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Effects of Field-Curing Practices, Artificial Drying, and Other Factors in the Control of Neck Rot in Stored Onions

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Introduction

Neck rot, caused by the fungus *Botrytis allii* Munn, occurs commonly wherever onions are grown commercially and is one of the most destructive diseases affecting the bulbs in storage. Walker (*9*) estimated that in certain seasons growers lose 50% or more of their crop because of this disease. Blodgett (*1*) estimated that 20 to 50% of the 1944 crop was lost in the Snake River Valley of Oregon and Idaho. Bond (personal correspondence) estimated that in the Snake River Valley 24% of the 1954 crop was lost due to neck rot. In most seasons, however, losses range from 2 to 10% of the crop.

Infection usually takes place through the neck tissues, but it may occur through wounds on any part of the bulb. The first symptom of infection is softening of the affected scale tissue which then becomes sunken and appears to have been cooked. A definite margin separates the healthy from the diseased tissue (*2*). As the mycelium of the fungus increases in the older diseased areas, the tissues become grayish in color and are covered by a dense mass of gray spores.

As early as 1917 Munn (*4*) pointed out that immaturity, imperfect curing, high humidity, high temperatures, and poor ventilation in storage houses favored development of neck rot in stored onions. Warm, dry weather during the late growing season and during the harvest period are unfavorable for disease development. When onions mature well and the tops fall over during dry weather, the chances for infection are greatly reduced. Onions with erect succulent necks at harvest are most likely to be infected. Even after infection of the tops has occurred, rapid drying of the neck tissues can prevent spread of the fungus into the bulbs.

Field curing and artificial drying usually have been most successful in reducing damage due to neck rot. Hoyle (*3*) found that field curing in burlap bags was, in general, unsatisfactory and that bruised onions and green material increased the incidence of storage rot, while artificial drying saved much time and was highly satisfactory. Boyd and Davis (*2*) in experiments with mechanically harvested onions showed that, for practical purposes, onions placed directly in the storage house after harvesting kept as well as those allowed to field cure, if good artificial curing conditions prevailed in the storage house.

In recent years, artificial curing of onions has been attempted by a number of workers. Newhall, Gunkel, and Ludington (*5*) found that losses were reduced by one-half by artificially curing onions. Roseburg and Johnson (*6*) stated that, with some limitations, favorable results were obtained by forced air drying, forced heated-air drying, electric infrared radiation, and gas fired infrared irradiation.

The purpose of the experiments reported here was to determine the influence of various methods of growing, field curing, and artificial drying upon the incidence of neck rot in storage, under eastern Oregon conditions.

Methods

These experiments were carried out in Malheur County, Oregon, with onions from commercial farms in the general vicinity of Ontario. The variety Yellow Sweet Spanish, which constitutes the bulk of the onion crop in the Snake River Valley, was used throughout the tests. Unless otherwise noted, the usual cultivation, irrigation, and fertilization practices were followed. These, of course, varied from grower to grower and from field to field. With a few minor exceptions, which will be specified, each test lot consisted of one sack, crate, or bulk pallet of onions.

No attempt was made to measure the degree of rotting—after three to four months of storage, each onion was examined and rated either healthy or rotted. In 1956 the healthy and rotted onions in each lot were both counted and weighed to determine which method of recording data should be used. Results indicated that both methods were equally accurate, and in subsequent years incidence of rot was determined by weight only.

Weather in eastern Oregon during the harvest season usually is warm and rainless. In order to be certain of a high incidence of neck rot, many of the onions used in the tests were inoculated artificially. In 1956 and 1957 half of the onions in each treatment were dipped in a suspension of spores of *Botrytis allii*, then drained for 30 minutes. While this method of inoculation was extremely effective (Table 1), it was too severe and was not comparable with conditions that might normally prevail in the field. This was particularly true of onions that had been cured until the necks were dry and then dipped so the necks were wet again. Drying of the outer scales of the bulbs and the neck tissues produces a very good defense against fungus infection.

Table 1. EFFECT OF INOCULATION BY DIPPING ONIONS IN A SUSPENSION OF SPORES OF *Botrytis allii*

Treatment	Onions rotted after three months' storage 1956	1957
	%	%
Check	1.7	3.0
Inoculated	48.8	38.7

Table 2. INFLUENCE OF SPRAYING WATER OR SPORE SUSPENSION ON ONIONS IN THE FIELD

Treatment	Neck rot after three months' storage
	%
None	2.9
Sprayed, plain water, 120 gpa	8.3
Sprayed, spore suspension, 120 gpa	9.1

LSD $P < .05$ between check and sprayed....4.33

Dipping the cured onions permits fungi to bypass the natural barriers after the onions would ordinarily be considered safe against such invaders.

