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Potato Weight Losses, Quality Changes and Cost Relationships During Storage

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College of Agriculture

Summary and Conclusions

The data obtained during this 2-year storage study with Russet Burbank potatoes show the lowest weight loss and highest fresh and processing quality was maintained when:

1. Storage temperature was held at 45° F.

2. Intermittent rather than continuous ventilation was used.

3. Relative humidity of the ventilating air was maintained at 95% or higher rather than 85%.

Least weight loss occurred when air containing 95% relative humidity was supplied on an intermittent basis at the rate of ½ cubic foot per minute per cwt of potatoes.

These data also show that:

1. The recovery rate, flavor, texture, and crispness of shoestring cut frozen french fried potatoes was better when the tubers were ventilated with air containing 95% relative humidity rather than 85%.

2. Potato granules manufactured from tubers which had been ventilated with 95% relative humidity air had higher quality characteristics than those processed from tubers ventilated with 85% relative humidity air.

3. Potato flakes made from tubers ventilated with air containing either humidity rated equal and acceptable as to texture, flavor, and after four hours on the steamtable. However, the sugars were found to be lower in the tubers ventilated with 95% relative humidity air. The color of the flakes was acceptable at both relative humidities.

4. The flavor, odor, and reconstituted product of dehydrated diced potatoes were equal and acceptable from the tubers which had been ventilated with air containing either relative humidity.

The costs associated with different lengths of storage season and different storage management practices were also estimated as a part of this research. Three categories of costs were considered:

1. Cost of weight loss.
2. Cost of quality change.
3. Ownership and operating costs.

After 330 days in storage the cost of weight loss was estimated to be:

1. $.09 per cwt of potatoes stored when the temperature was maintained at 45° F, the fans operated on intermittent basis, and the relative humidity maintained at 95%.

2. $.11 per cwt when fans were operated continuously using 95% relative humidity air.

3. $.15 per cwt when air containing 85% relative humidity was used intermittently for ventilation.

4. $.17 per cwt when tubers were ventilated continuously using air at 85% relative humidity.

The cost of quality deterioration after 330 days storage was estimated to be an additional:

1. $.09 per cwt when 95% relative humidity was used on an intermittent basis.

2. $.10 per cwt when fans were operated continuously using 95% relative humidity air.

3. $.17 per cwt with 85% relative humidity air and intermittent ventilation.

4. $.22 per cwt using 85% relative humidity air and continuous ventilation.

Storage ownership and operating costs were estimated for well-constructed facilities capable of maintaining the recommended storage environment for different lengths of storage season. These costs were estimated to be:

1. $.26 per cwt of potatoes stored in a non-refrigerated facility up to 4 months.

2. $.31 per cwt for potatoes stored in a non-refrigerated facility up to 8 months.

3. $.38 per cwt for potatoes stores in a refrigerated facility for as long as 12 months.

Acknowledgements

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Potato Weight Losses, Quality Changes And Cost Relationships During Storage

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Potatoes have long been regarded as a storable commodity. However, a high degree of risk and uncertainty was traditionally associated with storage operations due to the perishability of the potato tuber as well as the unpredictable nature of potato prices. In recent years significant advances have been made in the technological aspects of potato storage. As a result, quality deterioration and weight losses have been reduced. Fall crop potatoes can now be stored for a full year or longer without serious quality deterioration and with much lower weight loss than was formerly possible.

These technological advances provide an opportunity to reassess the storage and marketing alternatives facing the Idaho potato industry. Such reassessment implies a need to decide whether or not to adopt the new storage practices. Decisions relating to the volume of potatoes stored and the timing of sale or use of these potatoes throughout the storage season also need to be re-evaluated. The purpose of the research described in this report is to help firms make such evaluations. Of particular importance is the question of extending the storage and marketing season to provide 12-month operations.

The first phase of this report deals with the technological aspects of potato storage operations. Data on weight and quality changes in relation to storage environment and length of storage season were obtained through experiments at the University of Idaho Aberdeen Branch Agricultural Experiment Station. Additional data and observations on changes in processed product recovery rates and quality of finished products were obtained through cooperation with potato processing firms.

The second phase of the report considers the cost associated with potato storage operations. The technical data from phase one and information from industry sources are used to determine seasonal cost relationships under specified conditions. The factors which firms should consider in estimating their own storage costs are also presented.

The purpose of this report is to provide a framework for decision-making which may be used by firms in determining their own courses of action. While the study was directed toward the storage and marketing of Russet Burbank potatoes from Idaho, the report may also have implications for other potato producing areas.

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Potato Weight and Quality Changes During Storage

A number of factors or conditions influence the amount of physical losses of potatoes that occur during storage. Some of the conditions causing loss are determined before the potatoes are placed in storage. For example, the variety of potatoes, the cultural or climatic conditions under which they were produced and harvested, and the presence or absence of injury and diseases are all factors affecting the inherent "keeping quality" or storageability of potatoes.

The effects of storage environment upon potato weight or quality losses have been studied for a long time and much progress has been made in reducing such losses. These previous studies show that relationships exist between the storage environment, storage management practices, the length of the storage season, and the level of weight or quality losses that occur during the storage period. However, certain environmental factors, such as humidity and ventilation were not completely evaluated in terms of their effects on either weight or quality changes. To obtain additional information of this nature, storage and processing experiments were conducted as a part of the research project.

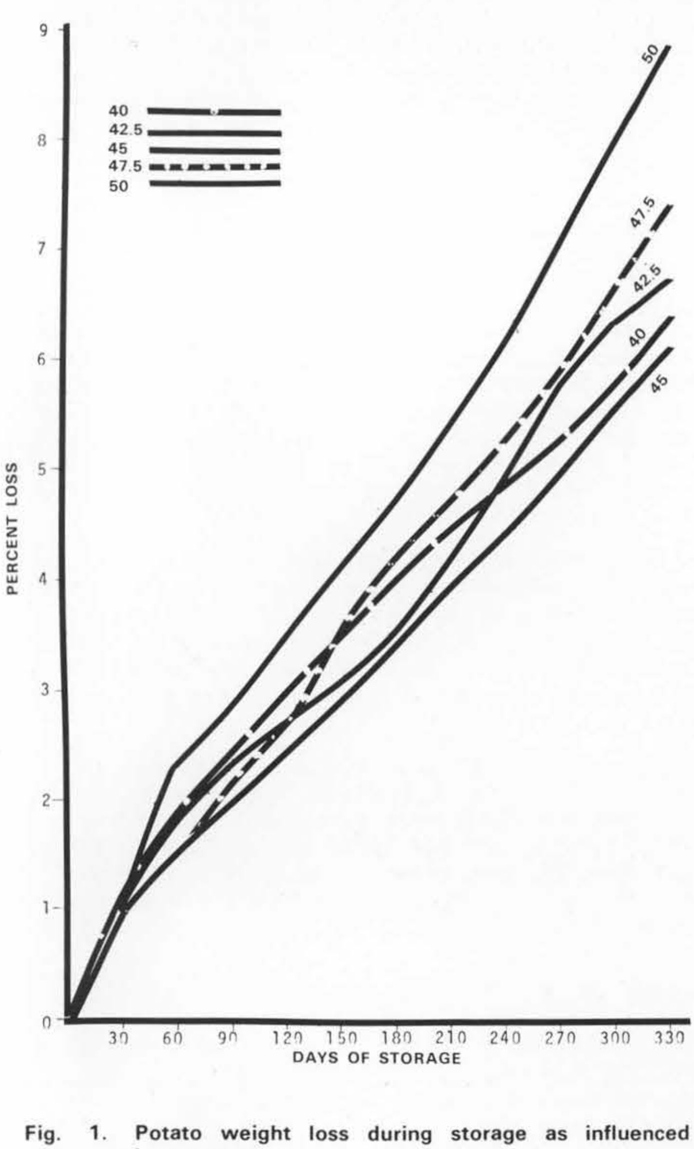

Fig. 1. Potato weight loss during storage as influenced by temperature.

