Bulletin 526

May 1971

Harvesting, Handling, and Storing Yellow Sweet Spanish Onions

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Idaho Agricultural Experiment Station

TEACHING RESEARCH SERVICE

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Contents

Introduction 3

Mechanical Topping and Harvesting Methods 5

Wakasugi Harvester 5

University of Idaho Rotary Blade Topper 8

Russell Topper 11

Oppel Topper 11

Using a Potato Loader With Sweet Spanish Onions 12

Ventilation Requirements for Bulk Onion Storage 13

Bulk Loading, Unloading, and Storage Quality Test 14

Lateral Bin Pressure Test 15

1966-67 Storage Experiment 15

1967-68 Storage Tests 17

1968-69 Storage Tests 19

Shigeta Bulk Storage Test 19

1969-70 Storage Tests 20

Conclusions 22

Acknowledgements 23

References 23

Appendix 24

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Agricultural Experiment Station

University of Idaho
Moscow, Idaho

College of Agriculture
2M NR 5-71

Bulk Harvesting, Handling, and Storing Yellow Sweet Spanish Onions

Larry G. Williams and DeLance F. Franklin

The Treasure Valley in southwestern Idaho and eastern Oregon is the third largest onion-producing area in the United States and is the top producer in yield per acre. Yellow Sweet Spanish or derived hybrids are the main varieties of onions grown in this area. Most of these onions are 3 inches or more in diameter. Approximately one-third of the onions produced in this area (about 7,000 carloads) are shipped annually to eastern markets. Despite a huge freight-price differential, Idaho growers have been able to compete with midwestern and eastern growers mainly because of higher yields, larger size, and a better quality onion.

By using mechanical harvesting and bulk handling and storage, midwestern growers have reduced production costs to as little as 20 cents per cwt for both harvesting and storing. Idaho growers are paying as much as 50 cents per cwt for storage and handling plus an additional 15 cents per cwt for topping. Approximately half of the harvesting and storage cost is for the container. The investment for crates and pallets is over $600 per acre (4).

Idaho growers have been slow to adopt mechanical harvesting and bulk handling methods because the Yellow Sweet Spanish onion is more susceptible to mechanical damage than the harder varieties grown in the midwest. Extremely heavy top growth makes it difficult to top the Sweet Spanish onion mechanically. With conventional harvesting and storing methods, long field-curing periods (9) are required to reduce the moisture in the neck to a safe level for storage. Also, large mechanical toppers such as those used in the midwest and east are not well adapted to the relatively small Idaho fields.

Idaho research indicates that Sweet Spanish onions can be stored in bulk to a depth of 8 feet without excessive damage. These same studies show that onions can be harvested and stored directly in forced-air ventilated storages with a minimum of field curing (5). By adopting bulk handling systems Idaho growers can decrease their harvesting and storage cost by half — from approximately 70 to 35 cents per cwt.

Mechanical harvesting, mechanical handling, and bulk storage of onions are closely related in that one generally is not economically feasible without the other two. Because of the enormous capital investment involved, growers are reluctant to change their methods of handling to an unproven method even though on paper it appears cheaper (4). Growers will not go to bulk storage until equipment is available for harvesting and handling the onions without excessive damage because losses from machine damage can be expected to be greater than losses from hand-topping and handling methods. Improved harvesting and handling techniques and an adequately ventilated storage must accompany the bulk storage system (5).

A research project was initiated in 1966 by the Agricultural Engineering Department in cooperation with the Parma Branch Experiment Station to study further the problems of bulk harvesting, handling, and storing onions. The principle objectives of the project were:

1. To evaluate present onion mechanical harvesting equipment with respect to mechanical damage and topping ability.
2. To develop a method of field topping onions which is adaptable to large and small acreages.
3. To develop economical methods of bulk handling onions from the field into and out of storage which will be compatible with a forced-air ventilation system.

Bulk handling and storage tests have been conducted since 1960. Tests before 1966 were reported in Idaho Agricultural Experiment Station Bulletin 479. This discussion will mainly be confined to work from the 1966-67 season to the 1969-70 season.

Table 1. Types and characteristics of onion toppers observed in the Treasure Valley. *

Name	Type of machine	Topping principle	Suitability	Limitations
Air-Flo Harvester	lifts, tops, and loads; trail-type	air stream lifts tops, sickle cuts tops	smaller onions dryer tops	not suited for larger onions, green tops, and smaller fields
Bruner Harvester	lifts, tops, loads; trail-type	spiral topping rolls squeeze, shear, and pull tops off	dry tops	tops must be fairly dry and speed of operation slow to prevent damage
U of Idaho Flail Topper	tops before lifting; trail-type	lifter and air stream help raise tops. Flail cuts pattern around onion.	green or dry tops	onions must be uniform in the row; lifters pull onions
Wakasugi Harvester	lifts, tops, loads; tractor-mounted	Bruner spiral roll topper	dry tops	tops must be fairly dry and speed of operation slow to prevent damage
Parma Water Lifter Harvester	lifts, tops, loads; trail-type	spiral rollers and air force onion tops down to shear rollers	dry tops	relatively low capacity
U of I Rotary Blade Topper	tops in ground; 3-pt hitch; PTO	tined wheel lifts tops; rotary blade for each row	green tops	low capacity due to plugging; some onions pulled
Russell Topper	lifts, tops, windrows; trail-type	spiral rollers orient tops downward; blades cut tops	dry tops	spirals sometimes stain onion skin; relatively low capacity
Oppel Harvester	topping rolls fit in potato harvester	spiral rollers orient tops downward; blades cut tops	dry tops	not always practical to use same machine for both onions and potatoes
Shigeta Topper	tops in ground trail-type	discs cut along row, rotary blade tops	observed with dry tops only	not tested with green tops

* Mention of company or trade names of specific equipment is for purposes of identification and does not imply commercial endorsement.

Mechanical Topping and Harvesting Methods

The mature Yellow Sweet Spanish onion produces a large, succulent, green top that is as much as 1 inch in diameter at the base of the neck and grows to a length of 2 feet. Most of the mature onions are at least 3 inches in diameter. When the neck of the onion bulb loses its stiffness sufficiently to allow the top to drop over readily, the onion is ready to be harvested. It has been standard practice in the past to undercut the bulbs and to cure the tops as much as circumstances will permit before topping them since well-cured bulbs have a longer life expectancy when stored than do uncured bulbs. Whether the onions are topped immediately or after some field curing, a high percentage of tops will be down.

Mechanical onion toppers have been under investigation for several years (3, 5, 6). No topping unit has been perfected to the degree where it is readily accepted by the Idaho industry. Toppers can be classified by topping method employed, and whether the machine tops onions still in the ground or tops the onions after digging. Table 1 is a classification of toppers in chronological order of observation and investigation.* The Air-Flo harvester and University of Idaho flail topper have been previously discussed (5). No research data have been obtained on the Parma Water Lifter Harvester, the Shigeta topper, or the Bruner harvester. The Bruner topper has not been widely accepted for harvesting Sweet Spanish onions because of a fear of excessive damage and the need for the tops to be very dry.

Wakasugi Harvester

Mamaro Wakasugi of Weiser, Idaho, has built a direct harvester for his personal use, using the Bruner topping rolls as the onion conveying device. The original Bruner harvester was a large tractor-drawn implement. The relatively small fields of southern Idaho require a more maneuverable machine. The principal component of the Wakasugi machine is a Lockwood potato harvester. The horizontal cross conveyor was removed, a Bruner topping bed installed in its place and the entire unit mounted as an integral part of a tractor (Fig. 1).

The onions are undercut with a conventional blade 3 weeks before harvesting. Three weeks is required to dry the tops enough for the Bruner topping rolls to work successfully.

The machine picks up three rows of onions and elevates them on the pickup conveyor to a short set of rubber rollers. As the onions pass over the rubber rollers an air blast from a fan separates dirt, weeds, and other foreign matter from the onions before they fall onto the topping bed. The spiral rollers of the topping bed perform two functions. They "bite" off the onion tops and then act as a spiral conveyor to move the onions across the machine to the final conveyor.

Field performance of the Wakasugi harvester was observed during the 1965-66 and 1966-67 seasons. This machine was selected because it appeared to do a satisfactory job of topping with a minimum of damage. The field study also provided opportunity to determine damage caused by the various components of a typical harvester.

The average ground speed of the tractor was about one mile per hour. Speeds up to 1½ mph were tried, but the higher speeds resulted in an overloaded condition on the topping bed. At a speed of 1 mph about one-fourth acre per hour was harvested.

The onions moved smoothly on the pickup conveyor with very little tumbling. The pickup conveyor had sufficient capacity even at the higher ground speeds.

As the onions leave the final conveyor, they fall onto a topping bed (Fig. 2) which is driven by a variable speed V-belt. Operating speed of the topping rolls is critical. At low speeds the onions pile up on the topping rolls and are bruised. If the top-

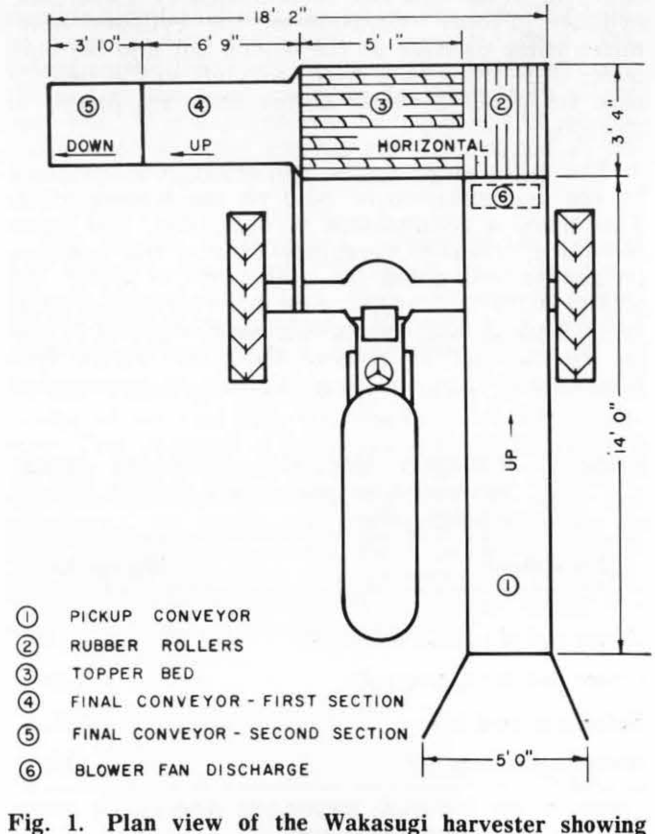

Fig. 1. Plan view of the Wakasugi harvester showing the arrangement of components.

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* Mention of company or trade names of specific equipment is for purpose of identification and does not imply commercial endorsement.

University of Idaho Rotary Blade Topper

Since mechanical ventilation in storage reduces field-curing requirements, the industry seems to need a topper which will work effectively on onions with green tops. Design criteria include:

1. The machine should be tractor mounted and maneuverable in small fields.
2. Field capacity should be about the same as that of mechanical field loaders.
3. The topper must work on green, uncured tops.
4. The topping machine must contain adjustment provisions on each component to make it operational over a range of field conditions.
5. Topping quality must meet the standards of the grading and shipping industry.
6. Onion damage must be held to an absolute minimum.

If the onion tops are to be removed without the conventional top-curing period, a logical time to top the onions is while they are still in the ground. Onion tops are usually badly lodged at harvest time. Any topper that removes the tops while the onion bulbs are still in the ground will require a device to pick up the lodged tops before they are cut off.

