

# THE EFFECT OF MOISTURE ON THE LOSS OF SUGAR FROM SUGAR BEETS IN STORAGE<sup>1</sup>

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## INTRODUCTION

The effect of temperature on the storage of sugar beets has been studied for years, but the effect of moisture on sugar-beet storage has apparently received little attention. The aim of the work reported in this paper was: (1) To obtain more information bearing on the earlier statements of the writer<sup>2</sup> that sugar beets lose less sugar when stored moist than when stored dry; (2) to determine the specific moisture conditions required by sugar beets during storage in order to decrease to a minimum the loss of sugar from them; and (3) to point out the necessity of special and definite moisture control in the storage of living tissues in general.

## METHODS

All these investigations were carried on under constant temperatures. Sugar beets which were healthy and fairly uniform in sugar content were selected for all experiments. The storage periods were long, *i. e.*, about 100 days or more in duration. After storage, all beets which showed signs of decay were discarded before the analysis. The values for sugar are given as sucrose. The order of sampling and weighing the beets was the same as reported earlier by the writer.<sup>3</sup> With this method comparable weights and percentages of sugar were obtained for each beet by analyzing the same individual beets both before and after storage.

## INVESTIGATIONS

In 1921, the writer for the first time found that sugar beets lost more sugar under dry than under moist storage. Early in 1922 this was confirmed by a further test in which five beets were packed in air-dry sand, at each of the following constant temperatures: 1.7°, 4.4°, 9.4°, and 14.4° C.; and similar lots of beets were packed in moist sand at the same temperatures. In general, the beets stored in dry sand lost more sugar than the corresponding lots stored in moist sand at each of the different temperatures.

On April 8, 1922, from 2 to 3 kilograms of beets were stored dry at each of the above-stated constant temperatures and similar check lots were stored moist at the same temperatures. Again the average loss was higher for the beets stored dry, though exceptions appeared at both the highest and lowest temperatures. These exceptions, however, were undoubtedly due to variations in moisture content of the sand.

<sup>1</sup>Received for publication, Oct. 15, 1925; issued, June, 1926.

<sup>2</sup>PACK, D. A. THE STORAGE OF SUGAR BEETS. Facts About Sugar 19: 178-180, 208-209, 232-233, 235, 251-253, illus. 1924.

<sup>3</sup>PACK, D. A. TIME FOR TESTING MOTHER BEETS. Jour. Agr. Research 26: 125-150. 1923.

In an experiment started on November 23, 1923, more constant moisture conditions were obtained by packing some beets in cans with 60 per cent saturated moist sand, and others in air dry sand. The cans contained from 8 to 10 beets each. A set of the moist and a set of the dry packed beets were placed at the constant temperatures of 1.7°, 4.4°, 9.4°, and 14.4° C. The average results showing the sugar lost by the moist and by the dry stored beets at each of the constant temperatures are given in Table I.

TABLE I.—*The effect of moisture as a condition of storage on the loss of sugar by sugar beets*

Temperature	Moisture conditions	Sugar content of beets at beginning of storage	Sugar lost	Sugar lost	Temperature	Moisture conditions	Sugar content of beets at beginning of storage	Sugar lost	Sugar lost
° C.		Grams	Grams	Per cent	° C.		Grams	Grams	Per cent
1.7	Moist.....	192	22	11.5	9.4	Moist.....	199	35	17.6
1.7	Dry.....	190	32	16.9	9.4	Dry.....	208	75	36.1
4.4	Moist.....	174	26	14.9	414.4	Moist.....	186	30	16.1
4.4	Dry.....	204	51	25.0	414.4	Dry.....	231	87	37.6

The analyses show consistently that the beets stored in moist sand lost less sugar under each of the constant temperatures than those stored dry.

On November 17, 1922, 64 beets were packed in sand, the moisture content of which was such that its surface tension was in equilibrium with an osmotic pressure of 6.0 atmospheres pressure at 4.4° C., and these beets were designated the moist lot. At this date 80 similar beets were packed in dryer sand, the surface tension of which was in equilibrium with an osmotic pressure of 10.0 atmospheres pressure at 4.4° C., and these beets were designated the dry lot. After 110 days' storage, it was found that the moist lot had lost 12.9 per cent of its sugar content, and the dry lot 16.5 per cent. Thus, over a prolonged period, only a slight increase in the moisture content of the packing medium resulted in a saving of 22 per cent more sugar.

