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to Potato Dormancy

and

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J. T. ROSA

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RELATION OF TUBER MATURITY AND OF STORAGE FACTORS TO POTATO DORMANCY

J. T. ROSA¹

FOREWORD

Though the buds on a newly harvested potato tuber do not grow for sometime after the whole or a part of it is planted, even under conditions favorable for growth, they sprout rapidly after the tuber has been held in storage for a period of from a few weeks to several months. The time after harvesting during which these buds will not sprout, or do so very slowly, is called the dormant period. The causes of the inception of this condition are unknown. Schmid⁽¹⁷⁾ and Appleman⁽³⁾ suggested that its continuance is largely due to a lack of oxygen in the internal tissues. Appleman showed that when the periderm was removed, or when oxygen was introduced by other means, sprouting of dormant tubers was hastened.

Knowledge of the conditions causing dormancy, and of methods for shortening or "breaking" the dormant period, are of practical value. The growing season in California and in the southern states is long enough to produce two crops of potatoes yearly. To do this economically, it is necessary to use tubers produced by the early or spring crop, as seed for the late or fall crop. The period intervening between the two crops is so short, however, that the dormancy of the spring crop tubers often results in slow and irregular sprouting, if they are used for planting the fall crop. Another aspect of the dormancy problem is in connection with storage of table or seed potatoes, where it is desired to continue the dormant condition as long as possible.

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Work on potato dormancy was begun at Davis, California, in 1922. In the years since, much data have been accumulated. Many of the experiments, however, were of a preliminary nature, and have not been followed up intensively, because other methods of treatment seemed more promising. Some of the results obtained with chemical stimulants have been reported elsewhere by Rosa^(15, 16) In this paper will be given the results of some of the experiments on certain phases of the problem, dealing with the behavior of potato tubers in relation to their maturity and their storage environment. No attempt is made to give results of the effect of the various treatments upon yield; the field experiments have not been extensive enough to give reliable data on this point. It may be assumed, however, that treatments which result in more rapid sprouting and in a higher percentage of germination, will increase the yield of both spring and fall crops, but especially of the latter, for which the growing period is usually cut short by frost.

MATERIALS AND METHODS

Two varieties, White Rose and Idaho Rural, have been used in most of the experiments. The first, which is the most important commercial variety in California, is also known here as Wisconsin, Wisconsin Pride, and Great Divide, and in the East as American Giant and Empire State. The second variety is little grown in California but is much used in the Pacific Northwest, where it is also known as Charles Downing and Earliest of All. A third variety, Irish Cobbler, was included in a few experiments. It has a long dormant period, which is difficult to break, while the White Rose and Idaho Rural varieties have short, easily broken dormant periods. Tubers grown at the University Farm, both in spring and fall crops, have been used. Experimental plantings have been made in soil in the field, and in sand in coldframes and in the greenhouse. The first method represents ordinary practical conditions, while the second and third allow better control of moisture and temperature. The tubers or seed pieces, which are hereafter referred to as "sets," were planted about 3 inches deep. Cut sets averaging about 30 grams in weight were used in all tests, unless otherwise specified. Counts were made every three or four days of the sprouts as they appeared above the surface of the soil.

In the calculation of results, the arrival of the sprouts above ground is referred to as emergence. The best index of the speed of sprouting is the average number of days required after planting for

the sprouts to reach the surface of the soil. This numerical index is low when sprouting is rapid and high when sprouting is slow. The proportion of the sets planted, which produced plants, is referred to as "per cent stand."

RELATION OF TUBER MATURITY TO DORMANCY

In 1925, samples were dug at 10-day intervals from the spring crop of White Rose and Idaho Rural, in 1926 of Idaho Rural, and in 1927 of White Rose, Idaho Rural, and Irish Cobbler. The first sample was dug as soon as tubers large enough for cut sets were available. At this harvest, as well as at the second, the plants were fully green and plants and tubers were growing rapidly. At the third and fourth harvests, the plants were showing signs of maturity, with some of the leaves dead. At the fifth harvest (in 1926 and 1927) the tops were completely dead. The tubers increased in size and in maturity during this period. Only at the last harvest in each year was the skin suberized sufficiently so that it did not rub off easily. Each sample was divided, one part being placed in cold storage at 4° Centigrade, the other in a cellar at 23° C, except in 1927, when cellar storage alone was employed. The samples were held until July 26 in 1925, July 14 in 1926, and July 27 in 1927, when they were removed from storage, cut and planted. Thus in 1925 the storage period for the first sample was 57 days and for the last, 26 days. In 1926 and 1927 the storage period ranged from 55 down to 15 days. No consistent differences in results were apparent between the halves of the samples stored at 4° and at 23° C, hence the data have been combined, as shown in table 1.

With the White Rose variety in 1925, the percentage of stand seemed to be slightly higher in the samples dug early, but in the other ten series it was higher in the lots harvested late. This was especially true in 1927, with all three varieties, both under coldframe and field conditions. Those sets which did not produce plants, decayed. This decay, which occurs within a few days after planting, is probably caused by fungi which invade the wounded surface of the cut sets. The early harvested, immature tubers in these experiments were rather small. In other tests, it has been noted that where large immature tubers were used, the amount of seed piece decayed was much greater. There is some evidence that cut sets from tubers fully ripened before harvest, are less subject to decay after planting.

With regard to the rate of sprouting, the twelve series of tests were all in agreement. The average number of days required for the

