NITROGEN—ITS EFFECT ON TRANSIT TEMPERATURES and MARKET QUALITY OF WESTERN LETTUCE SHIPPED in PIGGYBACK TRAILERS

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SUMMARY

Market quality of lettuce and transit temperatures in shipments made in piggyback trailers refrigerated with liquid nitrogen and in trailers equipped with both liquid nitrogen and mechanical refrigeration units were compared with those in shipments in conventional, mechanically refrigerated piggyback trailers. The lettuce was shipped from California to midwestern or east coast markets.

Trailers in which liquid nitrogen was the only source of refrigeration had excessive temperature variation within the load and average load temperatures were often too high, especially during the latter part of the trip. Decay was significantly higher in these trailers than in the conventional, mechanically refrigerated trailers, because of the high temperature. Incidence of russet spotting was significantly lower in these trailers than in the conventional trailers; this was the result of the low-oxygen atmospheres produced in the trailers refrigerated with liquid nitrogen.

Trailers equipped with both liquid nitrogen and mechanical refrigeration units had temperatures similar to those in conventional, mechanically refrigerated trailers. Decay was essentially the same in lettuce from both types of trailers. Incidence of russet spotting was significantly less in lettuce shipped in the mechanically refrigerated trailers supplemented with liquid nitrogen than in that shipped in conventional trailers with normal atmospheres.

INTRODUCTION

Trailers refrigerated with liquid nitrogen and trailers with both mechanical refrigeration and liquid nitrogen for atmosphere modification have been available to lettuce shippers since about 1964. Few critical studies have been made on transit temperatures in such equipment or on the effects of resulting low-oxygen atmospheres on produce quality. The U.S. Department of Agriculture, in cooperation with lettuce shippers, carriers, and suppliers of trailers equipped with liquid nitrogen systems, made tests in 1963, 1964, and 1965 on shipments from California to midwestern and eastern markets.

Controlled-atmosphere storage tests with lettuce, made by Watada and coworkers,[1] showed that lettuce was neither benefited nor harmed by oxygen concentrations as low as 1 percent for up to 8 days at 41° F. High concentrations of carbon dioxide, however, were harmful to lettuce. Other laboratory tests by Parsons and coworkers[2] showed that, at 33°, lettuce held at 1 or 0 percent oxygen developed less russet spotting than lettuce held in air. Lipton[3] stated that oxygen levels up to 8 percent during storage of lettuce reduced

[1] Watada, A. E., Morris, L. L., and Rappaport, L. modified atmosphere effects on lettuce. Fruit and Veg. Perishables Handling Conf. Proc., Univ. Calif., Mar. 23–25: pp. 82–85. 1964.

[2] Parsons, C. S., Gates, J. E., and Spalding, D. H. quality of some fruits and vegetables after holding in nitrogen atmospheres. Amer. Soc. Hort. Sci. Proc. 84: 549–556. 1964.

[3] Personal communication from W. J. Lipton, plant physiologist, U.S. Department of Agriculture. 1965.

russet spotting. However, he stated that oxygen levels at 0.5 percent or lower during storage, within the temperature range studied (36° to 50°), sometimes injured the heart leaves.

This report gives the results of shipping tests made under commercial conditions to determine comparative effects of liquid nitrogen and mechanical refrigeration on transit temperatures, on the quality of lettuce, and on the various disorders affecting lettuce on the market.

METHODS

Fifteen paired trailer shipments of vacuum-cooled lettuce were made from California to midwestern and east coast markets. Most shipments were made during the summer, from the Salinas-Watsonville district; but a few were made in the winter months, from the Imperial Valley of southern California (table 1). The trailers moved by rail on flatcars, except for a few short hauls by truck to or from railheads.

One trailer of each pair in a shipment was a conventional, mechanically refrigerated (MR) trailer; the other either was refrigerated by liquid nitrogen alone (N) or was refrigerated mechanically with liquid nitrogen used as a supplement (NMR) to modify the atmosphere. The nitrogen was dispensed in the trailers through a perforated tube running along the ceiling. The N trailers had the tube at the centerline; the NMR trailers had the tube near a wall. Four storage tanks, each holding 375 pounds of liquid nitrogen, were located in the nose of the N trailers. One tank, holding 100 gallons of liquid nitrogen, was attached to the undercarriage of each NMR trailer. The N trailers had no fans but depended only on convection and the release of nitrogen for air movement within the load compartment.

TABLE 1.—*Trailer type, shipping dates and points, and destinations of test shipments of lettuce from California to midwestern and east coast markets*

Trailer No.	Trailer type [1]	Shipping		Destination
		Date	Point	
1	N	July 9, 1963	Watsonville	Chicago, Ill.
2	MR	do	do	Do.
3	N	do	Salinas	Do.
4	MR	do	do	Do.
5	N	Feb. 19, 1964	El Centro	Do.
6	MR	do	do	Do.
7	N	Aug. 25, 1964	Salinas	Waverly, N.J.
8	MR	do	do	Hawthorne, N.J.
9	N	Aug. 26, 1964	do	Elmsford, N.Y.
10	MR	do	do	Do.
11	N	Mar. 23, 1965	Holtville	New York, N.Y.
12	MR	do	do	Do.
13	N	Mar. 25, 1965	do	Chicago, Ill.
14	MR	do	do	Decatur, Mich.
15	N	Aug. 5, 1965	Watsonville	Chicago, Ill.
16	MR	do	do	Decatur, Mich.
17	N	Aug. 17, 1965	do	Philadelphia, Pa.
18	MR	do	do	Do.
19	NMR	May 22, 1964	Salinas	Chicago, Ill.
20	MR	do	do	Do.
21	NMR	June 4, 1964	do	Do.
22	MR	do	do	Do.
23	NMR	July 29, 1964	do	Elkhart, Ind.
24	MR	do	do	Chicago, Ill.
25	NMR	Jan. 26, 1965	El Centro	New York, N.Y.
26	MR [2]	do	Holtville	Do.
27	NMR	Mar. 9, 1965	El Centro	Do.
28	MR	do	Holtville	Do.
29	NMR	Mar. 10, 1965	El Centro	Do.
30	MR	do	do	Do.

[1] N, liquid nitrogen refrigeration (low-oxygen atmosphere); MR, mechanical refrigeration (normal atmosphere); NMR, liquid nitrogen plus mechanical refrigeration (low-oxygen atmosphere).

[2] Rail car used for this shipment.

The thermostats in the conventional and NMR trailers were located in the air return behind the bulkhead at the front of the trailers. The thermostats in the N trailers were in the load compartment at the ceiling, about 6 feet from the bulkhead and 27 inches to the left of centerline.

