KEEPING QUALITY OF SUGAR BEETS AS INFLUENCED BY GROWTH AND NUTRITIONAL FACTORS[1]

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INTRODUCTION

The prevention of losses in storage of sugar beets (*Beta vulgaris* L.) during the period between harvest and processing in the factory constitutes a major problem of the sugar-beet industry. For example, a large western company, basing its estimates on the difference between the gross sugar purchased, as determined from tonnages and sucrose percentages, and the gross sugar in the beets actually sliced, placed the shrinkage in sugar for one campaign at more than $5,000,000. Some portion of this loss occurs as a result of respiration of the beet itself, but a large part is occasioned by the activities of organisms that cause decay of the root tissues during the period in which the sugar beets are being stored in piles.

In the western United States, except in California, where the harvest in general is gaged to factory capacity, deliveries of sugar beets in excess of the immediate factory needs are dumped into storage piles. Storage of the roots permits harvesting to proceed during favorable fall weather and assures the factory a supply of beets for continuous operation.

Heavy losses in storage have been noted that could be traced to such practices as storing frozen beets or allowing excessive amounts of soil or debris to be dumped in the piles. Careless handling of roots in the field or in piling may so injure the roots as to promote fungus invasion. Tompkins and Nuckols (*5*)[3] have given data on hook injury and other wounds made during harvesting that are contributing factors to excessive rotting. They have also shown (*6*) that the upper crown tissues are more resistant to attack by rot-producing organisms than are the tissues exposed if the beets are topped one-half inch or more below the leaf-scar level, indicating the desirability of emphasis on proper topping. Portions of the root tissues die and fungus invasion follows if excessive drying of the roots takes place either before storage or in the piles. Pack (*3*) has shown that wetting the roots in storage piles is a desirable practice for western areas. Heavy losses have been experienced in years of unseasonably high air temperature. Artschwager and Starrett (*1*), in experiments in which sugar beets were stored at a number of controlled temperatures and humidities within the range of conditions likely to be encountered in factory storage piles, have shown that wounded beets either do not form a

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[3] Reference is made by number (italic) to Literature Cited, p. 198.

protective wound periderm or form it so slowly as to be unable by this means to ward off attacking organisms.

Preventive measures against storage losses have been of a general nature, attention being given largely to the environmental conditions of storage. The purpose of this paper is to show that certain environmental factors concerned with nutrition and growth of the roots have a marked effect upon the keeping quality of sound roots.

The experiments reported in this paper were initiated because of observations made in 1931 on some immature sugar-beet roots that had been grown in nutrient cultures deficient in phosphorus. It was noted by L. M. Pultz [4] and the writer that these roots, in contrast with roots of similar age but grown with an adequate phosphorus supply, were extremely susceptible to invasion by *Phoma betae* (Oud.) Frank. Reports in the literature have called attention to the rotting of roots in the field as a result of nutritional deficiencies (*4*), but the nutritional or other growth conditions in their effects upon the keeping qualities of stored sugar beets have not, so far as the writer knows, received attention.

EXPERIMENTAL RESULTS

INFLUENCE OF SUPERPHOSPHATE AND OF A COMPLETE FERTILIZER ON KEEPING QUALITY

METHODS

Two sugar-beet fields located near Hyrum and Payson, Utah, which were known to be deficient in available phosphates, were chosen for growing the roots used in the storage experiments in 1932. Heavy applications were employed to secure maximum responses and to establish strong differences in quality between the roots receiving fertilizers and the unfertilized roots. Treble superphosphate (46 percent) was applied at the rate of 250 pounds per acre and a complete fertilizer (4–12–4) at the rate of 575 pounds per acre. The fertilizers were applied to strips of land running the full length of the field, an unfertilized strip being left between those fertilized. To avoid injury to the seedlings from the heavy applications, one-half of the fertilizer was broadcast and harrowed in before the seed was sown, the remainder being applied in the row with the seed.

In the 1933 experiment, at Hyrum, Utah, smaller amounts, more nearly corresponding with commercial applications, were used in similarly laid-out plots. The fertilized plots received 150 pounds of superphosphate (46 percent) or 350 pounds of the complete fertilizer (4–12–4) per acre. Cultivation and irrigation of the beets followed standard commercial practices for the area.

In the fall representative roots were selected from each of the three plots receiving the different treatments, namely, (1) phosphate fertilizer, (2) complete fertilizer, and (3) no fertilizer. The largest and smallest roots were discarded as not being representative. The beets selected were topped accurately at the bases of the lowest leaf scars, thus exposing comparable root tissues. After the desired number of roots had been secured from each treatment they were sorted into 10 approximately uniform groups. Nine of these were stored, and the tenth was divided into five samples and used at once in analyses to determine initial sucrose percentages and apparent purity coefficients. In the experiment of 1932 at Hyrum each of the 10 groups from each

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treatment consisted of 100 roots; in the experiment of 1932 at Payson each consisted of 75 roots; and in the experiment of 1933 at Hyrum each consisted of 50 roots.

