5-1926

The Spindle-Tuber Disease as a Factor in Seed Potato Production

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AGRICULTURAL EXPERIMENT STATION
RESEARCH BULLETIN 32

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SUMMARY

1. Spindle-tuber, a degeneration or virus disease of potatoes, has been found to be responsible for much of the "running out" or degeneracy of seed potatoes occurring in all parts of Nebraska, much of which had heretofore been considered as resulting from unfavorable environmental conditions during the season the seed tubers were produced.

2. Spindle-tuber causes tubers to be elongated and cylindrical, varying according to the severity of the disease and the variety. The disease also causes the production of smaller tubers. In colored varieties it reduces the intensity of the color, frequently causing a blotchy effect. In russet varieties the russeting frequently does not develop. The eyes are somewhat smaller, more shallow, and more numerous. It also seems to cause the development of a large number of conspicuous lenticels.

3. Spindle-tuber retards plant growth, when compared with normal plants, as manifested by a slower rate of plant emergence, low per cent of sprouting, and the development of small and less vigorous plants.

4. Spindle-tuber plants have an erect habit of growth. The leaves are smaller and narrower than normal. They are folded up along the midrib and are wavy along the margin.

5. Spindle-tuber is of commercial significance because it reduces not only the yield but also the market quality, in that the tubers are rough and of abnormal shape.

6. Spindle-tuber has been found in all varieties tested (representing 10 variety groups). No instance of immunity or resistance was discovered.

7. The disease is geographically quite generally distributed, having been found in serious amounts in seed stocks from 10 northern states.

8. The general low average per acre yield of potatoes in the irrigated regions in western Nebraska is attributed to spindle-tuber prevalence.

9. Spindle-tuber has been the leading factor causing fields to be rejected for certification during the last few seasons. However, the certified stock is showing a consistent annual decrease in spindle-tuber content, as the result of a general roguing and seed selection campaign.

10. The percentage of spindle-tuber was found to increase very rapidly from year to year, after initial infection occurred, in both tuber-line strains and commercial lots, when no control precautions were used. This increase was so rapid that after two or three years the entire strain or lot was generally worthless for seed.

11. Tuber-line selection was valueless for improving the yield or quality, when spindle-tuber existed in a strain.

12. Spindle-tuber increased more rapidly in irrigated than in dry-land plats, probably because of the more favorable environment for insects in irrigated fields, as the result of the rank vine growth.

13. The spread of spindle-tuber seemed to be checked or retarded by dry-land culture, but the amount of disease did not decrease, and furthermore, healthy stock often became infected with spindle-tuber on dry land.

14. Spindle-tuber increased more rapidly in eastern and central Nebraska than in western Nebraska dry-land grown lots.

15. Mulching with straw in eastern Nebraska resulted in the production of seed tubers the progeny of which contained a lower percentage of spindle-tubers, and this of a milder form, than did those from seed potatoes produced by ordinary methods of cultivation.

16. Late planting was effective in reducing the percentage of spindle-tuber in both rogued and unrogued plats in eastern Nebraska.

17. Spindle-tuber was transmitted from diseased to normal stock by tuber grafts and by means of exposing healthy plants to infection by planting them alternately with diseased plants. The progeny of plants to which spindle-tuber was transmitted produced plants that showed spindle-tuber in forms as severe as those manifested by the original diseased stock. Spindle-tuber was transmitted in fields across a number of rows of plants.

18. Infection occurred very early in the season of 1923. Plants exposed only the first 10 days, after which they were protected by insect-proof cages, produced seriously diseased stock.

19. In western Nebraska, in stock exposed to infection, early harvesting was of but very slight value as a means of escaping spindle-tuber, especially when compared with isolated rogued plats. In eastern Nebraska early harvesting seems to have been more effective.

20. The transmitting agency has not been determined. Aphids are present in such very small numbers in western Nebraska that it seems very unlikely that they are responsible for more than a trifle of the transmission that occurs.

21. Tubers produced by spindle-tuber plants in heavy soils at high temperatures or in soils with a high moisture content were more elongated than when the reverse of these conditions prevailed. Under very favorable conditions, spindle-tubers were of better type than healthy tubers produced under unfavorable conditions.

22. Spindle-tubers grown in northern Maine in 1923 were of relatively much better type than were the tubers produced in western Nebraska from the other halves of the same seed tubers. However,

when planted in Nebraska in 1924, both Maine and Nebraska grown spindle-tubers were of about the same type.

23. Seed selection of best type tubers from a lot infected with spindle-tuber was found to be a very ineffective or even useless method of maintaining a seed strain.

24. Roguing was found to be a very effective method of controlling the disease in lots containing only a low percentage of the disease, provided roguing was done early and often.

25. Seed stock produced in well rogued plats located in dry-land and irrigated fields were found to be about equally productive.

26. The tuber-index method has not been demonstrated as an effective method for controlling spindle-tuber. With a better knowledge of the spindle-tuber symptoms manifested under winter greenhouse conditions, it is hoped that this method may be more effectively used.

27. The selection of a strain entirely (or practically so) free from spindle-tuber and then growing it in an isolated and severely rogued seed plat is the best method known at the present time of controlling this disease.

The Spindle-Tuber Disease as a Factor in Seed Potato Production

H. O. WERNER *

The literature of the potato crop for the last ten years contains a very large number of reports concerning the failure of the various pure-line tuber selection methods as means of improving the market quality and increasing the yield of potatoes. In most of these cases one or more of the so-called " degeneration diseases " was present. The spread of these diseases (by insects, etc.) resulted in the rapid deterioration of many carefully selected strains. Mosaic and leaf roll have been reported most commonly as responsible for such conditions. A survey of the literature indicates that the spindle-tuber disease was frequently present and probably was often one of the most serious factors.

The tubers resulting from the spindle-tuber disease have been recognized as abnormal or " run-out " tubers for many years. Plants or tubers showing the symptoms were illustrated by Stuart, Stewart, Fitch, Whipple, Werner, and other writers.

The name " spindle-tuber " was first applied to this disease by Martin in 1922. The infectious nature of the disease was definitely established in 1922 by Schultz and Folsom (1923a), who later reported on numerous transmission experiments (Folsom 1923, Folsom and Schultz, 1924).

Since 1917 much experimental work with a large number of " run-out " or " degenerate " tuber-unit lines and strains of potatoes has been in progress at this station. In 1922-1923 it was concluded that these lots were " degenerates " because of infection with the " spindle-tuber " disease.

THE PROBLEM IN NEBRASKA

Emerson (1914) in Nebraska, working at Lincoln, reported a reduction in yield of 25 per cent as a result of having grown a strain of potatoes at Lincoln for one year, when compared with the yield of the original strain produced in the north. The yield continued to decrease with each successive year of production at Lincoln. He further reported that

* The author is indebted to William Morrow, Jr., for valuable assistance in the conduct of the field work during 1923.

when some of the tubers of these same lots of seed were grown under a straw mulch this degeneracy did not take place. The mulched seed stock was equally as productive as the northern grown stock. He also reported that degenerate lots were rejuvenated to their original state of productivity by growing them under a straw mulch for but one year. He was inclined to attribute these differences to the reduced soil temperature under the straw mulch. (The mean reduction in soil temperature resulting from a straw mulch was reported by Werner (1922) to be approximately 7° F. for the period from April 15 to August 28.) Emerson made no statement concerning whether there was any deterioration in the type of tubers, nor did he give data on any factors other than yield. It is, therefore, not possible to get any definite clue to determine whether any of the degeneration diseases now known were present.

Preliminary strain tests conducted by Howard in 1915-1916 showed that some very good strains of seed potatoes were then being produced in western Nebraska (Werner and Howard 1923). These tests were followed by extensive tuber-unit plantings in 1917. The work done from then till 1922 showed that there was much variation within strains in western Nebraska; that a type "running out," or degeneracy which became progressively worse each season, was prevalent in many strains; that this type of degeneracy was most prevalent in irrigated strains; and that, due to it, strains brought in from the dry-land districts deteriorated rapidly under irrigation conditions (Werner and Howard 1923). In view of the work of Emerson, as well as the prevalent view thruout the Corn Belt, that northern seed potatoes were superior to local seed because of the lower temperatures in the north, it was assumed by the author — till 1922 — that the superiority of western Nebraska dry land seed to that produced in eastern Nebraska was due to the lower temperature in the western part of the state (resulting from high altitude). The very regular unfailing deterioration which took place when strains were transferred from dry land to irrigation fields led to the theory that conditions resulting from irrigation were responsible for a somewhat similar deterioration, possibly of a physiological nature. Field observations in 1922 and some preliminary experiments conducted the same year led the author to believe that the type of degeneracy being studied was due to disease. As a result of correspondence and verbal discussion of the problem with Dr. Donald Folsom of the Maine Agricultural Experiment

Station, it was concluded that the disease corresponded with that which had just recently been described as "spindling-tuber" by Schultz and Folsom (February 1923). This disease was then named "spindling-tuber," and was later changed to "spindle-tuber" by the same authors (Folsom, August 1923).

NATURE OF EXPERIMENTAL WORK

The acceptance of the theory that the spindle-tuber disease was the probable cause of the type of degeneracy that was being worked with necessitated a distinct change in the conduct of several phases of the general experimental project

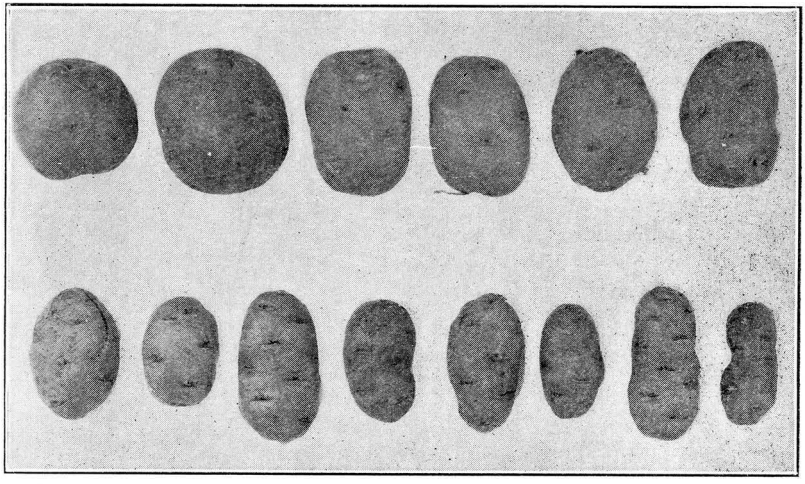


FIG. 1.— Effect of spindle-tuber upon the shape of Triumph potatoes. The upper left tuber is normal. All others are infected with spindle-tuber. The one at the lower right shows the most advanced symptoms.

dealing with this problem, as well as the addition of several new lines of endeavor. While the original experiments were designed for solving the problem in a different manner, a very large amount of the data obtained still proves very useful in a comprehensive discussion of the spindle-tuber problem.

The lines of experimentation that supplied the data herein reported, stated in very general terms, were as follows:

1. Tuber-line selection studies.

2. Relation of environmental conditions to seed-potato production.
3. Seed-potato strain trials of certified and uncertified stock.
4. Spindle-tuber transmission experiments.

Most of these general lines of experimentation will not be completely discussed as a unit in any one part of the bulletin. For the sake of clarity, consecutive thought, and elimination of repetition, data will be selected from any experiment for insertion and discussion under the most logical heading in any part of the bulletin. Unless otherwise stated, all the data presented in this bulletin deal with the Bliss Triumph variety.

SYMPTOMS OF SPINDLE-TUBER

The symptoms of spindle-tuber have previously been described elsewhere (Schultz and Folsom 1923, Werner and Howard 1923). This description will be enlarged and elaborated upon with data from detailed statistical studies of a large number of plants. These symptoms sometimes vary considerably from the description here given, due to environmental conditions. They also vary in degree with different varieties.

TUBER SYMPTOMS

SHAPE

The effect upon the shape of the tuber is the most conspicuous symptom of spindle-tuber, but in the early stages of the disease the diseased or spindle-tubers can not always be distinguished with certainty from normal, healthy tubers.

In the advanced stages the tubers are long, cylindrical, and pointed at the apical end. In the early stages the tubers are only slightly elongated, being somewhat blocky and tapering slightly toward the apical end. In the last stages the tubers are often crooked or ill-shaped (Figs. 1, 4, 5, 10, 20). Flat varieties become cylindrical and much elongated so that variety identification is practically impossible. The tubers are also more subject to growth cracks than are normal tubers (Figs. 5 and 10). The effect of spindle-tuber in causing tuber elongation is graphically shown in Fig. 2. The same relationship applies in general to tubers of all sizes, altho the symptoms are generally more distinct in the larger tubers. Measurement of thousands of tubers gave results similar to those plotted in Fig. 2.

The ratio of the width * to the length has been found to

* Length refers to the greatest dimension parallel to the structural axis of the tuber, and width and thickness refer respectively to the greatest and least dimensions perpendicular to this axis. Sometimes the width was greater than the length.

be a very satisfactory means of expressing tuber shape in the study of spindle-tuber. Tubers were measured with a steel bar caliper, which was read in millimeters. The ratio of the width to the length is designated by the formula W/L. The depth or thickness of tubers was also measured. Data on this dimension are not given, because it was found that the W/L ratio was more serviceable and that the third dimension seldom contributed any significant facts. (When thickness is considered it is expressed in ratio T/L.) This ratio of width to length (W/L) is expressed in percentage terms, 100 per cent representing a round potato, whereas numbers below 100 per cent designate potatoes that are longer than they are wide and numbers over 100 per cent indicate that tubers are wider than long. It is used as a means of describing the severity of spindle-tuber as manifested by tuber elongation.

The W/L ratio of 100 tubers from a strain generally infected with spindle-tuber and 100 normal tubers produced in 1923, are given in Table 1. The mean W/L ratio for spindle-tubers in this case is 82.65 per cent as compared with 103.0 per cent for normal tubers. The inferiority of the tuber shape, as indicated by the elongation tendency in this spindle-tuber strain, is quite marked. Schultz and Folsom have reported similar data on the basis of tuber measurements (1923-1924).

SIZE

The tubers produced on spindle-tuber plants are almost always smaller than those produced on normal plants, but plants showing the mildest symptoms of spindle-tuber frequently produce tubers equally as large as do normal plants. However, when the disease becomes more severe so as to be easily recognizable, the size of the tubers is always distinctly reduced.

The 100 spindle-tubers and 100 normal tubers used as a basis for Fig. 2 and Table 1 were weighed individually. The distribution of these tubers by 10 gram groups, given in Fig. 3, shows that the potatoes in the spindle-tuber group were decidedly smaller with a mean weight of 52.8 grams as compared with the mean of 96.9 grams in the case of the normal tubers. Data presented further on supplement this evidence.

NUMBER OF TUBERS PER PLANT

The number of tubers produced by spindle-tuber plants will average less than with normal plants. As with the type and size, this varies with the degree of severity. These

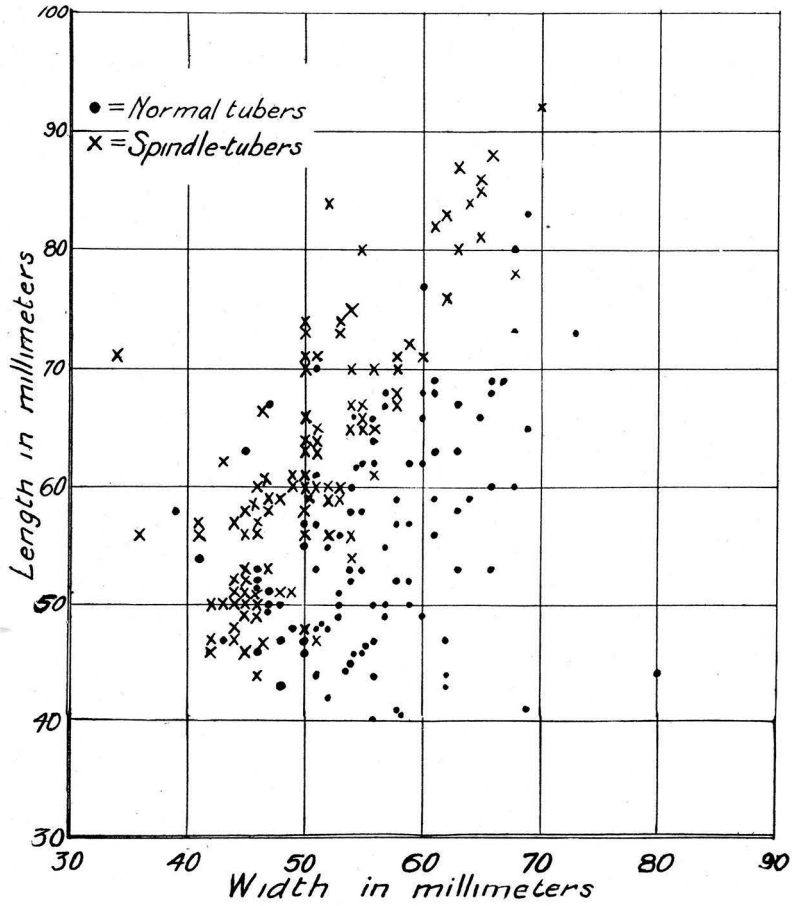


FIG. 2.— Relation of length and width of 100 Triumph spindle-tubers and 100 normal tubers grown in Scotts Bluff with irrigation in 1923. Spindle-tubers used for this chart were the first 100 tubers from tuber unit lines of Strain B (history on page 41). Normal tubers were from a lot practically free from spindle-tuber, which was certified in 1922. These tubers were used as basis for data in Table 1 and Figure 3.