The nitrogen-dispensing system in the N trailers was activated by the thermostat, except for N trailers 5, 7, and 9. The nitrogen release in these trailers was controlled by an oxygen sensor. These three N trailers also had thermostats that could shut off the supply of nitrogen if the temperature became too low.

The oxygen concentration in the NMR trailers was controlled by an oxygen sensor that activated the flow of nitrogen when the oxygen level in the trailer rose above the set point.

The oxygen concentration in the N trailers was lowered initially by the same system used to refrigerate the trailer in transit. The oxygen concentration in the NMR trailers was lowered immediately after loading by purging the trailer with nitrogen from an auxiliary supply.

Atmosphere samples were drawn from the load compartment through a ¼-inch plastic tube that led from the center of the load (between cartons) to the outside of the trailer through a water drain. Samples were taken at shipping point and at destination. Oxygen and carbon dioxide concentrations were determined with an Orsat gas analyzer. In some tests it was not possible to obtain samples at shipping point; and, if the trailer doors had been opened before a sample could be taken, no reading was obtained at destination.

Transit temperatures were obtained with small recording thermometers placed in the center of lettuce cartons at various locations throughout the load. In most trailers, the thermometers were located in cartons in the middle and top layers at the front, in the middle layer at half-length (one at the wall and one at centerline), and in the top and bottom layers at the rear of the trailer. All thermometers were at the centerline of the trailer except the one at the half-length adjacent to a wall. The trailers had a thermometer attached to the ceiling to record inside air temperatures. One trailer in each pair had a thermometer attached to the undercarriage to record outside air temperature.

Lettuce temperatures were measured manually at various positions during unloading.

Lettuce for the test cartons for each trailer of the paired shipments was selected from the same field to assure comparable lettuce. The lettuce was in the "firm" to "very firm" range of maturity. The six test cartons per trailer were located in the same positions as the six thermometers placed in the load.

Quality evaluations were made at arrival and after a simulated marketing period (4 days at 50° F.). One layer in each carton was used for the arrival examination and the remaining layer for the second examination. The arrival examination was made on the day of unloading or, in cases where one trailer was unloaded on a different day from the other trailer, the test cartons from the first trailer to be unloaded were held at 38° or 40° until those from other trailers could be unloaded.

External appearance of the heads was rated by the following scale: 1, unsalable; 2, poor; 3, fair; 4, good; and 5, excellent. Each head was completely torn apart to detect decay, russet spotting, pink rib, tipburn, or rib discoloration. These defects were rated by the following scale: 1, none; 2, trace; 3, slight; 4, moderate; and 5, severe.

All quality examinations were made by personnel of the U.S. Department of Agriculture's Market Pathology Laboratories at Chicago, Ill., or Belle Mead, N.J.

RESULTS

Temperatures in Conventional Trailers Vs. Those in Trailers Refrigerated With Liquid Nitrogen

The average load temperature of all the trailers refrigerated with liquid nitrogen (N) was 41° F. and that of the companion conventional, mechanically refrigerated (MR) trailers was 36° (table 2). The average temperatures ranged from 2° to 11° higher in the N trailers than in the MR trailers in individual paired tests. The two pairs of trailers in which average load temperatures differed by only 2° (trailers 5 and 6, 13 and 14) were shipped during February and March when outside temperatures were low. The average minimum and maximum outside air temperatures during shipment of trailers 5 and 6 were 25° and 45° F, respectively; those during shipment of trailers 13 and 14 were 45° and 70°.

Transit temperatures at the coolest and warmest positions and the average temperature of all positions in each trailer are given in table 2 and shown graphically in figures 1 and 2 for the N and companion, conventional MR trailers. The variation between coolest and warmest positions was excessive in most N trailers. However, the variation was not so great in the N trailers shipped during cool weather (5°–6°) as it was in those shipped during hot weather (6°–16°). The variation between the coolest and warmest position in the conventional MR trailers was some-

TABLE 2.—*Temperatures during shipment of lettuce in trailers refrigerated with liquid nitrogen (N) vs. during shipment in trailers with mechanical refrigeration (MR)*

Trailer No.	Trailer type [1]	Thermostat setting	Average transit temperatures						Maximum temperature at destination [4]
			Inside air at ceiling	Load average	Coolest position [2]	Warmest position [3]	Outside air		
							Average low	Average high	
		° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.
1	N	45	----------	39	37	43	60	90	54
2	MR	36	----------	35	34	36	60	90	37
3	N	45	----------	41	37	44	60	90	55
4	MR	36	----------	35	34	37	60	90	43
5	N	----------	45	39	36	42	25	45	39
6	MR	36	36	37	36	38	25	45	39
7	N	36	53	43	39	50	64	84	60
8	MR	36	38	38	37	39	64	84	41
9	N	36	46	41	37	46	58	77	53
10	MR	36	35	36	35	38	58	77	42
11	N	39	43	40	37	43	-------	-------	50
12	MR	36	36	36	35	37	-------	-------	39
13	N	45	47	38	36	41	45	70	----------
14	MR	36	35	36	35	37	45	70	----------
15	N	34	54	46	36	52	56	91	66
16	MR	34	31	35	33	39	56	91	42
17	N	37	51	44	39	52	54	79	61
18	MR	36	38	39	38	41	54	79	41
	Average:								
	N	----------	----------	41	37	46	-------	-------	55
	MR	----------	----------	36	35	38	-------	-------	41

[1] N, liquid nitrogen refrigeration (low-oxygen atmosphere); MR, mechanical refrigeration (normal atmosphere).
[2] Coolest average transit temperature; not coolest position in load at all times during transit.
[3] Warmest average transit temperature; not warmest position in load at all times during transit.
[4] Manual temperatures obtained by U.S. Department Agriculture personnel during unloading.

times, but not always, greater during hot than cool weather, and the variation was always less than in the companion N trailers.

The average difference between coolest and warmest positions in all the N trailers was 9° and in all the MR trailers was 3°. The highest average transit temperature at any one position in a N trailer was 52° F. and in a MR trailer was 41° (table 2).

The coolest position in all N trailers was in the middle layer at the front (adjacent to the liquid nitrogen storage tanks), and the warmest position was in the top layer at the rear of the trailer. The positions of the coolest and warmest temperatures were not consistent in the conventional MR trailers.

The average of the maximum temperatures of all the N trailers at destination was 55° F. and of all the conventional trailers was 41° (table 2).

Temperatures In Conventional Trailers Vs. Those in Trailers With Liquid Nitrogen Plus Mechanical Refrigeration

The average load temperature during transit was 38° F. in the nitrogen plus mechanically refrigerated (NMR) trailers and 40° in the conventional, mechanically refrigerated (MR) trailers (table 3).

