11-1951

Reduced Ascorbic Acid Content of Potatoes Grown with and without Straw Mulching and Irrigation in Eastern Nebraska

H. O. Werner

Ruth M. Leverton

Mary R. Gram

UNIVERSITY OF NEBRASKA COLLEGE OF AGRICULTURE

AGRICULTURAL EXPERIMENT STATION

Research Bulletin 170

Reduced Ascorbic Acid Content of Potatoes Grown with and without Straw Mulching and Irrigation in Eastern Nebraska

H. O. WERNER, RUTH M. LEVERTON, AND MARY R. GRAM

LINCOLN, NEBRASKA

NOVEMBER, 1951

UNIVERSITY OF NEBRASKA COLLEGE OF AGRICULTURE

AGRICULTURAL EXPERIMENT STATION

Research Bulletin 170

Reduced Ascorbic Acid Content of Potatoes Grown with and without Straw Mulching and Irrigation in Eastern Nebraska

H. O. WERNER, RUTH M. LEVERTON, AND MARY R. GRAM

LINCOLN, NEBRASKA

NOVEMBER, 1951

CONTENTS

Reduced Ascorbic Acid Content of Potatoes Grown with and without Straw Mulching and Irrigation in Eastern Nebraska

H. O. WERNER,[1] RUTH M. LEVERTON,[2] AND MARY R. GRAM [2]

POTATOES harvested from home gardens and in commercial early-producing fields in the Midwest are an important low-cost source of ascorbic acid from late June into September.

The major portion of the early commercial crop in Nebraska (harvested mostly in August) is produced with irrigation. Straw or litter mulching is a well established practice in the nonirrigated garden and farm potato patches. The value of these cultural methods for increasing yield is well known, but prior to this study [3] little was known about their influence on the ascorbic acid content of the tubers, or about the persistence of any such influence during the period of plant senility and during storage of the tubers.

REVIEW OF LITERATURE

Variability of ascorbic acid [4] content in potato tubers has been reported to be associated with genetic, physiological and environmental factors. Various aspects of the problem which have been studied include the effect of the variety, maturity, locality, cultural practice and storage conditions on ascorbic acid value. The first studies made by the chemical method showed great variation of ascorbic acid content in tubers of the same variety (Lyons and Fellers, *10*; Ijdo, *3*; Tedin, *20*). With greater recognition of the factors requiring control and with refinement of analytical methods, significant differences between varieties have been found by several investigators (Murphy *et al.*, *14, 15;* Karikka *et al.*, *4;* Smith and Paterson, *18;* Werner and Leverton, *23*; Kelly and Somers, *6*). The work of Rolf (*17*) and Murphy (*15*) has indicated that absolute varietal differences tend to decrease during storage but that relative differences still persist. After extensive study Werner and Leverton (*23*) concluded that the characteristic ascorbic acid value of a variety can be established only by analyzing many tubers produced under different conditions, harvested at different stages of development, and stored at different temperatures.

The physiological age of the tuber at the time it is harvested and analyzed influences its ascorbic acid content. Murphy *et al.* (*14*) studied

[1] Department of Horticulture.

[2] Department of Home Economics, Nutrition Research Laboratory.

[3] Manuscript submitted for publication December 1949.

[4] "Ascorbic acid" refers to the reduced form of ascorbic acid throughout the bulletin.

the ascorbic acid content of 10 early-maturing and 20 late-maturing varieties of potatoes which were all planted May 6, harvested September 15 and analyzed three to seven weeks later. They did not report during what portion of this period each variety was analyzed. They reported that the late-maturing varieties had higher ascorbic acid values than those maturing early. With data presented for only one harvest date it is not possible to determine whether values for the early-maturing varieties might have been greater if harvested at a comparable stage of maturity. Werner and Leverton (*23*) found highest values of ascorbic acid at about the time of maximum plant vigor. Smith and Gillies (*19*) and Kelly and Somers (*5, 6*) reported a decrease in ascorbic acid after the vines were dead. A 20 per cent decrease in ascorbic acid during the four weeks preceding death of the vines was reported by Rolf (*17*).

The effect of several environmental factors upon the ascorbic acid value of potatoes has been reported. Karikka *et al.* (*4*) and Smith and Paterson (*18*) found no differences in ascorbic acid content of the tubers when fertilizer was used on the soil. Karikka *et al.* (*4*) were not able to increase the ascorbic acid content of the tubers by the use of fertilizer containing varying amounts of nitrogen, phosphorus, and potassium, or by the addition of minor elements to a complete fertilizer. A range from 4.8 to 8.1 in the pH of the soil had no effect on the ascorbic acid value. Werner and Leverton (*23*) reported an increase in ascorbic acid of tubers grown under straw mulch and less ascorbic acid in irrigated tubers than in dryland tubers of the same variety.

Tedin (*20*) was among the first to report regional differences in ascorbic acid of the same variety of potatoes. Potatoes from southern Sweden were reported to be higher in ascorbic acid than potatoes of the same variety grown in northern Sweden. In a study of eight varieties in New York, Karikka *et al.* (*4*) reported a significant difference in ascorbic acid content of tubers from four counties. Werner and Leverton (*23*) reported small differences in ascorbic acid content of potatoes of the same estimated degree of maturity grown at different places in Nebraska. Murphy *et al.* (*14*), however, found no significant difference in the ascorbic acid content of 13 varieties of tubers grown in plots 150 miles apart. They concluded that locality differences when they appear, are a result of seasonal influences and that locality is a significant factor in ascorbic acid production only when these seasonal influences are characteristic and consistent in the locality. Lampitt *et al.* (*8*) did not find a difference in storage losses of ascorbic acid in potatoes grown at different locations.

Records are not complete enough in the various localities to indicate the role of sunlight in causing locality and seasonal differences

in the ascorbic acid content of tubers. The direct relationship between amount of sunshine and formation of ascorbic acid has been reported in apples (Murphy, *13*), tomatoes (Kohman and Porter, *7*; McCollum, *11, 12*), and turnip greens (Reder *et al. 16*).

A number of workers have reported loss of ascorbic acid content from tubers during storage. Rolf (*17*) found that loss was less in potatoes stored at 15.5° C. (59° F.) than in those stored at 4.5° C. (40° F.). Karikka *et al.* (*4*) reported smaller losses in ascorbic acid of tubers stored at 50° F. than at 40° F. Murphy (*15*) studied five different storage temperatures ranging from 32° to 70° F. and found that tubers stored at 50° or higher retained more ascorbic acid than those stored at lower temperatures. Werner and Leverton (*23*) found that tubers stored continuously at 40° F. lost as much ascorbic acid by mid-November as other tubers stored at 50° to 60° F. lost by late February or early March. They recommend prolonging the period of relatively high ascorbic acid content by storing potatoes at 50° to 60° F. during the first 12 to 16 weeks and then using 40° F. storage only as early as may be necessary to retard or prevent sprout growth.

Murphy *et al.* (*14*) concluded that there is no relation between starch and ascorbic acid content. However, Wokes and Nunn (*24*) present data that show a relatively close correlation between total solids and ascorbic acid content of a number of samples of Kerr's Pink variety.

It is generally acknowledged that certain cultural and fertilizer treatments exert a distinct influence upon the physiology of the potato plant, upon the time and rate of tuberization, and upon the composition of the tubers. Straw mulching in comparison with ordinary cultivation has been shown to reduce vine size but to prolong the life of the vine, to increase both the actual total yield of tubers and the yield in proportion to the weight of tops, and to increase the carbohydrate and protein content of tubers (Emerson, *1;* Werner, *21, 22*). Straw mulching has been found to be most effective in hot dry weather. Irrigation usually increases and prolongs vine growth and increases total yield of tubers. It frequently reduces the percentage of dry matter in the tubers.

It has been shown that the ascorbic acid content of tubers changes with the growth and decline of the plants. Analyses of tubers harvested on a given day may accurately depict a difference in ascorbic acid content, but this may merely be due to differences in the physiological age of the plants rather than the intrinsic influences of experimental treatments. The absence of basic information concerning environmental conditions under which tubers were produced places considerable limitation on determining whether certain treatments were responsible for differences in ascorbic acid content. Therefore,

it seemed desirable to investigate the possible influences of cultural practice by determining the effects of irrigation and surface mulching with straw upon the ascorbic acid content of tubers.

OBJECTIVES

The work reported in this bulletin was conducted to determine (1) whether straw mulching or irrigation is intrinsically capable of altering the ascorbic acid content of tubers; (2) whether ascorbic acid will be retained better by harvesting potatoes before or at maturity and holding them in storage, or by allowing them to remain in the field until there is danger of freezing; and (3) whether differences in ascorbic acid content of tubers will persist during storage.

FIELD AND HARVEST PROCEDURES

In each of three years—1944, 1945 and 1947—potatoes were planted at Lincoln during the first week in April and harvested at intervals beginning in late June or early July. The work was temporarily discontinued in 1946. Varieties used were Irish Cobbler in 1944, Red Warba in 1945 and both these varieties plus White Cloud in 1947. The latter is a new early white variety introduced by the Nebraska Agricultural Experiment Station in 1949 and formerly identified as Nebraska No. 2.

Each year about the time the first plants were emerging, the field was divided into four blocks of equal size. Half of each of these blocks was covered with a thin mulch of straw, and cultivation was continued in the other half. Half of the mulched and cultivated plots were irrigated and half were not. The latter are referred to in this bulletin as "dryland," as is the custom in the western high plains and intermountain area. The plots of these four combinations of culture and moisture were arranged in checkerboard style. The three varieties used in 1947 were planted in parallel rows through all the plots. Water was applied to the irrigated blocks by means of porous canvas hose whenever the plants appeared to be wilting in midday or the leaves were becoming noticeably darker.

The first tubers were harvested for analysis in late June or early July when they attained a diameter of 1½ inches (minimum size for table use). In the early part of the tuber production period, when tuber composition was changing rapidly, harvestings were at shorter intervals than later when vines were dying or dead. On each date three plants surrounded by a perfect stand of plants and typical of those of the plot were harvested from each plot. The vines were cut off and weighed just before harvesting. The tubers from the three hills of each plot were washed and weighed and then all tubers from each treatment were sorted according to size and weighed. Three

tubers selected from each of the four plots made up the tuber sample taken to the laboratory for analysis for ascorbic acid on the day of harvest or within two days after harvest. The tubers were held at room temperature between harvest and analysis. Tubers between 2 and 3 inches in diameter were used for analysis, except at the first and second harvests when it was necessary to use tubers slightly below 2 inches. Consequently the ascorbic acid values found at the first and second harvests may have been a trifle higher than if all sizes of tubers had been represented. However, the ascorbic acid content of the tubers of the size selected did not differ a great deal from that of the modal size of those harvested later. The values found in the first two harvests, therefore, may be considered as typical of the usable tubers produced by any date with any treatment.

ANALYTICAL METHODS

The 12 tubers taken to the laboratory for analysis were divided into three lots of 4 tubers each. The tubers were washed, the skin scraped off, the tubers were rinsed with a minimum of water and all visible moisture was removed with cleansing tissue. Wedge-shaped pieces varying slightly according to the size of the tuber were cut from each of the 4 tubers along the longitudinal axis, to make a composite sample of the lot which weighed 25 to 35 grams.

The method of Loeffler and Ponting (*9*) with the modification of Heinze and Kanapaux (*2*) was followed for the determination of reduced ascorbic acid.