In each of two years, potatoes from the Aberdeen Branch Agricultural Experiment Station were harvested, placed in storage research bins, and treated with a sprout inhibitor. The temperature, humidity, and flow rate of air through the potatoes were controlled. Weight losses of the potatoes were obtained by weighing the bins periodically throughout a 330-day storage period.

To obtain processing data, sample bins were removed from the storage at intervals. The potatoes were examined for defects, then run through the processing plant. The solids content of each lot was determined by the specific gravity method. In addition, chemical analyses were run to measure the percentage of sugars in the raw product. Finally, recovery rate and quality of the finished product from each lot of potatoes were determined.

Potato Weight Changes During Storage

Previous studies indicated that the weight loss of Russet Burbank potatoes is influenced by storage temperature as well as the number of hours, flow rate, and relative humidity of the ventilating air.

Storage Temperature and Weight Change

Other University of Idaho publications (2, 3, 4) have reported that storage at 45° F produced less weight loss in Russet Burbank potatoes than storage at any other temperature. Results of more recent studies (Fig. 1) again indicate that with the proper application of a sprout inhibitor, storage at 45° F will minimize weight loss with Russet Burbank potatoes.

Ventilation and Weight Changes

Sparks et al. (4) and Sparks, Smith, and Garner (3) reported that ½ cubic foot of air per minute per cwt of potatoes (½ cfm/cwt or 10 cfm/ton) supplied on an intermittent basis will maintain a uniform temperature throughout a pile of potatoes 20 feet deep. However, the interaction between length of fan operation and the relative humidity was not completely evaluated in terms of weight or quality change. Therefore in these studies, the flow rate of air through the tubers was maintained at a constant rate of ½ cfm/cwt while the fans were operated on a continuous or intermittent basis at each humidity.

When ventilated on an intermittent basis, the tubers were supplied with air only as often and as long as was necessary to maintain a uniform temperature within the mass of potatoes. With continuous ventilation, the air was supplied 24 hours every day during the storage season.

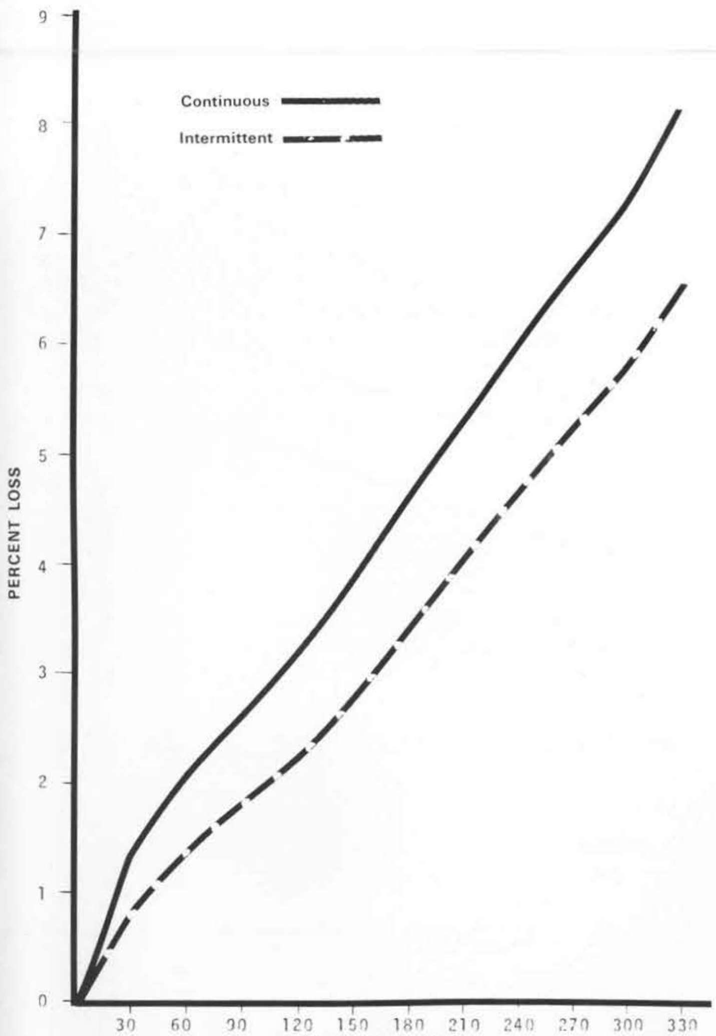

Fig. 2. Potato weight loss during storage as influenced by airflow.

Considering all bins, regardless of humidity, weight loss was lower with the intermittent ventilation (Fig. 2). Continuous fan operation permitted a 1.6% greater weight loss than ventilating with the same flow rate of air on an intermittent basis.

Relative Humidity and Weight Change

One of the most important and least studied factors affecting the weight loss of potatoes during storage is the relative humidity of the air used to maintain the temperature within the pile. When the relative humidity of the ventilating air was at least 95%, weight losses were considerably less than when it was only 85% (Fig. 3). After 330 days, the potatoes ventilated with 95% relative humidity air had lost only 5.6% of their weight compared to 9.0% for potatoes ventilated with air containing only 85% relative humidity.

Minimum Weight Change — Recommended Management

In these studies, minimum potato weight loss occurred when the tubers were maintained at a temperature of 45° F by ventilating with air containing 95% or more relative humidity at the rate of ½ cubic foot of air per minute per cwt of potatoes on an intermittent basis. Consequently these environmental conditions are recommended for the storage of Russet Burbank potatoes. The weight losses associated with these recommended practices are shown in Fig. 4. Weight loss after 330 days of storage was only 5%.

Many firms have reported losses considerably higher than these. The average weight loss experienced by the Idaho potato industry was not determined in this study. However, we assume their losses are similar to those referred to as 85% relative humidity in Fig. 4 using either continuous or intermittent ventilation. This assumption is based not only on observations of tuber quality, storage facilities, humidification procedures, and management practices, but also on comments obtained from industry personnel.

The other loss curve in Fig. 4 is the mean weight loss obtained from continuous ventilation using air containing 95% relative humidity. Even though this caused more weight loss than intermittent ventilation with 95% relative humidity air, it caused considerably less loss than intermittent or continuous ventilation using air containing only 85% relative humidity.

