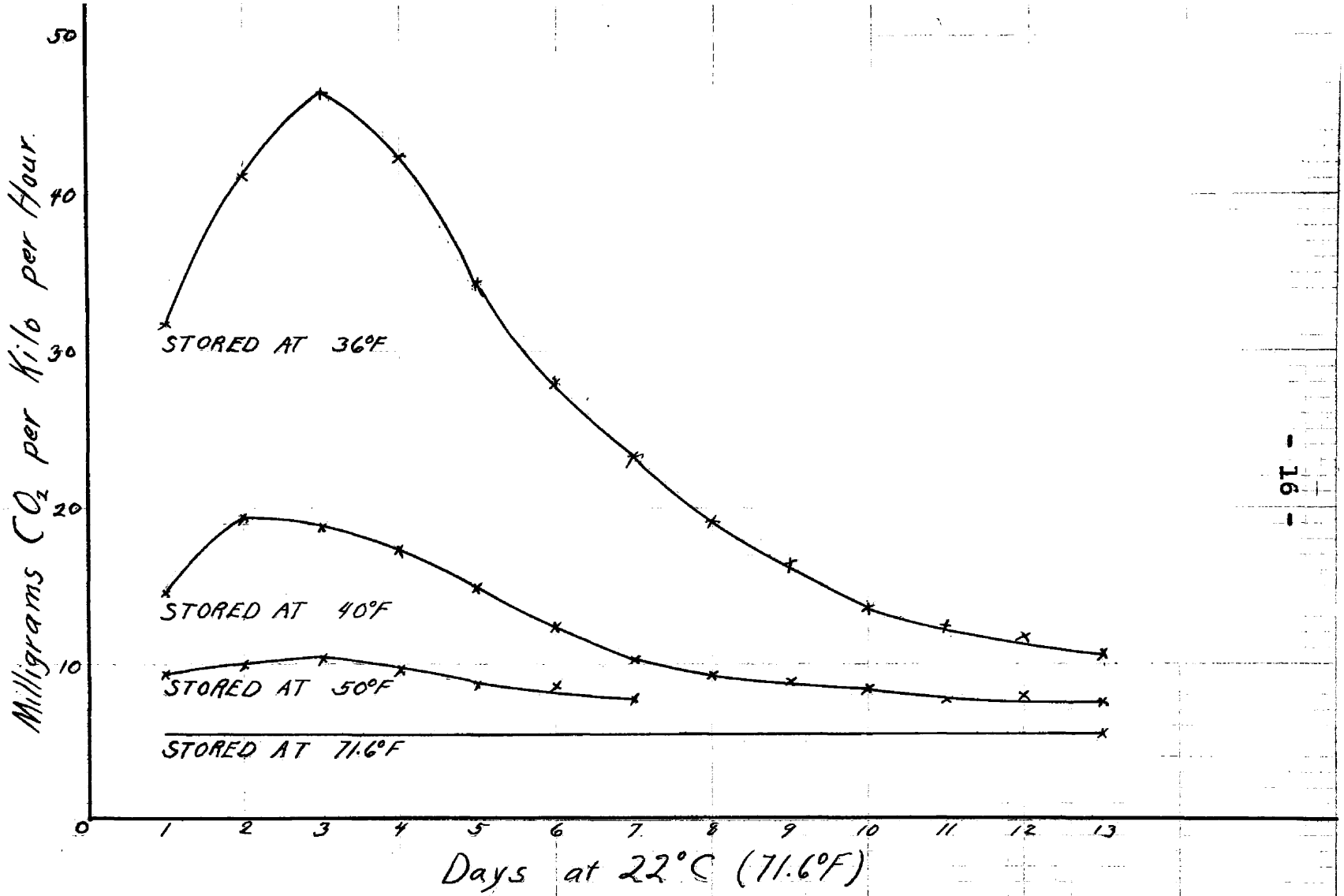
The thermograph records show that the temperatures of the three rooms were practically constant. There was a little more fluctuation in the 36°F room than in the 40°F room or the 50°F room. The temperature in the 36°F room fell to 33°F for a short period. The period of storage was from November first to February twenty-first.

The loss in weight of the samples during this period of storage is given in table 2.

TABLE 2. Percentage loss in weight during storage period at Arlington.

36°F Room	40°F Room	50°F Room
5.30	4.04	3.51

The effect of the previous storage temperature on the respiration rates at 22°C (71.6°F), is shown graphically in figure 2.



Effect of Storage Temperature on Rate of Respiration at 22°C (71.6°F)

Fig. 2

EUGENE DIETZGEN CO., NO 375

The initial respiration rates in the potatoes varied greatly with the previous storage temperatures. The lower the storage temperature the higher the initial respiration rate, and the longer the time necessary for the respiration rate to come to equilibrium at the constant temperature. A difference in storage temperature of only 4°F between 40°F and 36°F more than doubled the initial rate of respiration at 22°C (71.6°F). It is also interesting to note that a storage temperature as high as 50°F effects the respiration rate for a short time at the higher temperature. The maximum rate of respiration was not attained until the second or third day in the constant temperature chamber. No explanation has yet been found for this.

Having shown the effect of storage temperature on the respiration rate at a constant temperature of 22°C (71.6°F), it was thought advisable to determine the respiration rate in potatoes from cold storage, at other constant temperatures. This was done in order to find out the importance of the initial high rate of respiration at different temperatures.