Experimental Topper Design

During the fall of 1965, a tined-wheel pickup unit was designed and tested. This ground-driven unit used two tined wheels per row to pick up the tops so they could be removed by a horizontal blade. In 1966, a 6-row topper was designed using the tined-wheel principle to lift lodged tops and six 18-inch rotary blades to remove the tops. One pickup wheel unit is shown in Fig. 3. The rotary blades were positioned close to the tined wheels so the tops would be cut before the tined wheels released them. Four gauge wheels were used to maintain a uniform cutting height. The gauge wheels were positioned between the rows on top of the onion bed. The machine was designed to allow adjustments such as the horizontal and vertical angle of the tined wheels, gauge wheel height, and blade height. The tined wheels were mounted so they rode on the ground but could be lifted for turning, backing, or for road travel. The completed topper is shown in Fig. 4. The arrangement of the component parts is shown in Fig. 5.

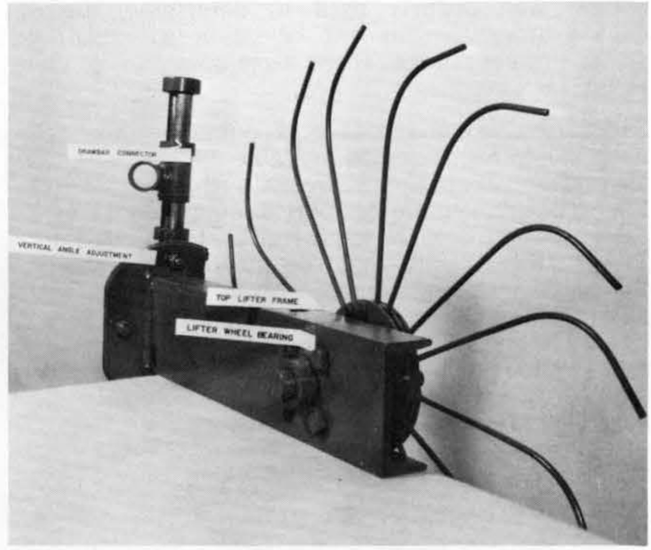

Fig. 3. The top lifter wheel assembly for the U-I rotary blade topper.

During the preliminary tests in August 1966, the tined wheels became plugged with tops that had been removed from the onions. Small power-driven tined wheels were added to clean the cut tops from the lifter wheels, and this improved the topper's operation.

Fig. 4. The completed U-I experimental topper.

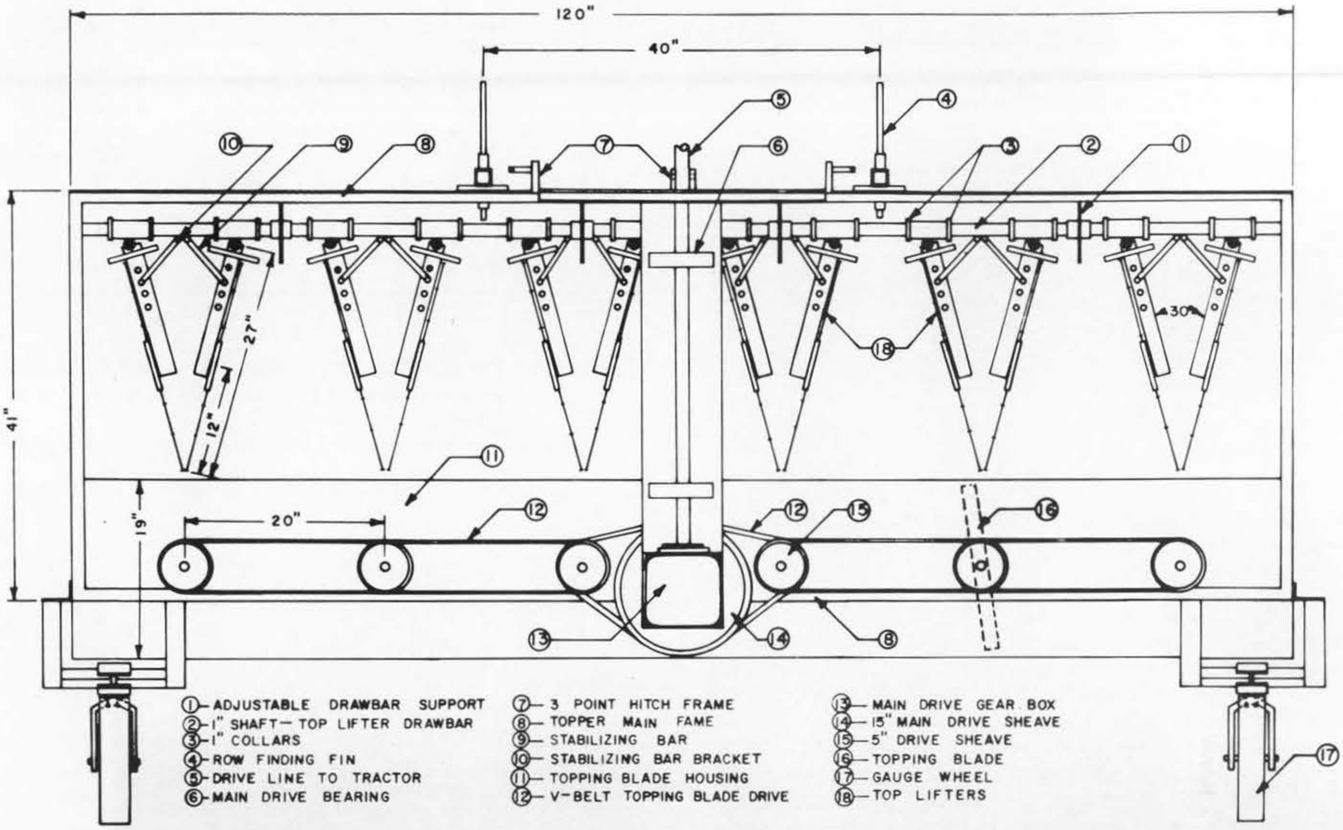

Fig. 5. Plan view showing the arrangement of components in the U-I rotary topper.

The Harvest Trial

The best operating position of the top lifters was difficult to determine. The most acceptable topping job was accomplished with the lifters at an angle of 25 degrees to the direction of travel and inclined away from the onion row 5 degrees from the vertical. All the adjustment provisions incorporated in the topper worked, but the lifter wheel adjustments were hard to make because the machine components were so crowded inside the main frame.

The problem of tops accumulating on the rear of the machine and on the lifter wheels was serious in this field trial also. In fact, the situation was much worse than in the preliminary trial, even before the addition of the cleaning wheels. Tops had to be cleaned frequently from the blade housing. This reduced the field capacity of the topper to a level that precluded its use for anything except research for the 1966 harvest season.

The topper performed better in the afternoon than in the early morning hours. The increased moisture content, and resulting turgidity, of the tops during the early morning hours probably had an adverse effect on the operation of the lifter wheels. Variation in moisture content of the tops from field to field also would affect the performance of the top lifter wheels.

The harvest trial also revealed that we could not separate true machine damage from that caused indirectly by interference from components other than the lifter wheels and the topping blades. As the tractor wheels and the front gauge wheels of the topper passed over the onion tops, the onions were loosened and some were pulled completely out of the ground. The lifter wheels then picked these onions off the ground and entangled them in the lifter tines where they were chopped up by the topping knives. When the onion bulbs became entangled in the lifter wheels, they decreased the effectiveness of the wheels by causing a rapid buildup of tops.

The pink root condition in this particular field, though probably typical for the area, also contributed to the lifter wheel clogging problem. The pink root-infected onions are only loosely attached to the soil and are easily pulled by the lifter wheels.

Topping Quality

Two different samples of mechanically topped onions were taken to determine their topping and storage qualities. The first group was taken to determine the direct mechanical damage and to estimate effectiveness of the topper. Two topping treatments were used. The first treatment was a single topping pass with the lifter wheels inclined 25 degrees with the direction of travel and 5 degrees in the vertical direction. Topping knives were set 4 inches above the ground.

The second treatment consisted of two passes with the topper over the same onions. For the first pass, the lifter wheels were inclined 15 degrees in the direction of travel and 5 vertically. Topping blades were set 6 inches above the ground. For the second pass, the lifter wheels were reset to 25 degrees and the topping knives lowered to a height of 4 inches above the ground.

All of the onions in each treatment were individually examined and the damaged onions counted. The untopped onions were counted for each treatment and the tops remaining on the onions were removed manually. The portion of the tops removed by hand was weighed and compared with the top weights of an adjacent hand-topped sample. The machine removed about 92% of the tops while damaging between 2 and 3% of the onions (Table 6).

Storage Quality

Three topping treatments were used in determining the storage quality of the onions. Each of the topping treatment plots was subdivided into two curing treatments.

The topping treatments were the same as those used in the topping quality evaluation, except each treatment was divided into a field-cured treatment and a mechanically cured treatment. One-half the topped samples was placed in a forced-air ventilated storage immediately, and the remainder was allowed to field cure for 10 days. The field-cured samples were then placed in the same forced-air storage building. The samples were taken out of storage and graded 10 weeks after harvest. The results of the storage quality evaluation are shown in Table 7.

Conclusions — U of I Topper Test

The onion losses that can be expected with the University of Idaho machine are direct mechanical damage in the field at the time of harvest and mechanical damage that is manifested only in storage losses. The direct field loss is about 2%. The average storage loss is about 10%. This compares with a storage loss of 11% on the topping rolls of the Wakasugi machine. The level of mechanical losses associated with the experimental topper is not so high as to preclude future experimental work with the machine to improve its topping characteristics.

The one-pass treatment is the most practical. Although more tops were removed by the two-pass treatment, the second pass directly damaged an additional 1% of the onions and subjected them to further indirect damage and storage losses as well.

Table 6. Results of tests of University of Idaho rotary topper.

Treatment	Tops removed by weight	Tops removed by number	Mechanical damage
	%	%	%
One pass	91.4	82.2	2.4
Two pass	93.7	89.9	3.2
Hand-topped	100.	100	0

Table 7. Percentage rot loss by weight during storage of onions from University of Idaho rotary topper test.

Cure treatment	Hand top	Topping treatment	
		One pass	Two pass
	%	%	%
Field cure	12.0	4.5	11.7
Mechanical cure	5.1	16.1	15.0

The use of this machine to top onions on a commercial basis would require the modification of storage facilities to include:

1. A forced-air ventilation system. In some instances supplemental heat will be required to accomplish drying before organisms can attack the onion bulb through the neck.
2. Facilities to run the onions over a stationary topper to remove the excess tops when the onions are taken out of storage, or use of additional laborers on the sorting table.

The tined wheels provide a satisfactory method of picking up lodged onion tops, but the topper needs to be modified to improve disposal of the onion tops after they are removed.

An onion topper of this type cannot attain the topping quality that is possible with hand labor because of the variations in onion height, moisture content of the tops, onion quality, and soil conditions between different fields and in many cases at different locations in the same field. However, it should be noted that the quality of hand topping today is much poorer than in previous years.

Russell Topper

Russell Brothers, Nyssa, Ore., designed and built a topping unit which was mounted on a 2-bed (4-row) windrower. A separate topping unit was used for each bed. Each topping unit consisted of 8 pairs of counter-rotating spiral rollers which oriented the onions so the tops protruded below the rollers. The roller speed was approximately 300 rpm. The tops were removed by a series of three lawn mower blades rotating directly below the spiral rollers at a speed of approximately 2,000 rpm. After topping, the onions were delivered onto a smoothly planed lane on the ground for pickup with a modified potato loader. The machine is shown in operation in Fig. 6.