The ascorbic acid was extracted from the potato with 1 per cent HPO_3 in a Waring Blendor. The extract was filtered. The concentration of ascorbic acid was determined by measuring its reduction of the dye, sodium 2,6-dichlorobenzenoneindophenol, in a photoelectric colorimeter which had been standardized with solutions of ascorbic acid of known concentrations. The turbidity was measured by decolorizing the solution with an ascorbic acid solution and re-reading the galvanometer.

In 1944 and 1945 dry matter was determined on the remaining portions of the 12 tubers that were not used for ascorbic acid analysis. A chopped sample of potatoes was dried to constant weight in a vacuum oven. In 1947 the specific gravity of all the tubers from each plant was determined by means of brine solutions of different concentrations.

CLIMATIC CONDITIONS AND CROP DEVELOPMENT

The more important aspects of early potato production in eastern Nebraska, as they pertain to the crops used in this experiment, are the following: the crop is planted about April 1—when the average daily temperature is about 45° F. The plants emerge about May 1. Tubers are differentiated in late May or early June when the daily temperature averages from 60° to 70° F. The first tubers of usable size are produced by late June. The maximum vegetative development is attained by early July and rapid tuber enlargement occurs during the three or four weeks before senility becomes apparent. At this time, i.e., the mid-portion of July, the temperature is generally near the maximum for the summer, usually averaging between 75° and 80° F. but frequently attaining maxima of 100° F. Plants of the early varieties used in the tests generally die gradually during late July and early August. During that period the tuber growth rate diminishes rapidly. There is actually a loss of tuber weight if the potatoes remain in the field after the vines have died.

With irrigation, straw mulching does not exert much influence on soil temperature during the early period of tuber development because the surface under the plants is generally completely shaded. However, beginning in late July as the vines are drying and tuber growth is being completed, straw mulching reduces the average temperature around the tubers. Without irrigation there is opportunity for straw mulching to function unless large vines are produced because of optimum weather conditions.

The three seasons during which this study was conducted were rather typical. The mean temperature, solar radiation and total precipitation in each month of the 1944, 1945 and 1947 potato seasons are shown in Table 1. Rainfall dates and amounts and daily mean temperatures for the three seasons are shown in Figures 1, 2 and 3. In 1944 April was cold and wet. Daily temperatures in May and to a large extent in June were considerably above average and rainfall was abundant in June. July temperatures were near average and rainfall was adequate until the end of the month. August was hot and dry. Vine growth was smaller than usual, having been restricted by the saturated soil condition throughout mid-June and severely damaged by an almost unprecedented infestation of leaf hoppers in July.

As a result of the July damage by these insects, tuber production was retarded, the yield by late July being only about one third of that in other years. Then, owing to the effective control of the leaf hoppers with DDT, the plants in the irrigated plots recovered sufficiently to resume tuber enlargement during August at an accelerated rate. The straw-mulched plants showed greatest recovery, attaining a final yield of about 250 bushels per acre. The dryland plants

TABLE 1.—Means of temperature and solar radiation and total precipitation in each month of the potato season in each of three years.

Month	1944	1945	1947
	Mean monthly temperatures, °F		
April	45.6−5.9 [1]	50.0−1.5	49.2−2.3
May	66.6+4.9	57.8−3.9	59.0−2.7
June	73.6+2.2	65.8−5.6	68.8−2.6
July	77.6+1.1	76.6+0.1	76.6+0.1
Aug.	76.0+1.6	77.1+2.7	84.5+10.1
Sept.	67.2+0.8	67.3+0.9	71.0+4.6
Oct.	57.4+3.2	56.0+1.8	65.0+10.8
	Solar radiation, mean gram calories per sq. cm. per day		
April	213.6	387.5	333.2
May	452.9	460.0	502.7
June	533.5	503.0	489.5
July	600.0	576.5	627.0
Aug.	495.2	469.1	530.2
Sept.	388.1	358.0	444.1
Oct.	310.3	292.9	303.6
	Mean monthly rainfall, inches		
April	9.1 +6.57 [1]	4.17+1.64	5.45+2.92
May	2.5 −1.58	5.62+1.54	3.37−0.71
June	6.18+1.86	7.03+2.71	9.95+5.63
July	2.17−1.68	2.73−1.12	3.06−0.79
Aug.	5.74+2.17	3.47−0.18	2.13−1.44
Sept.	.85−2.13	3.22+0.24	1.72−1.26
Oct.	1.17−0.71	0.07−1.81	2.67+0.79

[1] Number to right in each pair is deviation of monthly value from the long-time average.

were too badly damaged to recover and produced only about half as much as the irrigated plants. The dryland cultivated plot produced least of all.

The season of 1945 was unusually favorable for potatoes. The early April temperatures were slightly above the long-time averages (Figure 2), but generally temperatures were below average until mid-July. From then until late August they were above the average most of the time. Rainfall was abundant and frequent until mid-July, after which several irrigations were useful. Tuber growth occurred at a relatively constant rate throughout July, but an abrupt increase in temperature during late July and continued hot weather in August hastened the death of the vines. Tuber growth not only stopped but thereafter an actual reduction in yield occurred (Figure 4). Straw mulching exerted very little influence on tuber production prior to mid-July. About that time, although the heat was affecting the crop adversely, the yield with straw mulching continued to increase at almost the same rate as earlier. This was not true with cultivation. Irrigation was very useful in maintaining the vine growth in late July, thereby permitting an increase in yield of more than 100 bushels per acre over the dryland yield.

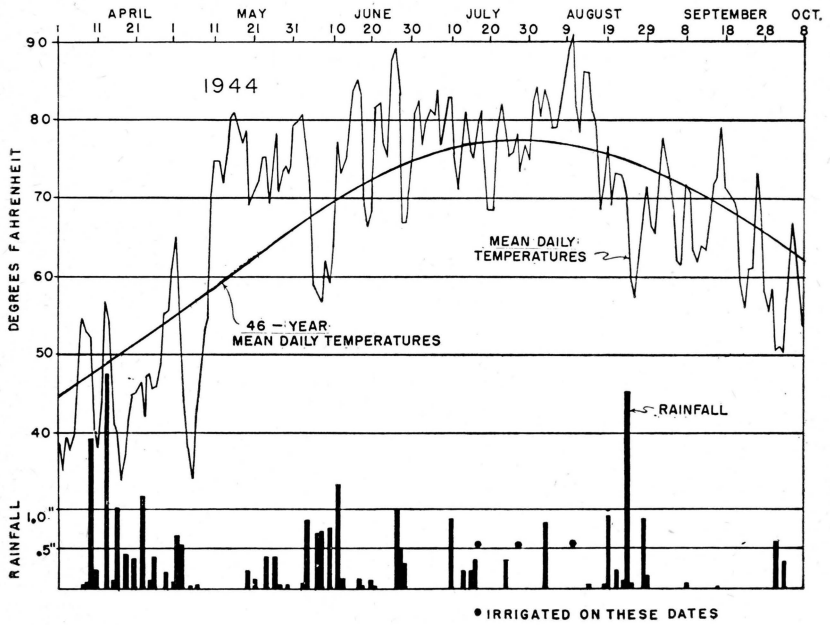
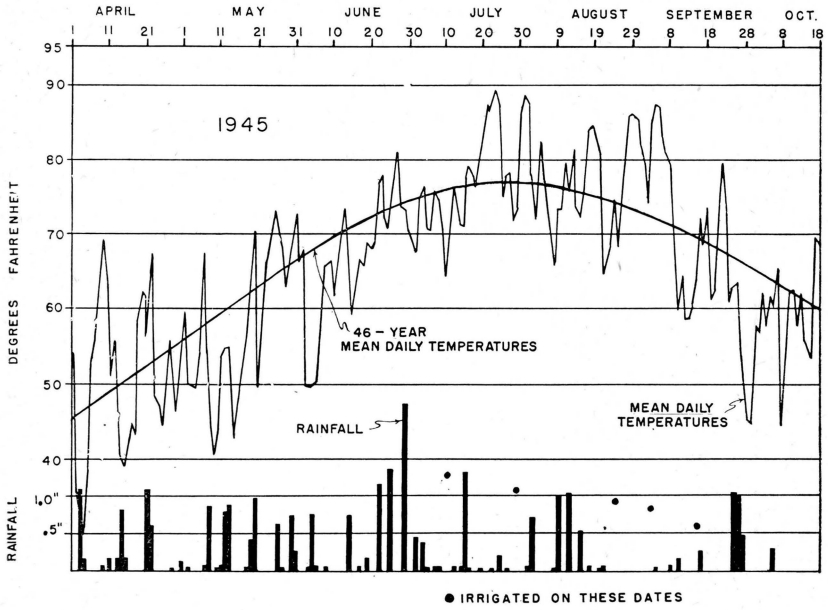


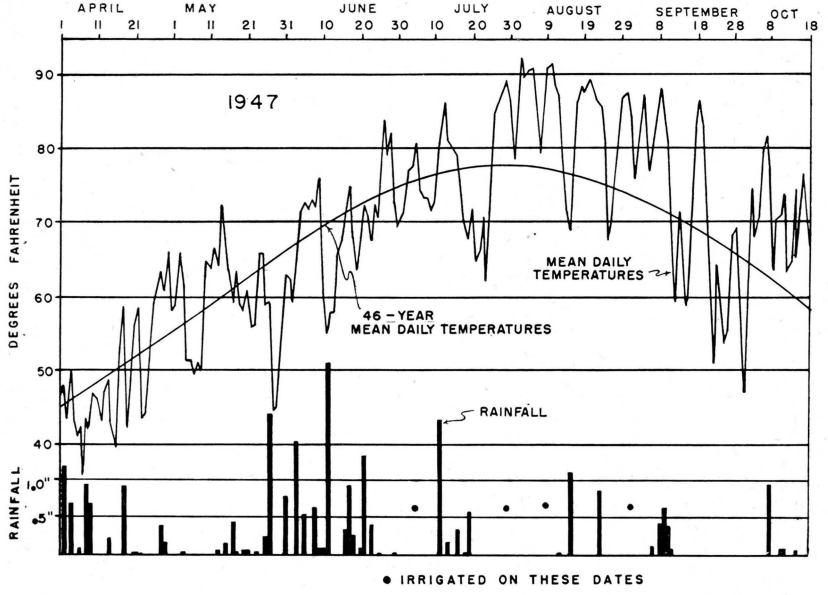
FIGURE 1.—Mean daily temperature and precipitation at Lincoln throughout 1944, and the 46-year mean daily temperature superimposed as a smoothed curve. Data from Monthly Weather Summaries for Nebraska, and Monthly Weather Review Supplement 25 (Charles F. Marvin), Weather Bureau, U.S. Department of Agriculture, 1925. (Data for Figures 2 and 3 from same sources.)

Climatic conditions in 1947 were similar to those in 1945. Spring temperatures fluctuated greatly but averaged close to the long-time average until late June (Figure 3). Thereafter they generally exceeded the average. In fact, the period from July 26 into November was one of the warmest since temperature records have been kept in this area. Early spring rainfall was below average but June was the wettest month on record. With only one good rain in July and two in August, irrigation was needed more than in 1945.

FIGURE 2. (Above).—Temperature and precipitation throughout 1945 season and 46-year mean daily temperature at Lincoln.

FIGURE 3. (Below).—Mean daily temperature and precipitation throughout the 1947 season and 46-year mean daily temperatures at Lincoln.


APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCT.
1945
DEGREES FAHRENHEIT
RAINFALL
46 – YEAR
MEAN DAILY TEMPERATURES
MEAN DAILY
TEMPERATURES
RAINFALL
1.0"
.5"
● IRRIGATED ON THESE DATES


APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCT
1947
DEGREES FAHRENHEIT
MEAN DAILY
TEMPERATURES
46 – YEAR
MEAN DAILY TEMPERATURES
RAINFALL
RAINFALL
1.0"
.5"
● IRRIGATED ON THESE DATES

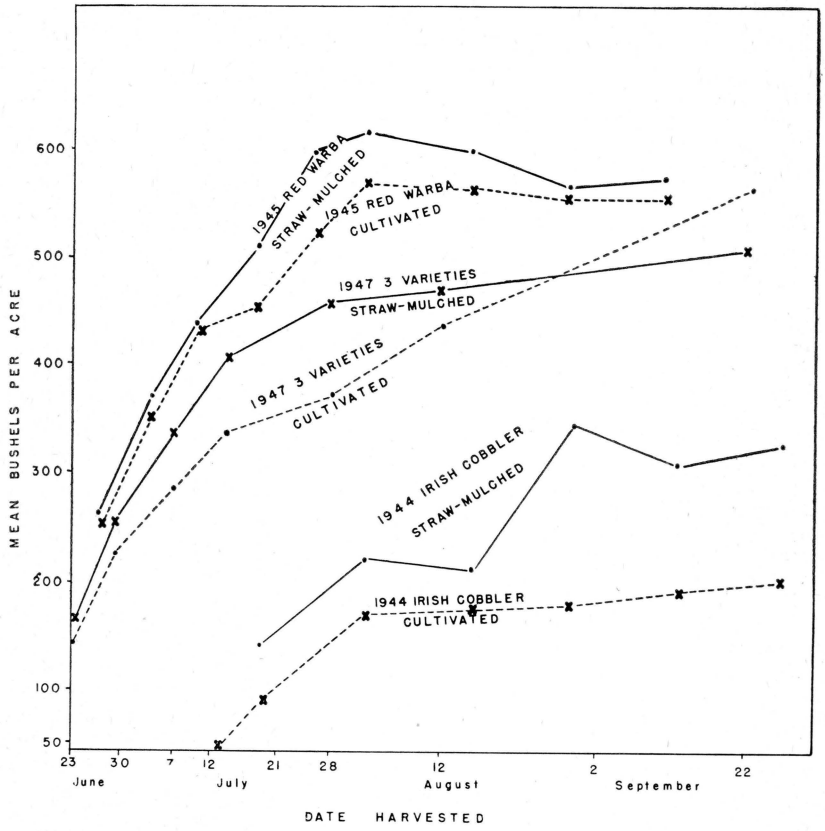


FIGURE 4.—Yields of straw-mulched and cultivated potatoes on various dates in each of the three years.

Vine growth was luxurious but tuber production was not as early or as great as in 1945. The waterlogged soil condition during June was unfavorable for maximum early tuber development and the high early August temperature prevented late tuber growth. However, Red Warba yields were almost as great as those of 1945.

Straw mulching was generally detrimental in 1947. Tuber production by White Cloud and Red Warba was much less with mulching than with cultivation. This difference increased as the season advanced. The response of Irish Cobbler was different; it yielded slightly more with straw mulching on and after July 21 than with cultivation. This was probably due to the greater duration of the vines of this variety. Irrigation increased yields of all varieties after mid-July.

DRY MATTER CONTENT OR SPECIFIC GRAVITY OF TUBERS

The dry matter content or specific gravity of the tubers was influenced by variety, age of plants, size of tubers, soil culture and moisture, light intensity, temperature and humidity, damage to plants by insect or other parasites, and finally by season, which includes variable combinations of most of these factors.

In the early stages of tuber development the dry matter content or specific gravity of the tubers was generally the lowest for the season. During the early period of rapid tuber enlargement it increased rapidly (Table 2). Dry matter content or specific gravity generally reached an initial high value about the time of maximum vegetative and tuber growth. During the several weeks of plant maturation and slightly lessened tuber growth, it generally dropped to a lower—but not the lowest—level. At this time, however, and at the time the plants were dying, dry matter content or specific gravity fluctuated widely because of climatic and soil moisture conditions.

TABLE 2.—Mean percentage dry matter or specific gravity of tubers from all treatments harvested on various dates.[1]

Mean percentage dry matter				Mean specific gravity in 1947			
1944 Irish Cobbler		1945 Red Warba			Irish Cobbler	Red Warba	White Cloud
	pct.		*pct.*				
				June 23	49.1 [2]	50.8	60.9
		June 28	17.6	June 30	57.5	58.9	66.6
July 6	16.7	July 6	19.2	July 7	69.2	70.1	75.7
		July 11	19.2	July 12	65.2	65.0	70.0
July 19	17.2	July 18	18.2	July 21	64.0	61.8	68.0
		July 26	18.7	July 28	64.1	60.9	67.8
Aug. 2	19.7	Aug. 2	18.0				
Aug. 16	19.0	Aug. 17	17.5	Aug. 12	72.0	65.2	69.9
Aug. 31	20.5	Aug. 30	19.3	Sept. 2	65.5	60.3	65.0
Sept. 13	21.2	Sept. 13	19.0				
Sept. 27	19.4			Sept. 22	67.3	55.8	61.6
Oct. 11	20.0	Oct. 16	18.2				
Oct. 26	19.4	Nov. 3	18.5				
Season	19.3		18.5		63.0	61.0	67.3

[1] Each value is the mean of four values of tubers from four treatments.
[2] For convenience, decimal point was moved three places to right and 1.0 was omitted in each mean for specific gravity values.

There was a tendency for the percentage of dry matter to decrease when soil moisture content was high and to increase when it was low (Figure 5). High temperatures during the period of vine senility and later caused a reduction in dry matter or specific gravity, probably because of tuber respiration and resorption of material into the dying plant. When the tubers were in the ground for a month or more after the vines had died, dry matter content was generally lower than in any tubers except those harvested during the brief initial period of rapid growth.

TABLE 3.—Mean percentage dry matter or specific gravity of tubers from straw-mulched and cultivated plots harvested on various dates.

Mean percentage dry matter						Mean specific gravity in 1947						
1944 Irish Cobbler			1945 Red Warba			Date	Irish Cobbler		Red Warba		White Cloud	
Date	Straw mulch	Cult.	Date	Straw mulch	Cult.		Straw mulch	Cult.	Straw mulch	Cult.	Straw mulch	Cult.
	pct.	*pct.*		*pct.*	*pct.*							
						June 23	47.5[1]	50.7	51.2	50.4	63.6	58.2
			June 28	17.6	17.8	June 30	57.6	57.4	57.8	60.1	66.9	66.4
July 6	16.7	16.7	July 6	19.0	19.3	July 7	70.0	68.3	69.9	70.3	77.6	73.7
			July 11	19.5	19.8	July 12	65.9	64.6	66.9	63.2	73.8	66.3
July 19	17.4	17.0	July 18	17.6	18.8	July 21	64.6	63.5	63.7	59.8	71.9	64.1
			July 26	19.5	17.9	July 28	65.4	62.9	62.3	59.5	70.1	65.6
Aug. 2	20.6	18.9	Aug. 2	18.8	17.2							
Aug. 16	20.1	18.0	Aug. 17	17.2	17.8	Aug. 12	74.4	69.7	67.3	63.2	71.5	68.4
Aug. 31	21.8	19.3	Aug. 30	18.6	19.9							
Sept. 13	22.3	20.1	Sept. 13	18.7	19.3	Sept. 2	66.6	64.3	59.4	61.3	65.7	64.4
Sept. 27	20.3	18.6				Sept. 22	67.1	67.6	55.3	56.3	61.5	61.7
Oct. 11	21.4	18.6	Oct. 16	17.8	18.5							
Oct. 26	20.8	17.9	Nov. 3	18.9	18.0							
Season	20.2	18.3		18.5	18.6		64.3	63.2	61.5	60.4	69.2	65.4

[1] For convenience, decimal point was moved three places to right and 1.0 was omitted in each mean for specific gravity values.

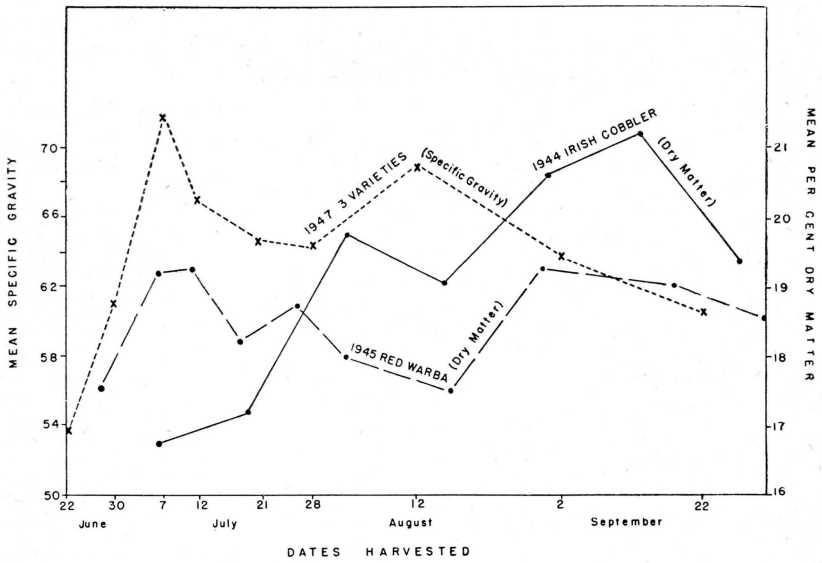


FIGURE 5.—Mean percentage of dry matter or specific gravity of tubers harvested on various dates during three years. For convenience, decimal point was moved three places to right and 1.0 was omitted in each mean for specific gravity values.

Tubers produced under a straw mulch were higher in dry matter than those given ordinary cultivation (Table 3). This difference did not occur until the plants were nearing physiological maturity but it continued until after they had been dead for several weeks. Then the dry matter diminished so that frequently there was little difference in the dry matter of the straw-mulched and cultivated tubers that remained in the ground until late in the season.

Irrigation was not an important factor until mid-July or later. Then it lowered the dry matter content of tubers (Table 4). This difference occurred with the very young tubers and increased as tubers remained in the ground after the death of the tops. It occurred each season and with all varieties used in this experiment.

The tubers of the highest average dry matter content were always produced with straw mulching on dryland, followed generally by those that were straw mulched and irrigated.

The three varieties differed in their dry matter content. In 1947 the seasonal mean specific gravity of tubers from four treatments harvested on nine dates was greatest with White Cloud, least with Red Warba and midway with Irish Cobbler (Table 2). White Cloud and Irish Cobbler exchanged top positions after the vines died. Not only was there a sharp increase in specific gravity of Irish Cobbler tubers in early August—but it was maintained at a relatively high

TABLE 4.—Mean percentage dry matter or specific gravity of tubers harvested from irrigated and dryland plots on various dates.

