STATION BULLETIN 294 JANUARY 1932

Potato Virus Diseases

Oregon Investigations 1924-1929

Agricultural Experiment Station
Oregon State Agricultural College
CORVALLIS

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SUMMARY

1. The bulletin reports results obtained in six years of field and greenhouse studies (1924-1929) conducted at the Oregon Agricultural Experiment Station at Corvallis with nine different virus diseases maintained on several different varieties of potatoes.

2. The chief symptoms and distinguishing characteristics are described for mild mosaic, interveinal mosaic, crinkle mosaic, rugose mosaic, leaf-rolling mosaic, leaf roll, spindle tuber, calico, giant hill, and witches'-broom.

3. Irish Cobbler appears to be resistant to mild mosaic.

4. Different methods of transmission were tried out. The leaf mutilation method was effective in transmitting mild mosaic, crinkle mosaic, rugose mosaic, leaf-rolling mosaic, calico, and spindle tuber, but not leaf roll.

5. The core-graft method was effective in transmitting mild mosaic, crinkle mosaic, rugose mosaic, leaf-rolling mosaic, leaf roll, and spindle tuber, but not calico.

6. The ability of four species of aphids to transmit various virus diseases was tested out.

MYZUS PERSICAE successfully transmitted crinkle mosaic, rugose mosaic, leaf-rolling mosaic, and leaf roll, but not mild mosaic.

ILLINOIA SOLANIFOLII transmitted leaf-rolling mosaic and leaf roll but with leaf roll proved much less efficient than the other species of aphids. It did not transmit mild mosaic, crinkle mosaic, or rugose

MYZUS PELARGONII transmitted leaf-rolling mosaic and leaf roll but not mild mosaic, crinkle mosaic nor rugose mosaic.

MYZUS CIRCUMFLEXUS transmitted crinkle mosaic, rugose mosaic, and leaf roll. It did not transmit mild mosaic.

7. Rugose mosaic passed from diseased to healthy plants under insect-proof field cages with the apparent absence of insects of any kind on the parts above ground. Mild mosaic, interveinal mosaic, and leaf roll were not transmitted under similar conditions. Giant hill was apparently not transmitted under similar conditions but appeared to be transmitted when the roots were disturbed by deep cultivation.

8. Tests showed reductions in yield amounting to as high as 73 percent by weight in the case of spindle tuber, 50 percent with crinkle mosaic, and 19 percent with interveinal mosaic.

9. Roguing of seed-plots by the tuber-unit method proved more effective in eliminating virus diseases than by the mass roguing method.

10. The tuber-indexing method proved to be the most effective means of eliminating virus diseases from seed stocks but is considered impracticable for general farm use.

11. The hill-indexing method proved unreliable as a method of effective control.

Potato Virus Diseases*

Oregon Investigations 1924-1929

By

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INTRODUCTION

THE subject of potato virus diseases is one of great and increasing importance in the conduct of successful potato culture. The experiments described in this bulletin were conducted at Corvallis, Oregon, and cover the potato virus disease work carried on from 1924 to 1929, dealing with symptoms, methods of artificial and natural transmission, effects on yield, and control measures. Some of the yield and roguing data and other 1930 observations are also included. A number of the experiments discussed are similar in character to experiments already reported by workers elsewhere. Except as noted, the results obtained here corroborate those of other investigators.

A large part of the work was carried on in field plots but the greenhouse was also made use of. In all work of this sort special care must be taken to prevent accidental transfer of the viruses or of the insect vectors. In these experiments rather uniform methods and procedures were used throughout.

METHODS USED IN FIELD CAGE WORK

In order to study the behavior of the different virus diseases, it was necessary to have tubers from plants known to carry the disease in question, grow diseased plants from them under proper safeguards against contamination, and use these as sources of inoculum for healthy potato plants that were likewise grown under protection against outside contamination.

All the field inoculation work, therefore, was performed on plants that were isolated by growing them under cages covered with muslin with the bottom edges buried in the soil (see Figure 1). These cages were set in position at the time the potato seed pieces were planted. This was done to prevent any insects not harbored in the soil which might be virus carriers from gaining access to the plants at any stage in their development. Each cage was large enough to cover three full-grown plants.

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*After 1926, these investigations were conducted cooperatively by the Office of Horticultural Crops and Diseases, Bureau of Plant Industry, United States Department of Agriculture, and the Oregon Experiment Station. A portion of this work was conducted in cooperation with the Montana Agricultural Experiment Station and the Utah Agricultural Experiment Station.

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The writers are indebted to Professor H. P. Barss and Dr. E. S. Schultz for aid in preparation of the manuscript.

In the inoculation work the cages employed for each test were grouped in a unit consisting of four cages set side by side. Three potato tubers, all of them usually being of the same variety and origin, were used in planting each group of cages. The first tuber was cut into four seed pieces. One of these was planted as Hill 1 in each of the four cages. The second tuber was then cut into four pieces one of which was planted as Hill 2 in each of the cages. The third was likewise cut and the seed pieces set as Hill 3 in each of the four cages. When they were about 5 inches high the plants in

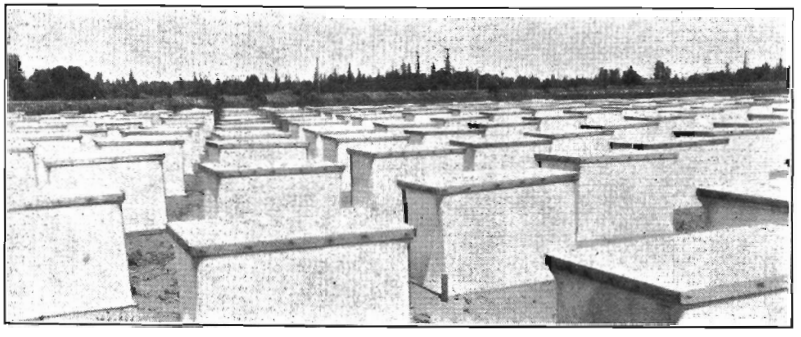

Figure 1. A view showing a part of the muslin-covered cages used in the experiments on the potato virus diseases. These cages are used mainly to confine test insects on the plants and to avoid free, uncontrolled migration of insects which might serve as vectors of the virus diseases among the potatoes.

the first three cages were inoculated by the investigator while the plants in the fourth cage were left uninoculated and kept as controls.

Observations on symptoms were made at regular intervals during the season the inoculations were made. The tubers from each hill were saved separately. The following year, the progeny from each inoculated hill and the progeny from the controls were planted again as hill lots in the open field, where observations were made on second-year symptoms. Occasionally a plant in a control cage showed disease symptoms. In such cases the results of the inoculated hills from the same tuber unit were discarded.

TECHNIQUE USED IN VIRUS TRANSMISSION

Various means of transfer of the several potato viruses were tried out. Certain methods were successful with some of the diseases while unsuccessful with others.

Leaf mutilation. In this method, as described by Schultz and Folsom,[22] cheesecloth was soaked with the juice from macerated foliage of diseased plants and the leaf of a healthy plant was rubbed, enough pressure being used to break the epidermis and mash or mutilate the tissues. This method was used to a large extent and proved to be successful in the transmission of rugose mosaic, crinkle mosaic, mild mosaic, leaf-rolling mosaic, spindle tuber, and calico. As shown later on, leaf roll was not transmitted by this method. On the other hand, rugose mosaic and spindle tuber were readily

transmitted by leaf mutilation, whereas mild mosaic and calico gave a low percentage of transmission.

Core grafts. Murphy and McKay[15, 16] and Goss[7] were the first to use core grafts as a means to transmit potato virus diseases. In this method a core of tissue removed by a cork borer from a virus-bearing tuber is inserted into a hole made in a healthy tuber by means of a cork borer slightly

TABLE I. INTERVARIETAL LEAF MUTILATION INOCULATIONS OF POTATO VIRUS DISEASES PERFORMED UNDER FIELD CAGES
1926-1929

Source of inoculum (potato variety)	Variety inoculated	Infected hills	Tubers infected in infected hills	Control
A. Mild mosaic				
American Wonder	Burbank	1/2*	3/4	0/4
Burbank	Burbank	1/6	3/3	0/2
American Wonder	Earliest of All	1/3	12/12	0/1
Burbank	Bliss	2/2	6/10	0/1
Green Mountain	Burbank	0/3	.....	0/1
Burbank	Irish Cobbler	0/5	.....	0/2
Burbank	White Rose	5/8	10/10	0/3
B. Crinkle mosaic				
Green Mountain	Earliest of All	3/6	6/12	0/2
Bliss Triumph	Burbank	3/9	13/15	0/3
Bliss Triumph	Bliss Triumph	5/6	16/19	0/2
Burbank	Green Mountain	3/3	6/6	0/1
Earliest of All	Garnet Chili	0/6	.....	0/2
Burbank	White Rose	2/3	9/9	0/1
Bliss Triumph	American Wonder	1/2	1/2	0/1
Bliss Triumph	Earliest of All	0/3	.....	0/1
Green Mountain	Irish Cobbler	0/3	.....	0/1
C. Rugose mosaic				
American Wonder	Burbank	3/3	7/7	0/1
Burbank	Earliest of All	13/15	38/43	0/5
Burbank	Bliss Triumph	5/5	10/10	0/2
Green Mountain	Idaho Rural	4/5	11/12	0/2
Green Mountain	Burbank	1/2	6/6	0/1
Green Mountain	American Wonder	2/3	8/8	0/1
Earliest of All	Earliest of All	16/18	29/45	0/6
Burbank	Burbank	13/16	21/36	0/6
D. Leaf-rolling mosaic				
Green Mountain	Burbank	2/3	4/4	0/1
Green Mountain	Earliest of All	2/3	2/8	0/1
Green Mountain	Bliss Triumph	3/5	15/16	0/2
Green Mountain	Irish Cobbler	2/3	3/3	0/1
Burbank	White Rose	1/2	3/3	0/1
Burbank	Garnet Chili	0/2	.....	0/1
E. Leaf roll				
Burbank	Burbank	0/6	.....	0/2
Green Mountain	Burbank	0/2	.....	0/1
Burbank	Earliest of All	0/9	.....	0/3
Bliss Triumph	Burbank	0/6	.....	0/2
Bliss Triumph	Earliest of All	0/9	.....	0/3
F. Spindle tuber				
Green Mountain	Burbank	9/9	59/62	0/3
Green Mountain	Earliest of All	4/6	18/21	0/2
Burbank	Bliss Triumph	2/2	9/9	0/1
Irish Cobbler	Burbank	4/5	21/21	0/2
Green Mountain	American Wonder	1/3	2/2	0/1

*Upper figure is number of plants diseased, lower figure total number of plants used.

smaller than the one used to remove the core from the diseased tuber, thus assuring a close contact between the diseased and healthy tissue. This method has the advantage of enabling one to make tuber grafts some time previous to planting. Infection is often evident soon after the plants are up. Unfortunately the method has not always been uniformly successful. In 1926, when a large number of tubers were core-grafted with different virus diseases, the results were entirely negative. When the grafted tubers were dug that summer, it was found that in practically all cases the cores had shriveled or rotted. This was perhaps due to the fact that the cores had failed to suberize and no organic union was established between the core and grafted seed piece.