On November 17, 1923, 5 lots of 50 beets each were placed in storage for 103 days under definite moisture conditions at the constant temperature of 4.4° C. Not only were the beets weighed and analyzed individually, both before and after storage, but the surface tension and the per cent of water in the sand were determined for each moisture condition. The detailed figures for these lots, 1, 2, 3, 4, and 5, are given in Tables II, III, IV, V, and VI, respectively. A summary of the results is given in Table VII. Table VIII gives these results reduced to the terms ordinarily used by the beet-sugar industries of Europe and America. These data show definitely that the percentage of sugar lost by beets during storage increases as the dryness of the storage condition increases.

TABLE II.—Data on beets of lot 1 before and after storage at 4.4° C., and air of 3.76 mm. vapor pressure

Tag No. of beet	Before storage			After storage				
	Weight of beet	Sugar as sucrose	Sugar content	Weight of beet	Sugar as sucrose	Sugar content	Loss or gain in weight	Sugar lost
	<i>Grams</i>	<i>Per cent</i>	<i>Grams</i>	<i>Grams</i>	<i>Per cent</i>	<i>Grams</i>	<i>Grams</i>	<i>Grams</i>
2007	975	18.2	177	700	21.4	150	-275	27
2091	1,280	18.2	233	830	22.6	187	-450	46
2094	1,020	18.2	186	515	27.6	142	-505	44
2102	905	18.4	167	460	30.6	141	-445	26
2119	975	18.4	179	680	23.6	160	-295	19
2120	850	19.6	167	450	29.0	130	-400	37
2135	795	19.2	153	361	26.0	94	-434	59
2162	1,005	18.6	187	650	24.8	161	-355	26
2163	980	18.8	184	507	27.8	141	-473	43
2168	1,110	18.4	204	575	31.0	178	-535	26
2169	1,290	18.0	232	650	31.0	201	-640	31
2200	970	17.6	171	540	22.0	119	-430	52
2209	1,050	17.6	185	730	16.0	117	-320	68
2225	830	19.4	161	520	28.2	147	-310	14
2266	980	18.4	180	680	22.6	154	-300	26
2268	1,340	17.8	238	1,040	19.8	206	-300	32
2277	915	17.8	163	495	19.6	97	-420	66
2284	1,170	18.2	213	750	13.8	103	-420	110
2287	1,415	18.4	260	960	20.6	197	-455	63
2318	1,000	18.2	182	530	29.0	154	-470	28
2329	845	19.0	160	500	28.0	140	-345	20
2354	1,180	18.0	212	840	22.4	188	-340	24
2355	925	17.8	165	430	29.2	125	-405	40
2359	1,435	17.8	255	852	24.6	209	-583	46
2363	1,430	18.2	260	725	31.0	225	-705	35
2367	815	19.4	158	400	31.8	127	-415	31
2371	1,350	17.8	240	575	29.8	171	-775	69
2373	1,090	18.4	200	475	33.4	159	-615	41
2393	915	18.8	172	500	25.6	128	-415	44
2395	810	19.4	157	465	20.2	94	-345	63
2400	1,025	18.0	184	450	30.4	137	-575	47
2403	1,070	18.0	193	490	33.4	164	-580	29
2408	1,550	17.4	270	825	28.0	231	-725	39
2411	1,625	17.0	276	1,000	21.4	214	-625	62
2412	1,680	17.2	289	900	21.2	191	-780	98
2414	1,135	18.0	204	465	34.8	162	-670	42
2415	1,220	18.0	220	890	21.0	187	-330	33
2416	1,230	17.4	214	680	24.2	165	-550	49
2417	835	19.2	160	450	27.6	124	-385	36
2426	1,350	17.4	235	750	25.4	190	-600	45
2432	955	18.0	172	460	33.6	154	-495	18
2434	910	18.4	167	650	23.0	149	-260	18
2439	1,000	18.4	184	670	24.0	161	-330	23
2456	1,015	18.8	191	690	21.8	150	-325	41
2598	725	18.6	135	450	26.8	120	-275	15
2599	1,455	17.6	256	715	29.0	207	-740	49
2606	1,605	17.2	276	870	23.6	205	-735	71
2610	1,125	18.2	205	760	23.6	179	-365	26
2636	895	17.6	158	420	32.0	134	-475	24
2639	1,080	17.6	190	645	25.0	161	-435	29