TABLE 1—*Effect of spindle-tuber in Triumph potatoes upon the shape of the tubers as expressed by the ratio of the width to the length and also by estimating the relative tuber type, also a comparison of these two systems as means of describing the shape of the tubers of any given lot. (For history of tubers used, see Fig. 2.)*

Ratio of tuber width to length:— $\frac{W}{L}$

Estimated tuber type	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	130	135	140	145	150	155	Total
Spindle-tubers																							
10																							0
9																							0
8								1	1	3													5
7								1			1	1											3
6						1	2	4	5	1	1	1	1										16
5					1	1	4	4	2	1	2												15
4					2	2	3	4	3		1												15
3			1		4	4	5	3	3														20
2					2	5	5	2															14
1	1			1	1	3	4	1		1													12
Total	1		1	1	10	16	23	20	14	6	5	2	1										100
Mean: Ratio of width to length 82.65 per cent Tuber type 5.04																							
Normal tubers																							
10										2	2	3	3	1	1	1						1	14
9									4	5		3	4		4	2	1		2				25
8							1		1	2	4	4			2	1				1			16
7								3	4	3	4	1	2	1	1				2				21
6						1		3	3	3		1	1	1									13
5				1	1		1	1	3					1				1					9
4					1			1															2
3																							0
2																							0
1																							0
Total				1	2	1	2	8	15	15	10	12	10	4	8	4	1	1	4	1		1	100
Mean: Ratio of width to length 103.0 per cent Tuber type 7.71																							

facts are brought out in Table 2, where it is shown that 93 sixteen-hill units affected with spindle-tuber produced 4.6 tubers per plant with a mean estimated tuber type of 2.6, whereas 6 normal sixteen-hill units (originally from the same field but not infected with spindle-tuber) used as checks produced 10.4 tubers per plant with a mean estimated tuber type of 7.5.

COLOR AND TEXTURE OF SKIN

In the Triumph variety, when spindle-tuber is present, the distinct red color gradually fades to a lighter red or distinct pink color, as the disease increases in severity. Eventually, in the most advanced stage (as discussed, page 19), this pink color almost disappears and considerable yellow color is in evidence, or there is a blotching of pink and yellow.

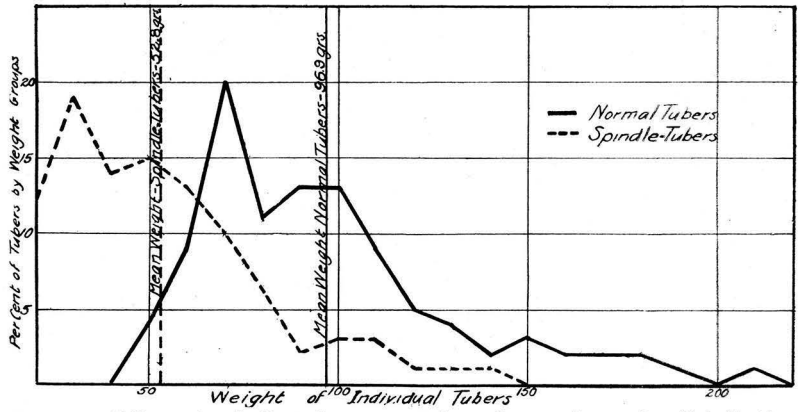


FIG. 3.— Effect of spindle-tuber upon tuber size as shown by distribution of 100 Triumph spindle-tubers and 100 normal tubers, raised in Scotts Bluff in 1923. (Tubers same as for Figure 2.)

There is sometimes a blotching of yellow with the characteristic red color, i.e., on tubers in which the pink color has not developed. The color of the tubers is not a reliable guide for detecting the early stages of the disease. In fact, the characteristic color is not evident till the shape is relatively poor, i.e., estimated type of about 5. However, the color of tubers in the advanced stages is always very abnormal. In all colored varieties the same general conditions prevail.

In all varieties the skin is generally smoother than normal, frequently having a shiny appearance and not developing the netting which develops on normal tubers in light, dry, or warm soils.

TABLE 2—*Reduction in number of tubers per plant caused by spindle-tuber and the correlation of this fact with reduced tuber type. (Triumph strain B, 1923.) Mean per plant on basis of 16-hill units of tuber type and number of tubers per plant. Check lots from same original field, kept free from spindle-tuber contamination.*

Relative type of tubers produced	Number of tubers per plant in 1923																												Total
	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0	13.5	14.0		
10.0																													
9.5																													
9.0																	1*												
8.5																													
8.0																					1*						1*		
7.5																		1*											
7.0																				1*									
6.0																													
5.5												1					1*											1	
5.0					1																							1	
4.5					1			1	2	1																		5	
4.0		1				3	2	1		1	1	1					1											11	
3.5			1			4	2	2		2							1											12	
3.0						1	3	5			3								1									13	
2.5		1	1			1	1	3	2					1														10	
2.0	1						2		4	2	1	2							1									13	
1.5					2		1	5	2	1			1															12	
1.0			4		2	2	1	3		3																		15	
Total	1	2	6	6	11	12	20	10	10	5	4	1	1	2	2													93	

Spindle-tubers (Series B) { Mean tuber type 2.60; Mean number per plant 4.61

*Check lots from original seed field { Mean tuber type 7.5; Mean number per plant 10.4

Russet varieties frequently develop russeting only in patches or not at all (Fig. 4).

As the disease develops to the more advanced stages, tuber type value of 5 or less, lenticels are slightly larger and conspicuous. This condition applies to tubers raised under extreme dry-land conditions as well as to those raised under irrigation.

TUBER EYES

The eyes of spindle-tubers are characteristically shallow. They are smaller than normal and have a general appearance of lack of vigor (Fig. 6). As the disease advances the eyes are more numerous (Table 3) and more shallow until they

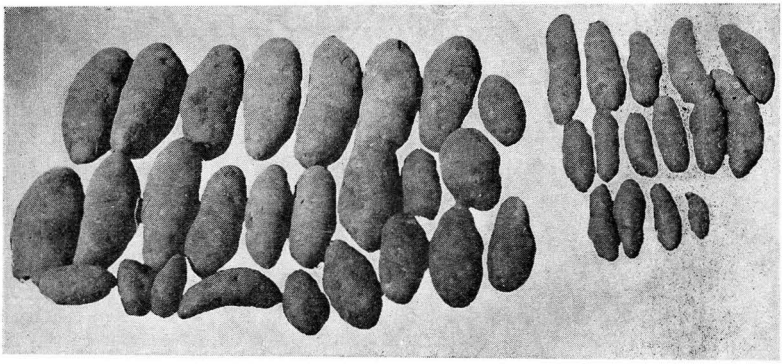


FIG. 4.— Spindle-tuber in Russet Burbanks (Idaho Gems). Tubers on left are product of 4-hill normal tuber unit, while those at right were produced in same field by a 4-hill tuber unit from a spindle-tuber.

are frequently bulging, almost always so in tuber types from 3 to 1.

In the colored varieties, the color of the skin within the eye remains practically unaltered or at least the eye retains a deep color, even tho the rest of the tuber has lost practically all of the normal color.

Rudimentary leaflets are frequently produced on the new tubers toward the end of the growing season.

TUBER TYPE

A system of estimating the tuber type, based on a consideration of the shape and all other tuber characteristics, was developed. By this system the tubers showing no symptoms of spindle-tuber are designated by the value 10. This

designation applies to supposedly normal or healthy tubers, and they need not be of perfect type. Tubers showing the first mild symptoms of spindle-tuber are designated by the value of 9. Tubers designated with numbers from 9 to 6 show gradually more elongation and more shallow eyes but still retain the normal red color. Tubers designated by 5 are distinctly cylindrical and have lost the characteristic solid red color for a blotching of red with yellow, or are a solid pale pinkish color. The lower numbers are used to designate tubers with the more severe symptoms. The value

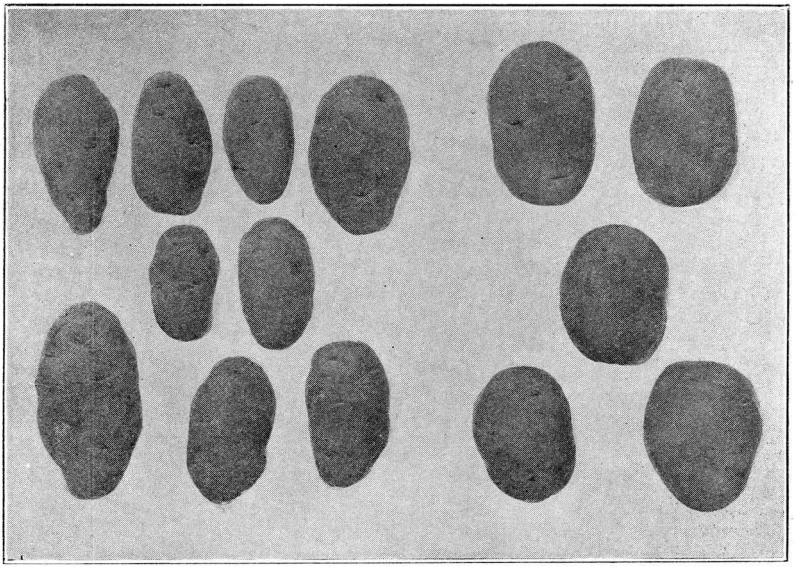


FIG. 5.— Downing potatoes — elongated tubers are spindle-tubers: blocky type tubers are normal healthy tubers.

1 is used for tubers of the most degenerate type. These are frequently almost without any trace of pink color, but have a whitish or pale yellow color, with extreme elongation and roughness.

Estimates of tuber type by this system compare fairly well with those secured by the more laborious system of measuring tubers and finding the W/L ratio. The author believes this system of estimating type is really most reliable, in that it takes into consideration all tuber symptoms and

thus more accurately describes the symptoms, especially when readings are made from a large number of tubers by the same person. In Table 1, the spindle-tubers and normal tubers are grouped according to the estimated type of each W/L ratio group. The spindle-tubers and normal tubers tend to group themselves toward opposite corners of the table. This same tendency in a more or less marked degree will be found in other distribution tables on the basis of these two systems. This system of tuber type estimation is well suited for use in seed potato certification work, where it is desirable to have an idea not only of the percentage of spindle-tuber present, but also of the degree of severity of the disease in the lot.

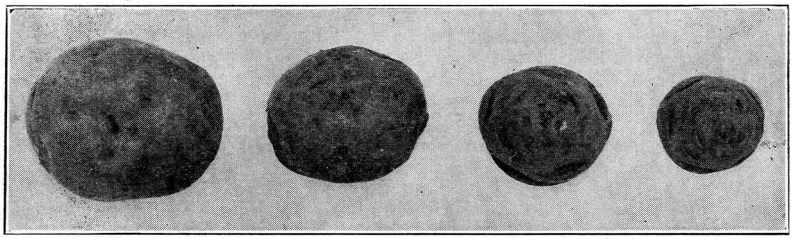


FIG. 6.—View of apical (bud) end of normal tuber at left and spindle-tubers of varying degrees of infection at right, showing increase in the number and decrease in the size of the eyes and greater prominence of the "eyebrows" as the spindle-tuber disease becomes more severe.

All the data presented on tuber type by this system are influenced by the fact that the following four distinct classes of tubers are encountered: (1) Diseased tubers showing symptoms, (2) diseased tubers with no symptoms, (3) healthy tubers, and (4) healthy tubers which appear diseased. Tubers referred to under (2) may be produced by plants that become infected late in the season, with the result that the tubers on the plant do not show the symptoms that season but produce diseased plants the next year. Healthy tubers may at times appear diseased (4), due to the effect of environmental conditions, as temperature, soil moisture, and soil texture, upon the shape of the tubers (see pages 98 to 109). These healthy tubers cannot always be distinguished from mild spindle-tubers. As a result of this condition, the tuber type value for healthy lots is at times reported as having

been as low as 8.5 or slightly less. Folsom (1923) reports different classes of tubers in a somewhat similar manner.

The disease symptoms were more noticeable in the tubers than in the plants. The most severe symptoms often develop in the tubers by the second season when the plants may be relatively vigorous. After that, tuber symptoms may not be much more severe but the symptoms continue to develop in the plant, causing more erect growth, more abnormal leaves, and smaller plants with rapidly diminishing yield.

TABLE 3.—*Increase of number of eyes per tuber with decrease in tuber type, caused by spindle-tuber. Triumph potatoes ranging in weight in each group from 80 to 110 grams.*

Number of eyes per tuber	Relative tuber type				
	1	3	5	7	10
	Number of tubers with given number of eyes				
(1)	(2)	(3)	(4)	(5)	(6)
8	.....	.....	.....	2	2
9	.....	.....	.....	1	3
10	.....	.....	.....	2	1
11	.....	.....	4	4	3
12	.....	1	3	1	1
13	.....	1	.....	.....	.....
14	.....	1	3	.....	.....
15	.....	1	.....	.....	.....
16	.....	.....	.....	.....	.....
17	1	2	.....	.....	.....
18	.....	1	.....	.....	.....
19	5	1	.....	.....	.....
20	4	1	.....	.....	.....
21	.....	1	.....	.....	.....
Mean number of eyes per tuber	19.2	16.6	12.2	10.1	9.8

PLANT SYMPTOMS

The symptoms here reported have been noted under field conditions. The symptoms noted under winter greenhouse conditions are described on page 121.

RETARDED GERMINATION OR EMERGENCE

Spindle-tubers are much slower in producing sprouts and in having plants emerge thru the soil than are normal tubers. This would be expected when considering the weak

TABLE 4.—*Effect of spindle-tuber upon rate of plant emergence as shown by the relation of the tuber type (as expressed by the mean tuber type of 16-hill units) to the per cent of plants emerged by June 30—23 days after planting in 1923. Strain B, Triumph potatoes.*

Relative mean type of seed tubers produced in 1922	Per cent of plants that had emerged June 30, 1923, 23 days after planting																				Total
	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	100	
7							1		2			1									4
6.5									1												1
6.0	1							1	2	1	2										7
5.5		1			2	1															4
5.0				1	1		2		2	2	1	1				1					11
4.5		1	1			2		1	2		2										9
4.0	1			1	3	3	2		1	1											12
3.5		1			1				1		1										4
3.0		2		3	2	6		1	2												16
2.5				1	2	1	1		1												6
2.0	1	1	3		2	3				1		2									13
1.5				1		1															2
1.0	1		2						1												4
Total	4	6	6	7	13	17	6	3	15	5	6	4				1					93

Mean: Tuber type—3.79
Mean: Per cent of plants emerged in 23 days —28.22 per cent
Mean: Per cent of plants emerged in 23 days with 7 check lots (original lot F)—93.8 per cent
Mean: Per cent of plants emerged in 23 days with 6 check lots (lot H)—96.7 per cent

appearance of the eyes. Germination is retarded in proportion to the extent of the development of spindle-tuber disease, as shown in Table 4. In 1923, 93 unit lines (Strain B) affected with spindle-tuber, with an average seed tuber type of 3.79, had 28.22 per cent of all hills planted emerging within 23 days after planting (by June 30). Within the same time, 7 check lots, originally from the same field (Lot F) but free from spindle-tuber, had 93.8 per cent of the plants emerging, and 6 lots from another lot of certified seed (Lot H) had 96.7 per cent emerging. This retarded germination results in a very uneven growth of plants in the field. Frequently germination is so much retarded that plants do not emerge till 100 or more days after planting. Furthermore, a considerable number of seed pieces never produce any plants. (See page 79.)

GENERAL HABIT OF GROWTH

Spindle-tuber plants lack vigor. They are erect and stiff, with very few stems per hill. The stems have practically no lateral branches.

A tapering enlargement of the stolons of spindle-tuber plants has often been seen, the stolons being about one-eighth inch in diameter at the plant stem and enlarging gradually to a diameter of about one-half inch at the end where the young tuber was attached. These stolons did not dry up or absciss by harvesting time, but remained firmly attached to the tubers.

The plants are reduced in size in proportion to the severity of the disease (Figs. 7 and 8). The relative size of the plants has been used as an expression of plant vigor. The relative vigor of individual plants was recorded by a numerical system somewhat similar to the one used in estimating tuber type (page 18). In the use of this system, the most vigorous, normal, healthy plants were given a score of 10 and all other plants were scored accordingly; the weakest plants — those barely growing — were given a value of 1. The relation between vine vigor and tuber type is brought out in Table 5. With 66 sixteen-hill tuber units that contained varying degrees of spindle-tuber, the mean vine vigor was 3.22 and the mean type of the tubers produced by the vines was 2.32, whereas the 6 check lots had a mean vine vigor of 9.42 and produced tubers with a mean type of 7.5.

TABLE 5.—*Effect of spindle-tuber upon vine vigor as recorded on a comparative basis in comparison with tuber type. Mean of tuber type and vine vigor based on sixteen 16-hill unit Triumph potatoes, (Lot B) in 1923. (6 units from original field—Strain F,—used for normal checks.)*

Relative mean tuber type in 1923	Relative mean vigor of vines in 1923																					Total
	.0	.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	
10																						
9.5																						
9.0																			1*			
8.5																						
8.0																				1*	1*	
7.5																					1*	
7.0																				1*		
6.5																						
6.0																						
5.5										1								1*				1
5.0																						
4.5							2	1			1											4
4.0				1				4	1	1				1								8
3.5				1	1	2	1	4	2		1											12
3.0						3	3		2	1												9
2.5				1	1	3	1	2		1												9
2.0						1	1	4	1	2		1										10
1.5					3	2		1	1													7
1.0				1	2	2	1															6
.5																						
.0																						
Total				4	7	13	9	16	7	6	2	1		1								66

Spindle-tubers—Mean vine vigor 3.22
Mean tuber type 2.32
Normal checks—Mean vine vigor 9.42
Mean tuber type 7.50
*Check Triumph units from original strain—Lot F.

LEAVES

The leaves of spindle-tuber plants are generally somewhat darker in color, with an erect, stiff appearance. They are folded upward along the midrib and show a distinct marginal waving. These latter characteristics are more pronounced at high temperatures. Generally the leaves are smaller and narrower than normal leaves.

The characteristic spindle-tuber symptoms shown in stem and leaf development are developed more at high temperatures, under droughty conditions, and late in the season, than under the opposite conditions.