Nine of the groups taken as representative of each treatment were put into coarse-meshed onion sacks for storage in commercial storage piles.[5] In this manner the identity of the experimental beets was retained, and the circulation of air and gaseous byproducts of respiration was unhampered. Three replicates of each treatment were placed on each of three levels in the storage piles, the various samples being so randomized that the storage-pile exposures were equalized so far as possible for the roots originating from the three conditions of field growth.

In the 1932 experiments final analyses for sucrose percentages and apparent purity coefficients were made on a single 20-beet sample taken at random from each replicate of each field treatment. In the 1933 experiment (Hyrum) two 10-beet samples chosen at random from each replicate of each field treatment were used. This method was adopted in preference to using a single 20-beet sample from each replicate because many of the roots were badly decayed. In the statistical reduction of data, the analysis of variance method (*2*) has been used except in those cases where it was appropriate to determine the standard error of each mean. The values given in Fisher's *t* table for a probability of 0.05 have been used in all experiments to determine the differences required for significance.

Experiment at Hyrum, Utah, 1932

In 1931 the field at Hyrum had grown a mediocre crop of beets, immediately following several years of alfalfa. In the 1932 experiment superphosphate stimulated growth to some extent during the seedling stage, but the greatest stimulation was obtained from the complete fertilizer. This difference between the two fertilizers soon disappeared, presumably as the soil nitrates became more available with the advent of warmer weather. Seedlings in plots receiving complete fertilizer were very vigorous, the loss after thinning being only 3 percent; seedlings in plots receiving superphosphate were considerably less vigorous, the loss amounting to 11 percent; while in the unfertilized strips 16 percent of the seedlings died after thinning. The unfertilized beets remained unthrifty throughout the season, showing symptoms typical of phosphorus deficiency. Many plants in these plots later became affected with *Phoma betae*, which accounted for another 15-percent loss of beets. Symptoms of nutritional deficiencies and disease were entirely absent in beets receiving the fertilizer treatments. At harvest, beets in the unfertilized strips yielded 8.22 tons per acre, those in the superphosphate-fertilized strips 13.49 tons per acre. Beets treated with the complete fertilizer yielded 14.61 tons per acre.

These beets were harvested on October 25 and were placed in storage at Lewiston the following day, where they remained until December 10. Three replicates of each treatment were lost in fluming out the commercial beets, so only six were available from which to take the final data. The record of roots decayed and of changes in sugar content that occurred during storage is summarized in table 1.

[5] Facilities for storage were provided in the storage piles of the Amalgamated Sugar Co. at Lewiston, Utah, and of the Utah-Idaho Sugar Co. at Payson, Utah.

TABLE 1.—*Effect of nutritional conditions on keeping quality of sugar-beet roots stored 45 days under commercial conditions at Hyrum, Utah, 1932*

[Initial readings and change during storage based on comparable samples. Results given as averages of 6 100-beet samples]

Treatment	Weight of 100 roots		Sucrose expressed as percent		Apparent purity coefficient		Indicated available sugar [1]		Roots invaded by organisms
	Initial	Change during storage	Initial	Change during storage [2]	Initial	Change during storage [2]	Initial	Change during storage [2]	
	Pounds	*Percent*					*Pounds*	*Percent*	*Percent*
Superphosphate (46 percent), 250 pounds per acre	134.83	−6.64	16.86	+0.45	88.46	+1.04	20.11	−3.04	14.17
Complete fertilizer (4–12–4), 575 pounds per acre	142.79	−7.79	16.52	+.15	89.00	−1.11	20.99	−8.13	8.33
Unfertilized	84.50	−8.63	16.42	+.04	89.79	−1.21	12.46	−9.63	38.00
Difference required for significance		.83		.19		1.39		1.26	5.68

[1] Obtained by computing for each sample and then averaging. Hence, the value given differs slightly from product of means shown in this table.
[2] See footnote 6.

In the experiment carried on at Hyrum in 1932, 38 percent of the roots in the samples taken from the unfertilized plots were invaded by rot-producing organisms. In contrast to this, only 8.33 percent of the roots which had received a heavy dosage of complete fertilizer during their growing period were invaded by organisms, and 14.17 percent of those that had been fertilized with superphosphate. The difference between the two lots receiving fertilizers reaches the value required for significance. The resistance to rot-producing organisms of roots fertilized with either of the commercial fertilizers was superior to that of the unfertilized roots; while roots receiving complete fertilizer were apparently more resistant than those receiving only treble superphosphate.