This machine was field-tested on October 8 and 9, 1969, using partially field-cured onions. The field capacity of this machine was quite low and considerable trouble was encountered with onions lodging between the rollers. The spirals often left dark stains on the onion skins which could be detrimental to grade. A sample of the stained onions is shown in Fig. 7. These stains remained throughout the storage season. A light rain that fell during the test may have increased the severity of the staining. While the topper left 15 to 20% of the onions untopped, its topping performance was considered satisfactory. Topping performance would probably be better had it not been raining, as dampness of the tops makes the shearing action less effective. Untopped onions were those having 5 inches or more of top remaining. Most onions were topped from 1 to 3 inches above the neck.

A total of 56 samples of hand-topped, machine-topped, and untopped onions were placed in 50-lb. bags and stored in a well-ventilated onion storage for later comparison. The onions were removed from storage on January 14, 1970, and graded. The results of the Russell Topping Experiment are summarized in Table 8. No significant increase in rots during the storage season can be attributed to the Russell Topper. Modifications have been made on the Russell Topper since it was tested to improve its topping performance and increase its field capacity.

Oppel Topper

Oppel Harvester, Boise, Idaho, developed a topping unit very similar to the Russell unit. The Oppel unit can be used to convert a potato harvester to an onion harvester. A stationary version of this topping unit was tested on onions as they were removed from storage during the 1969-70 season.

The Oppel topper uses 16 counter-rotating, chrome-plated, spiral rollers on a 4.5 by 7-foot topping bed. The spirals orient the tops downward and carry the onions along the bed while lawnmower blades remove the tops. The Oppel machine uses 6 blades in 2 staggered rows.

No provisions were made to control the speed of the topping rolls independent of the topping blade speed on the stationary experimental model. The

Table 8. Percentage rot loss by weight of onions from Russell topper test stored in sacks and well ventilated, 1969-1970.

Treatment	% rot by weight
Untopped	2.4a
Machine-topped	3.7ab
Hand-topped	4.7 b

• Figures followed by different letters are significantly different ($P \leq 0.05$).

Fig. 6. The Russell topper uses a separate topping unit for each bed before windrowing.

Fig. 7. During the topping trial, onion skins were stained by the spirals of the Russell topper.

topper was tested at as slow a speed as was possible with the unit's electric motor drive. This gave a roller speed of 285 rpm and a blade speed of 2300 rpm.

A limited number of onions were topped out of storage with the Oppel unit. Topping performance was judged good with 87% of the tops removed, and 1.4% of the onions visually damaged by the topping unit. Staining of the onion skins was not significant for these tests.

Although the capacity of the topping unit could not be determined during this test, it was easily capable of topping approximately 15 tons per hour. It appeared desirable to operate the rollers at a speed less than 285 rpm and maintain the knife speed at approximately 2200 rpm.

Using a Potato Loader With Sweet Spanish Onions

Potato loaders have been used successfully to load onions from the field into bulk trucks or tote boxes. Problems sometimes arise, however, because: (1) generally the row spacing will not accommodate the tractor wheels satisfactorily, (2) use of potato loaders doesn't eliminate the topping problem, and (3) onions that are topped before they are elevated tend to roll down the pickup thus decreasing capacity and causing some mechanical damage. A modified Curl potato loader, which was tested near Caldwell, largely overcame these problems. This loader is shown in operation in Fig. 8.

Much of the cost of topping is the cost of bagging and crating the onions as they are topped. Topping costs can be reduced from about 9 cents per stub to about 3 cents per stub if the onions are topped into windrows. Loading three rows into one windrow also eliminates the wheel spacing problem and provides enough onions to crowd the pickup elevator. This reduces the tendency for the onions to roll down the elevator and thereby reduces mechanical pickup damage.

The Curl potato loader was modified to improve its performance for loading onions. An eliminator chain conveyor was used over the clod rollers to move the onions over these rollers. Without the chain, the onions will roll between the rollers. This reduces the capacity of the machine and results in skin damage to the onions. The conveyor speed was reduced about 50% to a speed of about 100 feet per minute by changing drive sprockets. Pieces of belting were used to cushion the onion fall on both sides of the clod roller section. The onions could be loaded at a rate of about 30 tons per hour with a ground speed of about 100 feet per minute (1.15 mph). Performance of the machine was very good.

Fig. 8. Three rows of onions placed into one windrow provided a full load for the modified Curl potato loader. When the elevator was crowded like this, onion injury was minimized.

Crowding the onions into the elevator eliminated most mechanical damage during the loading operation. The onions were loaded directly into a bulk truck. A skillful operator can adjust the discharge spout so that practically no mechanical damage occurs in this operation. Only the first few onions are dropped directly on the truck bed.

Samples taken directly from the truck were placed in storage so that machine-loading and hand-loading losses could be compared (Table 9). All samples were hand-topped and windrowed. Only during the 1969-70 season were storage losses from machine-loaded onions significantly greater than losses from the hand-loaded onions.

Table 9. Percentage rot loss by weight of hand vs. machine field-loaded onions stored in sacks and well ventilated, 1966-1969.

	% rot loss by weight		
Treatment	**1966-67**	**1967-68**	**1969-70**
Machine-loaded	14.0	15.8	7.4*
Hand-loaded	9.5	16.1	4.7*

* Machine-loaded significantly different from handloaded in 1969-1970 ($P \leq 0.10$).

Ventilation Requirements for Bulk Onion Storage

Adequate forced ventilation with proper control is required to insure satisfactory storage. The storage season can be divided into three periods each having definite ventilation requirements. There is a curing period, cooling period, and holding period.

Curing

The object of the curing operation is to remove the excess moisture in the skin and tops of the onions while removing very little moisture from the onions themselves. From 3 to 5% moisture will be lost during the curing period. This drying process requires good natural drying conditions or heated air. Natural drying conditions are generally satisfactory during September and October, but onions stored very green may require heated air for curing in wet years.

An air-flow rate of 1.5 cfm/ft^3 is required to cure onions in 15 days with air at 50 degrees F and 50% relative humidity. Partially field-cured onions will require a somewhat lower air-flow rate. If the onions are field cured, then no curing period will be required in storage. Natural air curing conditions can generally be obtained best by operating the fans during the day when the temperatures are high and shutting them off at night.

Cooling

Following curing, the onions should be slowly cooled to a temperature of 32 degrees F. This cooling period should coincide with the natural seasonal cooling. An air-flow rate of approximately 0.75 cfm/ft^3 will be required to cool the onions 10 degrees F per month and to take care of the heat of respiration of the onions, providing automatic damper controls are used and the fans are shut off when daytime temperatures are high. This can best be accomplished with thermostatic control.

Holding Period

The onions in storage should be held as near 32 degrees F as possible. Forced ventilation is required to remove the heat of respiration, maintain a more uniform temperature and humidity through the onion mass, prevent freezing of onions next to outside walls, and to prevent moisture condensation on the building interior. An air-flow rate of from 0.25 to 0.50 cfm/ft^3 should be adequate for this purpose. The relative humidity should be held between 50 and 70%.

Distribution System

The air distribution system should be designed to obtain uniform air flow through the onions. This is generally accomplished by using one or two main ducts down the length of the building with lateral air ducts going across the storage. The lateral ducts can be of two types. In one type, the tunnels or ducts are recessed below floor level and covered with a slatted board cover. The ducts should be spaced no more than 8 feet apart. Portable ducts could be used on top of the floor but air distribution will be poorer. These ducts also may interfere with the unloading of the onions. The second type of distribution system is a slatted floor extending the full length and width of the building. An 8-foot depth of onions offers negligible resistance to air flow; therefore, the static pressure requirement of the fan will be only that which is necessary to obtain a uniform air distribution through the duct system.

Temperature Control

Temperature control systems which might be employed range from completely manual control to completely automatic control. Regardless of type, the control system must have provision for supplying outside air, inside air, and a mixture of inside and outside air. An automatic control system will be much more effective in providing the correct temperature conditions for storage and in insuring against freezing the onions.

One type of automatic control system which has worked very effectively makes use of four thermostats. One thermostat operates a modulating damper control motor that controls the temperature of the incoming air by regulating the mix of inside air and outside air used for forced ventilation. A thermostat in the onion mass is used to control the fan operation. A cooling thermostat and a heating thermostat are placed in the main duct for additional control and protection. This type of temperature control system was used for the bulk onion storage experiments at Parma.

Bulk Loading, Unloading, and Storage Quality Test

The primary goal of this test was to develop an economical method for loading and unloading onions into bulk storage. This also provided an opportunity to study sidewall pressure in a bulk storage and to obtain further data on bulk storage losses.

A removable slatted floor ventilation system for a bulk onion storage with provisions for loading and unloading onions was designed. A large bulk bin was constructed in a commerical storage owned by J. C. Watson Co. in Parma, Idaho. The bin was 24 feet long, 17 feet wide, and 10 feet high. Cables were placed horizontally across the bottom and top of the bin to carry the lateral pressures.

Onions for all the bulk storage experiments were provided by the Idaho-Eastern Oregon Onion Committee and the J. C. Watson Company.

The support for the floor system consisted of removable sections made up of short stud wall panels each 8 feet long. The panels were covered with quarter-inch plywood to form the sides of the air duct. Full 4 x 8-foot sheets of quarter-inch plywood formed the top of the duct. These sheets were connected to the side panels using 20 penny nails as pins dropped through drilled holes. This provides for rapid and easy assembly and disassembly of the floor system. The slatted floor was made of 2 x 6-inch boards. The alley was made 8 feet wide so that trucks could be backed into it. All of the floor system and duct system except that of the alley can be assembled prior to filling the bin. The alley boards can be installed as the bin is filled. A section of the completed floor is shown in Fig. 9.

Orifices in the sides and tops of the ducts are used to meter air into the area under the slatted floor. This is necessary because uniform air distribution cannot be obtained in a long storage by merely passing air under the slats. The slat spacing cannot be adjusted accurately enough to act as a metering system and the onions offer little opposition to air flow.

The slatted floor system shown in Fig. 9 illustrates the principles involved. However, each design would have to be adapted to the type of storage structure and the equipment used for loading and unloading the onions in the storage. The floor system shown in Fig. 9 has these characteristics:

1. The entire floor system can be easily disassembled and stored in a small area without the removal of nails, bolts, or other fasteners.
2. The floor section is modular and is easily adapted to various lengths and widths.
3. The sections can be easily assembled as the storage is being filled, thus eliminating long conveyors.
4. The entire system including the duct system and conveyor is above ground; therefore, it can be adapted to any storage.
5. Positive control of air flow is possible from adjustable gates or orifices in the ducts.
6. The same piler can be used for unloading and loading. The onions won't have to drop more than one foot in either loading or unloading and will fall directly on a conveyor.
7. The cost of materials for the floor and duct system would be about $1,500 for a 40 by 150-foot storage.

Fig. 9. The floor system used to provide air distribution and to facilitate loading and unloading the onions. The entire floor is easily removable.

Lateral Bin Pressure Test

The bulk bin was designed so the center 8-foot section of one wall was hinged at the bottom and supported by horizontal cables on top. By measuring the tension in the cables it was possible to compute the lateral force of the onions against the wall.

Strain gauge transducers were used to measure the cable tension immediately after loading for the 1966-67 test. Because the cables interfered with the loading operation, this test was not repeated in subsequent years. Dial gauges were used to measure the deflection of several sections of the center 8-foot wide section of floor. The side-wall force was at a maximum immediately after filling and decreased with settling. At the same time the load on the bin floor increased. The side walls carry a portion of the vertical load by friction, but transfer a portion of the load directly to the floor upon settling.