Transit temperatures at the coolest and warmest positions and the average temperature of all positions in the trailers are given in table 3 and shown graphically in figures 3 and 4. Temperature variation within the load was generally slightly less in the NMR trailers (averaged 2°) than in the companion MR trailers (averaged 3°). The greater temperature uniformity in the NMR trailers may have been due to chance, to differences in the amount of supplemental nitrogen, or to differences in the design of the trailers, mechanical refrigeration units, or the thermostats.

The temperature spread between coolest and warmest positions was greater in trailers 23 and 29 (4°) than that in any of the other NMR trailers tested (table 3).

The average of the maximum temperatures measured during unloading was 39° F. in the NMR trailers and 41° in the conventional MR trailers (table 3).

Atmosphere Modification in the Trailers

Most of the atmosphere data are limited to oxygen and carbon dioxide determinations of samples taken before shipment and at destination (table 4). However, oxygen concentration in the

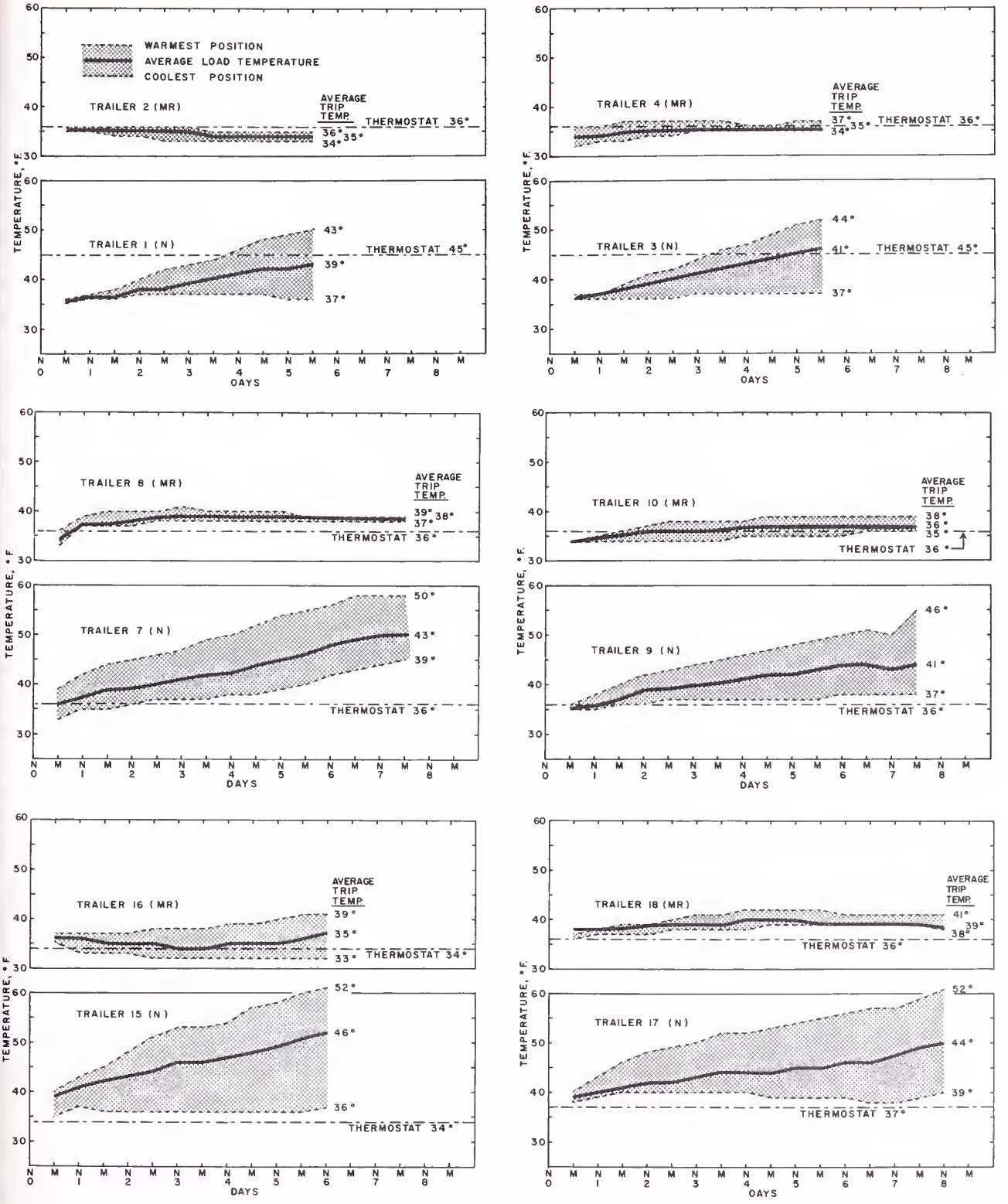


FIGURE 1.—Transit temperatures of lettuce shipped during hot weather in piggyback trailers under mechanical refrigeration (MR) and liquid nitrogen refrigeration (N). Nitrogen release in trailers 7 and 9 was controlled by an oxygen sensor. The thermostat was a safety device for shutting off the nitrogen if the temperature became too low. See table 1, p. 2, for shipping dates and points of departure and destination.