The roots receiving superphosphate during their growing period lost only 3.04 percent of their indicated available sugar, whereas the roots grown in complete fertilizer and the unfertilized roots lost 8.13 percent and 9.63 percent, respectively. Because of the limited invasion by organisms causing decay, it is probable that these losses came about as a result of respiration. Statistical analysis places the difference required for significance as to sugar loss at 1.26 percent.[6]

EXPERIMENT AT PAYSON, UTAH, 1932

Because of poor growing conditions, the beets in the experiment at Payson in 1932 did not develop normally. Responses to fertilizer treatments were less striking than at Hyrum, owing primarily to a refractory soil condition and a shortage of soil moisture. The unfertilized beets developed symptoms of both phosphorus and nitrogen deficiency, and invasion by *Phoma betae* caused heavy losses during the growing period. The phosphorus requirements of the crop apparently were satisfied by the fertilizers applied, there being no

[6] The assumption is made that the initial sampling of beets to determine sucrose percentage at the start of the storage period was adequate to establish a mean with negligible error from which to determine change when the beets were stored. The changes in sucrose percentage and in indicated available sugar in tables 1, 2, and 3 have been determined in accordance with that assumption and are expressed as differences between average initial and average final readings. Differences required for significance for these attributes have been determined from the standard deviation of the stored samples.

leaf necrosis nor invasion by *P. betae* to indicate a deficiency. However, the beets in the plots receiving the superphosphate fertilizer showed evidence of a nitrogen deficiency and reached maturity sometime before those beets that received the complete fertilizer. The beets were harvested on October 29 and were placed in the commercial storage pile at Payson the following day, where they remained until December 8. The results obtained on the keeping quality of these beets during storage are summarized in table 2.

TABLE 2.—*Effect of nutritional conditions on keeping quality of sugar beets stored 40 days under commercial conditions at Payson, Utah, 1932*

[Initial readings and change during storage based on comparable samples. Results given as averages of 9 75 beet samples]

Treatment	Weight of 100 roots		Sucrose expressed as percent		Apparent purity coefficient		Indicated available sugar [1]		Roots invaded by organisms
	Initial	Change during storage	Initial	Change during storage [2]	Initial	Change during storage [2]	Initial	Change during storage [2]	
	Pounds	*Percent*					*Pounds*	*Percent*	*Percent*
Superphosphate (46 percent), 250 pounds per acre	88.78	−8.76	16.88	+1.17	92.86	−1.94	13.91	−4.47	34.67
Complete fertilizer (4-12-4), 575 pounds per acre	87.75	−8.42	14.54	+.63	86.99	+.06	11.10	−4.40	44.44
Unfertilized	56.31	−8.19	16.50	+1.06	94.31	−3.95	8.76	−6.37	60.00
Difference required for significance		.77		.22		1.13		1.57	8.08

[1] Obtained by computing for each sample and then averaging. Hence the value given differs slightly from product of means shown in this table.
[2] See footnote 6, p. 188.

Isolations were made of organisms from discolored tissues of beets in the 1932 experiments at Hyrum and at Payson. When examined following the period of storage the beets did not show sufficient tissue involvement to permit trustworthy data being obtained by measuring the depth of penetration or by paring off the invaded tissues for weighings. Judgment was made as to soundness of the stored roots and as to invasion by organisms by observation of the individual roots. One hundred and eleven of the roots judged as invaded by organisms were subsequently cultured. Only 3 of these roots failed to yield organisms; 10 yielded *Penicillium* spp., and 98 yielded cultures of other organisms known to be associated with rotting of beet roots, distributed as follows: 65 cultures of *Phoma betae*, 26 of *Fusarium* spp., and 7 of phycomycetous fungi. The crown tissues and basal portions of the taproot were the chief avenues of fungus entrance; about 15 percent of the diseased beets showed invasion at the sides, 50 percent invasion of the basal portions, and 35 percent crown invasions. None of the various fungus species or groups indicated were restricted in their occurrence to any particular portion of the root or to any specific field treatment.

EXPERIMENT AT HYRUM, UTAH, 1933

Sugar-beet roots for the storage experiment at Hyrum in 1933 were grown in the same vicinity as those for the 1932 experiment. Fertilizer applications were inadequate to counteract the soil deficiencies; consequently beets of rather poor quality were produced in the fertilized plots as well as in the unfertilized plots. Foliage symptoms of phosphorus deficiency were prevalent in the unfertilized beets throughout the summer and fall and developed to some extent in the fertilized beets just prior to harvest on October 22. Symptoms of deficiency were less severe in the beets that received superphosphate than in those that received the complete fertilizer. Root rot caused by the invasion of *Phoma betae* was again prevalent in the unfertilized beets and resulted in a heavy loss.

Unseasonably high temperatures, a comparatively long storage period, and poor quality of beets operated to bring about rather heavy losses in this experiment. A high percentage of the roots throughout the treatments showed such advanced invasion by rot-producing organisms that it was possible to pare out and weigh rotted portions. Each sample of 50 beets was divided into 5 comparable 10-beet groups on the basis of size of root. Three of these aliquots were used in obtaining data on decayed tissues. The two remaining aliquots served as material for the final sugar and purity determinations (table 3).