Inoculation by spraying water or suspension of spores in water on the onions in the field before undercutting was tested in 1958. The success of this procedure illustrates the influence of even small amounts of rainfall during the harvest period on the incidence of this disease. Water alone was almost as effective as the spore suspension. In the tests, 120 gallons of water or of spore suspension per acre were sprayed on the plants just before dark on the evening before the onions were lifted. This treatment allowed the moisture to remain on the plants for the maximum period of time. This is only 0.00442 inches of water—hardly enough to be recorded as a trace of rainfall but enough if correctly timed to cause a decided increase in neck rot (Table 2). Although percentages of rotted onions were not as spectacular as those obtained by dipping the onions, it was felt that this method of inoculation more nearly paralleled the natural inoculation resulting from windborne spores and showers. Furthermore, the onions were not exposed to inoculation after they had established barriers (dry tissues in the necks and outer scales) against invasion by *B. allii*.

The fact that comparable results were obtained with plain water and with suspension of spores indicates that in the Ontario area an abundance of spores of *B. allii* is normally present in the air in late summer, but usually is ineffectual because of a lack of moisture for spore germination and infection. Whenever sufficient moisture is available, the fungus is present, and infection can occur.

Results of subsequent experiments with spore suspension or plain water sprayed on the plants were less conclusive. Apparently atmospheric conditions must be just right for neck rot to develop, and such conditions do not always prevail. When relative humidity is extremely low, as it frequently is in Malheur County at the time of onion harvest, evaporation of small amounts of moisture is so rapid that even during late evening the dead leaves and necks dry out before infection can occur.

All onions were topped by hand before they were brought in from the field, and all were stored in a large commercial warehouse in Ontario where good ventilation and good handling practices were provided.

Field Curing

Field curing practices vary with the grower and with the season. When the market is "good," growers often top onions immediately after lifting and prepare them for market. If the demand slackens, many of these onions find their way into storage without any curing. Furthermore, some growers believe onions cure better if they are topped immediately and cured in sacks or crates in the field, while others believe the tops act as "wicks" to remove the moisture rapidly from the necks. Investigations were carried out in several locations in Malheur County in 1956, 1957, 1958, and 1959 to determine the influence of curing on the ground with the tops on, topping immediately after lifting, curing in the field in sacks or crates, and combinations of these methods on incidence of neck rot. In 1958 and 1959, half of the onions, after curing in the field, were dried for 24 hours in a blast of warm air at 115° F. before being placed in storage.

Results

Less rot occurred in onions that had been cured in the field for at least five days (providing it did not rain) (Table 3). It apparently made little difference whether the field curing was with the tops on or off, in sacks, or in crates (either covered or uncovered). Except when rain fell during the curing period (1958), onions cured in crates developed slightly less rot during storage than those cured in sacks. In 1958 there was enough rain (0.29 inch) in the test field to

Table 3. INFLUENCE OF FIELD CURING PRACTICES ON DEVELOPMENT OF NECK ROT DURING STORAGE, 1957[a]

Days between lifting and topping	Days of field curing after topping	Field curing container	Rot after three months' storage
			%
0	0[b]	....	8.1
1	10	Crates (uncovered)	2.5
1	10	Crates (covered)	3.9
1	10	Sacks	3.8
3	0[b]	....	7.9
5	6	Crates (uncovered)	3.2
5	6	Crates (covered)	3.2
5	6	Sacks	2.8
9	0[b]	....	1.6
9	2	Crates	2.7

LSD $P < .01$........................5.84

[a] Inoculated by spraying with suspension of spores of *B. allii,* 50 gpa, evening prior to lifting.

[b] Stored in crates. Others stored in the same container used for field curing.

make a light crust on the soil. It was obvious that when rain occurred during the curing period, burlap sacks (which were wired shut at the top) gave some protection, while crates allowed the onions to become wet (Tables 4 and 5). In this instance onions cured after topping developed less rot during storage if they had been cured in sacks than if they had been cured in crates. It should be pointed out, however, that onions cured on the ground with the tops on had equally small percentages of rot even though they had no protection from the rain. These onions obviously dried more rapidly than those cured in crates. While four or five days of field curing reduced the incidence of rot during storage, if the onions were dried artificially at 115° F. before being placed in storage, field curing was not necessary.