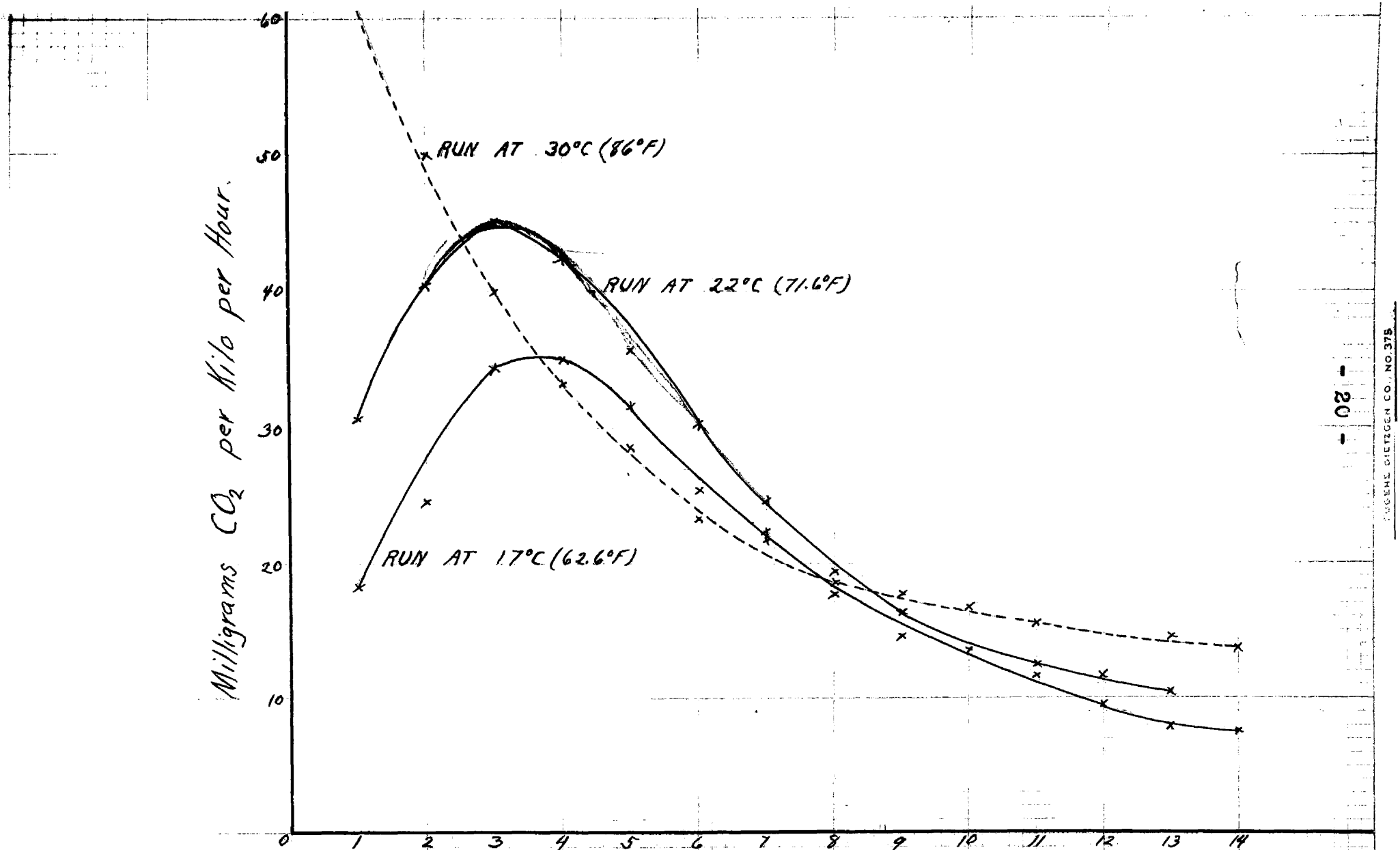
Experiment 2:- In this experiment the respiration rates in potatoes after a period of cold storage were compared at different constant high temperatures. Potatoes from storage at 36 and 40°F were used for respiration tests at constant temperatures of 17°C (62.6°F), 22°C (71.6°F),

and 30°C (86°F). All determinations were made in duplicate. The results are given in table 3 and figures 3 and 4. The averages of duplicate samples were used in constructing the graphs. The duplicates at 17°C (62.6°F) from 36°F storage did not check well on the fourth day, one increasing and the other slightly decreasing from the third day. Thus it is not certain whether the maximum rate at 17°C (62.6°F) in tubers from 36°F storage is reached the third or fourth day.

TABLE 3. Respiration rates in tubers from 36°F and 40°F storage at constant temperatures of 17°C(62.6°F) 22°C(71.6°F) and 30°C(86°F). CO_2 expressed in milligrams per kilo per hour.

	From 36°F storage						From 40°F storage					
	17°C		22°C		30°C		17°C		22°C		30°C	
24 hour interval	Sample A	Sample B	Sample A	Sample B	Sample A	Sample B	Sample A	Sample B	Sample A	Sample B	Sample A	Sample B
1	18.1	17.4	31.8	29.7	62.5	59.5	9.5	10.0	14.5	13.7	25.8	27.8
2	24.9	24.4	41.2	40.0	52.2	48.2	12.2	12.1	19.5	18.1	26.5	25.8
3	34.6	34.3	46.4	43.9	39.9	39.6	12.4	13.0	18.9	16.7	22.0	21.7
4	37.7	32.3	42.5	42.3	33.3	32.7	12.1	11.8	17.4	16.0	19.9	18.7
5	31.7	31.7	34.6	36.9	29.0	28.1	11.1	11.0	14.9	15.4	16.3	17.0
6	24.9	25.2	28.0	32.4	22.7	23.5	10.2	8.6	12.5	14.3	14.3	14.3
7	22.9	21.6	23.4	26.0	21.5	22.3	8.8	8.7	10.3	11.8	14.0	13.7
8	17.6	18.2	19.1		18.1	18.9	7.7	6.9	9.3		12.9	12.5
9	14.4	15.0	16.2		17.6	18.2	6.9	6.4	8.6		11.8	12.0
10 *			13.5		16.1	17.4			8.3		11.8	11.2
11	11.2	12.1	12.5		15.2	15.9	6.4	5.7	7.6		11.1	11.3
12	8.9	10.1	11.7				5.4	5.1	7.8			
13	7.9	8.1	10.2		14.1	15.2	5.0	5.4	7.3		10.8	10.8
14	7.6				13.4	14.0	4.8	4.9			10.6	10.3

* 48 hour interval instead of 24 hour.



Potatoes from 36°F Storage - Respiration Determined at Different Temperatures.

Fig. 3

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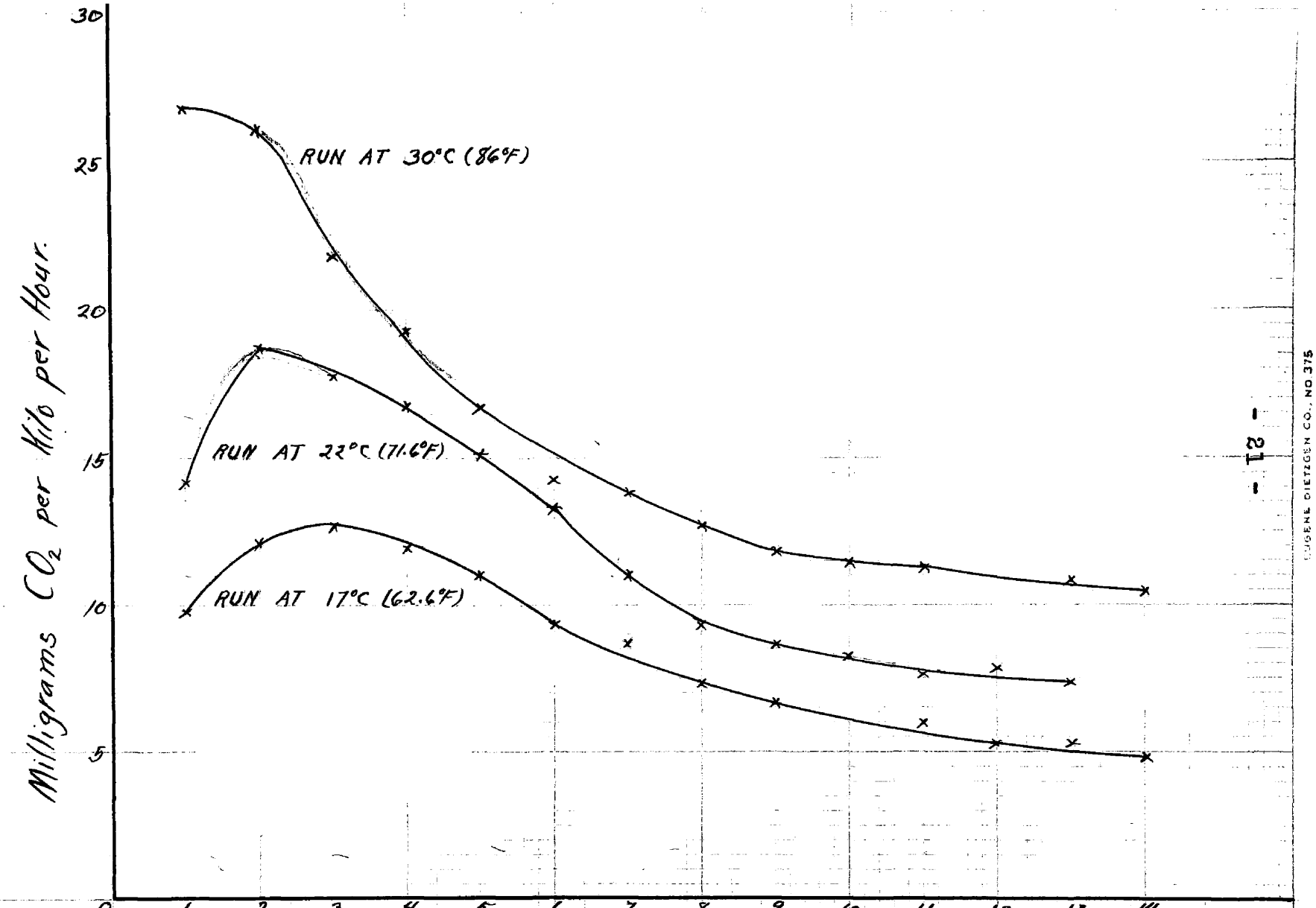