TABLE II. INTERVARIETAL CORE GRAFT INOCULATIONS OF POTATO VIRUS DISEASES PERFORMED UNDER FIELD CAGES
1926-1929

Source of inoculum	Variety inoculated	Infected hills	No. of infected tubers in infected hills	Control hills
A. Mild mosaic				
Burbank	Burbank	3/3*	12/12	0/1
Green Mountain	Burbank	0/3	.....	0/1
Green Mountain	Idaho Rural	1/3	1/3	0/1
Green Mountain	Earliest of All	3/3	6/9	0/1
Green Mountain	Bliss	3/3	8/13	0/1
American Wonder	Irish Cobbler	0/6	.....	0/2
B. Crinkle mosaic				
Green Mountain	American Wonder	0/2	.....	0/1
Green Mountain	Idaho Rural	0/3	.....	0/1
Idaho Rural	American Wonder	0/3	.....	0/1
Idaho Rural	Burbank	0/3	.....	0/1
Idaho Rural	Earliest of All	0/3	.....	0/1
Bliss Triumph	Bliss Triumph	1/2	3/3	0/1
Idaho Rural	Irish Cobbler	0/2	.....	0/1
C. Rugose mosaic				
Burbank	American Wonder	0/5	.....	0/2
Green Mountain	Burbank	1/3	1/1	0/1
Green Mountain	American Wonder	0/3	.....	0/1
Green Mountain	Irish Cobbler	0/3	.....	0/1
D. Leaf-rolling mosaic				
Green Mountain	Burbank	4/6	9/13	0/1
Green Mountain	American Wonder	1/3	10/10	0/1
Burbank	White Rose	2/2	4/4	0/1
Green Mountain	Bliss Triumph	2/3	3/3	0/1
Green Mountain	Earliest of All	0/3	.....	0/1
Green Mountain	Irish Cobbler	0/3	.....	0/1
E. Leaf roll				
Burbank	American Wonder	1/3	3/3	0/1
Bliss Triumph	American Wonder	1/3	4/4	0/1
Burbank	Earliest of All	3/3	6/9	0/1
Bliss Triumph	Earliest of All	1/2	4/7	0/1
Green Mountain	Bliss Triumph	2/3	5/5	0/1
Bliss Triumph	Garnet Chili	1/3	3/3	0/1
Burbank	White Rose	2/2	3/3	0/1
F. Spindle tuber				
Bliss Triumph	American Wonder	2/3	9/9	0/1
Bliss Triumph	Earliest of All	2/3	7/7	0/1
Bliss Triumph	Bliss Triumph	3/3	15/15	0/1
Bliss Triumph	Idaho Rural	0/3	.....	0/1

*Upper figure is number of plants diseased, lower figure total number of plants used.

In the early spring of 1927 better success was obtained. Halves of ten Bliss Triumph tubers were core-grafted with mild mosaic Burbank, and halves of six tubers were core-grafted with leaf roll Burbank. In this case the cores were washed with running water to remove the starch, and after each core was inserted into the seed piece to be inoculated, they were kept in humid air at room temperature for 48 hours to assure suberization. When planted in the greenhouse, nine of the ten seed pieces core-grafted with mild mosaic developed into plants with typical mild mosaic symptoms and all six seed pieces core-grafted with leaf roll developed into plants showing leaf roll. The plants grown as controls from the uninoculated half of each tuber in all cases remained healthy. As shown in Table II, however, such a high percentage of infection was not obtained in subsequent inoculations by the same method when the tubers were planted under cages in the field.

TABLE III. SUMMARY OF TRANSMISSION TESTS BY LEAF MUTILATION AND CORE GRAFT OF SEVEN DIFFERENT VIRUS DISEASES CONDUCTED IN FIELD CAGES. THE RESULTS FOR ALL POTATO VARIETIES USED HERE ARE COMBINED
1926-1929

Disease	By leaf mutilation		By core graft	
	No. of successful transfers	Percentage of infection	No. of successful transfers	Percentage of infection
		%		%
Mild mosaic	10/37*	27	10/21	48
Crinkle mosaic	18/41	42	1/18	6
Leaf-rolling mosaic	10/20	50	9/20	45
Rugose mosaic	57/67	84	1/14	7
Leaf roll	0/32	0	11/19	59
Spindle tuber	20/25	80	7/12	59
Calico	2/10	20	0/21	0

*Upper figure is number of plants diseased, lower figure total number of plants used.

Aphid transfers. Four species of aphids—namely, *Illinoia solanifolii* Ashm, *Myzus persicae* Sulz, *Myzus pelargonii* Kalt, and *Myzus circumflexus* Buckl—were tested as agents of spread for the different virus diseases under test. These aphids were identified by Dr. P. W. Mason of the Bureau of Entomology, United States Department of Agriculture. The two first-named species are commonly found in potato fields in Oregon. The two last-named species so far as known now do not ordinarily occur on potatoes in the field but colonize on them readily when transferred to them.

In the spring, tubers known to be infected with various virus diseases were planted in six-inch pots in the greenhouse and covered with individual muslin-covered cages. After the plants were about six inches tall, a number of individuals of one of the four species of aphids used were placed on these caged diseased plants and permitted to colonize. After a large colony had formed, about fifty aphids from a plant were transferred by means of a camel's-hair brush to healthy plants four to six inches high, growing under cages in the field. A week later all these caged plants to which aphids had been transferred were examined, and in case the insects had failed to colonize in a particular cage, a new supply of aphids from a similarly infected greenhouse plant was introduced. In practically all cases vigorous colonies developed. Three weeks after the aphids had been introduced, the

plants in the field cages were fumigated with 10 percent nicotine sulfate dust to kill the aphids and prevent them from stunting the plants.

Some efforts were also made to transfer disease by aphids to very young sprouts. In these tests the sprouted half of a diseased tuber was placed in a wide-mouthed quart jar with top covered by muslin. Aphids were introduced on to the sprouts and permitted to colonize. Aphids that had fed on the diseased sprouts were then transferred to the sprouts on healthy seed pieces kept in similar muslin-covered jars, one seed piece in each jar. Here they were allowed to remain for two weeks, after which the jars were fumigated to kill the aphids. The sprout-inoculated seed pieces were then planted under the usual muslin-covered cages in the field.

Root contact. A test was started to determine whether any of the potato virus diseases can spread by root contact or root mutilation. The procedure used was to plant a diseased tuber in the center of a field cage and a healthy seed piece on either side. In some cases after the plants had grown the soil between the plants was disturbed by means of a shovel, mutilating the roots. In other cases the soil between the plants was not disturbed. As a rule the diseased plant used was of a different variety and had tubers of a different color and shape from those of the variety used as the source of infection. This was an added precaution to eliminate the possibility of mixing tubers of the different hills in the cage at digging time.

SOURCES OF THE DIFFERENT VIRUSES STUDIED

In 1924 Green Mountain tubers containing mild mosaic, leaf-rolling mosaic, crinkle mosaic, rugose mosaic, leaf roll, and spindle tuber were furnished by Dr. E. S. Schultz of the U. S. Department of Agriculture from the experimental stocks grown at the field station at Presque Isle, Maine. In 1926 crinkle mosaic on Bliss Triumph and mild mosaic on Idaho Rural were furnished by the Montana Agricultural Experiment Station and spindle tuber on Irish Cobbler and interveinal mosaic of the same variety were sent by the Utah Agricultural Experiment Station. Virus-infected tubers collected from commercial fields in Oregon were also used after the identity of the diseases had been determined by comparison of symptoms with known material such as that provided by Dr. Schultz.

STUDIES ON INDIVIDUAL VIRUS DISEASES

The discussion of the individual diseases brings together the results of observations and experiments conducted by the authors. The symptoms as described are those met with under Oregon conditions. In general they are similar to those described by workers elsewhere for the same types of diseases.

MILD MOSAIC

Symptoms. This disease, which is fairly common in Oregon, is characterized by a mottling in the green of the leaf in which yellowish or light-colored areas alternate with similar areas of normal green. This is usually

accomplished by a crinkling but not a rolling of the foliage. These mottled areas are variable in size and shape and located without regard to the different tissues such as the veins of the leaf. This is in contrast to the loss of color occasioned by other factors than mosaic which may give rise to yellowish, somewhat circular, island-like areas of the leaf tissues between the larger veins. This latter type of discoloration is not to be confused with mosaic, for in the mild mosaic disease the lighter-colored areas are

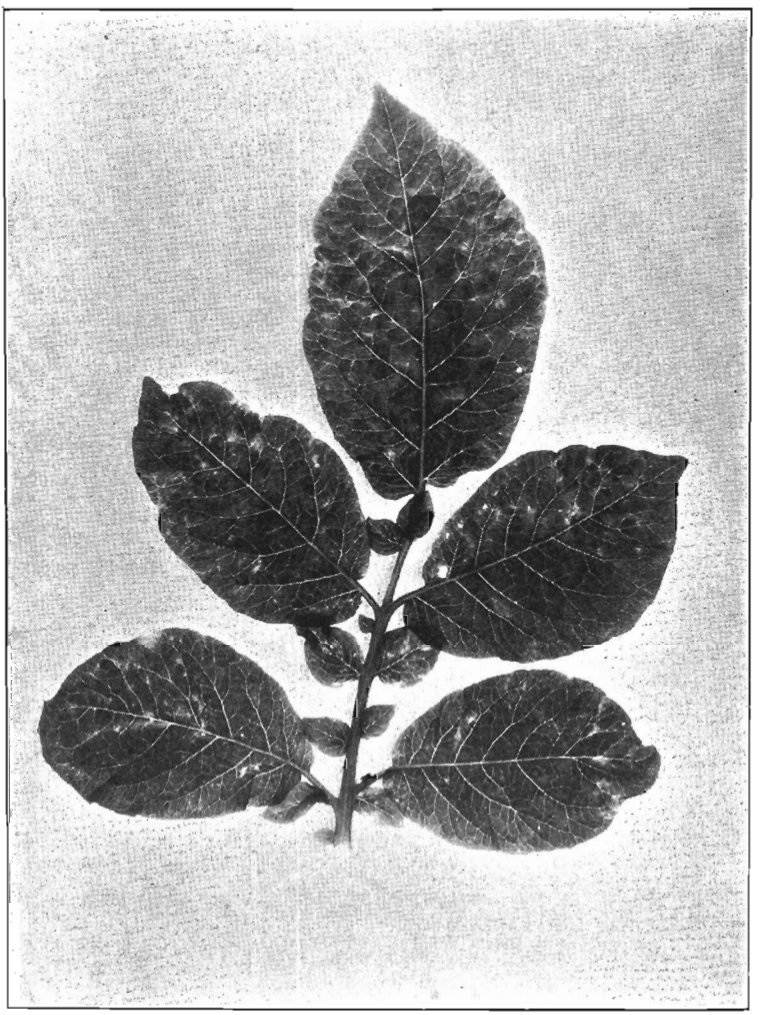

Figure 2. Mild mosaic, variety Burbank. Leaf showing mottled areas consisting of irregular patches of yellow-green color distributed without symmetry through the blade. Typically the leaves are not smooth and flat but have an uneven crinkled surface. Often the margins of the leaflets are wavy or ruffled.

not bounded or stopped by leaf veins. Diseased plants droop and die prematurely. No symptoms are evident in affected tubers. Symptoms are not often noted during the current season of inoculation but where they do appear on the new growth they are not different from those appearing in plants grown from infected tubers. The symptoms of mild mosaic are much less conspicuous in the growth of the plants that takes place during the warmer weather of summer than in growth that takes place in cooler weather. The masking of the symptoms is sometimes so pronounced as to make it difficult to identify the disease in attacked plants. The virus is always present, however, in plants grown from diseased tubers whether the particular plant shows the symptoms or not. If cooler weather prevails following a warm period when symptoms are marked, the symptoms will again become quite prominent.

Natural spread. In Oregon mild mosaic spreads fairly rapidly, but not as rapidly as rugose mosaic. In a test made in 1927, an isolated plot of 400 hills was planted with healthy Burbank potatoes, with the exception of one row of healthy Bliss Triumph. In this plot 10 percent or 40 tubers known to be infected with mild mosaic were planted uniformly through the plot. The mild mosaic was permitted to spread naturally to the other healthy plants. At digging time the tubers from the mild mosaic hills serving as the source of infection were discarded. The tubers from the remainder of the hills exposed to infection were saved as hill lots, planted as such in a separate plot the following year and symptoms observed. From the 2,643 Burbank tubers thus planted, 197 of the plants, or 7.5 percent, showed mild mosaic due to spread of the preceding year. From the 400 Bliss Triumph tubers, 111 plants, or 27.7 percent, developed mild mosaic. This shows that mild mosaic in this instance spread more rapidly in the Bliss Triumph variety than in Burbank. It has also been observed that under average field conditions Bliss Triumph is more readily infected with mild mosaic than most of the other commercial varieties in the Northwest, with the exception of White Rose.