TABLE III.—Data on beets of lot 2 before and after storage at 4.4° C., and a moisture condition which was in equilibrium with 132 atmospheres osmotic pressure

Tag No. of beet	Before storage			After storage				
	Weight of beet	Sugar as sucrose	Sugar content	Weight of beet	Sugar as sucrose	Sugar content	Loss or gain in weight	Sugar lost
	Grams	Per cent	Grams	Grams	Per cent	Grams	Grams	Grams
276.....	1,305	17.6	230	1,250	16.6	208	-55	22
432.....	1,710	18.0	308	1,650	17.0	281	-60	27
437.....	1,335	18.4	245	1,285	17.0	219	-50	26
468.....	1,620	17.6	285	1,460	17.5	256	-160	29
488.....	1,060	18.6	197	835	17.6	147	-225	50
508.....	1,640	17.6	289	1,500	14.5	218	-140	71
509.....	1,125	17.8	200	1,075	17.4	187	-50	13
512.....	1,190	18.0	214	1,080	13.8	149	-110	65
587.....	1,170	17.8	208	1,110	17.0	189	-60	19
588.....	1,770	18.2	322	1,675	15.2	255	-95	67
611.....	1,470	17.6	259	1,370	16.7	229	-100	30
617.....	1,360	18.0	245	1,260	16.8	211	-100	34
627.....	1,470	17.6	259	1,340	16.5	221	-130	38
698.....	1,370	18.4	252	1,210	18.4	223	-160	29
711.....	1,730	17.6	304	1,550	17.6	273	-180	31
717.....	1,380	18.0	248	1,330	18.0	239	-50	9
743.....	1,330	17.8	237	1,290	16.0	206	-40	31
745.....	1,540	17.8	274	1,430	15.6	223	-110	51
781.....	1,220	18.0	220	1,090	18.0	196	-130	24
786.....	1,390	18.0	250	1,300	17.8	231	-90	19
787.....	1,625	17.8	289	1,525	16.7	255	-100	34
790.....	1,160	17.8	206	1,050	17.6	185	-110	21
797.....	2,130	17.8	380	1,970	18.5	364	-160	16
814.....	1,100	17.6	193	1,012	16.4	166	-88	27
844.....	1,415	17.6	249	1,270	13.6	173	-145	76
873.....	1,400	17.6	247	1,252	19.0	238	-148	9
874.....	1,240	18.2	226	1,150	16.8	193	-90	33
877.....	1,830	18.2	333	1,745	17.8	311	-85	22
1069.....	1,320	18.2	240	1,125	18.9	213	-195	27
1159.....	1,700	17.6	299	1,620	15.8	256	-80	43
1183.....	1,350	17.6	237	1,280	17.2	220	-70	17
1185.....	1,160	17.6	204	1,090	18.0	196	-70	8
1190.....	1,380	17.8	246	1,240	17.6	218	-140	28
1210.....	1,450	18.0	261	1,375	15.2	209	-75	52
1275.....	1,390	18.2	253	1,345	16.4	221	-45	32
1287.....	1,620	18.0	292	1,550	18.0	279	-70	13
1292.....	1,730	17.6	305	1,625	17.6	286	-105	19
1300.....	1,520	18.0	274	1,360	15.8	215	-160	59
1358.....	1,130	18.0	203	1,050	15.7	165	-80	38
1316.....	1,100	18.0	198	1,050	17.2	181	-50	17
1340.....	1,320	18.0	237	1,100	12.2	134	-220	103
1365.....	1,125	18.4	207	1,025	17.9	183	-100	24
1429.....	1,875	17.0	319	1,715	14.6	250	-160	69
1433.....	1,360	17.4	237	1,240	17.2	214	-120	23
1437.....	1,550	17.8	276	1,450	17.6	255	-100	21
1439.....	1,240	17.6	218	1,150	18.0	207	-90	11
1443.....	1,425	18.0	257	1,380	17.4	240	-45	17
1444.....	1,360	17.8	242	1,275	18.1	230	-85	12
1446.....	1,350	17.8	241	1,275	18.0	229	-75	12
1451.....	1,620	17.6	285	1,455	17.4	253	-165	32