Mean percentage dry matter						Mean specific gravity in 1947						
1944 Irish Cobbler			1945 Red Warba			Date	Irish Cobbler		Red Warba		White Cloud	
Date	Irr.	Dry	Date	Irr.	Dry		Irr.	Dry	Irr.	Dry	Irr.	Dry
	pct.	*pct.*		*pct.*	*pct.*							
						June 23	50.9[1]	47.4	52.8	48.8	62.4	59.3
			June 28	17.4	17.9	June 30	55.9	59.1	58.0	59.9	64.1	69.2
July 6	15.9	17.6	July 6	19.3	19.1	July 7	68.3	70.0	70.4	69.8	75.1	76.3
			July 11	19.1	20.3	July 12	67.3	63.1	65.8	64.3	69.5	70.6
July 19	17.5	17.0	July 18	18.6	17.9	July 21	64.8	63.3	60.5	63.0	67.5	68.5
			July 26	19.0	18.4	July 28	64.7	63.6	60.8	61.0	65.7	70.0
Aug. 2	19.2	20.3	Aug. 2	18.4	17.6							
Aug. 16	18.1	20.0	Aug. 17	18.2	16.9	Aug. 12	70.2	73.8	65.6	64.9	66.1	73.8
Aug. 31	19.9	21.2	Aug. 30	19.2	18.8	Sept. 2	54.9	66.1	59.3	61.4	61.3	68.8
Sept. 13	20.7	21.7	Sept. 13	19.3	18.8							
Sept. 27	18.6	20.2				Sept. 22	66.3	68.4	54.6	57.1	56.0	67.2
Oct. 11	19.4	20.6	Oct. 16	18.7	17.7							
Oct. 26	18.9	19.9	Nov. 3	18.7	18.2							
Season	18.8	19.8		18.7	18.3		63.7	63.8	60.9	61.1	65.3	69.3

[1] For convenience, decimal point was moved three places to right and 1.0 was omitted in each mean for specific gravity values.

level for the remainder of the season. White Cloud under straw mulch maintained high specific gravity in July, and dryland culture brought about a similar maintenance after mid-July. With Red Warba and Irish Cobbler, differences caused by soil moisture were much smaller.

REDUCED ASCORBIC ACID CONTENT

Years and Harvest Dates

Each year the ascorbic acid content of the earliest tubers was relatively low—but it increased rapidly during the early part of the rapid tuber enlargement period (Table 5). In 1944 the maximum was not reached until August 2. In the 1945 and 1947 seasons, which were similar, it attained the maximum in early July. After the maximum values were attained the ascorbic acid content decreased slightly but remained relatively high during the next three weeks, which was the period of major tuber enlargement. During late July when the vines matured and tuber growth diminished or ceased the ascorbic acid content decreased slowly for a few weeks. Throughout August

TABLE 5.—Mean ascorbic acid content by years or varieties on each harvest date in milligrams per 100 grams fresh weight.

1944		1945		1947				
Irish Cobbler		Red Warba						
Date	Ascorbic acid	Date	Ascorbic acid	Date	Irish Cobbler	Red Warba	White Cloud	All varieties
					Ascorbic acid			
	mg.		*mg.*		*mg.*	*mg.*	*mg.*	*mg.*
				June 23	19.7	24.3	27.9	24.0
		June 28	28.7	June 30	30.3	33.0	34.7	32.7
July 6	34.1[1]	July 6	30.0	July 7	42.3	42.5	46.6	43.8
		July 11	37.8	July 12	37.8	39.5	44.1	40.5
July 19	38.0	July 18	38.1	July 21	37.7	39.2	41.5	39.5
		July 26	36.4	July 28	36.8	37.0	43.2	39.0
Aug. 2	48.3	Aug. 2	33.4					
Aug. 16	38.4	Aug. 17	28.7	Aug. 12	31.7	30.1	30.1	30.6
Aug. 31	31.9	Aug. 30	25.5	Sept. 2	23.2	19.3	20.2	20.9
Sept. 13	28.7	Sept. 13	21.4					
Sept. 27	24.7			Sept. 22	18.7	16.1	18.8	17.9
Oct. 11	23.7	Oct. 16	13.1					
Oct. 26	17.5	Nov. 3	15.6					
Mean of season	31.7		28.0		30.9	31.2	34.1	32.1

Statistical analysis

Factor	Dates 1944	Dates 1945	Dates 1947	Varieties	Varieties x dates
F values					
Calculated	139.1	142.7	266.2	28.2	4.4
For sign. @ 5%	2.07	2.04	1.52	1.32	1.00
@ 1%	2.78	2.72	1.79	1.48	2.20
L. S. D.[2]	2.23 mg.	2.01 mg.	2.36 mg.	0.90 mg.	3.94 mg.

[1] Each mean based on analysis of 12 samples of 4 tubers each.
[2] L. S. D. = least significant difference.

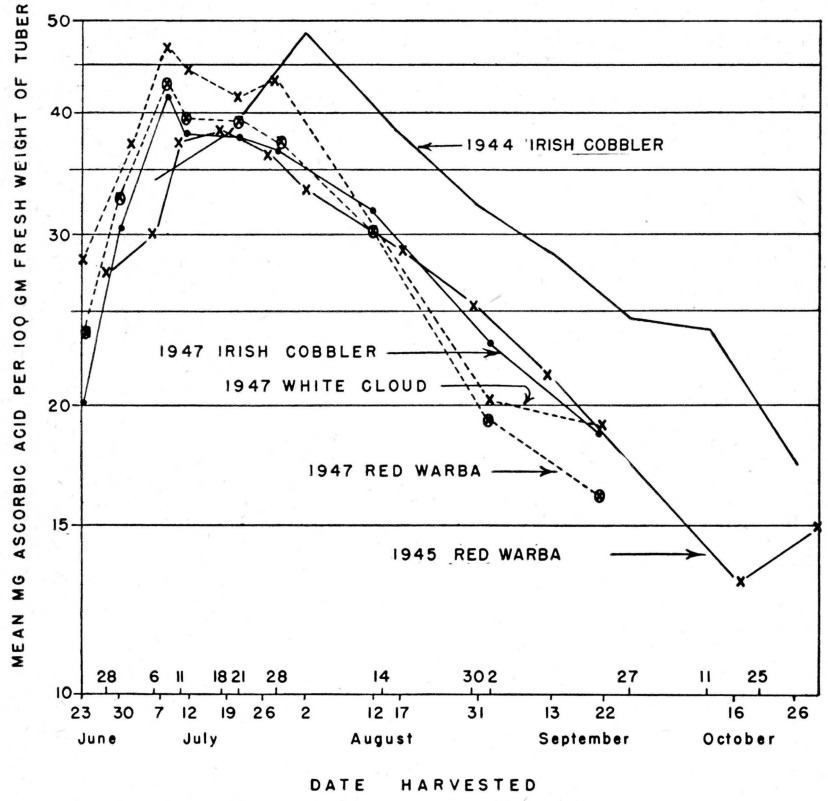


FIGURE 6.—Mean ascorbic acid content of each variety harvested on various dates in the years when grown. Ascorbic acid plotted on a semilogarithmic basis.

a higher but constant rate of loss was established. The relative constancy of these rates for the varieties and years is shown by means of the semilogarithmic graph (Figure 6).

The Red Warba provides a means of comparing 1945 and 1947 values. Ascorbic acid values of Red Warba in 1945 were not as high early in the season and rose to the maximum more slowly and slightly later than in 1947. The values were lower until August 12, after which they remained distinctly higher. It was during this period in 1947 that the temperature was unseasonably high.

The Irish Cobbler can be used for comparing the seasons of 1944 and 1947. The initial ascorbic acid value on June 23 was greatest in 1944 but it increased more slowly, not attaining the maximum until August 2. However, the 1944 maximum was much higher than that of 1947. After this date the ascorbic acid content decreased more rap-

idly than in 1947 but it remained higher throughout September. The ravages of the leaf hoppers were most severe during the first half of July when the increase in tuber growth and ascorbic acid was retarded. The ascorbic acid content was the same in both years on about July 20. During the following two weeks, however, the trends of the two years differed greatly. During the last 10 days of July 1944, with the disappearance of the leaf hoppers and accompanying recovery of some of the plants, a rapid increase in ascorbic acid content accompanied the greatly reaccelerated tuber growth. In 1947, with cool wet weather followed by very hot weather and termination of tuber growth, the ascorbic acid content decreased. The maximum ascorbic acid value was attained about 25 days later in 1944 than in 1947. During August and thereafter the 1944 values on any one date were practically the same as they were 25 days earlier with the 1947 crop.

In 1947 the Red Warba values were slightly higher than those of Irish Cobbler until late July—then the values of Red Warba decreased more rapidly and to a lower level than those of Irish Cobbler. White Cloud values were highest of all until mid-August, when they dropped below those of Irish Cobbler and continued almost as low as those of Red Warba.

These data show that when comparing the ascorbic acid content of potatoes produced in different years it is necessary to consider the physiological condition of the vines and the physiological age of the tubers at comparable stages of development.

Varieties and Harvest Dates

Differences or similarities in ascorbic acid content of tubers of three varieties can be seen in the 1947 results (Table 5). That year the values for the Irish Cobbler and Red Warba were similar. During the favorably cool weather up to late July the values for Red Warba were slightly greater than those for Irish Cobbler; these differences were highly significant. Thereafter, the values for Irish Cobbler were greatest with a high degree of significance. While the plants were alive the ascorbic acid values of White Cloud tubers were considerably greater than those of the two other varieties. They fell below those of Irish Cobbler about August 8 and thereafter were generally only slightly greater than those of Red Warba.

The superior values of the White Cloud tubers throughout the seven weeks from appearance of the first tubers to the death of the plants is comprehensive evidence of the genetic superiority of this variety in so far as ascorbic acid is concerned. On the other hand, the results with Irish Cobbler may indicate that its superior ability to resist unfavorable conditions is responsible for its ability to retain

a high ascorbic acid content in the tubers during hot weather and during and after the period of vine senility.

The trends of the ascorbic acid values calculated on the basis of dry weight of tubers in 1944 and 1945 were essentially the same as those calculated on the fresh weight basis.

Culture, Varieties, and Years

Straw mulching increased the average ascorbic acid content from 29.7 mg. to 32.7 mg., or 11 per cent above that of cultivated tubers (Table 6).

TABLE 6.—Effect of culture on ascorbic acid content of three varieties of tubers during three years.

Year and variety	No. of harvest dates	No. of analyses of each treatment	Ascorbic acid [1]		F values			L.S.D.
			Straw mulch	Cult.	Calc.	For sign. @ 5%	For sign. @ 1%	
			mg.	*mg.*				*mg.*
1944 Irish Cobbler	9	54	34.8	28.6	140.0	3.98	7.01	1.05
1945 Red Warba	11	66	28.6	27.5	6.9	3.95	6.92	.80
1947 Irish Cobbler	9	54	32.0	29.9	7.9	4.0	7.08	1.48
Red Warba	9	54	32.3	30.2	10.7	4.0	7.08	1.28
White Cloud	9	54	36.0	32.3	37.3	4.0	7.08	1.20
Three varieties	9	162	33.4	30.8	46.6	1.26	1.39	.76
					Varieties x culture			
					1.9	1.42	1.62	1.30
Mean of five groups		282	32.7	29.7				

[1] Mg. per 100 gm. fresh weight.

For each variety the ascorbic acid content of the straw-mulched tubers was significantly greater than the cultivated tubers. Greatest differences occurred with Irish Cobbler in 1944 and least with Red Warba in 1945. In 1947 the varieties differed in their response to straw mulching. That year the differences between straw-mulched and cultivated were greatest in the White Cloud and least in the Irish Cobbler. The extent of these annual differences is shown graphically in Figure 7.