Artificial Drying

It is known that curing onions in a blast of moderately warm air (90° F. to 115° F.) before or in the early part of the storage period reduces the incidence of onion neck rot, Munn (*4*), Hoyle (*3*). For tests of artificial drying, an electrical drier of 36-crate capacity was constructed capable of maintaining temperatures between 95 and 125° ± 1° F., with a temperature difference between the coldest and warmest parts of the drier of ± 1½° F. A test with an Alnor velometer #3002 showed that the air velocity was approximately 200 feet per minute along the side of the crates of onions when the drier was

Table 4. INFLUENCE OF FIELD CURING PRACTICES ON DEVELOPMENT OF NECK ROT DURING STORAGE, 1958[a]

Days between lifting and topping	Days of field curing after topping	Field curing container	Rot after three months	
			Not dried	Dried 115° F. for 24 hours
			%	%
0	0[b]	....	15.2	10.7
0	4	Crates		3.5
0	4	Sacks		5.8
0	11	Crates	23.6	—
0	11	Sacks	19.0	
4	0[b]	....	11.5	4.2
4	3	Crates		2.9
4	3	Sacks		2.8
4	7	Crates	7.9	
4	7	Sacks	8.5	
7	0[b]	....	8.8	3.7
7	3	Crates		5.2
7	3	Sacks		2.7
7	4	Crates	9.5	
7	4	Sacks	7.0	
10	0[b]	....	7.8	3.1

LSD $P < .01$ for dried vs not dried 7.24
for container 2.03
for treatments 6.41

[a] Inoculated by spraying with suspension of spores of *B. allii,* 120 gpa, evening prior to lifting.

[b] Stored in crates. Others stored in the same container used for field curing.

Table 5. INFLUENCE OF FIELD CURING PRACTICES ON DEVELOPMENT OF NECK ROT DURING STORAGE, 1959[a] (All onions stored in standard onion crates)

Days between lifting and topping	Days of field curing after topping	Rot after three months	
		Not dried	Dried 115° F. for 1 day
		%	%
0	0	9.4	3.6
0	5[b]	2.9	0.2
0	10[b]	1.4	1.8
5	0	3.9	1.9
10	0	0.7	0.0

LSD $P < .01$ for treatments 4.72
for days of field curing 3.34
for dried vs not dried 2.11

[a] Inoculated by spraying with suspension of spores of *B. allii,* 270 gpa, the evening prior to lifting.

[b] Cured in crates, after topping.

packed to capacity. The average sample in these tests was 10 crates (replicates) per treatment.

Drying at moderate temperatures reduced the percentage of neck rot to a very low figure (Tables 6 and 7). Drying at higher temperatures caused severe losses. Early experiments showed that 72 hours at 115° F. and 48 hours at 125° F. caused partial cooking of the outer scales. The onions appeared to be firm when they were removed from the dryer, but rapid spoilage occurred when they were placed in storage. Sixteen to twenty-four hours at 115° F. or longer periods at lower temperatures gave excellent control of neck rot, and most later experiments were conducted at lower temperatures. Rapid circulation of the air without artificial heat proved satisfactory when the drying period was extended to three days. It is necessary to remove moisture from the outer scales and necks, but this removal of moisture must be accomplished without overheating the onions.

Table 6. INFLUENCE OF DRYING PERIOD AND TEMPERATURE ON DEVELOPMENT OF NECK ROT IN STORED ONIONS

Drying period	Temperature	Rotted after three months' storage	
		1957[a]	1958[b]
		%	%
Check	(No drying)		4.5[c]
24 hrs.	95° F.		1.9
48 hrs.	95° F.		1.8
72 hrs.	95° F.		2.0
Check	(No drying)	7.4	4.5[c]
24 hrs.	105° F.	6.3	2.3
48 hrs.	105° F.	3.5	2.6
72 hrs.	105° F.	2.1	2.3
Check	(No drying)	5.8	4.5[c]
24 hrs.	115° F.	2.4	5.4
48 hrs.	115° F.	1.4	4.1
72 hrs.	115° F.	30.3	45.2
Check	(No drying)	5.9	
24 hrs.	125° F.	3.8	
48 hrs.	125° F.	87.1	
72 hrs.	125° F.	90.6	

LSD $P < .01$ ....3.99 (Excludes the obviously cooked onions [125° for 48 and 72 hours]).

[a] Inoculated by spraying with spore suspension of *B. allii* the evening prior to lifting (50 gpa).

[b] Inoculated by spraying with a spore suspension of *B. allii* the evening prior to lifting (120 gpa).

[c] A similar, but not a true check. These checks were harvested approximately the same time and from the near vicinity.