Potatoes from 40°F Storage - Respiration Determined at Different Temperatures.

Fig. 11

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The graphs show that the initial high rate of respiration varies considerably with the temperature at which the determinations were made. The shape of the curve also varies with the temperature. The respiration rate falls most rapidly at 30°C (86°F). With potatoes from 36°F storage the respiration rate was higher at 22°C (71.6°F) than at 30°C the third day in the constant temperature chamber. The respiration rate at 30°C (86°F) even fell below that at 17°C (62.6°F) during part of the period of high respiration. The rate of respiration at 17°C (62.6°F) was high, but it at no time was as high as that at 22°C(71.6°F) for the same period at the constant temperature.

It was hoped to determine by this experiment whether the amount of carbon dioxide given off above the normal rate is specific. That is whether the amounts given off in excess of the normal rate for the different temperatures would be the same. The time necessary to bring the rates of respiration to actual equilibrium was so long that this was not done. Equilibrium was approximated to such an extent however that rough estimations may be made. The excess carbon dioxide given off at 30°C (86°F) and 22°C (71.6°F) from potatoes from 36°F storage was approximately the same. The excess given off at 17°C (62.6°F) was, however, somewhat less.

The shape of the curves at the different temperatures practically precludes the possibility of fitting the ef-

fect of temperature on the high rate of respiration to general laws or generalizations.

The time at which the maximum temperature was reached varied with the temperature at which determinations were made. The determinations for the first 24 hours interval at 30°C (86°F) were made in two twelve hour intervals, the respiration rate being slightly higher in the second than in the first.

The initial respiration rate at 17°C (62.6°F) shows that potatoes do not have to be changed from cold storage to a very high temperature to produce an appreciably higher rate of respiration than is normal for the given temperature.

THE EFFECT OF FLUCTUATING LOW STORAGE TEMPERATURES ON RESPIRATION IN POTATOES AT HIGHER TEMPERATURES

In the previous experiment the storage temperatures were constant. Large quantities of potatoes are stored in common cellar storage with fluctuating low temperature. For this reason experiments were performed with potatoes stored in a storage cellar and with potatoes which were changed from lower to higher cold storage temperatures.

Experiment 1:- Some samples of Rural New Yorker potatoes were stored in a vegetable storage cellar soon after digging. Samples were removed at intervals of one month and respiration rate determined at 22°C(71.6°F). The results are given in table 4.

TABLE 4. Respiration of potatoes at 22°C (71.6°F) after different periods of cellar storage.

Temperature		Date of Removal from Storage	No. of days in Storage	Milligrams of CO_2 per kilo per hour						
Ave. Daily Mean	Range			1st day	2nd day	3rd day	4th day	5th day	7th day	9th day
49.0	42.0-60.0	Dec. 6	29	8.05	11.63	11.88	11.39	9.44	8.62	7.91
42.96	38.0-48.5	Jan. 6	60	8.82	11.31	12.79	13.24	12.02	9.66	7.24
41.97	35.5-48.0	Feb. 7	89	10.26	15.99	17.69	16.66	14.29	10.61	8.03
41.6	31.5-49.0	Mar. 7	120	12.47	15.83	17.21	16.26	13.54	10.02	7.52
46.8	39.5-53.0	Apr. 7	150	9.90	10.95	12.10	12.51	11.16	10.37	9.25
52.8	42.8-58.3	May 7	181	9.74	10.48	10.48	9.15	8.33	8.34	

The mean temperature for the month preceding removal from storage was in no case very low, so very high initial rate of respiration was not obtained on any of the samples. The respiration rate seemed to be influenced by the mean temperature rather than by the extremes. In general the lower the mean temperature for the month preceding removal from storage, the higher the initial rate at 22°C (71.6°F). The data also indicate that the period in the storage life of the tubers has no appreciable influence on the initial high rate of respiration on removal from storage, but that this varies with the storage temperature.

Experiment 2:- Scotch Rural potatoes which had been stored in a brick vault were used for this experiment. On January 21 samples were selected and stored at a temperature of about 0°C (32°F), maintained in a large box surrounded with ice. At the end of four weeks the samples were removed from this temperature. Respiration determinations were started at once on one sample while other samples were stored at a temperature of about 45°F. These were removed at intervals for respiration tests.

Results are given in table 5.

TABLE 5. Effect of change from lower to higher storage temperature on respiration rate at 22°C (71.6°F).

Period of storage	Mean temp. of storage	Milligrams of CO_2 per kilo per hour for 24 hours						
		1	2	3	4	5	6	7
Weeks								
0		39.7	42.0	36.7	34.5	30.6	25.6	21.1
1	46.0	40.1	41.3	38.5	31.3	22.0	17.4	
2	44.85	26.6	28.7	23.6		19.2	16.3	
4.	45.1	22.0	21.3	20.8		16.8	11.4	

The results show that there is a decrease in initial rate of respiration at 22°C (71.6°F) varying with the length of storage at the higher storage temperature. The rate of respiration after one week of storage is, however, very little different from that immediately after removal from the container surrounded with ice. How much lower the rate would have gone if samples had been left longer at the higher storage temperature is not known.

Experiment 3:- Some Rural New Yorker potatoes which had been stored at 36°F at Arlington since digging were changed to 40°F on Feb. 24, and allowed to remain at this temperature for four weeks. They were then removed and respiration determined at 22°C(71.6°F). The results obtained are given in table 6.

TABLE 6. Comparison of respiration rate in tubers which had been stored at 36°F for more than three months then changed to 40°F for four weeks with rates in tubers from 36°and 40°F storage.