The Rankine equation (1) is commonly used to evaluate the force on a bin side wall. The Rankine equation gives the total pressure on a wall as:

$$L = 1/2\left[wh^2 \tan^2 (45^\circ - \frac{\phi}{2})\right]$$

L = total pressure per foot of wall length, pounds

w = weight of material, pounds per cubic foot

h = height of the wall, feet

ϕ = angle of repose of material (tangent equals coefficient of friction between granules of material)

The main problem in applying the Rankine equation is obtaining accurate values for the angle of repose. The Rankine equation is for a large bin where the width of the bin is equal to or greater than $h/\tan \phi$. Table 10 is a summary of results for the lateral pressure test using the maximum force observed.

This is only one static test of side-wall pressures. The angle of repose may vary considerably with changes in size and uniformity. Vibrations from proximity to railroad trains or unusual conditions during loading or unloading may increase the lateral forces. Table 11 compares typical forces for potatoes (7) and onions using the onion data from Table 10 and the Rankine equation.

The lateral pressures for onions can be expected to be only slightly less than potatoes stored to the same depth. It would generally be good practice to design the bulk storage for potato pressures so the storage could be used for onions or potatoes. Data on wall pressures of potatoes is available from the U.S.D.A. (8).

Table 10. Results of lateral pressure test.

Item and Unit	Observed or calculated result
Onion depth (ft)	7
Unit weight (lb./ft^3)	38
Force per foot of wall width (lb.)	220
Force at 7-ft depth (lb./ft^2)	63
Calculated angle of repose (degrees)	32

Table 11. Comparable lateral pressures of onions and potatoes.

Item and unit	Potatoes	Onions
Storage depth (ft)	10	10
Unit weight (lb./ft^3)	48	38
Angle of repose (degrees)	37	32
Force per ft of wall depth (lb./ft)	596	584
Force at 10-ft depth (lb./ft^2)	119	117

1966-67 Storage Experiment

The bulk bin was filled with 120,680 pounds of uncured onions on September 17 and 18, 1966. It was impossible to evaluate the time required to fill an ordinary storage by this method because it was necessary to take samples continuously during the filling period. Space limitations within the storage also hampered the operation. It was impossible to back the truck directly into the bin alley so unloading had to be done at right angles to the piler. This was responsible for most of the damage caused by the loading operation. The filled bin with tote bin checks is shown in Fig. 10.

Fig. 10. Exterior view of the 24' x 17' bin used for the bulk handling and storage experiment. Other onion treatments were stored in sacks in the ventilated tote bins.

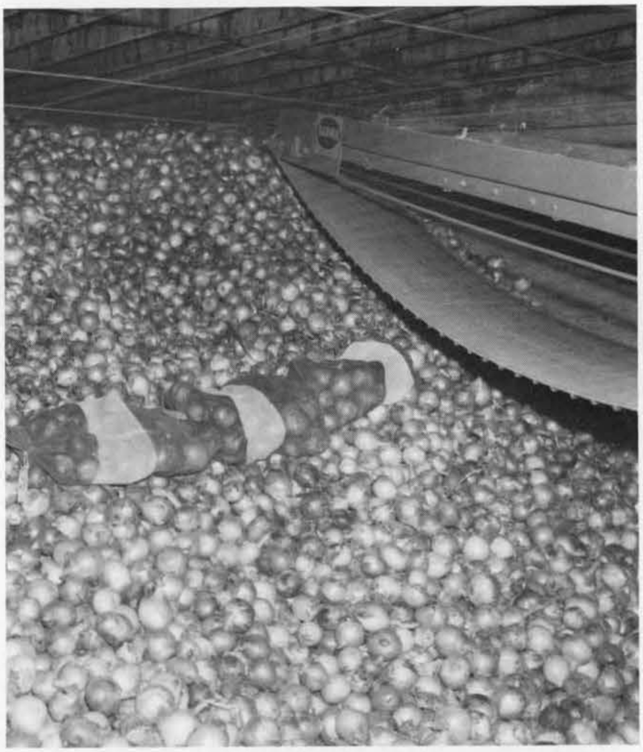

Fig. 11. Samples for grading were placed in sacks and stored throughout the pile so damage from pressure bruises could be evaluated.

Fig. 12. Space limitations made it necessary to load and unload onions at a right angle to the truck. This required an extra cross-conveyor for unloading.

Samples for later evaluation were put in sacks and placed throughout the onion mass. Samples were taken both before and after the onions went over the piler. These were compared with samples of hand-loaded onions which were stored both in bulk and in tote bins. Samples were placed near the top, center, and bottom of the pile in 15 locations across the bin (Fig. 11). Treatments and results for each year's experiment are summarized in Appendix Tables 1 through 4.

The piler used for loading and unloading the onions (Fig. 13) was furnished by the Southwestern Idaho Onion Growers Association. Constructed by Parma Water Lifter Company, it is hydraulically controlled and propelled and uses cleated rubber conveyor belting to reduce damage.

One difficulty encountered during the loading operation was inability to obtain adequate height with the piler. This was due to the small angle of repose of the newly piled onions. This angle of repose was measured several times and found to be about 34 degrees. Another problem was the inability of the piler to distribute the onions laterally. A swivel-type extension on the piler would increase its length and make it possible to distribute onions to both sides.

On November 21 and 22, onions were removed from bulk storage. The same piler was used (Fig. 12). The limited space hampered the unloading operation just as it hampered the loading operation. Since the onions had settled, considerable difficulty was encountered in getting them to feed into the conveyor. The angle of repose was measured several times during the unloading operation and found to be about 60 degrees. Two men were required to feed onions into the piler. Improvements are needed to facilitate unloading. A method is needed to make the onions flow more easily — perhaps some gentle vibrator applied to the bin walls.

Ventilation and Storage Conditions — 1966-67

An air-flow rate of approximately 3 cfm/ft^3 was used from September 17 to September 27. This is higher than necessary for in-storage curing but was used because the onions which went into the bin were extremely green. On September 27, the air-flow rate was reduced to about 1.5 cfm/ft^3 and maintained at that value through the test.

Table 12. Percent rots and percent pressure bruises in bulk storage of onions mechanically cured, machine loaded and machine piled, 1966-67.

Treatment	Rots	Pressure bruises
	%	%
Bulk storage		
2 ft depth	34.7	0
4.5 ft depth	36.3	0.75
7 ft depth	40.5	6.8
Bulk storage average	37.1	2.5
Tote bins	39.9	0

Table 13. Percent rots and bruises of hand- vs. machine-harvested and loaded onions in mechanically cured bulk storage, 1966-67.

Treatment	Rots *	Pressure bruises
	%	%
Hand harvested and loaded	19.0a	2.9
Machine harvested and loaded (piler)	37.1 b	2.5

* Different letters indicate significant statistical difference ($P \leq 0.001$).

The temperature was automatically controlled using a modulating control motor to operate a damper motor which mixed inside and outside air. The onion temperature was reduced gradually from 65 degrees F at the start of the test to about 45 degrees F at the end. Abnormally warm temperatures in early November prevented the fans from operating for several days at a time. An electrical failure blew the motor overload protection fuse sometime in early November and no ventilation was provided at all during the last 2 weeks of the experiment. Temperature and humidity conditions for each year's experiment are shown in Appendix Figs. 1 through 4.

The onions were removed from storage on November 21 and 22 and graded. The results of the storage test are summarized in Tables 12, 13, and 14. Approximately 2,000 kw-hr of electrical energy were used to cure and store about 60 tons of onions. Normally about 7 to 10 kw-hr of electrical energy per ton-month will be required to operate the fans.

Losses were unusually high for the experiment. These can be attributed to (1) the greenness and immaturity of the onions when they went into storage, (2) a generally poor storage season, (3) lack of fan operation during November, (4) rain leaking directly into the bulk storage, and (5) rough handling in the piling operation due to the lack of space to maneuver the piler. Despite the high losses, many conclusions can be drawn from the results. These can be summarized as follows:

1. Depth of storage did not materially affect the amount of rotting. Bruise damage was negligible at a depth of 4.5 feet and only 6.8% at a depth of 7 feet (Table 12).
2. Losses are high for all onions handled by the piler regardless of how they were stored. The data in Table 12 show that losses were slightly higher for onions stored in tote boxes that those stored in bulk where both received the same machine handling.
3. Losses for hand handling and harvesting were only about half of what the losses were for complete machine handling. Other results indicate that most of this damage was due to how they were handled in storage using the piler.
4. Losses were low for handling onions by hand whether they were mechanically cured or field cured. Mechanically cured onions had significantly fewer losses than the field-cured onions although both losses were low enough to be acceptable.

Table 14. Percent rots of mechanically cured and field-cured onions, hand harvested and loaded, and stored in sacks, 1966-67.

Treatment	Rots
	%
Mechanically cured	5.1 *
Field cured	9.5

* Difference is statistically significant ($P \leq 0.10$).

1967-68 Storage Tests

The 1967-68 storage tests were almost identical to the previous year's tests. The bin was moved so there would be direct access for loading and unloading. First-year results indicated the onions must be handled more carefully as they are put into storage, since the piler was responsible for about 10% of the storage losses.

The piler was modified by adding an 8-foot extension on the discharge side (Fig. 14). The extension, a rubber conveyor similar to the piler conveyor, was powered by a remote hydraulic motor. The extension was actually a distributor which could be angled sideways and vertically using hydraulic cylinders.

Storage Results — 1966-67

The onions were inspected periodically during the storage season. They were found to be well cured out in early October and extremely dry. Shortly after November 1, the weather warmed up and a

Fig. 13. This hydraulically operated piler was constructed by Parma Water Lifter Company and furnished by the Southwestern Idaho Onion Growers Assn. for use in the bulk handling experiment.

Fig. 14. An 8-foot extension distribution conveyor, added to the hydraulically operated piler for the 1966-67 experiment, was helpful in reducing onion damage.

long rainy period began. The fan was set on automatic and operated only a negligible amount after November 1. A leak in the roof funneled a large part of the rain falling on the roof into the bulk bin; however, other samples remained dry. During the first week in November, the fan stopped due to an electrical failure. Inspection on November 20 indicated the onions were rotting and should be taken out of storage immediately.

The modified piler performed excellently while both loading and unloading 55 tons of Sweet Spanish onions from the experimental storage. With the extension, the onions were dropped no more than 2 feet onto the pile where they stayed in place without rolling. No damage was attributed to the unloading operation. The piler handled approximately 20 tons per hour which is probably lower than most field loaders. The capacity of the modified Curl loaders used for the field tests was 30 tons per hour.

Onions for the experiment were piled to a depth of 7½ feet on top of the slatted floor. The piler elevated the onions from the discharge of the truck to the top of the piler, a vertical distance of about 8 feet in a horizontal distance of 22 feet. The overall length of the piler with the extension was 33 feet.

The experimental bulk bin was force-ventilated with an air flow of about 1.1 cfm/ft^3. The temperature was controlled within limits by automatically mixing inside and outside air. Thermostats controlled the fan operation so that the fan would operate when ventilation was needed and these conditions could be obtained with natural air.