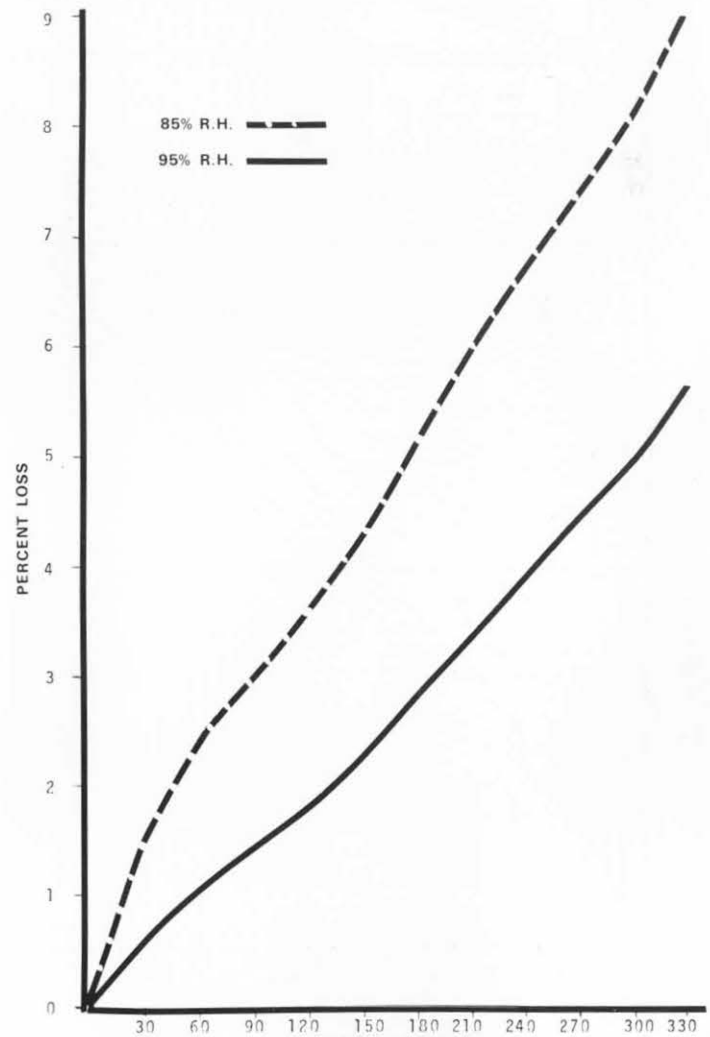

Fig. 3. Potato weight loss during storage as influenced by humidity.

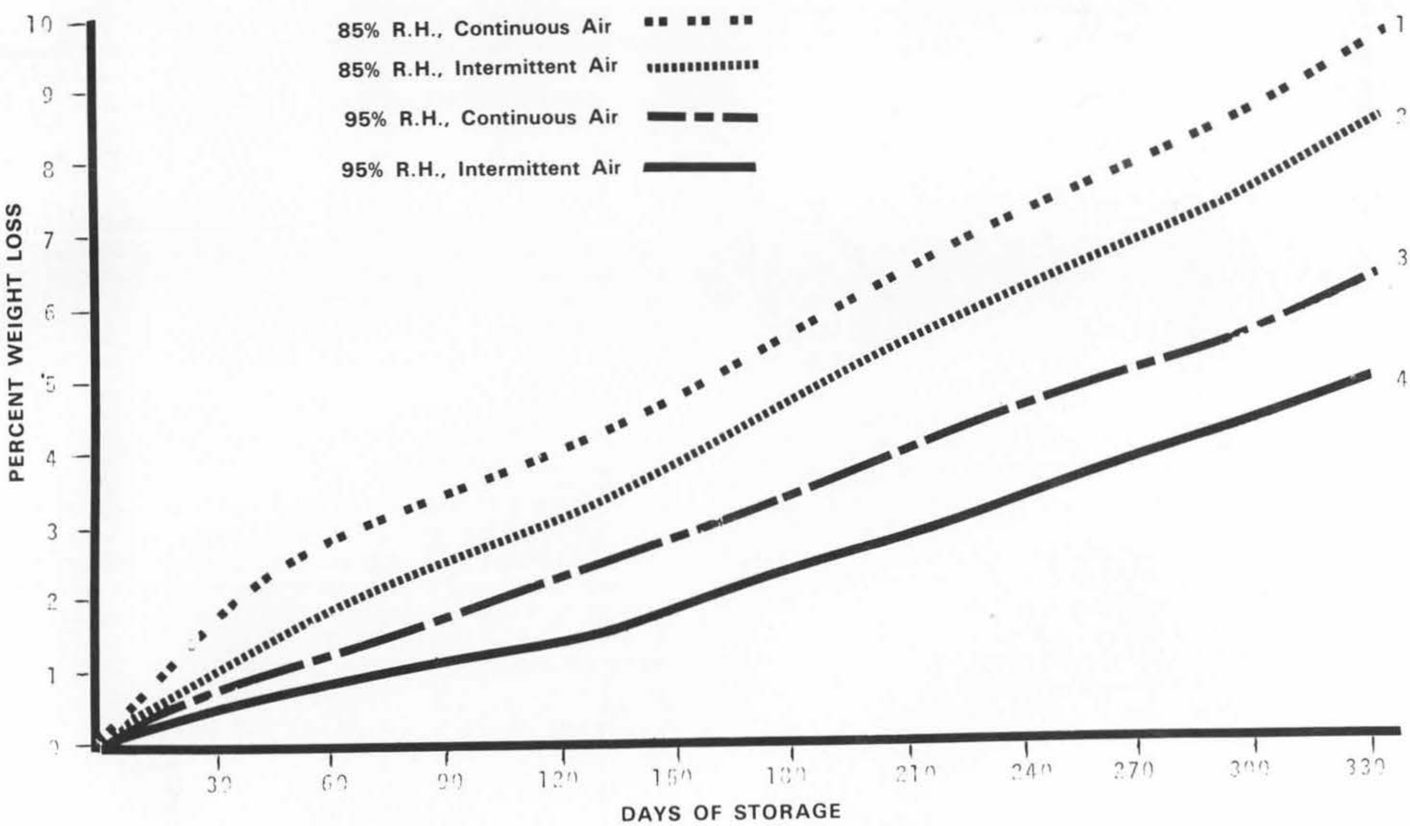

Fig. 4. Potato weight losses over 330 days as influenced by various storage practices.

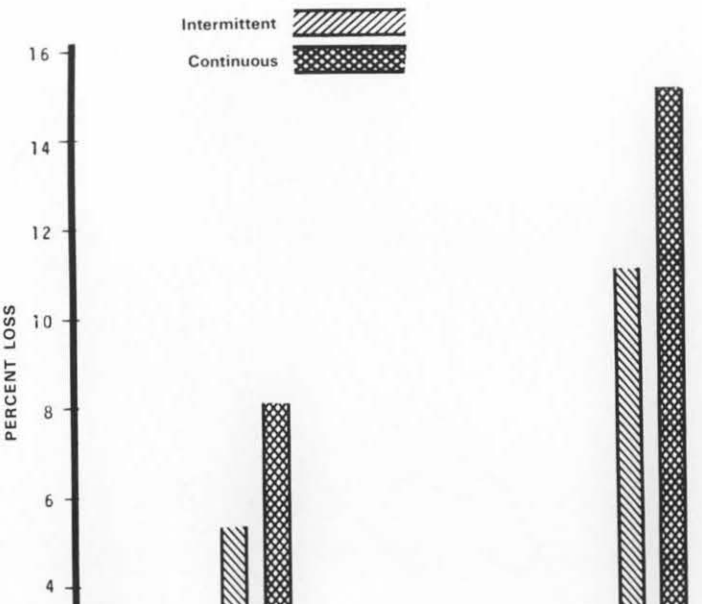

Fig. 5. Potato quality changes after 330 days storage as influenced by airflow.