Storage treatment	Respiration determined at 22°C (71.6°F). Milligrams CO_2 per kilo per hour for 24 hour periods								
	1	2	3	4	5	6	7	8	9
36°F	31.8	41.2	46.4	42.5	34.6	28.0	23.4	19.1	16.2
36°F changed to 40°F	28.6	35.6	36.0	32.3	26.2	22.7	20.3	18.1	15.5
40°F	14.5	19.5	18.9	17.4	14.9	12.5	10.3	9.3	8.6

After four weeks at 40°F the rate is somewhat lower than in potatoes brought direct from 36°F storage. Still it is very much higher than inttubers which had been stored at 40°F since they were dug. Results given in the table for potatoes from 36 to 40°F were not obtained at the same time as those which had been changed from 36°F to 40°F in storage, but results of other experiments indicate that the difference in time makes little, if any, difference.

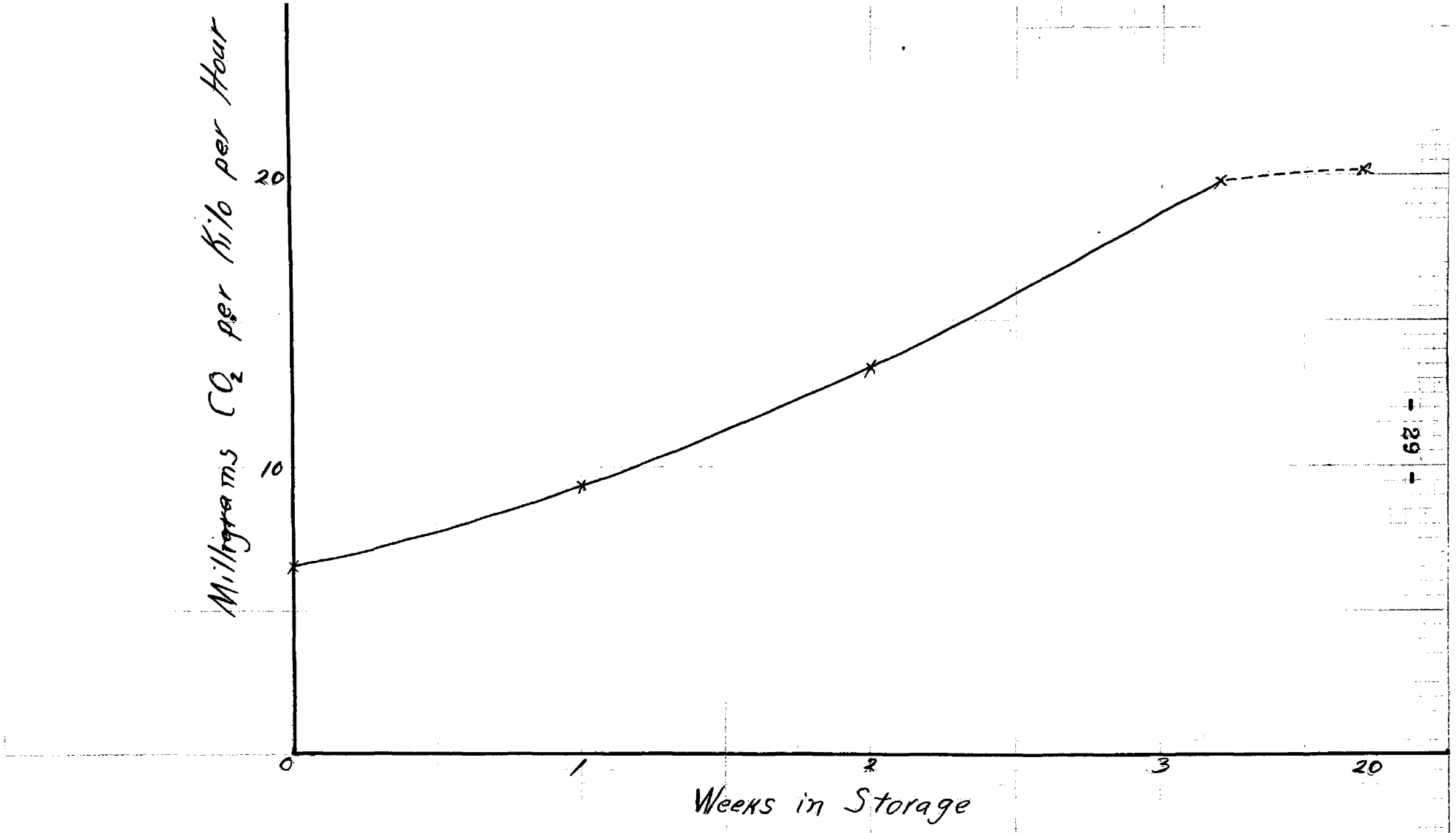
It would seem then that the effect of storage at a lower temperature is felt inppotatoes changed to a higher storage temperature for a relatively long time. This would indicate that when the temperature goes up in ordinary cellar storage in the spring if the mean temperature has been low for some time, that the respiration rate is likely to be excessively high.

PERIOD OF STORAGE AT LOW TEMPERATURE REQUIRED TO OBTAIN THE MAXIMUM RESPIRATION IN POTATOES WHEN EXPOSED TO A HIGHER TEMPERATURE.

The effect of storage at low temperatures for comparatively long periods on the respiration rate in potatoes at higher temperatures has been shown. The following experiments were conducted to determine the minimum storage period which would produce the maximum respiration rate at a higher temperature.

Experiment 1:- On March 3, 1924 samples of Rural New Yorker potatoes were stored at a constant temperature of 22°C (71.6°F). They were kept at this temperature until March 19, in order to allow the respiration rate to come to equilibrium. The respiration rate was then determined on one sample and the others were stored at a temperature of 36.5°F, but the temperature fluctuated rather regularly between 35 and 39°F. Samples were removed at intervals of one week and respiration rates determined at 22°C (71.6°F).

The results of this experiment are shown graphically in Fig. No. 5.



Storage Period Necessary to Produce Maximum Respiration Rate at 22°C (71.6°F)

Fig. 5.

EUGENE DIETZGEN CO., NO. 375

The graph in fig. 5. shows that there is an increase in respiration rate with period of storage up to about three weeks. There is no appreciable difference between the maximum respiratory rate at 22°C(71.6°F) after 23 days storage at the low temperature and the rate in a sample that had been stored in the same place for about five months.

Experiment 2:- Samples of mature Irish Cobbler potatoes were dug Aug. 18 and respiration determinations started on duplicate samples. Similar lots of tubers were stored at a constant temperature of 37°F. Other lots of the same potatoes were placed in common cellar storage where the temperature was fairly constant at about 65°F for the duration of the experiment. Samples were removed from both types of storage at intervals of one week and respiration rates determined. On account of the high room temperature during the first three weeks of this experiment it was not possible to obtain accurate temperature control in the respiration chambers. The respiration rate in the tubers from the cellar storage was considered as a check with which to compare the rates in tubers after storage at the low temperature. The respiration rate fluctuated with fluctuations in temperature.