Experimental transmission. Inoculation by leaf mutilation performed in plants in insect cages did not result in the development of any current-season symptoms, but when the progeny was planted the following year, some infection was evident. Leaf mutilation was sometimes effective in bringing about infection but not always. Bliss Triumph and White Rose were more easily infected than Earliest of All, Idaho Rural, and Burbank. This is shown in Table I. In eleven trials mild mosaic was not transmitted to Irish Cobbler. Schultz and Folsom[28] and Young and Morris[27] also failed to transmit this disease to Irish Cobbler. It appears that this variety is resistant or immune to mild mosaic.

The difficulty in transmitting mild mosaic by leaf mutilation has also been mentioned by Johnson.[11]

Core grafting proved somewhat more effective in transmitting mild mosaic than leaf mutilation, as shown in Table II.

All our attempts to transmit this disease by means of the four species of aphids used from infected Burbank, Bliss Triumph, Green Mountain, to Burbank, Bliss Triumph and Earliest of All failed. Schultz and Folsom[22, 28] transmitted mild mosaic by means of *Illinoia solanifolii* and *Aphis abbreviata,*

while negative results were obtained with flea beetles and Colorado potato beetles. Table IX shows the reduction in yield caused by mild mosaic in Idaho Rural.

INTERVEINAL MOSAIC

Interveinal mosaic, which has been found occasionally in fields in Oregon, appears like a mild type of mild mosaic. The leaves are smooth and not crinkled as in the latter. The symptoms of the disease correspond to those originally described for this malady by Quanjer,[20] although exact comparison with type material was impossible owing to the fact that tubers from Holland affected with Quanjer's interveinal mosaic were not available.

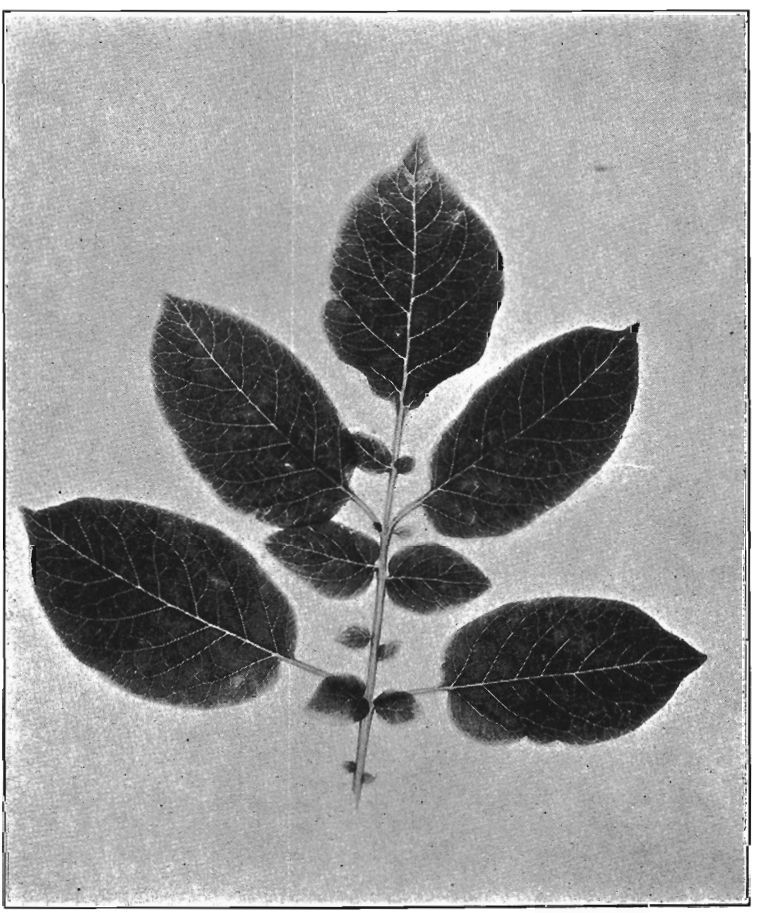

Figure 3. Interveinal mosaic, variety American Wonder. The leaves are smooth and not crinkled as in mild mosaic. The mottled areas are similar to those in mild mosaic and are often masked in the warmer weather. This disease appears like a mild type of mild mosaic but is distinct from it.

This type of mosaic is often found on Irish Cobbler, which variety appears to be immune from mild mosaic. This disease had been transmitted by core grafts from Irish Cobbler to American Wonder and Bliss Triumph, on which it produces symptoms different from those produced by mild mosaic.

Young and Morris[27] describe this disease as super mild mosaic. They were successful in transmitting the disease by core grafts. Affected Netted Gem, sent by Young and Morris from Montana, showed a reduction in yield of 19 percent when planted at Corvallis in spite of the fact that the symptoms were masked as is commonly the case under summer temperatures. See Table IX.

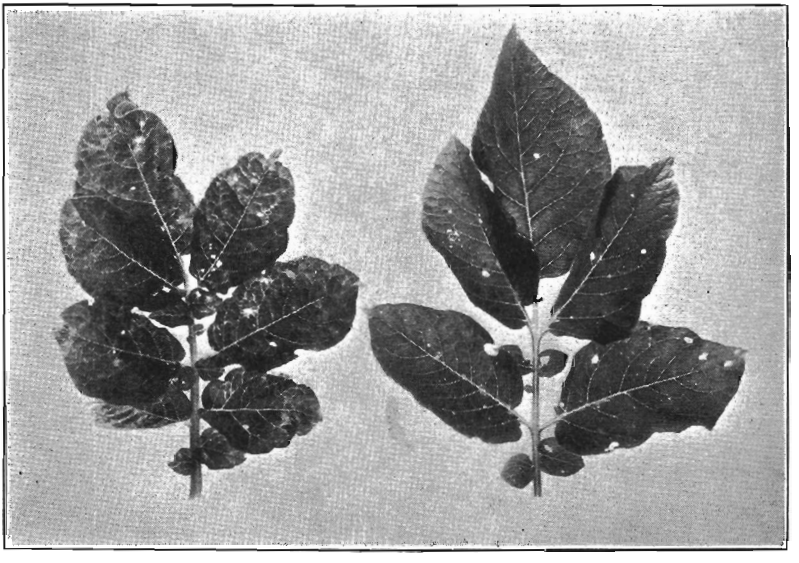

Figure 4. Crinkle mosaic left, healthy right, variety Earliest of All. In this disease the mottled areas are more abundant and prominent than in mild mosaic. Typically they are grouped more abundantly and closer together on the margins and particularly toward the tip of the leaflets.

CRINKLE MOSAIC

Crinkle mosaic has been found in Oregon only occasionally. It is characterized by a prominent mottling and crinkling of the leaflets. The mottled spots are large and have a tendency to be noticeable especially around the margin of the leaflets. The symptoms are partly or completely masked by high temperature. It differs from mild mosaic in that the leaflets are more ruffled and the blotches are larger. It can be distinguished from rugose mosaic by the larger blotches and by the absence of necrosis on the veins of the lower leaves.

This disease as originally described by Schultz and Folsom[23] is not identical with the crinkle of Murphy[13] and Quanjer[20] which resembles our rugose mosaic.

The disease was transmitted by leaf mutilation, but as a rule only a low percentage of infection resulted. Core grafts in a small number of trials resulted in transmitting the disease only once. One case of transmission by means of *Myzus persicae* and one by *Myzus circumflexus*, by tuber sprout inoculation, was recorded. In tests conducted in 1928 and 1929, aphids failed to transmit the disease from Green Mountain, Burbank and Bliss Triumph to Burbank, Bliss Triumph and Earliest of All.

Table IX shows the reduction in yield caused by crinkle mosaic in Bliss Triumph.

RUGOSE MOSAIC

Symptoms. Of the potato virus diseases of the mosaic type that occur in Oregon, rugose mosaic is the commonest and most severe. It can be readily differentiated from mild and crinkle mosaic, in that the mottled areas are smaller, more numerous, and grouped closer to the main veins. During high temperature the mottling may be completely masked, but the crinkling of the leaves and their tendency to curl slightly downward persist and make the identification of this disease certain. Some of the veins of the lower leaves generally are necrotic, resembling black, pencil-like lines. The affected plants are noticeably stunted and generally die prematurely.

If spread takes place early in the season, the current-season symptoms develop; these are characterized by a burning or necrosis of the veins of the newly developed leaves and a dying of the tissue between the veins. These leaves will eventually drop, or hang on by a thread of tissue of the stem. Current-season symptoms of rugose mosaic have been referred to as 'streak' by other workers who did not recognize them as due to this malady. A disease referred to as streak but different from rugose mosaic has been described by Schultz and Folsom,[22] but the writers have never encountered this disease in the field nor maintained it in culture in cages.

Experimental transmission. Rugose mosaic was readily transmitted by leaf mutilation, 100 percent infection often being obtained by this method. The disease was also transferred by core grafts, but in these experiments this method was not as effective as leaf mutilation.

Transmission by aphids was not found easy. *Illinoia solanifolii*, as shown in Table VI, persistently failed to transmit this disease, whereas it was occasionally transferred by *Myzus persicae* and *Myzus circumflexus*.

Schultz and Folsom[22] claim to have transmitted rugose mosaic by aphids. They state that current-season symptoms of rugose mosaic following aphid inoculations were less marked than after parallel leaf-mutilation inoculations.

Incubation period. The incubation period was studied for rugose mosaic under Oregon conditions in the field and found to be from three to four weeks. In the summer of 1928, twelve healthy caged Earliest of All plants were inoculated by leaf mutilation with rugose mosaic. One week from the date of inoculation, and once every week thereafter for six weeks, a few leaves from each of the twelve inoculated plants were taken and the juice used to inoculate by the same method six healthy caged Earliest of All plants, a new set of plants being used each week.

Eight out of the twelve plants serving as the source of inoculum became diseased, but they did not show any current-season symptoms of rugose mosaic until the fourth week after inoculation. At three weeks, however, when no symptoms as yet were visible, the disease was transmitted from these plants to one of the set of six plants inoculated at that time.

Four weeks after inoculation, when symptoms had become evident, and also at the fifth and sixth weeks, the disease was transmitted to a high percentage of the test plants. This is shown in Table IV.

It is interesting to note that when the tubers produced by the diseased test plants were grown in the field later, those that came from the earlier tests produced fewer diseased plants proportionally than those from the later tests. Too few plants were included, however, to justify the conclusion that the results are of any significance. The controls remained healthy.

A somewhat similar experiment was set up the same year to determine the incubation period of rugose mosaic, attempting to use the aphid *Illinoia solanifolii* as a means of transfer of the virus to the test plants. This experiment, however, gave no results. The insects did not transmit the disease in a single instance although the plants on which they fed carried the virus as shown by the performance of the progeny.

Figure 5. Current-season rugose mosaic, variety Burbank. This burning of the veins and leaf-blade is usually the first symptom shown when plants are infected during growth. This symptom is so characteristic that current-season infection by this disease can be accurately determined. However, if infection takes place late no symptoms may be produced. The leaves illustrated here were photographed six weeks after inoculation in muslin-covered cages. For the performance of the tubers from this plant see Figure 6.

