The Effect of Low, Medium and High Nitrogen Fertilizer Rates on the Storage of Sugar Beet Roots at High and Low Temperatures[1]

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In many parts of the country, several outstanding changes in the sugar beet industry have occurred almost simultaneously in the past 20 years: (A) the mechanization of harvest with increased acres of beets per farm; (B) the increase in the yield per acre; (C) the increase in the use of all fertilizers and especially mineral nitrogen fertilizer per acre; (D) the increase in the percentage of beets piled before processing; (E) the lengthening of the processing campaign; and (F) the decrease in the percent recovery of crystallized sugar from the beets. In a good many cases, a trend toward a decrease in the percentage sucrose in the beets at harvest has been suspected. It has frequently been shown that respiration in the roots leads to a decrease in the sugar content during storage, and this increases with a rise in temperature. Thus, the longer the beets are stored, and the higher the temperature during storage, the greater the sugar loss. It has been suspected that in years of low sugar content, large acre yields, and consequent long periods of storage, deterioration in storage was especially severe, and in fact, more than it would have been, had the sugar percentage in the roots been high. In this paper, the storage behavior of sugar beets field-grown with different amounts of nitrogen fertilizer will be described.

Literature Review

No papers were found that related precisely to this problem. Pack (8)[3] has presented abundant data relating to the temperature and moisture conditions necessary to avoid excessive sugar loss, sprouting, and decay in storage. He quotes Stoklasa (Pack, p. 252) as stating "immature beets respire many times faster than mature beets," and emphasizes the consistent and characteristic differences in respiration rate and sugar loss of different individual beets. Stout (10) reviews the effects of soil nitrogen on beet quality, with many pertinent references. Hoff (6) describes a sugar beet quality survey in many northern California

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[3] Numbers in parentheses refer to literature cited.

fields, in which petiole nitrate was generally found to be inversely related to both sucrose and purity. Walker *et al.* (12) describe in detail the compositional changes that occur in the diffusion juice from sugar beets stored at temperatures of about 34° and 55°, and show that, while both sucrose and purity regularly decrease more at the higher temperature, the outstanding change during storage is the increase in invert sugar, which, they suspect, will lead to greater color and lime salts in the thin juice.

Dexter and Frakes (4) describe the losses in % sucrose and clear juice purity in beets with high, medium and low specific gravity, etc., when stored frozen, near freezing, and buried in the company pile, and show improved storage, particularly in the company pile, when beets have higher purity and sucrose content. In an analysis of six consecutive years of company figures relating to total sucrose in beets delivered vs. in beets sliced, Dexter (5) indicates an average loss of 26.5 pounds of sucrose per ton of beets delivered and paid for and 40 pounds per ton of beets stored. Silin (9) p. 31 states that beets to be stored should be sorted and that "defective (unripe, frost-bitten, wilted, mildewy, rotten, hollow) roots should not be mixed with beets intended for long storage," and remarks that (p. 50) "excessive nitrogenous fertilizing retards ripening," especially when combined with late planting. He states, however, that "interfering-nitrogen content does not increase in good storage, but may drop slightly since protein is obviously synthesized from amino acids in the root." He attributes the decrease in purity during storage not only to the decrease in sucrose content, but also to "an increase in invert sugar and soluble pectic substances," and emphasizes that "deteriorated beets should be handled at a lower temperature in the diffusion process." (p. 50) Bush (2) relates yield, % sucrose and thin juice purity to time of harvest and planting.

Methods and Materials

Sugar beets were grown on two fields. In one, fertilizer rates were high (230 lbs N per acre), medium (90 lbs N) and low (30 lbs N). In the second, rates were medium (80 lbs N) and low (0 lbs N). In the second field, a heavy crop of wheat straw had been plowed down the fall before planting and much of it remained unrotted when the field was plowed after harvest. Precautions were taken to grow these beets to avoid all possible variation due to irregularity of stand, etc. Data relating to yields will be presented in detail elsewhere, but approximated 20 tons per acre throughout. The roots harvested from the replicated plots in the five fertilizer treatments were bulked in five piles. They were washed and permitted to dry under cover. From each pile, 10-beet samples were placed in tared mesh bags and weighed. In each case, there were sufficient beets so that both extra large and extra small beets could be discarded, in an attempt to achieve uniformity between samples.