TABLE 1
GROWTH-RESPONSE OF TUBERS HARVESTED AT DIFFERENT STAGES OF MATURITY

		Coldframe planting				Field planting		
		Number of sets planted	Per cent stand	Average number of days to emerge	Average number of stems per set	Number of sets planted	Per cent stand	Average number of days to emerge
<i>White Rose, 1925</i>								
Harvested	May 30.....	60	76.7	37.2	1.15	167	67.7	44.3
	June 10.....	60	78.3	33.7	1.40	162	63.0	43.8
	June 20.....	119	73.6	30.0	1.22	172	58.7	35.7
	July 1.....	60	63.4	25.4	1.58	157	58.6	29.7
<i>Idaho Rural, 1925</i>								
Harvested	May 30.....	59	78.0	47.1	1.13	166	66.2	55.7
	June 10.....	60	79.3	34.9	1.26	145	61.5	49.6
	June 20.....	90	80.0	35.6	1.16	172	59.2	39.0
	July 1.....	60	73.1	37.5	1.33	149	76.5	39.2
<i>Idaho Rural, 1926</i>								
Harvested	May 20.....	60	81.7	37.6	1.10	215	45.0	58.5
	May 30.....	62	81.9	37.4	1.20	213	45.2	54.8
	June 9.....	80	90.3	34.1	1.35	207	53.0	48.7
	June 19.....	333	81.3	33.6	1.36	716	63.3	46.1
	June 29.....	60	91.6	28.3	1.67	183	64.5	40.4
<i>White Rose, 1927</i>								
Harvested	June 2.....	30	40.0	37.5	1.17	117	62.4	49.5
	June 12.....	20	3.0	.....	.....	105	48.6	46.1
	June 22.....	20	15.0	37.7	1.00	100	28.0	41.6
	July 2.....	130	72.3	33.5	1.28	577	61.7	34.0
	July 12.....	30	80.0	25.0	1.46	120	71.6	36.9
<i>Idaho Rural, 1927</i>								
Harvested	June 2.....	30	13.3	38.5	1.00	114	44.7	53.5
	June 12.....	20	.....	.....	.....	100	42.0	49.0
	June 22.....	20	30.0	35.2	1.17	112	39.3	42.4
	July 2.....	90	57.7	35.6	1.15	554	56.5	37.7
	July 30.....	30	66.6	32.1	1.05	120	74.1	45.8
<i>Irish Cobbler, 1927</i>								
Harvested	May 23.....	30	26.6	43.4	1.00	100	46.0	48.5
	June 2.....	30	43.3	43.8	1.31	114	64.0	48.2
	June 12.....	20	25.0	36.0	1.20	119	53.7	41.0
	June 22.....	20	65.0	38.8	1.15	115	60.8	39.6
	July 2.....	60	80.0	37.2	1.25	120	78.6	36.2

sprouts to emerge was greatest in the samples harvested earliest, and decreased regularly with the period of harvesting, the time required being shortest in the samples dug most mature. This is somewhat surprising, as the samples dug early had a much longer period in storage before planting. These results probably explain why fall crop potatoes are slow in sprouting when used as seed for the spring crop, a fact noted previously by Roca⁽¹⁴⁾ and by Martin *et al.*⁽⁷⁾ Fall crop

potatoes are harvested immature, as the tops are usually green when killed by frost. Similar results have recently been published by Kolterman,⁽⁵⁾ in Germany. He states that the earlier a tuber is separated from its plant, the more time it needs to ripen and to germinate.

The more rapid sprouting of tubers harvested mature in these experiments are not to be considered as opposing the results of Mueller and Molz⁽⁸⁾ and of many other investigators, who have found more vigorous plant growth and higher yields with seed tubers harvested immature. In experiments of the latter class, the tubers were stored over winter, ample time being allowed for even immature tubers to reach the end of the dormant period.

The average number of stems arising from each set increased with the maturity of the tubers. This point is of practical importance, for the yield increases with the number of stems to the plant, within limits.

DURATION OF THE DORMANT PERIOD

Is the dormant period of definite duration, or is dormancy dissipated gradually? Since the response of tubers harvested immature and fully matured is different, it has to be determined separately on each class of tubers. Samples were harvested July 30 from an April 15 planting of White Rose and Idaho Rural, the plants being almost completely dead at this time, and from the fall crops of the same varieties a few days after the green plants were frosted in November. The tubers in the latter case were nearly full grown but were immature and the skin was easily rubbed off. The tubers were all stored at 20 to 23° C and plantings made at intervals in the greenhouse. The time for sprout emergence for different plantings is shown in table 2.

TABLE 2
RATE OF SPROUTING OF MATURE AND IMMATURE TUBERS PLANTED AT DIFFERENT PERIODS AFTER HARVEST

Number of days after harvest, planted	Mature tubers		Number of days after harvest, planted	Immature tubers	
	Average number of days to emerge			Average number of days to emerge	
	White Rose	Idaho Rural		White Rose	Idaho Rural
6	55.9	77.3	10	84.8	82.7
15	38.2	60.8	15	84.2	74.2
28	20.0	38.4	22	73.8	70.8
39	18.2	30.2	33	43.0	38.4
55	21.2	29.7	43	36.0	32.3
....	.....	.....	66	29.8	37.5

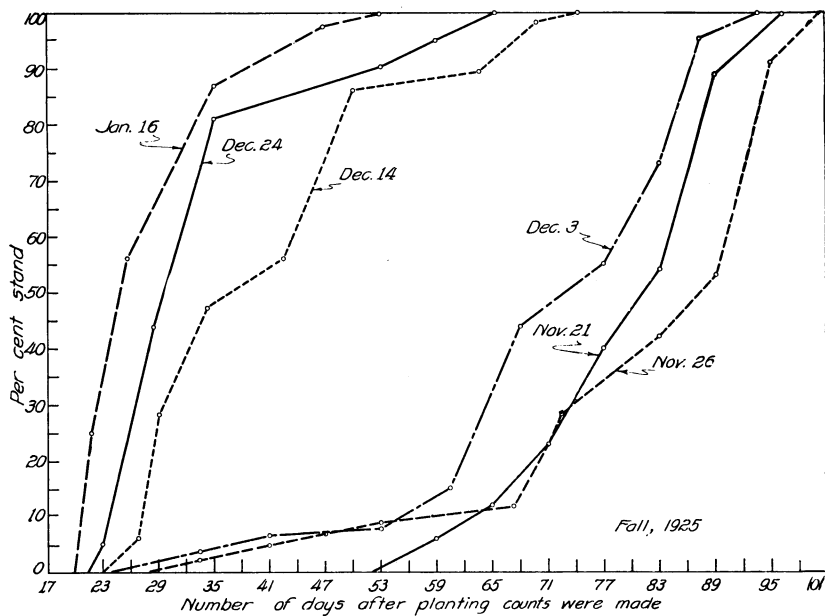


Fig. 1. Rate of sprouting of White Rose potatoes planted at different dates after harvest. Harvested immature, Nov. 11, 1925.

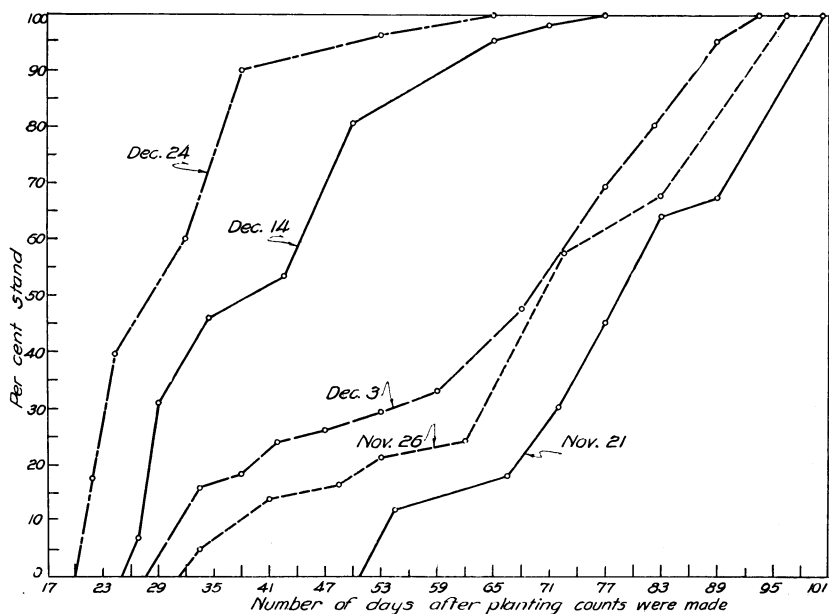


Fig. 2. Rate of sprouting of Idaho Rural potatoes, planted at different dates after harvest. Harvested immature, Nov. 11, 1925.