Potato Quality Change During Storage

Potato quality must be considered from the standpoint of both the fresh and processing markets. The fresh market is concerned with appearance as well as cooking quality. The processing market is concerned with tuber characteristics which influence the quality of the processed product. Quality of the raw product is affected by both storage management and environmental factors during the storage period.

Grade Defects

Tubers defined as having grade defects were those which contained rot, were shriveled, or had poor appearance due to sprouting or flattening. Because of bruising, handling procedures and other factors, no attempt was made to measure grade defects at regular intervals during the storage period. Rather, these measurements were made only at the end of a 330-day storage period.

Ventilation and Grade Defects

After 330 days of storage, there was no significant difference in the percentage of rotten tubers regardless of the ventilation period (Fig. 5). However, intermittent ventilation resulted in a significantly smaller amount of flattened tubers and significantly less shriveled tubers than continuous ventilation. The intermittent ventilation also resulted in fewer sprouted tubers. In total quality changes, including rot, flat, shriveled, and sprouts, the continuous ventilation resulted in 15.1% defects compared to 11% with intermittent ventilation.

Relative Humidity and Grade Defects

There was no significant difference in rot between tubers stored at 95% relative humidity from those stored at 85% (Fig. 6).

Storage at 95% relative humidity produced significantly fewer flattened, shriveled, and sprouted tubers. A total of 18.5% grade defects was found in the tubers stored at 85% relative humidity; only 7.8% in the tubers at 95% relative humidity.

Minimum Grade Defects

Fig. 7 shows the various types and levels of grade defects at the end of 330 days storage under various storage management practices. The least quality change occurred when the tubers were maintained at 45° F by ventilating with air containing 95% or more relative humidity on an intermittent basis. There was no difference among the treatments as to the amount of rot found, but bins of tubers ventilated by either management practice using air containing 85% relative humidity had more flattened, shriveled, and sprouted tubers, and had the greatest total quality change. These changes were significantly greater than those found in the bins using 95% relative humidity air. The defect percentages found when 85% relative humidity air was used appear to be somewhat comparable to the losses reported by the industry during recent years.

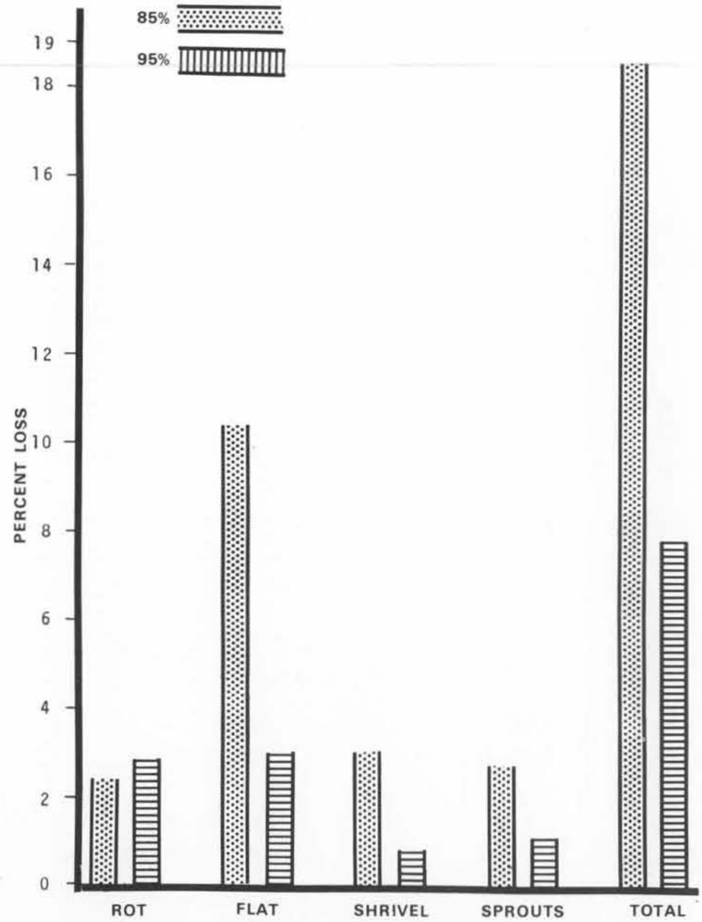

Fig. 6. Potato quality changes after 330 days storage as influenced by humidity.

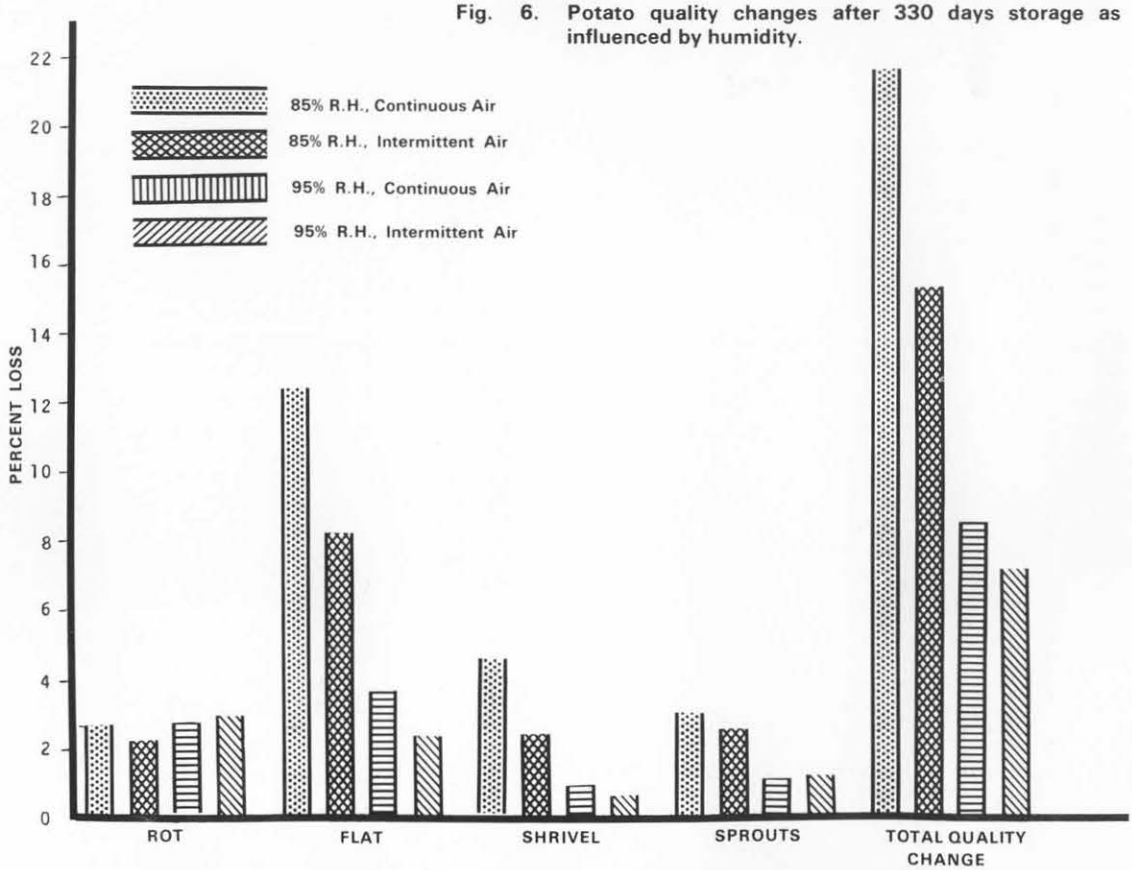

Fig. 7. Potato quality changes after 330 days as influenced by various storage practices.