Sufficient samples were prepared so that 4 could be analyzed from each lot to establish the initial sucrose content and clear juice purity. The 5 lots of samples were stored in two walk-in refrigerators, one maintained near 35° F. and the other near 60° F. until December 1, and 50° F, thereafter, in an attempt to simulate temperatures in a storage pile. In each refrigerator, the samples were covered in an attempt to prevent excessive shrinkage. Since experience in previous years had shown this to be difficult, a heavy jute blanket was used, in addition to plastic, and was sprayed with water daily. This precaution proved to be useless and was discontinued, since the moisture froze on the cooling coils, inactivating them. Extra, unbagged beets were added to fill up vacant spaces, and to provide for additional reduction in shrinkage of the bagged samples. While these covering and moisturizing efforts were far from satisfactory, beets with little obvious deterioration, beyond wilting, were available for the duration of the campaign.

At intervals, 3 bag samples of each lot were taken, reweighed and analyzed for sucrose (Sachs-Le Docte) and for clear juice purity. (1) (3) The ratio of the sample weight after storage to the original weight made it possible to convert sucrose analyses to the original sample by simple multiplication, thus permitting a computation of sucrose lost. Clear juices were analyzed further for sodium, potassium (flame photometer) and amino nitrogen (7), and betaine (3).

A more fundamental evaluation of quality was also possible, by means of the formula of The Great Western Sugar Co. (11), which takes into account the differences in clear juice purity as well as those in sucrose in computing bagged sugar per ton.

Results

Table 1 shows the percent sucrose in the beets, corrected to the original weight of the samples by multiplication by the shrinkage factor after storage. Storage from October 22 to January 7 was a period of 77 days.

Analyses taken on February 11 should probably be disallowed (particularly with beets stored warm) since in many of these beets, obvious flecking with black, dead tissue occurred where beets had dehydrated excessively in the almost empty storage boxes. Table 2 shows the clear juice purities for storage of the five lots at the two temperatures. The sample with the 71% clear juice purity was obviously not fit for analysis on this date. Table 3 shows the bagged sugar per ton of original beets, from the five lots on the several days of analysis, according to the formula of The Great Western Sugar Co. (11). Again, the data for February 11 should probably be disallowed, except as they indicate trends.

Trends are perhaps most easily seen by assigning an arbitrary value of 100 to the sucrose, the clear juice purity, and the bagged sugar for the "high"nitrogen treatment in the high, medium and low N series. Both medium and low N beets in

Table 1.—Percent sucrose on original beets,—i.e. corrected for loss of weight.

Field 1 Nitrogen	Oct. 22	Nov. 11	Dec. 3	Jan. 7	Feb. 11
		Cold (about 35°)			
High	15.60	14.76	14.74	14.58	14.33
Medium	16.39	15.23	16.07	15.30	15.17
Low	16.51	16.38	16.28	16.25	15.24
		Warm (about 60-50°)			
High		14.19	14.74	13.01	12.50
Medium		15.52	15.95	14.57	12.66
Low		15.76	15.90	15.14	13.50
Field 2					
		Cold (about 35°)			
Medium	17.68	17.63	18.15	17.01	17.78
Low	17.78	17.69	17.64	17.24	16.73
		Warm (about 60-50°)			
Medium		17.50	16.52	13.69	12.81
Low		16.96	16.42	11.03	12.70

Table 2.—Clear juice purities by Carruthers' method.

Field 1 Nitrogen	Oct. 22	Nov. 11	Dec. 3	Jan. 7	Feb. 11
		Cold (about 35°)			
High	91.06	90.20	92.09	91.24	86.68
Medium	92.58	92.01	93.30	93.13	89.99
Low	93.41	95.23	94.35	94.41	90.38
		Warm (about 60-50°)			
High		89.45	88.74	81.34	80.00
Medium		91.65	91.10	87.63	80.55
Low		93.07	92.10	90.22	83.65
Field 2					
		Cold (about 35°)			
Medium	94.41	96.54	96.20	96.33	93.74
Low	96.05	96.64	97.41	96.75	93.26
		Warm (about 60-50°)			
Medium		94.40	93.20	84.73	73.83
Low		94.75	93.59	71.84	78.51

Table 3.—Pounds of bagged sugar per ton of original beets.

Field 1 Nitrogen	Oct. 22	Nov. 11	Dec. 3	Jan. 7	Feb. 11
		Cold (about 35°)			
High	256	238	248	240	209
Medium	279	255	278	263	242
Low	286	294	288	287	245
		Warm (about 60-50°)			
High		223	228	157	142
Medium		258	262	217	148
Low		271	267	244	178
Field 2					
		Cold (about 35°)			
Medium	313	319	334	313	311
Low	325	326	325	328	290
		Warm (about 60-50°)			
Medium		308	285	187	104
Low		302	285	69	133

lot 2 appeared to be so "low" in nitrogen, that there is little object in comparing them further.

