RELATIONSHIP OF RELATIVE MATURITY AND STORAGE TEMPERATURES TO WEIGHT LOSS OF POTATOES IN STORAGE[1]

W. M. Iritani, C. A. Pettibone and L. Weller[2]

Abstract

Harvest date had no significant influence on weight loss in storage of tubers which were grown under a low fertilizer regime (vines died prematurely). However under a higher fertilizer regime, tubers harvested 21-45 days after vine kill lost significantly less weight than those harvested 2-13 days after vine kill. An average of 4 years' data indicates that tubers stored continuously at 45 F (7.2 C) lost significantly less weight than those stored at 42 F (5.5 C) or 48 F (8.9 C). This is attributed to lack of suberization and delayed maturation of tubers at 42 F resulting in increased weight loss and to higher respiration at 48 F in comparison to tubers held at 45 F storage. Considerable seasonal differences in weight loss were recorded. The 1971 growing season which was characterized by a prolonged period of extremely high temperatures resulted in tubers which lost significantly more weight during storage than was the case in the other seasons. Air ventilization rates from 20 to 80 cfm/T were used to cool potatoes from 60 F to ambient temperatures of 48 F. No significant differences in weight loss were obtained after 3 week's continuous cooling with air at 93-95% R. H. regardless of air ventilation rate.

Resumen

La fecha de cosecha no tuvo influencia significativa en la pérdida de peso de tubérculos almacenados, los cuales fueron cultivados en un regimen bajo de fertilizante (el follaje murió prematuramente). Sin embargo, bajo un regimen alto de fertilizante, los tubérculos cosechados 21-45 días después de matar el follaje perdieron significativamente menos peso que aquellos cosechados 2-13 días después de matar el follaje. Un promedio de datos de 3 años indica que tubérculos almacenados continuamente a 45°F (7.2°C) perdieron significativamente menos peso que aquellos almacenados a 42°F (5.5°C) ó 48°F (8.9°C). Esto se atribuye a la falta de suberización y maduración retardada de los tubérculos a 42°F resultando en un aumento de la pérdida de peso y a una alta respiración a 48°F en comparación a tubérculos mantenidos en el almacén a 45°F. La estación de crecimiento 1971, que se caracterizó por un periodo prolongado de

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[2] Horticulturist, Agricultural Engineer, and Technical Aide, respectively.

extremadamente altas temperaturas resultó en tubérculos que perdieron significativamente más peso durante el almacenamiento que las otras estaciones. Tazas de ventilación desde 20 a 80 cfm/T fueron usados para enfriar las papas desde 60°F a temperaturas ambiente de 48°F. No se obtuvieron diferencias significativas en pérdida de peso después de 3 semanas de enfriamiento contínuo con aire de 93-95% H.R., cualquiera que hubiese sido la taza de ventilación.

Introduction

Excessive weight loss in storage as a result of poor storage construction or poor management practices can mean considerable monetary loss to a grower as well as to a processor. Weight loss from potatoes is a result of physical movement of water out of the tubers (transpiration) and from respiration. The loss due to respiration is relatively small, amounting to approximately 10% of the total loss (6). A number of factors which influence weight loss by potatoes in storage have been studied (1,2,3,5,6,8,9,-10,12,13,17,19,20.) The most obvious factor involved is relative humidity. Schippers (15) observed that weight loss during storage was closely related to the product of the vapor pressure deficit of the storage atmosphere and length of time in storage. Sparks (19) obtained considerably less weight loss and fewer grade defects with 95% R. H. as compared to 85%.

Storage temperatures have been found to be influential in determining weight loss (4,18,19). The storage period should probably be divided into two temperature regimes. The first portion is for curing or suberization and the second, more lengthy phase, is the holding period. Singh (16) reported that potatoes held for 10-12 days at 64.4 F (18 C) lost considerably less weight during storage than those held at 42.8 F (7 C) prior to permanent storage. Sparks (18,19) reported consistently less weight loss at a storage or holding temperature of 45 F in comparison to 42 F or 48 F. No mention was made of an initial curing temperature in that study. Schippers (14) observed that curing temperature did not have much influence on subsequent weight loss during storage if it was not lower than 45.5 F. Butchbaker, et a. (4) found a reasonably good correlation ($R^2 = 0.61$) between storage temperature and weight loss of the stored tubers.