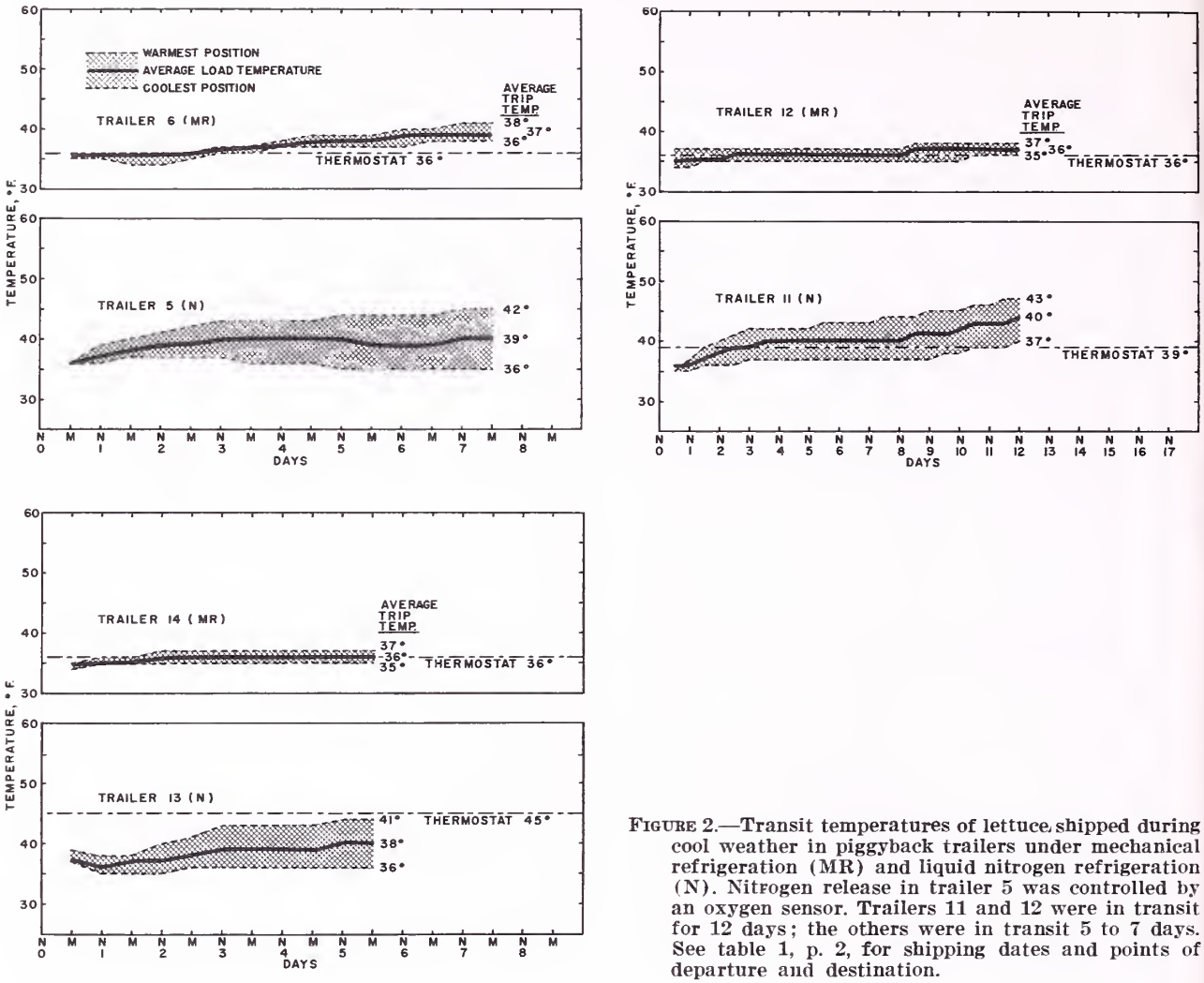


FIGURE 2.—Transit temperatures of lettuce shipped during cool weather in piggyback trailers under mechanical refrigeration (MR) and liquid nitrogen refrigeration (N). Nitrogen release in trailer 5 was controlled by an oxygen sensor. Trailers 11 and 12 were in transit for 12 days; the others were in transit 5 to 7 days. See table 1, p. 2, for shipping dates and points of departure and destination.

load was measured continuously during transit in N trailer 7 (fig. 5). The oxygen concentration in this trailer dropped to about 5 percent in 8 hours and only increased above this concentration briefly two times during the rest of the trip. The oxygen concentration in this trailer dropped to below 1 percent during one brief period in transit. It averaged about 2.6 percent during transit.

Purging the nitrogen plus mechanically refrigerated (NMR) trailers with nitrogen reduced the oxygen concentration to 1 to 2 percent at departure.

Oxygen concentrations were generally lower in the nitrogen-refrigerated (N) trailers at destination than in the NMR trailers because the nitrogen supply in the latter was usually exhausted, or nearly so. The lowest oxygen concentration found at destination in the N trailers was about 0.2 percent and in the NMR trailers was 2.0 percent. Average oxygen concentrations of less than 1 percent during simulated transit conditions have injured lettuce in laboratory tests.[4] Oxygen concentrations in the conventional trailers ranged from 17.8 to 20.6 percent at the shipping point and from 16.1 to 20.4 percent at destination.

The carbon dioxide concentration in the trailers was generally about 1 to 3 percent at destination. The highest carbon dioxide concentration found in any of the trailers at destination was 7.1 percent (N trailer 7). Continuous concentrations of 5 to 10 percent carbon dioxide may be detrimental to lettuce.[5]

Quality of Lettuce Shipped in Conventional Trailers Vs. That Shipped in Trailers Refrigerated With Liquid Nitrogen

The external appearance of lettuce with wrapper leaves attached was slightly better when shipped in conventional, mechanically refrig-

[4] Personal communication from W. J. Lipton. 1965.
[5] See footnote 1, p. 1.

erated (MR) trailers than when shipped in nitrogen-refrigerated (N) trailers (table 5). Wrapper leaves of lettuce from both types of trailers deteriorated in quality at the same rate during 4 days at 50° F.

After the wrapper leaves were removed from the heads, there was no significant difference in the appearance of the lettuce shipped in the N or conventional MR trailers. Butt discoloration was slightly more severe in lettuce from the N trailers than in that from the conventional MR trailers. This was probably due to the relatively high temperatures in the N trailers.

The average severity ratings for russet spotting, pink rib, tipburn, and rib discoloration were not significantly different for lettuce from the two types of trailers (table 6). Decay was slightly more severe in lettuce from the N trailers than in that from the conventional MR trailers. Incidence and severity of decay, russet spotting, and pink rib increased significantly during the 4 days at 50° F. (table 6), but the increase in these disorders was not influenced by trailer type.

The severity ratings for disorders in lettuce did not reflect differences in the incidence of decay and russet spotting. Although the average severity ratings for these disorders were between "none" and a "trace," lettuce from the N trailers had about five times as many heads with decay as that from the conventional MR trailers on arrival and about twice as many heads with decay after 4 days at 50° F. (table 6). Lettuce from the N trailers had about half as many heads with russet spotting at the first examination and about one-third as many at the second examination as lettuce from the conventional MR trailers. The higher incidence of decay in the N trailers was the result of the higher temperatures in those trailers than in the MR trailers. The lower incidence of russet spotting in the N trailers was due