Although the planting intervals for the two classes of tubers do not correspond exactly, it is easily seen in table 2 that the mature tubers reach a condition where they sprout rapidly, sooner than the immature ones. Thus, mature White Rose tubers may be said to be approaching the end of their dormant period at 28 days, and mature Idaho Rural at 39 days, after harvest. On the other hand, immature tubers of both varieties were still somewhat dormant at the end of 66 days. Emergence from the dormant condition is not abrupt; it is a gradual transition. The rates of sprouting for the immature tubers planted at successive dates are shown in figures 1 and 2. The graphs show that the longer tubers are held after harvest, the sooner do they sprout when planted; furthermore, the later planted tubers all sprout within a relatively short space of time, whereas the sprouting is irregular with tubers planted while still dormant.

It may be concluded that, from a practical point of view, spring crop potatoes to be used as seed for the fall crop should be allowed to become as mature as possible before harvesting, even though the subsequent storage period be very short. Also, it is indicated that when tubers harvested immature are used as seed, the need for the use of stimulants to hasten sprouting is greater than in the case of fully matured ones. Furthermore, immature tubers may be expected to remain unsprouted longer, when stored at ordinary temperatures, than mature ones.

RELATION OF STORAGE TEMPERATURE TO DORMANCY

It has been believed generally that placing dormant potatoes in cold storage for a period would result in growth-releasal upon their removal to temperatures suitable for growth. Müller-Thurgau⁽⁹⁾ stated that storage of tubers at 0° C shortened the dormant period. His chief experiment involved 10 tubers harvested July 28 and held at 0° C for 40 days, then planted at 20° C. Sprouts formed about three weeks later. In a second test, tubers harvested August 28 were held at 20° C for 10 days, then at 0° C for 16 days longer. The tubers were then planted at 20° C, and formed sprouts within 18 days, a total period of 44 days after harvesting. No control or check lot held at ordinary temperature is mentioned in his report on either experiment. Newton,⁽¹¹⁾ working at the California Experiment Station, reported that immature tubers stored at 5° C sprouted slightly more rapidly than similar tubers stored at 20° C. His experimental lots, while very small (ten sets per culture), still gave consistent differ-

ences in several plantings made at successive intervals. Stuart⁽¹⁹⁾ also writes: "The effect of the low temperature on the new potato is to shorten the rest period and hasten sprouting."

To test this hypothesis, samples dug June 20 and July 1, 1925, from nearly mature plants were placed in cold storage at 1° C and in a cellar at 23° C. The storage period was 36 days for the June 20 and 26 days for the July 1 samples. The tubers were large and their skin was moderately suberized. They were cut and planted July 26. The plantings were replicated in most cases two or more times. The results of both field and coldframe plantings are given in table 3, the data for samples stored for 36 days and 26 days being combined.

TABLE 3
RELATION OF STORAGE TEMPERATURE TO SPROUTING OF TUBERS HARVESTED
NEARLY MATURE, 1925

Variety	Storage temperature	Coldframe planting			Field planting		
		Number of sets	Per cent stand	Average number of days to emerge	Number of sets	Per cent stand	Average number of days to emerge
White Rose.....	1°C	89	68.0	28.5	172	52.1	35.0
White Rose.....	23°C	120	70.0	26.5	157	67.8	33.3
Idaho Rural.....	1°C	60	83.3	36.9	180	65.0	43.0
Idaho Rural.....	23°C	120	74.2	36.2	156	71.0	37.1
Irish Cobbler.....	1°C	30	60.0	57.3	131	52.7	51.3
Irish Cobbler.....	23°C	30	86.6	44.8	122	62.3	39.0

In five of the six comparisons possible in table 3, the cellar-stored samples gave a higher percentage of stand than the cold-storage ones. In every case, the tubers stored at the higher temperature sprouted somewhat more rapidly than those from cold storage, though in several cases the difference in average number of days to emerge is hardly significant. This result is contrary to the general belief on this point, and contrary to the results of some other investigators. However, the results given here are borne out by the results of most of the later experiments.

In 1926, samples were harvested June 19 from nearly mature plants of two varieties, and were stored at 4°, 8°, 23°, and 30° C. They were cut and planted July 14, after only 25 days in storage. The results are given in table 4.

Storing the Idaho Rural variety at different temperatures seemed to result in no consistent difference in percentage of stand, but with

the White Rose, which was less mature at harvest time, the lots at the two higher temperatures gave a higher percentage of stand than did those in cold storage. There was little difference in time of emergence of the samples stored at 4°, 8°, and 23° C, though the field plantings indicate more rapid sprouting of tubers that had been stored at the higher temperatures. But in all cases those which had been stored at 30° C sprouted much more rapidly than those at lower temperatures. The 30° C storage was in a basement room, heated with electric light globes, the air being constantly stirred by a fan. As the air was drier than that of any of the other storage rooms, the moisture conditions seemed to be the less favorable for sprouting.

TABLE 4
RELATION OF STORAGE TEMPERATURE TO SPROUTING OF POTATOES, 1926

Variety	Storage temperature	Coldframe planting			Field planting		
		Number of sets	Per cent stand	Average number of days to emerge	Number of sets	Per cent stand	Average number of days to emerge
<i>Idaho Rural</i>	4°C	90	89.2	32.1	208	69.2	42.5
	8°C	55	78.6	33.5	109	56.7	38.6
	23°C	161	76.8	34.6	399	61.6	31.0
	30°C	60	86.6	26.5	106	65.1	31.0
<i>White Rose</i>	4°C	30	63.2	32.3	78	47.5	42.2
	8°C	60	52.6	32.7	106	49.1	39.8
	23°C	60	74.9	34.3	57	58.0	32.1
	30°C	30	86.6	25.1	108	52.2	27.8

In 1927, three varieties were employed for the temperature experiments. The White Rose and Idaho Rural were dug July 6, and stored at the different temperatures from July 8 to July 27, a period of 19 days. The plants were nearly dead at harvest time, and the tubers were fairly well suberized when they were placed in storage. The Irish Cobbler potatoes were fully matured; they were stored for a period of 25 days. The results are given in table 5.