In all of the years and with all varieties straw mulching did not bring about any change in the ascorbic acid content of tubers during the period of early development (Table 7). However, by the middle or latter part of July, shortly after maximum values were usually attained, the mean ascorbic acid content of straw-mulched tubers exceeded that of cultivated tubers by a significant margin. By this part of the season vines had lost enough foliage to expose the ground surface and permit the straw mulch to exert its characteristic influence on the soil. During the earlier portion of this period, i.e., late July and early August, growth continued later and to a greater extent

TABLE 7.—Mean ascorbic acid content of different varieties of straw-mulched and cultivated tubers harvested on various dates during three years.

Date harvested	1944		1945		1947							
	Irish Cobbler		Red Warba		Irish Cobbler		Red Warba		White Cloud		Three varieties	
	Straw mulch	Cult.	Straw mulch	Cult.	Straw mulch	Cult.	Straw mulch	Cult.	Straw mulch	Cult.	Straw mulch	Cult.
	mg.	*mg.*[1]	*mg.*	*mg.*	*mg.*	*mg.*	*mg.*	*mg.*	*mg.*	*mg.*	*mg.*	*mg*
June 23					19.7	19.8	23.8	24.9	28.0	27.9	23.8	24.2
June 28			28.6	28.3								
June 30					30.7	30.0	33.4	32.7	35.1	34.3	33.1	32.3
July 6	35.0	33.1[2]	30.0	29.9								
July 7					43.0	41.6	41.3	43.7	50.3	42.9	44.9	42.7
July 11			36.9	38.6								
July 12					37.9	37.6	40.2	38.8	45.7	42.5	41.3	39.6
July 10			38.7	37.5								
July 19	37.7	38.3										
July 21					37.4	38.1	40.7	37.8	43.9	39.1	40.7	38.3
July 26			37.4	35.3								
July 28					37.4	36.1	39.6	34.4	45.1	41.3	40.7	37.3
Aug. 2	49.8	46.9	33.5	33.3								
Aug. 12					35.2	28.2	31.6	28.7	31.9	28.2	32.9	28.4
Aug. 16	42.4	34.4										
Aug. 17			29.6	27.8								
Aug. 30			27.3	23.8								
Aug. 31	38.2	25.6										
Sept. 2					25.6	20.7	21.3	17.2	24.0	16.4	23.7	18.1
Sept. 13	32.6	24.8	22.4	20.4								
Sept. 22					20.7	16.8	18.7	13.6	19.6	18.0	19.7	16.1
Sept. 27	28.4	21.1										
Oct. 11	27.3	20.1										
Oct. 16			14.2	12.1								
Oct. 26	21.9	13.2										
Nov. 3			16.0	15.1								
Statistical analysis (culture x date)												
F values												
Calculated	66.6		.95		1.64		1.73		1.58		2.59	
For sign.												
@ 5%	2.07		2.04		2.10		2.10		2.10		1.62	
@ 1%	2.78		2.72		2.82		2.82		2.82		1.97	
L. S. D.	3.15 mg.										2.30 mg.	

[1] Mg. ascorbic acid per 100 gm. fresh weight.
[2] Each mean of variety x culture x date is based on analysis of 6 samples of 4 tubers each, those for three varieties on 18 samples.

with mulched than with cultivated tubers. Later in the season mulching retarded the loss of ascorbic acid. The percentage of ascorbic acid retained (calculated from the maximum value in midsummer to the low value at the end of the field season) was greatest with straw-mulched tubers (Table 8).

In 1944 the higher ascorbic acid values in the straw-mulched tubers throughout the season might have been attributable to (1) smaller

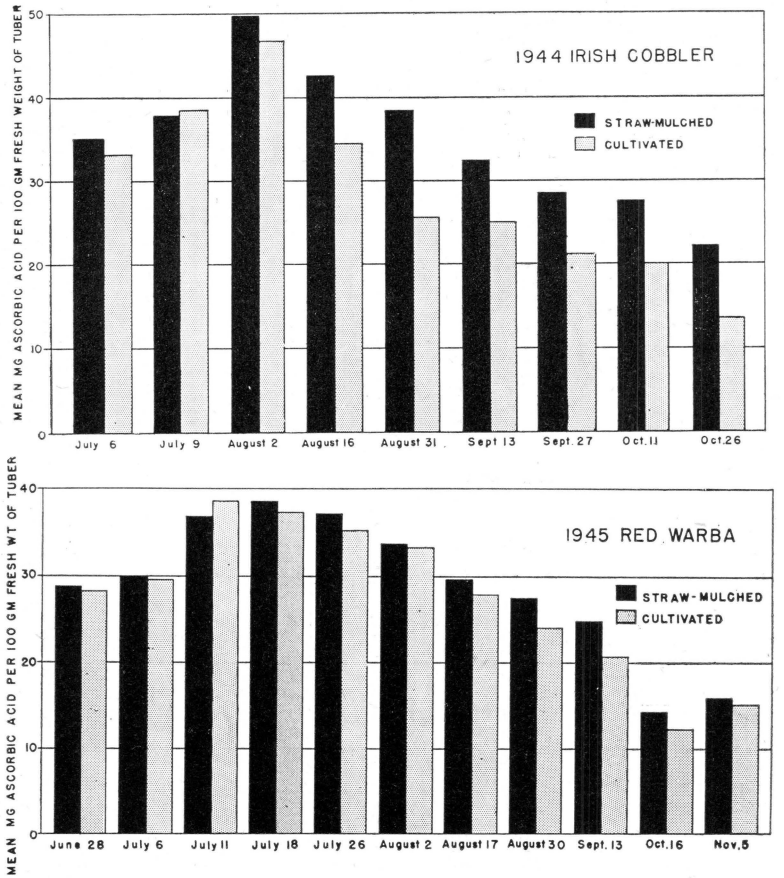
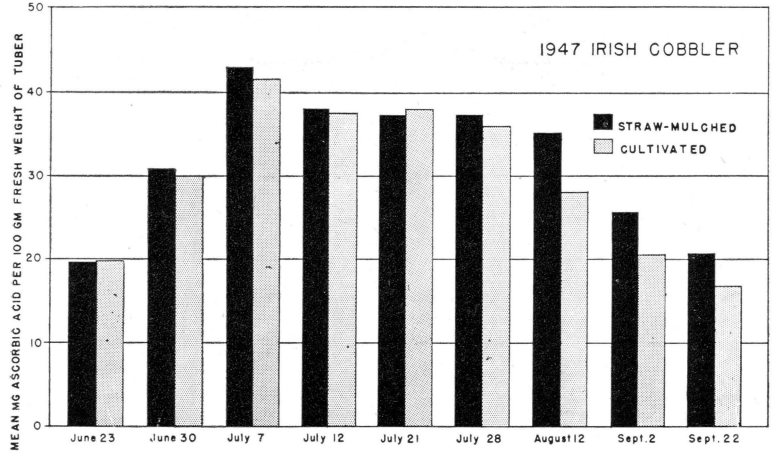
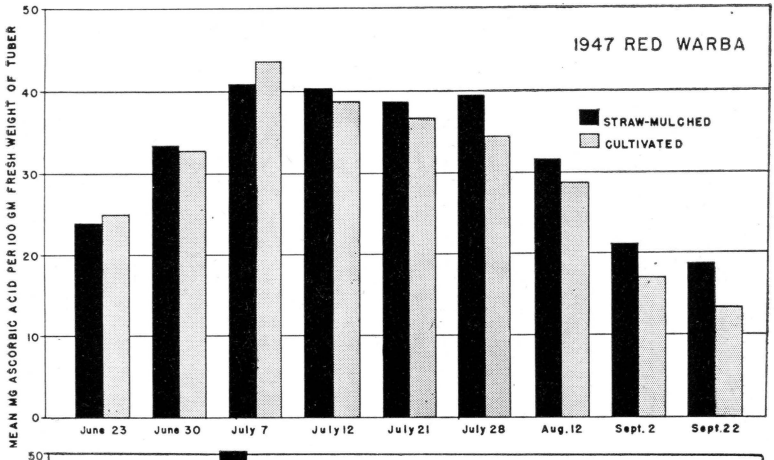


FIGURE 7.—Mean ascorbic acid content of potatoes harvested from straw-mulched and cultivated plots on each date in the various years. Value shown by each histograph is based on analysis of 6 samples of 4 tubers each.

vines which meant greater opportunity for shading by the mulch and (2) better survival and recovery of the plants during and after the leaf hopper invasion. However, the insect depredation that year was a dominant factor, and these differences may have been partly due to the indirect effect of the straw mulch which better enabled the plants to survive the insect attack.

During the 1947 season, with its very hot and dry weather after July 25, the ascorbic acid values of straw-mulched tubers of all varieties were always considerably greater than those of the cultivated


1947 IRISH COBBLER
STRAW-MULCHED
CULTIVATED
MEAN MG ASCORBIC ACID PER 100 GM FRESH WEIGHT OF TUBER
0
10
20
30
40
50
June 23
June 30
July 7
July 12
July 21
July 28
August 12
Sept. 2
Sept. 22


1947 RED WARBA
STRAW-MULCHED
CULTIVATED
MEAN MG ASCORBIC ACID PER 100 GM FRESH WEIGHT OF TUBER
0
10
20
30
40
50
June 23
June 30
July 7
July 12
July 21
July 28
Aug. 12
Sept. 2
Sept. 22

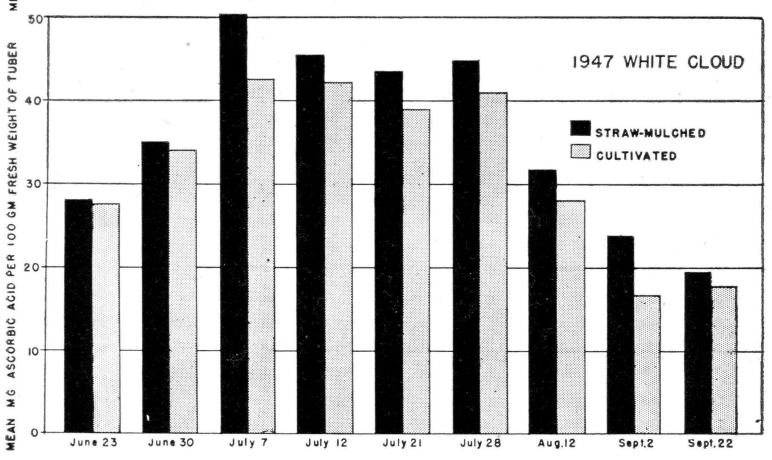

1947 WHITE CLOUD
STRAW-MULCHED
CULTIVATED
MEAN MG ASCORBIC ACID PER 100 GM FRESH WEIGHT OF TUBER
0
10
20
30
40
50
June 23
June 30
July 7
July 12
July 21
July 28
Aug. 12
Sept. 2
Sept. 22

TABLE 8.—Percentage of ascorbic acid retained in straw-mulched and cultivated potatoes from time of maximum value to late September or October.

Treatment	1944 Aug. 2 to Oct. 26 Irish Cobbler	1945 July 18 to Oct. 26 Red Warba	1947 July 7 to Sept. 22		
			Irish Cobbler	Red Warba	White Cloud
	pct.	*pct.*	*pct.*	*pct.*	*pct.*
Straw mulched	44.0	36.7	48.1	45.4	39.0
Cultivated	26.2	32.9	40.4	31.1	41.7
Statistical analysis					
	Culture	Culture	Culture (each variety)		
F values					
Calculated	7.40	7.80	14.1	23.0	56.3
For sign. @ 5%	4.15	4.15			
@ 1%	7.50	7.50			
L. S. D.	1.82%	1.34%	2.26%	1.78%	1.11%

tubers. The difference in ascorbic acid values of straw-mulched and cultivated tubers at the time of maximum content was greatest with White Cloud and least with Irish Cobbler. Straw mulching appeared to be of greater value in the retention of ascorbic acid with Irish Cobbler and Red Warba than with White Cloud potatoes, i.e., there was a greater difference in the percentage retained by the former (Table 8).