TABLE IV. INCUBATION PERIOD OF RUGOSE MOSAIC
As indicated by the ability of the juice from inoculated plants to transmit the disease to healthy plants in tests at weekly intervals

Interval of time after inoculation of original plants	Plants tested with juice from inoculated plants		Tubers from diseased test plants		
	No. tested	No. becoming diseased	No. harvested	No. producing diseased plants	Percentage carrying disease
1 week	6	0	----	----	----
2 weeks	6	0	----	----	----
3 weeks	6	1	3	1	33
4 weeks	6	5	14	7	50
5 weeks	6	6	19	16	84
6 weeks	6	5	11	8	72

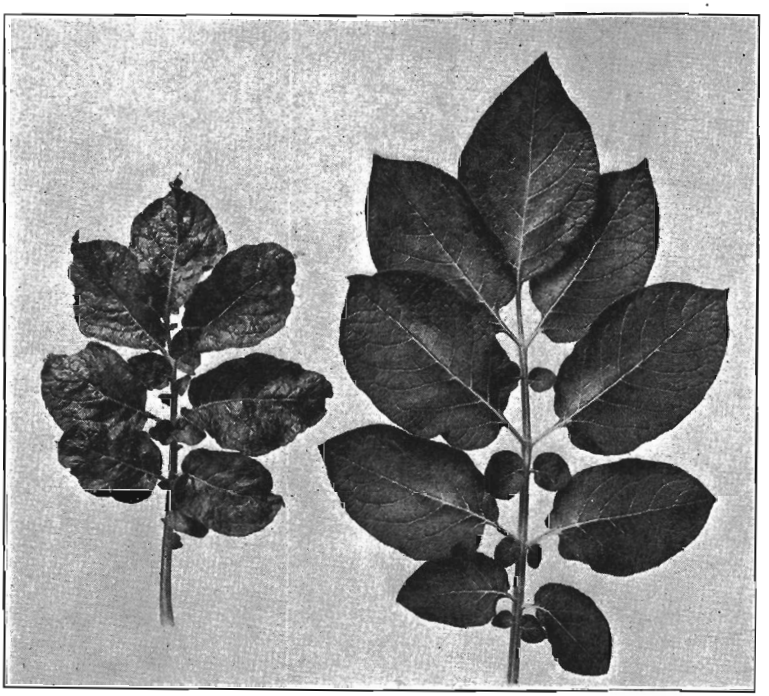

Figure 6. Rugose mosaic and healthy leaves from sister plants, variety Burbank. The tubers which produced these leaves were grown by two sets of the same tuber. The difference in their performance is due to the fact that one set was inoculated with rugose mosaic and the other was kept as a healthy control. Crinkling of the leaf blade and ruffling of the margin are very prominent here. Mottling is not distinct in this specimen. Under some circumstances the mottling is quite plain. Typically the mottled areas are small and located more abundantly near the main veins. The tuber which produced the diseased leaf was grown by the plant illustrated in Figure 5.

LEAF-ROLLING MOSAIC

Leaf-rolling mosaic, although not of any serious economic importance in Oregon, is occasionally found in commercial fields.

The mottling of the leaflets of plants infected with leaf-rolling mosaic is diffused and resembles the type found in rugose mosaic. The leaves generally show a rolling upwards, but the leaves are flaccid and resemble the type of rolling found in plants affected with Rhizoctonia or black-leg.

Figure 7. Leaf-rolling mosaic, variety White Rose. The mottling of the leaflets is diffused and resembles somewhat the type found in rugose mosaic. The leaves particularly on the lower half of the plant commonly show a soft, upward rolling.

This complex of symptoms, the rolling and the mottling, is apparently due to a single virus and as such is always transmitted.

There appears to be a distinct difference in the severity of the symptoms. The rolling and mottling are almost masked in Burbank and Irish Cobbler. In some of the other varieties, like Earliest of All, Idaho Rural, Bliss Triumph, Green Mountain, and White Rose, the leaves show a distinct rolling, and the mottling is generally distinct, although under high temperature it is partly or completely masked.

Leaf mutilation and core grafts have given practically the same fair percentage of infection (Tables I, II). The disease also was occasionally transmitted by aphids (Table VI).

LEAF ROLL

This disease is found in fields in Eastern and Central Oregon, but is seldom found in the western part of the state. It is believed that this fact can be explained on the basis that this disease was introduced with seed purchased from regions where the disease occurs, and that the growers in the western part of the state have been fortunate in obtaining seed free from this disease.

Symptoms. Plants affected with leaf roll have an upward rolling of the leaflets on the midrib giving them a tubular form and the plant a stiff, erect appearance. The lower leaves are always rolled and leathery or brittle, often dying from the tips backward in advanced stages. Other leaves may roll also. The leaves are generally somewhat chlorotic and the plants are considerably dwarfed. When the plants are affected by current-season infection the leaf rolling and loss of color show up first in the topmost (younger) leaves.

Some of the tubers infected with leaf roll show net necrosis, but this is not a constant symptom. This tuber symptom has been reported by Schultz and Folsom[21] and by Gilbert.[6] Quanjer[20] stated that net necrosis is not a tuber symptom in leaf roll tubers of Dutch varieties.

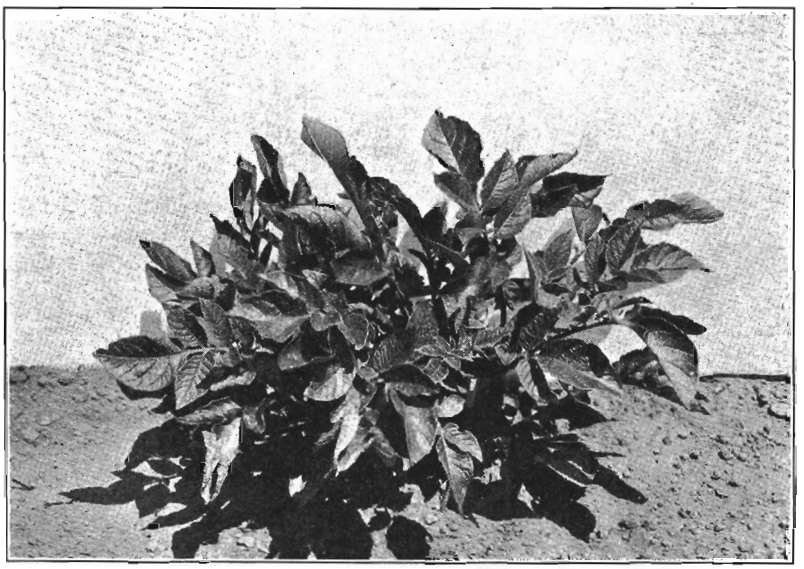

Figure 8. Leaf roll, variety Burbank. Rolling is particularly prominent in the lower leaves though it is evident also in the upper ones. The foliage tends to be rigid and leathery and not soft and flexible as in normal plants. Diseased plants are noticeably stunted and lighter in color than the healthy.

Experimental transmission. Several attempts were made to transmit this disease by leaf mutilation but always with negative results. Schultz and Folsom[22] and Young and Morris[27] also were unable to transmit this disease by this method.

Core grafts proved to be an effective method of transmitting leaf roll (Table II). Murphy and McKay[15] also transmitted leaf roll by core grafts.

Aphid transmission of leaf roll was first demonstrated by Oortwyn Botjes[18] in 1919, and in 1920 was independently confirmed by Schultz and Folsom.[21] The Oregon experiments have demonstrated that a high percentage of leaf roll transmission results when *Myzus persicae, Myzus pelargonii,* and *Myzus circumflexus* are used as agents of spread. *Illinoia solanifolii* transmitted this disease only occasionally (Table VI).

Natural spread. When the disease is present in stock in Western Oregon, it spreads as was manifested in 1927. Then a row of healthy Bliss Triumph was planted adjoining a row of Netted Gem, 100-percent infected with leaf roll. The following year 50 percent of the Bliss Triumph plants were shown to be infected with leaf roll.

In 1927, in an isolated plot of 400 hills, 10 percent of leaf roll plants were introduced and the disease was permitted to spread. This plot was surrounded by a corn field, and the soil was of poor texture and fertility. The plants were stunted and showed lack of vigor. This may have been a reason why insects were not attracted to these plants; at any rate a very low percentage of spread took place that year. The following year the progeny from this plot was planted, and showed that only 2.5 percent leaf roll had spread to the Burbank and Netted Gem varieties and 6 percent to Bliss Triumph.

SPINDLE TUBER

This disease is not common in Oregon, but is occasionally found in imported stock. Plants affected with spindle tuber are characterized by slenderness and uprightness, and the foliage is of a darker green color than that of healthy plants. The tubers, especially long tubers like Netted Gem and Burbank, are abnormally spindling. Cylindrical tubers become more blocky and develop deep eyes. In the case of Bliss Triumph a lighter red color is obtained than in healthy tubers of the same variety.

As shown in Table I, spindle tuber was fairly easily transmitted by leaf mutilation. It also was transmitted by core grafts, but in these experiments was not as easily transmitted by this method as by leaf mutilation. Goss[7] found that spindle tuber is readily transmitted by core grafts. Goss[7] also reported successful transmission of spindle tuber by rubbing together freshly cut surfaces of infected and healthy potatoes. He was likewise able to transmit the disease by cutting healthy seed with a knife previously used to cut infected tubers.

In 1929, an experiment was started to determine the effectiveness of transmitting spindle tuber by a seed-cutting knife. Healthy potatoes were selected. One seed piece was then cut from each tuber with a sterile knife and planted to serve as a control. After this, a knife was inserted into a Bliss Triumph tuber infected with spindle tuber and then used to cut a seed piece from a healthy White Rose tuber. This procedure was repeated until

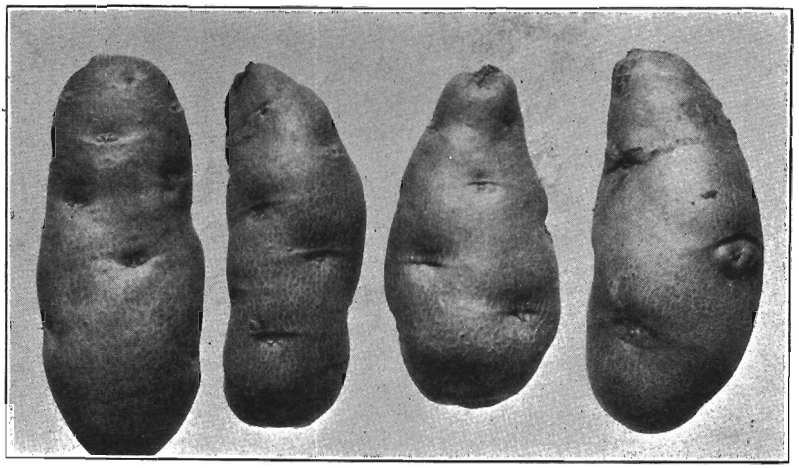

Figure 9. Tubers affected by spindle tuber disease, variety Netted Gem. Typically affected tubers are elongated and more pointed at the ends than normal tubers. Oval tubers become more elongated.

the tuber was entirely cut up. A number of other tubers were cut in the same manner and all the seed pieces were planted. When White Rose was used, of the 114 plants growing from seed pieces cut in this manner 17 plants, or 16 percent, developed typical symptoms of spindle tuber. In the

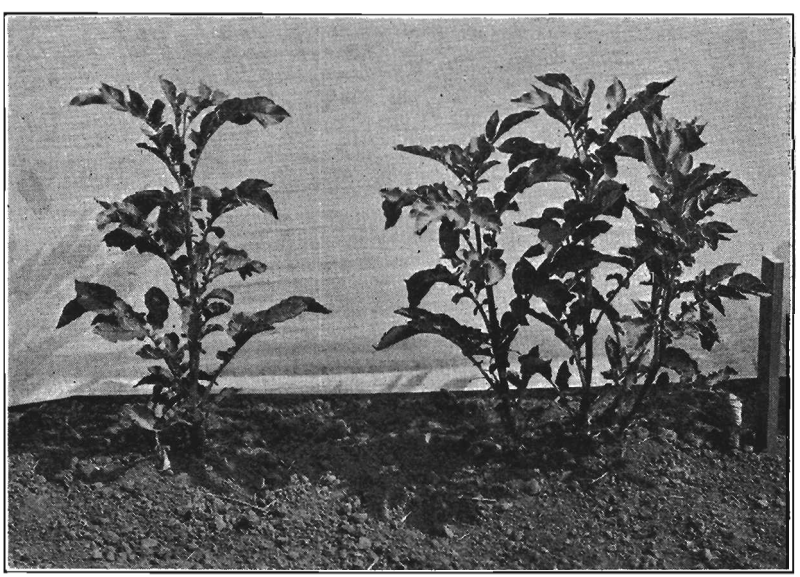

Figure 10. Plants affected by spindle tuber disease, variety Burbank. Affected plants are more upright, less vigorous and not so broad or bushy as healthy ones. The leaf petioles form a more acute angle with the stem, giving the plant a stiff, erect appearance.