To prepare Figure 1, the values for percentage sucrose, clear juice purity and bagged sugar per ton in Field 1, in Tables 1, 2 and 3 were condensed. On each date, a value of 100 was

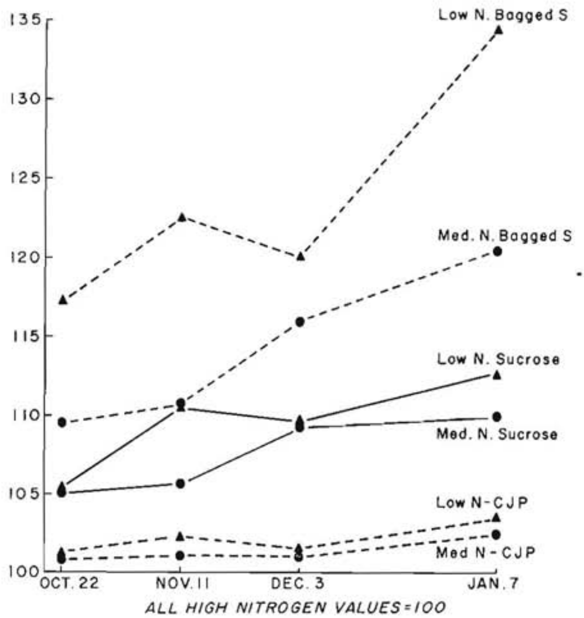

Figure 1.—The effect of rate of nitrogen fertilizer on percent sucrose, purity and bagged sugar per ton of beets in storage.

Table 4.—Milligrams potassium per 100 grams sugar in the clear juice.

Field 1	Mg Potassium / 100 grams sucrose			
Nitrogen	Oct. 22	Nov. 11	Dec. 3	Jan. 7
	Cold (about 35°)			
High	1267	1126	1184	1427
Medium	1135	1161	970	1182
Low	1033	847	1047	1023
Avg	1145	1045	1064	1211
	Warm (about 60-50°)			
High		1432	1229	1425
Medium		1044	956	1181
Low		984	962	1119
Avg	1145	1153	1049	1242
Field 2				
	Cold (about 35°)			
High	678	446	686	576
Low	554	399	494	570
Avg	616	423	590	573
	Warm (about 60-50°)			
High		543	635	893
Low		474	615	995
Avg	616	509	625	944

assigned "high nitrogen" value shown for storage at 35 and 60-50°. The proportionate value for medium- and low-nitrogen beets on each date was computed. In Figure 1, all values for the high-nitrogen beets appear as arbitrarily superimposed horizontal lines at the value of 100. Those for the medium- and low-nitrogen beets start somewhat above 100 and rise somewhat further as the season advances. The upward slope of the curves for the medium- and low-nitrogen beets indicates a slower deterioration in storage of these beets than of the high-nitrogen beets. Similarly, medium-nitrogen beets deteriorated somewhat more in storage than did low-nitrogen beets. A similar and more prominent trend can be shown for cold versus warm storage.

Table 4 shows the potassium content of the clear juice in mg per 100 g of sugar in the clear juice. Potassium was clearly higher in high-nitrogen beets than in medium and low, although the potassium fertilization was the same for all. As the sugar decreased with time of storage, and particularly with storage at a warm temperature, the potassium per 100 g of sugar increased correspondingly. Table 5 shows the ratio of amino-nitrogen to potassium in the clear juice. It has been remarked before that the amino-nitrogen in the clear juice may actually decrease during storage (9). Thus, no breakdown of proteins into compounds with alpha-amino-nitrogen was indicated in this storage experiment, but rather the reverse as indicated by the

Table 5.—The ratio of mg amino-nitrogen to mg potassium in the clear juice.