The fan operation began immediately after the onions were loaded into storage on September 29

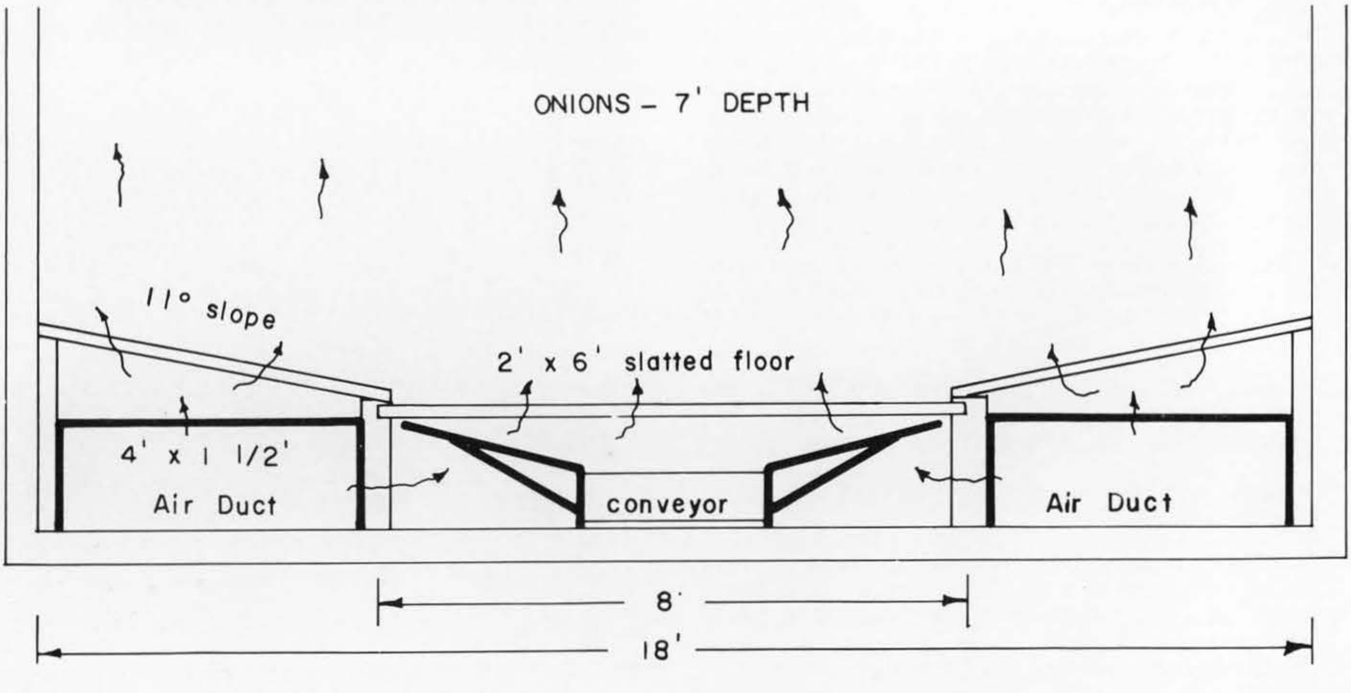

Fig. 15. Floor system with 8-foot alleyway.

in a partially field-cured condition. Warm air was passed through the onions during the first 2 weeks to cure or remove excess moisture from the necks. The onions were then gradually cooled as the outside air temperature decreased. Air-flow rate was dropped to 0.6 cfm/ft^3. Normally a storage temperature of 34 degrees F can be reached in November in the Parma area. Due to a combination of mechanical equipment and control failures and rather unusual weather, the onions never reached 34 degrees F and were generally 10 degrees F to 20 degrees F above normal temperatures.

On January 16, 1968, the onions were unloaded from storage and the samples analyzed for rot and pressure bruises. The pressure bruises in the samples were negligible. For some unexplainable reason the samples stored in sacks were not representative of the onions surrounding them; therefore, a comparison of the samples is somewhat meaningless. The average loss from rot was approximately 35% for the samples stored in net bags in the onion bulk pile. However, total loss from the 55 tons of onions stored in bulk was only 1.4% as determined by the actual pack-out recorded by the commerical shipper. Total loss from tote bins for onions from the same field stored in another commercial storage was 1.25%.

1968-69 Storage Tests

Problems were encountered in unloading the bin in both previous years, using the floor system with 8-foot alley (Fig. 15). For the 1968-69 test, the alley was eliminated and the slope of the floor was increased from 11 to 17 degrees (Fig. 16). This floor could be hinged at the walls and lowered as the storage was filled.

Approximately 55 tons of partially field-cured onions were loaded into the storage on September 26. Samples were not placed throughout the mass as had been done for the previous tests. An adjacent speed centrifugal fan was installed which provided an air-flow rate of 1.5 cfm/ft^3 during a 20-day curing period and 0.9 cfm/ft^3 during the storage period.

A partial bin failure while the bin was being filled, made it impossible to test the floor system while unloading the onions. The partial bin failure also affected the air distribution within the bin, so only limited data were taken on storage quality when the onions were unloaded on January 2, 1970. No attempt was made to compare handling with mechanical handling. The average storage loss for samples from the bulk storage was 30.7% compared with 27.9% loss for samples stored in bags under well-ventilated conditions.

Shigeta Bulk Storage Test

Bulk storage was also observed at the Gorgey Shigeta farm at New Plymouth, Idaho, in which all handling operations were mechanized. Onions were stored 8 feet deep in 2 compartments in a well-insulated 60 x 96-foot potato storage. The onions were field cured until dry, then topped with a rotary topper (Table 1) and loaded into bulk trucks with a potato loader. They were loaded into the storage with a conventional piler and unloaded out of storage with a Spudnik potato loader. The storage had an earth floor which was covered with about 6 inches of straw before filling.

Air distribution within the storage was accomplished using three steel culvert lateral ducts for

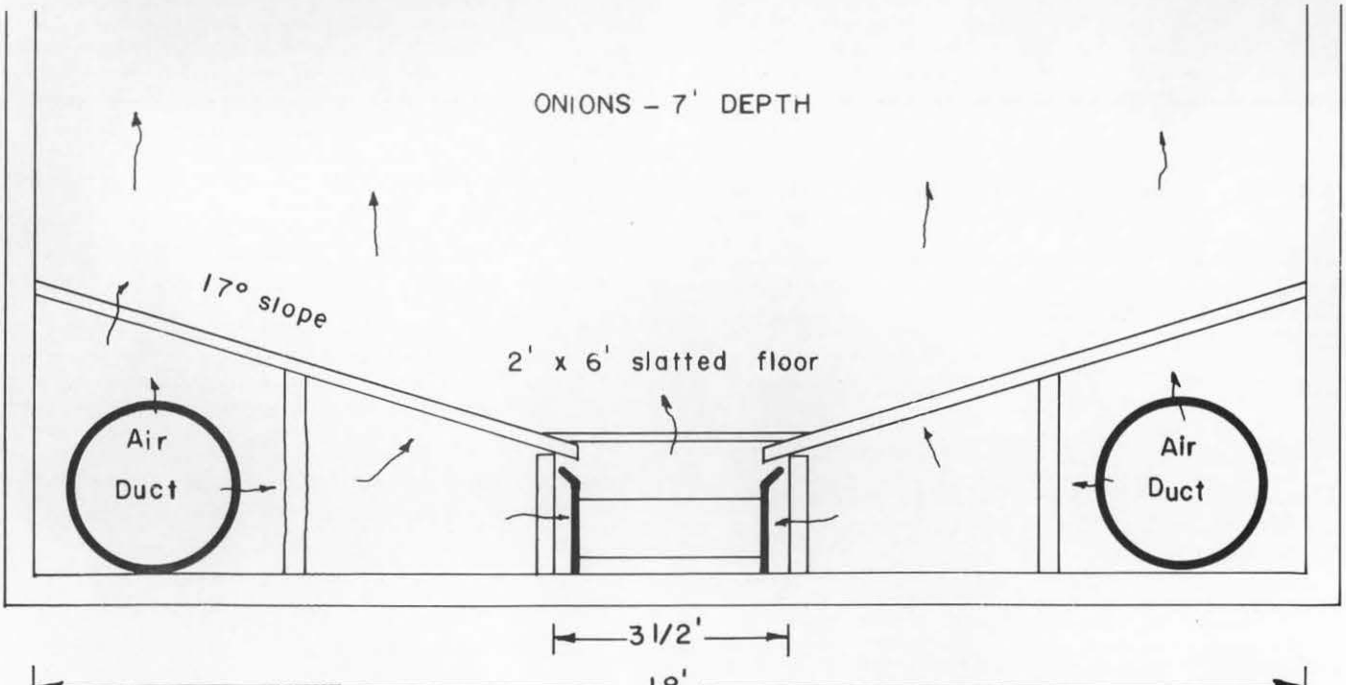

Fig. 16. Floor system without alleyway.

each of the 32-foot wide compartments, a maximum duct spacing of 10 feet (Fig. 17). A 7½ horsepower fan provided an air-flow rate of 0.55 cfm/ft^3. The system was equipped with a commercial automatic control system which used a modulating motor to mix inside and outside air to obtain the desired air temperature.

The storage was filled in mid-October, 1968, and emptied beginning January 13, 1969. The onion temperature was gradually lowered to approximately 40 degrees F with the seasonal drop in temperature. The relative humidity was excessively high during November and December because of the exceptionally high natural humidites plus a lack of exhaust capacity of the ventilation system. The system was actually designed for potatoes which require less outside air than onions.

Tests were made on 73 samples taken from various locations throughout the storage and from the truck after being loaded with the Spudnik loader. While storage losses were fairly high for this experiment (Table 15), the results are encouraging. The onions had undergone complete mechanical handling from topping to the unloading operation. Air distribution may not have been uniform as indicated by the higher losses in the rear of the storage. The duct spacing appears slightly excessive since losses from samples located between the ducts were greater than losses from the onions sampled directly above the duct. These differences were not statistically significant. The unloading operation was responsible for a great deal of damage as evidenced by the increase in cuts, bruises, and baldness of the mechanically loaded onions (Table 16).

A few onions were stored without being topped. Three samples taken from the untopped onions had 8.0% rot loss as compared to 12.5% for all topped samples taken from the pile. Topping after storage caused some soiling of outer scales which the shipping point inspector found objectionable.

Table 15. Storage losses at different sample locations within Shigeta bulk storage, 1968-69.

Sample location	Avg rots	Statistical significance
	%	
Top	9.8	Top to middle, 2% level
Middle	14.3	Top to bottom, 10% level
Bottom	13.4	Middle to bottom, none
Front	9.3	Front to rear, 0.2% level
Center	10.9	Center to rear, 0.1% level
Rear	17.4	Front to rear, none
Bottom layer (between ducts)	14.9	Between ducts to over-ducts, none
Bottom layer (over ducts)	11.5	

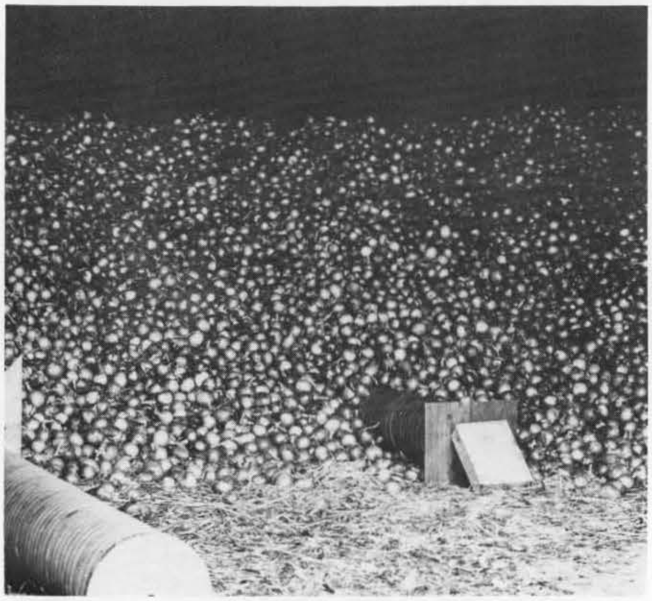

Fig. 17. In the Shigeta storage, air was distributed through culverts into which small orifices had been cut.