Another factor which can have an influence on weight loss is air ventilation rate. However, the available data are not in complete agreement. Ventilation rates recommended in Europe are higher than in the United States. Ophius (11) reported that increasing the quantity of air forced through potato piles resulted in little or no increase in evaporation or weight loss. Similar findings were reported by Butchbaker (4). Bennet, et al. (1) observed increased weight loss with higher air flow rates. Sparks (19) reported less weight loss of stored potatoes with intermittent ventila-

tion in comparison to continuous fan operation regardless of humidity conditions used.

With the increase in production and processing of potatoes in the Pacific northwest the requirements and manner of handling potatoes are changing. The tendency in many areas is to use increased rates of fertilizer, to strive for higher yields with the result that more potatoes are harvested and stored in less than mature condition. This study was conducted to determine the influence of factors such as relative maturity on weight loss and suggest means by which loss can be held to a minimum.

Materials and Methods

Russet Burbank potatoes grown at the Othello Field Station, Washington State University, were used in these studies. Planting, vine killing and harvest dates as well as fertilizer rates are shown in Table 1. Fertilizer rates and harvest dates were selected to obtain wide differences of maturity in terms of skin set and thickness of periderm layer. In 1970, the difference between high and low fertilizer plot was 50 lbs (22.5 kg) of N. Moreover, maturity differences were enhanced by the later planting date of the high fertility plot. For the other growing seasons, fertilizer rates of 130 lbs/A (146.2 kg/ha) of N in a triple 16 fertilizer and 320 lbs/A (363.6 kg/ha) of N were used with the same planting dates. The time between vine killing and the first harvest date varied from 2 to 13 days for the different years. The time lapse between the first and second harvest dates for the

TABLE 1.—*Planting date, fertilizer rate, percent dead vines at time of vine kill, vine killing and harvest dates of tubers used in storage and weight loss studies.*

Season	Planting date	Fertilizer rate (lbs of N)	% dead vines	Vine killing date	Harvest date
1970-71	5/ 9/70	190	50	9/10/70	9/23/70
	"	"	"	"	10/15/70
	5/27/70	240	10	9/10/70	9/23/70
	"	"	"	"	10/15/70
1972-73	4/18/72	130	70	9/15/72	9/27/72
			Second harvest date not obtained		
	4/18/72	320	5	9/15/72	9/20/72
	"	"	"	"	10/11/72
1973-74	4/18/73	130	100	Dead	9/17/73
	"	"	"	"	10/03/73
	4/19/73	320	30	9/15/73	9/17/73
	"	"	"	"	10/03/73
1974-75	4/23/74	130	100	9/16/74	9/18/74
	"	"	"	"	10/07/74
	4/23/74	320	10	9/16/74	9/18/74
	"	"	"	"	10/07/74

different years varied from 17 to 23 days. Data on second harvest for the low fertilizer rate during the 1972 season were not obtained.

Similar methods of handling the potatoes after harvest were used each year. U. S. No. 1 grade tubers were sorted out, washed and placed in 50 lb burlap bags. They were covered with plastic and allowed to suberize at 60 F (15.6 C) for one week, after which the bagged tubers were placed in controlled temperature storage of 42 F, 45 F and 48 F, with 93-95% R. H. Five bags of each treatment were placed in each of the chambers and weighed monthly from October through May to determine weight loss.

Air ventilation rate

The influence of air ventilation rate on weight loss was determined by placing approximately 500 lbs (227.3 kg) of potatoes in 2′ x 2′ x 4′ (0.6 x 0.6 x 1.2 m) boxes which were equipped with an air duct and plenum at the bottom. A small centrifugal fan was placed at the top to draw air up through the potatoes. The boxes were insulated with 1.5 inches of expanded polystyrene. Air flow rates of 20, 40, 60 and 80 cfm/T of potatoes were used. Velocity was monitored by use of an Alnor Hotwire anemometer. Warm potatoes (60 F) were placed in the boxes, which were placed in a controlled temperature room of 48 F with 93-95% R. H. The cooler air of the chamber was drawn up through the boxes continuously for a period of 3 weeks. This is equivalent to intermittent cooling of 8 hrs/night for a period of approximately 2 months. Weight loss of the boxes was determined weekly.

Weight loss potential changes

Weight loss potential changes of tubers were determined during the 1974-1975 season. Tubers from high (immature) and low (mature) fertilizer plots (refer to table 1), were placed in 42 F and 48 F controlled temperature storages with 95% relative humidity on September 24. Samples (about 30 lbs) were taken out weekly from each of the chambers, carefully weighed and then placed in a controlled storage at a temperature of 46 F (7.8 C) and relative humidity of 46-50%. After one week under these conditions, the samples were carefully reweighed. Changes in weight loss potential were determined weekly from September 24 until December 3.