Table 7. INFLUENCE OF DRYING PERIOD AND TEMPERATURE ON DEVELOPMENT OF NECK ROT IN STORED ONIONS

Treatment	Rotted after three months	
	Inoculated[a]	Not inoculated
	%	%
Topped, sent direct to storage	9.3	1.3
Topped, cured at 115° F. for 8 hours	4.7	0.9
Topped, cured at 115° F. for 16 hrs.	1.4	1.6
Topped, cured at 115° F. for 24 hrs.	1.8	2.0
Topped, sent direct to storage	8.0	1.0
Topped, air blast for 24 hrs.	7.2	3.2
Topped, air blast for 48 hrs.	4.1	0.6
Topped, air blast for 72 hrs.	3.8	0.9

LSD $P < .01$ for treatments 5.01
for inoculated vs not inoculated 1.77

[a] Inoculated by spraying with a spore suspension of *Botrytis allii,* at the rate of 270 gpa. All onions lifted the same day, treated and stored in wooden crates.

Temperatures, measured by #30 wire, copper constantan thermocouples, were only slightly different under one scale or one-half inch below the surface when onions were cured at 115° F. (Figure 1). On the other hand, interior temperatures during the first 12 hours of drying were considerably below air temperatures, and it was believed that the lower temperatures were due to the latent heat of evaporation of water from the surface of the onions. This may account for the fact that onions were not injured when dried at 115° F. or 125° F. for short periods of time.

Shrinkage losses during drying never were excessive and should not be considered in deciding whether or not to dry onions artificially (Table 8).

To determine whether "pasteurization" at high temperatures for relatively short periods might increase the effectiveness of other drying practices, onions of uniform size (about 3 inches in diameter) from plots inoculated by spraying with *Botrytis allii* spore suspension at the rate of 270 gpa prior to lifting were exposed to temperatures of 140 and 162° F. for one hour, then dried at 115° F. for 24 hours. Instead of increasing the effectiveness of the drying operation, however, such treatments proved very injurious. After three months storage, 71.9% of the onions exposed to 162° F. were rotted, 22%