Results are given in Tables Nos. 7 and 8. The data in table No. 8 were obtained by dividing the respiration rate in potatoes from cold storage by the rate in the check. In this way fluctuations due to varia-

tions in the temperature at which respiration was determined were largely avoided since comparable ratios are obtained.

TABLE 7. Respiration of Irish Cobbler potatoes after different periods of storage at 37°F and the cellar at 65°F.

Period of storage weeks	Mean temperature of storage	Milligrams of CO_2 per kilo per hour for 24 hour intervals.						
		1	2	3	4	5	6	7
0		10.2	9.2	10.4	8.8	8.7		
1	37°F	34.8	24.9	17.7	17.0	14.1		13.3
1	65°F	9.8	9.1	9.8	10.9	10.4		10.3
2	37°F	76.1	40.3	21.6	16.6	12.7		5.8
2	65°F	13.1	12.2	8.5	7.2	5.9		4.4
3	37°F	26.7	29.9	20.3	18.9	18.0	16.9	13.4
3	65°F	5.7	6.2	4.8	5.1	6.2	6.6	6.4
4	37°F	19.1	21.7	20.9	17.7	15.0	12.7	11.4
4	65°F	6.5	6.4	6.3	6.2	6.3	6.3	5.9

TABLE 8. Period of storage necessary to produce the maximum respiration rate at 22°C (71.6°F). Results are expressed as ratio between respiration rates of potatoes stored at 37°F and 65°F.

Period of storage at 37°F. Weeks	Ratio based on determinations at 24 hour intervals.						
	1	2	3	4	5	6	7
1	3.35	2.74	1.81	1.56	1.36		1.29
2	5.80	3.30	2.54	2.31	2.15		1.32
3	4.68	4.82	4.23	3.71	2.90	2.56	2.09
4	2.94	3.39	3.32	2.85	2.38	2.02	1.93

Again it was found that the initial respiration after removal from storage, increased with the storage period up to 3 weeks. No explanation is offered for the respiration rate being less after four weeks of storage than after three weeks of storage. The reasnn why the maximum rate was attained the first day after removal from storage after one and two weeks and the second day after three and four weeks is not wknown.

Experiment 3:- At digging time Oct, 30, 1923, samples of Rural New Yorker potatoes were selected and placed in storage at a mean temperature of about 36°F. At intervals of one month samples were removed and respiration rate determined at 22°C (71.6°F).

Results are given in table 9.

The respiration rates in potatoes removed in different months are not appreciably different. This is further evidence showing that after a certain period of storage further storage at the same temperature does not increase the initial high rate of respiration in tubers changed to higher temperature.

TABLE 9. Respiration of potatoes at 22°C (71.6°F) after different periods of storage at 36°F.

Temperature		Date of Removal from storage	No. of days in storage	Milligrams CO_2 per kilo per hour					
Ave. Daily Mean	Range			1st day	2nd day	3rd day	4th day	5th day	7th day
36.86	33.0-49.0	Dec. 3	34	17.8	19.5	19.0	17.1	15.0	12.2
36.68	33.5-42.0	Jan. 2	64	19.3	23.0	22.1	20.7	18.8	14.1
35.63	32.0-40.2	Feb. 2	95	15.0	18.2	19.1	19.5	16.7	12.5
36.21	33.5-39.5	Mar. 3	124	11.8	15.0	14.8	14.5	13.4	11.4
36.47	33.0-40.0	Apr. 2	154	16.2	19.6	20.1			13.4
36.53	33.7-39.5	May 2	184	16.8	17.8	17.8	16.7	17.5	14.1

INVESTIGATIONS CONCERNING THE CAUSE OF THE INITIAL HIGH RATE OF RESPIRATION IN POTATOES WHEN MOVED FROM A LOW TO A HIGHER TEMPERATURE.

Since carbon dioxide is more soluble in cold water, it might be thought that the initial high rate of respiration when potatoes are moved from cold storage to higher temperature is due to the driving off at the higher temperature of carbon dioxide backed up in the tissues at the lower temperature. Magness (12) found a higher content of carbon dioxide in the intercellular spaces of potatoes at high temperatures than at low temperatures and he believed that considerable carbon dioxide had come out of solution. When potatoes were removed from 36°F and 40°F storage and respiration rate determined at 22°C (71.6°F). (table 3), it was found that the maximum respiration rate was not attained until the second or third day. If the high rate of respiration were due to carbon dioxide backed up in the tissues the maximum rate should be obtained as soon as the tubers attained the temperature of the constant temperature chamber. The rate should also decline rather rapidly, but this was usually not true. Calculations showed that in some cases more carbon dioxide was given off in excess of the normal rate than could be dissolved in the water of the potatoe at the storage temperature.

Experiment 1- Some determinations of the CO_2/O_2 ratio

were obtained by the method of Magness and Diehl (13) modified as previously explained. Determinations were made as soon as possible after removal from cold storage and after being at 22°C (71.6°F). for varying lengths of time. In this way, the respiratory quotient was obtained for different rates of respiration during the period of initial high respiration. The results are given in table 10.

TABLE 10. Respiratory quotient determined at 22°C (71.6°F) in tubers from cold storage.

Respiratory Quotient	Reppiration rate in mgs. per kilo per hour.
1.02	49.7
1.10	47.8
0.99	33.9
0.94	32.7
1.03	32.0
1.04	27.5
0.95	6.5

Although the respiration rate during each succeeding 24 hour period showed a marked decrease, the variation in the respiratory quotient was well within the experimental error of the method employed. As the respiratory quotient during the period of initial high respiration after removal from storage, was found to be unity, the carbon dioxide given off during this period must be due to true respiration. All the evidence at hand indicates that the initial

high rate of respiration when potatoes are changed from cold storage to higher temperature is not due to the driving off of carbon dioxide backed up in the tissues.

Experiment 2:- Spoehr and McGee(16) found a relationship existing between amino acid content and respiration rate in sunflower leaves. Higher amino acid content seemed to be associated with higher respiration rate. It was thought that there might be an accumulation of amino acids in potatoes, as has been found in some other plant tissues, when exposed to cold temperatures.

Amino nitrogen was determined in a water extract from the tubers, that had been stored two months at Arlington at the following respective temperatures: 36, 40, and 50°F. Results are given in table 12. Calculations are based on the average of closely agreeing duplicates.

TABLE 11. Percentage amino nitrogen in tubers stored at different temperatures based on fresh weight.

Temperature of storage	50°F	40°F	36°F
Amino nitrogen	0.128	0.121	0.111

No accumulation of amino acids was found at lower temperatures, and so this cannot account for the high respiration rate after removal from storage.

Muller-Thurgau (14) and Appleman (1 & 2) found that sugar accumulated in Irish potatoes which were held for

a time at low temperature. If the tubers in which sugar had accumulated were changed to a higher temperature, the accumulated sugar gradually disappears. Because of the parallelism between sugar content and respiration rate when potatoes are moved from cold storage to higher temperatures, Muller-Thurgau believed that the sugar content was the explanation of the high respiration rate. Recently Hopkins (11) has emphasized the relationship between sugar content and the increased respiration observed in potatoes at temperatures below 5°C. He attributes the higher respiration at 0°C to sugar accumulation. He believes however, that sugar may accumulate to such an extent that respiration rate may be decreased. Bennett and Bartholomew (8) also attribute the higher respiration in tubers held at low temperatures to increased sugar content. Appleman (unpublished data) found, however, that in tubers removed from cold storage a to 30°C (86°F) there might be an increase in sugar content, both reducing and total sugars, while respiration rate fell rapidly. Hasselbring and Hawkins (10) found the respiration rate in sweet potatoes, at 30°C (86°F) previously stored at low temperature, was so high that they did not think that it could be explained on the basis of sugar content alone.