TABLE IV.—Data on beets of lot 3 before and after storage at 4.4° C., and a moisture condition in equilibrium with 35.7 atmospheres osmotic pressure

Tag No. of beet	Before storage			After storage				
	Weight of beet	Sugar as sucrose	Sugar content	Weight of beet	Sugar as sucrose	Sugar content	Loss or gain in weight	Sugar lost
	Grams	Per cent	Grams	Grams	Per cent	Grams	Grams	Grams
47.....	1,250	17.6	220	1,185	16.8	199	-65	21
242.....	1,630	17.8	290	1,550	16.2	251	-80	39
325.....	1,440	18.4	265	1,420	16.8	239	-20	26
374.....	1,155	17.6	203	1,125	16.9	190	-30	13
445.....	1,270	18.2	231	1,220	17.6	215	-50	16
449.....	1,370	18.0	247	1,310	16.6	217	-60	30
450.....	1,250	18.2	227	1,220	17.4	212	-30	15
442.....	1,680	17.6	295	1,580	16.0	253	-100	42
472.....	1,920	17.8	342	1,780	16.6	295	-140	47
476.....	1,725	18.4	317	1,640	16.4	269	-85	48
517.....	1,340	18.2	244	1,320	16.0	211	-20	33
555.....	1,580	18.4	293	1,550	17.0	264	-30	29
535.....	1,540	17.8	274	1,400	16.6	232	-140	42
566.....	1,075	18.4	198	1,050	17.5	184	-25	14
578.....	1,490	18.0	268	1,450	16.6	241	-40	27
582.....	1,500	18.0	270	1,475	17.6	261	-25	9
598.....	1,680	18.0	302	1,600	17.4	278	-80	24
626.....	1,220	17.8	217	1,100	15.4	169	-120	48
639.....	1,275	17.8	227	1,215	16.4	199	-60	28
647.....	1,690	17.6	297	1,600	16.8	269	-90	28
653.....	1,770	18.2	322	1,700	17.4	295	-70	27
685.....	1,375	18.0	247	1,230	15.6	192	-145	55
691.....	1,080	18.0	194	1,030	18.0	185	-50	9
727.....	1,220	18.4	225	1,140	17.2	196	-80	29
864.....	1,830	18.2	333	1,825	16.2	296	-5	37
878.....	1,430	18.0	257	1,366	16.3	222	-64	35
1052.....	1,430	17.8	254	1,380	17.0	235	-50	19
1108.....	1,060	18.2	193	1,050	18.0	189	-10	4
1146.....	1,550	17.8	276	1,525	16.0	244	-25	32
1154.....	1,350	18.4	249	1,280	12.8	164	-70	85
1207.....	1,230	17.6	217	1,090	16.2	177	-140	40
1211.....	1,200	17.6	211	1,080	15.4	166	-120	45
1216.....	1,160	17.8	206	1,160	16.2	188	0	18
1226.....	1,250	18.4	230	1,240	16.4	203	-10	27
1228.....	1,290	17.8	229	1,250	16.6	208	-40	21
1223.....	1,420	17.8	253	1,454	17.0	247	+34	6
1231.....	1,200	18.4	221	1,250	15.2	190	+50	31
1239.....	1,900	17.6	335	1,800	17.6	317	-100	18
1245.....	1,500	18.0	270	1,555	16.0	249	+55	21
1253.....	1,260	17.8	224	1,170	12.6	147	-90	77
1257.....	1,070	18.4	197	1,145	17.2	197	+75	0
1270.....	1,220	18.2	222	1,300	14.6	190	+80	32
1271.....	1,350	18.0	243	1,330	16.4	218	-20	25
1276.....	1,590	18.0	286	1,550	17.0	266	-40	22
1293.....	1,375	18.2	250	1,340	16.6	222	-35	28
1308.....	1,500	18.2	273	1,465	17.0	249	-35	24
1311.....	1,670	17.4	291	1,775	14.8	262	+105	29
1312.....	1,210	18.2	220	1,175	17.2	202	-35	18
1313.....	1,180	18.4	217	1,250	15.4	193	+70	25
1326.....	1,225	17.8	218	1,235	16.7	206	+10	12