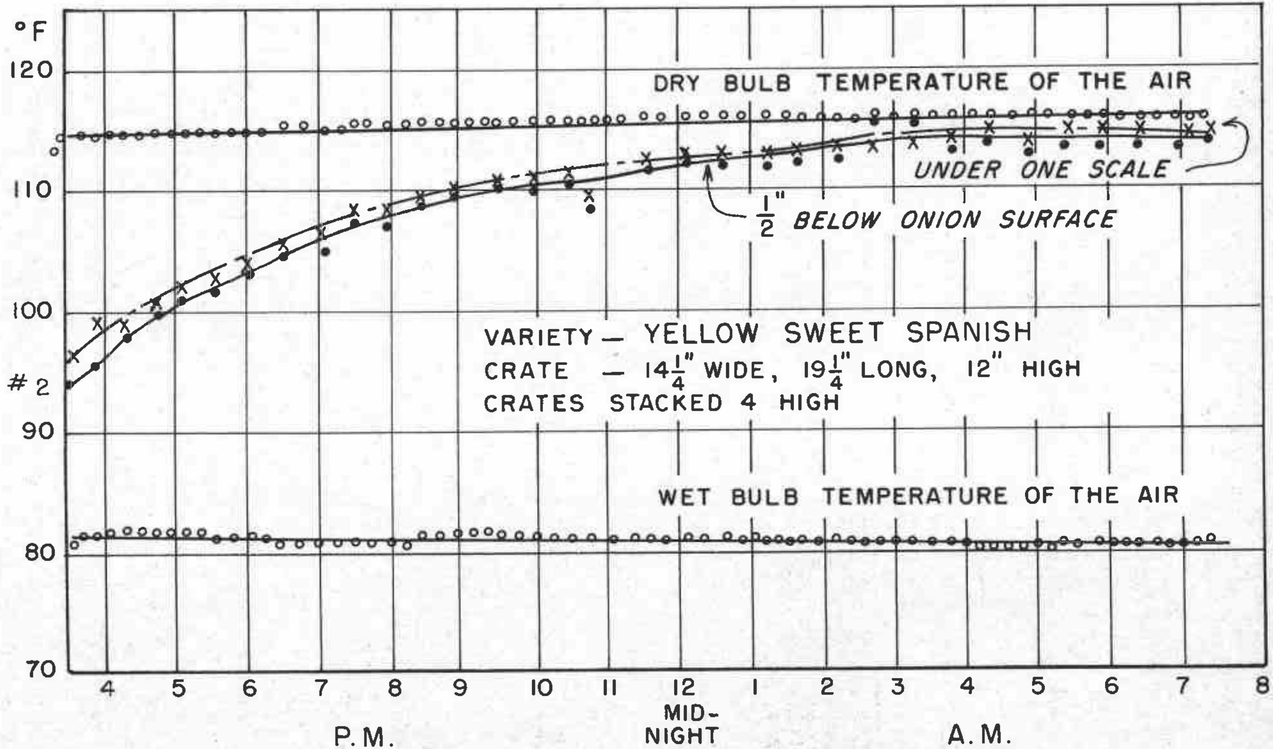

Figure 1. Temperature on the surface and one-half inch under the surface of an onion during drying.

Table 8. INFLUENCE OF DRYING PERIOD AND TEMPERATURE ON THE LOSS OF WEIGHT DURING DRYING

		Loss in weight during drying		
		1957 Relative humidity	1958[a] Relative humidity	
Drying period	Temperature	Uncontrolled	Uncontrolled	50%
		%	%	%
24 hrs.	95° F.		0.9	0.1
48 hrs.	95° F.		1.7	1.3
72 hrs.	95° F.		2.5	1.5
24 hrs.	105° F.	2.0	1.1	0.7
48 hrs.	105° F.	3.3	2.0	1.4
72 hrs.	105° F.	4.8	3.0	2.1
24 hrs.	115° F.	1.6	1.9	1.2
48 hrs.	115° F.	2.5	4.4	2.8
72 hrs.	115° F.	4.4	6.8	5.0
24 hrs.	125° F.	2.0		
48 hrs.	125° F.	4.0		
72 hrs.	125° F.	4.8		

LSD $P < .01$ for treatments ....0.54..........................0.57
for relative humidity ...... —..........................0.19
for treatments × relative humidity .... —..........................0.33

[a] In 1958 a humidity control device maintained 50% relative humidity in the drier. All other drying periods were without humidity control.

of those exposed to 144° F., and only 0.8% of those dried at 115° F. without exposure to higher temperatures. Obviously such high temperatures cannot be tolerated by the Sweet Spanish onion.

Perhaps the most spectacular results from drying were made in tests conducted in 1957. Two hundred onions of various sizes were cut halfway through the neck at the junction of the neck with the bulb, using a knife freshly dipped in a suspension of spores of *Botrytis allii.* All were held in crates in the sun for six hours. One-half were then sent directly to storage and the other half were dried for 48 hours at 115° F. before storage. Those dried for 48 hours at 115° F. had only 25.5% rotted after three months' storage, while those that went into storage without artificial drying had 100% rotted. This indicated that rapid drying of the necks will largely prevent neck rot even after infection has taken place.

Effect of Type of Storage Containers

Onions usually are stored in slatted wooden crates (19″ x 14½″ x 12″) or in burlap bags (60 to 80 pounds). The former afford better ventilation but the latter are less expensive. To determine whether the type of storage container would influence the incidence of neck rot, onions treated in various ways in the field were stored in the two types of containers. In 1956 and 1957 all onions were inoculated by dipping in a *Botrytis allii* spore suspension. In 1958 the plants were sprayed with a spore suspension the evening prior to lifting. In all cases there was significantly less neck rot in the onions stored in wooden crates (Table 9).

Table 9. Effect of Type of Storage Container on Development of Neck Rot During Storage

	Neck rot after three months' storage		
	1956	1957	1958
Type of container	%	%	%
Burlap bags	30.0	24.3	9.9
Wooden crates	25.0	17.4	6.4
LSD $P < .01$ for container	2.86	3.42	2.03

In recent years, increasing quantities of onions have been handled in large bulk pallets, each holding about 1,500 pounds of onions. In 1958 a comparison was made of conventional and bulk methods of handling. Unfortunately, rains fell during the field-curing period. In this instance onions placed in storage without field curing developed less neck rot than onions stored under similar conditions after curing in the field for 10 days. On the other hand, among onions receiving identical periods of field curing, there were significant differences (Table 10). While the results may not be typical of what might be expected in a rainless harvest period, they do present interesting evidence of the value of certain curing practices under adverse curing conditions.

As noted in an earlier section, burlap bags provided some protection against wetting and the consequent development of neck rot. An inverted onion crate placed in the center of the pallet before filling provided added ventilation and reduced the incidence of neck rot. By contrast, only negligible losses occurred in onions from the same field when they were cured on the ground with the tops on for 10 days (during which time they were exposed to the same rains as the onions cured in pallets), topped, and cured in crates in the field for an additional 5 days before being placed in storage.