Burbank variety 3 plants from the 110 seed pieces, or 2.7 percent, developed spindle tuber symptoms. The controls remained healthy.

Insect transmission was not attempted in the Oregon work, but Goss[8] has reported transmission by grasshoppers, flea beetles, tarnished plant bugs, and Colorado potato beetles.

Table IX shows the decrease in yield caused by this disease.

CALICO*

This trouble of potatoes is occasionally found in Central and Eastern Oregon but only rarely in Western Oregon. It is characterized by the occurrence of large irregular yellow to cream-colored spots on the leaves. The spots may be sparse or numerous and well distributed over the plant.

Hungerford[9] first described calico in 1920 from Idaho. He states that "all evidence to date seems to show that this condition is tuber perpetuated, but not infectious." Young and Morris[27] were unable to transmit calico to healthy potatoes by means of core grafts in twenty-two trials. They state that it may be a genetic abnormality instead of a disease.

In 1927 calico was successfully transmitted by leaf mutilation from Earliest of All to Burbank. The tuber from which the seed piece to be inoculated was cut was indexed in the greenhouse the preceding winter and was healthy. The other three seed pieces from the same tuber unit were also planted, but unfortunately all three decayed, so that no control plant was available.

The disease, however, undoubtedly developed as a result of the leaf mutilation, since the first symptoms became evident about five weeks after inoculation. The progeny from this hill when planted the following year also showed typical calico symptoms.

In 1929 when three Bliss Triumph plants were inoculated by leaf mutilation with calico on Burbank, the disease was transmitted to one plant. During the current year no symptoms developed, but when the progeny of the hill was planted in 1930 one of the eight plants showed the characteristic symptoms of calico. The other seven plants were healthy. The controls also were healthy. Two out of the ten attempts to transmit this disease by leaf mutilation were successful.

A total of twenty core grafts were made, but the results were negative.

GIANT HILL

Giant hill is found throughout Oregon but is not considered important. It is characterized in affected plants by abnormally large coarse vines. This symptom generally does not become evident until the plant is mature. Affected plants remain green longer than healthy plants, and also are somewhat resistant to frost.

Tubers from affected plants are generally large and often knobby, although some tubers may be smooth and of average size.

*After submitting this manuscript for publication, a copy of "The infectious nature of Calico," Hilgardia, 6, 1931 (California Agr. Exp. Sta.) was received in which D. R. Porter reports a relatively high percentage of Calico obtained by leaf mutilation.

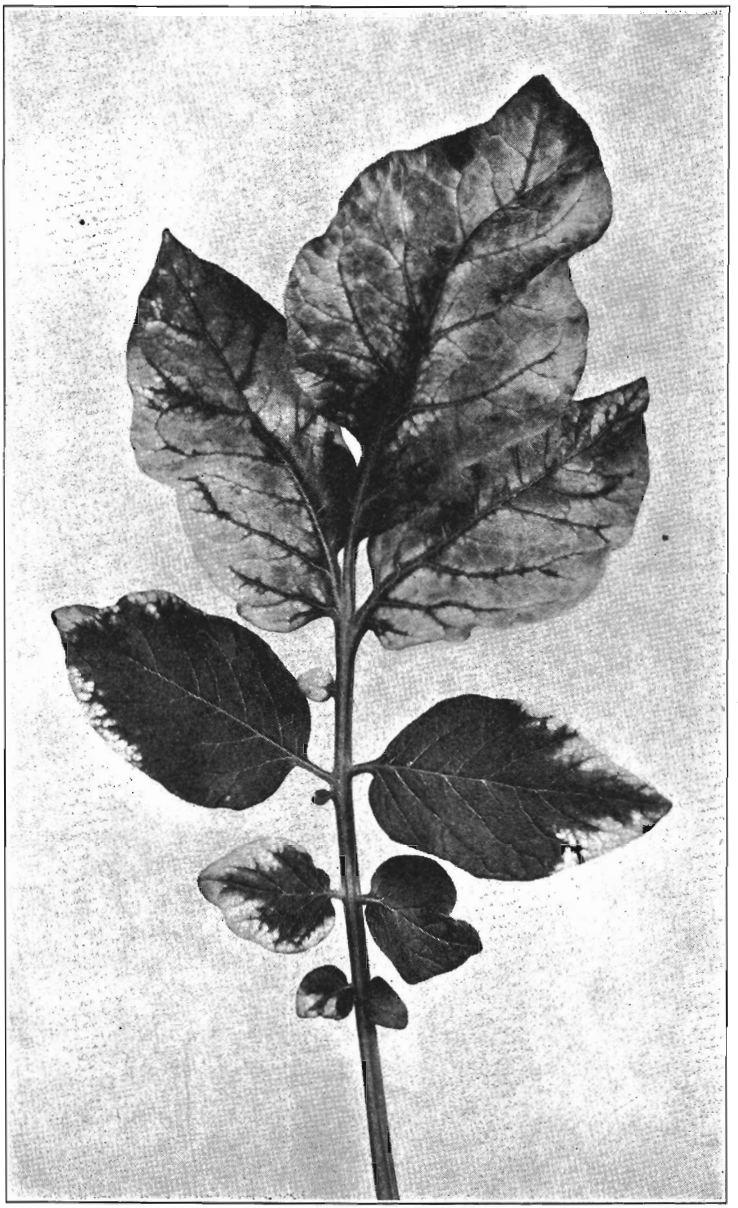

Figure 11. Calico, variety Earliest of All. This disease is distinguished by the occurrence of large irregular yellow to cream-colored splotches on the leaves and by a stunting of the plant. Tubers from affected plants will perpetuate the disease.

Giant hill in Netted Gem and Earliest of All has been maintained for six years by planting tubers from affected hills under insect cages and out in the open. The characteristic symptoms appear each year in the progeny of most plants, but some individual plants from affected parents appear normal and are difficult to distinguish from healthy plants.

Several attempts were made to transmit giant hill by core grafts and leaf mutilation, but no definite evidence that it was transmitted by this means was secured. Dana[4] reports that he transmitted giant hill in one inoculated plant by core grafts.

In an isolated plot at Corvallis where 10 percent giant hill was allowed full natural opportunity to spread to 400 healthy hills, no definite evidence of transmission was secured.

It appeared that giant hill was spread in cages by root mutilation, as shown in Table VIII but on account of the small number of plants involved, these results cannot be considered conclusive.

We do not have enough evidence to date to determine whether giant hill is a transmissible disease, a physiological abnormality, or a mutation.

WITCHES'-BROOM

Witches'-broom is widely distributed in Oregon, occurring in all areas of the state. Generally the percentage of affected plants is quite small, though occasionally in some fields a majority of the plants are affected.

Figure 12. Witches'-broom and part of healthy plant, variety Bliss Triumph. This plant shows the typical performance obtained from badly diseased tubers. Sometimes hundreds of sprouts or branches are produced and none of the tubers set acquire much size. The leaves are often somewhat rounded and velvety in appearance.

Plants affected with this disease are characterized by numerous spindling stems and small leaves velvety in appearance. The tubers produce numerous slender, spindling sprouts. Some of the affected tubers show net necrosis.

As a rule affected plants yield a large number of tubers, but none or only a few are of marketable size. The majority of the tubers may be about the size of a marble.

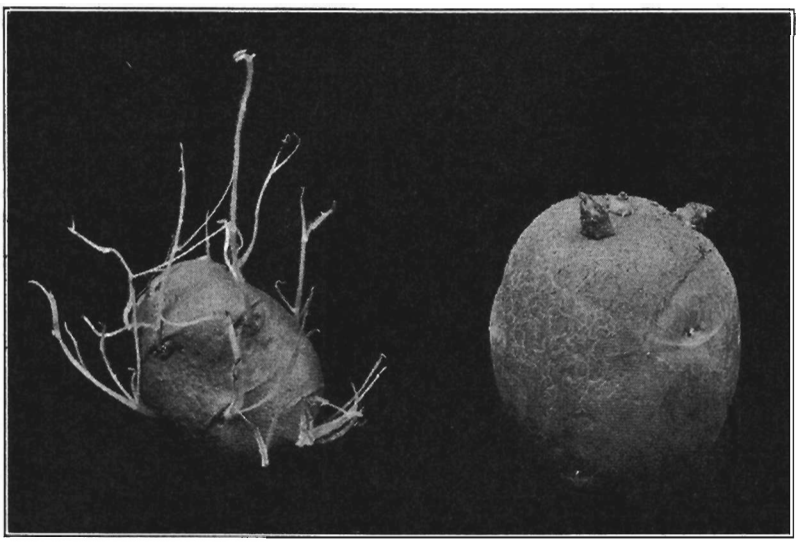

Figure 13. Spindling sprouts caused by witchs'-broom disease in tuber held in storage till late in comparison with sprouts of normal potato, variety Up-to-Date.

This disease was first briefly described by Bisby and Tolaas[2] as occurring in Minnesota. The first good description of the disease was given by Hungerford and Dana.[10] Young and Morris[26] were the first to prove that it is a transmissible disease. They transferred it by means of core grafts.

In the Oregon experiments several attempts were made to transmit the disease by leaf mutilation, but the results were always negative. Aphids found in storage on witches'-broom sprouts at a farm where this disease was quite serious failed to transmit it. Young and Morris[27] also were unable to obtain infection by means of aphids.

The manner in which the disease spreads from plant to plant in the field is not known. In our experimental plots direct spread to healthy plants in the row did not seem to occur even when alternate plants were diseased.

APHIDS AS VECTORS OF POTATO VIRUS DISEASES

Numerous experiments were carried on with various species of aphids to determine their capacity to transmit various potato virus diseases. In 1925 *Myzus pelargonii* were colonized on sprouts of a tuber infected with leaf roll and from there transferred to the sprouts of six half tubers from healthy plants. All six plants developed leaf roll the same season, whereas the control half of each tuber developed into healthy plants. At that time the same species of aphids was also colonized on sprouts of a tuber infected with rugose mosaic, and from there transferred also to the sprouts of six half tubers from healthy plants. In contrast to the 100-percent infection resulting from the leaf roll transfer, these aphids failed to transmit rugose mosaic in a single instance.

Every year since that time aphid transfer by sprout inoculation and also by colonizing aphids on the leaves of diseased plants and then transferring them to leaves of healthy plants was conducted on a small scale until 1928 and 1929, when extensive experiments were started along these lines. The results are shown in Tables V and VI.