As in previous experiments tubers stored at 22° and 30° gave in most cases a higher per cent of stand than those held in cold storage. This was especially marked in the field planting.

The lot stored at —0° C were in a room supposedly constant for 0° C, but the temperature fell below this point. The exact temperature range for this room is unknown; however some of the tubers stored there were frozen and decomposed promptly upon removal from storage. Over half the tubers did not freeze but remained

sound, though they must have been subject to prolonged under-cooling at below-freezing temperatures. Comparing the germination of these under-cooled tubers to those stored at higher temperatures, it appears that they sprouted somewhat more rapidly. Wright and Peacock⁽²⁰⁾ report somewhat similar results with under-cooled tubers.

Comparing the lots stored at 4° to those stored at 22° C, it is again seen that sprouting is somewhat slower in tubers that have been stored at the lower temperature. This is true for both coldframe and field plantings of the three varieties used in this experiment. As in the tests of the previous year, however, the difference in sprouting

TABLE 5
RELATION OF STORAGE TEMPERATURE TO SPROUTING OF POTATOES, 1927

Variety	Storage temperature	Coldframe planting			Field planting		
		Number of sets	Per cent stand	Average number of days to emerge	Number of sets	Per cent stand	Average number of days to emerge
<i>White Rose</i>	-0°C	30	90.0	32.5	102	75.4	31.7
	4°C	65	80.4	37.7	118	36.5	34.3
	8°C	30	76.6	34.8	120	40.8	43.2
	22°C	130	72.3	33.6	577	61.7	34.0
	30°C	60	90.0	22.3	238	63.3	24.1
<i>Idaho Rural</i>	4°C	89	86.0	44.3	217	49.6	43.2
	22°C	90	57.7	35.6	554	56.5	37.7
	30°C	60	71.6	24.3	200	63.5	28.9
<i>Irish Cobbler</i>	4°C	29	72.1	42.0	120	42.5	45.0
	22°C	60	80.0	37.2	236	78.6	36.2
	30°C	30	63.3	35.3	120	52.0	35.0

rate between 22° and the lower temperatures are slight, compared to the large difference between 22° and 30°. Tubers that had been stored at the latter temperature sprouted much more rapidly. Figure 3 shows the difference in number of plants above ground, 25 days after planting, in experiments with tubers stored at 4° and at 30° C.

It may be suggested that this striking effect of high temperature upon dormant tubers be due to some direct physical effect, beside the increase in the normal growth rate of the bud primordia and to the increased rate of chemical reactions in the cells associated with higher temperatures. In this connection, it may be noted that Müller-Thurgau and Schneider-Orelli⁽¹⁰⁾ found that exposures of tubers to temperatures of 38°, 40° and 42° C for four to eight hours resulted in an increased respiration rate after their removal to a lower temperature. This indicates an increased oxygen intake by the tubers

after exposure to high temperature, which may be important in connection with increased growth rate. These writers concluded that the effect of heat was fundamentally a weakening of the protoplasm, like that ensuing normally as the age of the tuber increases. Appleman⁽³⁾ found that heating potatoes at 40° C for 8 hours in a moist chamber hastened sprouting, though the same treatment in a dry chamber had less effect. Ajrekar and Ranadive⁽¹⁾ found that sound tubers of some varieties could be kept for 9 days at temperatures as high as 42° C, while others developed black heart at this temperature.



Fig. 3. Potato plants in coldframe, 25 days after planting, Aug. 21, 1927. The four rows at the right are from tubers stored at 30° C. At the left are four rows from tubers stored at 4° C.

Further evidence of the effect of storage temperature upon dormancy was obtained in another experiment during the winter of 1925. Immature tubers that were large enough to cut into four or more sets of about one ounce each were used. These were the product of the fall crop, the plants of which had been frosted on November 5 and the tubers harvested a week thereafter. They were stored in rooms at 4°, 20°–22° and 27°–30° C. No sprouts appeared on the tubers during storage at 4°; in fact, this temperature is somewhat below the minimum for vegetative growth of the potato. At 20° to 22°, sprouts appeared on the apical end of the tubers about the middle of January, and at 27° to 30° late in December. Samples were removed and planted in the greenhouse at intervals through the winter. Forty

sets were planted in each test, and a 100 per cent stand was obtained in all cases. The time for emergence of the different plantings is shown in table 6.

After 10 days in storage, the time for sprouting was the same in tubers from the three temperatures, but after 15 days there was a slight tendency to more rapid sprouting in samples from the higher temperature. This became marked at the 22-day and later periods. However, when the 66-day period was reached, there was again rather little difference in the rate of sprouting, for by this time even the tubers at 4° probably were near the end of their dormant period. It

TABLE 6
RATE OF SPROUTING OF IMMATURE WHITE ROSE POTATOES, AFTER STORAGE AT
DIFFERENT TEMPERATURES

Planting date	Average number of days to emerge		
	Stored at 4°C	Stored at 20°-22°C	Stored at 27°-30°C
Nov. 21, 10 days after harvest.....	85.0	84.8	85.9
Nov. 26, 15 days after harvest.....	88.7	84.2	78.0
Dec. 3, 22 days after harvest.....	81.5	73.8	60.6
Dec. 14, 33 days after harvest.....	66.0	43.0	No test
Dec. 24, 43 days after harvest.....	41.0	36.0	No test
Jan. 16, 66 days after harvest.....	30.9	29.8	23.5

seems evident that tubers emerge from dormancy more slowly when stored at low temperatures. The differences in the time of sprout emergence as affected by temperature of the previous storage of the tubers, is shown graphically in figure 4, for the December 3 plantings. The maximum differences would probably be shown in the December 14 planting, 33 days after harvest, were that series complete. It should be remembered that the tubers used were harvested immature and are therefore not comparable to other tests, in which nearly mature tubers were used.

RELATION OF STORAGE HUMIDITY TO DORMANCY

It was suspected that the rather striking results secured in the temperature experiments might be due, at least in part, to the varying humidity of the storage rooms maintained at different temperatures. Appleman⁽³⁾ showed that placing immature non-suberized tubers under moist conditions tended to prevent suberization and to promote earlier growth. As cold storage rooms often have a higher relative humidity than those at higher temperatures, the humidity factor may have been the cause of conflicting results of other investigators.