Table 10. Effect of Field Curing Practices and Type of Storage Container on Development of Neck Rot During Storage[a]

Curing practice	Storage container	Rotted after three months' storage
		%
Topped immediately, no field curing, sent directly to storage	Bulk pallets[b]	10.1
Topped immediately, cured in field 5 days in burlap bags	Burlap bags	12.8
Topped immediately, cured in field 10 days in bulk pallets[b]	Bulk pallets	14.3
Topped immediately, cured in field 10 days in bulk pallets[b]	Bulk pallets	16.5
Cured in field 10 days before topping, cured in field 5 days in crates	Crates	2.3

[a] Measurable rain fell on the 3rd, 5th, and 7th days after lifting.
[b] Inverted standard onion crate placed in center of pallet before filling—to provide better ventilation.

Table 11. Incidence of Storage Rots in Mechanically Harvested and Hand Harvested Onions

	Rotted after three months' storage
	%
Mechanically topped and stored	16.59
Hand topped and stored	0.52
LSD $P < .01$	4.81

In 1962 field-cured onions from the same field, and therefore having the same disease potential, were topped by hand and with a Gates mechanical harvester. Twenty crates of onions from each lot were stored for three months under identical conditions.

Economic engineering studies of harvesting with the machine showed total costs for topping and storing to be almost eight cents per hundredweight lower than for hand topping and storing. Inspection showed, however, that the incidence of storage rots in the machine-harvested onions was much greater than in the hand harvested onions (Table 11). The greater incidence of rots must be attributed to mechanical injuries which permitted the fungus to circumvent the normal protective barriers. The saving of 8 cents per cwt. was more than offset by the value of the 16 pounds of onions lost per cwt. Until a means can be devised to reduce the bruising by the machine, it would appear to be of no economic value to the grower.

Effect of Onion Tops During the Curing Period on the Moisture Content of the Necks

Botrytis allii usually invades the dead or dying leaves of the onion plant, then grows downward through the necks into the bulbs. Freedom from, or development of, neck rot depends upon the moisture content of the neck when the onion is placed in storage. Neck tissues that are sufficiently dry effectively prevent growth of the neck-rot fungus.

In 1958 a test was conducted to determine whether onion necks dried more rapidly with the tops on or off during the curing period. Ten lots of 100 onions each were selected, all with tops still erect and green at the time of undercutting. Five lots were cured on the ground for 10 days with the tops on. The remaining five lots were topped two inches above the bulb and cured for 10 days in crates covered with burlap sacks. At the end of the 10-day curing period, all necks were removed at the junction of the neck and bulb and the moisture contents determined.

Results (Table 12) indicated that presence or absence of tops during the curing period had little influence on the rate at which the necks dried. A possible source of error occurred during the test, however; rain fell during the curing period. Onions with tops removed were protected by sacks laid over the tops of the crates. Onions on the ground were unprotected.

Effects of Excess Nitrogen and Water

The eastern Oregon onion market is based on the large, sweet, soft, "hamburger-type" onions, three inches or more in diameter, and the grower must obtain high yields to remain in business. To secure the maximum tonnage and size of onions, growers sometimes use excessive amounts of nitrogen fertilizer and/or continue irrigation late in the growing season. To determine whether these practices influence the susceptibility of the onions to neck rot, the following experiments were conducted:

In 1956, 60 pounds of nitrogen per acre more than the usual grower application was applied as a side dressing when the onions were about 10 inches high, and the onions received one extra irrigation at the end of the growing season. Weather during August and early September was warm and dry, and the onions matured well. There were no significant differences between the onions grown normally and those that received the extra nitrogen and water. In 1957, 100 pounds of extra nitrogen per acre, and one extra irrigation were applied. Although the amount of neck rot was significantly greater in the onions that received the extra nitrogen and water (Table 13), the differences are believed to be indirect, through the effect on size and maturity on the onions rather than an effect on resistance or susceptibility of the onion plant.

Although the direct effect of extra nitrogen and irrigation water was not great, tests were run to determine whether size itself might influence the probability of infection. In 1956, when more than 60,000 onions were examined, the average weight of the onions that developed neck rot was 8.82 ounces, compared with 6.94 ounces for the onions that remained healthy. On each of three farms in 1957, onions that were grown "normally" and those that received 100 pounds of extra nitrogen per acre plus one extra irrigation at the end of the

Table 12. Moisture Content (Wet Basis) of Onion Necks[a] After Ten Days Field Curing

	On ground with tops on	In crates, topped
	%	%
	83.7	81.7
	82.4	81.2
	83.4	81.8
	81.1	81.0
	82.6	79.2
Average	82.3	80.9

LSD $P < .05$ for treatments..............1.478.