TABLE 3.—*Effect of superphosphate and complete fertilizer treatments on keeping quality of sugar-beet roots stored 75 days under commercial conditions at Hyrum, Utah, 1933*

Treatment	Weight of 50 roots		Sucrose expressed as percent [1]		Apparent purity coefficient		Indicated available sugar [1] [2]		Decayed tissue [4]	
	Initial	Change during storage	Initial	Change during storage [3]	Initial	Change during storage [3]	Initial	Change during storage [3]		
	Lb.	*Pct.*					*Lb.*	*Pct.*	*Lb.*	*Pct.*
Superphosphate (46 percent), 150 pounds per acre	53.80	−5.44	19.48	−0.35	97.13	−7.11	10.19	−12.73	2.10	4.23
Complete fertilizer (4–12–4), 350 pounds per acre	54.57	−6.96	18.63	−1.01	96.82	−8.79	9.84	−19.88	3.14	6.18
Unfertilized	30.14	−7.20	19.00	−3.04	96.89	−18.03	5.66	−34.94	4.80	17.48
Difference required for significance	-------	1.59	-------	1.51	-------	5.26	-------	9.26	1.23	3.42

[1] Based upon 2 10-beet samples from each replicate.
[2] Obtained by computing for each sample and then averaging. Hence the value given differs slightly from product of means shown in this table.
[3] See footnote 6, p. 188.
[4] Calculated for the 50-beet sample from the average of three 10-beet samples.

This experiment afforded an opportunity for observing the beneficial effects of corrective fertilization of sugar beets during their growth period on the keeping quality of the roots during a long period of storage. The conditions were conducive to heavy losses from fungus invasion in addition to those resulting from respiration of the stored roots. It will be noted that 17.48 percent, by weight, of the root tissues of beets from the unfertilized plots was destroyed by rot-producing organisms during the 75-day storage period, as compared with only 4.23 percent in roots that came from the phosphate-fertilized plots and 6.18 percent of roots that received the complete fertilizer. A comparison of the results of the 1932 experiments at Hyrum and Payson with these results shows conclusively that the destruction of tissues by rotting organisms in all cases had a direct bearing on the loss of sucrose during storage. In the 1933 experiment, in which root decay was most pronounced, samples of roots that received superphosphate fertilizer during growth lost 12.73 percent of sugar (indicated available) during storage, and samples taken from the plots receiving complete fertilizer lost 19.88 percent, as compared with a loss of 34.94 percent in the unfertilized beets. The difference between the two fertilizer treatments does not reach the value required for significance, but in both cases the fertilized roots showed a significantly lower loss of sugar than those not fertilized. In this experiment the loss of sucrose due to respiration of the root tissues is obscured by the heavy losses caused by rot-producing organisms.

EFFECT OF FERTILIZER, MANURE, AND SOIL-MOISTURE TREATMENTS IN THE FIELD ON KEEPING QUALITY AT HYDE PARK, UTAH, 1932

Field experiments for the control of "dry rot" or "late blight" of sugar beets were carried on near Hyde Park in 1932. Roots from these plots were used to test the influence of the nutrition and of the water supply furnished the growing beet on invasion and decay by organisms during storage. The soil used was extremely low in fertility, and thus it was possible to study the effect of a complete fertilizer as well as of the individual elements in relation to keeping quality of sugar beets. As shown in table 4, four inorganic-fertilizer treatments and an untreated check were used alone and in combination with barnyard manure under two conditions of soil moisture. The manure was applied in the spring before the ground was plowed. The commercial fertilizers, containing 20 percent of plant food, were applied at a uniform rate of 400 pounds per acre at seeding time. Rainfall was meager during the summer, so the crop was almost entirely dependent upon irrigation for moisture. The plots designated as having inadequate soil moisture were irrigated on June 28, July 21, and August 23, as contrasted with the plots receiving adequate water, which were irrigated every 2 weeks, beginning June 14 and continuing to September 15.

The results on the keeping quality of beets as measured by invasion and extent of decay caused by rotting organisms are summarized in table 4. Because of the variability in size and weight of roots taken from the various field treatments, the data have been presented as actual weight of decayed tissue and as percentages of tissue decayed.

Considering first the tests without manure applications, the data obtained are in accord with the results of the preceding experiments in that the application of superphosphate or complete fertilizer during the growth of the beet materially improved the keeping quality of the roots during storage, judgment being based upon the extent of decay occurring. Nitrogen (as ammonium sulphate) applied to this nitrogen-deficient soil produced beets that were markedly superior in keeping quality to those from the unfertilized plots. Beets fertilized with potassium sulphate were likewise superior to the unfertilized roots. Apparently these soils were so deficient in fertility that the addition of any fertilizer produced a favorable response. Shortage of water during the growth period decidedly increased the amount of decay, in some cases almost nullifying the beneficial effects of the fertilizer.