Field 1	Mg NH_2 nitrogen per 100 g sucrose			
	Mg Potassium per 100 g sucrose			
Nitrogen	Oct. 22	Nov. 11	Dec. 3	Jan. 7
		Cold (about 35°)		
High	.349	.420	.372	.308
Medium	.270	.330	.316	.275
Low	.229	.222	.187	.176
Avg	.283	.327	.292	.253
		Warm (about 60-50°)		
High		.349	.413	.358
Medium		.380	.309	.315
Low		.254	.231	.223
Avg	.283	.328	.315	.299
Field 2				
		Cold (about 35°)		
High	.257	.251	.182	.126
Low	.213	.286	.162	.102
Avg	.235	.269	.172	.114
		Warm (about 60-50°)		
High		.258	.196	.126
Low		.222	.126	.110
Avg	.235	.240	.161	.118

ratio amino-nitrogen/potassium in Table 5. In view of the well recognized and clearly shown increase in impurities as storage proceeded, the nature of the added impurities is of some interest (9, 12).

The milligrams of apparent impurities in the clear juice per 100 grams of sucrose may be simply calculated from the clear juice purity as follows: Suppose a clear juice purity of 90%, or 10 parts by weight of impurities for every 90 of sucrose, i.e., 90 parts of sucrose for each 100 parts of total soluble solids. Stated in milligrams, 10,000 milligrams of impurities per 90 g of sucrose equals 111.11 mg impurities per 1 g of sucrose. And multiplying by 100 gives 11,111 mg impurities per 100 g of sucrose. This is the conventional way of expressing impurities in thin juice in the factory.

Carruthers (3) has suggested that a realistic value for the weight of the impurities associated with potassium, sodium and amino-nitrogen can be calculated by multiplying potassium values by 2.5, sodium by 3.5 and amino-nitrogen by 10, since such multiplication gives the approximate molecular weight of the molecules in which these substances are found in thin juice. By so doing, he has been able to account for something like 75% of the impurities in most thin juices. Table 6 condenses the data by averaging the values for high, medium and low nitrogen beets on the successive storage dates to show the trends, and includes the proportion of the total impurities in the clear juice that was accounted for by the impurities associated with potassium, sodium, amino-nitrogen, as well as the proportion not accounted for. Betaine contents were almost unchanged during the period of storage and are not included.

As the total impurities rise, as in the case of storage at warmer temperatures, the proportion of the impurities accounted for by 2.5 × K decreased very sharply. The same may be said of 3.5 × Na, and 10 × Amino-N and of the sum of the three. In other words, although shrinkage was much the same in storage at either high or low temperatures, the proportion of soluble materials in the clear juice other than those specified was greatly increased and this increase in unaccounted-for soluble substances seems to be closely related to the warmer temperature of storage. Since these materials were not removed by liming, heating and phosphating, one may conclude that they are soluble and undecomposed under those conditions, and since they are not high in potassium, sodium or amino-nitrogen, it is reasonable to suppose that they are decomposition products of the sugar and/or the cell wall constituents. The results of a few trials suggest that they are partly organic acids that give soluble calcium salts.

While Table 6 shows the fractions of total impurities unaccounted for, the general picture may be clearer if expressed

Table 6. — Fractions of total apparent impurities in clear juice accounted for by potassium compounds, sodium compounds, and amino-nitrogen compounds after storage for various periods.

	Compounds of	Oct. 3	Nov. 11	Dec. 3	Jan. 7
Beets	Temperature 35°				
Field 1	Potassium	0.365	0.359	0.397	0.433
(H,M&L)	Amino nitrogen	0.417	0.389	0.446	0.429
	K, Na & amino nitrogen	0.802	0.820	0.862	0.892
	Unaccounted for	0.198	0.180	0.138	0.108
	Temperature 60-50°				
	Potassium	0.365	0.316	0.275	0.227
	Amino nitrogen	0.417	0.408	0.323	0.261
	K, Na & amino nitrogen	0.802	0.745	0.642	0.498
	Unaccounted for	0.198	0.255	0.358	0.502
	Temperature 35°				
Field 2	Potassium	0.330	0.269	0.450	0.434
(M & L)	Amino nitrogen	0.308	0.342	0.306	0.197
	K, Na & amino nitrogen	0.651	0.721	0.767	0.645
	Unaccounted for	0.349	0.279	0.233	0.355
	Temperature 60-50°				
	Potassium	0.330	0.245	0.235	0.136
	Amino nitrogen	0.308	0.234	0.153	0.054
	K, Na & amino nitrogen	0.651	0.547	0.397	0.159
	Unaccounted for	0.349	0.453	0.606	0.841

in milligrams of impurities unaccounted for per 100 g of sucrose. This figure is obtained by subtraction of the sum of the impurity factors (2.5 K + 3.5 Na + 10 NH_2-N) from the total apparent impurities (Table 7).