TABLE V.—Data on beets of lot 4 before and after storage at 4.4° C., and a moisture condition in equilibrium with 7.6 atmospheres osmotic pressure

Tag No. of beet	Before storage			After storage				
	Weight of beet	Sugar as sucrose	Sugar content	Weight of beet	Sugar as sucrose	Sugar content	Loss or gain in weight	Sugar lost
	Grams	Per cent	Grams	Grams	Per cent	Grams	Grams	Grams
230	1,275	18.2	232	1,280	17.0	218	+5	14
260	1,170	18.2	212	1,210	15.2	184	+40	28
355	1,215	18.4	223	1,175	17.6	208	-40	15
448	1,160	18.8	218	1,180	16.6	193	0	25
478	1,970	18.2	359	2,050	15.0	308	+80	51
484	1,480	17.6	260	1,555	16.4	255	+75	5
496	1,250	17.8	223	1,320	15.6	206	+70	17
504	1,490	17.6	262	1,520	16.6	252	+30	10
510	1,200	17.8	214	1,300	15.4	200	+100	14
554	1,575	17.6	277	1,440	16.0	230	-135	47
563	1,540	18.4	283	1,500	17.6	264	-40	19
564	1,330	17.6	234	1,315	15.5	204	-15	30
575	1,430	17.8	254	1,500	14.0	210	+70	44
616	1,375	18.0	247	1,460	15.2	222	+85	25
619	1,160	18.4	213	1,230	15.6	192	+70	21
620	1,340	18.0	241	1,375	16.4	225	+35	16
641	1,410	18.0	253	1,450	16.1	233	+40	20
651	1,870	18.0	337	1,900	16.6	315	+30	22
657	1,125	18.2	205	1,150	15.4	177	+25	28
678	1,225	18.0	220	1,220	16.0	195	-5	25
700	1,860	18.2	339	1,750	16.2	284	-110	55
701	1,570	17.6	276	1,550	15.8	245	-20	31
784	1,175	18.4	216	1,160	18.0	209	-15	7
839	1,440	17.8	256	1,475	15.8	233	+35	23
859	1,320	17.6	232	1,325	16.0	212	+5	20
879	1,330	17.8	237	1,375	16.8	231	+45	6
899	1,250	17.6	220	1,230	16.6	204	-20	16
947	1,300	17.6	229	1,315	15.5	204	+15	25
985	1,700	17.8	303	1,735	16.5	286	+35	17
986	1,430	17.6	252	1,360	17.2	234	-70	18
1014	1,520	17.6	267	1,550	15.9	247	+30	20
1017	1,620	18.0	292	1,650	16.3	269	+30	23
1033	1,380	18.2	251	1,400	16.9	237	+20	14
1044	1,075	17.6	189	1,120	15.2	170	+45	19
1048	1,770	17.6	311	1,830	16.0	293	+60	18
1058	1,370	18.2	249	1,350	16.8	227	-20	22
1061	1,390	18.4	256	1,470	16.2	238	+80	18
1063	1,960	17.8	349	1,990	16.0	318	+30	31
1065	1,600	17.6	282	1,660	15.2	252	+60	30
1092	1,580	18.0	285	1,630	16.0	261	+50	24
1107	1,430	18.0	257	1,440	16.6	239	+10	18
1110	1,790	17.8	319	1,825	16.6	303	+35	16
1112	1,400	17.8	249	1,420	15.6	222	+20	27
1122	1,380	17.6	243	1,425	15.6	222	+45	21
1128	1,530	18.2	279	1,630	16.0	261	+100	18
1166	1,150	19.2	221	1,210	16.0	194	+60	27
1277	1,250	18.2	227	1,340	16.5	221	+90	6
1302	1,500	18.4	273	1,550	17.4	270	+50	3

TABLE VI.—Data on beets of lot 5 before and after storage at 4.4° C., and a moisture condition in equilibrium with 4.4 atmospheres osmotic pressure