Results

Results of combined 4 years statistical analyses of data are shown in Table 2. Weight loss differences due to harvest date x fertilizer rate interaction were highly significant, indicating greater weight loss of tubers from high fertilizer plots harvested shortly after vine kill as compared to those harvested later, or from low fertilizer plots where the vines had died prematurely. No differences in weight loss were obtained between the first and

TABLE 2.—*Results of combined 4 years' data on weight loss of potatoes stored 7 months.*

Percentage Total Loss 7 Months Storage

Harvest date x Fertilizer rate **

	Low (130 lbs N)	High (320 lbs N)
1st harvest	4.5	5.4
2nd harvest	4.5	4.2

** *LSD Interaction* @ 1% = 0.47

Harvest date x storage temperature (N. S.)

	42 F	45 F	48 F	Av.
1st harvest	5.3	4.3	5.2	4.9**
2nd harvest	4.5	3.7	4.7	4.3

** LSD Harvest dates @ 1% = 0.33

Harvest date x Fertilizer rate x storage temperature (N. S.)

Storage temp **	Av. % loss	Harvest date	Fertilizer rate Low	High
42 F	4.9	1st	4.6	6.0
		2nd	4.5	4.4
45 F	4.0	1st	4.0	4.7
		2nd	3.8	3.5
48 F	4.9	1st	4.8	5.5
		2nd	5.0	4.5
		Av.*	4.4	4.8

* LSD Fertilizer Rate @ 5% = 0.34

** LSD Storage Temperature @ 1% = 0.40

second harvest dates of tubers from the low fertilizer treatment. The interaction of harvest date x storage temperature was not significant. However, tubers from the first harvest date lost significantly more weight than those harvested later. The second order interaction of storage temperature x fertilizer rate x harvest date was not significantly different. However, storage at 45 F resulted in significantly less percentage weight loss than storage at either 42 F or 48 F. This can be seen from a different viewpoint in Fig 1 where monthly loss at the different temperatures is shown. The greater loss occurred at the lowest storage temperature. As was expected, tubers from the high fertilizer plots lost significantly more weight than tubers from the low fertilizer plots (Table 2). However, this was true only for the first harvest date. No differences in weight loss due to fertilizer rate were obtained for the second harvest date.

In Table 3 is shown yearly variation in percentage weight loss and the interaction of treatments with years. Weight loss in 1971 was significantly greater, and in 1974 was significantly less than in the other three years, indicating considerable yearly variation. Interaction of storage temperature x year was not significant indicating no difference in yearly behavior due to storage temperature. Harvest date x year interaction was highly significant. In 1971 and 1973, significantly greater weight loss was

obtained on the first harvest date as compared to the second harvest date, whereas in 1974 and 1975, no differences in weight loss were obtained be-

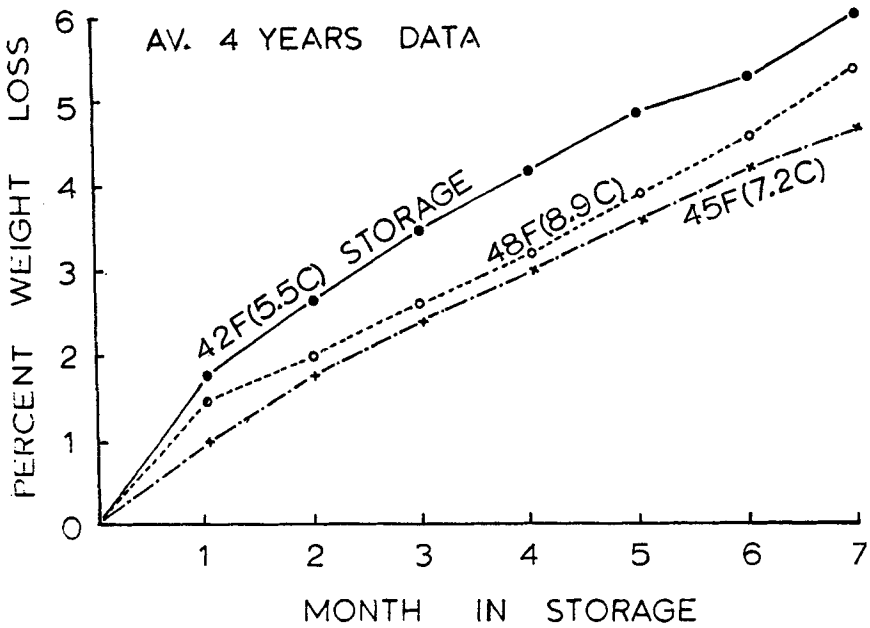

FIG. 1. Average monthly weight loss of tubers stored continuously at 42, 45, and 48 F for 7 months. Average of 4 years' data.