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TABLE 4.—*Decay of root tissues as influenced by fertility and soil-moisture conditions during growth of sugar beets near Hyde Park, Utah, 1932*

[Data given as averages of seven 10-beet samples stored 170 days in root cellar]

Fertilizer treatment: Commercial	Fertilizer treatment: Organic	Weight of sample	Weight of decayed tissue	Proportion of sample decayed	Invaded beets per sample
ADEQUATE SOIL MOISTURE DURING GROWING SEASON					
		Pounds	*Pounds*	*Percent*	*Number*
Superphosphate	Manure	23.07	1.32	5.72	6.7
	None	19.82	1.36	6.86	8.3
Complete (4–12–4)	Manure	19.86	.71	3.58	6.4
	None	16.21	2.21	13.63	8.9
Potassium sulphate	Manure	19.46	1.86	9.56	8.1
	None	13.64	2.07	15.18	8.3
Ammonium sulphate	Manure	21.85	.32	1.46	4.3
	None	18.14	1.39	7.66	7.6
None	Manure	18.18	2.25	12.38	7.1
	None	13.04	3.61	27.68	9.3
INADEQUATE SOIL MOISTURE DURING GROWING SEASON					
Superphosphate	Manure	16.18	1.64	10.14	7.0
	None	10.86	4.71	43.37	9.4
Complete (4–12–4)	Manure	14.54	1.61	11.07	7.0
	None	9.39	5.29	56.34	9.7
Potassium sulphate	Manure	14.86	2.18	14.67	8.9
	None	7.46	3.07	41.15	9.9
Ammonium sulphate	Manure	16.11	1.50	9.31	6.3
	None	10.21	4.43	43.39	9.9
None	Manure	13.11	3.00	22.88	8.9
	None	9.04	5.68	62.83	9.7
Difference required for significance			.91	5.97	1.3

The use of barnyard manure alone as a fertilizer produced beets of superior keeping quality as compared with beets from the unfertilized plots. When used in conjunction with a commercial fertilizer, manure significantly increased the beneficial effects except when used with superphosphate and potassium sulphate in the series having adequate soil moisture. In the case of the latter, the value approaches significance. It seems fair to conclude that adequate phosphate nutrition of the beets is a prime essential to keeping quality, and that the manure applications function by influencing phosphate and other nutritional conditions as well as by exerting a very definite effect upon the water relations. From a comparison of the two moisture series, it is evident that barnyard manure did much toward counteracting the deleterious effects of inadequate soil moisture during the growing period on the keeping quality of the roots during storage. The necessity for an adequate supply of soil moisture during growth and its influence in the promotion of storage quality seem clearly demonstrated by contrasting the results of the two irrigation series.

Isolations of the associated organisms were made from decayed tissues of 16 beets selected at random from each of the 20 treatments. A section of each root was given surface disinfection with a mercury-bichloride solution (1 : 1,000) and then rinsed several times in distilled water. Isolations of the organisms were made from newly invaded tissues, in duplicate, on potato-dextrose agar. Of the 320 roots from which isolations were made, *Phoma betae* was obtained in pure culture from 224 beets and was found associated with *Penicillium* spp. in 19 others. Eleven roots had been invaded by *Fusarium* spp. and four by *Pythium* spp. The remainder of the cultures were sterile, owing either to deep penetration of the disinfectant into the tissues or to culturing from uninvaded tissues. The distribution of the several fungus forms was approximately uniform throughout the various treatments, there being no association between treatment and type of organism involved.