Tag No. of beet	Before storage			After storage				
	Weight of beet	Sugar as sucrose	Sugar content	Weight of beet	Sugar as sucrose	Sugar content	Loss or gain in weight	Sugar lost
	Grams	Per cent	Grams	Grams	Per cent	Grams	Grams	Grams
2008	870	19.2	167	906	16.0	145	+36	22
2010	1,140	17.6	201	1,216	14.4	175	+76	26
2021	840	19.0	159	941	15.6	147	+101	12
1026	800	18.8	150	891	15.6	139	+91	11
2058	1,040	18.0	187	1,206	13.4	162	+166	25
2074	840	19.4	163	928	16.0	148	+86	15
2088	925	18.6	172	1,028	15.4	158	+101	14
2098	1,060	18.0	191	1,131	15.4	174	+71	17
2136	865	19.2	166	956	14.6	140	+91	26
2139	840	19.4	163	941	16.8	158	+101	5
2166	1,335	17.8	238	1,441	14.2	205	+106	33
2178	975	17.6	172	1,111	14.2	158	+136	14
2181	890	19.0	169	951	16.6	158	+61	11
2188	1,110	17.8	198	1,176	15.8	186	+66	12
2193	1,050	18.2	191	1,091	15.4	168	+41	23
2211	780	19.2	150	856	17.0	146	+76	4
2220	930	18.8	175	1,041	15.0	156	+111	19
2248	1,160	17.8	206	1,201	15.0	180	+41	26
2267	860	19.2	165	921	15.2	140	+61	25
2295	870	19.4	169	956	15.8	151	+86	18
2321	895	18.6	166	951	14.6	139	+56	27
2341	1,070	18.0	193	1,146	14.4	165	+76	28
2346	1,080	18.0	194	1,201	15.2	183	+121	11
2350	1,025	18.0	185	1,096	15.2	167	+71	18
2351	860	17.6	151	921	15.0	138	+61	13
2398	915	18.0	165	1,136	13.0	148	+221	17
2401	1,050	18.2	191	1,126	15.2	171	+76	20
2404	560	19.0	106	626	15.4	96	+66	10
2410	1,375	17.6	242	1,416	15.8	224	+41	18
2435	1,060	18.0	191	1,166	16.0	187	+106	4
2436	1,165	17.6	205	1,261	13.8	174	+96	31
2437	800	18.8	150	861	16.4	141	+61	9
2449	830	19.4	161	951	15.6	148	+121	13
2512	1,000	17.8	178	1,116	13.2	147	+116	31
2514	1,080	18.4	199	1,241	15.2	189	+161	10
2515	1,100	18.4	202	1,166	14.8	173	+66	29
2519	1,050	17.4	183	1,261	14.2	179	+211	4
2522	860	18.8	162	946	13.8	131	+86	31
2523	1,560	17.2	268	1,731	14.8	256	+171	12
2525	785	18.6	146	841	12.2	103	+56	43
2529	1,160	18.0	209	1,351	14.0	189	+191	20
2533	1,290	17.0	219	1,501	13.8	207	+211	12
2534	910	18.4	167	1,046	14.4	151	+136	16
2535	1,195	18.2	218	1,261	15.0	189	+66	29
2536	1,165	18.0	209	1,251	14.8	185	+86	24
2544	950	18.2	173	1,101	15.2	167	+151	6
2594	900	17.8	160	951	15.8	150	+51	10
2613	1,400	17.4	244	1,426	14.6	208	+26	36
2617	960	17.6	169	978	15.6	152	+16	17
2632	1,015	17.4	177	1,112	13.6	151	+97	26

TABLE VII.—Per cent loss of sugar accompanying loss or gain in weight of sugar beets during storage, as effected by various moisture conditions of storage

Condition of storage	Osmotic pressure <sup>a</sup>	Water in storage air and sand	Before storage		After storage		Average loss or gain in weight	Average loss or gain in weight	Average sugar lost	Average loss of sugar
			Average weight of beet	Average sugar content	Average weight of beet	Average sugar content				
Very dry	Atmosphere <sup>(b)</sup>	Per cent	Grams	Grams	Grams	Grams	Grams	Per cent	Grams	Per cent
Dry	132.0	0.36	1,103	200	632	159	-471	-42.7	41	20.5
Medium	35.7	1.20	1,423	254	1,317	222	-106	-7.4	32	12.6
Moist	7.6	1.64	1,400	252	1,359	223	-41	-2.9	29	11.5
Very moist	4.4	4.87	1,430	257	1,456	235	+26	+1.8	22	8.6
		8.87	1,005	183	1,100	164	+95	+9.5	19	10.4

<sup>a</sup> Osmotic pressure in atmospheres which was found to be at equilibrium with the surface tension of the water in the sand.