Soil Moisture

The average ascorbic acid content of irrigated tubers was slightly lower than that of the dryland tubers (Table 9). In three of the five combinations of years and varieties the mean for the dryland ex-

TABLE 9.—Mean ascorbic acid content of three varieties of potatoes grown with and without irrigation (dryland) for three years.

Year and variety	No. of harvest dates	No. of analyses of each treatment	Ascorbic acid [1]		Statistical analysis			
					F values			L.S.D.
					Calc.	For sign.		
			Irrig.	Dryland		@ 5%	@ 1%	
			mg.	*mg.*				*mg.*
1944 Irish Cobbler	9	54	30.8	32.7	13.22	3.98	7.01	1.05
1945 Red Warba	11	66	27.4	28.7	9.34	3.95	6.92	.80
1947 Irish Cobbler	9	54	30.8	31.0	.05	4.00	7.08	
Red Warba	9	54	31.4	31.1	.21	4.00	7.08	
White Cloud	9	54	34.2	34.0	.13	4.00	7.08	
Three varieties	9	162	32.1	32.0	.09	1.26	1.39	
Mean of five groups		282	30.9	31.5				

[1] Mg. per 100 gm. fresh weight.

TABLE 10.—Mean ascorbic acid content of irrigated and nonirrigated (dryland) potatoes of different varieties harvested on various dates during three years.

1944			1945			1947								
Date harvested	Irish Cobbler		Date harvested	Red Warba		Date harvested	Irish Cobbler		Red Warba		White Cloud		All varieties	
	Irrig.	Dry		Irrig.	Dry		Irrig.	Dry	Irrig.	Dry	Irrig.	Dry	Irrig.	Dry
	mg.[1]	mg.		mg.	mg.		mg.	mg.	mg.	mg.	mg.	mg.	mg.	mg.
						June 23	21.6	17.9	26.6	22.0	29.5	26.3	25.9	22.1
			June 28	28.2	28.7	June 30	29.6	31.0	33.0	33.1	34.6	34.8	32.4	33.0
July 6	33.6[2]	34.6	July 6	29.6	30.3	July 7	39.0	45.6	40.9	44.0	43.8	49.3	41.3	46.3
			July 11	37.2	38.4	July 12	36.7	38.8	37.7	41.3	44.1	44.1	39.5	41.4
July 19	36.7	39.4	July 18	37.5	38.7	July 21	36.4	39.1	37.7	40.8	42.1	40.9	38.7	40.3
			July 26	33.9	38.8	July 28	38.5	35.0	39.0	35.0	45.1	41.3	40.9	37.1
Aug. 2	47.6	49.0	Aug. 2	33.4	33.4									
Aug. 16	36.1	40.8	Aug. 17	28.3	29.1	Aug. 12	32.1	31.4	31.1	29.2	28.8	31.3	30.6	30.6
Aug. 31	31.8	32.0	Aug. 30	23.2	27.8	Sept. 2	24.6	21.7	20.2	18.4	19.1	21.3	21.2	20.5
Sept. 13	26.9	30.4	Sept. 13	20.3	22.5									
Sept. 27	23.5	26.0				Sept. 22	19.0	18.5	16.3	15.9	21.0	16.6	18.8	17.0
Oct. 11	23.0	24.4	Oct. 16	14.3	12.0									
Oct. 26	17.7	17.4	Nov. 3	15.3	15.8									
Statistical analysis (moisture x date)														
F values														
Calculated	1.01			2.04			2.47		2.50		2.71		6.11	
For sign.														
@ 5%	2.07			2.04			2.10		2.10		2.10		1.62	
@ 1%	2.78			2.72			2.82		2.82		2.82		1.97	
L. S. D.				2.02 mg.			3.15 mg.		3.84 mg.		2.55 mg.		2.30 mg.	

[1] Mg. per 100 gm. fresh weight.
[2] Each mean is based on analysis of 6 samples of 4 tubers each.

TABLE 11.—Mean ascorbic acid content of tubers of three varieties produced in three years with combinations of two cultural and two soil moisture treatments.

Year and variety	No. of dates	No. of analyses of each treatment	Ascorbic acid [1]				Statistical analysis			
			Irrigated		Dryland		F values			L.S.D.
			Straw mulch	Cult.	Straw mulch	Cult.	Calc.	For sign. @ 5%	For sign. @ 1%	
			mg.	*mg.*	*mg.*	*mg.*				*mg.*
1944 Irish Cobbler	9	27	33.7	27.8	36.0	29.4	2.37	2.07	2.77	4.45
1945 Red Warba	11	33	27.5	27.3	29.7	27.6	2.69	2.04	2.72	4.02
1947 Irish Cobbler	9	27	35.6	32.8	36.3	31.7	.45	2.10	2.82	
Red Warba	9	27	31.8	29.9	32.1	29.9	.53	2.10	2.82	
White Cloud	9	27	32.5	30.3	32.1	30.1	1.62	2.10	2.82	
Mean of five sets		141	32.2	29.6	33.2	29.7				

[1] Mg. per 100 gm. fresh weight.

ceeded that for the irrigated tubers. During the first two years this difference was highly significant. In 1947 there was no difference, the seasonal means for dryland and irrigated values being almost identical.

On the various dates throughout the three seasons there was no indication of a consistent influence of irrigation on the ascorbic acid content of any variety (Table 10). The statistical analyses indicate that there was significant interaction between dates and moisture conditions and that differences were significant—owing to the very great differences between dates. When calculated on the basis of dry weight of tubers the situation was essentially the same.

Culture and Soil Moisture

Combinations of culture and soil moisture treatments resulted in some consistent differences. Straw-mulched dryland culture produced tubers with the highest ascorbic acid content except in the White Cloud variety in 1947 (Table 11). The straw-mulched irrigated potatoes were generally second highest but there was little difference between irrigated and dryland cultivated tubers. However, only in 1944 did the mean values for dryland straw-mulched tubers exceed any of the others significantly.

Interaction Between Ascorbic Acid Content and Dry Matter or Specific Gravity

Some interesting relationships between specific gravity and ascorbic acid content may be observed in the 1947 values. When the values for mean specific gravity are plotted against the mean ascorbic acid values of tubers of a variety harvested one day from plots receiving a given culture in 1947, it is found that as specific gravity increased the ascorbic acid also increased (Figure 8).

From the time of the earliest harvest on June 23 (date No. 0 in figure 8) to the third harvest on July 7 (No. 2) there was an increase in both ascorbic acid and specific gravity. On each harvest date both values of the mulched tubers were generally higher than those of the cultivated tubers. Generally the values of White Cloud were greatest, followed by those of Irish Cobbler and by those of Red Warba.

With tubers harvested on July 12 and 21 (dates No. 3 and 4 were omitted from Figure 8 for clarity) there was little change in ascorbic acid but a slight decrease in specific gravity. Beginning with the August 12 harvest (No. 6) a distinct drop in ascorbic acid occurred. This continued through the September 2 (No. 7) and September 22 (No. 8) harvests. When this pronounced drop in ascorbic acid occurred there was also a decrease in specific gravity, but it was much less. By September 2 (harvest No. 7) the ascorbic acid values had dropped

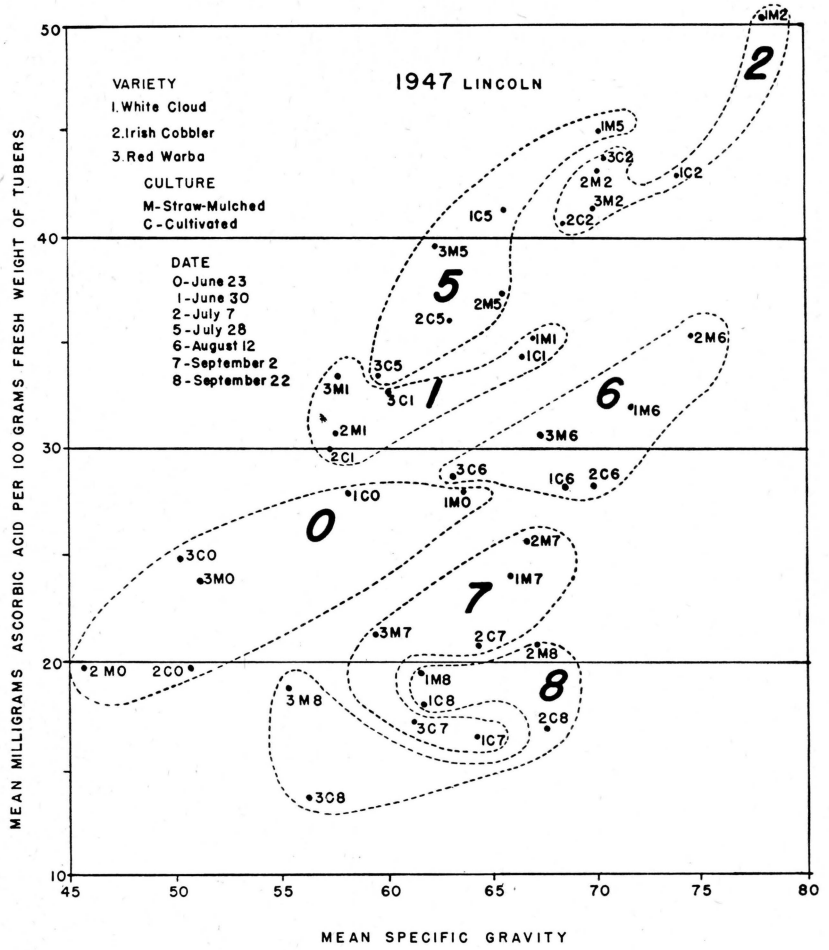


FIGURE 8.—Distribution of mean values for ascorbic acid plotted against mean specific gravity of tubers of three varieties grown by two cultural methods and harvested on each of seven dates in 1947. (Dotted lines enclose values for a given analysis date.)

so that they were a trifle lower than on June 23 but the specific gravity of the tubers was slightly higher. Thus, although there was a close relationship between ascorbic acid content and specific gravity as they were rapidly increasing to a maximum on July 7, thereafter the ascorbic acid content decreased much more rapidly than the specific gravity.

In 1947 the correlation coefficient between specific gravity and ascorbic acid was 0.75 for values of all varieties and of all treatments harvested from June 23 to August 12 inclusive—the period during which early potatoes are most likely to be harvested and used.

As the tuber production season progressed, interrelationships of ascorbic acid and specific gravity differed slightly with the three varieties. During late August and September ascorbic acid and specific gravity decreased in Red Warba and White Cloud but in the Irish Cobbler the specific gravity decreased less and more slowly.

In 1944 with Irish Cobbler and 1945 with Red Warba a similar interrelationship existed between ascorbic acid and percentage of dry matter. In both these years the ascorbic acid content dropped decidedly but the dry matter content decreased relatively little when the potatoes were left in the soil after death of the vines.