Several experiments were carried out which give further evidence concerning the relationship between respiration and sugar content.

Experiment 3:- Mature Rural New Yorker potatoes were dug Oct. 29, 1924. On the day of digging uniform samples of tubers were selected. Respiration determinations were started, at 22°C (71.6°F) on one sample, immediately and the other samples were stored at 36°F. At intervals of one week, samples were removed and respiration rate determined for 24 hour intervals for one week at 22°C (71.6°F). Three tubers were sampled for sugar content when respiration determinations were started. Sugar content was determined again immediately after removing tubers from the constant temperature chamber.

Results obtained are given in table 12. Sugar content is expressed in percentage of original fresh weight.

TABLE 12. Relation of sugar content to Respiration in Potatoes.

Rural New Yorker Dug Oct. 30, 1924.

Period of storage at 36°F.	Respiration determined at 22°C: Milligrams CO_2 per kilo per hour for 24 hour periods							Percentages of sugar in the potatoes at the beginning and end of the respiration determinations: Reducing Sugar		Total Sugar	
	1	2	3	4	5	6	7	Beginning	End	Beginning	End
Weeks											
0	28.0	15.2	11.7	9.8	9.7	7.9	7.7	0.00	0.00	0.15	0.14
1	27.1	22.6	18.3	16.2	14.9	12.9	11.6	0.34	0.17	1.01	0.43
2	22.8	25.3	24.3	22.2	17.3	16.0	11.8	0.77	0.23	1.69	0.50
3	25.9	31.7	32.4	27.7	22.9	18.9	15.1	0.74	0.39	1.54	0.77
4	25.7	31.8	33.3	28.8	22.2	18.1	14.9	1.16	0.51	1.98	0.77

Immediately after digging the respiration rate is high but it falls rapidly when kept at 22°C (71.6°F) for one week, however, the sugar content did not change, no reducing sugar being found at the end of this period. After one week of storage the sugar content and respiration rate were both increased and both decreased after a week at 22°C (71.6°F). After two weeks storage there was a considerable increase in sugar content, but only a slight increase in respiration rate. After three weeks storage no increase in sugar content was obtained but the respiration rate was higher than after two weeks storage. After four weeks storage the respiration rate was about the same as after three weeks storage but the sugar content was higher. More reducing sugar was present after three and four weeks storage and one week at 22°C (71.6°F) than immediately after removal from storage of one week yet respiration rates are very different. The time that the maximum respiration rate is reached at 22°C (71.6°F) varied with the length of storage.

Experiment 4:- Another experiment similar to the one just described, was run with immature Scotch Rural potatoes. Respiration determinations were started on duplicate samples at 22°C (71.6°F) immediately after digging and the other samples stored at 36°F. Duplicate samples were removed at intervals of one week for respiration determinations. Eight tubers were sampled just before

the tubers were placed in the constant temperature chamber and again immediately after removal, in order to determine the sugar content.

Results are given in table 13.

TABLE 13. Relation of Respiration to Sugar Content in Potatoes. Scotch Rural - Dug Nov. 3, 1924

Period of storage at 36°F	Respiration determined at 22°C: Milligrams CO_2 per kilo per hour for 24 hour periods							Percentages of sugar in the potatoes at the beginning and end of the respiration determinations			
								Reducing Sugar		Total Sugars	
	1	2	3	4	5	6	7	Beginning	End	Beginning	End
Weeks 0	24.2	20.4	17.4	16.1	13.3	12.9	12.7	0.20	0.43	0.42	0.58
1	38.1	31.6	24.1	19.5	17.4	14.8	12.8	0.95	0.80	1.22	0.98
2	33.9	31.8	25.5	19.8	15.9	13.6	12.6	1.07	0.88	1.36	1.08
3	30.1	29.9	22.8	19.3	16.1	13.6	12.0	1.07	0.81	1.38	1.00

Sugar content was low at digging time, but increased after a week at 22°C (71.6°F) while the respiration rate fell to half of what it was at the start. After one week of storage the sugar content increased considerably and the respiration rate at 22°C (71.6°F) also increased. The respiration rate fell rapidly during the week at 22°C (71.6°F), while the sugar content decreased only slightly. The slight decrease in sugar content could hardly explain the great difference in respiration rate on the first and seventh day. After two weeks of storage there was a slight increase in sugar content but there was no increase in rate of respiration. Again though the respiration rate fell rapidly during the week at 22°C (71.6°F) the decrease in sugar content is not marked. Muller-Thurgau (14) did not find that sugar accumulated rapidly in new potatoes so it was a surprise to find the rapid increase of sugar in these potatoes after a week or two of storage. As there is not a very appreciable difference between sugar accumulation after one and three weeks it may be that further increase in sugar content due to low temperature might not have occurred for several weeks. Sugar accumulated in this variety, Scotch Rural, seems to be largely reducing sugar.

Experiment 4:- In a paper read before the Physiological Section of the American Botanical Society at the meeting of the American Association for the Advancement of Science for 1924, Hopkins stated that wounding po-

tatoes caused an increase in sugar content. He attributed the higher respiration found by other workers, in wounded potatoes to be due to the increased sugar content.

An experiment was carried out to determine whether wounding caused an increase in sugar in tubers previously stored at low temperature.

On January 21, some old Irish Cobbler potatoes were placed in a container surrounded with ice. Ice was kept around the container for four weeks. Two samples were then selected and placed at 22°C (71.6°F) for 6 hours in order to allow the tubers to come to the desired temperature. Then one lot was wounded by hacking with a knife and the other was left unwounded. Carbon dioxide free air was drawn over the samples for half an hour and respiration determinations started. Determinations were made at the end of 12 and 24 hours. A composite sample of six tubers were analyzed for sugars. Samples were taken just before the respiration tests and at the end of 12 and 24 hours. Tubers sampled after 12 hours received the same treatment as the ones, on which respiration determinations were made, but were in a different containers. This was done so that there would be no interference with the respiration in the tubers.

Results are shown in tables No. 14 and No. 15.

TABLE 14. Effect of wounding on respiration rate in tubers. Respiration at 22°C (71.6°F).

	CO_2 per mg. per kilo per hour.	
	1st 12 hours	2nd 12 hours
Unwounded	32.8	27.7
Wounded	53.4	47.9

TABLE 15. Effect of wounding on sugar content in tubers

	Percent Moisture	Total Sugars: Per cent		Reducing Sugars: Per cent	
		Fresh: Wt.	Dry Wt.	Fresh Wt.	Dry Wt.
Before wounding	81.49	2.891	15.01	0.334	1.809
12 hrs after wounding	81.09	3.059	16.17	0.485	2.562
24 hrs.after wounding	80.56	2.914	14.99	0.292	1.503

The data show that the wounding caused a rather large increase in rate of respiration, even though the rate was high in the unwounded tubers due to storage at low temperature. After 12 hours there was a slight increase in reducing sugars over that present at the start. After 24 hours the reducing sugar was slightly less than it was at the start. Most of the sugar that accumulated in storage in this case was not reducing sugars and the amount of sugar, other than reducing, was practically the same at the different times of sampling. It hardly seems justifiable, in this case to attribute the large increase in respiration rate obtained after wounding to the slight increase in reducing sugar that was present after wounding.