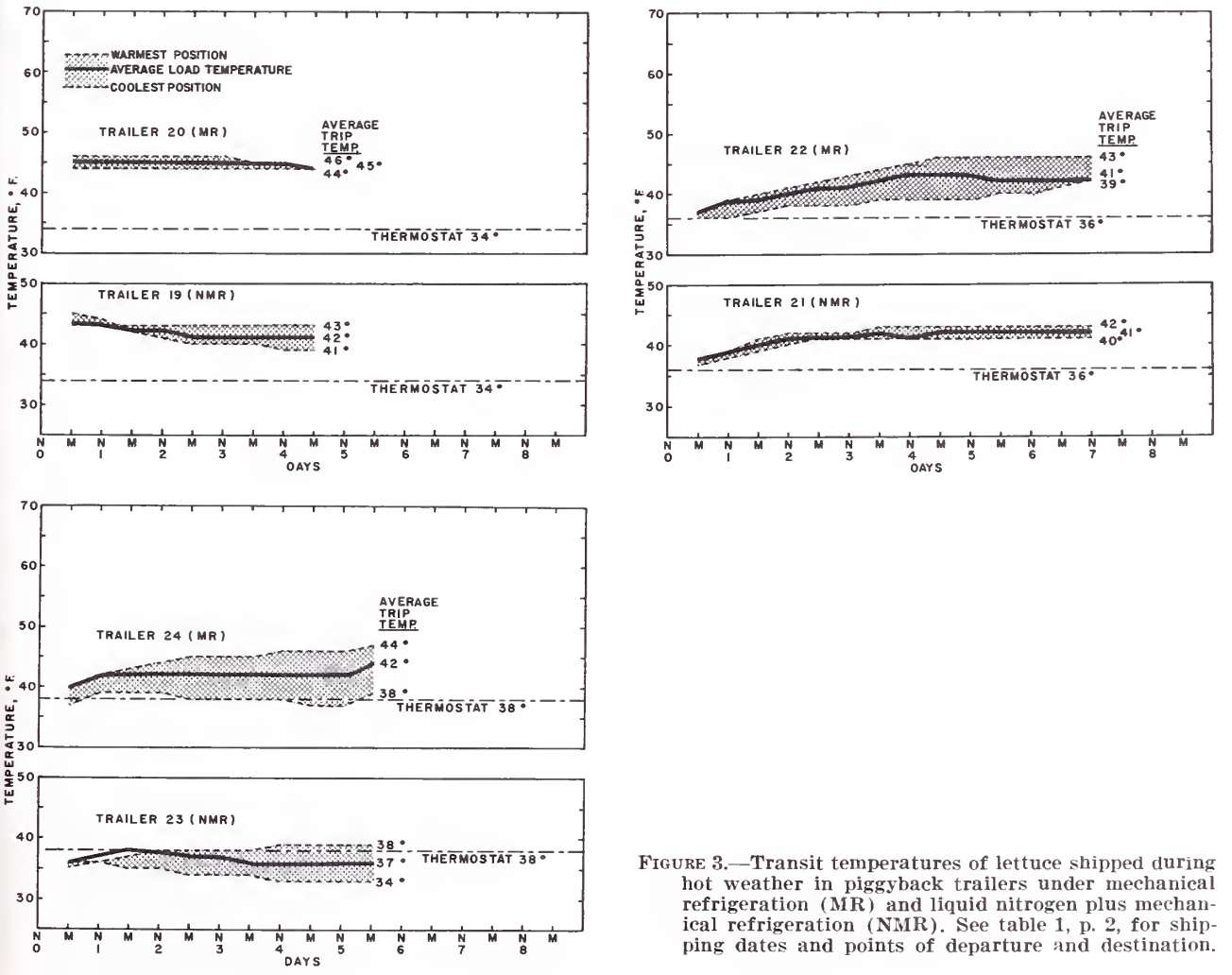
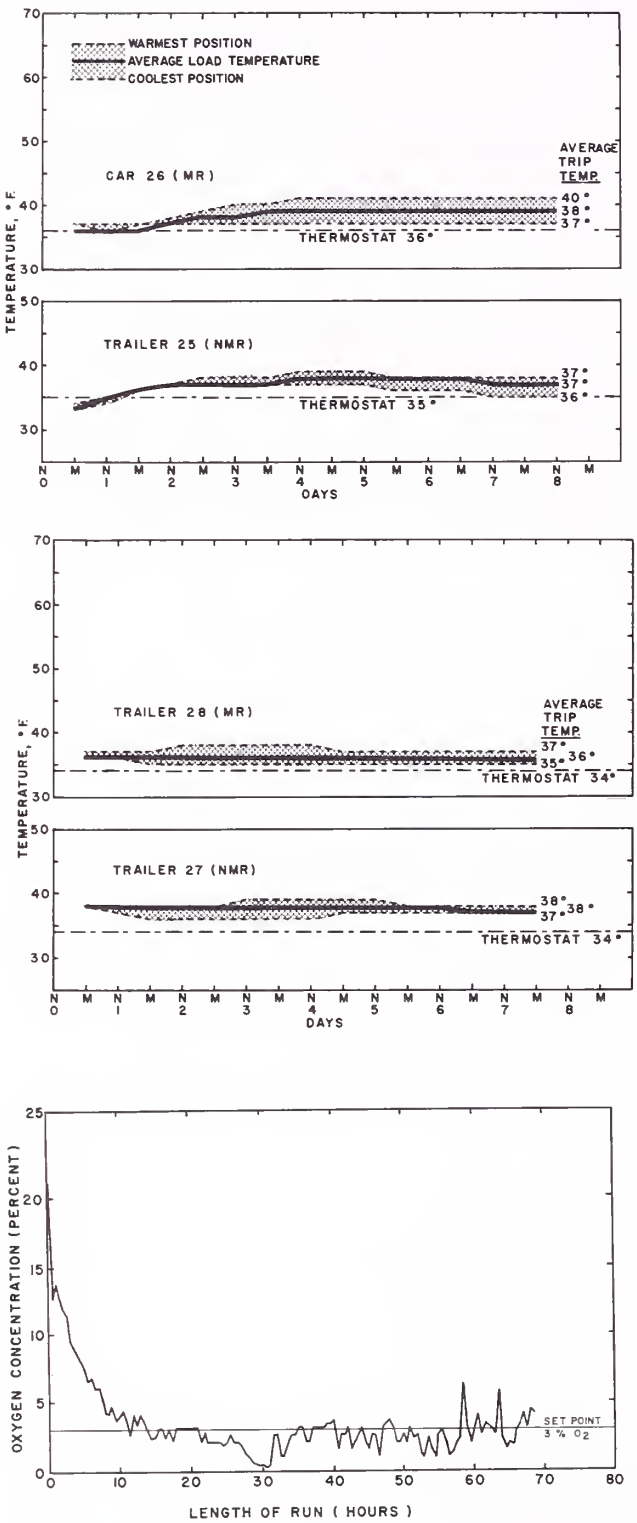


FIGURE 3.—Transit temperatures of lettuce shipped during hot weather in piggyback trailers under mechanical refrigeration (MR) and liquid nitrogen plus mechanical refrigeration (NMR). See table 1, p. 2, for shipping dates and points of departure and destination.