[a] First two inches above the bulb.

Table 13. Effect of Added Nitrogen and Water on the Occurrence of Neck Rot During Storage

	Rotted after 10 weeks' storage	Rotted after 11 weeks' storage
Field treatment	1956	1957
	%	%
Normal nitrogen and water	31.9	17.7
Extra nitrogen[a] and one extra irrigation	28.9	24.4
LSD $P < .01$		3.24

[a] Sixty lbs./acre in 1956; 100 lbs./acre in 1957.

growing season were graded into onions two inches or less in diameter and those larger than four inches. After curing in the field for three days, each lot was topped and stored in wooden crates. The large onions had mostly large succulent necks that dried slowly, while the small ones had mostly slender necks that dried rapidly.

In neither the small nor the large onions were there significant differences in neck-rot incidence resulting directly from the extra nitrogen and water. The effect of these growing practices was indirect. Significantly greater percentages of neck rot occurred in the larger onions (Table 14). However, since there are more "jumbo" size onions in fields that receive high rates of nitrogen fertilizer or are irrigated late in the growing season, and especially since these large onions remain erect and succulent later in the season, greater percentages of neck rot develop in the onions from such fields.

Table 14. Effect of Size of Onion, and of Extra Nitrogen Fertilizer and Extra Irrigation Water on Development of Neck Rot During Storage

Size of onion	Rotted after 10 weeks' storage	
	Normal N and water	Extra N and water
	%	%
2 inches in diameter, or less	0.9	1.1
4 inches in diameter, or greater	13.9	10.3

LSD $P < .01$ for size 7.29

Effect of Bruising

A number of experiments were conducted to determine the effect of bruising on the development of Botrytis rot in storage. Results of many of these tests were not significant because hot, dry weather conditions did not favor the development of neck rot. In 1958 rain fell during the harvest season, creating conditions favorable for epidemic development of the disease. The influence of bruising during this year can be seen in Table 15.

Results indicated that while bruising increases the incidence of rot, the increase in percent of onions infected is not proportional to the amount of bruising. In making disease ratings, an onion was recorded as either healthy or rotted. Any decay renders an onion unmarketable, and the number of infections per onion or the degree of

Table 15. Influence of Bruising on Subsequent Development of Neck Rot

Degree of injury	Rotted after three months' storage
	%
None	3.8
Mild[a]	6.0
Moderate[b]	11.0
Severe[c]	13.2
LSD $P < .01$	6.99

[a] Dropped once from sorting table onto concrete floor.
[b] Dropped twice from sorting table onto concrete floor.
[c] Dropped three times from sorting table onto concrete floor.

tissue involvement were not taken into consideration. If the number of infections per onion or the rate of progress of decay in individual onions had been determined, results probably would have been quite different.

Effect of Potash Fertilizer on Ability of Onions to Withstand Rough Handling

Increasing numbers of onions are being handled mechanically and are subjected to bruising and crushing not usually encountered in hand topping and handling. Potash is believed to cause increased "hardness" in straw, in certain fruits, and perhaps in other plant parts. To determine whether a high level of potash in the soil would affect the resistance of yellow Sweet Spanish onions to injuries resulting from rough handling, and consequently affect the development of Botrytis rot, a series of experiments were undertaken for a three-year period. In each case half the onions received 100 pounds of potash more than the usual grower rate per acre, as a side dressing when the plants were about 10 inches high. In 1959 there was significantly less rot in roughly handled onions that received the extra potash fertilizer. In 1960 and 1961 there was no comparable trend (Table 16). Addition of extra potash as a means of reducing Botrytis rot losses would seem, therefore, to be of questionable value.

In 1959 there were significantly greater losses in the roughly handled onions that had not received extra potash. In 1961 greater losses occurred in the roughly handled onions, either with or without the extra potash fertilizer. In 1960 losses due to *Botrytis allii* infection were uniformly low in all experiments.