The general conclusion is that tubers of approximately the same physiological age, which have not lost more than 25 to 30 per cent of their maximum ascorbic acid content because of ageing of vines, exhibit a direct relationship between high ascorbic acid and high specific gravity or dry matter content. This correlation was greatest in rapidly growing tubers and became less pronounced as tubers remained on senile vines or in the ground after the death of the vines.

Ascorbic Acid Content of Stored Potatoes

The only season during which potatoes were stored (1944-45) the loss of ascorbic acid took place with potatoes from all treatments in much the same manner as reported by numerous other workers.

Field vs. cellar storage during autumn. Some of the tubers were harvested on August 16 and stored in a cellar. These were analyzed for ascorbic acid every two weeks for ten weeks. They lost ascorbic acid at about the same rate as tubers left in the field and harvested at the same interval (Table 12, Figure 9). In the table, "management" refers to these practices of leaving tubers in the field or harvesting early and storing. The small differences had no statistical significance. However, the tubers left in the field appeared to have lost much more ascorbic acid in late October—during which time the field temperature decreased rapidly—than those held in storage where there was only a slight drop in temperature.

The beneficial influence of straw mulching was apparent throughout the storage period. The mean ascorbic acid content of straw-mulched tubers for the 10 weeks of autumn storage was 26 per cent greater than that of the cultivated tubers (Tables 13 and 14, Figure 9). When the crop was left in the field, values for straw-mulched potatoes averaged 42 per cent greater than for those cultivated. Whether it was best to harvest and store potatoes when near maturity or to leave

TABLE 12.—Effect of field and cellar storage from August 16, 1944 on ascorbic acid content of tubers.[1]

Date analyzed	Left in field	Stored in cellar	Mean each date
	mg.[2]	*mg.*	*mg.*
Aug. 16	38.4	38.4	38.4
Aug. 31	31.9	30.9	31.4
Sept. 13	28.7	28.0	28.4
Sept. 27	24.7	25.9	25.3
Oct. 11	23.7	21.9	22.8
Oct. 26	17.5	18.4	17.9
Management mean	25.3	25.0	25.2

Statistical analysis

Factor	Management	Date	Manage. x date
F values			
Calculated	.4	97.9	1.43
For sign. @ 5%	3.92	2.48	2.48
@ 1%	6.84	3.56	3.56
L. S. D.		1.48 mg.	2.09 mg.

[1] Each mean of date x method of management is based on analysis of 48 samples of 4 tubers each.
[2] Mg. per 100 gm. fresh weight.

TABLE 13.—Effect of field and cellar storage upon ascorbic acid content of potatoes grown with and without straw mulching in 1944.

Management August 16 to Oct. 26	Ascorbic acid content		
	Straw mulched	Cultivated	Management
	mg.[1]	*mg.*	*mg.*
Field	29.7[2]	20.9	25.3
Cellar storage	27.9	22.1	25.0
Mean	28.8	21.5	25.16

Statistical analysis

	Management	Culture	Manag. x cult.
F values			
Calculated	.4	244.0	9.59
For sign. @ 5%	3.92	3.92	3.92
@ 1%	6.84	6.84	6.84
L. S. D.	1.48 mg.	.93 mg.	1.32 mg.

[1] Mg. per 100 gm. fresh weight.
[2] Each mean of culture x management is based on analysis of 30 samples of 4 tubers each.

them in the field to be harvested at intervals depended upon the field culture. With straw mulching it was best to leave them in the field. With cultivation early harvesting and cellar storage was slightly better.

On each date the ascorbic acid content of straw-mulched tubers exceeded that of the cultivated to a significant extent. This differ-

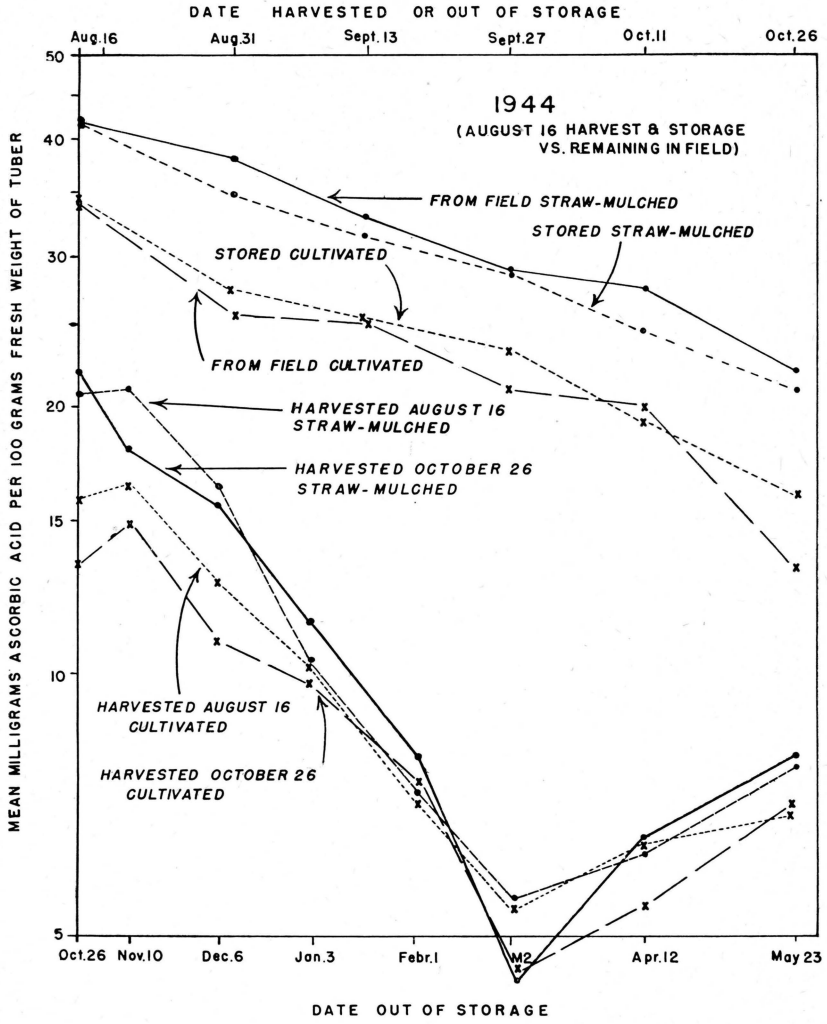


FIGURE 9.—Comparison of ascorbic acid loss with early and late harvest and subsequent storage losses whether in ground or in cellar storage.

(Upper portion of graph) Mean ascorbic acid values of straw-mulched and cultivated Irish Cobbler potatoes either harvested on August 16 and removed from cellar storage or left in the field and harvested on various dates.

(Lower portion of graph, continuation of upper portion) Tubers from same treatment as above harvested on August 16 and October 26 and removed from storage on various dates. Plotted on semilogarithmic basis.

ence was proportionately greater with the potatoes left in the field than with those stored in the cellar. During the last half of August, when the mulched tubers were completing a period of accelerated growth, their ascorbic acid content was almost 50 per cent greater than that of the cultivated potatoes which had lost much more while remaining in the field. Throughout September and early October the ascorbic acid content of the straw-mulched tubers was approximately one third greater than that of the cultivated. During the last half of October, with the lower soil temperature, the ascorbic acid content of the tubers in the field diminished at an accelerated rate.

The difference in ascorbic acid content between straw-mulched and cultivated potatoes in cellar storage after August 16 was generally less on each analysis date than between straw-mulched and cultivated potatoes left in the field. During the first few weeks after August 16 straw-mulched tubers lost ascorbic acid more rapidly in cellar storage than in the field but cultivated tubers lost it more rapidly in the field (Table 14). On most dates the ascorbic acid values of the straw-mulched tubers taken from the cellar were lower than those of the tubers taken directly from the field, whereas with the cultivated plots they were higher (Figure 9).

TABLE 14.—Mean ascorbic acid content of straw-mulched and cultivated Irish Cobbler tubers harvested or removed from cellar storage on five dates after August 16, 1944.[1]

Date analyzed	In field after Aug. 16			In cellar after Aug. 16		
	Ascorbic acid [2]		Per cent increased by straw mulching	Ascorbic acid		Per cent increased by straw mulching
	Straw mulch	Cultivated		Straw mulch	Cultivated	
	mg.	*mg.*		*mg.*	*mg.*	
	Culture x management x date					
Aug. 16	42.4	34.4	23	42.4	34.4	23.
Aug. 31	38.2	25.6	49	34.8	27.0	29
Sept. 13	32.6	24.8	31	31.2	24.9	25
Sept. 27	28.4	21.1	34	28.5	23.3	22
Oct. 11	27.3	20.1	36	24.4	19.4	26
Oct. 26	21.9	13.2	66	20.8	15.9	31
Culture x manage.	29.7	20.9	42	27.9	22.1	26

Statistical analysis

Factor	Culture x date	Management x date	Culture x management x date
F values			
Calculated	2.64	1.43	.43
For sign. @ 5%	2.48	2.48	
@ 1%	3.56	3.56	
L. S. D.	2.09 mg.		

[1] Each mean is based on analysis of 6 samples of 4 tubers each.
[2] Mg. per 100 gm. fresh weight.

When plotted on a semilogarithmic scale the rate of loss of ascorbic acid is found to have proceeded at a practically constant rate throughout the 10-week period regardless of culture or location of the tubers (Figure 9).

Throughout the late summer and fall the average ascorbic acid content of 60 four-tuber samples of irrigated potatoes was significantly less than that of the same number of dryland tubers. The difference of approximately 10 per cent was mostly in the tubers left in the field. The initial superiority of the dryland tubers harvested August 16 diminished rapidly and almost disappeared in storage (Table 15).

TABLE 15.—Mean ascorbic acid content of irrigated and dryland tubers harvested or removed from storage on various dates.

Date analyzed	Ascorbic acid content [1]					
	Field		Cellar storage		Mean	
	Irrig.	Dry	Irrig.	Dry	Irrig.	Dry
	(6)[2]	(6)	(6)	(6)	(12)	(12)
	mg.	*mg.*	*mg.*	*mg.*	*mg.*	*mg.*
Aug. 16	36.1	40.8	36.1	40.8	36.1	40.8
Aug. 31	31.8	32.0	32.5	29.8	32.3	30.7
Sept. 13	26.9	30.4	27.2	28.9	27.1	39.6
Sept. 27	23.5	26.0	25.1	26.7	24.2	26.4
Oct. 11	23.0	24.4	20.5	23.3	21.7	23.8
Oct. 26	17.7	17.4	18.1	18.6	17.9	18.3
Mean—management x moisture	24.6	26.0	24.7	25.4	24.6	25.7

Statistical analysis

Factor	Moisture	Management x moisture	Date x moisture	Date x moisture x management
F values				
Calculated	5.30	.71	1.43	.87
For sign. @ 5%	3.92	3.92	2.48	2.48
@ 1%	6.84	6.84	3.56	3.56
L. S. D.	.93 mg.		2.09 mg.	

[1] Mg. per 100 gm. fresh weight.
[2] Parenthetical number = number of 4-tuber samples on which mean is based.

Winter storage. The loss of ascorbic acid during storage continued at a constant rate until early March when the content was less than one third as great as in late October (Figure 9, Table 16). Thereafter the ascorbic acid increased until the last analysis in late May, at a rate almost as rapid as it had been decreasing earlier.