Appleman, in unpublished results, found that if tubers are sealed in containers with little air space,

very little sugar accumulated at low temperature and that accumulated sugar is not readily changed to starch at higher temperatures if tubers are kept sealed. In order to test respiration of cold storage potatoes which were sealed up, the following experiment was conducted.

Experiment 5:- Samples of potatoes were stored at Arlington November 7, 1924 at 36°F. They were kept at this temperature until February 24, 1925, on which date a sample of five tubers was used for sugar analysis, and two samples were changed to 40°F. One of these samples was sealed in a desiccator and the other was not sealed. After four weeks storage at 40°F the samples were removed. Four tubers in each sample were sampled for sugar analysis and respiration determinations made on the remaining tubers of the samples.

Results are given in tables No. 16 and No. 17.

TABLE 16. Respiration rate in tubers sealed and unsealed, changed from storage at 36°F to 40°F. Respiration determined 22°C (71.6°F).

	Milligrams CO_2 per kilo per hour for 24 hour periods.								
	1	2	3	4	5	6	7	8	9
Unsealed	28.6	35.6	36.0	32.3	26.2	22.7	20.3	18.1	15.5
Sealed	61.3	50.8	40.4	35.8	33.5	32.7	33.1	32.0	30.6

TABLE 17. Percentage sugar in tubers sealed and unsealed changed from storage at 36°F to 40°F.

	Percent Moisture	Total Sugars Per cent		Reducing Sugars Per cent	
		Fresh Wt.	Dry Wt.	Fresh Wt.	Dry Wt.
From 36°F	81.57	4.058	22.00	1.813	9.834
36°F to 40°F Unsealed	81.65	2.876	15.67	1.244	6.779
36 to 40°F Sealed	81.12	4.454	23.59	2.185	11.573

When the samples were removed from the constant temperature chamber the tubers were cut and examined for blackheart. None of the tubers that had not been sealed in storage were affected. All of the tubers that had been sealed had hollowe centers, which apparently were due to the drying up of blackheart tissue. The presence of blackheart in tubers sealed in storage interferes somewhat with interpretation of results. Sugar had accumulated at 36°F storage. When the samples were changed to 40°F and kept there for four weeks the sugar content decreased in the unsealed tubers but there was a slight increase of sugar in the sealed tubers. The respiration rate was higher in tubers that had been sealed, and though the rate fell rapidly at the start it seemed to be coming to equilibrium while still high. Presence of black heart might explain this. Sugar had decreased in the unsealed sample but was still present in rather large amounts.

Experiment 6:- February 25, 1925 two samples of Rural New Yorker potatoes which had previously been used for other experiments, but had been around the laboratory long

enough for their respiration rates to come to equilibrium were stored at Arlington at 36°F. One sample was sealed in a desiccator and the other was unsealed. After four weeks of storage the samples were removed, 6 tubers of each lot sampled for sugar analysis, and respiration started on the remaining tubers of the samples. No blackheart was found in the tubers used in this experiment.

Results are given in tables No. 18 and No. 19.

TABLE 18. Respiration rate in sealed and unsealed tubers stored at 36°F for four weeks. Respiration determined at 22°C (71.6°F).

	Milligrams CO_2 per kilo per hour for 24 hr. periods								
	1	2	3	4	5	6	7	8	9
Unsealed	26.3	29.5	26.4	25.6	22.5	20.1	17.8	17.2	15.2
Sealed	45.1	37.0	28.8	21.3	14.9	12.2	11.5	10.5	10.6

TABLE 19. Sugar content in sealed and unsealed tubers stored at 36°F for four weeks.

	Moisture Per cent	Total Sugars Per cent		Reducing Sugars Per cent	
		Fresh Wt.	Dry Wt.	Fresh Weight	Dry Weight
Unsealed	82.63	2.084	11.998	0.332	1.911
Sealed	81.48	0.621	3.353	0.221	1.193

The respiration rate in the unsealed sample was much lower than was found in potatoes that had been stored at Arlington at 36°F soon after digging. The respiration rate in the tubers which had been sealed was much higher than u the unsealed at the start, but the fall was more rapid and was less from the fourth day on. Little re-

ducing sugar was present in either sample, but there was less in the sealed sample. There was considerable accumulation of total sugars in the case of the unsealed sample, but little in the sealed one. It is possible that there is some backing up of dissolved carbon dioxide in the tissues of tubers that are sealed in containers where the tubers occupy practically all of the space. This would be true also for the experiment described previous to this one, so it would seem that the sugar content cannot explain the difference in respiration rate in both cases.

Experiment 7:- On January 21, 1925, some potatoes variety Scotch Rural, which had previously been stored in the vault, since soon after digging, were placed in a container for four weeks. The tubers were then removed. Respiration determinations were started at once on a sample and 6 tubers were sampled for sugar content. The other tubers were stored at 45°F. Samples were removed at intervals of one, two, and four weeks and sampled for sugar content and respiration rate determined at 22°C (71.6°F)

Results are given in tables No. 20 and No. 21.

TABLE 20. Respiration rate and sugar content in tubers kept cold with ice four weeks then stored at temperature of about 45°F for varying periods.

Weeks in Storage	Temperature Mean	Temperature Range	Mg. CO_2 per kilo per hr, for 24 hr. periods: 1	2	3	4	5	6	7
0	46.0	43-48	39.7	42.0	36.7	34.5	30.6	25.6	21.1
1	46.05	43-48	40.1	41.3	38.5	31.3	22.0	17.4	
2	44.85	40-49	26.6	28.7	23.6		19.2	16.3	
4	45.1	40-575	22.0	21.3	20.8		16.8	11.4	

TABLE 21. Percentage sugar in cold storage potato after different periods of storage at about 45°F.

Period of storage	Per cent Moisture	Total Sugars Per cent Fresh wt.	Total Sugars Per cent Dry wt.	Reducing Sugars Per cent Fresh Wt.	Reducing Sugars Per cent Dry wt.
Wks. 0	80.29	3.16	16.03	2.43	12.33
1	80.76	2.85	14.82	2.29	11.89
2	79.90	2.39	11.87	2.00	9.94
4	80.53	1.74	8.92	1.45	7.44

The respiration rate decreased with the length of time of storage at the higher temperature, though the rate after one week was not very different from the rate at the start. The sugar content also decreased with the length of storage at the higher temperature. The reducing sugar content was high immediately after removal from the ice surrounded container. After potatoes were four weeks at about 45°F, reducing sugar was still present in appreciable quantities, though it had decreased considerably from the content at the start.