FLOWERS

Spindle-tuber plants have a tendency to bloom more profusely and somewhat earlier than normal plants. The blossoms are very conspicuous, generally extending a considerable distance above the leaves, because the blossom stems are quite stiff (Fig. 9). The dead blossoms adhere to the plants longer than in the case of normal plants. The blossom stems are much in evidence on spindle-tuber plants late in the season.

MATURITY OF VINES

Spindle-tuber plants are shorter-lived than normal plants, when considering the number of days they are above ground. Their leaves seem to be more susceptible to tipburn than those of normal plants. When considering the period required to mature the plants, counted from planting time, spindle-tubers will generally be found to occupy the ground for a longer time and to produce marketable tubers later, due to later emergence.

THE SPINDLE-TUBER COEFFICIENT

In order to describe the relative severity of spindle-tuber in a unit, strain, or lot of seed of any kind, as shown by the plant parts above ground, a system of numerical value was adopted. This system is to some extent the reverse of that for describing vigor, tho not exactly so, because it gives consideration to more factors than size. Normal plants showing no spindle-tuber symptoms are designated as 0. Those plants showing the faintest indications of spindle-tuber are described by 10, those in the most advanced or final stage by 100. The extent of the spindle-tuber symptoms in each plant

is recorded. The sum of all these values is divided by the total number of plants, thereby giving the spindle-tuber coefficient. *

FIG. 7.— Triumph vine and tubers produced by it. Irrigation field, Scotts Bluff, October, 1924. (Compare with Figure 8.)

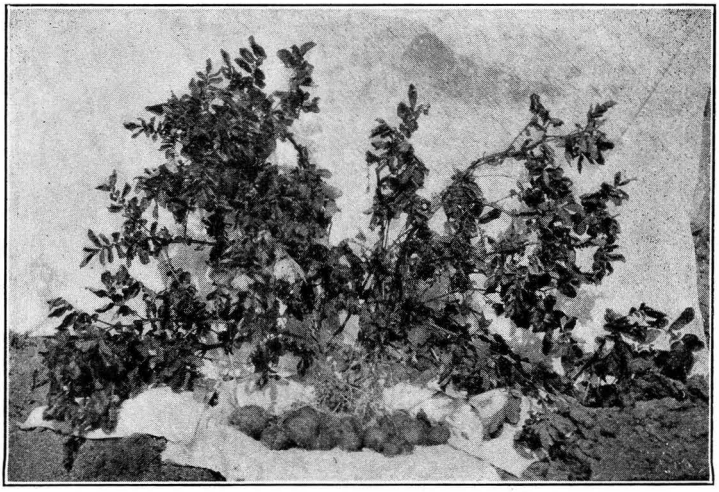


FIG. 8.— Normal Triumph plant and tubers. Irrigation field, Scotts Bluff, October, 1924. (Compare with Figure 7.) Both plants were same distance from camera.

* This is expressed by the formula:— $\text{S T Coef.} = \frac{\Sigma}{n}$

S T Coef. = Spindle-tuber coefficient.
Σ = Summation: i.e., sum of products of fv.
f = Frequency or number of variants (plants) in any variant group.
v = Variant or extent of spindle-tuber.
n = Total number of plants.

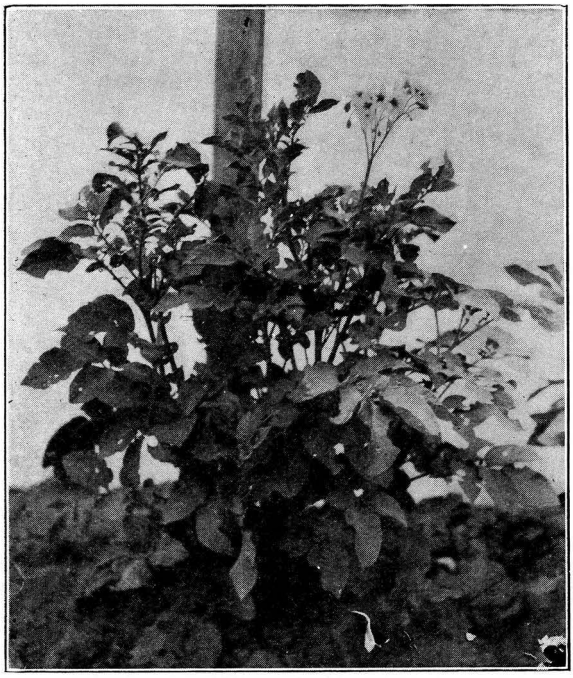


FIG. 9.— Spindle-tuber Downing plant showing characteristic growth habit and large conspicuous flower cluster.

TABLE 6.—*Relation of poor type of seed tubers and high spindle-tuber coefficient in plants produced. Triumph Strain B. Seventy-four lines planted in 1924 in Scotts Bluff.*

Mean tuber type in 1923	Spindle-tuber coefficient in 1924																				Total
	0.	5.	10.	15.	20.	25.	30.	35.	40.	45.	50.	55.	60.	65.	70.	75.	80.	85.	90.	95.	100.	
10																						
9																						
8					1											1						2
7										1	2		2	3		2						10
6							1			1			1	1	1	1	1	1				8
5									1			2		2	3	1	2	3	2			16
4												1	2	2	4	5	3	4	2			23
3															3	2	2		3	1		11
2																	1	1		1		3
1																		1				1
0																						0
Total					1		1		1	2	2	3	5	8	11	12	9	10	7	2		74

Mean tuber type in 1923—4.67
Mean spindle-tuber coefficient in 1924—71.8 per cent

The spindle-tuber coefficient has been found to be of more value in determining the status of a strain than a statement concerning the per cent of plants infected, as such statement does not indicate whether the disease is present in a mild or severe form. They, however, supplement each other considerably. The use of the spindle-tuber coefficient is illustrated in Table 6. A high spindle-tuber coefficient and low tuber type estimate (Table 6) are correlated positively.

VARIETAL MODIFICATION OF SYMPTOMS

The preceding discussion has been limited almost entirely to the Triumph variety. As the different symptoms develop to different degrees in the various varieties, some additional comments, based on observations in Nebraska, will be noted concerning some of these. (Thus far, all varieties of potatoes grown or observed by the author have been found to be susceptible to spindle-tuber, and furthermore, none of them seem to show any degree of resistance.)

Early Ohio.— Tubers become extremely elongated, sometimes 4 to 5 times as long as wide. They also lose practically all pink or red color, assuming one of creamy yellow. The skin is very subject to cracking, in the form of numerous short, very narrow cracks (Fig. 20).

Irish Cobbler.— Considerable difficulty has been experienced in distinguishing between spindle-tuber and normal plants until the plants were more than about 6 inches tall. After that there was no special difficulty. The spindle-tubers of this variety are very easily detected by the shallow eyes. The disease causes tubers to be extremely elongated, cylindrical, and rough, with very numerous shallow or bulging eyes, the apical buds never being sunken. The skin color changes from a creamy-white to a darker yellow (Fig. 10).

Downing.— Seed-tubers produce only one stem per hill instead of the characteristically large number (3 to 8). Plant assumes a very erect habit, greatly in contrast to the very spreading habit normal for the variety. The tubers become excessively elongated and cylindrical, with very many eyes,— instead of the normal type which is flat and blocky with relatively few eyes (Fig. 5). The number of tubers per hill is greatly reduced.

Russet Rural New Yorker.— Tubers frequently develop no russeting or if so only in blotches. Tubers become elongated

and cylindrical and seem quite subject to large growth cracks. Plants seem to bloom more profusely and also seem to develop more seed balls.

Peach Blow or Red McClure.— Potatoes become elongated as much as Triumph but do not seem to lose normal color

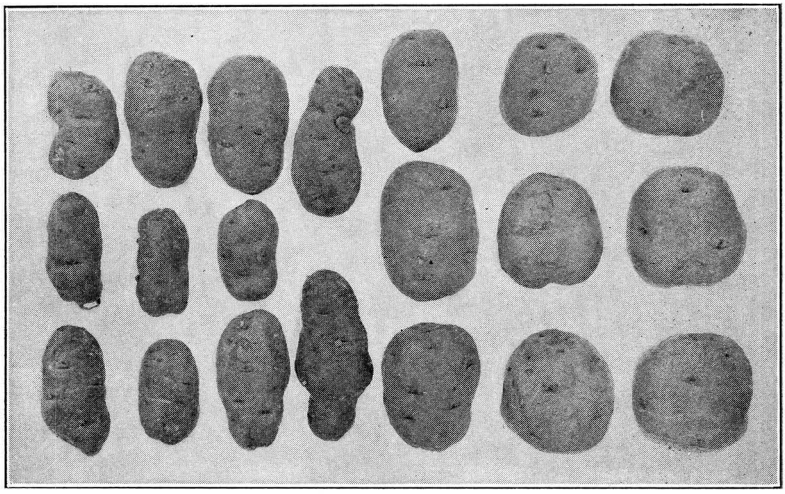


FIG. 10.—Irish Cobbler potatoes — tubers at left seriously infected with spindle-tuber, normal tuber in upper right hand corner.

as rapidly. Spindle-tubers of this variety are extremely subject to very large and deep growth cracks. These cracks frequently extend almost the complete length of the tuber and are at times half an inch or more in depth. Sometimes there are three or four cracks on one potato.

King.— In this variety the characteristic King color was somewhat intensified as spindle-tuber developed. This may have been due to the fact that this is a late variety and, therefore, the spindle-tubers were relatively more immature.

COMMERCIAL CONSIDERATIONS

Many commercial considerations are involved in connection with the spindle-tuber disease of the potato crop. While this disease does not cause total destruction of the crop and does not cause storage losses, it does cause a serious reduc-

tion in the total production, as could be inferred from Table 1 and Fig. 3 and as is quite definitely shown later in Tables 7, 8, 13, 14, 27, etc. A further loss to the producer results from the smaller size of the tubers (Figs. 1 and 3) which together with fewer potatoes per hill (Table 2) results in a lower yield of marketable size potatoes. The rough, irregular shape of the tubers causes many spindle-tubers to be sorted out. A very definite relation exists between the per cent of U. S. No. 1 grade potatoes produced by any lot of seed and the spindle-tuber coefficient of such a lot (Tables 7 and 8).

A lot seriously affected with spindle-tuber is sold at a discount because of the rough shape and abnormal appearance of the potatoes. The rough shape involves additional waste in peeling. The abnormal appearance makes the tubers unattractive as well as a commercially non-standard article.

PREVALENCE OF SPINDLE-TUBER

VARIETIES

Spindle-tuber has been found in varying amounts in most of the important commercial varieties. Varieties in which it has been found in Nebraska are, Triumph, Early Ohio, Irish Cobbler, Downing (Idaho Rural), Pearl (Peerless), Rural New Yorker (also Russet form), Green Mountain, Russet Burbank, King, Peach Blow (Red McClure), Early Rose, Hebron, and Blue Victor. These varieties represent 10 of the 12 variety groups described by Stuart (1923). None of these varieties showed any resistance to the disease when exposed to infection, and eventually the disease occurred with equal severity in all. However, some varieties seem to develop the more severe forms slightly more rapidly than do others. This seems to be the case with the Irish Cobbler and Pearl varieties.

GEOGRAPHIC DISTRIBUTION

In potatoes assembled in Nebraska for strain and variety tests between 1919 and 1924, spindle-tuber in all stages has been found in seed stocks secured from Michigan, Wisconsin, Minnesota, North Dakota, South Dakota, Wyoming, Montana, Idaho, and in those from all parts of Nebraska.

In trials with 218 strains of Triumph potatoes conducted by the Louisiana Agricultural Experiment Station at Baton Rouge in 1924, spindle-tuber in varying quantities was found in strains secured from each of the states represented. These

strains were secured from Nebraska, Montana, Wyoming, Wisconsin, North Dakota, South Dakota, Minnesota, and Vermont. There was about equal variation in the severity of the disease in the lots from the various states (disease readings made by the author in April, 1924).

This disease is thus apparently very generally distributed and probably occurs in all extensive potato sections. It has probably been quite generally present for many years.

PREVALENCE IN NEBRASKA

COMMUNITY TRIAL PLATS

The mean yield per acre of potatoes on the North Platte Valley Reclamation Project for the years 1920 to 1923 has been 147, 132, 123, and 97 bushels per acre, respectively (Annual Report 1923 of North Platte Water Users Association). During the same periods the mean yield per acre of strains of good seed, relatively free from spindle-tuber, used in the various experiments reported in this and previous bulletins (Werner 1922, and Werner and Howard 1923) was generally at least twice as great as these averages, thereby showing the possibilities where good seed was used. Some of the data presented later very forcibly suggest the reason for these relatively low average yields.

In the spring of 1923, representative seed samples were selected from 105 lots of potatoes that were being planted on a commercial scale, mostly in the irrigated regions of western Nebraska. This was done for the purpose of determining: (a) the extent (percentage of infection) to which this disease existed in commercial lots; (b) the severity of the disease in these lots and the damage being done; and (c) whether the cultural history of these lots had any relation to their seed value (phase (c) is discussed on pages 66 to 68). These lots were planted in comparative trials on irrigated alfalfa sod land in Scotts Bluff County.

All of the 56 Triumph lots showed some spindle-tuber. The extent of the spindle-tuber infection is shown in Table 7, by 5 per cent spindle-tuber coefficient groups. The mean spindle-tuber coefficient for all lots was 15.91 per cent. The mean yield per acre was 141.8 bu. which while above the average yield per acre of 97 bu. for 7,903 acres on the North Platte Valley Reclamation project during 1923 (North Platte Water Users Association Report 1923) was far below the average production of the certified checks. An inspection of the table (column 3) shows that as the spindle-

tuber coefficient increased from the 0.1 – 5.0 per cent group to the 60.1 – 65.0 per cent group the yield decreased. There was also a steady decline in the percentage of grade No. 1 tubers. Thus spindle-tuber was responsible, not only for a decreased yield but also for a very material decrease in the quality. The eight check lots of seed showed a spindle-tuber coefficient of only 3.55 per cent and a total yield of 235.2 bu. of which 88 per cent were of No. 1 grade. (The slightly irregular

TABLE 7.—*Extent of spindle-tuber occurrence and the effect upon yield and market quality in 56 commercial lots of Triumph potatoes assembled in western Nebraska (mostly from irrigated regions). Results secured in comparative trials, Scotts Bluff County, 1923.*

Spindle-tuber coefficient (Growing plants)	Number of lots	Mean total yield per acre	Mean per cent of tubers of U. S. No. 1 grade
(1)	(2)	(3)	(4)
Per cent		*Bushels*	*Per cent*
0.1— 5.0	14	190.6	84.7
5.1—10.0	7	185.9	85.3
10.1—15.0	10	153.6	82.8
15.1—20.0	8	108.2	76.7
20.1—25.0	2	122.8	81.1
25.1—30.0	6	127.3	72.9
30.1—35.0	4	46.4	56.4
35.1—40.0	3	84.9	60.2
40.1—45.0	....	.....	.....
45.1—50.0	1	76.6	76.2
50.1—55.0	....	.....	.....
55.1—60.0	....	.....	.....
60.1—65.0	1	31.0	64.6
Total Mean of all lots	56	141.8 bu.	78.0
Mean spindle-tuber coefficient 15.91 per cent			
8 Checks certified seed from dry land	8	235.2	88.0
Mean spindle-tuber coefficient 3.55 per cent			

tendencies in columns (3) and (4) are due to the additional presence of a high per cent of mosaic in some of the lots, as in the 15.1 – 20.0 per cent. This resulted in a reduction greater than that resulting from spindle-tuber.

Spindle-tuber was present to about the same general extent in all the varieties being grown in western Nebraska,

TABLE 8.—*Occurrence of spindle-tuber and effect upon yield and market quality in 105 commercial lots of potatoes representing eight varieties. Lots mostly assembled in irrigated regions. Trials at Scotts Bluff in 1923.*

Variety	Number of lots in trial	Spindle-tuber coefficient			Yield per acre				Per cent of total U. S. No. 1
					Total yield			Mean U. S. No. 1 grade	
		Highest in any lot	Lowest in any lot	Mean of all lots	Lowest of any lot	Highest of any lot	Mean of all lots		
		Per cent	*Per cent*	*Per cent*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Per cent*
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Triumph	56	65.0	3.28	15.91	31.0	288.9	141.8	110.6	78.0
Russet Rural New Yorker	12	55.6	1.55	18.04	105.0	327.0	232.7	209.7	90.0
Early Ohio	15	75.0	9.6	23.22	27.3	208.7	109.7	72.4	66.0
Irish Cobbler	7	56.1	3.16	43.66	41.7	290.2	130.7	99.5	76.2
Downing	6	37.38	2.82	25.28	74.0	261.1	129.0	82.8	64.2
Peach Blow	4	48.90	28.88	39.18	220.7	290.7	250.4	165.9	66.3
Pearl	3	38.20	25.13	31.17	96.6	237.7	184.8	131.9	71.5
King	2	11.49	3.67	7.58	198.3	227.3	212.5	182.5	85.9
Triumph checks from dry land	8	8.57	0.23	3.55	194.0	272.3	235.2	206.0	87.6

as shown by data in Table 8. The yield and quality decreased with the increase in the spindle-tuber coefficient regardless of the variety. (The variation in productiveness of these varieties when represented by normal lots must be taken into consideration in making yield comparisons. See Nebraska Bulletin 184 and Nebraska Research Bulletin 24.) Other diseases were frequently present in these lots, sometimes to a serious extent, but no other disease was nearly as generally present as was spindle-tuber.