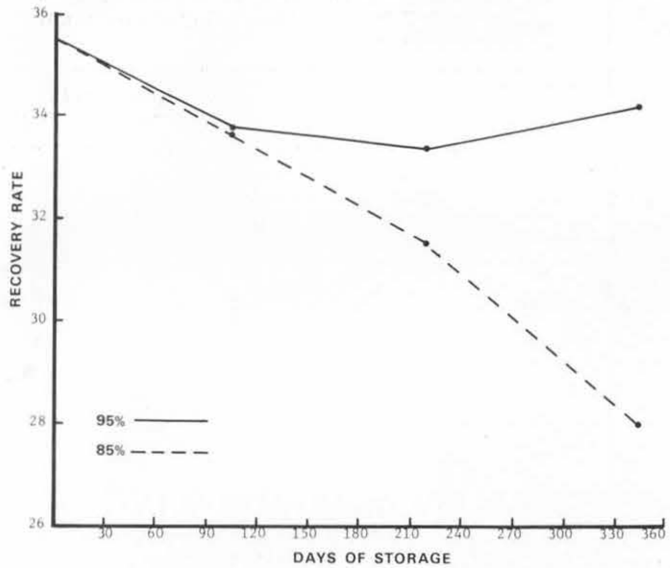

Fig. 8. Recovery rate of shoestring cut frozen french fried potatoes as influenced by humidity and duration of storage.

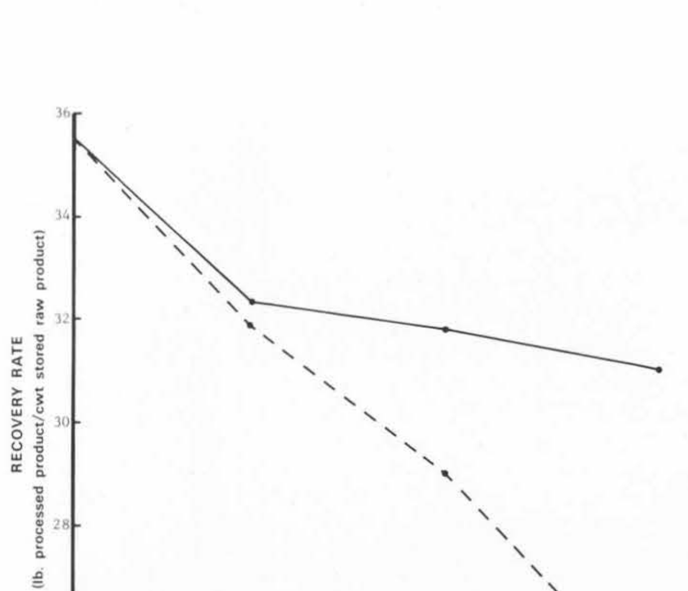

Fig. 9. Recovery rate of shoestring cut frozen french fried potatoes as influenced by humidity and duration of storage.

Recovery Rate of Frozen French Fried Potatoes

One of the most important aspects of quality to the processing industry is the percent recovery rate. It is usually defined as the number of pounds of processed product obtained from every 100 pounds of raw product, at time of processing.

During the first year of this study, potatoes from a common source were put into the research storage bins. After 30 days, a sample was removed and run through a frozen french fry plant. The recovery rate at this time was found to be 35.7% for the "shoe-string" cut french fry used throughout the study. In February, a second set of samples was processed. The potatoes ventilated with air containing 85% relative humidity had a recovery rate of 31.2%; those ventilated with 95% relative humidity air had a 32.7% recovery rate. The third sample was planned for April but the processing plant burned down in late March. The plant was not rebuilt and processing did not start again until August.

After 327 days of storage, on August 30, another series of samples was run using the new line and new processing plant. The potatoes ventilated with 85% relative humidity air had a 32.4% recovery rate compared to 34.9% for those receiving 95% relative humidity air. Although a completely new and more efficient processing plant was used in August, these data do indicate that potato tubers ventilated with 95% relative humidity air gave a higher recovery rate than those receiving 85%.

The next year, the research bins were again filled with potatoes from a common source. Some of these tubers were processed into frozen french fries at harvest time in October with a recovery rate of 35.5% (Fig. 8). After 104 days of storage, the recovery rate was 33.8% for tubers ventilated with 85% relative humidity air, and 33.9% for tubers ventilated with 95% relative humidity air.

After 220 days of storage, the recovery rate was 31.5% for tubers receiving 85% relative humidity and 33.4% for those supplied with 95%. After 347 days of storage, the final tubers from this common source were processed. The recovery rate for tubers ventilated with air containing 85% relative humidity was 28.1%; for those ventilated with air containing 95% relative humidity, it was 34.4%. This 6.3% is a highly significant difference in favor of ventilating potatoes with air containing at least 95% relative humidity rather than 85%.

If the data from these above trials are computed on the basis of the recovery rate of processed product over 100 pounds of raw product put into the storage structure at harvest time, the recovery rate curve is slightly altered as shown in Fig. 9.

The formula used to calculate the recovery rate from harvest (RRFH) is as follows:

$$RRFH = \frac{Wt. - (WL + Rot)}{Wt.} \times \%\ \text{Recovery Rate No. 1}$$

Wt. = the number of pounds of potatoes put into storage at harvest time

WL = the number of pounds of weight lost during storage

Rot = the number of pounds of potatoes lost due to rot during storage

% recovery rate No. 1 = the number of pounds of processed product per 100 pounds of raw product at time of processing.

The only real difference between the two methods of calculating the recovery rate is that the RRFH (recovery rate from harvest) takes directly into account the weight and rot losses,while the recovery rate at time of processing does not. Either method of calculation is acceptable, provided the interpretation of results is properly understood. Most firms, at present, use the recovery rate at time of processing method of computation.

Processed Product Quality

Many workers have shown that potatoes stored at a temperature of 40° F or lower have a higher sugar content and give darker colored potato chips and french fries than tubers stored at warmer temperatures. Work at this station (1, 2, 5) shows that french fry color, sugar content, flesh color, mealiness, sloughing, and specific gravity are related to the temperature at which the raw product is stored. Storage temperatures lower than 45° F resulted in poorer quality. Storage temperatures of 47.5° F or 50° F resulted in a greater loss of weight, and did not give significantly better quality from the standpoint of sugar buildup, flesh color, mealiness, or fry color than storage at 45° F. A storage temperature difference of only 2.5° F (42.5° F as compared to 45° F) was enough to make a difference between acceptable and non-acceptable color on unblanched french fried potatoes.