Table 16. INFLUENCE OF POTASH FERTILIZER ON ABILITY OF YELLOW SWEET SPANISH ONIONS TO WITHSTAND ROUGH HANDLING

Treatment		Rotted after three months	
		Usual fertilizer	Extra potash
		%	%
1959	Normal handling	2.7	2.3
	Bruised[a]	7.5	2.2
	Crushed[b]	7.6	2.5
1960	Normal handling	2.1	1.6
	Bruised	2.9	1.9
	Crushed	1.9	2.6
1961[c]	Normal handling	10.9	11.9
	Bruised	21.2	19.3
	Crushed	12.9	28.4

[a] Bruised: Pushed twice from a table 36 inches high onto a rough concrete floor.
[b] Crushed: Dumped roughly into crates 36 inches deep.
[c] In 1961 data were recorded from only the bottom half of each crate, where crushing would be greatest.

Discussion

The warm, rainless weather and low relative humidity that usually prevail during the harvest season undoubtedly have contributed immeasurably to the success of the onion-growing industry in the Malheur onion-growing area. In some seasons it was practically impossible, even with artificial inoculation, to secure neck rot infections sufficiently severe to yield significant data on any control practices. During the six years of these investigations, losses of 10% or more were experienced only when rain fell during the harvest period.

These tests clearly show the need for five or more days of field curing before onions are placed in storage. Whether they are cured with tops on or after removal of the tops appeared to be of little significance. It would be meaningless, however, to arbitrarily state how many days of field curing are necessary for control of neck rot. Maturity of the crop at the time of undercutting; percentage of large, succulent, green necks; rainfall during the harvest period; and the interval between harvesting and sale to the consumer all influence the degree of neck-rot damage and amount of curing that is necessary. Onions that are uniformly mature or that are to be marketed promptly need comparatively little curing if the harvest period is rainless. Onions that are not fully mature or that include considerable numbers of large-necked green onions at the time of lifting require comparatively long curing periods before being placed in storage. When onions are wet by rainfall just before lifting or during the curing period, some artificial drying is needed. Actually the grower can largely determine the degree of danger of neck rot in storage. If all onions have necks that feel dry and are brittle when handled, there is little danger of neck rot. If the necks feel moist or pliable, a longer curing period or artificial drying is indicated.

Added nitrogen fertilizer and/or extra irrigation apparently have no direct effect on the development of neck rot during storage. Both practices tend to increase the number of onions with large green tops and to delay maturation of the onions. Since extra large onions frequently have green, succulent necks, they cure more slowly and are more liable to neck-rot infection.

During rainless harvest periods (considered normal in the Malheur Valley area), onions cure better and keep better in wooden crates than in burlap bags. If rain falls during the curing period, bags provide a degree of protection against wetting and may be preferrable to crates.

Perhaps one of the most significant findings in these experiments was that in a blast of rapidly moving air it was necessary to raise the temperature only a few degrees above the prevailing air temperature to reduce neck rot to very small proportions. It should be noted, however, that these results were obtained with a small dryer, where temperatures could be quickly adjusted and where very rapid movement of air was possible. In a larger, commercial storage facility somewhat longer periods of artificial drying might be required. This could be done most easily and economically in existing storages by adding portable heating systems to present or expanded air-circulating systems. Care must be taken to see that air coming from the drier is not too hot, since only slight cooking of the outer scales results in rapid spoilage. Supplemental heat will be needed only in about one year in five; but it is a necessity when low temperatures and high humidity prevail during the harvest period. Even without supplemental heat, a considerable degree of protection against neck rot can be obtained by providing adequate forced circulation of air for a considerable period of time. Shrinkage losses due to artificial drying, either with or without supplementary heat, are negligible.

Summary

Practices that reduced the incidence of onion neck rot and minimized losses caused by the disease during storage were:

Careful handling, to avoid unnecessary bruising.

Curing in the field for at least five days, preferably in wooden crates or bulk pallets that provide optimum conditions for drying of the necks and outer scales. Curing in burlap bags was better than no curing, but inferior to curing on the ground or in open wooden crates or pallets.

Artificial curing. Under eastern Oregon conditions, supplemental heat is required only when low temperatures, rainfall, or high humidity prevail during the harvest season. Shrinkage losses and neck rot losses were small in onions cured artificially. Warning: Artificial drying temperatures in excess of 125° F. for 24 hours, or 115° F. for 48 hours, caused serious injury and severe losses during storage.

Practices that increased incidence of neck rot during storage were:

Bruising during lifting, curing, and storing the onions.

Failure to cure onions before placing them in storage.

Application of extra potash fertilizer at midseason had no apparent effect on incidence of rot during storage.

Application of extra nitrogen fertilizer and extra irrigation water had no apparent direct effect on incidence of rot during storage. These practices did result in larger onions having large, succulent necks. Such onions are difficult to cure and were most susceptible to neck rot.

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