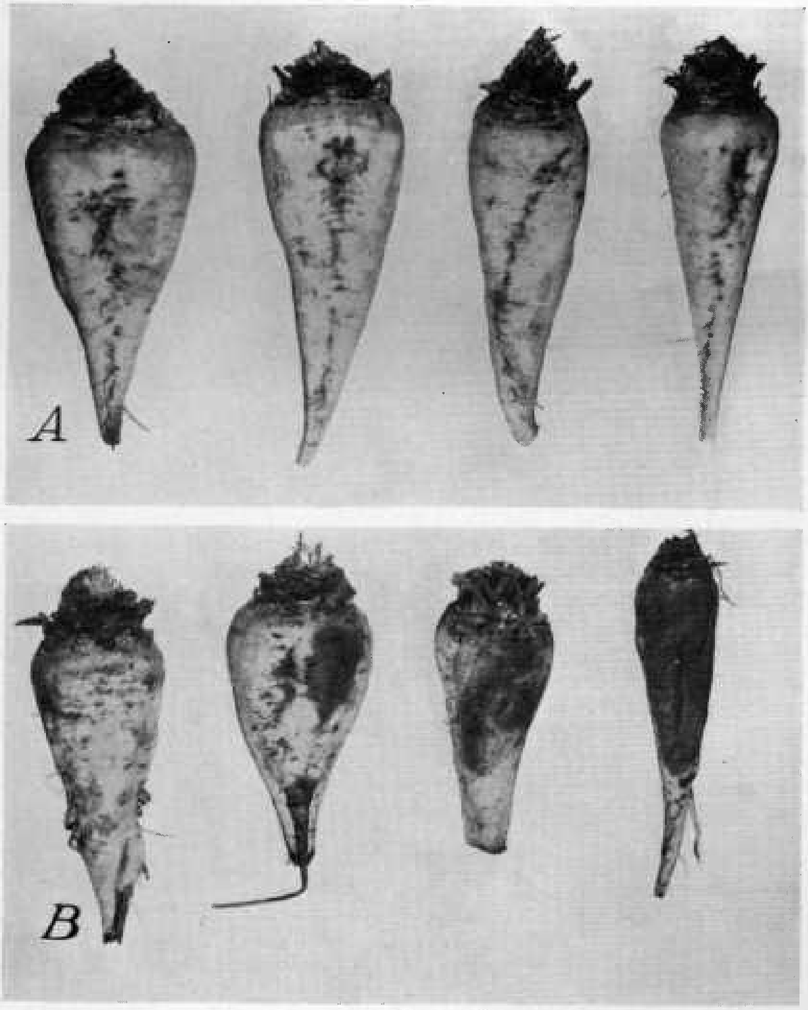

FIGURE 1.—Roots after 45 days' storage in root cellar at Salt Lake City, Utah, in 1933: *A*, Roots from plots well-nourished with respect to phosphorus; *B*, roots from plots deficient in phosphate nutriments.

ROOT CELLAR STORAGE TEST IN 1933 AT SALT LAKE CITY, UTAH

Further evidence of the influence of phosphorus on resistance of root tissues to invasion by organisms was obtained in a test in which beets were stored in a root cellar at Salt Lake City, Utah, for 45 days in 1933 (fig. 1). The soil in which these beets were grown, near Hyde Park, was too deficient in available phosphates to maintain growth without phosphate fertilizer. Beets in treatments designated as relatively high nitrogen were taken from border rows and were characterized by extremely heavy top growth, while those in treatments designated as relatively low nitrogen were taken from adjacent rows. Foliage symptoms of phosphorus deficiency developed during September in beets that received only 150 pounds of superphosphate (46 percent) per acre, as contrasted with a healthy condition of beets that were fertilized with 275 pounds per acre of superphosphate (46 percent). The data on invasion by rot-producing organisms during storage of roots that were grown under these conditions are shown in table 5.

TABLE 5.—*Influence of available phosphorus and nitrogen on resistance of beets to invasion by rot-producing organisms during storage*

[Data taken after 45 days of storage in root cellar at Salt Lake City, Utah, 1933] [1]

Treatment	Beets stored	Beets invaded	
	Number	*Number*	*Percent*
Relatively high nitrogen:			
Superphosphate, 275 pounds	57	[2] 3	5.3
Superphosphate, 150 pounds	74	23	31.1
Relatively low nitrogen:			
Superphosphate, 275 pounds	64	[2] 6	9.4
Superphosphate, 150 pounds	75	24	32.0

[1] The writer is indebted to L. M. Pultz, formerly associate physiologist, Division of Sugar Plant Investigations, for taking the data presented in this table.
[2] Incipient stages of tip invasion.

It is to be noted from these tests that the quantity of phosphate available determined the keeping quality of the beets in storage. Under the fertility conditions in which these beets were grown, 150 pounds per acre of superphosphate was insufficient to maintain optimum growth and to promote good keeping quality of the roots during storage. Applications of 275 pounds per acre of superphosphate (46 percent) materially reduced the incidence of decay, the only evidence of rotting being incipient tip invasion of a few roots. Available nitrates showed little, if any, effect. However, it is evident that relatively high available nitrate during growth of the beets did not show detrimental effect on keeping quality during storage under the conditions of this experiment.

EFFECT OF PHOSPHATE FERTILIZATION ON RESISTANCE OF BEET TISSUES TO INVASION BY PHOMA BETAE

An inoculation test to determine the effect of phosphate fertilization on resistance to invasion by *Phoma betae* was made with sugar-beet roots grown in the Cache Valley of Utah. The field had grown alfalfa for several years, and the soil, of dolomitic origin, was deficient in available phosphates and relatively high in nitrates. The fertilized roots were taken from a plot that had received 150 pounds per acre of 46-percent superphosphate at planting time. An adjacent untreated strip in the field served as a source of unfertilized roots for the inoculation test. When harvested, the fertilized roots ranged in weight from 175 to 325 g each and the unfertilized roots from 50 to 120 g each.

The roots were surface-sterilized with mercury bichloride solution (1 : 1,000), rinsed in sterile distilled water, and dried with sterile gauze. They were then cut uniformly at the base of the lowest leaf scars to expose uniform crown tissues for inoculation and were cut near the basal region of the taproot for the tip inoculations. The organism with the agar substratum was placed on the freshly cut surfaces, each root receiving the same quantity of inoculum. Moistened sterile cotton was placed over the inoculated areas, the roots being wrapped in waxed paper to prevent desiccation. Each treatment consisted of 10 inoculations of individual roots.

Tompkins and Pack (7) have shown that strains of *Phoma betae* differed in rate of advance into beet tissues and also react differently with respect to temperature. In these tests two isolates of *Phoma betae*, both originating from storage rotted beets, were selected on the basis of their rate of growth on artificial media. Isolate no. 63 was a rapid grower, producing a heavy mat of aerial mycelium, while isolate no. 31 grew somewhat slower and was characterized by sparse aerial mycelium. Inoculated roots were stored under two temperature conditions: 4° to 6° C., representing a good temperature for storage; and 18° to 22°, temperatures that are occasionally encountered in storing beets.