TABLE 9.—*Amount of spindle-tuber infection in all lots of dry land grown Triumph potatoes, given bin inspection.*

County	Tuber inspection							
	1921		1922		1923		1924	
	No. Fields	Av. % S.T.	No. Fields	Av. % S.T.	No. Fields	Av. % S.T.	No. Fields	Av. % S.T.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Banner	....	.....	....	.....	5	2.5	....	.....
Box Butte	11	5.54	31	5.29	22	1.38	46	1.78
Cheyenne	....	.....	....	.....	6	7.33	....	.....
Dawes	7	4.6	42	1.99	17	3.69	34	1.45
Kimball	9	10.4	39	3.54	29	3.06	26	2.66
Scotts Bluff	....	.....	12	1.57	9	2.06	3	2.40
Sheridan	....	.....	....	.....	11	2.29	7	.87
Sioux	5	9.7	20	.61	32	2.39	24	1.00
Average	32	7.24	144	2.8	131	2.63	140	1.69

The seriousness of the disease in the commercial seed lots of the irrigated regions is very apparent in Tables 7 and 8. Very similar results were secured from trials of other lots of seed in the same way in 1920 and 1922.

CERTIFIED SEED POTATO INSPECTION

The spindle-tuber disease has been quite prevalent in the dry land areas for a considerable length of time. The most

comprehensive information on this point is supplied by the seed potato certification inspection service. Spindle-tubers were first noted by the Nebraska certified seed inspection service in 1921. In 1921 and 1922 the trouble was described as "run out" plants or tubers. Spindle-tuber was quite generally prevalent each year in all of the western counties where inspections were made (Table 9). In each of the years 1921-1924, some spindle-tuber plants or tubers have been found in every field at one or more of the inspections. In some counties the disease has been very serious each year, whereas in other counties it has been much less serious. This is largely due to the presence or absence of the disease

TABLE 10.—*Spindle-tuber as a cause for rejection of fields inspected for seed certification in western Nebraska in 1923.*

Cause of rejection	Field Inspections				Bin or tuber inspection		Total all inspections	
	First Inspection		Second Inspection					
	No. of fields	Acres	No. of fields	Acres	No. of fields	Acres	No. of fields	Acres
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Spindle-tuber	57	790	26	294	3	22	86	1106
Mosaic	61	932	4	33	.....	.....	65	965
Total all causes.....	133	1974	43	516	31	407	207*	2897*

* Total entered for inspection, 346 fields of 5,772 acres.

in the seed stocks originally disseminated. The gradual decrease in the mean percentage is probably due to the larger number of fields inspected, the elimination of the worst lots, and the roguing practiced as a part of the certification program. It is apparent that spindle-tuber has not been prevalent to so great an extent in the dry land as in the irrigated regions (Tables 7, 8 and 9). This phase is given more consideration at another place.

A more accurate idea concerning the widespread occurrence of this disease in dry land seed stocks may be secured from a study of the causes for rejection of fields being inspected for certification. In 1923, the presence of spindle-tuber was responsible for the rejection of more fields, repre-

senting also more acres of potatoes, than any other cause (Table 10). Rejections due to mosaic were higher than normal in 1923 because the symptoms could be seen more readily as a result of the low temperature (Goss 1924). As this low temperature was less favorable for reading the spindle-tuber symptoms (Goss and Peltier 1924, Goss 1924), the general prevalence of the disease is quite evidently not overestimated by these data. The data also indicate that spindle-tuber is being controlled by certified seed growers, as the mean percentage in tubers inspected has been decreasing each year till reduced to an average of 1.69 per cent in 1924.* This decrease in the mean is the result of roguing and the annual elimination of lots with the highest percentage of spindle-tuber.

CERTIFIED SEED TRIALS

Comparative trial plats have been used for the purpose of growing all lots of potatoes inspected for certification under the same conditions, thereby quite largely eliminating environmental factors as causes of variations. These plats have been planted in Louisiana (February to April) and in western Nebraska (May to October). By means of these plats, disease readings of seed strains could be made in advance of the normal planting season in western Nebraska. Thus far these plats have been most valuable in detecting mosaic, but with a greater knowledge concerning spindle-tuber symptoms it is being found possible to utilize them to advantage in the control of this disease.

In 1924, spindle-tuber readings were made during the growing season in Louisiana (April) and western Nebraska (July). The readings at both places were found to be comparable for any of the strains.

In the western Nebraska plat, the total spindle-tuber percentage reading July 21 compared quite closely with the percentage of spindle-tubers of No. 1 size, secured when the crop was harvested. However, the percentage of severe spindle-tuber plants in the field was a better indicator of the percentage of the total weight of spindle-tubers to be expected at harvest time.

In 1923-24, spindle-tuber occurred to a less serious extent in certified seed lots than it did before it was recognized as a transmissible disease. The trial plats, however, show that it is very generally disseminated in all dry-land seed lots, the

* In 1925 the 79 fields showed 0.86 per cent of spindle-tubers at the bin inspection.

TABLE 11.—*Per cent of spindle-tuber plants in each lot of potatoes planted in comparative certified seed trial plat at Scotts Bluff in 1924. Based generally on 200 to 250 hills. (For per cent of spindle-tubers harvested see Table 12.)*

Per cent of spindle-tuber plants	Number of lots in each group			
	Certified in 1923	New lots entered for certification in 1924	Lots rejected for all reasons in 1923	Lots rejected because of spindle-tuber in 1923
(1)	(2)	(3)	(4)	(5)
0	.....	4	.....	.....
0.1— 2.5	17	19	1	.....
2.6— 5.0	43	10	4	.....
5.1— 7.5	21	6	7	1
7.6—10.0	13	3	2	1
10.1—12.5	9	3	8	4
12.6—15.0	6	1	7	4
15.1—17.5	1	2	2	1
17.6—20.0	3	.....	.....	.....
20.1—22.5	1	1	3	1
22.6—25.0	.....	.....	.....	.....
25.1—27.5	.....	.....	2	1
27.6—30.0	.....	.....	3	1
30.1—32.5	.....	.....	3	1
32.6—35.0	1	.....	.....	.....
35.1—37.5	.....	.....	1	1
37.6—40.0	1	.....	2	2
40.1—42.5	.....	.....	3	2
42.6—45.0	.....	.....	1	.....
45.1—47.5	.....	.....	1	1
47.6—50.0	.....	.....	.....	.....
50.1—52.5	.....	.....	2	1
52.6—55.0	.....	.....	.....	.....
55.1—57.5	.....	.....	.....	.....
57.6—60.0	.....	.....	.....	.....
60.1—62.5	.....	.....	.....	.....
62.6—65.0	.....	.....	.....	.....
65.1—67.5	.....	.....	1	1
87.6—90.0	.....	.....	1	1
Total	116	49	51	23
Mean	6.77%	4.90%	20.81%	28.60%

better ones of which are represented by those inspected for certification. In the 1924 trial plat, all but 4 lots of seed showed some spindle-tuber, altho a number contained less than 0.5 per cent (Table 12). The several lots certified in 1923 that showed a high percentage in 1924 were lots which

had been rogued late in the 1923 season or lots out of which spindle-tubers had been sorted before the bin inspection. However, such stock passing certification requirements contained a high per cent of tubers carrying infection which was not distinctly apparent in the tubers. It is these tubers that produced the large quantity of spindle-tubers in 1924

TABLE 12.—*Spindle-tuber percentage in all lots in comparative certified seed trial plat at Scotts Bluff in 1924. (Based on total production of 100 hills—or 1/100 acre.)*

Per cent spindle-tubers of grade No. 1 size	Number of lots in each group			
	Certified in 1923	New lots entered for certification in 1924	Lots rejected for all reasons in 1923	Lots rejected because of spindle-tuber in 1923
(1)	(2)	(3)	(4)	(5)
0	.....	4	.....	.....
0.1— 2.5	61	18	10	.....
2.6— 5.0	22	13	6	.....
5.1— 7.5	15	6	5	1
7.6—10.0	7	3	8	3
10.1—12.5	4	3	5	3
12.6—15.0	1	.....	3	3
15.1—17.5	3	2	1	1
17.6—20.0	2	.....	2	2
20.1—22.5	1	.....	3	2
22.6—25.0	.....	.....	1	1
25.1—27.5	.....	.....	1	1
27.6—30.0	.....	.....	.....	.....
30.1—32.5	.....	.....	1	1
32.6—35.0	.....	.....	4	4
35.1—37.5	.....	.....	.....	.....
37.6—40.0	.....	.....	.....	.....
40.1—42.5	.....	.....	1	1
Total	116	49	51	23
Mean per cent spindle-tuber	5.0%	4.12%	12.0%	20.2%

[Table 12 (2)]. For this reason, field inspections should be very rigid and the certification system should be planned to eliminate all spindle-tuber fields on the basis of field inspections. Lots of seed potatoes rejected for certification in 1923, (4) and (5), especially those rejected because of spindle-tuber (5), contained a much greater amount of spindle-tuber than did the certified lots.

PROGRESSIVE ADVANCE OF SPINDLE-TUBER

The degeneracy now recognized as being the result of spindle-tuber was previously reported by the author (Werner 1920, 1921, and Werner and Howard 1923) as being of a progressive nature, i.e., becoming more serious and more prevalent within a strain from year to year. In the first stages,— i.e., when tubers have an estimated type of 8 or 9,— it is almost impossible to tell with absolute certainty whether spindle-tuber is present or not. Many conditions can cause abnormal tuber appearance (shallow eyes and elongation), which may easily be confused with spindle-tuber symptoms. However, if spindle-tuber is present, this mild form does not continue as such. With each succeeding season, plants with more severe symptoms are produced; and if no selection is made, the percentage of such plants increases rapidly till eventually all the plants and tubers are affected and the strain as a whole is worthless for potato production, sometimes failing to reproduce itself.

INCREASE OF SPINDLE-TUBER IN ONE COMMERCIAL LOT

One lot of Triumph potatoes referred to thruout this bulletin as Lot F has been disseminated quite extensively in western Nebraska. This was due to the fact that it has always shown a very low percentage of mosaic and has also produced very high yields in comparative trials (see Forsling lot, Stuart 1920, p. 57). The variety type of this strain, as produced by the original grower, was never considered as entirely satisfactory in so far as the accepted ideal for the Triumph was concerned. The tubers were almost all slightly elongated and the eyes were rather shallow. The cause of the shallow eyes was at first attributed to the light soil on the original farm. However, as the strain became disseminated these peculiar type characteristics persisted even with different cultural conditions. In 1921 (in the course of seed potato certification work) the author noted that the original lot contained 5 per cent of "run-out" tubers. This was the first year that these "run-out" tubers were present to such a noticeable extent in this strain. Prior to 1921, no special effort was made to remove these "run-out" tubers or plants from the stock, except that they were avoided in planting. During the 1922, 1923, and 1924 seasons, the original field was severely rogued with a resulting decrease in the per cent of severe spindle-tuber as compared with that found in 1921. Relatively few distinctly severe type spindle-tuber plants

or tubers are found in the introducer's field. However, almost all the plants have a peculiar slightly erect type of growth that is probably characteristic of the very mildest form,— or perhaps it is the very first stage of spindle-tuber, and the tubers show the peculiar characteristics previously referred to. When potatoes from this original farm are planted at other places, if careful systematic roguing is not practiced, the stock deteriorates very rapidly, and a high percentage of severe type spindle-tuber plants are produced. When roguing is not practiced, it is not unusual for the strain to degenerate completely (especially in irrigated regions) by the second year.

A partial history of this strain showing the per cent of spindle-tuber found at tuber inspection time is shown in Fig. 11. The lots which were well rogued each year, as the F group and lots BB, C, and D, contained a relatively low percentage of spindle-tubers. Other lots which were rogued indifferently or late in the season soon showed a very high percentage of spindle-tuber. The yield and market quality always decreased as the spindle-tuber percentage increased. Neglect of roguing at any one time resulted in a rapid apparently permanent increase in spindle-tuber. In a few cases, the strain became infected with mosaic. Then degeneracy was much more rapid. This was probably because of the combination of the two diseases in the same plants (Goss 1924). This is illustrated by lot A which was planted adjacent to a lot containing mild mosaic in 1922. This was the beginning of the end of both lots, for the mild mosaic lot acquired spindle-tuber and was soon very unproductive.

Apparently spindle-tuber cannot be entirely eliminated from this strain by even the most thoro roguing. It is also apparent that constant vigilance is necessary in order to maintain a strain of seed in a productive condition when it has once become infected with spindle-tuber, even tho only of a mild type.

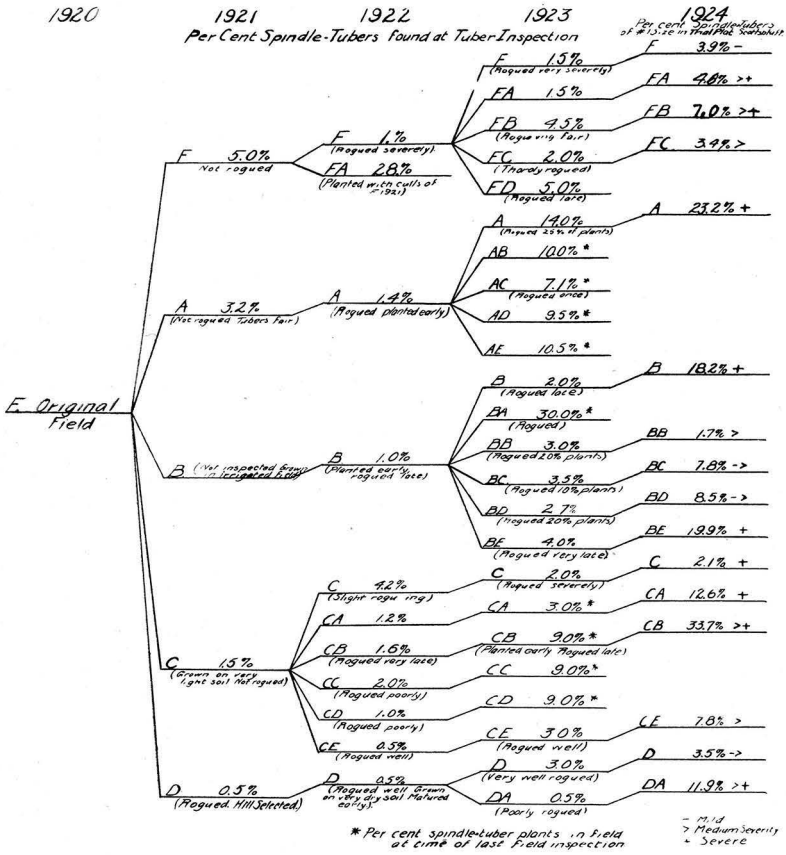


FIG. 11.— Graphic history of a strain of Triumph potatoes that became infected with spindle-tuber. When fields were rogued well and early in the season spindle-tuber was held in check. When roguing was delayed or not done properly spindle-tuber increased to such an extent that the lot was valueless for seed purposes.

A TUBER-LINE STUDY

OUTLINE OF THE EXPERIMENT

In the spring of 1921, 100 Triumph tubers were secured from a 40-hill tuber-line of 1920, started as a 4-hill tuber-unit in Triumph lot F (previously discussed) in 1919. These 100 tubers were planted as 4-hill tuber-units in an irrigated field on alfalfa sod (40 of these seed tubers shown in Fig. 12). These units were near to another similar line of

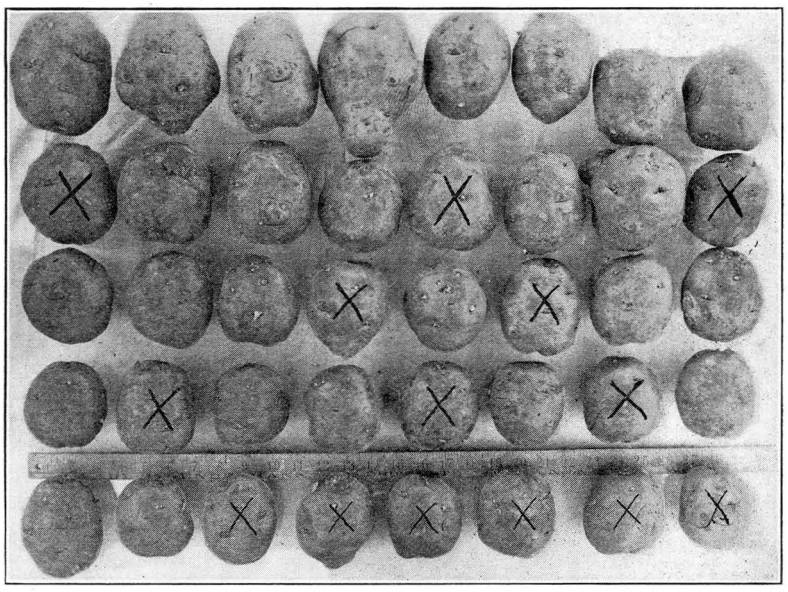


FIG. 12.—Triumph seed tubers from a 40-hill unit grown in 1920 and planted in 1921 as tuber unit lines of Strain B. The progeny of all tubers shown here, *except* those marked X, were carried thru 4 years under various cultural conditions, they being the 25 tuber lines discussed.

Triumph tuber-units on one side and on the other side tuber-units of Downing, Irish Cobbler, and Russet Rural New Yorker, while about 7 rows removed there were some badly "run-out" Triumph units of another experiment (Nebr. Res. Bul. 24, 1923, Table 12, p. 38).

In 1921, a degenerating tendency was evident within the units of the strain. This is not surprising in view of the similar history of the parent field (Fig. 11). After 1921,

the disease increased consistently. In 1921, some spindle-tuber may have been contracted from the plants 6 rows away. After 1921, it is quite probable that very little infection resulted from plants not belonging to these units.

Altho the original object of this experiment was to determine the possibility of building up a high-yielding strain of potatoes under irrigation conditions by tuber-line selection, with the appearance of spindle-tuber in this strain during the growing season of 1921 and the development of other facts the plan of the experiment was changed. This was largely an observance and mathematical study of the symptoms of the spindle-tuber disease.