To determine the probable effect of the humidity factor, experiments were carried out in 1927 with two varieties at three temperatures. Table 7 gives the results on large, nearly mature, well suberized tubers. Those samples designated in the table as "dry" are the same as those previously referred to in the temperature experiment. They were simply sacked and placed on shelves in the different temperature

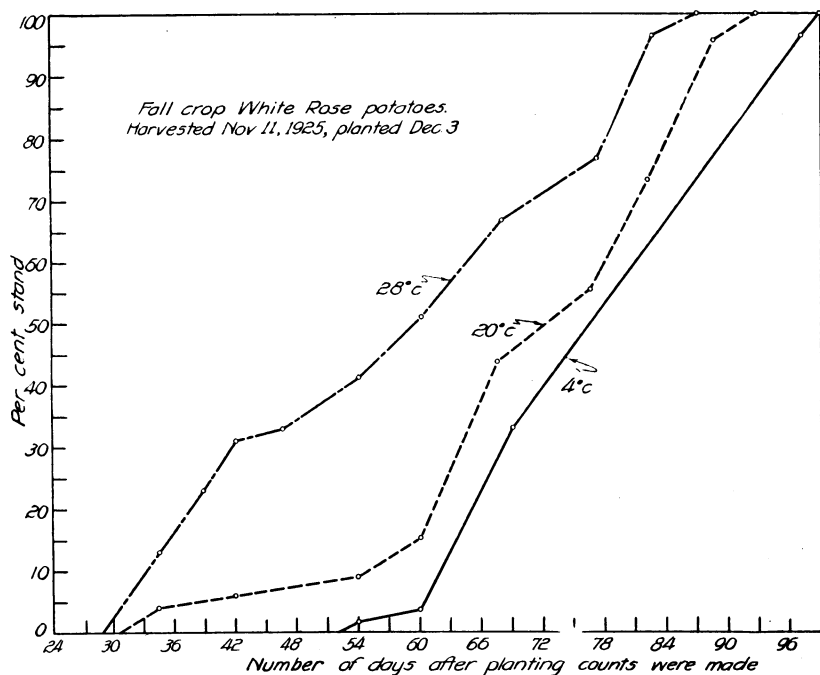


Fig. 4. Rate of sprouting of potatoes harvested Nov. 11 and planted Dec. 3, after storage at different temperatures.

chambers. The relative humidity of the air in these chambers was approximately 75 at 4°, 55 at 22°, and 60 at 30°. The samples referred to as "moist" were moistened, placed in boxes, and covered with moist sawdust. This maintained an approximately saturated atmosphere around the tubers continuously, yet with free access of air to the tubers. Different rooms were used for the dry and the moist experiments at 30°, but neither room deviated over one-half of a degree from this temperature.

Table 7 shows that at 4° and at 30°, the humidity around the potato is without effect upon the subsequent rate of sprouting; those stored under both dry and moist conditions sprouted at approximately the same rate, except the field planting of the Idaho Rural, in which

the moist sample sprouted more rapidly. There were many well developed sprouts on the tubers of this lot at the time they were removed from storage. However, at the intermediate temperature, 22° C, the moist samples in every case sprouted much more rapidly than the dry or check lots. Apparently, humidity has an important effect upon dormancy of the tuber at ordinary temperatures. Besides inhibiting further suberization of the skin, it may be that the moisture also renders the skin more permeable. These effects, however, do little

TABLE 7

EFFECT OF HUMIDITY DURING STORAGE UPON SUBSEQUENT SPROUTING OF POTATO TUBERS, SUMMER OF 1927. STORAGE PERIOD 19 DAYS

Variety	Storage temperature degrees Centigrade	Coldframe planting			Field planting		
		Number of sets	Per cent stand	Average number of days to emerge	Number of sets	Per cent stand	Average number of days to emerge
<i>White Rose</i>	4° dry	65	80.4	37.7	118	36.5	34.3
	4° moist	30	100.0	41.8	120	79.0	33.4
	22° dry	120	72.3	33.6	577	61.7	34.0
	22° moist	30	90.0	25.6	120	84.2	23.9
	30° dry	60	90.0	22.3	238	63.3	24.1
	30° moist	30	100.0	22.3	117	60.7	25.7
<i>Idaho Rural</i>	4° dry	59	83.2	44.0	217	49.6	43.2
	4° wet	30	86.6	43.7	119	72.2	37.9
	22° dry	90	57.7	35.6	554	56.5	37.9
	22° wet	30	93.3	22.8	118	80.5	29.9
	30° dry	60	71.6	24.3	200	63.5	28.4
	30° wet	30	86.6	24.7	107	80.3	22.9

to abbreviate dormancy at 4° C, due to the limitation of the low temperature, and at 30° the effect of the moisture is not generally additive, because the high temperature itself brings about the most rapid termination of the dormant condition that is possible.

In almost every case, a higher per cent stand was obtained from the seed which had been stored under moist conditions. Just why the cut sets of the moist-stored tubers escaped decay to such an extent is not clear, but the fact is of much practical importance.

CHANGES IN THE TUBER DURING THE DORMANT PERIOD

No significant difference in the chemical composition of dormant and non-dormant potato tubers has yet been established. Appleman⁽³⁾ showed that the accumulation of sugar, which occurs when tubers are stored for a few weeks at temperature near 0° C, had no causal

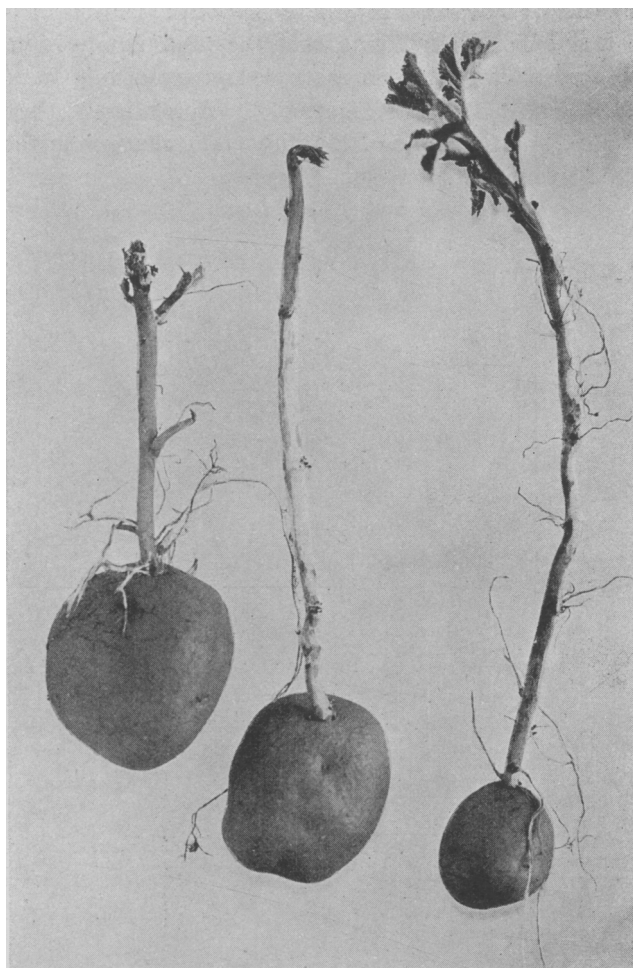


Fig. 5. Vegetative sprouts arising from young partly grown tubers, while still attached to the mother plant. British Queen variety, Davis, California, June, 1924.

relation to growth releasal. Neither were there significant changes in the form of the nitrogen and phosphorous compounds during the dormant period. The same worker found that active diastase and invertase were present at all stages but did not increase until sprouting began. Oxidase and catalase activity also were found to be greater at the end of the dormant period.