TABLE V. INTERVARIETAL SPROUT INOCULATIONS OF POTATO VIRUS DISEASES WITH APHIDS IN 1928

Source of inoculum (potato variety)	Variety inoculated	Species of aphids	No. of hills infected	No. of infected tubers in infected hills	Control hills
A. Crinkle Mosaic					
Burbank	Bliss Triumph	*Myzus pelargonii*	0/1*	.....	0/1
Earliest of All	Bliss Triumph	*Myzus pelargonii*	0/1	.....	0/1
Green Mountain	Bliss Triumph	*Myzus pelargonii*	0/1	.....	0/1
Burbank	Bliss Triumph	*M. persicae*	0/1	.....	0/1
Earliest of All	Bliss Triumph	*M. persicae*	1/1	2/2	0/1
Burbank	Bliss Triumph	*M. circumflexus*	0/1	.....	0/1
Earliest of All	Bliss Triumph	*M. circumflexus*	1/1	10/10	0/1
Green Mountain	Bliss Triumph	*M. circumflexus*	0/1	.....	0/1
B. Leaf roll					
Green Mountain	Bliss Triumph	*Myzus pelargonii*	0/0	.....	0/0
Burbank	Bliss Triumph	*Myzus pelargonii*	1/1	5/5	0/1
Bliss Triumph	Bliss Triumph	*Myzus pelargonii*	1/1	6/6	0/1
American Wonder	Bliss Triumph	*Myzus pelargonii*	1/1	4/6	0/1
Netted Gem	Bliss Triumph	*Myzus pelargonii*	1/1	2/2	0/1
Green Mountain	Bliss Triumph	*M. persicae*	0/1	.....	0/1
Burbank	Bliss Triumph	*M. persicae*	1/1	4/4	0/1
Bliss Triumph	Bliss Triumph	*M. persicae*	1/1	2/2	0/1
American Wonder	Bliss Triumph	*M. persicae*	1/1	3/5	0/1
Green Mountain	Bliss Triumph	*M. circumflexus*	0/1	.....	0/1
Burbank	Bliss Triumph	*M. circumflexus*	1/1	4/4	0/1
Bliss Triumph	Bliss Triumph	*M. circumflexus*	1/1	3/3	0/1
American Wonder	Bliss Triumph	*M. circumflexus*	0/1	.....	0/1
Netted Gem	Bliss Triumph	*M. circumflexus*	0/1	.....	0/1

*Upper figure is number of plants diseased, lower figure total number of plants used.

These show that leaf roll has been consistently transmitted by *Myzus persicae*, *Myzus pelargonii*, and *Myzus circumflexus*, whereas *Illinoia solanifolii* transmitted the disease only occasionally. Murphy and McKay[17] report that in experimental work with aphids, extending from 1922 to 1928, the number of successful leaf roll infections obtained with *Myzus persicae* was 19 out of 25;

TABLE VI. INTERVARIETAL APHID INOCULATION OF POTATO VIRUS DISEASES PERFORMED IN FIELD CAGES

Source of inoculum (potato variety)	Variety inoculated	Species of aphids	No. of hills infected	No. of infected tubers in infected hills	Control hills
A. Rugose mosaic, 1928 Experiments					
Earliest of all	Earliest of All	*Ill. solanifolii*	0/3*	.....	0/1
Burbank	Burbank	*Ill. solanifolii*	0/3	.....	0/1
Earliest of All	Bliss Triumph	*Ill. solanifolii*	0/3	.....	0/1
Earliest of All	Earliest of All	*M. pelargonii*	0/3	.....	0/1
American Wonder	Earliest of All	*M. pelargonii*	0/3	.....	0/1
Green Mountain	Bliss Triumph	*M. pelargonii*	0/3	.....	0/1
Green Mountain	Burbank	*M. pelargonii*	0/3	.....	0/1
Earliest of All	Earliest of All	*M. persicae*	1/3	2/4	0/1
Burbank	Earliest of All	*M. persicae*	0/2	.....	0/1
Rugose mosaic, 1929 Experiments					
Earliest of All	Burbank	*Ill. solanifolii*	0/6	.....	0/2
Bliss Triumph	Burbank	*Ill. solanifolii*	0/3	.....	0/1
Earliest of All	Bliss Triumph	*Ill. solanifolii*	0/2	.....	0/1
Earliest of All	Earliest of All	*Ill. solanifolii*	0/48	.....	0/16
Earliest of All	Burbank	*M. pelargonii*	0/9	.....	0/3
Earliest of All	Earliest of All	*M. pelargonii*	0/9	.....	0/3
Earliest of All	Bliss Triumph	*M. pelargonii*	0/3	.....	0/1
Earliest of All	Burbank	*M. persicae*	1/10	2/10	0/4
Earliest of All	Earliest of All	*M. persicae*	0/6	.....	0/2
Earliest of All	Bliss Triumph	*M. persicae*	2/3	5/8	0/1
Earliest of All	Burbank	*M. circumflexus*	1/15	2/2	0/2
Earliest of All	Earliest of All	*M. circumflexus*	2/8	4/5	0/3
B. Leaf-rolling mosaic					
Green Mountain	Bliss Triumph	*Ill. solanifolii*	0/3	.....	0/1
Bliss Triumph	Bliss Triumph	*Ill. solanifolii*	0/3	.....	0/1
Green Mountain	Earliest of All	*Ill. solanifolii*	0/3	.....	0/1
Earliest of All	Burbank	*Ill. solanifolii*	1/3	3/3	0/1
Green Mountain	Bliss Triumph	*Myzus pelargonii*	0/3	.....	0/1
Bliss Triumph	Bliss Triumph	*Myzus pelargonii*	0/3	.....	0/1
Green Mountain	Earliest of All	*Myzus pelargonii*	1/2	1/2	0/1
Earliest of All	Earliest of All	*Myzus pelargonii*	1/3	.....	0/1
Green Mountain	Bliss Triumph	*M. persicae*	1/3	2/2	0/1
Bliss Triumph	Bliss Triumph	*M. persicae*	0/3	.....	0/1
Earliest of All	Earliest of All	*M. persicae*	0/3	.....	0/1
Earliest of All	Burbank	*M. persicae*	1/3	3/3	0/1
C. Leaf roll, 1928 Experiments					
Green Mountain	Burbank	*M. solanifolii*	0/6	.....	0/2
Burbank	Burbank	*M. solanifolii*	0/6	.....	0/2
American Wonder	Bliss Triumph	*M. solanifolii*	1/2	1/2	0/1
Green Mountain	Burbank	*M. pelargonii*	5/5	15/15	0/2
Burbank	Burbank	*M. pelargonii*	3/6	6/9	0/2
American Wonder	Bliss Triumph	*M. pelargonii*	3/3	10/10	0/1
Green Mountain	Burbank	*M. persicae*	4/4	11/11	0/2
Burbank	Burbank	*M. persicae*	2/2	5/5	0/1
Burbank	Earliest of All	*M. persicae*	2/3	5/5	0/1
American Wonder	Bliss Triumph	*M. persicae*	3/3	7/7	0/1
Leaf Roll, 1929 Experiments					
Bliss Triumph	Burbank	*M. solanifolii*	0/2	.....	0/1
Burbank	Burbank	*M. solanifolii*	1/6	1/2	0/2
Bliss Triumph	Earliest of All	*M. pelargonii*	3/3	8/8	0/1
Bliss Triumph	Burbank	*M. persicae*	3/3	9/10	0/1
Bliss Triumph	Earliest of All	*M. persicae*	2/2	6/6	0/1
Burbank	Bliss Triumph	*M. persicae*	2/2	5/5	0/1
Bliss Triumph	Burbank	*M. circumflexus*	3/3	9/9	0/1
Bliss Triumph	Earliest of All	*M. circumflexus*	3/3	18/18	0/1

*Upper figure is number of plants diseased, lower figure total number of plants used.

with *Illinoia solanifolii*, 1 out of 151; and with unidentified aphids, 5 out of 34. The Oregon results with *Illinoia solanifolii* correspond very closely with theirs.

Positive results failed when *Myzus pelargonii* and *Illinoia solanifolii* were used as agents for the transmission of rugose mosaic, whereas the disease was occasionally transmitted by *Myzus persicae* and *Myzus circumflexus*.

All attempts to transfer mild mosaic by any of the four named species of aphids failed.

Crinkle mosaic was transmitted occasionally by *Myzus persicae*, and *Myzus circumflexus* in a sprout-inoculation test, but the results were negative when any of the other two species were tested.

Leaf-rolling mosaic was occasionally transmitted by *Illinoia solanifolii*, *Myzus persicae*, and *Myzus pelargonii*.

Schultz and Folsom[23] report successful virus disease inoculation by means of three species of aphids, *Myzus persicae*, *Illinoia solanifolii*, and *Aphis abbreviata*. They found that *Illinoia solanifolii* transmitted mild mosaic, both alone and in combination with leaf roll. In 1925 these investigators[23] experienced difficulty with aphid inoculation. They state that aphids sometimes do not transmit disease under conditions that apparently are the same as those giving positive results. Murphy and McKay are of the opinion that several species of aphids are transmitters of mosaic, but they also find that under apparently similar conditions, inoculation is often not successful. They state:[14] "We have at different times successfully conveyed mosaic and leaf roll infection from tuber to tuber by means of aphids on the sprouts, but on many occasions the results have been mainly or entirely negative. Three different aphids were used at times, these being *Myzus persicae*, *Illinoia solanifolii*, and *Myzus pseudosoloni*; all have carried infection at times so that the conflicting results do not depend on the sort of aphids used, neither do they appear to be determined by the number of aphids used, the length of their stay on the source of infection or on the plants being infected."

Murphy and McKay[15] are of the opinion that various potato insects other than aphids are carriers of leaf roll, though not necessarily of mosaic. They give the following insects as carriers: the Capsid bug, *Calcocoris bipunctatus*, and the Jassid, *Thyphlocba ulmi*. They state that their results furnish hardly more than a suspicion that the flea beetle can act as a carrier of leaf roll; that there is little doubt that both Capsid bugs and Jassids act as sufficient transmitters of leaf roll.

K. M. Smith[25] also came to the conclusion that under certain conditions the aphids *Myzus persicae* and *Illinoia solanifolii* can act as efficient transmitters of potato mosaic. He says: "In the present state of our knowledge of this subject it is not possible to say what these conditions may be."

Elze[6] experimented with leaf roll, common mosaic, crinkle, stipple streak, interveinal mosaic, aucuba mosaic, and spindling sprout. With the above-mentioned diseases infections were carried out with *Myzus persicae*, *Myzus pseudosolani*, *Aphis rhamni*, *Aphis fabae*, *Eupteryx auratus*, *Typhlocyba solani*, *Lygus pratensis*, *Psylliodes affinis*, *and Mamestra barssicae*. He found that infection with other insects than aphids was always more difficult to accomplish. But there were also differences between aphids. With *Aphis fabae* few results were obtained; the infecting power of *Myzus persicae* was the greatest. Leaf roll was of all diseases the easiest to transmit.

TABLE VII. SUMMARY OF TRANSMISSION TESTS CONDUCTED UNDER FIELD CAGES WITH FOUR SPECIES OF APHIDS USING FIVE DIFFERENT VIRUS DISEASES. THE RESULTS FOR ALL POTATO VARIETIES USED ARE HERE COMBINED.
1928-1929

Disease	Aphids	No. of successful transfers	Percentage of infection
			%
Mild mosaic	*Illinoia solanifolii*	0/16*	0
Mild mosaic	*Myzus pelargonii*	0/14	0
Mild mosaic	*M. persicae*	0/10	0
Mild mosaic	*M. circumflexus*	0/13	0
Crinkle mosaic	*Illinoia solanifolii*	0/17	0
Crinkle mosaic	*M. pelargonii*	0/18	0
Crinkle mosaic	*M. persicae*	1/16	6
Crinkle mosaic	*M. circumflexus*	1/8	13
Leaf-rolling mosaic	*Illinoia solanifolii*	1/12	8
Leaf-rolling mosaic	*M. pelargonii*	1/15	7
Leaf-rolling mosaic	*M. persicae*	2/15	13
Leaf-rolling mosaic	*M. circumflexus*	0/1	0
Rugose mosaic	*Illinoia solanifolii*	0/71	0
Rugose mosaic	*M. pelargonii*	0/29	0
Rugose mosaic	*M. persicae*	4/23	17
Rugose mosaic	*M. circumflexus*	4/19	20
Leaf roll	*Illinoia solanifolii*	2/22	9
Leaf roll	*M. pelargonii*	18/22	82
Leaf roll	*M. persicae*	21/23	92
Leaf roll	*M. circumflexus*	8/11	72

*Upper figure is number of plants diseased, lower figure total number of plants used.