Experiment 8:- Because the maximum rate of respiration is not attained the first day at a constant temperature of 22°C (71.6°F) an experiment was carried out to determine the change in sugar content at the time of maximum respiration rate. Duplicate samples of Rural New Yorker potatoes, which had been stored at Arlington November 7, 1924, were removed from the 36°F and the 40°F room respectively on the afternoon of April 8, 1925. On the morning of April 9, four tubers from each storage temperature were sampled for sugar content. Respiration determinations were started at 22°C (71.6°F). Two and a third days after respiration determinations were started one of the samples from each of the previous storage temperatures was sampled for sugar content, and respiration determinations continued on the other samples. After twelve days at 22°C (71.6°F) the respiration determinations were stopped and samples were again taken for sugar analysis. When removed from the constant temperature chamber sprouts were about 0.9 cm. long on tubers from 36°F storage and about 1.5 cm. long on tubers from 40°F storage.

Results are given in tables No. 22 and No. 23.

TABLE 22. Respiration rate in tubers from 36°F and 40°F storage.

Respiration rate - Mg. CO_2 per kilo per hour for 24 hr. periods										
From	1	2	3	4	5	6	7	8	9	10
36°F	35.2	43.9	46.2	39.5	34.1	29.7	25.6	22.2	19.0	16.0
40°F	12.9	13.2	14.0	13.6	11.8	11.6	11.3	9.7	9.7	9.5

TABLE 23. Sugar content in tubers from 36°F and 40°F storage.

Previous Storage Temperature	Days at 22°C	Per cent moisture	Total Sugars Per cent		Reducing Sugars Per cent	
			Fresh wt.	Dry wt.	Fresh wt.	Dry wt.
36°F	0	82.46	3.618	20.630	1.502	8.564
36°F	21/3	82.68	3.051	17.616	1.154	6.663
36°F	12/3	83.35	0.054	0.324	0.019	0.113
40°F	0	82.4	0.061	0.346	0.039	0.219
40°F	21/3	82.31	0.051	0.288	0.031	0.177
40°F	12	83.0	0.027	0.159	0.009	0.0547

The data show that while the initial high rate of respiration was increasing in the tubers from both temperatures of storage, the sugar content was decreasing. Thus for a time there is no parallelism between sugar content and respiration rate. It may be thought, as Hopkins(11) thinks possible that sugar may accumulate to such an extent that respiration rate may be retarded and after some decrease in sugar the rate will increase. This could not be true for the potatoes stored at 40°F however,. The change in sugar content from the beginning to the end of

the experiment is much greater, in proportion, than the change in rates of respiration. The sugar content in tubers from 36°F after 12 days at 22°C (71.6°F) was about half the sugar content of tubers from 40°F at the start, yet the respiration rates are about the same.

Experiment 9:- During the storage season of 1923-24 some tubers were stored at 32°F for about 3.5 months. The temperature went down to as low as 28°F at one time and many of the tubers were noticeably cold injured when removed from storage on February 21. A few tubers that were apparently uninjured were selected and the respiration rate determined at 22°C (71.6°F). The respiration rate obtained is shown in the following table.

TABLE 24. Respiration rate in tubers stored at 32°F at Arlington.

Milligrams of CO_2 per kilo per hour, for 24 hour periods.									
1	2	3	4	5	6	7	8	9	10
148.3	121.1	88.1	70.3	60.4	52.0	47.5	43.9	38.8	41.3

When it is remembered that the normal rate of this variety at 22°C (71.6°F) is about 5.5 mg. CO_2 per kilo per hour, it is hardly conceivable that increase in sugar content could have been the cause of this extremely high rate. No analysis was made however. Sprouts grew on all of the tubers but they were not healthy. Low temperature had probably injured the tubers to some extent.

The evidence presented concerning the relation of respiration rate to sugar content shows that there is often a parallelism between the two but that is not always true. It seems doubtful whether we can just ~~by~~ attribute the high rate of respiration when potatoes are moved from storage at low temperatures to higher temperatures to the accumulation of sugar at low temperatures. It seems that some other factor or factors may be involved. This does not lessen the importance of sugars in the process of respiration. The important thing is probably ~~t~~ not the amount of sugar present, but in the speed of the transformation of starch into sugar. In the potato tuber there is an abundance of starch and if the change of starch is rapid enough to meet the needs of respiration, the quantity of sugar present in the tissues would not necessarily be important.

DISCUSSION .

Considered both from the standpoint of the abnormally high respiration rate when removed from cold storage and the dormancy of the tubers, 40°F is probably the best storage temperature for potatoes. The respiration rate in tubers moved from 40°F to market temperatures was abnormally high, but it was not half as high as in tubers from 36°F storage. Temperatures above 40°F can hardly be considered for late storage because the tubers will not be kept sufficiently dormant.

The period of abnormally high respiration in potatoes after a period of cold storage also emphasized the importance of special attention to ventilation of these potatoes at higher temperatures to prevent heating in large quantities of potatoes. This would also probably apply to potatoes in storage cellars when the temperature rises in the spring.

The cause for the abnormally high rate of respiration when potatoes are moved from cold storage to market temperatures is not definitely known. That we have to deal with actual respiration seems established. Evidence has been presented to show that there is not always a parallelism between sugar content and respiration rate in potatoes but this does not prove that sugar content is not an important factor in respiration. There is some evidence

to indicate that the respiration rate may be limited by the permeability of the skin to gases. There are likely to be changes in the tissues, brought about by low temperature, which at present are not known.

SUMMARY

1. The respiration rate in tubers placed at 22°C (71.6°F) was high immediately after digging, but after coming to equilibrium remained constant.

2. When Irish potatoes were moved from storage at temperatures ranging from 32° to 50°F to a constant higher temperature the initial rate of respiration at the higher temperature was greater than the respiration rate in potatoes kept continuously at the higher temperature.

3. The lower the storage temperature the higher the initial rate of respiration at the higher temperature.

4. Respiration rates in potatoes after cold storage determined at constant temperatures of 30°C (86°F), 22°C (71.6°F), and 17°C (62.6°F) in tubers from 36°F and 40°F varied with the temperature at which respiration was determined.

5. The initial rate of respiration was not maintained but after attaining a maximum decreased over a period of several days depending upon the storage temperature.

6. A storage period of three weeks seemed necessary to cause the maximum rate of high respiration in the tubers when removed from storage temperature of 36°F.

7. After a storage period long enough to cause the maximum respiration rate when removed from storage, the period

in the storage life of the tubers seems to have no appreciable influence on the respiration rate when potatoes are removed from storage.

8. The respiration rate at 22°C (71.6°F) in tubers changed from 36°F to 40°F for four weeks was much higher than in tubers stored at 40°F only.

9. A respiratory quotient of approximately one shows that actual respiration causes the excessive amounts of carbon dioxide given off when tubers are moved from storage to higher temperatures.

10. No correlation was found between amino acid content and respiration in potatoes.

11. There is not always a parallelism between sugar content and respiration rate in Irish potatoes.

ACKNOWLEDGMENT.

The writer wishes to express his deepest appreciation to Dr. C. O. Appleman, Plant Physiologist, University of Maryland, for very helpful guidance and assistance during the progress of the work reported in this paper.

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