1969-70 Storage Tests

In every storage test conducted since 1960, untopped onions have kept as well as or better than topped onions. Onions can be topped from storage using a stationary unit either at the storage or packing shed.

The 1969-70 tests were divided into three bulk storage lots consisting of hand-topped onions, untopped onions, and machine-topped onions using the Russell topper. The onions were partially field-cured and loaded into bulk trucks with the modified Curl potato loader. Loading into and out of storage was again done with the modified Parma Water Lifter Piler. Samples were also stored in sacks in a well-ventilated condition to compare with the bulk-stored onions and to evaluate handling damage.

Fifty-five tons of onions were loaded into the bulk bin on October 18 in a semi-field-cured condition. The onions were cured for 2 weeks using natural air at an air-flow rate of 1.3 cfm/ft^3. This was accomplished using only outside air by setting the thermostats so the fan could operate only when the air temperature was above 50 degrees F. After 2 weeks the air-flow rate was reduced to 0.7 cfm/ft^3,

Table 16. Storage quality as affected by unloading equipment, Shigeta bulk storage, 1968-69.

Sample source	Avg rots	Avg cuts & bruises	Avg baldness	Total loss
	%	%	%	%
Pile (avg of samples)	12.5*	3.9	0.5	16.0
Truck (avg of samples)	19.4	9.5	1.1	30.0

* Difference is statistically significant ($P \leq 0.001$).

and the thermostats were adjusted to lower the temperature of the onions gradually until they reached a storage temperature of 32-34 degrees F. The bulk storage was unloaded on January 8, 1970. Results of the storage test are summarized in Tables 17, 18, and 19.

The 17-degree sloping floor (Fig. 16) facilitated unloading of the onions into the piler hopper. This unloading operation can easily be done by two men. Slightly more trouble was encountered in unloading the untopped onions, but this did not seem to be a serious problem.

The sacked samples were stored with air circulating around each sack. Consequently, they are not comparable to commercially stored sacked onions. The tote bins were in much better storages than the bulk onions, so losses from tote bins are not directly comparable to losses from bulk-stored onions.

Machine-topped, mechanically handled onions had significantly greater losses than hand-topped, mechanically handled onions (Table 17) when stored in sacks and in bulk ($P \leq .005$, $P \leq .05$ respectively). Hand-topped onions stored in sacks had significantly greater losses than the untopped onions ($P \leq .05$).

For all three topping treatments, completely mechanically handled onions had greater losses than completely hand-handled onions (Table 18). Mechanically handled, machine-topped onions had a 19.1% storage loss compared with a 4.8% loss for machine-topped onions handled by hand. The combination of several machine-handling operations appears to compound the storage losses.

The increase in losses caused by the piling operation during unloading (Table 19) is partly due to operating the piler at less than full capacity. When this happens, many onions will stay in the hopper and roll on the feeding rolls instead of being conveyed up the belt. Since the piler can distribute onions across and up and down the pile, practically no damage resulted from dropping the onions from the piler onto the pile.

Table 17. Percent rots for hand-topped, machine-topped, and untopped onions, mechanically handled, 1969-70.

Topping method	Storage method *		
	Sacks **	Bulk	Tote Bins
	%	%	%
Hand-topped	7.4 b	13.5	5.9
Untopped	3.6 c	8.8	--
Machine-topped	18.0a	19.3	6.6

* Sack and bulk onions stored in Ford storage, Parma; hand-topped tote bins in Nyssa storage, and machine-topped tote bins in Young storage, Parma.

** Figures within columns with different letters are significantly different ($P \leq 0.05$).

Table 18. Percent rots of hand- vs. mechanically harvested and handled onions stored in sacks, 1969-70.

Handling method	Rots
	%
Hand-topped	
Hand-handled	6.1
Mechanically handled	7.9
Untopped	
Hand-handled	1.5
Mechanically handled	6.9 *
Machine-topped	
Hand-handled	4.8
Mechanically handled	19.1 **

* Difference is significantly greater than untopped hand-handled ($P \leq 0.05$).

** Difference is significantly greater than machine-topped, hand-handled ($P \leq 0.005$).

Table 19. Percent rots of onions mechanically vs. hand-unloaded into bulk storage, 1969-70. *

Topping method	Percent rots	
	Mechanically piled	Hand-piled
	%	%
Lot 1, hand-topped	21.9	11.0 **
Lot 2, untopped	6.9	0.4 ***
Lot 3, machine-topped	19.1	16.8
Lot 4, hand-topped	7.9	7.0

* Onions were machine loaded in the field and stored in sacks.

** Difference is significantly less than mechanically piled ($P \leq 0.005$).

*** Difference is significantly less than mechanically piled ($P \leq 0.05$).

Conclusions

Mechanical Topping

Of all the toppers observed, the roll-type toppers which use counter-rotating spiral rolls to orient the onion top and rotary blades to remove the onion top performed the best. Staining the onion skins was a problem during rainy weather with the Russell machine, but chrome-plating the rollers should reduce this problem considerably. Modifications have been made on the Russell machine since it was tested.

The University of Idaho rotary topper performs satisfactorily with green-topped, uncured onions for which it was designed. However, clogging is a problem and field adjustments are critical. A conventional rotary cutter could also be used on green tops, followed by a second treatment with a stationary topper as the onions go into or out of storage. Onions topped green may require supplemental heat for curing to dry the neck before disease organisms reach the onion bulb.

Topping units can successfully be mounted into loaders to eliminate one machine-handling operation. The main disadvantage of the one-machine operation is the difficulty of getting adequate capacity from the topping unit. The choice of how the topping unit is utilized is largely one of management practices.

In almost all storage tests conducted since 1960, field-cured or partially field-cured onions kept better in storage with the tops intact. One reason for this is that the topping operation provides an opportunity for decay organisms to enter the onion neck. The tops also provide a cushioning effect during the handling operations. Consideration should be given to storing onions with the tops intact and removing them as the onions are taken out of storage. This could be done either at the place of storage or at the packing shed using a stationary unit. The tops will not interfere with air distribution if they are fairly uniformly distributed throughout the mass. Some trouble will be encountered in handling untopped onions, especially when they are not well cured. There is a tendency for them to tangle, preventing easy unloading from the truck. Staining of onions has been observed from topping onions out of bulk storage using roll-type toppers.

Harvesting and Handling

Potato loaders can be successfully used to load onions provided that operating speeds are reduced and modifications are made to prevent excessive cutting and bruising. Of special importance is the elimination of unnecessary corners and excessive free falls such as from the elevator into a tote bin or bulk truck.

Hand topping three rows into a windrow and picking them up with a potato loader is an economical semi-mechanical method of harvesting requiring less labor than conventional methods and producing less damage than completely mechanical handling.

Bulk harvesting and storage require the onions to be handled several times. They must be loaded in the field, unloaded into storage, reloaded out of storage, and unloaded at the packing shed. Each handling increases the opportunity for damage. Damage prior to storage is greatly compounded by storage losses. Thus extreme care must be exercised in each handling operation. Some growers will succeed in mechanical handling while others will fail as a result of care in using the machine.

The piler used to load the onions into storage should have a capacity equal to the unloading rate of the trucks and should be able to distribute the onions to a uniform depth without hand leveling. It is generally possible to use the same piler for both loading and unloading the storage.

Consideration should be given to how the onions can be mechanically removed from bulk storage without excessive damage. A false floor with a 17 degree slope will allow the onions to flow freely with a minimum of hand labor. Mechanical vibration may be useful in obtaining free flow.

Storage

Onions can be stored successfully at a depth of 8 feet if damage during handling is minimized and forced ventilation is provided. Bulk storage of extremely green onions was not successful in these experiments but no supplemental heat was used. No problem has been encountered with partially field-cured onions.

The main advantage of storing partially field-cured onions is that early storage would be possible in years when field-curing conditions are poor. Since these same years offer the poorest natural in-storage curing conditions, some form of supplemental heat may be desirable. The heat can also be used in very cold weather to permit greater circulation of outside air or during damp weather to reduce the relative humidity.

A false floor will provide space for the air distribution system. However, a way to meter the air from the distribution ducts is needed to obtain uniform distribution. If ventilation ducts are used without a false floor they should be spaced no more than 10 feet apart. Closer spacing will be necessary for onion depths less than 8 feet. The air supply system should be designed for uniform air distribution with provisions for circulating inside air, outside air, or a mixture of the two.

Bulk onion storages should be designed to carry lateral loads equivalent to potatoes at the same depth. The use of a false floor will raise the height of the onions and thus increase the bending moment on the wall.

Acknowledgements

The authors extend thanks to the Idaho-Eastern Oregon Onion Committee for their financial assistance; to James F. Watson, Parma, for making storage facilities, labor, and harvesting equipment available; and to Harry Kawahara for his cooperation and assistance in testing the field equipment.

Acknowledgement is also given to William M. Carson, Jr. who, as a graduate student in Agricultural Engineering, was largely responsible for the design, construction, and testing of the rotary topper, and to Ralph N. McGraw, Agricultural Engineering Department, for his assistance in constructing, setting up, and testing harvesting and storage equipment.

Special thanks is given to Joe Perecz Jr., Sam Munden, and Ed Schultz for the many hours of work they devoted to caring for the storage experiments and for their assistance in all phases of the harvesting and storage work.

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Appendix

Appendix Table 1. Summary of treatments and results of bulk onion storage experiment, 1966-67.

Treatment [1]		Type of storage [2]	Curing [3]	Handling [4] Field	Handling [4] Storage	Sample wt. loss	Rots	Pressure bruises
						%	%	%
A-1	hand-topped	sacks in bulk	M	H	H	6.83	19.0	2.9
A-2	hand-topped	sacks in bulk	M	H	H	--	5.1	--
A-3	machine, one pass	sacks	M	H	H	--	14.1	--
A-4	machine, two passes	sacks	M	H	H	--	15.0	--
A-5	hand-topped	sacks	F	H	H	--	12.0	--
A-6	machine, one pass	sacks	F	H	H	--	4.6	--
A-7	hand-topped	sacks in bulk at 2-ft depth	M	M	P	7.22	34.7	0
A-8		sacks in bulk at 4½-ft depth	M	M	P	4.92	36.3	0.75
A-9		sacks in bulk at 7-ft depth	M	M	P	5.71	40.5	6.8
A-10	machine, two passes	sacks	F	-	-	--	--	--
A-11	hand-topped	sacks	F	H	H	4.3	9.5	--
A-12	hand-topped	sacks in tote bins	M	M	M	--	39.9	--
A-13	hand-topped	tote bins	F	M	M	--	14.0	--

[1] All treatments were undercut on Sept. 16 and topped on Sept. 17.

[2] Onions were stored in force-ventilated bulk bin 18'x24'x7½' deep. All bulk samples were in loosely woven net sacks distributed within the bin. Curing period — Sept. 17 to 27; storage period — Sept. 27 to Nov. 21. Air-flow rate: 3 cfm/ft^3 for curing; 1.5 cfm/ft^3 for cooling.

Total weight into bulk storage was 120,680 lb. Weight out — 114,100 lb.

Total weight loss — 6,580 lb., or 5.2%. Pack-out — 48.5%

[3] Mechanically cured (M) onions were placed in bins Sept. 17 and cured until Sept. 27. Semi-field cured (F) onions were left in the field until storage Sept. 27. These onions were rained on the morning of Sept. 26.