During the winter storage period from October 26 to May 23 there was no significant difference between the ascorbic acid content of tubers harvested August 16 and held in cellar storage until late October and those harvested and stored on October 26. The means of

TABLE 16.—Mean ascorbic acid content of tubers harvested on two dates in 1944 and removed from storage for analysis on seven dates throughout the winter.[1]

Date analyzed	Ascorbic acid content		
	Harvested Aug. 16	Harvested Oct. 26	Average both harvest dates
	mg.[2]	*mg.*	*mg.*
Oct. 26	18.4	17.5	17.9
Nov. 10	18.7	16.4	17.5
Dec. 6	14.5	13.3	13.9
Jan. 3	10.1	10.5	10.3
Feb. 1	7.1	7.6	7.4
Mar. 2	5.6	4.2	4.8
Apr. 10	6.2	5.9	6.1
May 23	7.3	7.6	10.6
Mean—each harv. date	9.9	9.4	9.6

Statistical analysis

Factor	Harvest date	Harvest date	Harvest date x analysis date
F values			
Calculated	2.15	83.7	1.10
For sign. @ 5%	3.94	2.19	2.19
@ 1%	6.90	2.99	2.99
L. S. D.	.....	1.42 mg.	.....

[1] Each value for harvest date x analysis date is based on analyses of 12 samples of 4 tubers each—or 48 tubers.
[2] Mg. per 100 gm. fresh weight.

these tubers at the beginning of this storage period on October 26 were 18.4 and 17.5 mg. ascorbic acid respectively and their winter means were 9.9 and 9.4 mg. The tubers harvested on August 16 had slightly more ascorbic acid during November and December than the tubers left in the field until October 26. These differences are probably because of lower initial ascorbic acid value as a result of field chilling of the tubers harvested in October. After midwinter there was no consistent difference in lots harvested on different dates.

The superiority of straw-mulched tubers persisted throughout the storage period (Table 17). The mean for the winter of 10.4 mg. ascorbic acid in straw-mulched tubers was significantly greater than that of 8.9 mg. in cultivated tubers. The time of harvest did not alter this comparative relationship materially. The mulched tubers had superior values on all but one analysis date. In early March when values were lowest, means were the same for both cultural practices. The resumption of the difference between straw-mulched and cultivated tubers during the period of increase in ascorbic acid late in the storage season is indicative of the intrinsic difference of the straw-mulched tubers.

During the long winter storage period effects of irrigation were only faintly apparent. The seasonal ascorbic acid mean for the dryland tubers was 9.7 mg. and that for irrigated tubers was 9.5 mg. This slight

TABLE 17.—Mean ascorbic acid content of straw-mulched and cultivated tubers when removed from winter storage on seven dates in 1944-45.[1]

Date analyzed	Ascorbic acid	
	Straw mulch	Cultivation
	mg.[2]	*mg.*
Oct. 26	21.4	14.5
Nov. 10	19.4	15.7
Dec. 6	15.9	11.9
Jan. 3	10.7	9.9
Feb. 1	7.5	7.2
Mar. 2	4.8	4.8
Apr. 12	6.4	5.8
May 23	7.9	7.0
Mean of each culture	10.4	8.9

Statistical analysis

Factor	Culture	Date x culture
F values		
Calculated	15.2	2.70
For sign. @ 5%	3.94	2.19
@ 1%	6.90	2.99
L. S. D.	.76 mg.	2.01 mg.

[1] Each value for culture x date based on analysis of 12 samples of 4 tubers each—or 48 tubers.
[2] Mg. per 100 gm. fresh weight.

TABLE 18.—Mean ascorbic acid content throughout storage period from November 26 to May 23 of tubers produced with four combinations of culture and soil moisture.[1]

Soil moisture	Culture		Mean of each soil moisture
	Straw mulch	Cultivated	
	mg.[2]	*mg.*	*mg.*
Dryland	10.7	8.8	9.7
Irrigated	10.1	9.0	9.5
Mean	10.4	8.9	9.6

Statistical analysis

Factors	Culture	Soil moisture	Cult. x moisture
F values			
Calculated	15.2	.35	.88
For sign. @ 5%	3.94	3.94	3.94
@ 1%	6.90	6.90	6.90
L. S. D.	.76 mg.		

[1] Each mean of culture x moisture based on analysis of 21 samples of 4 tubers each—or 84 tubers.
[2] Mg. per 100 gm. fresh weight.

difference was apparent on each date. None of the differences due to soil moisture had any statistical significance.

The greatest mean ascorbic acid values for combinations of culture and soil moisture were in straw-mulched dryland tubers (Table 18). The dominating influence of straw mulching is further apparent in the second highest mean—that of straw-mulched irrigated tubers. The amount of soil moisture exerted little influence on the ascorbic acid content of cultivated tubers.

SUMMARY

1. Reduced ascorbic acid analyses were made on potatoes harvested at frequent intervals from plants grown as an early crop at Lincoln during three seasons (1944, 1945, 1947) with and without straw mulching and with and without irrigation. In one year (1944) the analyses were continued during storage.

2. Irrigation and straw mulching prolonged the life of the plants and increased the yield of tubers, but in two of the years because of high rainfall these increases were not as great as in most Nebraska seasons.

3. Dry matter content (or specific gravity) was lowest in the irrigated and cultivated tubers. It generally increased rapidly as the new tubers were enlarging, remained relatively constant until the vines died, then decreased slowly but with considerable fluctuation according to the environmental conditions.

4. The dry matter content was greatly influenced by variety, that of White Cloud (a recently introduced variety) being greatest followed by that of Irish Cobbler and Red Warba. As the vines were dying, and later, the dry matter content of Irish Cobbler tubers did not decrease as rapidly as that of the other varieties.

5. Reduced ascorbic acid content of tubers increased rapidly during the period of rapid initial development, attaining the maximum about the time of maximum plant size, and then remained relatively high for a few weeks as plants were maturing and tuber growth was being completed. The ascorbic acid decreased steadily and rapidly during the period when the plants were dying. After the death of the plants, while tubers were still in the field, the decrease in amount of ascorbic acid was less but the rate of loss was proportionately the same as earlier.

6. The ascorbic acid content of White Cloud tubers was greatest, and that of Irish Cobbler least, but the latter tubers lost ascorbic acid more slowly as the plants died and after they had died.

7. In these years little or no difference in ascorbic acid content was attributable to soil moisture or cultural conditions except during and after the period of maximum plant growth. Then and thereafter straw-mulched tubers had significantly higher values. Irrigation sometimes decreased ascorbic acid content slightly but not consistently or significantly.

8. There was a positive correlation between ascorbic acid and specific gravity of tubers removed from living plants. With the death of the vines ascorbic acid decreased much more rapidly and more extensively than did the specific gravity of the tubers.

9. Tubers harvested when vines were partly mature and then held in storage lost ascorbic acid at about the same rate as those left in the field until midautumn.

10. The tubers harvested in midautumn had slightly less ascorbic acid throughout the winter and spring than those harvested in mid-August.

11. Straw-mulched tubers had higher ascorbic acid values throughout the storage period than the cultivated tubers.

LITERATURE CITED

1. EMERSON, R. A., 1903. Experiments in mulching garden vegetables. Nebr. Agr. Exp. Sta. Bul. 80.
2. HEINZE, P. H. AND KANAPAUX, M. S. Modifications of the ascorbic acid method. (Personal communication. P. H. Heinze is Physiologist, Bureau of Plant Industry, Soils and Agricultural Engineering, U.S.D.A., and M. S. Kanapaux is Biochemist, Regional Vegetable Breeding Laboratory, Charleston, S. C.)
3. IJDO, J. B. H., 1938. Vitamin C content of different species of potatoes. C. R. VeCongr. internat. tech. chim. indust. agric. Scheveningen, Holland. 1:127-131 Nutr. Abs. and Rev. 7:612.
4. KARIKKA, K. J., DUDGEON, L. T., AND HAUCK, H. M., 1944. Influence of variety, location, fertilizer, and storage on the ascorbic acid content of potatoes grown in New York State. Jour. Agr. Res. 68:49-63.
5. KELLY, W. C., AND SOMERS, G. F., 1948. The influence of certain rootstocks and scions on the ascorbic acid content of potato tubers. Plant Physiology 23:338-344.
6. KELLY, W. C., AND SOMERS, G. F., 1949. The effect of time of harvest, variety and storage on the ascorbic acid content of potato tubers. Amer. Potato Jour. 26:47-53.
7. KOHMAN, E. F., AND PORTER, D. R., 1940. Solar rays and vitamin C. Science 92:561.
8. LAMPITT, L. H., BAKER, L. C., AND PARKINSON, T. L., 1945. Vitamin C content of potatoes. 1. Distribution in the potato plant. 2. The effect of variety, soil and storage. Jour. Soc. Chem. Indust. 64:18-22, 22-26.
9. LOEFFLER, H. J. AND PONTING, J. D., 1942. Rapid determination of ascorbic acid in fresh or dehydrated fruits and vegetables. Ind. & Eng. Chem. Anal. Ed. 14:846-849.
10. LYONS, M. E., AND FELLERS, C. R., 1939. Potatoes as carriers of vitamin C. Amer. Potato Jour. 16:169-179.
11. MCCOLLUM, J. P., 1944. Some factors affecting the ascorbic acid content of tomatoes. Proc. Am. Soc. Hort. Sci. 45:382-386.
12. MCCOLLUM, J. P., 1946. Effect of sunlight exposure on the quality constituents of tomato fruits. Proc. Am. Soc. Hort. Sci. 48:413-416.
13. MURPHY, E. F., 1938. Vitamin C and light. Proc. Am. Soc. Hort. Sci. 36:498-499.
14. MURPHY, E. F., DOVE, W. F., AND AKELEY, R. V., 1945. Observations on genetic, physiological, and environmental factors affecting the vitamin C content of Maine-grown potatoes. Amer. Potato Jour. 22:62-83.
15. MURPHY, E. F., 1946. Storage conditions which affect the vitamin C content of Maine-grown potatoes, Amer. Potato Jour. 23:197-217.
16. REDER, R., ASCHAM, L., AND EHEART, M., 1943. Effect of fertilizer and environment on ascorbic acid content of turnip greens. Jour. Agr. Res. 66:375-388.
17. ROLF, L., 1940. Effect of cooking and storage on the ascorbic acid content of potatoes. Jour. Agr. Res. 61:381-395.
18. SMITH, A. M., AND PATERSON, W. Y., 1937. A study of variety and virus disease infection in tubers of *Solanum tuberosum* by the ascorbic acid test. Biochem. Jour. 31:1992-1999.
19. SMITH, A. M., AND GILLIES, J., 1940. The distribution and concentration of ascorbic acid in the potato (*Solanum tuberosum*). Biochem. Jour. 34:1312-20.
20. TEDIN, O., 1941. Further vitamin C studies in potatoes. Sveriges Utsädesför. Tidskr. 51:238-255. Nutr. Abs. and Rev. 12:3355.

21. WERNER, H. O., 1929. Effect of cultural methods and maturity upon the seed value of eastern Nebraska potatoes. Nebr. Agr. Exp. Sta. Res. Bul. 45.

22. WERNER, H. O., 1933. Soil management experiments with vegetables. Nebr. Agr. Exp. Sta. Bul. 278.

23. WERNER, H. O. AND LEVERTON, RUTH M., 1946. The ascorbic acid content of Nebraska-grown potatoes as influenced by variety, environment, maturity, and storage. Amer. Potato Jour. 23:265-267.

24. WOKES, FRANK AND NUNN, GORDON, 1948. Vitamin C in potatoes. Nature 162:900-903.

2½ M