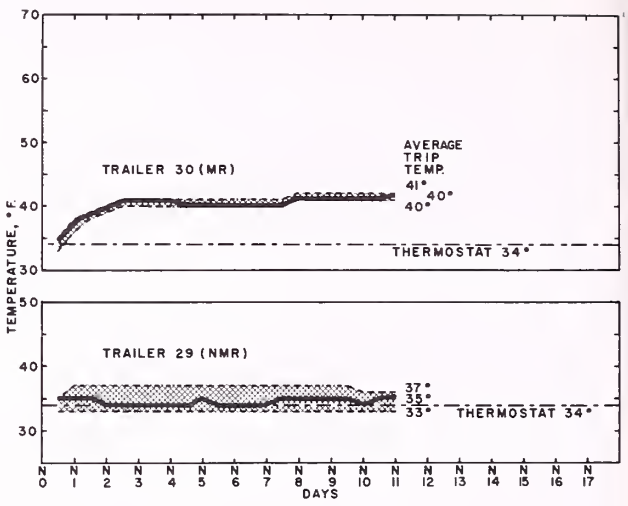


FIGURE 4.—Transit temperatures of lettuce shipped during cool weather in piggyback trailers, except as indicated, under mechanical refrigeration (MR) and liquid nitrogen plus mechanical refrigeration (NMR). Trailers 29 and 30 were in transit for 11 days; the others were in transit 8 days. See table 1, p. 2, for shipping dates and points of departure and destination.

FIGURE 5.—Oxygen concentration in load compartment of liquid nitrogen (N) trailer (No. 7) shipped from California to Waverly, N.J.
Data from Linde Division, Union Carbide Co.

to the lower oxygen concentrations. The relative increase in incidence of decay and russet spotting was about the same in lettuce from both types of trailers during 4 days at 50°.

Incidence of pink rib, tipburn, and rib discoloration was not significantly different in lettuce from the two types of trailers either at arrival or after 4 additional days at 50° F.

Quality of Lettuce Shipped in Conventional Trailers Vs. That Shipped in Trailers With Nitrogen Plus Mechanical Refrigeration

Average ratings for external appearance, either with or without wrapper leaves, were not significantly different in lettuce from the two types of trailers (table 7). Neither did butt discoloration differ in relation to trailer type. The relative deterioration in appearance was about the same in

TABLE 3.—*Temperatures during shipment of lettuce in trailers refrigerated with liquid nitrogen plus mechanical refrigeration (NMR) vs. during shipment in conventional trailers with mechanical refrigeration (MR)*

Trailer No.	Trailer type [1]	Thermostat setting	Average transit temperatures						Maximum lettuce temperature at destination [4]
			Inside air at ceiling	Load average	Coolest position [2]	Warmest position [3]	Outside air		
							Average low	Average high	
		° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.
19	NMR	34	36	42	41	43	58	86	38
20	MR	34	41	45	44	46	58	86	41
21	NMR	36	40	41	40	42	60	83	42
22	MR	36	40	41	39	43	60	83	42
23	NMR	38	33	37	34	38	63	92	38
24	MR	38	37	42	38	44	63	92	40
25	NMR	35	----------	37	36	37	-------	-------	40
26	MR	36	37	38	37	40	-------	-------	41
27	NMR	34	35	38	37	38	37	46	40
28	MR	34	35	36	35	37	37	46	35
29	NMR	34	33	35	33	37	33	53	38
30	MR	34	----------	40	40	41	33	53	44
	Average:								
	NMR	----------	----------	38	37	39	--------	--------	39
	MR	----------	----------	40	39	42	--------	--------	41

[1] NMR, liquid nitrogen plus mechanical refrigeration (low-oxygen atmosphere); MR, mechanical refrigeration (normal atmosphere).
[2] Coolest average transit temperature; not coolest position in load at all times during transit.
[3] Warmest average transit temperature; not warmest position in load at all times during transit.
[4] Manual temperatures obtained by U.S. Department Agriculture personnel during unloading.

lettuce from both types of trailers during the 4 days at 50° F. Average severity ratings for decay, russet spotting, pink rib, tipburn, and rib discoloration were not significantly different in lettuce from the liquid nitrogen plus mechanically refrigerated (NMR) trailers than in the conventional, mechanically refrigerated (MR) trailers (table 8). The relative increase in severity of the disorders was about the same in lettuce from both types of trailers during 4 days at 50°.

The incidence of decay, pink rib, tipburn, and rib discoloration was not significantly different in test cartons of lettuce shipped in the two types of trailers (table 8), but incidence of russet spotting was significantly less in lettuce from the NMR trailers than in that from the conventional MR trailers. The relative increase in incidence of the various disorders was about the same in lettuce from both types of trailers during the 4 days at 50° F.

TABLE 4.—*Oxygen and carbon dioxide concentrations in test trailers of lettuce shipped from California to midwestern and east coast markets*

Trailer No.	Trailer type [1]	O_2 level after purging	O_2 level control	Atmosphere composition at indicated place			
				Shipping point		Destination	
				O_2	CO_2	O_2	CO_2
		Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1	N					7.4	2.0
2	MR						
3	N					3.8	1.0
4	MR						
5	N		[2] 3.5				
6	MR						
7	N		[2] 3.0	6.5	1.0	1.7	7.1
8	MR			20.5	0	[2] 17.7	[2] 2.5
9	N		[2] 3.0	7.0	2.0	[2] 1.2	
10	MR			19.0	1.0		
11 [3]	N			12.0		3.7	5.0
12	MR			20.6		20.0	.4
13 [3]	N			13.7	1.6	.2	1.3
14 [4]	MR			19.0	1.5	16.3	1.3
15 [4]	N			1.0	.9		
16 [4]	MR			19.2	1.6		
17 [4]	N			15.5	1.9	8.8	2.9
18 [4]	MR			20.5	.3	20.4	.4
19	NMR			4.0		2.0	
20	MR						
21	NMR	[5] 1.5		7.5		18.8	2.0
22	MR			20.0		20.0	1.0
23 [4]	NMR	1.8		4.7	1.0	13.9	1.0
24 [4]	MR			17.8	2.5	16.1	2.0
25	NMR	[5] 1.0				16.4	3.4
26	MR						1.2
27	NMR	[5] 1.5				6.1	2.3
28	MR						
29	NMR	[5] 2.0				17.4	1.5
30	MR					18.3	2.4

[1] N, liquid nitrogen refrigeration (low-oxygen atmosphere); MR, mechanical refrigeration (normal atmosphere); NMR, liquid nitrogen plus mechanical refrigeration (low-oxygen atmosphere).
[2] Data obtained by Linde Co. personnel.
[3] Vacuum was broken by nitrogen after vacuum cooling of lettuce.
[4] Atmosphere measurements obtained the day after loading.
[5] Data obtained by Best Express Co. personnel.