All of the 100 tuber-lines were planted in 1922 in 16-hill units. Some units were lost that year and in 1923 because they did not yield enough tubers to reproduce themselves. A few units were dropped because of confusion in numbers (during storage), making absolute identity uncertain. Consequently complete data cannot be presented for the entire 100 units for all the years. In view of these facts complete data in table and chart form are presented for 25 units that were represented each year in the tuber-line studies and also in some environmental studies (pages 59 to 67). Careful study of the data has shown that these units have been representative of the total number of units. In 1921, one tuber was saved separately from each hill of the unit. In 1922, one 4-hill unit was planted from each of the 4 potatoes saved. In the fall of 1922, the second or third hill of each of the 4 4-hill units was saved. In 1923, 4 units of 4 hills each were again planted and seed was saved as in 1922. Thus during the first 3 years, all parts of the original seed tuber were equally represented. The 4-hill tuber-unit system could not be followed in 1924 because of the small size of many of the tubers, so then 20 hills were planted from random selections among the seed saved. In the fall 20 representative tubers were selected, more or less at random, for detail study. No plants were rogued out at any time. The plantings were made each year on suitable soils on the Scotts Bluff County Experimental Farm. They were irrigated from 2 to 5 times according to the season, but never excessively.

During the 1923 season, which was very favorable for reading mosaic, careful observations of these units did not reveal more than a trace of mild mosaic and none of the severe forms. Thus the degeneracy was not a result of complications of spindle-tuber and mosaic. It is quite possible, how-

TABLE 13.—*Progressive degeneracy, from 1921 to 1924, of 25 tuber-lines of Triumph (strain B) grown on the same farm each year.*

Year	Lot	Per cent of plants emerging by normal date*	Total number of tubers per hill	Mean weight per tuber	Tuber type		Mean Yield—Per acre			Per cent U. S. No. 1 grade
					Mean of Estimate of each tuber	Mean ratio W/L	Total Yield	U. S. Grade No. 1 Size		
								Yield	Per cent of check	
		Per cent		*Grams*		*Per cent*	*Bushels*	*Bushels*	*Per cent*	*Per cent*
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
1921	Units	.....	4.07	143.1	6.61	90.0	215.8	203.3	94.5	94.2
	Check	.....	.....	.....	.....	.....	239.2	236.3	100.0	98.8
1922	Units	.....	7.85	47.6	4.66	No record	224.5	189.5	79.9	84.4
	Check	.....	.....	.....	.....	92.2	270.3	237.0	100.0	87.7
1923	Units	31.4	4.20	53.1	3.52	78.6	85.8	65.4	29.4	76.2
	Check	98.0	10.4	97.0	7.5	97.2	243.2	222.2	100.0	91.4
1924	Units	27.4	5.54	62.1	2.59	72.2	106.6	50.7	13.8	47.6
	Check	95.0	.....	194.5	.....	82.7	387.3	369.2	100.0	95.3

*Dates were:—1923, June 30, or 23 days; 1924, June 28, or 21 days.

ever, that spindle-tuber as referred to here may later be found to consist of more than one distinct type of disease, just as various forms of mosaic are now recognized.

INCREASE IN AMOUNT AND SEVERITY OF THE DISEASE

From the standpoint of commercial consideration, the degeneracy of these units was about complete in 1923, the third season (Table 13). Absolute degeneracy — that is, the point when there would be insufficient or too small tubers for reproduction of all units — had not yet been attained in 1924 but was not far off. The annually increasing severity of the spindle-tuber disease is manifested by comparison with check lots * in: slow growth, i.e., low rate of emergence by a normal date, (column 3); fewer tubers per hill (4); smaller tubers (5); inferior tuber type (6); lower W/L ratio, indicating greater tuber elongation (7); reduced total yield (8); also much greatly reduced yield of No. 1 grade tubers (9); and a reduction in the percentage of tubers of grade No. 1 (11). From 1922 to 1924, the reduction in production of grade No. 1 tubers, as compared with the checks, decreased in approximately arithmetical proportion (10). A more detailed analysis of this degeneracy is presented herewith.

DECLINE IN YIELD

The tuber yield decreased very materially with each succeeding year as the spindle-tuber disease increased. This is shown in the summary in Table 13. Because of the normal variation as a result of climatic conditions the relation of the tuber-lines to the check, when considering the decrease caused by spindle-tuber, is of more significance than the absolute yield. The distribution of the means for total yield per plant of each unit-line compared with the checks is given in Table 14. These data show a very consistent decline, for the entire group, in mean yield per plant, for each succeeding year. The trend toward lower production existed in all the units. Reduction in yield of grade No. 1 potatoes was even more rapid than in the case of the total yield (Table 13).

DECLINE IN RATE OF GROWTH

The effect of spindle-tuber in retarding the normal rate of growth was measured in two ways: (a) by the time required for emergence or by the percentage of plants emerging by any one date; and (b) estimating the vine vigor of all plants (individually) at some date during the growing season.

* Check lots were from seed secured each year from the original field (see lot F in Fig. 11).

TABLE 14.—*Relative decline in total yield caused by spindle-tuber in 25 tuber-lines of Triumph potatoes (strain B) as compared with checks from original field.*

Yield of unit line compared with check	Number of units in each percentage group each year			
	1921	1922	1923	1924
Per cent (1)	(2)	(3)	(4)	(5)
5				1
10			1	1
15			2	1
20			3	5
25			2	1
30			5	9
35			3	4
40			4	3
45	1		3	
50		1		
55		1	2	
60		2		
65	2	3		
70	2	3		
75	2			
80	6	4		
85	2			
90	1	3		
95	1	4		
100	3	2		
105				
110				
115				
120	2			
125	2			
130				
135				
140		2		
145				
150				
155	1			
Mean	89.8	83.2	32.4	27.2
	Pounds per plant			
Yield of check per plant	1.435	1.622	1.459	2.324
Mean yield of units per plant	1.295	1.347	.515	.640

Emergence, in comparison with the checks, was very much delayed in both 1923 and 1924, but this delay was greater in 1924 than in 1923 [Table 13 (3)]. On August 13, 1924, the stand of plants of the units was 90.5 per cent, while the stand of check plants was 99.1 per cent. During the 1924 season, the average number of days for the emergence of the last plant (figured in the stand percentage given) was 39.2 days for the spindle-tuber units and 21.5 days for the checks. In the case of the spindle-tuber units some plants were still emerging at harvesting time in early October. However, any plants emerging after August 1st did not figure in tuber production.

In all comparative plantings with normal plants, the reduced vine vigor of spindle-tuber is very evident. With the units under consideration, this continual reduction in vine vigor was very evident. The vigor of some of the plants

TABLE 15.—*Decline in plant vigor caused by spindle-tuber in 25 tuber-lines of Triumph potatoes (strain B) on basis of estimated relative plant vigor.*

Vine vigor. Mean of unit	Number of unit lots in each mean plant vigor group		
	1921	1923	
	Units	Units	Checks
(1)	(2)	(3)	(4)
0.5	.....	.....	.....
1.0	.....	.....	.....
1.5	.....	1	.....
2.0	.....	2	.....
2.5	.....	4	.....
3.0	.....	4	.....
3.5	.....	6	.....
4.0	.....	4	.....
4.5	.....	2	.....
5.0	.....	2	.....
5.5	.....	.....	.....
6.0	1	.....	.....
6.5	1	.....	.....
7.0	2	.....	.....
7.5	.....	.....	.....
8.0	6	.....	.....
8.5	7	.....	.....
9.0	7	.....	1
9.5	.....	.....	3
10.0	1	.....	2
Mean vigor	8.28	3.28	9.42

TABLE 16.—*Decline in tuber type caused by spindle-tuber, as shown by the increase in inferior or "run-out" type tubers in 25 tuber-lines of Triumph (strain B).*

Relative tuber type	Per cent of total in each type group					
	Tubers of 25 tuber lines				Tubers of checks from original field	
	1921	1922	1923	1924	1923	1924
(1)	(2)	(3)	(4)	(5)	(6)	(7)
10	4.0	Individual tuber type not estimated. Mean based on mean of estimated type of each unit.	.....	.....	14.0	3
9	8.0		0.3	.....	25.0	8
8	20.6		5.0	.....	16.0	22
7	29.7		4.7	.....	21.0	28
6	21.3		11.0	.....	13.0	32
5	.....		13.8	1.1	9.0	.....
4	7.5		14.8	20.5	2.0	.....
3	1.6		16.3	32.5	.....	3
2	6.4		15.7	28.3	.....	4
1	1.1		18.2	17.6	.....	.....
No. of tubers....	369.0		318.0	48.3	100.0	100.0
Mean tuber type	6.61	4.66	3.52	2.59	7.71	6.84

The 1921 notes were recorded by a system of letters instead of numbers and because of that, tubers of the value of 5 were unintentionally not recorded. Consequently the values for 6 and 4 are too high. A similar error exists in the high percentage for type 2, which should be distributed to 3 more than to 1. In 1924, the system of selecting 20 tubers from each 20-hill unit instead of using all the tubers evidently resulted in another slight error in that the tubers selected were a trifle larger and of a trifle better type than the general population. It was impossible to have the same person do the detail work each year. A check-up of the detail notes indicates that the person that did the detail work in 1924 scored the tubers a trifle higher than the previous workers.

was considerably reduced in 1921, but the mean vigor of the group was fairly good, i.e., 8.28 (Table 15). However, by 1923 the vigor of the highest unit was lower than that of the lowest in 1921 and the mean was 3.28 as compared with a vigor of 9.42 for the check. In 1923, the mean vigor of 66 units was 3.22. (Vigor notes were not taken in 1922 because of other field work while in 1923 notes were taken for determining the ST Coef.) An increase in the spindle-tuber coefficient is generally very positively correlated with a decrease in vine vigor. By 1924, the ST Coef. of these units was very high (Table 6). The relation of vine vigor to tuber

type for 66 units of this group has been shown in Table 5. (Tables 5 and 6 are based on a larger number of units than are here discussed, but include these 25 units.)

INCREASE IN SEVERITY OF SYMPTOMS IN THE TUBERS

The degeneracy of the type of the tubers in the tuber-lines with each succeeding year was a very conspicuous indicator of the damage being done. Here, type is considered the shape

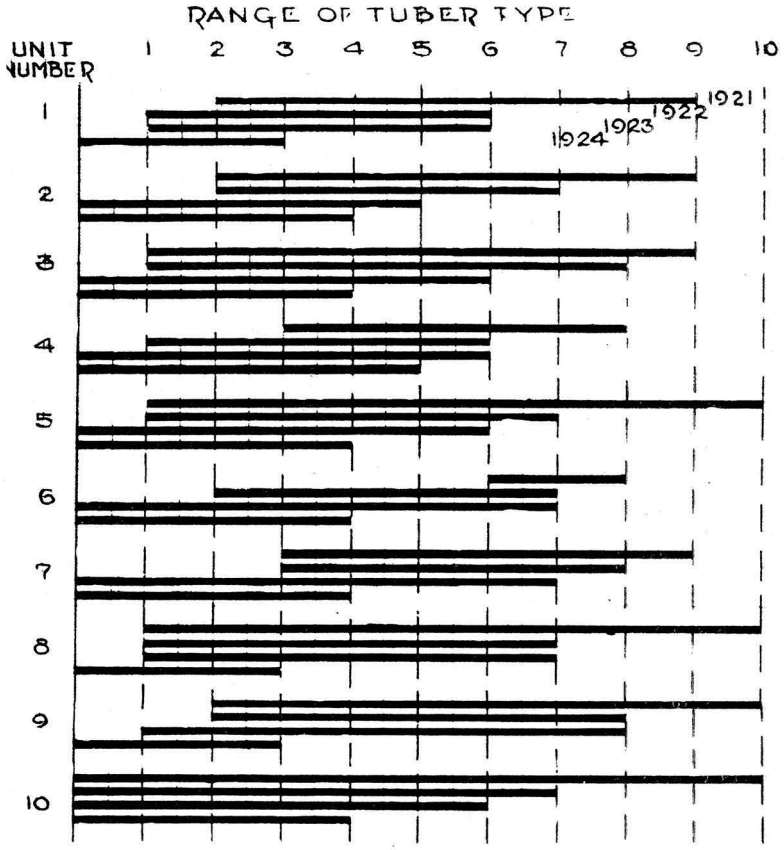


FIG. 13.— Range of tuber type within tuber lines and the degeneracy of these lines, when spindle-tuber was present. The original seed tubers of these unit lines are the first eight tubers and the eleventh and twelfth tubers (numbers 9 and 10 in this graph) shown in Figure 12.

of the tuber and also characters as color and smoothness of skin, character of eyes, presence or absence of abnormal conditions as cracks, excessively numerous or conspicuous lenticels, etc.

During three of the four years the tuber type of all tubers saved (for system of selection see page 42) from each unit

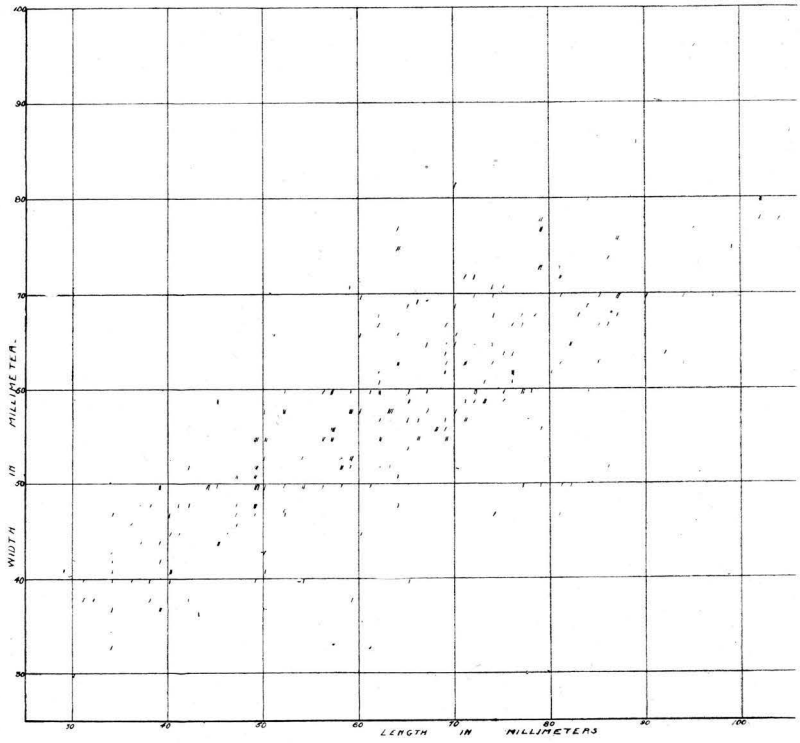


FIG. 14.— Length and width of Triumph tubers produced in 1921 by the 25 units of Strain B. Seed tubers shown in Figure 12. The tubers were not generally elongated except in the case of the larger tubers.

was estimated at the time of weighing and calibrating. The distribution of these tubers by type groups, given in Table 16, for each of the three years shows that, (a) there was a strikingly constant decrease in the mean tuber type each year; (b) there was greater variation in type, i.e., a greater range of distribution and greater coefficient of variability

during the first year, but this declined till there was very little variation in 1924; (c) in 1921, 16.6 per cent of the tubers had a tuber type of 5 or lower, but that in 1923, 79 per cent of the tubers were below 5 and in 1924 all were in this lower group.

This constant degeneracy in tuber type took place within the unit-lines in the same manner as in the larger group. The tubers of each unit varied in type but there was a very steady decline (Fig. 13) as in the case of another strain reported in Nebraska Research Bulletin 24, Figs. 4 and 5.

At this point it must be remembered that the best tuber within the sub-unit was always planted. If all tubers or especially some of the poorest type tubers had been planted

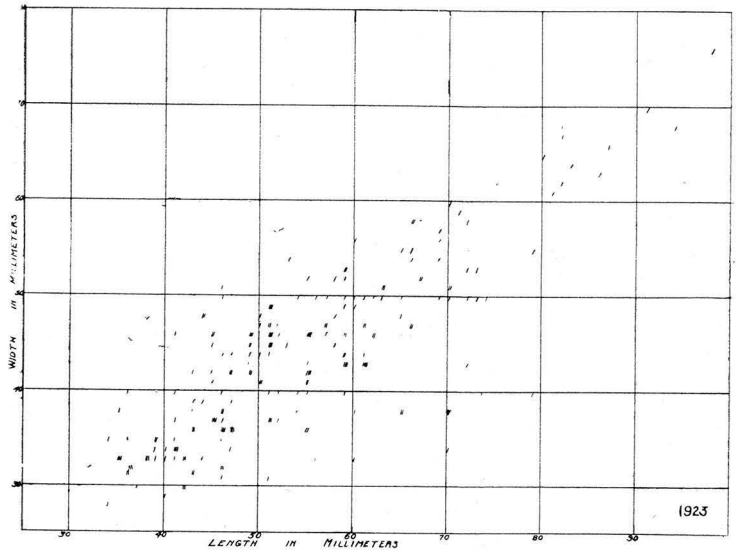


FIG. 15.— Length and width of tubers of 25 tuber lines of Triumph Strain B, in 1923. As a result of spindle-tuber presence the tubers were much more elongated in 1923 than in 1921 and less than in 1924.

the decline in type would undoubtedly have been much more rapid. Since tubers of type 5 and less are very undesirable as commercial stock, the product of these units would have been practically valueless at the end of the third season.

Once in a great while a hill of much better type tubers was produced in a unit with inferior type. During the first year, the reverse was very frequently the case; that is, one

or two hills of "run-out" tubers were produced while the other hills of the unit were apparently normal. [Similar condition was reported by Schultz and Folsom (1923).]