[4] Field loading by hand (H) or machine (M); storage handling by hand (H) or piler (P). Piler was Parma Water Lifter before modification. Bulk bin was poorly located for mechanical loading. Tote bins were handled mechanically by lift truck.

Appendix Table 2. Summary of treatments and results of bulk onion storage experiment, 1967-68.

Treatment[1]		Type of storage[2]	Location of sample in bulk bin	Handling[3] Field	Handling[3] Storage	Sample wt. loss	Rots	Pressure bruises
						%	%	%
B-1	bulk A-H	sacks	bottom	H	H	13.5	61.7	0
B-2	bulk A-H	sacks	middle	H	H	14.8	56.7	0
B-3	bulk A-H	sacks	top	H	H	--	20.9	0
B-4	bulk A-T	sacks	bottom	M	H	14.2	39.4	0.6
B-5	bulk A-T	sacks	middle	M	H	11.1	36.9	0.06
B-6	Bulk A-T	sacks	top	M	H	--	25.1	0
B-7	bulk A-P	sacks	bottom	M	M	15.9	48.7	0.13
B-8	bulk A-P	sacks	middle	M	M	--	56.6	0.1
B-9	bulk A-P	sacks	top	M	M	--	25.8	0
B-10	bulk B-H	sacks	bottom	H	H	7.8	25.1	0
B-11	bulk B-H	sacks	middle	H	H	9.9	21.1	0
B-12	bulk B-H	sacks	top	H	H	--	11.4	0
B-13	bulk B-T	sacks	bottom	M	H	11.8	52.8	0
B-14	bulk B-T	sacks	middle	M	H	14.3	56.3	0
B-15	bulk B-T	sacks	top	M	H	--	6.5	0
B-16	bulk B-P	sacks	bottom	M	M	8.4	58.6	0.06
B-17	bulk B-P	sacks	middle	M	M	12.8	56.3	0
B-18	bulk B-P	sacks	top	M	M	--	7.6	0
B-19	bulk B	tote bins		M	M	--	1.3	0

[1] Onions were undercut Sept. 16, topped and windrowed Sept. 18, and semi-field cured in windrow. Part (Bulk A) went into storage Sept. 27 and 28; the rest (Bulk B) went into the bin Sept. 28 and 29.

Samples (H) were taken from hand-loaded and hand-stored onions.

Samples (T) were taken from the bulk truck.

Samples (P) were taken from onions after they had crossed the piler.

[2] Onions were stored in force-ventilated storage bulk bin 18'x24'x7½' deep. All bulk samples were stored in loosely woven net sacks. Air-flow rate was 1.1 cfm/ft^3 for the 2-week cooling period and 0.6 cfm/ft^3 for storage. Onions were removed from storage January 16.

Total weight into storage was 112,515 lb., a possible scale error.

Total weight out of storage was 116,010 lb. Pack-out from bulk storage — 98.6% (also a possible error, since this is unrealistically high); pack-out from tote bins — 96.3%.

[3] Hand (H) or machine (M). Mechanical field loading is with the modified Curl potato loader. Piler is the modified Parma Water Lifter Piler with distribution extension.

Appendix Table 3. Summary of treatments and results of bulk onion storage experiment, Shigeta storage, 1968-69.

Treatment[1]		Location of sample in bulk bin	Handling in storage[2]	Rots	Baldness	Machine cuts and bruises
				%	%	%
C-1	sampled after unloading	front	M	22.3	.66	2.6
C-2	sampled after unloading	middle	M	18.1	.23	4.5
C-3	sampled after unloading	back	M	18.9	.43	4.2
C-4		front, top	H	8.74		
C-5		middle, top	H	9.33		
C-6		back, top	H	11.46		
C-7		front, 4' down	H	10.11		
C-8		middle, 4' down	H	14.64		
C-9		back, 4' down	H	18.1		
C-10	between ducts	front, 7' down	H	9.15		
C-11	above duct	front, 7' down	H	8.53		
C-12	between ducts	middle, 7' down	H	9.6		
C-13	above duct	middle, 7' down	H	7.36		
C-14	between ducts	back, 7' down	H	25.85		
C-15	above duct	back, 7' down	H	18.56		

[1]Onions were stored in one 32'x60' compartment in the 96'x60' Shigeta storage at New Plymouth. All onions were mechanically topped, after field curing, with Shigeta topper, and mechanically loaded with a potato loader. Loaded into storage in October and unloaded beginning January 13. The storage unit has a straw-covered earth floor. Forced-air ventilation is provided at 0.55 cfm/ft^3 through three 60' lateral ducts per compartment.

[2]Machine (M); hand (H). Mechanical loader used to unload onions from storage was the Spud-nic potato loader.

Appendix Table 4. Summary of treatments and results of bulk onion storage experiment, 1969-70.

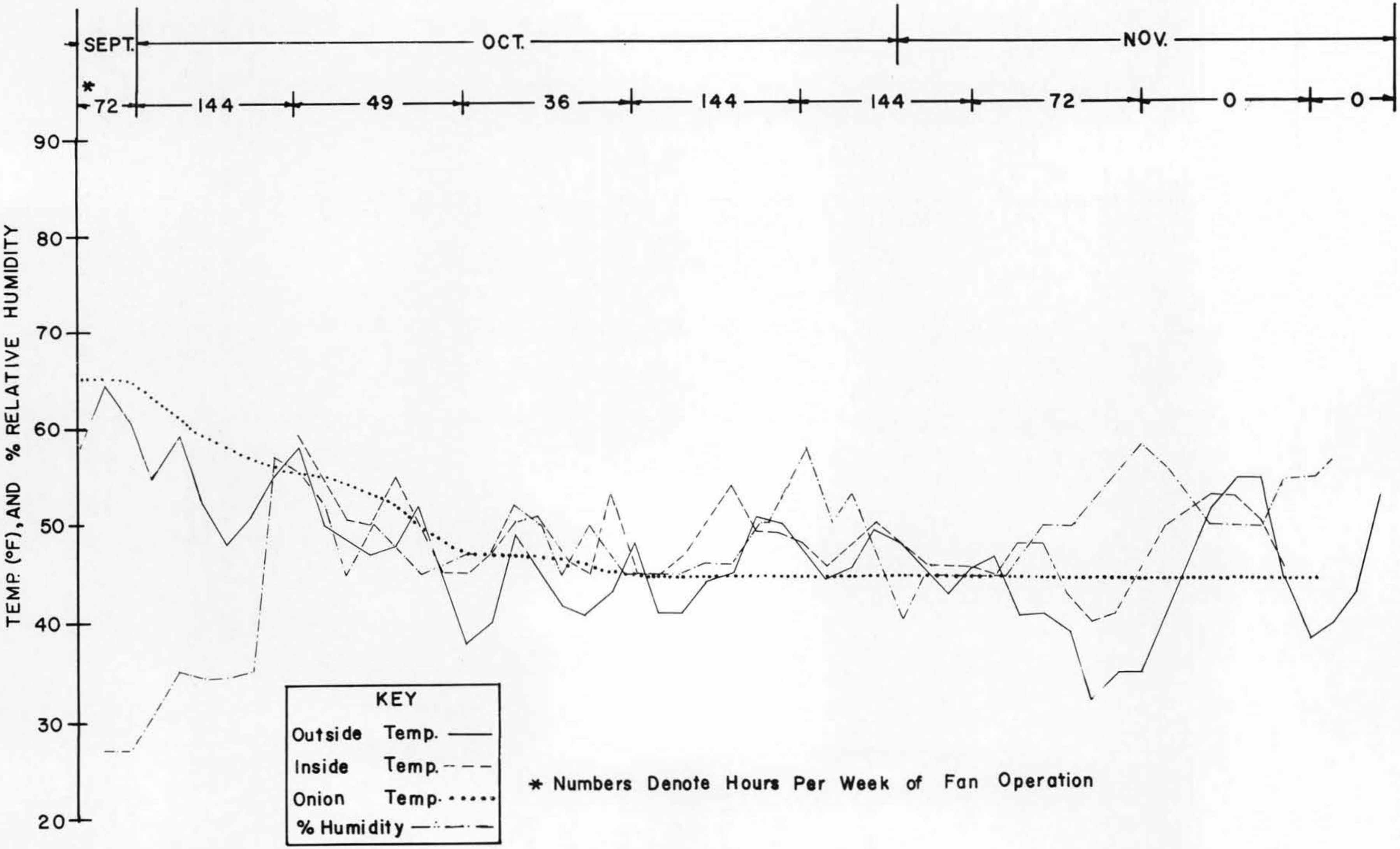
Treatment[1]		Type of storage[2]	Handling[3] Field	Storage	Rots	Sample wt. loss	Untopped	Stained
					%	%	%	%
D-1	untopped (a)	sack	H	H	2.4	--	76.6	--
D-2	Russell topper (c)	sack	H	H	3.7	--	17.0	34.0
D-3	hand-topped (a)	sack	H	H	3.2	--	5.1	--
D-4	hand-topped (a)	sack	H	H	6.3	--	5.7	--
D-5	untopped (b)	sack	H	H	1.5	--	86.6	--
D-6	Russell (c)	sack	H	H	4.8	--	20.9	13.7
D-7	hand (a)	sack	M	H	11.0	4.5	4.0	--
D-8	hand (a)	sack	M	P	21.9	--	0.3	--
D-9	untopped (b)	sack	M	H	0.4	3.3	82.7	--
D-10	untopped (b)	sack	M	P	6.9	--	66.7	--
D-11	Russell (c)	sack	M	H	16.9	4.9	19.7	--
D-12	Russell (c)	sack	M	P	19.1	--	14.0	--
D-13	hand (d)	sack	M	H	7.0	--	3.7	--
D-14	hand (d)	sack	M	P	7.9	--	2.0	--
D-15	hand (d)	bulk	M	P	13.5	--	1.8	--
D-16	Russell (c)	bulk	M	P	19.3	--	15.8	15.8
D-17	untopped (b)	bulk	M	P	8.9	--	85.0	--
D-18	Oppel (b)	bulk	M	P	16.9	--	12.3	--
D-19	hand (a)	bulk	M	P	35.2	--	13.5	--
D-20	Russell (c)	tote[4]	M	T	6.6	--	15.6	26.6
D-21	hand (d)	tote[4]	M	T	6.0	--	6.4	--

[1] All treatments were undercut on Sept. 20 and semi-field cured. Lots (a) and (d) were topped Sept. 30 and Lot (c) on Oct. 8. Lot (a) was stored on Oct. 8 before a rain; Lots (b), (c), and (d) on Oct. 9 after rain.