From the values of impurities unaccounted-for it appears that the actual amounts of such impurities, per 100 g of sugar, actually decreased in the storage of all 5 lots of beets at low temperatures. The tendency is perfectly clear, in even the first 20 days of storage, for the warm beets to increase in unaccounted-for impurities. One might remark that the factories are processing a qualitatively different sort of thin juice from fresh beets and beets stored cold vs. beets stored warm. Table 6 shows that 0.108 of the impurities in the thin juice of beets from Field 1 on January 7 were not accounted for in the case of beets stored cold, while the figure for beets stored warm was 0.502. In Field 2, 0.355 and 0.841 are the proportions for cold and warm storage.

On January 7 the mg of impurities not accounted for was about 10 times as high per 100 g sugar in beets stored warm than in those stored cold in beets of lot 1, and about 20 times as high in those of lot 2 (Table 7). Beets grown with large amounts of nitrogen fertilizer seemed to deteriorate more quickly at warmer temperatures than those with medium or

Table 7.—Total milligrams of apparent impurities per 100 grams of sugar in the clear juice, minus the sum of the impurities associated with potassium, sodium and amino-nitrogen per 100 grams of sugar.

Fertilizer nitrogen	Oct. 22 mg	Nov. 11 mg	Dec. 3 mg	Jan. 7 mg
		35° storage		
Field 1				
High	1447	2517	608	683
Medium	1440	1276	1143	443
Low	1615	661	956	1006
Average	1501	1485	902	711
		60-50° storage		
High	1447	2255	3533	12,005
Medium	1440	2294	3496	6192
Low	1615	1983	3109	4573
Average	1501	2177	3379	7590
Field 2				
		35° storage		
Medium	2082	927	1122	1314
Low	1260	919	397	1045
Average	1671	923	759	1180
		60-50° storage		
Medium	2082	2532	3880	12,837
Low	1260	2326	4020	33,138
Average	1671	2429	3950	22,487

low nitrogen, with the accumulation of soluble impurities of an undetermined nature. The more rapid deterioration of beets from Field 2 may be due to the fact that these beets were considerably smaller and dehydrated more in storage than those of Field 1.

At the completion of the processing campaign, beets that had been stored in the company piles were sorted over, and re-topped to detect and discard beets with rotten regions. These beets were washed, dipped in Captan solution, superficially dried, and weighed into mesh bags as before. Five lots were analyzed on February 16. The mesh bags were placed in canvas bags in refrigerated storage as before, near 35°, and piled with plastic covers, and after a month, placed in steel barrels, plugged with damp jute, in an attempt to provide adequate aeration while preventing excessive shrinkage. Analyses for sucrose, clear juice purity, and potassium, sodium and amino-nitrogen were made on March 25, April 26 and May 24, on 4 replications from cold storage in each case. The purpose of this trial was to see how much longer unshrunken beets, from pile storage, could be stored at a low temperature, and how much deterioration occurred.

On April 26 one beet out of 40 seemed slightly flecked with dead tissue. On May 24, moldy spots appeared on about half of the beets, and the samples could be graded visually as to probable clear juice purity and sugar percent. Deterioration was very clearly under way during these months, with additional impurities showing up in the beets that were not originally accounted for (last column in Table 8). Again, however, these impurities were not apparent in the analysis for amino-nitrogen.

Table 8.—Beets obtained from the company pile in February and stored until May at 30-35°F. Sucrose % and pounds of bagged sugar are calculated to the weight of original beets.

	Sucrose %	C.J.P. %	Bagged sugar lbs/ton	Per 100 gram sucrose in clear juice					
				Mg K	Mg Na	Mg NH_2-N	App. Imp*	Sum**	Diff.***
Feb. 16	14.96	92.15	246	1357	284	308	8519	7467	1052
March 25	15.55	93.38	269	880	156	257	7089	5316	1773
April 26	14.57	91.40	241	1029	207	314	9407	6438	2971
May 24	14.04	89.67	222	1037	177	253	11520	5742	5478

* $\frac{100\text{-C.J.P.} \times 100{,}000}{\text{C.J.P.}}$ = mg apparent impurities per 100 g sucrose.