The calibration of the selected tubers of these 25 tuberlines, the estimated type of which has just been discussed, showed that longer tubers were produced during each succeed-

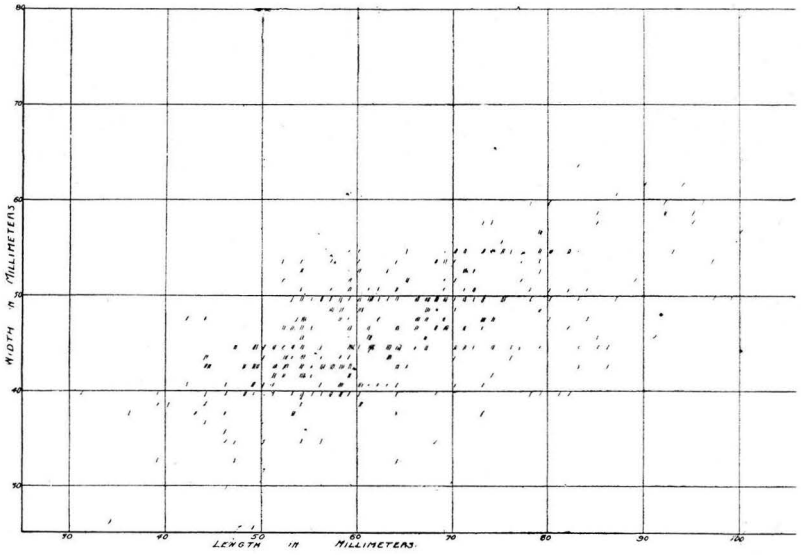


FIG. 16.— Length and width of those tubers produced in 1924 from Triumph Strain B. Practically all tubers were longer than wide, and most of them, especially the larger ones, were extremely elongated.

ing year. The length and width of the tubers produced in 1921, 1923, and 1924 are plotted in Figures 14 to 16. The mean W/L for these years is given in Table 13. The larger tubers were relatively longer than the smaller tubers. This is evident in the graphs for each year, but most especially so in 1921. The smaller tubers quite frequently had a greater width than length. These tendencies still prevailed in 1924 (Fig. 16), when every tuber showed advanced spindle-tuber symptoms. From these and other data it is evident that the little potatoes from a strain seriously infected with spindle-tuber may have a good shape and yet be very undesirable for seed because they contain spindle-tuber. [In 1922, field FA (Fig. 11), which had been planted with screenings

from the crop produced in field F in 1921, contained 28 per cent of spindle-tubers (by weight) at the time of tuber inspection. These ranged from mild to severe forms of spindle-tuber.] Furthermore, it follows that spindle-tuber

TABLE 17.—*Decrease in percentage of Grade No. 1 size tubers (over 1 7/8-inches in diameter), caused by spindle-tuber, in 25 Triumph tuber-lines of strain B.*

Per cent of grade No. 1 size	Number of units in each percentage group			
	1921	1922	1923	1924
Per cent (1)	(2)	(3)	(4)	(5)
20	.....	.....	.....	1
25	.....	.....	.....	2
30	.....	.....	.....	3
35	.....	.....	.....	1
40	.....	.....	1	2
45	.....	.....	.....	4
50	.....	.....	1	2
55	.....	.....	1	2
60	.....	.....	1	3
65	.....	1	.....	3
70	.....	1	3	2
75	.....	1	5	1
80	.....	4	6	.....
85	1	9	3	.....
90	6	8	.....	.....
95	14	1	4	.....
100	4	.....	.....	.....
	Per cent No. 1 grade size			
Mean for units	94.2	84.4	76.2	47.6
Check	98.8	87.7	91.4	95.3

* Market quality decreased more than this table indicates, because the appearance of the tubers was injured and the shape undesirable.

can be sorted out of a lot of large potatoes somewhat better than out of a lot consisting mostly of small to medium-sized potatoes, altho sorting is recommended only when the per cent of spindle-tuber is low.

DECREASE IN MARKET QUALITY

The decrease in market quality caused by spindle-tuber has been referred to at several other places. Much of this decrease is the result of a reduction in size of the tuber and

the production of a more unmarketable tuber resulting from elongation. This decrease in market size is shown in Table 17. Each year the tubers were sorted at harvest time according to size only. Other factors entering into grade No. 1 were not considered. In 1921, all units had a uniformly high per cent of grade No. 1 size. In each later year, the percentage decreased and the lots became more variable. In comparison with the yield of the checks the production of grade No. 1 size by the units decreased more than Table 17 indicates, for the total yield also decreased rapidly [Table 13, (8), (9), (10)]. The extent of decrease in the number of tubers per plant and the decrease in the weight of the tubers is shown in comparison with the check for the same year in Table 13, (4), (5).

DISCUSSION ON INCREASE OF SPINDLE-TUBER

After spindle-tuber became established in a commercial lot that was practically free from mosaic, it continued to increase very rapidly. This increase was in the form of a higher percentage of plants with the more severe forms of spindle-tuber or a higher percentage showing very mild symptoms, some of them so slight that they could not be determined with certainty. Unless potato fields from this lot were rogued early in the season and severely, the percentage of spindle-tuber increased very rapidly. The degeneracy was accelerated when any of the lots also acquired mosaic. It has thus far been impossible to eliminate spindle-tuber from this strain, tho by constant vigorous roguing it is kept down to a quantity sufficiently low that the strain is still profitably productive.

In 25 tuber-lines coming originally from the same tuber the degeneracy caused by the increase in the prevalence and severity of spindle-tuber resulted in a constant gradual decrease in the (a) total yield, (b) marketable yield, (c) rate of growth as shown by retarded germination and reduced vine vigor, (d) tuber-type as portrayed by the declining value of the tuber-type estimate and the increasing relative length of tubers as determined by calibration. The spindle-tuber causing the degeneracy was probably all in the original units the first year or at least no additional amount was introduced after the first year. As no effort was made to eliminate the disease by roguing, we have here an example of the completeness of the degeneracy caused by this disease. The units were all practically worthless after the second year, when their market production was already reduced 20 per cent. During

the fourth year, none of the units had any commercial merit. From prospects in 1924, it is doubtful if these units would reproduce themselves more than one more year. Much of this degeneracy resulted from a gradual increase in the severity of the disease after it was once in the tuber-lines. However, the advance of the disease was at times so rapid as to suggest very strongly that infection was spread from adjacent plants of the same strain affected with the more severe forms.* It is quite possible that the severity of the disease within a plant is increased if infected with a somewhat different type or stage of the disease; however, we have no evidence on this point. When spindle-tuber is present within a strain, tuber-line selection is valueless for potato improvement, unless an immune or resistant strain is discovered.

RELATION OF ENVIRONMENT TO THE DISEASE

The "running out" of seed potatoes has in the past frequently been attributed to environmental conditions. Especially has this been the case in the Corn Belt, where temperature has been considered the causal factor, (Fitch 1914, Emerson 1914). Decreased yields and "running out" of potatoes that had been irrigated the previous year or years have been reported (Sandsten 1921, Christensen 1921, Werner 1920, 1921, Werner and Howard 1923). In 1923, Werner and Howard reported that the degeneracy discussed by them (and previously by Werner 1920, 1921) was due to spindle-tuber but that this degeneracy was more severe in irrigated than in dry land regions. Work done thruout the seasons of 1923 and 1924 has verified the previous statement. Data presented herewith show that environmental conditions seem to influence the rate of spread and the increase in severity of the disease.

IRRIGATION VS. DRY LAND CULTURE OF SEVERAL VARIETIES

In 1919, lots of potatoes of several different varieties were divided, part planted on dry land at Bushnell and part in an irrigated field at Morrill. In 1920, 10 tubers from each of 5 varieties from each source were planted by the tuber-unit method at Morrill. In the 1920 comparative trials, the mean of the tuber type of the dry land grown units was higher than of the irrigated units and the difference in yield was still greater (Table 18). Environment evidently provided conditions which caused more of the disease in one lot of seed than in the other.

* See notes in Appendix, pages 127-128, on cutting knife transmission.

From 1919 to 1922, seed potatoes of 8 distinct varieties produced on dry land outyielded those produced on irrigated land in almost every instance, when compared under the same conditions. There was a relatively constant decrease in yield with each additional year that a lot was grown in an irrigated field. In every case the decreasing yield was associated with a similar decrease in tuber-type and an increase in the percentage of tubers showing symptoms of spindle-tuber. There is no doubt that spindle-tuber was the cause of this degeneracy. (For the complete data along this line, the reader is referred to Tables 13, 14, and 15 of Nebraska Research Bulletin No. 24.)

One of the theories now advanced by the author to explain these results is, that probably the dry land conditions with low moisture retarded the development of the symptoms (page 98), which became more marked in the irrigated fields.

TABLE 18.—*Relation of environment surrounding seed tubers to increase in degeneracy, as measured by relative tuber type and yield of progeny. (Abstract of Nebraska Research Bulletin 24—Table 11.)*

Variety	Mean tuber type		Total yields per 4-hill unit	
	Bushnell dry land	Morrill irrigation	Bushnell dry land	Morrill irrigation
			Pounds	*Pounds*
Triumph	8.7	6.2	2.79	7.28
Early Ohio	7.0	6.0	3.04	6.27
Irish Cobbler	8.9	4.1	4.24	8.60
Downing	6.6	2.1	4.02	7.06
Pearl	7.3	3.9	4.82	8.81

Another possible cause was that spindle-tuber became more generally established in this experimental irrigated stock because of (a) probable infection from the surrounding commercial stock which contained a high percentage of "run-out" tubers, and (b) conditions in the irrigated field,— with very rank succulent vines and probably harboring more disseminating insects, being more favorable for spread of infection in the trial plat. (There was a considerable percentage

of spindle-tuber in the original seed of several of the varieties, but this was quite largely held down in the dry-land plat by seed selection. Seed selection alone was not sufficient in the irrigated plat, even tho the best type seed tubers of the lot were always planted.) Another theory on the cause of this rapid deterioration of the dry land lots brought into the irrigated plats for trial is that they were unintentionally exposed to infection, by being planted each year adjacent to the previously irrigated lots which contained a high percentage of spindle-tuber. If the dry land grown stock had been exposed to as much infection while on dry land as was the

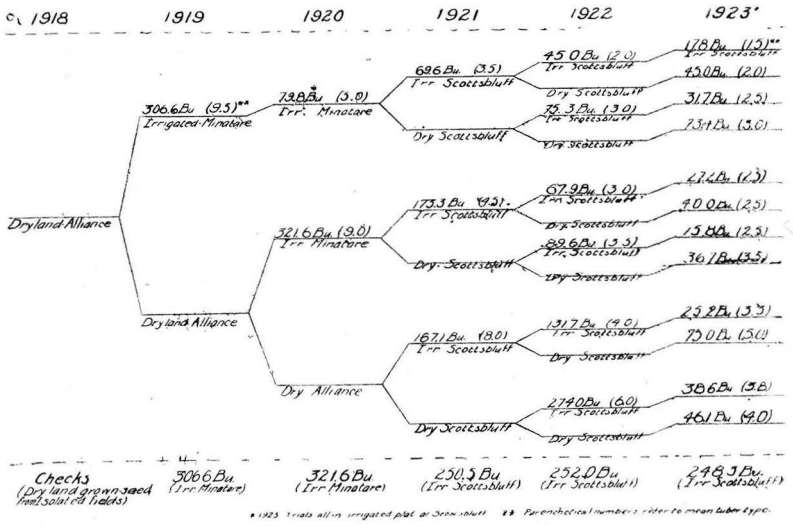


FIG. 17.— Graphic history of an originally very productive dry-land Triumph tuber unit line showing the rapid degeneracy in type and yield that resulted from exposure to infection with spindle-tuber. Degeneracy resulting from this cause was most extensive in the irrigated fields. Dry-land culture retarded the advance of spindle-tuber but did not reduce either the percentage or the severity of the disease.

irrigated stock under irrigation, the difference would probably not have been as great. Considering dry-land fields in general, it has been observed that the stand is greatly reduced when spindle-tubers are planted on dry land. When these plants do come up they are small, thereby reducing the possible source of infection. Other workers have found that with

other virus diseases of the potato, environment affects the dissemination of the disease. (Folsom 1923, Murphy 1923, 1924, Schultz and Folsom 1923b, Schultz and Folsom 1925.)

EFFECT OF IRRIGATION AND DRY LAND CULTURE UPON SPINDLE-TUBER IN TUBER LINES

PROGENY OF TUBER LINE OF TRIUMPH STRAIN (AT 760)

In previous publications (Werner 1920, Werner 1921, Werner and Howard 1923) the degeneracy of tuber-lines, when brought into an irrigation field from a dry land field, was discussed. In the latest publication, data were presented (Nebraska Research Bulletin 24, Table 12) which seemed to indicate that when these units were returned to dry-land conditions there was a retardation of the degeneracy or perhaps a slight improvement of the unit as a whole, due to the fact that the more diseased plants tended to eliminate themselves, as registered by the increased yields of some of the units.

The data on total yield and tuber type of one strain (No. 760) for a six-year period are given in Figure 17. In 1919, tubers from Alliance were cut into halves, one-half being planted in the original dry-land field and the other in the irrigated field at Minatare. Unit-plantings were made on dry land at Alliance in 1919 and 1920. The Alliance dry-land field was practically free from "run-out" plants or tubers and consequently the unit-line plants retained their original degree of vitality. In 1921 and 1922, the dry land plat was located at the Scotts Bluff County Experimental Farm. Many "run-out" plants in other lots were growing in the same dry-land plat in Scotts Bluff. In 1921, some "run-out" plants were planted in rows adjacent to the new stock from Alliance. The irrigated lots were planted on a farm north of Minatare till 1920, after which time they also were moved to the Experiment Farm.

The progeny of this original unit degenerated very rapidly in the irrigated plats and also under certain conditions in the dry-land plats. The extent of this degeneracy was measured by noting the yield and tuber type (Fig. 17) and vine vigor (Fig. 18). By analysis of the data shown in these figures, it is seen that:

(a) The dry-land-grown lots almost invariably out-yielded the lots grown one year in the irrigated plats.

(b) With each successive year of culture in the irrigated plats, there was a reduction in yield until in 1922 the lot grown from seed that had been in the irrigated plats during

3 previous years yielded only 45 bushels per acre as compared with 274 bushels from the lot that was continually on dry land, a loss in production of 84.6 per cent.

(c) After the units were grown in the dry-land plat at Scotts Bluff for two years, the yield was only slightly better than that secured from irrigated plat lots when compared with the check. This was probably due to spindle-tuber infection from the numerous spindle-tuber plants in the dry-land plat.

(d) When lots which had started to degenerate in the irrigated plats were grown in the dry-land plats, the follow-

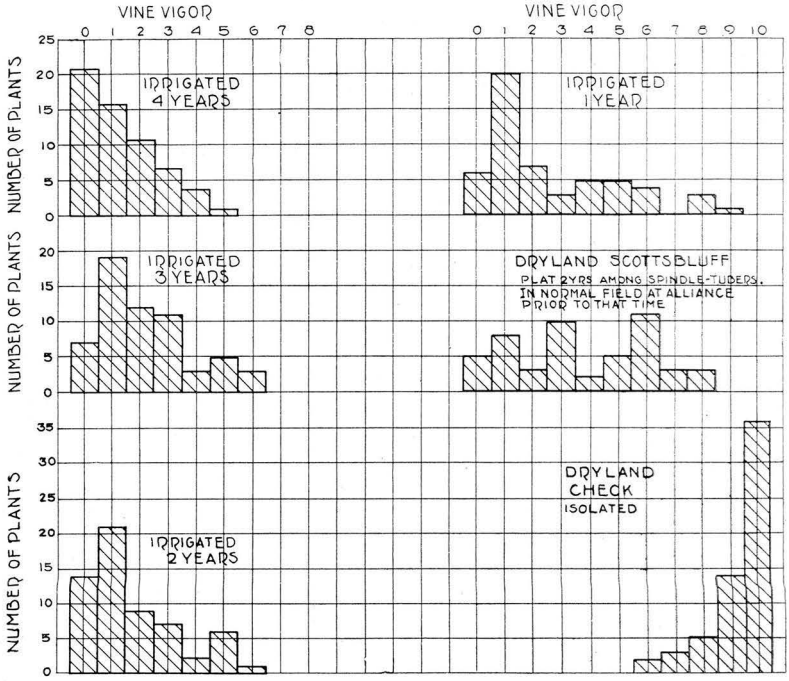


FIG. 18.— Decline in vine vigor of a tuber line strain of Triumphs grown under different cultural conditions over a 5-year period. Spindle-tuber was present in both the irrigated fields and the dry land field at Scotts Bluff. With each succeeding year of culture in such fields the percentage of weak plants increased. Eventually large numbers of seed pieces never produced plants. Graph based on 60 plants of each seed lot grown in Scotts Bluff in 1923. (Yield and type data of this strain shown in Figure 17.)

ing year the yield from such lots (in both 1922 and 1923) was in every instance greater than from the lots grown continuously in the irrigated plat.

(e) The tuber type degenerated in the same way as did the yield; that is, more tuber type degeneracy took place in irrigated than in dry land plats.

(f) Cultural treatment never resulted in any improvement of the tuber type in the spindle-tuber lots.

(g) After being subjected to infection in the Scotts Bluff plat, the tuber type of the progeny from the dry-land units was never equal to what it had been when the seed was grown in the clean Alliance field.

(h) In the tuber-lines there was a very marked decrease in the percentage of high vigor plants and an increase in the number of plants of very low vigor, with each additional year of culture in the irrigated plats (Fig. 18).

According to these data, spindle-tuber degeneracy takes place most rapidly in irrigated fields, but when the dry-land field contains equally as many spindle-tuber plants of a similar degree of severity, severe degeneracy results, but never to as great an extent as in the irrigated plats. These facts support the theories advanced on pages 55 to 56.

PROGENY OF TUBER LINES OF TRIUMPH STRAIN B

In 1922, one of the tubers from each of the 100 tuber-units of Triumph strain B grown at the Scotts Bluff Experiment Farm in 1921 was cut into two pieces. From one-half of each tuber 4 hills were grown on dry land at Bushnell and from the other half 4 hills were grown in the irrigated plat at the experiment farm. For various reasons some of the unit lots were lost in one plat and were then discarded in both plats, so that progeny of only 76 of the units were available for comparable planting at the experiment farm in the irrigated field in 1923 and also for dry land continuation planting on dry land at the experiment farm. This number of units was further reduced to 25 for planting in 1924. Consequently when the data extend over the complete 4-year period they represent only these 25 units.