Through the cooperation of several potato processing companies, additional data were obtained on potato granules, potato flakes, dehydrated diced potatoes, and french fried potatoes. Since there was no way of obtaining samples large enough to get quality analyses on the various types of processed products during the storage season, this additional information was obtained only from potatoes stored for at least 330 days. The tubers were taken from the various treatments and run through the pilot plants or quality testing laboratories under lot number.

Table 1. Quality of frozen french fried potatoes as influenced by storage of raw product for 330 days at different relative humidities.

Quality characteristic	Relative humidity	
	85 %	95 %
Color	Good 2.0	V. Good 1.5
Flavor	Good-	Good
Texture	Good	Good+
Crispness	C	B
Limp units	9	6

Table 2. Quality of potato granules as influenced by storage of the raw product for 330 days at different relative humidities.

Quality characteristics	Relative humidity	
	85 %	95 %
% Solids	23.4	22.9
% Peel loss	10.6	8.7
% Trim loss	9.0	7.6
Residue (GMS)	8.1	7.4
Seed cleaning	50.2	48.0
+50 Mesh	12.4	11.8
-50 Mesh	38.0	38.5

Frozen French Fries

The color of frozen french fried potatoes was better when they were made from tubers ventilated with air containing 95% relative humidity (Table 1). The flavor, the texture, and the crispness were also better. There were also fewer limp units — another way of measuring crispness — in the potatoes ventilated with 95% relative humidity air than 85%.

Potato Granules

The data supplied by granule manufacturers show that the solids content of potatoes ventilated with air containing 85% relative humidity was greater than tubers ventilated with 95% relative humidity air (Table 2). However, the peeling and trim losses were less on the tubers ventilated with 95% relative humidity air. The waste products from the granule process - residue and seed cleaning - as well as the large granules or clumps of granules which would not pass through a 50 mesh screen were less from the tubers ventilated with air containing 95% relative humidity. Thus, in every quality aspect, potato granules made from tubers ventilated with air containing 95% relative humidity had higher quality characteristics than granules made from tubers ventilated with air containing 85% relative humidity.

Potato Flakes

The solids were higher in the tubers ventilated with 85% relative humidity air than 95% (Table 3). While the color of the flakes was slightly better from tubers ventilated with air containing 85% relative humidity, each was acceptable. The product from tubers stored at either humidity was rated equal and acceptable for texture and flavor, and after 4 hours on the steamtable. However, a low sugar content is one of the most important quality characteristics. In these samples, the sugars were lower in the tubers ventilated with 95% relative humidity air than 85%. This again indicates the value of storing potatoes at a high humidity.

Table 3. Quality of potato flakes as influenced by storage of the raw product for 330 days at different relative humidities.

Quality characteristic	Relative humidity	
	85%	95%
% Solids (2 stage)	23.4	22.2
% Sugar	4.1	3.5
Color	69.0	68.0
Texture	A	A
Flavor	Good	Good
4 hour steamtable	Good	Good

Dehydrated Diced Potatoes

The percent solids was higher for tubers ventilated with air containing 85% relative humidity (Table 4). Flavor and odor quality characteristics were equal and acceptable. The reconstitution ratio was slightly higher from the potatoes ventilated with 85% relative humidity air but the color of the reconstituted product was better from the tubers ventilated with air containing at least 95% relative humidity.

Table 4. Quality of dehydrated diced potatoes as influenced by storage of the raw product for 330 days at different relative humidities.

Quality characteristics	Relative humidity	
	85%	95%
% Solids	22.3	21.5
Visual color	Sl. grey	Good
Flavor	V. Good	V. Good
Odor	V. Good	V. Good
Reconstitution ratio	3.6:1	3.5:1

Summary

All data in this section pertains to processed products made from tubers that had been stored for at least 330 days. From these data it appears that each of the processed products had acceptable quality characteristics. When the temperature of the tubers was maintained at 45° F by ventilating with air containing at least 95% relative humidity, higher quality processed products resulted than when 85% relative humidity air was used.

Storage Cost Relationships

A complete analysis of storage costs would involve consideration of a number of variables. The type of storage facility, the size or capacity of the facility, the length of the storage season, and the internal storage environment maintained during the storage period can all be expected to influence the cost of storing potatoes. Moreover, these cost relationships might be expected to differ depending on the economic and technological conditions in different geographic areas at different points in time.

Consideration of all these factors was beyond the scope of this study. Rather, major emphasis was placed on the relationship between storage environment, length of storage period, and costs. The costs presented were estimated on the basis of the physical loss relationships described in previous sections of this report along with informal observations of cost conditions facing the potato industry in Idaho. These estimates reflect certain cost and price information reported by potato storage owners and related industry representatives. However, no attempt was made to systematically collect or tabulate cost data throughout the industry. Consequently, the costs presented should not be interpreted as average storage costs in Idaho. Instead, they are estimates of costs which, in the judgment of the authors, would be incurred under Idaho conditions if the specified storage environment were to be maintained over the specified length of storage period.

The total costs associated with potato storage operations can be considered in three separate categories. The first two categories represent losses during the storage period: (1) shrinkage or weight loss and (2) quality deterioration. The previous section indicated that both of these types of physical storage losses can be reduced by maintaining a proper environment. However, some level of losses must be expected even under ideal conditions. The third category involves the direct costs of owning and operating storage facilities.

Costs Associated with Storage Losses

Physical storage losses can be converted to monetary costs by assessing a value to the weight and quality changes that occur during storage. A problem arises, however, in establishing this value in light of the quality variation among individual lots of potatoes and the variation in potato prices within the industry.

The value used in estimating the monetary costs of storage losses in this study was $1.78 per cwt. This is an estimate of a typical or representative contract price received by Idaho growers for field-run potatoes at harvest time during the 1970 season. This estimate assumes that a typical lot of potatoes will grade 60% U.S. number ones at $2.35 per cwt, 35% U.S. number two processor grade at $1.05 per cwt, and 5% tare or unusable potatoes. The costs associated with each level of losses were computed by multiplying the respective physical losses by this estimated value.

Table 5. Cost of potato weight losses as influenced by type of storage practices and length of storage season.

Days in storage	Cost of Losses by type of storage practices			
	95% R.H. Int. fan	95% R.H. Cont. fan	85% R.H. Int. fan	85% R.H. Cont. fan
	$/cwt			
30	.0078	.0141	.0198	.0335
60	.0134	.0230	.0344	.0513
90	.0182	.0320	.0454	.0600
120	.0235	.0404	.0554	.0707
150	.0315	.0491	.0676	.0844
180	.0406	.0596	.0824	.0999
210	.0495	.0703	.0965	.1152
240	.0582	.0801	.1093	.1282
270	.0684	.0895	.1223	.1412
300	.0776	.0981	.1340	.1533
330	.0895	.1105	.1501	.1705

Cost of Weight Losses

The minimum weight loss curve shown in Fig. 4 was obtainable only when recommended environmental conditions were maintained throughout the storage period. The other curves indicated the losses when certain deviations from the recommended practices occurred. These data were used in connection with the value estimate described above to construct Table 5.