Schultz and Folsom[22] reported negative results when the Colorado potato beetle *Leptinotarsa decemlineata*, and the flea beetle *Epithrix cucumeris* were used as agents of spread of mild mosaic. Goss[8] reported transmission of spindle tuber by grasshoppers, flea beetles, tarnished plant bugs, and Colorado potato beetles. Cleveland[3] transmitted leaf roll by means of potato leaf hoppers *Empoasca fabae*.

TRANSMISSION BY CONTACT IN FIELD CAGES

In 1927 an experiment was started to ascertain whether or not contact of the seed pieces, roots, and shoots of virus-infected plants with those of healthy plants would produce infection. A diseased seed piece was planted in the center of a muslin-covered field cage, and a healthy seed piece was planted on either side of the diseased one. In some cases after the growth

TABLE VIII. ROOT CONTACT EXPOSURE OF BLISS TRIUMPH IN FIELD CAGES SHOWING PERFORMANCE OF PROGENY OF EXPOSED PLANTS

Disease	Soil treatment	Hills infected
Rugose mosaic	Cultivated	1/2
	Not cultivated	1/2
Interveinal mosaic	Cultivated	0/4
	Not cultivated	0/2
Mild mosaic	Cultivated	0/4
	Not cultivated	0/2
Giant hill	Cultivated	2/8
	Not cultivated	0/2
Leaf roll	Cultivated	0/4
	Not cultivated	0/2

of the plants the soil between the plants was disturbed by means of a small shovel, which effect somewhat corresponds to that caused by cultivating potatoes in the field, as it mutilates the roots. In other cases the soil was not disturbed with the exception of removing weeds. Generally the diseased plant was of a different variety and had tubers of different color and shape from the healthy ones used for the contact infection tests.

The plants in the cages were examined at regular intervals for the presence of aphids or other insects.

The results presented in Table VIII show that rugose mosaic was transmitted from diseased to healthy plants under insect-proof cages in the absence of aphids, leaf mutilation and root mutilation. Rugose mosaic was also transmitted when root mutilation was practiced.

Although giant hill appeared in two out of eight plants from healthy seed in cages where root mutilation was practiced, the number of plants was too small to warrant any definite conclusion as to the transmissibility of the condition. Interveinal mosaic, mild mosaic and leaf roll were not transmitted by root mutilation or ordinary contact under cages.

Controls, consisting of seed pieces from the same tuber unit as the ones that were exposed to diseased plants were planted in separate cages and remained healthy.

Schultz and Folsom[23] found that root and foliage contact with spindle tuber and leaf roll plants under insect-free greenhouse conditions resulted in no transmission, but they report that mosaic was transmitted by this means.

REDUCTION IN YIELD CAUSED BY VIRUS DISEASES

In 1929 and 1930, plots were planted to determine the reduction in yield caused by interveinal mosaic, mild mosaic, crinkle mosaic, and spindle

TABLE IX. RESULTS OF YIELD TESTS WITH INTERVEINAL MOSAIC, MILD MOSAIC, CRINKLE MOSAIC, AND SPINDLE TUBER IN 1929 AND 1930

Variety	Disease	Year	No. of hills	Average yield per hill in ounces	Yield per acre	Percent reduction in yield
				Ounces	*Bushels*	*%*
Netted Gem	Healthy	1930	152	24.7	281	.....
Netted Gem	Interveinal mosaic	1930	136	20	227	19
Idaho Rural	Healthy	1929	119	24	273	.....
Idaho Rural	Mild mosaic	1929	124	14	160	36
Idaho Rural	Healthy	1930	156	25	284	.....
Idaho Rural	Mild mosaic	1930	156	16	182	35
Bliss Triumph	Healthy	1929	133	12	136	.....
Bliss Triumph	Crinkle mosaic	1929	129	6	68	50
Bliss Triumph	Healthy	1930	212	25.3	288	.....
Bliss Triumph	Crinkle mosaic	1930	196	9.5	108	62
Bliss Triumph	Healthy	1929	197	12.5	142	.....
Bliss Triumph	Spindle tuber	1929	98	5	57	60
Bliss Triumph	Healthy	1930	212	25.3	288	.....
Bliss Triumph	Spindle tuber	1930	164	10.4	118	59
Netted Gem	Healthy	1929	161	16.6	190	.....
Netted Gem	Spindle tuber	1929	132	4.5	51	73
Netted Gem	Healthy	1930	164	20	227	.....
Netted Gem	Spindle tuber	1930	168	4.5	51	77

tuber. The potatoes were generally planted in tuber units of four—that is, each tuber was cut into four seed pieces and these four pieces from the same tuber planted one after the other in the row. The diseased and healthy units were planted alternately in the same row. The seed pieces from both the healthy and the diseased tubers were of approximately the same size and weight and in many instances came from tubers of about the same size. The seed pieces were planted 15 inches apart in the row and the rows were 39 inches apart. This method of planting gives a total of 10,920 hills per acre.

At digging time each hill was weighed separately. To arrive at the total yield per acre, the tubers from the two inside plants of each unit were weighed. It was thought that this method would compensate for the difference in weight which might be found in the end plants, especially of the healthy units. In a check up, very little difference in average weight per hill was found, regardless of whether the weight was taken of the yield of all four plants in the unit or of the inside plants only. Wherever individual diseased-plant units showed a combination of diseases the yields were not included in computing the average weight per hill.

In 1929 the yields were small, undoubtedly because the soil in which these potatoes were grown was sandy and the growing season was unusually dry. In 1930 there were not enough healthy Bliss Triumph tubers to serve as a yield control for crinkle mosaic. The units of Bliss Triumph affected with crinkle mosaic were therefore planted in the row without alternating with healthy units. The percentage of reduction in yield caused by this disease was estimated by using for comparison the weight of the healthy Bliss Triumph yields in the rows where they alternated with spindle tuber Bliss Triumph. The total yield per acre in 1930 was higher than in 1929, owing undoubtedly to better soil, but the percentage of reduction in yield by the different diseases was practically the same in each of the two years as shown by Table IX. Here the serious effects on yield produced by both diseases are clearly brought out. Spindle tuber, however, appears to be capable of reducing yields somewhat more than crinkle mosaic under the conditions of these tests. The reduction in yield caused by these diseases corresponds very closely to the results obtained by Young and Morris.[27]

CONTROL METHODS

The nature of potato virus diseases is such that control measures have to be based upon prevention of spread rather than upon cure, and prevention of spread has to be based either upon the eradication of agents of spread or upon the removal of the source of infection.

The evidence, although not completely convincing, indicates that insects are the chief agents of spread. The attempt to suppress potato virus diseases by eradicating insect carriers presents such difficulties that this method has not appeared to be economically feasible. Very frequent expensive insecticide applications would be necessary from the time the earliest shoots come through the ground until the plants have reached the end of the season if anything like effective protection were to be maintained against constantly repeated insect invasions. The program would probably be too costly and time-consuming for the average grower. Per-

haps there might be an exception where it seemed important to protect seed-plots of a choice variety especially susceptible to virus diseases.

The control measure now most relied upon by growers for the suppression of potato virus diseases is roguing—that is, the removal of the "rogues," in this case the plants containing the virus and acting as sources from which carriers may spread disease to healthy plants.

Seed-plots. It has proved to be almost or quite impossible to do effective roguing in ordinary commercial fields and this is not recommended. On the other hand, it has proved entirely practicable to deal with virus diseases through the maintenance of special seed-plots, which can usually be managed and rogued out in such a manner that virus diseases in the seed stocks can be reduced to a minimum. The subsequent use of seed from such plots for planting commercial fields will result in greatly reducing the losses from virus diseases which otherwise take large tolls from the grower.

For the seed-plot a piece of ground should be selected that has not produced potatoes for several years. To reduce the danger of disease invasion from the outside, this plot should be separated from any other potato fields by a distance of at least 500 feet. Weeds should be kept down not only in the plot itself but in the adjoining land since weeds may serve as sources of virus diseases.

Starting with seed stocks as free as possible from virus diseases to begin with, such as certified seed, various methods may be used to remove the infected material present. In the Oregon experiments tests were made of different practices to determine their comparative effectiveness.

Tuber indexing. This method was first described by Blodgett and Fernow.[1] It involves the numbering of all seed tubers and the growing of one eye from each tuber, well in advance of field planting, to determine whether the tuber is healthy. Generally the indexes are grown in pots in the greenhouse. In some regions in Oregon where potatoes are planted late, the indexes may be grown in the field ahead of the main planting. All the tubers whose index plants show up as diseased are then discarded, and the remaining healthy tubers are planted in an isolated seed-plot preferably as tuber units. This method is too time-consuming and expensive to be used by most growers but is the most effective way to insure clean planting stock.

Hill indexing. In this method, the tubers from apparently healthy potato hills of the previous year are kept as separate hill lots and one tuber from each hill is grown in advance of field planting. Only those hill lots whose index plants appear healthy are used in the general planting. This method eliminates some disease in the seed stock, but is entirely inadequate to rely upon as an effective means of controlling potato virus diseases as shown by tests.

In 1925 several hills of Earliest of All were indexed by this method. By this means 15 percent rugose mosaic was eliminated, but when the hills indexed as healthy were planted in the field it was found that 8.5 percent of the plants were still infected with rugose mosaic. This is explained by the fact that when a plant is infected late in the season, or after the disinte-

Figure 14. A seed-plot planted in mass—that is, each seed piece was planted without regard to the tuber it came from. Thus each plant has to be judged as to disease or health from its own appearance. Roguing under such circumstances is more difficult and does not give the best elimination of the diseases. These illustrations show the stage of development in 1926 at the first, second, and third roguings, which were made at weekly intervals. Some tuber-perpetuated disease was found and removed at each of these three roguings but none was found at the later roguings. However, during the last half of the season some plants were found that were diseased by current-season infection. Thus in contrast to the results mentioned in Figure 15 it took more roguing and a longer time to remove the tuber-perpetuated disease from the mass-planted plot than it did from the plot planted by tuber-units. By very careful roguing, however, the disease in the mass plot was reduced, as shown by the following figures of percentage of disease rogued each year obtained from a continuation of this plot over a period of five years: 4.5, 3.2, 1.7, 0.6 and 0.8. To accomplish results as good as this by mass roguing has required very careful and consistent work, starting very early each year.

gration of the seed tuber has removed the union between the plants grown from one set, the hill lot may contain some tubers that are diseased and some that are healthy. Murphy and McKay,[17] Quanjer[19] and Schultz and Folsom[22] arrived at this conclusion.

During 1928, 1929, and 1930 more than five thousand hills, progeny from some of the roguing plots, were planted as individual hill lots. Records were made of the total percentage of disease present and the number of hills totally diseased and partly diseased. It was found that in 75 percent of the diseased hills infected with rugose mosaic, due to spread of the preceding year, some diseased and some healthy tubers were found in the

Figure 15. A seed-plot planted in tuber-units separated by stakes in the row. Such a planting allows early and accurate roguings, which are essential to control of the potato virus diseases. The upper illustration shows the stage of development when the first roguing was made in 1926 and the lower one shows the same plot at the second roguing one week later. Some tuber-perpetuated rugose mosaic was found and removed at each of these two roguings but none was found at the later roguings. However, some plants were found during the season that became diseased by current-season infection as a result of spread. The early thorough roguings kept this to a minimum and resulted in reducing the disease from 5 percent to 2.5 percent in the one year.