<sup>b</sup> This value would probably correspond to several hundred atmospheres.

<sup>c</sup> Per cent of moisture in air.

TABLE VIII.—Relative amounts of sugar lost by beets accompanying the loss or gain in weight of sugar beets during 103 days' storage at 4.4° C. and under various moisture conditions

[The results are calculated from Tables II, III, IV, V, VI, and VII]

Before storage		After storage					
Weight of beets	Weight of sugar in beets	Condition of storage	Loss or gain in weight of beets during storage	Sugar lost during 103 days' storage	Sugar lost per 100 kg. of beets	Sugar lost per 100 kg. of beets per day	Sugar lost per ton of beets per day
Kilogram	Kilogram		Per cent	Kilogram	Kilogram	Kilogram	Pounds
55.135.....	9.980	Very dry....	-42.7	2.050	3.7181	0.0361	0.722
71.160.....	12.700	Dry.....	-7.4	1.600	2.2484	.0218	.436
69.975.....	12.590	Medium.....	-2.9	1.430	2.0436	.0198	.396
68.660.....	12.326	Moist.....	+1.8	1.049	1.5277	.0148	.296
50.245.....	9.135	Very moist..	+9.5	.933	1.8569	.0180	.360

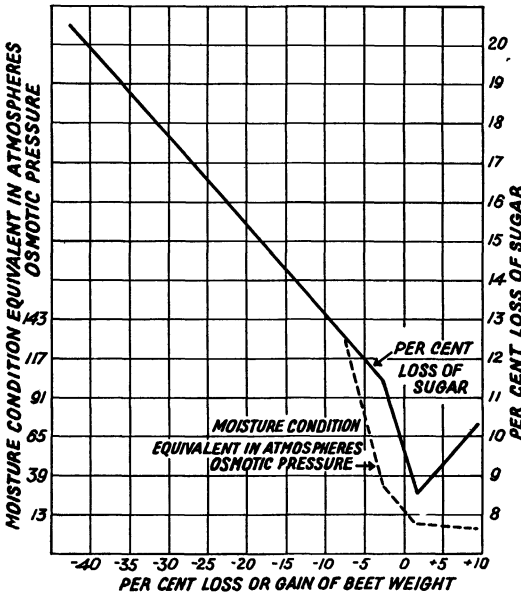


FIG. 1.—Graphs showing the relation between the per cent gain or loss in weight of sugar beets, and the per cent loss of sugar from them, during storage

Figure 1 shows the relation between the per cent gain or loss of weight of beets and the per cent loss of sugar during storage. These values (taken from Table VII) indicate that the smallest loss occurs when the beets retain their normal amount of water. The normal water content was maintained by keeping the moisture in the packing material equivalent to, or a little higher than that of normal beet tissues.

The values for the mean and standard deviation of per cent loss of sugar, the per cent loss or gain in weight of the beets in lots 1, 2, 3, 4, and 5, and the differences for lots 1 and 4, are given in Table IX. These data were calculated from the per cent loss or gain for each



beet. The results show, as was earlier reported by the writer<sup>4</sup> that individual beets are irregular as to the per cent loss of sugar and the per cent change in weight during storage. These irregularities are due to individual characteristics of the beets and their condition at the time of storing. Some of the causes of these irregularities in weight were earlier reported by the writer.<sup>5</sup> The differences between the amount of sugar lost and the changes in weight of the beets of lots 1 and 4 are significant and of value to the industry.

TABLE IX.—The mean and standard deviation values for the per cent loss of sugar and the per cent loss or gain in weight of the five lots of beets given in Tables II, III, IV, V, and VI

Lot No.	Per cent loss of sugar by beets		Per cent loss or gain in weight of beets	
	M	$\sigma$	M	$\sigma$
1	20.48±0.87	9.16±0.62	-42.94±0.87	9.14±0.62
2	12.82±.75	7.83±.53	-7.58±.34	3.54±.24
3	11.28±.62	6.54±.44	-2.82±.35	3.67±.25
4	8.56±.35	3.63±.25	+1.83±.33	3.40±.23
5	10.58±.60	6.29±.42	+9.68±.43	4.54±.30
Difference, 1-4	11.92±.94		44.77±.93	

To determine the limit of the beneficial effect of increased moisture during storage, beets were submerged in water at 4.4° C. for 164 days. These beets lost an average of 55 per cent of their sugar. Some fermentation had started before the end of this period. The excessive loss of sugar in this case apparently was due to lack of aeration rather than to the increased supply of water. This was substantiated in further tests in which the sugar beets were abundantly supplied with free water, but were well aerated. Here the loss in sugar was appreciably less.