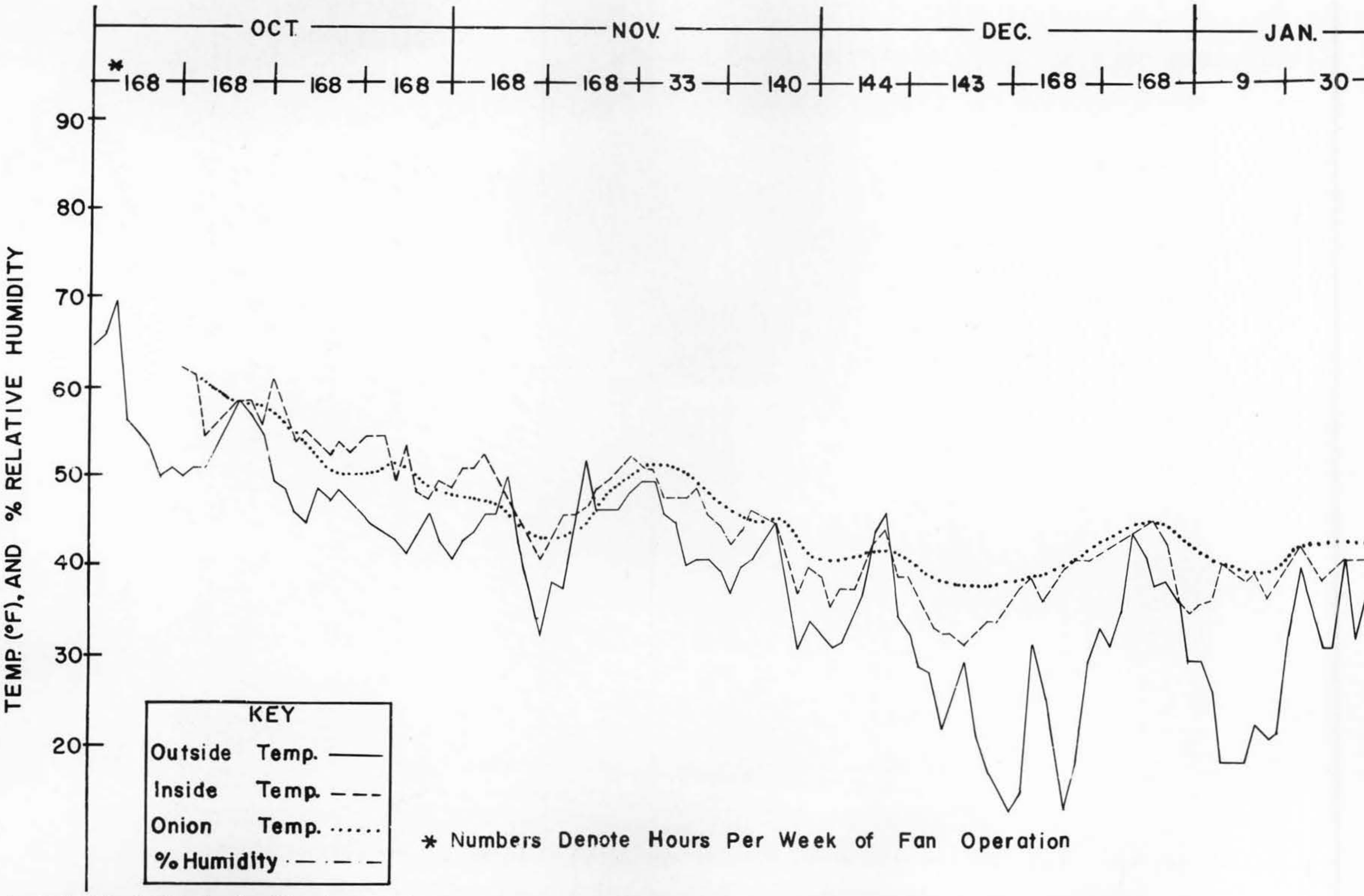
[2] Bulk - stored onions were in force - ventilated 18'x24'x7½' deep bin. Air-flow rate was 1.3 cfm/ft³ for curing (11 days) and 0.7 cfm/ft³ for cooling and storage. Sacks are well-ventilated sample sacks using the same air as bulk onions. All removed from storage Jan. 8, 1970.

[3] Hand (H); machine (M); piler (P); lift truck (T). Machine field loading was with the modified Curl potato loader. The piler was the modified Parma Water Lifter Piler with the distribution extension.

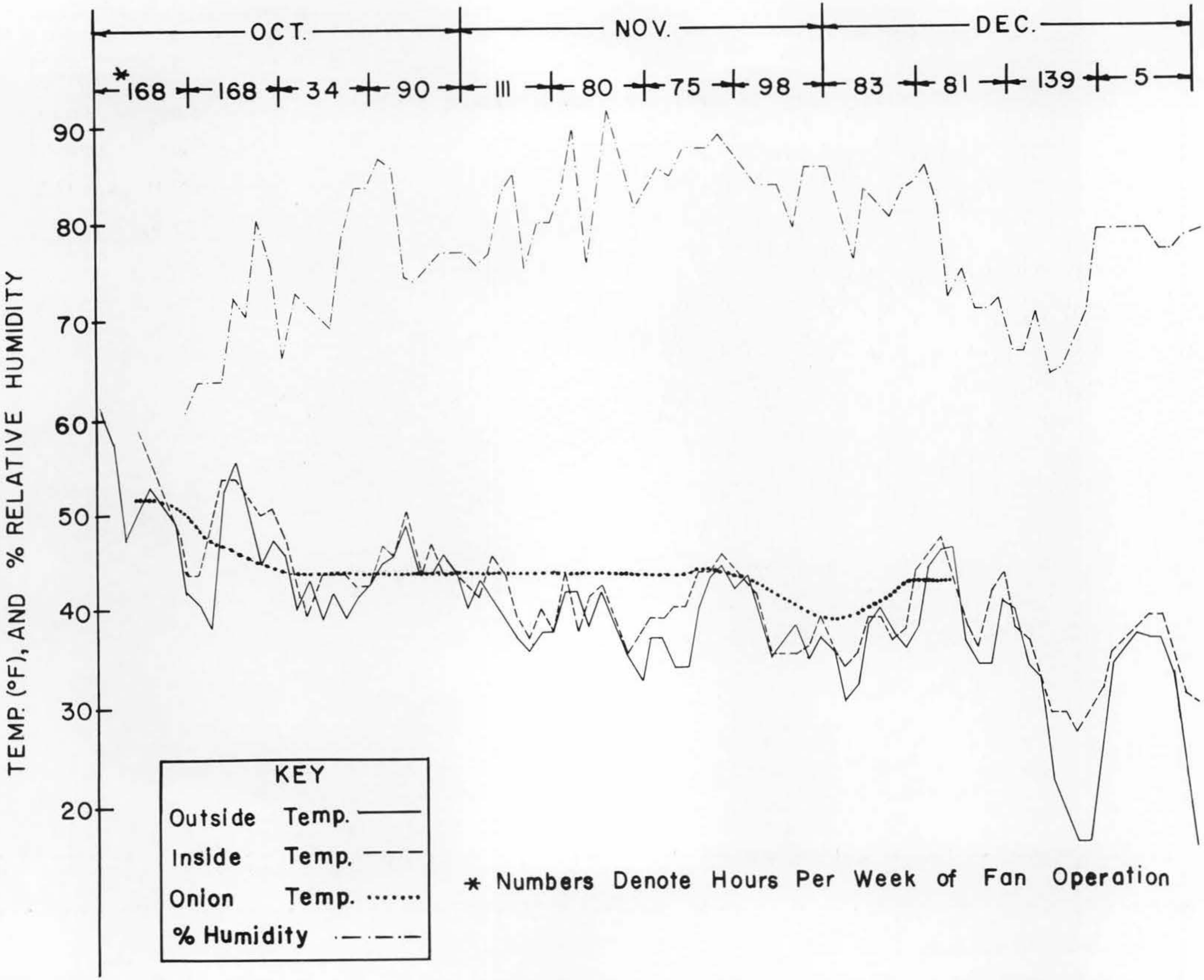
[4] Tote bins for treatment D-20 were stored in the Young storage; for D-21, in the Nyssa storage.



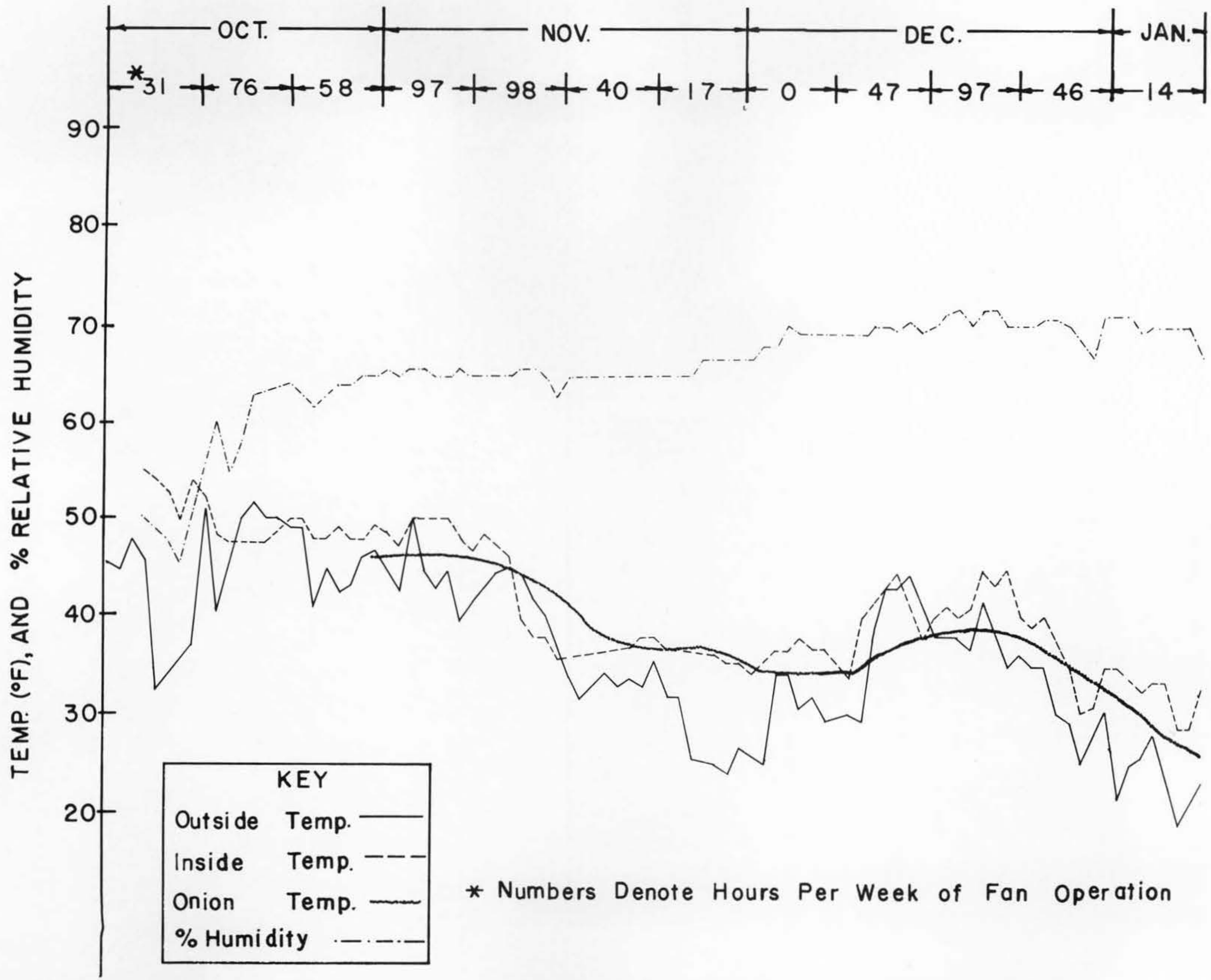
Appendix Fig. 1. Relative humidity, hours of fan operation per week, and temperatures recorded during the 1966-67 bulk onion storage test, Ford storage, Parma.



Appendix Fig. 2. Relative humidity, hours of fan operation per week, and temperatures recorded during the 1967-68 bulk onion storage test, Ford storage, Parma.



Appendix Fig. 3. Relative humidity, hours of fan operation per week, and temperatures recorded during the 1968-69 bulk onion storage test, Ford storage, Parma.



Appendix Fig. 4. Relative humidity, hours of fan operation per week, and temperatures recorded during the 1969-70 bulk onion storage test, Ford storage, Parma.