Degeneracy, as the result of spindle-tuber, was much more rapid in the irrigated than in the dry land fields. However, it will be shown that not all of this difference can be attributed to culture, but that some is the result of the condition (regarding spindle-tuber) of the surrounding plants. The degeneracy which took place is depicted in a graphical way by a presentation of the means of various characters

TABLE 19.—*Relations of environment to rate of degeneracy of 25 Triumph tuber lines (strain B) affected with spindle-tuber, on basis of tuber type.*

Tuber type	Year	Type of culture given lots each year								
	1921	Scotts Bluff Irrigation								
	1922		Scotts Bluff Irrigation	Scotts Bluff Irrigation	Bushnell Dry Land		Scotts Bluff Dry Land	Scotts Bluff Irrigation	Bushnell Dry Land	
	1923			Scotts Bluff Irrigation	Scotts Bluff Irrigation	Scotts Bluff Dry Land	Scotts Bluff Irrigation	Scotts Bluff Irrigation	Scotts Bluff Irrigation	Scotts Bluff Dry Land
	1924							Scotts Bluff Irrigation	Scotts Bluff Irrigation	Scotts Bluff Irrigation
		Year for which results are reported								
		1921	1922	1923					1924	
		Per cent of total number in each type group								
(1)		(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
10		4.0	Type not estimated by individual tubers		2.9	1.3	Type not estimated by individual tubers		0.5	1.2
9		8.0		0.3	6.9	9.7			1.0	1.8
8		20.6		5.0	13.5	17.1			1.6	4.0
7		29.7		4.7	11.3	16.4			1.4	7.9
6		21.3		11.0	8.8	10.1			1.8	8.4
5		0		13.8	14.5	9.3		1.1	1.8	2.0
4		7.5		14.8	16.1	7.0		20.5	13.7	28.2
3		1.6		16.3	8.7	4.0		32.5	24.6	27.6
2		6.4		15.7	10.9	9.7		28.3	24.7	10.9
1		1.1		18.2	6.3	15.4		17.6	28.9	7.9
Mean tuber type		6.61	4.66	3.52	5.21	5.34	5.00	2.59	2.64	4.02
Number of tubers		369		318	726	474		483	485	496

during the four years, in Fig. 19. Tables 19 to 21 contain more detailed data.

In 1921, the mean tuber type of the tubers from the 25 units of strain B, produced at Scotts Bluff with irrigation, was 6.61 (Table 19). During the 1922 season, the tuber type of tubers grown at the same place (estimated by units) was reduced to 4.66. Tuber type of the 1922 Bushnell and Scotts Bluff dry-land lots was not estimated. By 1923, the data show that the type of the lots in the irrigated plats in 1921 and 1922 was still further reduced, and that the type of lots grown on dry land at Bushnell (5) (6) and Scotts Bluff (7) was considerably better, in fact somewhat better than the 1922 crop of irrigated stock (3), but inferior to the 1921 parent units (2). However, the type of the tubers from the Scotts Bluff dry-land plat of 1922 (7) was inferior to the type of the Bushnell dry-land stock in both irrigated and dry-land plats (5) (6). This is probably due to the fact that in 1922 the Bushnell dry-land stock was exposed to no more spindle-tuber infection than was contained in the units, whereas at Scotts Bluff the units were exposed to infection from some other lots that contained much spindle-tuber.

In 1924, the units grown on dry land at Bushnell in 1922 and Scotts Bluff 1923 (10) had tubers with type superior to the other lots. The lot at Bushnell in 1922 and irrigated in 1923 (9) lost practically all of its superiority as compared with the lot irrigated continuously (8). Some good type tubers were still produced in 1924 (10), but these were produced as individual tubers or individual hills among spindle-tubers, as every unit produced some tubers that were rated as low as 1 on type.

The tuber-calibration data presented graphically in Fig. 19 reveal a degeneracy in type from year to year as indicated by tuber elongation (lower W/L) and the production of less flat tubers (lower T/L). The differences as due to culture are less marked than in the case of the estimated type; however, they show the same trend.

The yield was reduced in about the same way and to much the same extent as was the type. [Fig. 19 (c) Table 20.] The yield of each unit for each year was reduced to a comparable basis, by calculating the percentage that the unit-yield was of the mean check yield (Table 20). Upon this basis it is seen that there has been a steady decline in the total yield with each succeeding year in an irrigation field [(2) (3) (4) (8)]. The superiority of seed receiving one year of dry-land culture in a good environment is shown

TABLE 20.—*Relation of environment to rate of degeneracy of 25 Triumph tuber-lines (strain B) affected with spindle-tuber, on basis of ratio of yield of each unit to yield of check.*

Year	Type of culture given lots each year								
1921	Scotts Bluff Irrigation								
1922		Scotts Bluff Irrigation	Scotts Bluff Irrigation	Bushnell Dry Land		Scotts Bluff Dry Land	Scotts Bluff Irrigation	Bushnell Dry Land	
1923			Scotts Bluff Irrigation	Scotts Bluff Irrigation	Scotts Bluff Dry Land	Scotts Bluff Irrigation	Scotts Bluff Irrigation	Scotts Bluff Irrigation	Scotts Bluff Dry Land
1924							Scotts Bluff Irrigation	Scotts Bluff Irrigation	Scotts Bluff Irrigation

Yield of unit line compared with check	Year for which results are reported								
	%	1921	1922	1923			1924		
		Number of units in each percentage group							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	5							1		
	10			1				1	1	2
	15			2				1		
	20			3				5	2	
	25			2		1		1	2	
	30			5			1	9	1	1
	35			3			2	4	1	1
	40			4		2	3	3		3
	45	1		3		2	4			3
	50		1			1	2		2	1
	55		1	2	1	2			2	
	60		2				5		3	3
	65	2	3			2	2		3	1
	70	2	3		2		2		2	
	75	2			2				1	2
	80	6	4		2	3	1			1
	85	2			1	1	2		1	1
	90	1	3		3				2	1

TABLE 20.—*(Concluded)—Relation of environment to rate of degeneracy of 25 Triumph tuber-lines (strain B) affected with spindle-tuber, on basis of ratio of yield of each unit to yield of check.*

Year	Type of culture given lots each year								
1921	Scotts Bluff Irrigation								
1922		Scotts Bluff Irrigation	Scotts Bluff Irrigation	Bushnell Dry Land		Scotts Bluff Dry Land	Scotts Bluff Irrigation	Bushnell Dry Land	
1923			Scotts Bluff Irrigation	Scotts Bluff Irrigation	Scotts Bluff Dry Land	Scotts Bluff Irrigation	Scotts Bluff Irrigation	Scotts Bluff Irrigation	Scotts Bluff Dry Land
1924							Scotts Bluff Irrigation	Scotts Bluff Irrigation	Scotts Bluff Irrigation

Yield of unit line compared with check	Year for which results are reported								
	1921	1922	1923				1924		
%	Number of units in each percentage group								
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
95	1	4		2	1	1		1	2
100	3	2		3	2				1
105				1				1	
110				4	1				
115									1
120	2				2				
125	2			2	1				1
130				1	1				
135					2				
140		2							
145									
150									
155	1				1				
160					1				
165				1					
Mean	89.8 Per cent	83.2 Per cent	32.4 Per cent	97.6 Per cent	91.8 Per cent	56.6 Per cent	27.2 Per cent	57.2 Per cent	58.8 Per cent

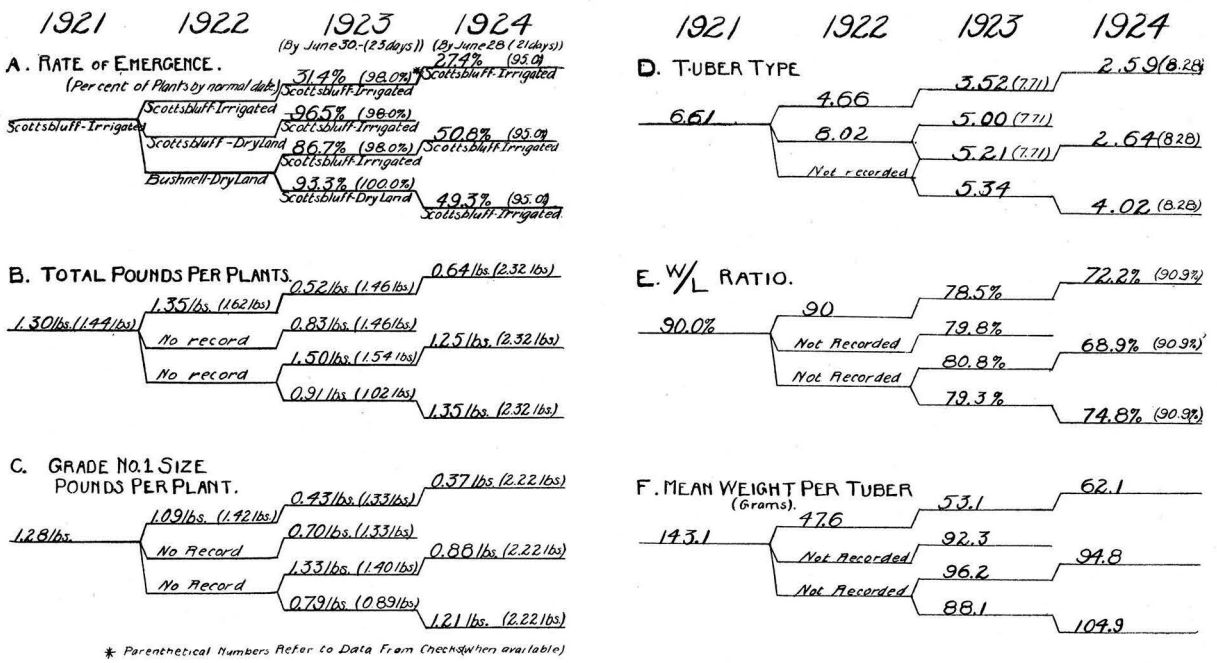


FIG. 19.—Mean performance record of 25 tuber lines of Triumph (Strain B), showing progress of degeneracy as manifested by decline in rate of emergence, type, yield, etc., and also the retarding effect of dry land conditions upon spindle-tuber advance.

[(5) and (6)]. Less favorable dry-land conditions (due to more spindle-tuber in the environment) resulted in yields superior to those from units from irrigated fields but inferior to the preceding (7). In 1924 there was little difference in yield between the lots from seed grown on dry land in 1922, even tho grown in irrigated and in dry-land plats

TABLE 21.—*Relation of environment to increase in spindle-tuber coefficient of 25 tuber-unit-lines of Triumph potatoes affected with spindle-tuber. Scotts Bluff irrigation plat. Readings made July 24, 1924.*

Degree of Spindle-tuber	Previous cultural history				
	Scotts Bluff—irrigation 1921			Checks	
		Bushnell dry land 1922			
	Scotts Bluff irrigation 1922 and 1923	Scotts Bluff irrigation 1923	Scotts Bluff dry land 1923	Check from original dry land, normal field	Selected spindle-tubers
	Per cent of growing plants in each group				
(1)	(2)	(3)	(4)	(5)	(6)
0*	.....	0.67	9.72	63.24	.....
1	.....	0.45	4.98	1.71	.....
2	0.23	2.03	2.71	.43	1.76
3	0.71	3.83	1.81	3.85	2.95
4	1.66	5.18	2.94	10.26	2.95
5	5.45	9.23	9.27	9.40	9.42
6	10.19	14.87	10.64	8.12	12.94
7	15.88	17.12	14.48	1.71	11.77
8	18.96	19.60	15.15	.....	15.83
9	19.20	13.96	13.35	1.85	18.23
10	25.60	13.06	14.93	0.42	26.50
Spindle-tuber coefficient	80.82%	74.16%	61.84%	13.24%	78.44%
Stand of plants August 13	90.5%	93.3%	94.6%	99.5%	83.0%

* 0 represents normal plants, i. e., showing no distinct spindle-tuber symptoms.

in 1923. However, there was a serious difference in market quality (Fig. 19 e) and in type (Fig. 19 f and Table 19). The matter of row competition may have entered in here in 1924 as a factor in reducing the yield of the 2-year dry land lot [Table 20 (10)] because it had a vigorous check lot on one side, whereas the other two lots in 1924 had no such competition, being adjacent to weak lots containing about as much spindle-tuber as they did.

TABLE 22.—*Spindle-tuber coefficients of numerous commercial lots classified by previous culture. Scotts Bluff trials, 1923.*

Spindle-tuber coefficients	Cultural conditions under which seed was produced												
	Dry land		Number of years grown under irrigation										Mean of all lots
	Certified	Not certified	1	2	3	4	5	6	7	8	10	13	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Triumph variety (56 lots)													
Number of lots	7	7	19	8	6	3	3	1	1			1	
S. T. coefficient—Maximum	P.Ct. 15.1	P.Ct. 25.9	P.Ct. 25.98	P.Ct. 65.00	P.Ct. 37.63	P.Ct. 30.52	P.Ct. 28.37	P.Ct.	P.Ct.	P.Ct.	P.Ct.	P.Ct.	P.Ct. .....
S. T. coefficient—Minimum	0.50	.....	0.45	11.34	15.70	11.83	.....	.....	.....	.....	.....	.....	.....
S. T. coefficient—Mean	3.28	9.55	12.02	29.18	26.17	20.47	14.98	19.71	32.20	.....	.....	24.23	15.91
Russet Rural New Yorker (12 lots)													
Number of lots	1		5	3	1		1				1		
S. T. coefficient—Maximum	.....	.....	31.80	7.56	.....	.....	.....	.....	.....	.....	.....	.....	.....
S. T. coefficient—Minimum	.....	.....	2.68	2.50	.....	.....	.....	.....	.....	.....	.....	.....	.....
S. T. coefficient—Mean	1.55	.....	15.52	4.85	21.82	.....	55.6	.....	.....	.....	45.4	.....	18.04
Downing variety (6 lots)													
Number of lots		1			3	1					1		
S. T. coefficient—Maximum	.....	.....	.....	.....	35.80	.....	.....	.....	.....	.....	.....	.....	.....
S. T. coefficient—Minimum	.....	.....	.....	.....	4.75	.....	.....	.....	.....	.....	.....	.....	.....
S. T. coefficient—Mean	.....	2.82	.....	.....	25.72	37.38	.....	.....	.....	.....	38.3	.....	25.28
Triumph checks (8 plats)													
Number of plats	8												
S. T. coefficient—Maximum	8.57	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
S. T. coefficient—Minimum	0.23	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
S. T. coefficient—Mean	3.55	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

The spindle-tuber coefficient (in 1924) was high in all lots, but was highest in those lots which had been in irrigated plats and lowest in those from the dry-land plats, (Table 21). The tubers that had been on dry land 2 years, even tho from a field containing much spindle-tuber (in 1923), still produced normal plants to the extent of 9.72 per cent (4). These plants produced the normal tubers previously referred to (pages 21 and 50). This group showed a bimodal tendency for spindle-tuber coefficient which was also evident in the tuber type distribution table [Table 19 (10)]. This same tendency was manifested on dry land in 1923 [Table 19 (6)].

The same general effect of the various conditions upon rate and extent of advance of the spindle-tuber disease was manifested in some additional plant characters, not previously referred to in detail, principally as follows:

(a) Retarded rate of emergence of plants (Fig. 19 a).
(b) Reduced plant vigor (Fig. 19 b).
(c) Reduction in market quality of tubers (Fig. 19 d and e).
(d) Reduction in weight per tuber (Fig. 19 b).
(e) Reduction in number of tubers per hill.
(f) Reduction in ultimate stand of plants (Table 21).

The data herewith show that a lot of potatoes containing spindle-tuber deteriorated much more rapidly in irrigated than in dry-land fields.

CULTURAL HISTORY OF COMMERCIAL LOTS AND THEIR SPINDLE-TUBER CONTENT

The cultural history of the commercial lots assembled in 1923 (see pages 30–31) was secured with special reference to the number of years each lot had received dry land or irrigation culture.

Considerable spindle-tuber was found in many of these lots, as previously reported, (see Tables 7 and 8). When classified on the basis of cultural history, it was discovered that in the case of both dry-land and irrigated groups some lots showed little or no spindle-tuber while others contained a great deal (Table 22). However, the irrigated group as a whole contained a greater amount of spindle-tuber than did the dry-land group. As the number of years of irrigation increased, spindle-tuber generally became more severe, as indicated by the mean spindle-tuber coefficients. However, some lots which had been irrigated for 5 years or more showed very little spindle-tuber and others after 13 years

TABLE 23.—*Total yield per acre produced by 113 commercial lots of potatoes, classified by previous culture. Trials at Scotts Bluff in 1923.*

Variety	Cultural conditions under which seed was produced													Mean of all Lots
	Dry land		Number of years grown under irrigation											
	Certified	Not Certified	1	2	3	4	5	6	7	8	9	10	13	
(1)	*Bushels* (2) (7*)	*Bushels* (3) (7)	*Bushels* (4) (19)	*Bushels* (5) (8)	*Bushels* (6) (6)	*Bushels* (7) (3)	*Bushels* (8) (3)	*Bushels* (9) (1)	*Bushels* (10) (1)	*Bushels* (11)	*Bushels* (12)	*Bushels* (13)	*Bushels* (14) (1)	*Bushels* (15) (56)
Triumph	192.2	182.9	156.4	130.1	102.3	76.3	81.1	89.4	76.6				101.	141.8
Russet Rural New Yorker	(1) 311.4		(5) 239.8	(3) 276.0	(1) 232.0		(1) 105.0					(1) 117.0		(12) 232.7
Early Ohio		(4) 91.8	(4) 138.2	(3) 142.0		(2) 51.0	(1) 105.0	(1) 92.0						(15) 109.7
Irish Cobbler	(1) 290.2		(2) 223.7		(2) 169.7	(1) 164.4					(1) 67.1			(7) 130.7
Downing	(1) 261.1				(3) 118.7	(1) 72.3						(1) 84.6		(6) 129.0
Peach Blow				(1) 256.6	(2) 262.2	(1) 220.7								(4) 250.4
Pearl				(2) 223.4				(1) 96.6						(3) 184.4
King					(1) 227.3	(1) 198.3								(2) 212.5
Checks (Triumph certified)														(8) 232.5

*Number in parenthesis refers to total number of lots

showed less than did a few of the dry-land lots. These exceptional lots almost always had been grown on relatively isolated farms and had not become infected by bringing diseased seed potatoes onto the farm.