TABLE 5.—*Market-quality ratings of lettuce after shipment in trailers refrigerated with liquid nitrogen (N) vs. after shipment in conventional trailers with mechanical refrigeration (MR)*

[Each rating represents average of ratings from 7 replicated test trailers]

Time of examination	Trailer type [1]	External-appearance rating [2]		Butt-discoloration rating [3]
		With wrapper leaves	Without wrapper leaves	
Arrival	N	3.3	3.5	4.0
Do	MR	3.5	3.7	3.6
4 days after arrival [4]	N	2.8	3.0	3.9
Do [4]	MR	3.1	3.2	3.9
Statistical significance: [5]				
Trailer type (T)		*	NS	*
Examination (E)		**	**	NS
T X E		NS	NS	NS

[1] N, liquid nitrogen refrigeration (low-oxygen atmosphere); MR, mechanical refrigeration (normal atmosphere).
[2] Rating scale: 1, unsalable; 2, poor; 3, fair; 4, good; 5, excellent.
[3] Rating scale: 1, none; 2, trace; 3, slight; 4, moderate; 5, severe.
[4] Held at 50° F.
[5] NS, not significant; *, significant at 5-percent level; **, significant at 1-percent level.

TABLE 6.—*Severity ratings and incidence of various disorders of trimmed lettuce heads after shipment in trailers refrigerated with liquid nitrogen (N) vs. after shipment in conventional trailers with mechanical refrigeration (MR)*

Time of examination	Trailer type [1]	Severity of indicated disorder [2] [3]				
		Decay	Russet spotting	Pink rib	Tipburn	Rib discoloration
Arrival	N	1.2	1.1	1.0	1.1	1.1
Do	MR	1.1	1.3	1.0	1.1	1.1
4 days after arrival [4]	N	1.9	1.2	1.2	1.2	1.1
Do [4]	MR	1.5	1.5	1.1	1.2	1.0
Statistical significance: [5]						
Trailer type (T)		*	NS	NS	NS	NS
Examination (E)		**	**	*	NS	NS
T X E		NS	NS	NS	NS	NS

Time of examination	Trailer type [1]	Incidence of indicated disorder [6] [7]				
		Decay	Russet spotting	Pink rib	Tipburn	Rib discoloration
		Percent	*Percent*	*Percent*	*Percent*	*Percent*
Arrival	N	6.2	3.7	0.6	3.8	1.7
Do	MR	1.3	6.0	.7	2.1	1.7
4 days after arrival [4]	N	25.5	8.5	6.0	3.9	4.0
Do [4]	MR	12.1	25.2	4.0	3.8	2.1
Statistical significance: [5]						
Trailer type (T)		**	**	NS	NS	NS
Examination (E)		**	**	*	NS	NS
T X E		NS	NS	NS	NS	NS

[1] N, liquid nitrogen refrigeration (low-oxygen atmosphere); MR, mechanical refrigeration (normal atmosphere).
[2] Each rating is average of ratings from 7 replicated test trailers, except for tipburn (6 replications).
[3] Rating scale: 1, none; 2, trace; 3, slight; 4, moderate; 5, severe.
[4] Held at 50° F.
[5] NS, not significant; *, significant at 5-percent level; **, significant at 1-percent level.
[6] Each percentage based on 9 replicated test trailers, except tipburn (6 replications) and rib discoloration (7 replications).
[7] Geometric mean of percentage of heads affected.

TABLE 7.—*Market-quality ratings of lettuce after shipment in trailers with liquid nitrogen plus mechanical refrigeration (NMR) vs. after shipment in conventional trailers with mechanical refrigeration (MR)*

[Each rating represents average of ratings from 5 replicated test trailers, except "external appearance with wrapper leaves" (4 replications)]

Time of examination	Trailer type [1]	External-appearance rating [2]		Butt-discoloration rating [3]
		With wrapper leaves	Without wrapper leaves	
Arrival	NMR	3.4	3.6	3.8
Do	MR	3.5	3.6	4.0
4 days after arrival [4]	NMR	3.0	3.4	4.1
Do [4]	MR	3.0	3.2	4.0
Statistical significance: [5]				
Trailer type (T)		NS	NS	NS
Examination (E)		*	**	NS
T X E		NS	NS	NS

[1] NMR, liquid nitrogen plus mechanical refrigeration (low-oxygen atmosphere); MR, mechanical refrigeration (normal atmosphere).
[2] Rating scale: 1, unsalable; 2, poor; 3, fair; 4, good; 5, excellent.
[3] Rating scale: 1, none; 2, trace; 3, slight; 4, moderate; 5, severe.
[4] Held at 50° F.
[5] NS, not significant; *, significant at 5-percent level; **, significant at 1-percent level.

TABLE 8.—*Severity ratings and incidence of various disorders of trimmed lettuce heads after shipment in trailers with liquid nitrogen plus mechanical refrigeration (NMR) vs. after shipment in conventional trailers with mechanical refrigeration (MR)*

Time of examination	Trailer type [1]	Severity of indicated disorder [2] [3]				
		Decay	Russet spotting	Pink rib	Tipburn	Rib discoloration
Arrival	NMR	1.0	1.1	1.1	1.2	1.3
Do	MR	1.1	1.2	1.1	1.1	1.2
4 days after arrival [4]	NMR	1.2	1.5	1.3	1.2	1.4
Do	MR	1.3	1.6	1.2	1.3	1.3
Statistical significance: [5]						
Trailer type (T)		NS	NS	NS	NS	NS
Examination (E)		**	NS	**	NS	NS
T X E		NS	NS	NS	NS	NS

Time of examination	Trailer type [1]	Incidence of indicated disorder [6] [7]				
		Decay	Russet spotting	Pink rib	Tipburn	Rib discoloration
		Percent	*Percent*	*Percent*	*Percent*	*Percent*
Arrival	NMR	0.8	2.1	3.3	4.9	9.0
Do	MR	1.6	6.9	5.7	4.3	9.5
4 days after arrival [4]	NMR	8.4	8.4	6.3	8.4	10.0
Do [4]	MR	10.9	11.1	6.4	15.3	9.7
Statistical significance: [5]						
Trailer type (T)		NS	*	NS	NS	NS
Examination (E)		**	*	NS	**	NS
T X E		NS	NS	NS	NS	NS

[1] NMR, liquid nitrogen plus mechanical refrigeration (low-oxygen atmosphere); MR, mechanical refrigeration (normal atmosphere).
[2] Each rating is average of ratings from 5 replicated test trailers.
[3] Rating scale: 1, none; 2, trace; 3, slight; 4, moderate; 5, severe.
[4] Held at 50° F.
[5] NS, not significant; *, significant at 5-percent level; **, significant at 1-percent level.
[6] Each percentage based on 5 replicated test trailers.
[7] Geometric mean of percentage of heads affected.