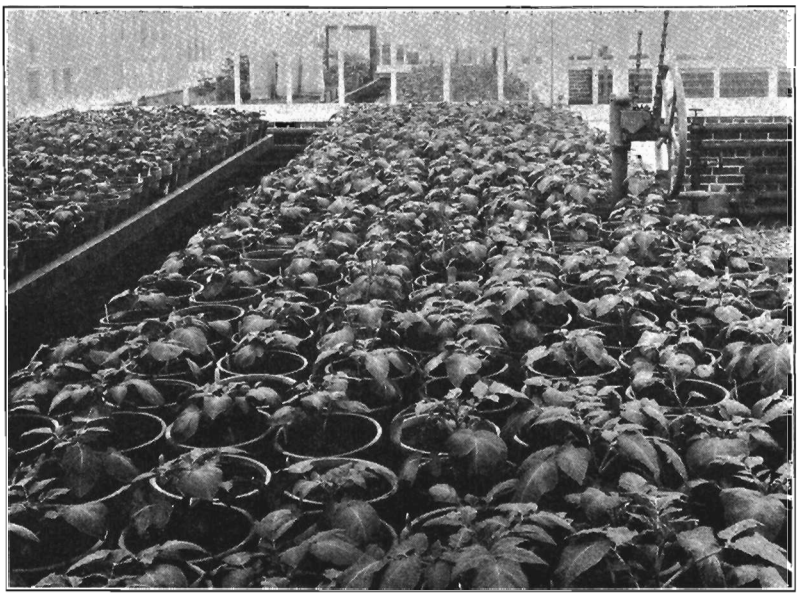

Figure 16. Portion of the Oregon Experiment Station greenhouse devoted to the tuber indexing of seed potatoes for the control of mosaics and other virus diseases. Each pot contains a plant grown from one eye cut from a separate potato and numbered to correspond. If the test plant, grown here in advance of the field planting, shows disease the tuber from which it came is discarded for seed. If the test plant is healthy, then the tuber is kept for planting in the seed-plot. Seed-plots planted with indexed seed are best planted in tuber-units, isolated from other potatoes, and rogued for any undesirable condition. This is the most nearly ideal method for controlling the potato virus diseases that has been designed but it is practicable only for exceptional cases. The careful grower can accomplish nearly if not quite as good results by the right kind of roguing in tuber-unit planted seed-plots without tuber-indexing.

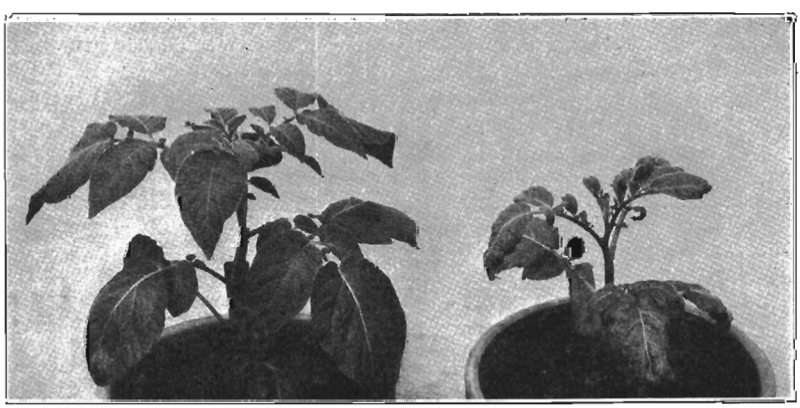

Figure 17. Two index plants from lot shown in Figure 16 each grown from one eye of a separate tuber, left healthy, right rugose mosaic. The tuber from which the plant at the right came will be discarded and not used for seed.

same hill, as evidenced by diseased and healthy plants grown from these tubers. This same condition was also found in 70 percent of the diseased hills of leaf roll, in 80 percent of the diseased hills of spindle tuber and mild mosaic, and in 70 percent of the diseased hills of crinkle mosaic. The records show that of the hills naturally infected the previous year, an average of only about 25 percent were totally diseased. In the other 75 percent only a part of the tubers were diseased. It is this presence of both healthy and diseased tubers in many hills that makes the hill-indexing method so unreliable when used as the sole method of eliminating virus troubles.

Mass roguing vs. tuber unit roguing. In mass roguing of seed-plots the tubers are planted at random, either as whole or as cut seed. As soon as the plants are high enough so that the disease symptoms can be accurately diagnosed, the diseased plants are removed including seed pieces, placed in a closed container such as a gunny sack, and disposed of at a safe distance.

In tuber-unit roguing, the seed pieces from each tuber are planted one after another in the row. As soon as one or more hills of a unit show the disease the entire unit is removed. This permits roguing some seed pieces, potential sources of infection, before they are up.

To demonstrate the comparative value of mass roguing and tuber-unit roguing, seed-plots handled by these two methods were maintained from 1925 to 1929. The practice generally followed was to start with a lot of tubers known to contain a certain amount of a specific disease. The plots were rogued once a week from the time about 50 percent of the plants were up and high enough to diagnose the symptoms. The rogued plants were placed in a sound gunny sack, carried off the field and disposed of at a safe distance. At harvest time one or two tubers were saved from each hill in the mass plot, depending upon the amount of disease present and one tuber was saved from each hill in the tuber-unit plot. These tubers were planted again the following year and these fields were rogued again. It is believed that one tuber from each hill gives a fairly accurate index of the total percentage of disease in the progeny. Generally the remainder of each hill was planted as a hill unit, to check up on the percentage of diseased tubers present in diseased hills. There generally was very little difference in the total percentage of disease present in the two lots.

To provide suitable material to start with, in 1924 one acre consisting of thirty-five rows of healthy Burbank potatoes was planted with the exception of one row in the center of the field, which was planted with Up-to-Date tubers, 52 percent of which had rugose mosaic. The rugose mosaic was allowed to spread that year. At digging time, the center row was eliminated, and one tuber from each of the other hills was saved and planted again as a mass plot. This plot was subjected to mass roguing and the progeny planted again in a mass-rogued plot. This was repeated with the progeny for several successive years. Table X shows the gradual reduction of disease which took place.

In 1927 eight hundred Burbank seed pieces, 18.4 percent of which had rugose mosaic, were planted as a mass roguing plot, and two hundred Burbank tubers of which 14 percent had rugose mosaic were planted and rogued as tuber units. Eight hundred Netted Gem seed pieces having 17

TABLE X. RESULTS OF MASS ROGUING RUGOSE MOSAIC FROM POTATO PLOT

Year	Total plants	Percentage rogued in first roguing*	Percentage rogued in second roguing	Percentage rogued in third roguing	Total percentage rogued
		%	%	%	%
1925	8641	4.3	0	0.08	4.4
1926	8939	1.4	1.3	0.4	3.1
1927	8373	0.2	0.9	0.2	1.3
1928	3114	0.3	0.15	0.05	0.5
1929	2839	0.17	0.66	0.08	0.9
1930	1780	0.2	0.2	0	0.4

*First week after plants were up, subsequent roguing at weekly intervals.

percent leaf roll were planted as a mass roguing plot, and two hundred Netted Gem tubers having 17 percent leaf roll were planted and rogued as tuber units.

These plots also were rogued weekly in the manner previously described. Table XI shows that rugose mosaic in the mass-rogued plot was reduced in one year from 18.4 percent to 4.2 percent, whereas in the tuber-unit rogued plot it was reduced from 14 percent to 2.3 percent. In the leaf roll plot the results were more striking, as in the mass planting the leaf roll was reduced in one year from 17.8 percent to 8.2 percent and in the tuber-unit plot the disease was reduced from 18.5 percent to 2.3 percent. There was very little difference, however, in the total percentage of disease present in the crops from the mass and tuber unit plots in 1929. This is contrary to what ordinarily would be expected.

TABLE XI. RESULTS OF ROGUING RUGOSE MOSAIC AND LEAF ROLL FROM MASS-PLANTED AND TUBER-UNIT-PLANTED POTATO PLOTS IN 1927, 1928, AND 1929

Disease	Method of roguing	Percentage of plants rogued at different roguings 1927	Total percentage rogued in 1927	Percentage of plants rogued at different roguings 1928	Total percentage rogued in 1928	Percentage of plants rogued at different roguings 1929	Total percentage rogued in 1929
		%	%	%	%	%	%
Rugose mosaic	Mass	1st— 6 2d— 8 3d— 3 4th— 0.2 5th— 0.5 6th— 0.7	18.4	1st—2.7 2d—1.1 3d—0.4	4.2	1st—0 2d—0.2	0.2
Rugose mosaic	Tuber unit	1st—11.5 2d— 2 3d— 0.5	14	1st—1.7 2d—0.4 3d—0.4	2.3	1st—0.2 2d—0.2	0.4
Leaf roll	Mass	1st— 6.4 2d— 7.7 3d— 3 4th— 0.2 5th— 0.5	17.8	1st—0.7 2d—7 3d—1.1	8.2	1st—0.36 2d—0.36 3d—0.54	1.2
Leaf roll	Tuber unit	1st— 8.5 2d— 8.5 3d— 1.5	18.5	1st—0.5 2d—0.9 3d—0.9	2.3	1st—0 2d—0 3d—0.2	0.2

Roguing tests were also conducted with crinkle mosaic and spindle tuber although these diseases are not common in this state. In 1929 eight hundred Bliss Triumph seed pieces having 45 percent crinkle mosaic were planted as a mass plot. A tuber-unit plot of two hundred units having 29 percent crinkle was also planted.

In the same year eight hundred Netted Gem seed pieces having 38 percent spindle tuber and two hundred tuber units having 20 percent spindle tuber were planted as a mass plot and tuber-unit plot respectively.

Table XII shows that in the tuber-unit plot practically all the diseased plants were removed in the first roguing, whereas in the mass plots a considerable number of diseased plants remained to be removed in the second roguing. The superiority of tuber-unit roguing over mass roguing was clearly demonstrated.

TABLE XII. ROGUING CRINKLE MOSAIC AND SPINDLE TUBER FROM POTATO PLOTS

Disease	Method of roguing	Percentage of plants rogued at different roguing dates, 1929	Total percent rogued, 1929	Percentage of plants rogued at different roguing dates, 1930	Total percentage rogued, 1930
		%	%	%	%
Crinkle mosaic	Mass	1st—38 2d— 5.5 3d— 0.8	44.3	1st— 6.6 2d— 5.6 3d— 0.5	12.7
Crinkle mosaic	Tuber unit	1st—28 2d— 1	29	1st— 2.4 2d— 5.5	7.9
Spindle tuber	Mass	1st—30 2d— 6.4 3d— 1.6	38	1st— 2.3 2d—10.9 3d— 1	14.2
Spindle tuber	Tuber unit	1st—19.5 2d— 0.5	20	1st— 0.6 2d— 8 3d— 0.6	9.2

Roguing in order to be effective should be done early and often. To demonstrate the necessity of this, triplicated seed-plots with identical seed containing 12 percent rugose mosaic were rogued in 1925. One plot was rogued early and at weekly intervals. This plot gave 1.6 percent current-season rugose mosaic and 5.4 percent disease in the progeny. The plot rogued late gave 2.4 percent current-season symptoms and 16.4 percent disease in the progeny. The plot not rogued at all, but where all diseased plants that could be identified by symptoms were removed at digging time, gave 9.2 percent current-season symptoms and 15 percent disease in the progeny.

These data show that when the roguing was done early and frequently, the disease was reduced in one year from 12 percent to 5.4 percent, whereas two roguings, one at mid-season and the other late, were not effective in avoiding an increase in the amount of disease in the stock.

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