Observations on inception of decay were made after 9 days of storage. At that time invasion in roots stored at temperatures of 4° to 6° C. could not be measured, the only evidence of organism invasion being incipient decay in the case of the unfertilized roots. In the roots stored at 18° to 22°, after 9 days the decay had advanced to such an extent that it was possible to determine by measurement the depth of invasion. Similar measurements could not be made in the roots stored at 4° to 6° until 18 days after inoculation. The results in this test, expressed as depths of invasion in millimeters, are given in table 6, as averages for the 10-beet groups.

TABLE 6.—*Specific influence of phosphate fertilizer on resistance of sugar-beet tissues to invasion of Phoma betae under different conditions of storage*

Fertilizer treatment	Isolate no.	Crown-tissue inoculations			Basal root-tissue inoculations		
		Depth invaded [1]		$\frac{D}{S.E._D}$	Depth invaded [1]		$\frac{D}{S.E._D}$
ROOTS STORED 9 DAYS AT 18° TO 22° C.							
		Mm			*Mm*		
Superphosphate	31	6.2±	0.3590		7.1±	0.7520	
None	31	12.2±	1.0924		14.8±	1.1813	
Difference		6.0±	1.1489	[2] 5.22	7.7±	1.4000	[2] 5.50
Superphosphate	63	3.1±	.6227		3.8±	.7860	
None	63	6.6±	.5416		12.3±	.9776	
Difference		3.5±	.8252	[2] 4.24	8.5±	1.2530	[2] 6.78
ROOTS STORED 18 DAYS AT 4° TO 6° C.							
Superphosphate	31	5.0±	0.4956		5.9±	0.5667	
None	31	7.9±	.4819		8.6±	.5416	
Difference		2.9±	.6814	[2] 4.26	2.7±	.7839	[2] 3.44
Superphosphate	63	1.6±	.1633		5.5±	.9690	
None	63	8.2±	.5333		10.5±	.6541	
Difference		6.6±	.5578	[2] 11.83	5.0±	1.1705	[2] 4.27

[1] Average of 10 inoculations.
[2] 2.2 necessary for significance.

It is evident from the results of these inoculation tests that beets that had been well nourished with respect to phosphorus during their growing period were more resistant to invasion by *Phoma betae* than beets that were grown under conditions of a phosphorus deficiency. Statistical analysis of data shows a significant difference in the rate of invasion of the organism under all conditions of storage.

Depths of invasion into crown tissues and root tissues when compared are found to show statistically significant differences in three instances, when isolate no. 63 was used. In the storage test at 4° to 6° C., basal-root tissues of both fertilized and unfertilized roots were invaded to greater depths than were crown tissues. Similar results were obtained with unfertilized roots stored at 18° to 22°, differences with fertilized roots not reaching significance. In the case of the other pathogen used, isolate no. 31, significant differences were not obtained. From this test, however, some basis is given for the conclusion that crown tissues of the beet are more resistant to invasion than basal-root tissues.

DISCUSSION AND CONCLUSIONS

The foregoing investigations furnish evidence that the keeping quality of sugar beets is definitely related to the conditions under which the beets are grown. Nutritional factors and water supply of the growing plant produce effects that carry over when the beet roots are stored.

In general, giving the growing plant enough phosphate to prevent the appearance of marked symptoms of phosphate deficiency, at least early in the season, had not only an influence upon production but also upon the keeping quality of the roots. The effects secured seemed dependent upon the degree to which the phosphorus requirements of the plant were satisfied. The improvement in keeping quality may have been twofold, (1) in decreasing the invasion and decay caused by rot-producing organisms and (2) in reducing the loss of sucrose as a result of the physiological processes accompanying respiration. On the latter phase the data are only suggestive. It seems clearly shown that the incidence of decay caused by organisms was lower in roots which were well-supplied with phosphorus than in phosphorus-deficient roots, and that the tissues were more resistant to the advance of organisms when invasion occurred.

Although in some cases the results indicate that other food materials which were supplied might also have improved keeping quality, these seem secondary to the phosphate effect. Under the fertility conditions at Hyde Park in the 1932 experiment, the decay of the sugar beets, as measured by the percentage of tissue decayed, did not differ significantly in plots receiving superphosphate and those receiving ammonium sulphate (adequate soil-moisture series). If the ammonium sulphate plots receiving manure are compared with those not receiving manure, it is seen that the difference is significant as measured in percentage and in weight of decayed tissue, whereas manure applications did not affect the plots fertilized with superphosphate. From this it seems reasonable to attribute the effects to phosphate relations primarily. Records as to foliage conditions indicate that the nitrogen additions were not large enough to induce a phosphate deficiency in the plants, but rather that they had a favorable influence upon yield. The records from other experiments, such as those in which a complete fertilizer was used and those in which, in 1933, high and low superphosphate applications were used in combination with high and low nitrate treatments, indicate that there was no deleterious effect on resistance of root tissues to decay if phosphorus deficiency was avoided.