DISCUSSION

Liquid nitrogen serves two purposes in transportation equipment for produce. It provides refrigeration and it modifies the atmosphere by lowering the oxygen concentration. The only benefit of low-oxygen atmospheres to lettuce quality observed in these tests was a statistically significant reduction in incidence of russet spotting at destination. Since russet spotting is one of the more serious market disorders of lettuce, the use of liquid nitrogen in transportation equipment appears to have some potential. However, when liquid nitrogen was the only source of refrigeration, temperature variation and maximum temperatures within the load were excessive. Decay was significantly greater in lettuce from the trailers in which liquid nitrogen was the only source of refrigeration than in that from trailers that were mechanically refrigerated because of the high temperatures in the former trailers. Since decay is such a serious factor in determining the marketability of lettuce, the high incidence of this disorder in lettuce shipped in nitrogen-refrigerated equipment presents a problem yet to be solved. Some modifications in the system are being tested, which may improve temperature uniformity and provide lower average load temperatures.

Lettuce shipped in trailers having both a liquid nitrogen system and mechanical refrigeration (NMR) had a significant reduction in russet spotting with no increase in decay, compared with that shipped in conventional, mechanically refrigerated (MR) trailers with normal atmospheres. Incidence and severity of decay were essentially the same in lettuce from both types of trailers because the temperatures were similar.

Russet spotting of lettuce is not a problem in all shipments of lettuce; some lots of lettuce develop excessive amounts of russet spotting during transit and marketing while others have little or none. Lipton [6] found that when air temperatures in the field exceeded 86° F. for two or more consecutive days, 9 to 14 days before harvest, there was a substantial increase in russet spotting. The cause of russet spotting and methods of complete control are not known. However, it can be reduced by proper precooling, proper transit refrigeration,[7] and by providing low-oxygen atmospheres during transit.

The performance of conventional piggyback trailers still leaves something to be desired. More than one-fourth of these trailers had average load temperatures of 40° F. or higher during transit, even though all but one thermostat was set at 36° or lower. The average transit temperature of all conventional MR trailers was 38°.

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[6] LIPTON, W. J. INFLUENCE OF MAXIMUM AIR TEMPERATURES DURING GROWTH ON THE OCCURRENCE OF RUSSET SPOTTING IN HEAD LETTUCE. Amer. Soc. Hort. Sci. Proc. 83: 590–595. 1963.

[7] LIPTON, W. J., and BARGER, W. R. MARKET QUALITY OF HEAD LETTUCE IN RELATION TO DELAYS BETWEEN HARVEST AND PRECOOLING AND TEMPERATURE AFTER COOLING. U.S. Dept. Agr. Agr. Res. Serv. ARS 51–5, 14 pp. 1965.

APPENDIX: Atmospheres Obtained by Using Nitrogen To Break the Vacuum-Cooling Cycle

Breaking the vacuum-cooling cycle with nitrogen rather than air affords the possibility of quickly lowering the level of oxygen within the lettuce carton. Although low-oxygen atmospheres have some desirable effects on lettuce quality, it was not known whether or not such an atmosphere would be lost before the lettuce could be loaded.

Tests in the U.S. Department of Agriculture's pilot vacuum-cooling plant at Fresno, Calif., showed the speed at which the oxygen concentration returned to normal after the vacuum was broken by nitrogen. Air samples were drawn with a hypodermic needle from heads of lettuce from various locations in the cartons at various times after the vacuum was broken by nitrogen. The oxygen concentrations increased by about 1 percent per minute for the first 15 minutes and then increased at a more gradual rate (fig. 6, appendix). Within one-half hour or less, the oxygen concentration was essentially back to normal.

Similar results were obtained in two commercial tests (trailers 11 and 13). Oxygen samples taken from a tube placed in the center of cartons of lettuce at various times after the vacuum was broken with nitrogen showed an increase in the oxygen level by about 1 percent per minute. The oxygen level was essentially back to normal before the lettuce could be loaded in the trailer.

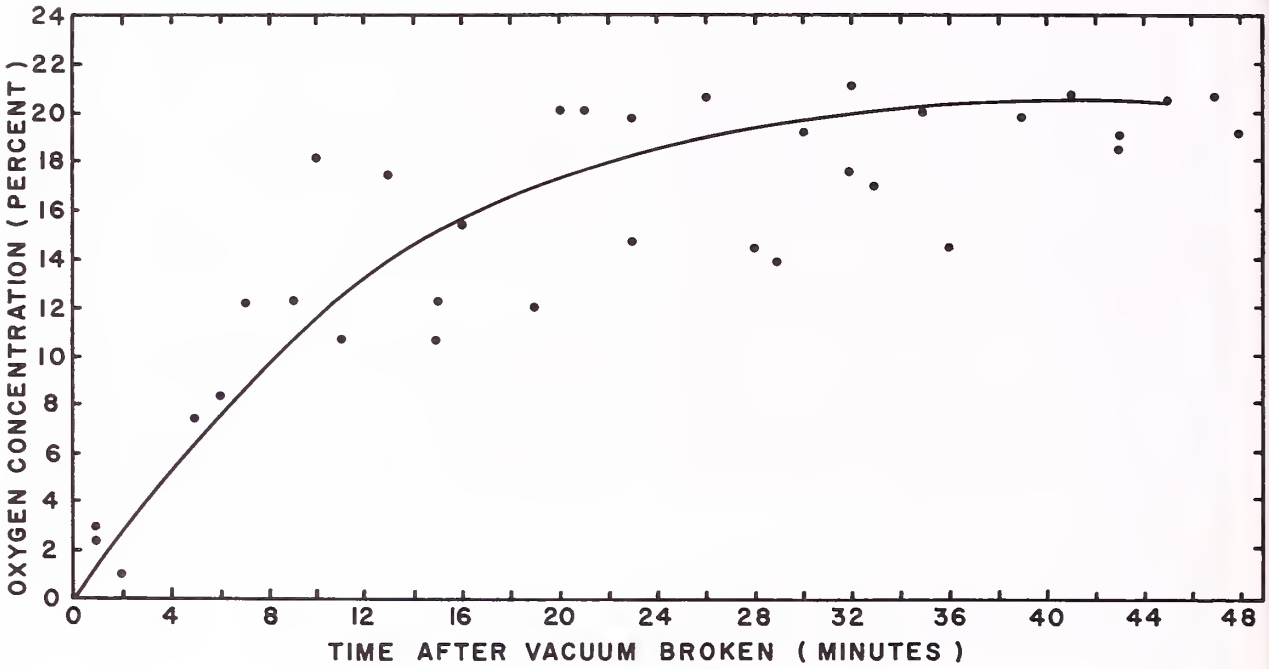

FIGURE 6.—Oxygen concentrations in cartons of vacuum-cooled lettuce after breaking the vacuum with nitrogen.

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