TABLE 3.—*Yearly differences in weight loss and interaction behavior of years x treatments.*

	Percentage Total Loss 7 Months Storage			
Storage temperature x years (N.S.)				
	1971	1973	1974	1975
42 F	6.9	4.4	3.7	4.6
45 F	6.0	3.7	3.0	3.2
48 F	6.0	4.7	3.9	5.2
Av.	6.3*	4.3	3.5	4.4
* *LSD for year @ 5%* = 0.47				
Harvest date x years**				
	1971	1973	1974	1975
1st	7.1	4.5	3.6	4.5
2nd	5.5	3.7	3.5	4.2
**LSD Interaction @ 1%* = 0.65				
Fertilizer x year (N.S.)				
	1971	1973	1974	1975
Low (130 lbs N)	6.2	4.1	3.5	3.9
High (300 lbs N)	6.4	4.3	3.6	4.8

tween the first and second harvest dates. Fertilizer rate x year interaction was not significant, indicating similar yearly weight loss behavior between high and low fertilizer rates.

TABLE 4.—*The influence of different air flow rates on weight loss of four different lots of potatoes cooled continuously with 48 F temperature and 93-95% R. H. air for three weeks (equivalent to approximately two months of intermittent eight hours daily cooling).*

	Air Flow Rate cfm/Ton			
Lot no.	20	40	60	80
	Av. Weekly Percentage Loss			
1	0.62	0.80	0.76	0.75
2	0.31	0.28	0.32	0.41
3	0.28	0.28	0.22	0.28
4	0.30	0.37	0.38	0.34
Av.	0.38	0.43	0.40	0.44
LSD air flow rate (N. S.)				

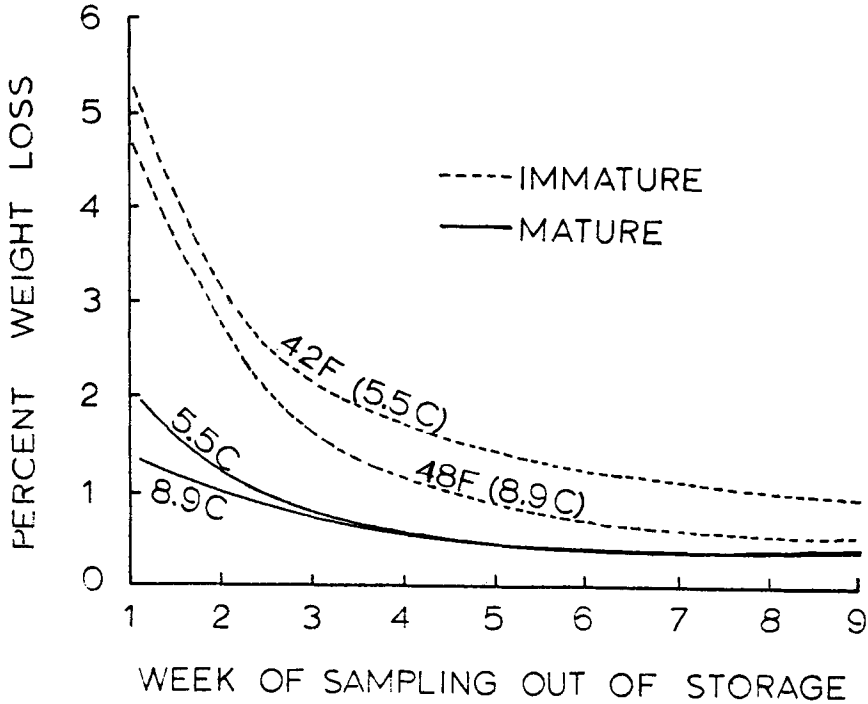

FIG. 2. Weekly change in weight loss potential of mature and immature tubers stored at 42 F and 48 F. Weight loss potential determined by placing tubers at 48% R. H. and 46 F temperature for one week and determining weight loss. Data are not accumulative.