The tests with potassium sulphate were too limited to permit any conclusion to be stated except that when used at Hyde Park in 1932 it was not outstanding in its effect on keeping quality.

The effects of partially decomposed manure when used alone or in combination with inorganic fertilizers were pronounced except in the phosphate plots with adequate moisture already mentioned. Beets grown in manured soils were, irrespective of irrigation rates, decidedly superior in keeping quality. As is well known, the effects of manure application come from a combination of factors; it is believed that the effects in this experiment can be attributed to liberating phosphate and to improving water relations.

Another clear-cut response shown in the tests reported, notably the experiment at Hyde Park in 1932, is the influence of adequate water supply for the growing plants on the production of roots capable of keeping well in storage. If the plots without manure applications in this test are considered as a whole, it is seen that in every case, irrespective of treatment, the decay in the sugar beets from the plots receiving an inadequate moisture supply significantly exceeded the decay in beets grown with enough soil moisture. The test at Payson in 1932, in which a high percentage of invasion occurred, gives further evidence in this respect. It seems reasonable to conclude that the other factors influencing growth, such as organic fertilizers and soil moisture, may have operated beneficially because of their indirect effects in making phosphates available.

The results from the inoculation experiment were in complete accord with the results of the field test in that roots grown with an adequate supply of phosphates were markedly more resistant to invasion and decay by *Phoma betae* than undernourished roots.

From these experiments the conclusion is drawn that under the conditions of the experiments, sugar beets that were well nourished, especially with respect to phosphate, and adequately watered, showed less deterioration by decay when stored than did beets grown under less favorable conditions. Some indication was found in the tests where analyses of the stored roots were made that beets fertilized with phosphate showed lower losses from respiration than those not fertilized. The results obtained indicate accessory benefits to be derived from the use of manure and commercial fertilizers in growing sugar beets. Sugar beets from fields in which high yields indicate favorable conditions for growth may be expected to keep best in storage. In normal campaigns of 80 to 100 days, many thousands of tons of sugar beets are accumulated in piles and may remain in storage 40 to 50 days or even longer before being processed. With storage conditions continuing as at present, the relative resistance to deterioration shown by properly nourished roots must have an important bearing on loss reduction.

SUMMARY

Sugar-beet roots grown under conditions of adequate and inadequate phosphate supply were obtained for comparison as to keeping quality from Utah fields known to be deficient in available phosphate.

Roots from plots receiving superphosphate or a complete fertilizer high in phosphate showed less decay than roots from unfertilized plots. In these tests the roots were placed in coarse-meshed net sacks and exposed to conditions of commercial storage piles. There were indications that, aside from reduction of loss by decay, the phosphate fertilization reduced the loss of sucrose reserves due to respiration.

In an experiment in which other factors influencing growth of plants were considered, phosphate fertilization and, to some extent, fertilization with nitrogenous fertilizers improved keeping quality. Adequate moisture during the growing season was found to be favorable. Barnyard manure applied to the plots showed beneficial effects on keeping quality; this was believed to be chiefly because of its content of available phosphate, its indirect action in making soil phosphate available, and its effect on soil moisture.

Inoculations with *Phoma betae* corroborated the conclusion drawn from field tests, since sugar beets grown with an adequate phosphate supply showed significantly less decay than unfertilized roots used as controls.

In making up storage piles at the factory, if care is taken to store sugar-beet roots that have been grown under the conditions found conducive to good keeping quality, losses from decay and, in some measure, respiration losses should be lessened.

LITERATURE CITED

(1) Artschwager, E., and Starrett, R. C.
1933. SUBERIZATION AND WOUND CORK FORMATION IN THE SUGAR BEET AS AFFECTED BY TEMPERATURE AND RELATIVE HUMIDITY. Jour. Agr. Research 47: 669–674, illus.

(2) Fisher, R. A.
1932. STATISTICAL METHODS FOR RESEARCH WORKERS. Ed. 4, rev. and enl., 307 pp., illus. Edinburgh and London.

(3) Pack, D. A.
1926. THE EFFECT OF MOISTURE ON THE LOSS OF SUGAR FROM SUGAR BEETS IN STORAGE. Jour. Agr. Research 32: 1143–1152, illus.

(4) Richards, B. L., and Tompkins, C. M.
1931. THE LATE BLIGHT OF THE SUGAR BEET. Phytopathology 21: 289–314, illus.

(5) Tompkins, C. M., and Nuckols, S. B.
1928. DEVELOPMENT OF STORAGE DISEASES IN SUGAR BEETS RESULTING FROM HOOK INJURY. Phytopathology 18: 939–941, illus.

(6) ——— and Nuckols, S. B.
1930. THE RELATION OF TYPE OF TOPPING TO STORAGE LOSSES IN SUGAR BEETS. Phytopathology 20: 621–635, illus.

(7) ——— and Pack, D. A.
1932. EFFECT OF TEMPERATURE ON RATE OF DECAY OF SUGAR BEETS BY STRAINS OF PHOMA BETAE. Jour. Agr. Research 44: 29–37, illus.