** 2.5 × mg K + 3.5 × mg Na + 10 × mg NH_2-N per 100 g sugar.

*** Difference between * and **, is mg impurities unaccounted for/100 g sugar.

Discussion and Summary

In this experiment, the use of large amounts of nitrogen in the fertilizer led to lower percentages of sucrose, and particularly, to larger proportions of impurities in the clear juice. Each pound of impurities leads to about 1.5 pounds of sugar lost in the molasses, and it seems, at times, as if the problem could be stated more clearly if the impurities per 100 pounds of sugar were emphasized, arithmetically, rather than the pounds of sugar per 100 pounds of total soluble solids. Thus:

Clear juice purity				Imp. lbs / Sugar lbs
97% means	3 pounds of impurities	/97 pounds of sugar	or	3.09/100
96	4	/96		4.17/100
95	5	/95		5.26/100
94	6	/94		6.38/100
93	7	/93		7.53/100
90	10	/90		11.11/100
87	13	/87		14.94/100
80	20	/80		25.00/100

With harvested and stored beets having 96 to 97% clear juice purity, the sucrose loss in the molasses was relatively slight—perhaps 5 or 6 pounds per 100 pounds of total sugar (i.e., 1.5×3 or 4 lbs imp/100 lbs sugar). When the purity fell to 93%, the loss in the molasses was doubled, and redoubled when it fell to 87% and almost redoubled again in falling to 80%. Thus, the percentage recovery as crystallized sugar varies almost entirely with the clear juice purity, in the manner that is illustrated above, and has little to do with the percent sucrose in the beet, per se. While the percentage sucrose in the factory juices can be varied essentially at will by increased evaporation of water, the proportion of impurities to sugar is practically unaltered. In this experiment, there was a distinct tendency for the clear juice purities to improve slightly during early storage, in the case of originally high purity beets that were stored near the freezing point. Deterioration of higher quality beets was relatively slow during the first 6 or 8 weeks of storage, even at higher temperatures. It is unfortunate that the storage facilities available did not permit avoidance of extreme shrivelling of the beets so that very long storage of high quality beets could have been achieved. On January 7, the low nitrogen beets from Field 2, stored at 60-50° had shrunk to about 53% of their original weight, due to small beets and poor positions in the small storage pile.

With the renewal of the storage, in February, with beets stored since October in the company piles, it was possible, with the one lot of samples, to improve appreciably in avoiding shrivelling in storage. The maintenance of moisture relations such that the live tissues do not wither, and yet do not mold, is not a simple matter. Pack (8) found that beets in piles shrivelled badly in piles at 100% R.H. In our case, however, the beets were stored for about 3½ months in the company pile, followed by 3½ months in the walk-in refrigerator, with a 89.7% clear juice purity at the end of the 7-month period.

The experiment tends to corroborate the often expressed feelings in the industry that "beets don't store as well as they used to." With poorer topping and more crown tissue, this must be expected. (9) With more bruising in mechanical handling, it seems inevitable that storage quality will deteriorate, as it does with every other live plant material. With longer storage, trouble would be expected. And with the physiologically immature and growing beets that sometimes result from too much nitrogen, further complication of the storage problem is not surprising. (9) It is somewhat surprising, however, that merely by lowering the temperature in storage so much of this trouble can be avoided.

It would appear that more cautious and realistic use of nitrogen fertilizer would be notably helpful. From this and other work this year, it is apparent that different fields vary so much in their nitrogen status that blanket recommendations for nitrogen use are not completely reliable (6) when quality is considered. In the case of some fields, their nitrogen supplying ability is so high, without the addition of further nitrogen fertilizer, that it is difficult to grow a beet with good sucrose and clear juice purity percentages (Field 1) while on other fields, with different management (Field 2), the supply of nitrogen may become sufficiently depressed before harvest, that good quality results even with moderately large applications of nitrogen fertilizer. From the appearance of Field 2 in the fall, it was apparent that the beets were not suffering from an excess of nitrogen.

In view of the obvious economic advantages of having a long processing season if the quality of the beets can be reasonably well-maintained, it would seem that a far more critical mental attitude toward the "accounting" for sucrose losses in storage is needed. In a certain factory in Michigan, no beets were piled between 1945 and 1949, and the processing campaign averaged 45 days in length. During the next five years. enough beets were piled on the average to run the factory 15 days. But during the past five years, enough beets were piled, on the average, to run the factory 73 days of each campaign. An accounting attitude toward loss before factory processing that was reasonable in 1945, when no beets were piled, or in 1949 when 12% of the beets were stored, is hardly reasonable now when about 2/3 of the total crop is stored. Storing beets 15 days before winter begins is quite a different matter than storing them 73 days with the last 50 or 60 days in the dead of winter. Under present conditions, a greater interest in the magnitude, the cause and the prevention of storage losses is imperative. A need for larger-scale storage experiments with protected and refrigerated beets of various qualities is indicated.

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