Moreover, while Appleman and Miller⁽⁴⁾ found that tubers harvested at different stages of maturity differed in composition when harvested, the composition of all was about the same at the end of the

dormant period. These workers paid especial attention to the various nitrogen fractions. They found that the total non-protein nitrogen, the amide and amino nitrogen increased progressively in tubers harvested at different stages of maturity. Accordingly they consider protein hydrolysis to be one of the important changes in the ripening



Fig. 6. Section through an eye of a partly grown tuber, weighing 91 grams, harvested May 31, 1924. The meristem of the sprout is seen beneath overlapping bracts at the base of the eye depression.

of the tuber. While these nitrogenous constituents tended to come to about the same value in immature and mature tuber after four months' storage for the former and two months for the latter, this after-ripening process probably is incomplete in tubers planted in less than two months after harvest, as was the case in the writer's experiments. Newton⁽¹¹⁾ considered that the ending of the dormant period depends in part upon the activity of the proteolytic enzymes and the enzymes which convert amino to amide nitrogen.

The dormant period of potato tubers probably is not an essential part of the life cycle. Some varieties of potatoes, when grown under conditions of high temperature and abundant moisture, may form vegetative sprouts from partly grown tubers. Figure 5 shows a case of this kind in the British Queen variety. Kolterman⁽⁵⁾ reports a similar development in Germany, following an unusual drought. Dormancy must depend upon physical and chemical conditions within the tuber.

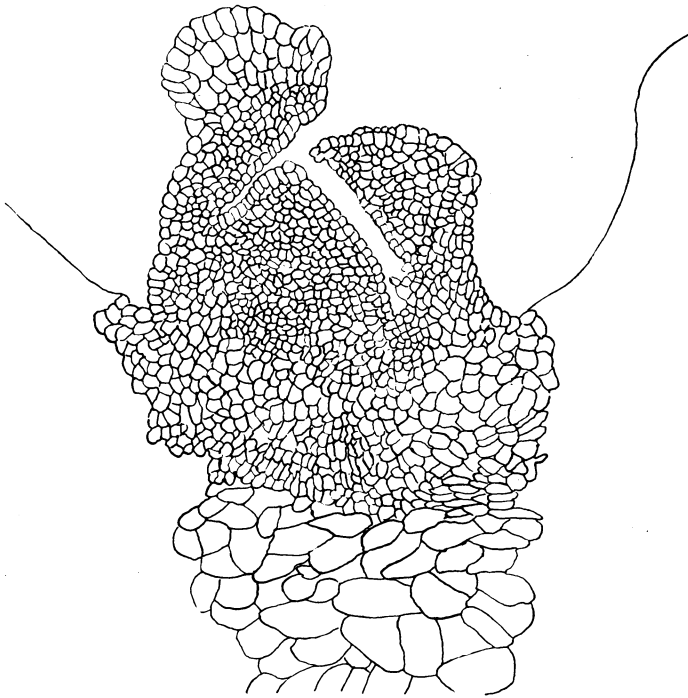


Fig. 7. Section through the eye of a large, immature White Rose tuber, just after harvest, Nov. 12, 1925. The central sprout, with its attendant bracts, is raised somewhat above the base of the eye depression.

The condition of the bud primordia in tubers at different stages of maturity and at different times in the dormant period has been investigated. Figure 6 is a section through an eye on the middle portion of a young White Rose tuber harvested May 30, 1925, and weighing 91 grams. While the bud primordia are present even in such very young tubers, sprout development has not commenced and the meristematic region is still deeply embedded in the tissue surrounding the eye. Smaller meristematic regions are visible on both sides of the bracts which envelop the central meristem. If the central

sprout is destroyed, other sprouts may be developed from the former. Figure 7 shows the apical eye of a large tuber, weighing 350 grams, harvested when nearly full grown but still immature. The sprout has already begun to form, though it is partly enclosed by the incurved bracts on each side. As the White Rose variety shows strong apical dominance, the apical sprout is much further developed than any

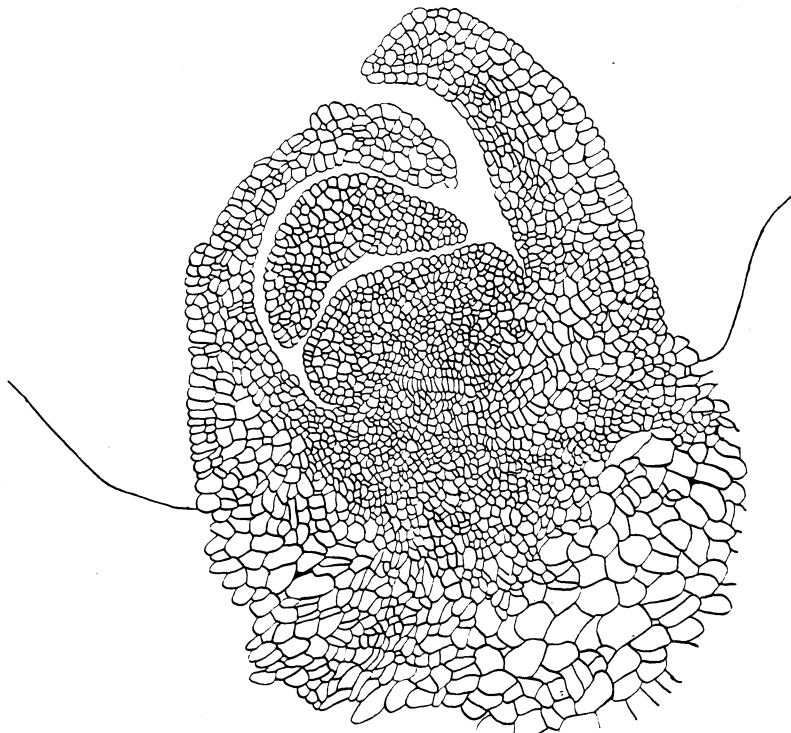


Fig. 8. Section through an eye of a large tuber similar to that shown in figure 7, 32 days after harvest. The young sprout shows further development in this interval. The storage was at 20° C.