The minimum weight loss after 330 days in storage was 5.03% of the potatoes placed in storage. This minimum level of loss resulted from maintaining the storage temperature at 45° F, by ventilating with air containing at least 95% relative humidity at a rate of ½ cubic foot of air per minute per cwt, and operating the fans on an intermittent basis. With potatoes valued at $1.78 per cwt, the cost associated with this loss was approximately $.09 per cwt of potatoes stored. This would compare with about $.11 per cwt when the same environmental conditions were maintained except that the fans were operated continuously during the storage period. When the relative humidity of the ventilating air was only 85% the costs of weight losses were estimated at $.15 and $.17 per cwt respectively with intermittent or continuous fan operation.

Table 6. Cost of potato quality changes as influenced by type of storage practices after 330 days in storage.

Type of defect	Cost by type of storage practice			
	95% R.H. Int. fan	95% R.H. Cont. fan	85% R.H. Int. fan	85% R.H. Cont. fan.
	$/cwt.			
Rotted	.0525	.0479	.0390	.0465
Flattened	.0212	.0328	.0735	.1105
Shriveled	.0061	.0091	.0214	.0326
Sprouted	.0101	.0098	.0224	.0267
Total	.0899	.0996	.1563	.2163

Cost of Quality Changes

Potatoes during storage also suffer some deterioration in quality. Some tubers will rot, flatten, shrivel, and sprout during storage and should be counted as part of the cost of storage. The percentages of each of these grade defects occurring after 330 days storage under four types of storage environment were shown previously in Fig. 7.

Assuming that all of the potatoes in the rot category, and 50 percent of the tubers in the flattened, shriveled, and sprouted categories are unusable, cost estimates due to quality changes during storage were calculated. Those estimates are shown in Table 6.

Only 5.04% of the potatoes stored were considered "unusable" after 330 days storage under 95% relative humidity and intermittent fan operation. This multiplied by the $1.78 per cwt value assumed for the potatoes equals a loss of $.09 per cwt. When fans were operated continuously with the same relative humidity, the cost of quality loss was estimated to be $.10 per cwt. When the relative humidity of the ventilating air was only 85%, these costs were estimated at approximately $.16 per cwt under intermittent fan operation and $.22 per cwt under continuous fan operation.

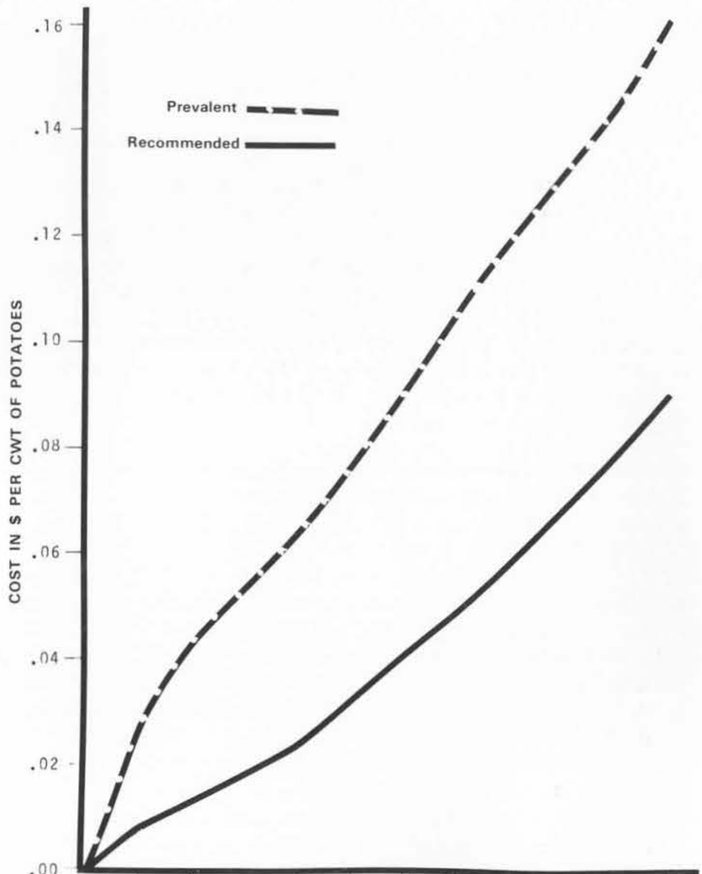

Fig. 10. Cost of potato weight loss during storage as influenced by recommended or prevalent storage practices.

Ownership and Operating Costs

The cost relationships described in the previous two sections involved losses of potatoes resulting from shrinkage and quality deterioration during storage. These costs represent resources which were actually expended in producing the potatoes. They might also be interpreted as potential income which was never realized. In contrast, the third category of costs involves additional expenditures by the firm in order to provide storage services. These are the costs associated with the ownership and operation of storage facilities.

Analysis of the first two cost categories involved relationships between storage environment, length of the season, and cost of potato losses. However, these relationships involved only a rather narrow range for the two environmental conditions studied — 85% vs 95% relative humidity and the two management practices — continuous vs intermittent ventilation. In light of the small additional investment required to maintain humidity at 95%, the additional cost per cwt of potatoes stored during the life of the facilities would appear to be negligible. In a similar vein, the ownership and operating costs associated with intermittent rather than continuous ventilation are practically nil. Very little additional investment would be required to equip fans with time clocks or thermostatic controls, but this would be at least partially offset by lower power usage under intermittent fan operation. Consequently, no attempt was made to differentiate costs in relation to storage environment in this section. Instead, costs are estimated in relation to length of storage season.

In order to relate storage cost to length of season, separate ownership and operating costs were estimated for refrigerated and non-refrigerated storage facilities. It is assumed, however, that refrigerated storage would only be used for potatoes stored into the late spring or summer months.

There are some storage facilities still in use in Idaho which do not provide the minimum level of environmental control specified in this study. These units probably incur lower annual ownership and operating costs than those specified below. However, the risks associated with such facilities are difficult to assess. With good luck, potatoes can be stored over several months without excessive losses. On the other hand, losses can be very high even over a very short period if potatoes begin to deteriorate. Owners of storages without provisions for environmental control may want to compare their losses and costs against those specified in this study in determining the need for such control in present or prospective facilities. Few, if any, storage facilities have been built in recent years which do not provide some facilities for forced air ventilation and temperature control.

Table 7. Representative costs of ownership and operation for non-refrigerated and refrigerated potato storages.

Cost elements	Non-refrigerated Storage 1-4 mos.	Non-refrigerated Storage 5-8 mos.	Refrigerated Storage 9-12 mos.
Depreciation	.05	.05	.07
Interest, taxes, insurance	.06	.06	.07
Handling	.13	.13	.13
Operation and maintenance	.02	.03	.07
Sprout inhibitors	.00	.04	.04
Total	.26	.31	.38

Estimates of the ownership and operating costs associated with well-constructed, well-managed potato storages are presented in Table 7. Several individual elements are included within this cost category. The bases for estimating each of these elements are discussed in the following sections.

Depreciation

Depreciation costs for non-refrigerated storages were estimated on the basis of $1 per cwt of capacity and a 20-year economic life of the facility. This assumes a well-insulated structure complete with ventilating and humidifying equipment. An additional 2 cents per cwt of capacity was estimated as annual depreciation for a refrigeration unit required for longer storage seasons.