To determine the applicability of these results to commercial practice, several hundred pounds of beets were stored 43 days, during the fall of 1924, in bins corresponding to sections of commercial sugar-beet piles. The beets of one bin were stored just as in the ordinary storage pile. Those of a second bin were similarly stored, except that they were kept moist. As reported in an earlier publication,<sup>6</sup> the beets as ordinarily stored lost 75 per cent more sugar than did the beets which were kept moist.

## DISCUSSION

In the commercial storage of beets, the sugar losses and chemical changes resulting from the physiological processes of the living and healthy stored beets receive attention. It should be clearly understood that the storage of rotten, diseased, or dead beets is not under consideration here, and furthermore the ordinary methods of food preservation by means of heat, chemicals, sugar in high concentrations, drying, or freezing are not effective. In this connection it should be remembered that when sugar beets are killed by chemicals, heat, or freezing the loss of sugar and decomposition processes

<sup>4</sup> PACK, D. A. TIME FOR TESTING MOTHER BEETS. Jour. Agr. Research 26: 125-150. 1923.

<sup>5</sup> PACK, D. A. THE STORAGE OF MOTHER BEETS. Facts About Sugar 20: 874-875. 1925.

<sup>6</sup> PACK, D. A. STORAGE OF COMMERCIAL BEETS. Through the Leaves 13: 157-159, 206-207, 272-274, illus. 1925.

proceed rapidly, unless careful protection is afforded. To carry these treatments to a point where they would stop all biological and catalytic action on so large an amount of material, even if otherwise practicable, would be too costly. Under such difficulties, sugar beets must be kept alive in storage.

The results of the present investigation show that in order to conserve the maximum amount of sugar, the conditions of storage must be so controlled that the water content of the beet is kept normal. On the other hand, the beet seems to be under optimum conditions for growth and respiration, when it contains its normal amount of water. These processes, of course, tend to consume the reserve sugar of the beet, but the difficulty is overcome by subjecting the beet of normal water content to a low temperature. The writer<sup>7</sup> has found that 1.7° C. would inhibit growth and reduce to a minimum the respiration of normal sugar beets; thus the life processes which use up the reserve sugar are inhibited or slowed up. The writer has kept sugar beets healthy and at a high sugar content for 18 months under these conditions. Even though reserve food is slowly used up by these retarded physiological processes, the loss is near the minimum, and in the development of the dormant habit in nature an economical storage method, at least for living tissues, has been evolved. It is interesting to note that in order to reduce to a minimum the sugar lost by beets during storage, the tissues must not only be kept alive, but they must be kept as dormant as possible.

#### SUMMARY

These investigations indicate the importance of moisture in the storage of sugar beets, and show that moist-stored sugar beets lose less sugar than similar sugar beets stored dry.

The loss of sugar by sugar beets increases as the degree of dryness of the storage conditions increases; thus dry storage accelerates while moist storage retards this loss of sugar.

The specific moisture conditions required by sugar beets during storage, in order to reduce to a minimum their loss of sugar, is a moisture condition which is in equilibrium with the water content of the beet tissues. This moisture condition is equivalent to about 12 atmospheres osmotic pressure.

The sugar losses of commercial sugar beets, under practical conditions of storage, were decreased from 40 to 50 per cent by moist storage.

Sugar beets should be kept alive in storage. The best results are obtained when the tissues of these living beets have normal water content, are healthy, properly aerated, and dormant. Dormancy under such conditions may be brought about by low temperatures.

<sup>7</sup> PACK, D. A. THE STORAGE OF SUGAR BEETS. *Facts About Sugar* 19: 178-180, 208-209, 232-233, 235, 251-253, illus. 1924.