other on the tuber. Figure 8 shows the apical eye of a tuber from the same lot as figure 7, but kept in storage at 20°–22° C for 32 days after harvesting. Further development of the sprout during this interval is shown. Figure 9 shows the sprout from an apical eye of a tuber from the same lot as that shown in figures 7 and 8, but kept in storage for 70 days after harvest. At this time, well developed sprouts were visible. These sections show that the bud primordia develop considerably during the late stages of tuber growth, and that some development of the sprout proceeds even during the so-called dormant

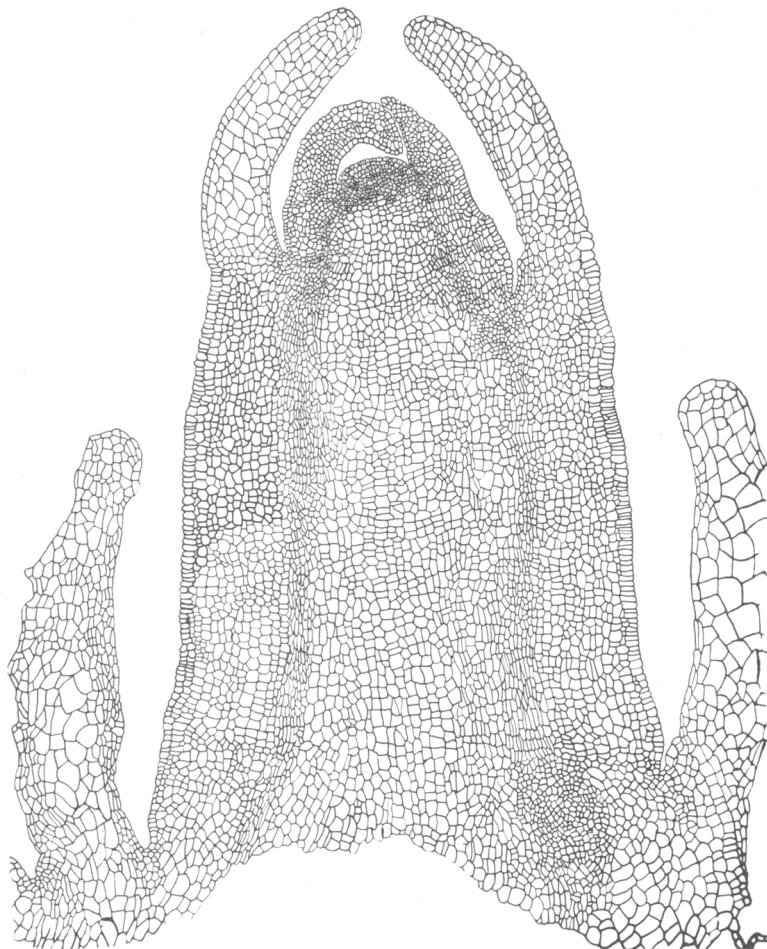


Fig. 9. Section through the sprout from an apical eye of a large tuber 70 days after harvest, and several days after planting. Elongation of the sprout becomes rapid at this stage.

period, if the tubers are stored at temperatures favorable for growth. The rate of sprout development increases toward the end of the dormant period.

VARIETAL DIFFERENCES IN DORMANCY

It is known that some varieties, such as McCormick, Bodega Red, and Irish Cobbler, remain dormant longer than others. Müller-Thurgau observed that the American variety, Early Rose, had a short dormant period when grown in Germany. Wilson Popenoe, of the U. S. Department of Agriculture, found a yellow-fleshed variety in

Peru which was said to have no dormant period. Probably some of the differences observed in length of dormant period were due to differences in the stage of maturity at which the tubers were dug. Differences between the tubers within a variety may be due to the depth of the eyes. Deep-eyed tubers have a longer dormant period than shallow-eyed ones, probably because the bud primordia are so located in the former that the oxygen supply is less adequate for growth. The spindle-tuber disease has been reported to delay sprouting, but mosaic and other virus diseases have not been found to affect the dormancy of the tuber.

Several varieties grown in a spring crop (1924) were harvested June 22, when they were approaching maturity, though the tops were only partly dead. After one month's storage at 22° C, the tubers were cut and planted in the field, each plot consisting of 170 sets. The final count of the plants was made on October 13. Table 8 gives a summary of the results.

TABLE 8
VARIETAL DIFFERENCES IN THE RATE OF SPROUTING OF DORMANT POTATOES

Variety	Number of plots	Per cent stand	Average number of days to emerge
White Rose.....	15	62	39.0
Early Rose.....	1	55	39.4
Green Mountain.....	1	47	42.5
Idaho Rural.....	8	34	50.6
American Wonder.....	4	60	51.0
Bliss Triumph.....	1	32	55.0
Irish Cobbler.....	3	38	56.5
Garnet Chili.....	1	52	56.6

It appears that the White Rose and Early Rose varieties have the shortest dormant period and are the best suited, of those tested, to the practice of growing two crops a year. Thirty years ago, the Early Rose was much used in this way in the South Atlantic states, but the practice ceased when the Irish Cobbler became the leading commercial variety in that section. The longer natural dormant period in the latter variety probably made it difficult to grow two crops a year. The difference in length of dormant period noted here between Green Mountain and Irish Cobbler is in agreement with the results of Martin *et al.*,⁽⁷⁾ who compared mature Maine-grown seed of these varieties with immature fall crop tubers from New Jersey. In the East Indies, Paravinci⁽¹²⁾ reported that the Dutch varieties used there required a storage period of 100 days between harvest and planting in order to start growing promptly when planted.

SEED PIECE DECAY

Premature decay of the sets has been the chief cause of poor stands in potatoes planted during the summer at Davis. This is especially true of the field plantings. This decay is probably caused by fungi which invade the wounded cells of the cut surface. Tubers planted whole are much less subject to decay. MacMillan and Meckstroth⁽⁵⁾ found that invasion of the potato sets by *Fusarium oxysporium* is a common cause of decay in Colorado. They found that this fungus did not invade the sets at 14° C or below, but that infection increased as the temperature was raised above this point. Ajrekar and Ranadive⁽¹⁾ found, in India, that bacteria and *Sclerotium* sp. were associated with the decay of potatoes at temperatures above 20° C. Probably these facts explain the prevalence of seed piece decay in plantings during hot weather. The decay usually begins in that portion of the set which comes from the center of the tuber. In that region the cells are larger and are less densely filled with starch and other substances than are the cells near the surface. Appel⁽²⁾ and other workers have noted that the cut surface of a tuber "heals" so that a new protective layer is formed, which excludes fungi as effectively as the original periderm of the tuber. Appel found that this layer appeared 48 to 60 hours after cutting, and was completed in two additional days. Shapovalov and Edson⁽¹⁸⁾ found that the new periderm or protective layer generally developed much less toward the center of a tuber than near the periphery. This may be the reason that decay of the set usually begins in the part coming from the center of the tuber.