In Table 4 is shown the average percentage weekly weight loss of potatoes cooled with different ventilation rates. No significant differences in weight loss were obtained despite wide differences in air ventilization rates.

Changes in weight loss potential of immature and mature tubers stored at 42 F and 48 F are shown in Fig 2. Considerable decrease in weight loss potential with time was found for the immature tubers stored at both 42 F and 48 F. After approximately 6 weeks, a constant amount of weight loss was observed on tubers stored at 48 F. Those stored at 42 F leveled off after 7 weeks, however, at a higher level than those stored at 48 F. Weekly weight loss of the low fertilizer potatoes leveled off after 3 weeks. The initial weight loss potential was higher at 42 F storage for the mature tubers; however after the second week there was no difference in weight loss changes.

Discussion

The amount of weight loss incurred by potato tubers during storage is a result of many factors. The present studies have tried to determine the interaction effect of storage temperatures and relative maturity of tubers on weight loss in storage. The results (Table 2) indicate that at the low fertilizer rates (very mature tubers), harvest dates had no influence on weight loss regardless of storage temperatures. Significantly greater weight loss was incurred by tubers from the high fertilizer plot (immature tubers) on the first harvest date in comparison with tubers from the low fertilizer treatment. However, no differences in weight loss due to fertility rates were obtained for tubers from the second harvest date. It appears it is possible to mature tubers (set and thicken the periderm) to a degree comparable to tubers from plants which died prematurely, by killing green vines two to three weeks prior to harvest.

No interaction effect of harvest date x storage temperature was obtained indicating that significant less weight was lost by tubers from the second harvest regardless of storage temperatures. However, tubers stored at 45 F lost significantly less weight than those stored at either 42 F or 48 F regardless of fertilizer rate. Similar results were reported by Sparks (17) in Idaho. It appears that increased weight loss at 42 F is due to slower rate of suberization and a lack of thickening of the periderm in comparison with tubers stored at 45 F. On the other hand, greater weight loss at 48 F (8.9 C) may be due to a higher respiration rate. Since rot was not observed in the potatoes, it is assumed that rot development was not a factor in these results.

Considerable seasonal differences in weight loss were obtained. Loss in the 1971 crop was significantly greater than in the other three years (Table 3). On the other hand, during the 1974 season the least weight loss was incurred. The results coincide with sugar development in that dur-

ing the 1971 season, sugar development was particularly troublesome (7) whereas, in 1974, sugar development in storage caused very little problem. The factor (high temperature stress) which caused considerable sugar development problems in storage in 1971 also appeared to influence, indirectly, increased weight loss in storage.

Four different lots of potatoes were cooled with air ventilation rates ranging from 20 to 80 cfm/T of potatoes. Contrary to some reports (1,19) high air flow rates did not necessarily cause increased weight loss as shown in Table 4. Under conditions of low humidity this may be true. Relative humidity in these studies was maintained between 93-95% as measured by a wet and dry bulb thermometer. Despite air ventilation rates over four times the recommended rate, weight loss differences were not significantly different.

Potato tubers appear to change in weight loss potential with time in storage. Immature tubers (from the high fertility plot) had very high potential for weight loss after one week storage at both 42 F and 48 F (Fig 2). However, the weight loss potential decreased quite rapidly with time. The weight loss potential of tubers held at 48 F decreased faster than those held at 42 F until approximately 5 to 6 weeks, when a constant rate of weekly loss occurred. It appears that potential weight loss of tubers stored at 42 F leveled off at around 7 to 8 weeks, however, at a much higher level than those held at 48 F. The leveling off of weight loss potential may be due to several factors. The readily available moisture had been removed such that a constant loss level had been attained or the periderm had suberized and thickened to a degree where constant moisture loss occurred. Probably both of these processes take place. The mature tubers (from low fertilizer plots) attained a constant loss level after approximately 3 weeks and at a slightly lower level than immature tubers stored at 48 F. No differences between 42 F and 48 F storage of the mature tubers were present after the first 2 weeks. It appears that the capacity of tubers to lose weight changes with time and temperature of the early storage period. For minimum weight loss, in storage, from tubers harvested in an immature condition, it is necessary to keep them at a higher temperature level for a longer period than mature tubers (preferably 48 F and above) in order for maturation (suberization and thickening of periderm) to take place.

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