No attempt was made to relate storage construction costs and hence annual depreciation charges to specific sizes or types of facilities. On a logical basis, it would seem that some cost savings would be gained by building a larger rather than a very small facility. However, such savings appear to be rather small after some minimal scale is reached. For example, wide structures require heavier trussing and support. The duct work and ventilating equipment also become duplicative in very large structures. Consequently, we can assume that the depreciation cost estimates in Table 7 apply to a range of sizes from about 20,000 to 75,000 cwt capacity.

Similarly, we assumed that the depreciation charges shown in Table 7 apply to a rather wide range of structural types and ventilating systems. The initial investment may vary depending on the basic building materials (concrete, steel, or wood), insulating materials, and ventilating systems used in the facility. However, some of these differences in initial investment are offset by differences in length of life and annual maintenance requirements associated with both the size and storage type variables.

Interest, Taxes, and Insurance

Investment in storage facilities requires a considerable capital outlay and frequently requires borrowed funds for financing. The interest rate and terms of repayment vary from one lending institution to another. No attempt is made to account for all such variation in financing charges. For the purpose of this analysis, interest is charged at a rate of 6% against the average level of investment (6% times one-half of the initial investment).

Insurance rates and taxes also vary among firms. A charge of 3% of the initial investment level is assessed for these costs.

Handling

This element of cost was estimated to be $.13 per cwt. Some variation can be expected among different operators depending on the handling system used. This estimate includes the costs of unloading and piling the potatoes in the storage as well as the cost of removal from storage. Trucking costs from the field to storage or from the storage facility to market are not considered in the estimate shown in Table 7. Handling costs are incurred regardless of the length of storage season. Consequently, this element is shown as a constant in Table 7.

Operation and Maintenance

This element of cost varies according to the length of the storage period. Its major components include the power for the ventilating and refrigerating units and the servicing required to keep them operating. These costs will be comparable for both the refrigerated and non-refrigerated storages during the first 7 to 8 months of storage, unless the refrigeration unit is utilized during the harvest season to remove field heat from the potatoes. Operation and maintenance costs will also vary among firms depending on the type of facility in question and the rates paid for utilities and services.

Sprout Inhibitors

Sprout inhibitor is usually applied only once during the storage season. Consequently, after the initial cost has been included, the length of the storage season does not alter this cost element. There are different types of inhibitors applied at different times and costing different amounts. However, an estimated value of 4 cents per cwt was charged for the application of sprout inhibitors for potatoes stored longer than 4 months

Total Ownership and Operating Costs

The totals shown in Table 7 relate the costs of ownership and operation of well-managed storages to the length of the storage season. These costs appear to be representative of the better storage operations in the Idaho potato industry. However, the reader is encouraged to make adjustments in any of the cost elements to reflect local area or firm differences.

Potato Price Increases Required To Offset Storage Losses and Costs

The loss and cost data presented in previous sections can be used to estimate the potato price increases necessary to offset the losses and costs incurred over different lengths of storage seasons under different conditions of storage environment. Table 8 contains such estimates for potatoes priced at four different levels at harvest time. These estimates were computed by adding storage ownership and operating costs to four alternative prices at harvest and dividing these totals by the percentages of original potato weight remaining after specified lengths of storage season. In Table 8 these percentages were based on the weight losses reported previously for the recommended storage environment (45° F temperature, 95% relative humidity, and intermittent fan operation). The estimates in each of the last four columns can be interpreted as

Table 8. Potato prices required to offset losses and costs under 95% relative humidity with intermittent fan operation.

Length of storage period	Storage ownership and operating costs	Potato weight losses during storage	Prices required to offset storage weight losses and costs at specified field-run prices at harvest			
			$1.00 cwt	$1.50 cwt	$2.00 cwt	$2.50 cwt
Days	$/cwt	Percent	$/cwt			
30	$ .26	.44	$ 1.27	$ 1.77	$ 2.27	$ 2.77
60	.26	.75	1.27	1.77	2.28	2.78
90	.26	1.02	1.27	1.78	2.28	2.79
120	.26	1.32	1.28	1.78	2.29	2.80
150	.31	1.77	1.33	1.84	2.35	2.86
180	.31	2.28	1.34	1.85	2.36	2.88
210	.31	2.78	1.35	1.86	2.38	2.89
240	.31	3.27	1.35	1.87	2.39	2.90
270	.38	3.84	1.43	1.96	2.48	3.00
300	.38	4.36	1.44	1.97	2.49	3.01
330	.38	5.03	1.45	1.98	2.51	3.03

Table 9. Potato prices required to offset losses and costs for potatoes stored at 85 percent relative humidity with continuous fan operation.

Length of storage period	Storage ownership and operating costs	Potato weight losses during storage	Prices required to offset storage weight losses and costs at specified field-run prices at harvest			
			$1.00 cwt	$1.50 cwt	$2.00 cwt	$2.50 cwt
Days	$/cwt	Percent	$/cwt			
30	$ .26	1.88	$ 1.28	$ 1.79	$ 2.30	$ 2.81
60	.26	2.88	1.30	1.81	2.33	2.84
90	.26	3.37	1.30	1.82	2.34	2.86
120	.26	3.97	1.31	1.83	2.35	2.87
150	.31	4.74	1.38	1.90	2.42	2.95
180	.31	5.61	1.39	1.92	2.45	2.98
210	.31	6.47	1.40	1.94	2.47	3.00
240	.31	7.20	1.41	1.95	2.49	3.03
270	.38	7.93	1.50	2.04	2.58	3.13
300	.38	8.61	1.51	2.06	2.60	3.15
330	.38	9.58	1.53	2.08	2.63	3.19

prices at which potatoes must be sold after various lengths of storage season in order to return the same income that would be realized at harvest.

Note that the price per cwt must increase by more than the direct cost of owning and operating storage facilities in order to compensate for the loss in weight of potatoes sold.

The prices in Table 8 do not explicitly reflect the quality changes which occurred during the storage period due to the fact that prices are stated on a "field-run" or "cellar-run" basis. This means, essentially, that prices must increase to the specified level in spite of any quality deterioration which occurred. Had prices been specified on a U.S. No. 1 or some other quality basis, then account would also need to be taken of the changes in price in relation to changes in quality.

Table 8 illustrates the price increases required under the minimum losses which were obtained when recommended storage practices were followed. For comparative purposes similar price estimates were prepared for a higher rate of weight losses. These estimates are shown in Table 9 and are based on the weight losses reported previously for potatoes stored at 85% relative humidity with continuous fan operation. As might be expected, the required price increases are all proportionately greater as a result of the higher weight losses. For example, with potatoes valued at $2.00 per cwt at harvest, a price increase of $.51 per cwt was required to offset the losses and costs associated with recommended storage conditions over a 330 day season. In contrast, an estimated $.63 increase was required under the higher loss rate used in constructing Table 9.

While the weight losses used in constructing Table 9 were higher than those used for Table 8, they are not particularly high in relation to losses which have been experienced by some firms in the industry. However, no attempt was made to measure average losses or costs for the industry. For similar reasons, the price increase estimates shown in Tables 8 and 9 should not be interpreted as average price increases required to cover storage costs.

In summary, these estimates as well as the storage cost estimates presented in previous sections are intended to represent the situation Idaho firms would face if they adopted improved storage practices and/or extended the length of the storage period. They are intended to be illustrative of the factors which firms should consider in evaluating their own courses of action. However, individual firms should also consider conditions which are unique to their operations in making such decisions.

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