Priestley and Woffenden⁽¹³⁾ studied the conditions under which the healing process takes place. They find that a warm moist atmosphere with normal oxygen content is most favorable. They show that under these conditions, the cut surface is "blocked" in 24 to 48 hours by a deposit of fatty substances on the wounded surface. Two to five days later, a cork layer forms, as a result of rapid cell division, below the blocked surface. This results in a permanent protective layer.

With the idea that the decay of the sets in plantings during warm weather might be prevented by allowing a period for the development of the protective periderm before planting, experiments were conducted in 1925. Somewhat immature tubers were harvested July 9 and 11, samples were cut, sacked, and stored at different temperatures until July 28, when they were planted together with appropriate check lots that were cut at planting time. The results are given in table 9.

The lots cut at harvest time and stored at 1° C gave only a slightly higher percentage of stand and sprouted more slowly than the checks. Examination of the sets upon removal from storage indicated that periderm formation did not take place, to any marked extent, at 1° C. The other cut lots in storage at higher temperatures showed decay in direct proportion to the increasing temperature. Furthermore, the sprouting was much retarded in these lots, indicating that the dormant condition was prolonged, or that a secondary dormancy was

TABLE 9
EFFECT OF CUTTING IN ADVANCE UPON DECAY OF THE SETS AND RATE OF SPROUTING.
STORAGE PERIOD 16 TO 18 DAYS. SUMMER, 1925

	Coldframe planting			Field planting		
	Number of sets	Per cent stand	Average number of days to emerge	Number of sets	Per cent stand	Average number of days to emerge
<i>White Rose</i>						
Cut July 9—stored at 1°C.....	30	76.6	34.0	170	65.3	39.3
Cut July 9—stored at 7°C.....	30	30.0	.....	170	48.8	50.9
Cut July 9—stored at 13°C.....	30	26.7	.....	175	38.3	45.5
Cut July 9—stored at 22°C.....	30	10.0	.....	170	31.2	50.0
Cut July 8, check.....	30	66.6	25.7	175	64.6	32.2
<i>Idaho Rural</i>						
Cut July 11—stored at 1°C.....	30	100.0	65.7	170	47.6	58.9
Cut July 11—stored at 7°C.....	30	93.2	64.1	170	47.0	68.3
Cut July 11—stored at 22°C.....	30	10.0	.....	160	15.0	65.5
Cut July 28, check.....	30	90.0	55.7	150	49.3	57.6

induced, by cutting in advance of planting and storing at intermediate temperatures. The cuts set stored at 7°, 13° and 22° formed a periderm over the wounded surface, which interfered with gas exchange, hence retarded sprouting, yet did not protect the sets from decay when planted in the soil.

A similar experiment was conducted in 1927, using shorter storage periods for the cut sets, which were placed in shallow trays in the different storage chambers. The results are presented in table 10.

As in the previous experiment, the sets cut in advance of planting decayed to a greater extent than those cut at planting time. The retardation of sprouting in the suberized sets is also evident. The lot stored at 4°, which became only slightly suberized, and the lot stored at 22° in wet sawdust, showed the least decay and sprouted somewhat more rapidly than the check.

No means of preventing decay of cut sets under high temperature conditions has yet been found. The suberization and healing of the cut surfaces prior to planting offers a promising line of attack for further investigation, however. Meantime, practical advantage may be taken of the fact that cut sets from medium to small tubers are less subject to decay than sets from large tubers; that tubers fully matured before harvest have less decay than those harvested immature; and tubers stored at high temperatures (22° – 30°) or under moist conditions at lower temperatures, decay less when planted than tubers which have been held in cold storage. Those factors which make for more rapid sprouting also generally give a better stand.

TABLE 10
EFFECT OF SUBERIZATION OF CUT SETS UPON DECAY AND RATE OF SPROUTING.
WHITE ROSE VARIETY. SUMMER OF 1927

	Coldframe planting			Field planting		
	Number of sets	Per cent stand	Average number of days to emerge	Number of sets	Per cent stand	Average number of days to emerge
<i>Cut and stored for 6 days at</i>						
4°C, dry.....	30	50.0	30.9	107	45.8	37.3
12°C, dry.....	30	40.0	40.5	114	38.6	46.5
22°C, dry.....	30	7.0	53.5	111	26.1	47.4
22°C, in wet sawdust.....	30	60.0	31.2	117	67.5	35.1
Room temperature, 15–35°C.....	30	0	.....	100	20.0	59.8
<i>Cut and stored for 13 days at</i>						
4°C, dry.....	30	56.7	30.6	110	61.0	41.7
22°C, dry.....	30	7.0	69.0	110	39.0	47.6
<i>Check—cut at planting.....</i>	70	68.6	33.5	117	65.2	37.3

SUMMARY AND CONCLUSIONS

The more nearly mature potato tubers are when harvested, the shorter is the dormant period, as indicated by more rapid sprouting when they are cut and planted.

The rate at which mature tubers sprout increases rapidly with the length of storage before cutting and planting. Tubers harvested immature emerge from dormancy more slowly. The emergence from the dormant condition is a gradual, not a sudden change.

The temperature at which potatoes are stored influences the rate of emergence from the dormant condition, but previous claims as to the hastening of sprouting by cold storage are not substantiated.

Storage at 4° C may retard sprouting somewhat, compared to storage at 20° to 23°, when plantings are made in the early or middle portion of the dormant period. Storage at 28° to 30° has a marked accelerating effect upon subsequent sprouting, as compared to lower temperatures.

The humidity of the storage has little effect upon dormancy at very low temperature (4°), or at high temperature (30°). But at intermediate temperature (22°), tubers stored under moist conditions sprout much more rapidly after they are cut and planted.

The primordia of the vegetative sprouts develop during the later stages of tuber growth, as well as during the dormant period. At temperatures favorable for growth, the meristematic region is probably never entirely inactive. In the emergence from the dormant period, this activity increases greatly.

The normal duration of the dormant period for potato varieties differs, as well as their response to dormancy-breaking treatments.

One of the difficulties in growing a fall crop of potatoes in California is the prevalence of seed piece decay when the planting is made during hot weather. The amount of decay is increased and the dormancy of the sets is prolonged by cutting several days before planting and allowing the cut surface to become suberized.

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