As the lots received one or more years of irrigation, the yield decreased constantly (Table 23). The mean decrease in yield was more marked than the increase in the mean spindle-tuber coefficient. This decrease in yield is attributed to the spindle-tuber content and not to irrigation, altho the irrigation environment undoubtedly was responsible for the increased amount of spindle-tuber and thus was indirectly a contributing factor.

A careful study of the data revealed no correlation between the producing qualities of the spindle-tuber content of any lot and the soil type upon which it had been produced. The soil types ranged from very fine sands to silts. There was about equal variation in the yields and disease content between the lots from each soil type.

RELATION OF PLACE AND CULTURE TO SPINDLE-TUBER IN EARLY OHIO TUBER LINES

In the spring of 1922, 200 large Early Ohio potatoes were selected from a good commercial lot grown near Alliance (this lot contained a trace of spindle-tuber as then recognized). These tubers were all divided into 12 pieces. One piece from each tuber was planted in each of 12 plats (described later). During 1922 and 1923, the plants from each original seed piece were staked individually. Due to the great volume of labor involved, the number of unit-lines was reduced in 1924 to 25 which were still represented in all plats. In 1924, one tuber from each unit from 8 plats was planted in comparative plantings on irrigated land at the North Platte Experimental Substation.

The plats were located in distant parts of the state. The cultural methods also varied very much. At Alliance the units were planted on dry land in a commercial field that contained very few diseased plants.

The Bushnell plat had the greatest altitude of any (about 5000 feet). It was also located in a good commercial dry-land field. At both Alliance and Bushnell, the planting was done in June and harvesting about October 1st. None of the plats were rogued at any time.

Four plats were located at North Platte. Two of these were planted early (April 15) and two late (about June 25). At each planting time, one plat was planted on irrigated land

TABLE 24.—*Effect of environment upon spindle-tuber development in Early Ohio potatoes. Comparative trials at North Platte with irrigation in 1924.*

Treatment in 1922 and 1923			1924 results at North Platte			
			Percent of tubers in various grades			
Place	Culture	Time of Planting	U. S. No. 1 Size Normal Type	U. S. No. 1 Size Spindle-tubers	U. S. No. 2 and culls	Defective Potatoes No. 1 Size Normal Type *
			Per cent	*Per cent*	*Per cent*	*Per cent*
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Alliance	Dry land	Late	93.7	1.8—**	4.5	25.3
Bushnell	Dry land	Late	80.0	5.3—+	14.7	17.8
North Platte	Dry land	Early	33.6	58.8—+	7.5	10.5
North Platte	Dry land	Late	38.7	50.1+	11.1	29.2
North Platte	Irrigation	Early	15.7	69.8+	14.5	8.2
North Platte	Irrigation	Late	21.5	64.9++	13.6	6.8
Lincoln	Mulch	Early	3.9	84.9++	11.1	3.9
Lincoln	Cultivation	Early	5.5	75.2++	19.3	5.5

*Refers to potatoes with knobs, growth cracks, etc.

**Symbols indicate degree of spindle-tuber: — mild; ± medium; + severe; ++ very severe.

and the other on dry land (about 200 feet higher). In 1922 another strain was planted several rows away from these units. In 1923 no other lots were planted in close proximity. All lots of seed at North Platte were of similar quality, so probably these units acquired no more disease than was contained among their own plants.

At Lincoln, two plats were planted in early April and harvested in October. One was given ordinary cultivation, the other was mulched with straw just before the plants emerged. The situation at Lincoln regarding disease and other lots was about the same as at North Platte.

There was a much more rapid increase of spindle-tuber in the lots grown at North Platte and Lincoln than in those grown at Alliance and Bushnell, as shown by Table 24. The spindle-tuber in the harvested crop at North Platte from the two western-grown dry-land lots of seed was also relatively mild. The dry-land stock from North Platte contained a lower percentage of spindle-tuber than did the irrigated stock. In both dry land and irrigated groups, the seed lots secured from late planting produced a lower percentage of spindle-tubers the following year than did those from early planting. The spindle-tubers from the irrigated lots were of a more severe type than from the dry-land lots. The lots grown at Lincoln showed more spindle-tuber (all of which was of the most severe form), than those from any other source. The data in Table 24 show a higher per cent of spindle-tuber of No. 1 size from the mulched than the cultivated Lincoln lots. However, the disease was slightly more serious with the cultivated seed lots, which produced a higher percentage of small potatoes (Col. 6). Thruout the entire series the percentage of normal type tubers decreased as the spindle-tuber percentage increased (Col. 4). The yield also declined with the increase in spindle-tuber. The yield records are not reported, since a few of the plantings were made in single row plats and therefore some were subjected to more interrow competition than others, thus making yield data unreliable for comparative purposes.

This series of experiments serves to further emphasize the very direct relation existing between both geographic location and culture, and the increase in the amount and severity of spindle-tuber in a lot of seed potatoes. This suggests very forcibly that much of the potato degeneracy in the Corn Belt heretofore attributed to climate (heat) is associated with climate but probably not the direct result thereof. Conditions were much more favorable for insect

life at Lincoln and North Platte during these years than in the western part of the state. There were also more insects in the irrigated than in the dry land plats at North Platte, especially in 1923. Aphids and leaf hoppers were especially prevalent in the Lincoln plats, probably 25 to 50 aphids per plant. In 1922 careful searching revealed no aphids in the Alliance and Bushnell plats, and in 1923 only a few were found in these plats, that is, 2 to 3 aphids on 1 per cent to 3 per cent of the plants.

ENVIRONMENTAL EXPERIMENTS AT LINCOLN

The superiority of potatoes grown under a straw mulch, when used the next year as seed potatoes, as determined by Emerson (1914) has been referred to previously. In 1923, duplicate experimental plantings of Early Ohio potatoes were made at Lincoln about every 2 weeks, starting with the lots planted on April 10. The April 10 and May 18 planted lots are especially considered here. One set of each of these plantings was straw mulched, May 10 and June 16 respectively. They were separated by only a 10-foot alley. Each planting consisted of 9 adjacent rows of 25 hills each. All rows in one plat were planted with the same seed tubers, i.e., one piece from each tuber in each row. The seed for the two plats was carefully selected from a commercial strain of certified seed produced at Hay Springs, Nebr., (altitude about 4800 feet); and while not always identical in both plats, it was very comparable. One row was harvested from each plat at as regular intervals as weather conditions permitted. All lots were placed in cold storage (at a temperature of 35° F. to 40° F.) promptly after harvesting, where they were kept until planting time in April, 1924.

In 1924, all lots were planted on April 4 in a field given normal cultivation. Check rows were planted every eleventh row, with potatoes from the original source. The potatoes harvested on the same date in 1923 from cultivated and mulched rows were planted adjacent to each other. Rows were 50 feet long with 40 hills per row. Plantings were replicated, but data are available for only one set, which has been used as a basis for tuber type studies. (The project will be reported upon more completely at a later date.)

The tuber type was determined by the individual tuber estimating method described on page 18. Typical examples of the various type values as applied to the Early Ohio variety are shown in Fig. 20. There was considerable land variation

in some parts of the field. As this variation seemed to have a relatively regular trend the yields were corrected by the system described by Kiesselbach (1917).

CULTIVATION VS. STRAW MULCHING

Spindle-tuber coefficient readings made June 30, 1923, showed some spindle-tuber present in all lots. It was also observed that the symptoms could be seen more distinctly in the plants in all the cultivated lots than in the mulched lots. The mean spindle-tuber coefficient for the plants in 9 culti-

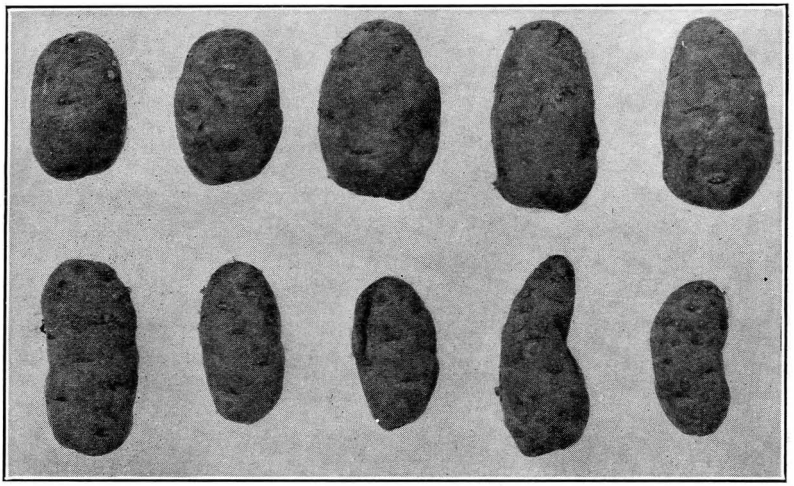


FIG. 20.— Spindle-tuber in Early Ohio potatoes. Tuber in upper left corner is normal, the one in the lower right row shows advanced symptoms of spindle-tuber, others infected progressively to a more serious extent.

vated plats of 25 hills each was 9.43 per cent, whereas for the companion mulched plants the spindle-tuber coefficient was only 3.0 per cent. In this connection it is well to consider that the straw mulch was applied on May 10 and delayed the emergence of most of the plants till about May 25, whereas in the cultivated plats most plants had emerged by May 12.

In the 1924 comparative plantings (Table 25), the potatoes raised from the seed mulched in 1923 averaged larger and of considerably better type than those from the cultivated plat, the mean type of mulched stock being 7.47 and

TABLE 25.—*Cultural methods (cultivation and straw mulching) and time of harvesting Early Ohio seed potatoes, as factors influencing spindle-tuber and yield. Results from seed produced at Lincoln in 1923, when planted at Lincoln in comparative plats in 1924.*

Harvest in 1923	Cultural treatment in 1923 of lots planted April 10								Straw mulched lots of 1923 planted May 18		
	Cultivation			Straw Mulch			Superiority of mulched lots				
	Number of tubers	Mean tuber type	Total yield per acre	Number of tubers	Mean tuber type	Total yield per acre	Mean tuber type	Total yield per acre	Number of tubers	Mean tuber type	Total yield per acre
			Bushels			*Bushels*		*Bushels*			*Bushels*
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
July 5	224	5.02	243.1	226	8.81	405.2	3.79	160.1	.....	.....	.....
July 12	231	6.40	269.8	236	8.02	338.2	1.62	68.4	.....	.....	.....
July 19	261	5.48	229.3	230	8.57	343.9	3.09	114.6	.....	.....	.....
August 9	226	3.42	192.9	215	7.20	307.6	3.78	114.7	.....	.....	.....
August 18	255	4.27	205.4	227	7.61	330.3	3.34	124.9	86	7.87	288.7
Sept. 7	263	3.38	172.0	228	7.60	290.3	4.22	118.3	285	8.88	412.7
Sept. 20	159	3.80	194.6	233	6.95	270.5	3.15	75.9	190	6.98	280.6
Oct. 4	255	2.81	158.5	256	6.31	269.1	3.50	110.6	218	7.02	316.5
Oct. 20	269	3.71	198.6	231	6.80	294.6	3.09	96.0	208	7.65	308.6
Total number of tubers	2143	.....	.....	2082	.....	.....	.....	.....	.....	.....	.....
Mean of cultural groups	.....	4.34	207.1	.....	7.47	316.6	3.13	109.5	.....	.....	.....
Mean of 3 checks of series	.....	6.97	306.7	.....	.....	.....	.....	.....	.....	.....	.....
5 lots harvested on late dates	240	3.51	185.8	1175	6.29	290.9	.....	.....	9.87	7.76	325.4
Mean of 2 checks	.....	.....	.....	.....	.....	.....	.....	.....	.....	8.87	378.2

of the cultivated stock 4.34. The mean tuber type of every lot from mulched seed was superior to the mean type of the companion cultivated lot.

The total yield followed the trend of the tuber type very closely. The yield of the mulched seed outyielded the cultivated in every instance, the mean difference being 109.5 bushels per acre, a decrease of 34.6 per cent below the mean

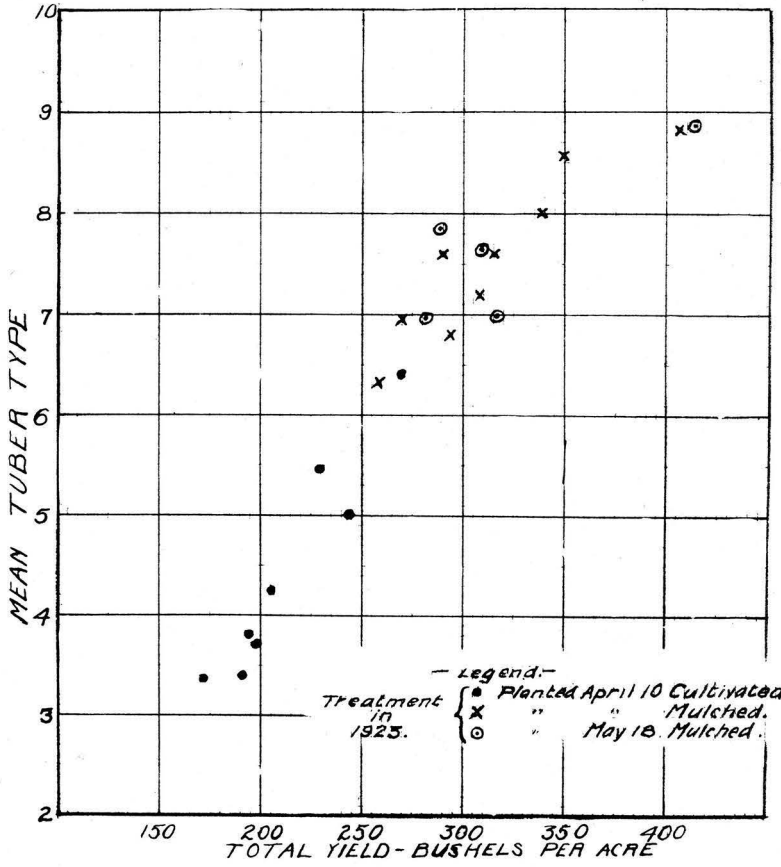


FIG. 21.— Good tuber type and high yield were very definitely correlated in potatoes from environmental study plats at Lincoln. Low yielding and poor type lots were severely infected with spindle-tuber. The superiority of mulched seed was evident in both type and yield of progeny. (Based upon data in Table 25.)

yield of the mulched stock, 316.6 bushels. This same relation existed thruout all the series of this experiment, involving 225 plats. The mulched seed was superior to the check from the original source in both tuber type and yield. The difference in yield of marketable potatoes between progeny from mulched and cultivated seed was greater than for total yield, because of the smaller size of tubers in progeny from cultivated stock. (The spindle-tuber content of the progeny from the mulched stock may not all have come from the seed tubers. Some may have been acquired in 1924 by virtue of the adjacent planting of the more seriously infected cultivated lots.)

Apparently, spindle-tuber does not develop nearly as rapidly in a mulched as in a cultivated seed plat located at Lincoln. Just why this is so, cannot be determined from these experiments. Some important differences resulting from the application of a straw mulch can very conceivably be important contributing factors. The author (Werner 1922 and Werner and Howard 1923) has previously called attention to the lower and more uniform soil temperature as determined in mulched and cultivated soils by thermographs. The moisture content of the straw mulched soil is generally higher and always more constant. The vine growth of the mulched plants is smaller than that of the cultivated plants. Thus when planted at the same distance there is more open space around the mulched plants. The environment may be a trifle less favorable for insect carriers. The vine growth of the cultivated plants, being more rank and probably more succulent may be more susceptible to infection, as suggested by the experience of Elmer (1922). It may also be due to nutritional conditions within the plants which may be influenced by the changed chemical conditions in the soil. For instance, Albrecht (1922) reported greatly retarded nitrate formation in straw-mulched soils as compared with cultivated and scraped soils. Whatever the cause, there is no doubt that mulching retarded spindle-tuber development in these experiments. (Experiments are now in progress to determine the influence of these cultural conditions upon normal seed-stock protected from infection by insect-proof cages.)

EARLY VS. LATE HARVESTING

In 1923 the potatoes harvested early were superior for seed purposes to those harvested late (Table 25). In the 1924 progeny, the tuber type was best from the early-harvested

tubers, as was also the yield. There was a gradual declining tendency in both tuber type and yield of progeny from lots harvested at successively later dates. This decline in type and yield was due to the presence of spindle-tuber. Lots harvested late in the season showed some inconsistencies. These are, however, of little significance, as practically all plants in this series were dead ripe by September 5. The results were the same with both mulched and cultivated seed lots. The superiority of the mulched stock was relatively constant thruout the series. There was a very positive correlation between tuber type and yield. The greater degeneracy shown by late-harvested lots probably results from their more prolonged exposure to infection in 1923. The smaller amount of spindle-tuber rather than the immaturity of the seed was probably the most important factor.

EARLY VS. LATE PLANTING

Lots of seed were planted at successive dates for the purpose of determining their seed value as immature tubers, compared with those planted early and harvested early.

The 1924 progeny from the mulched series planted May 18, 1923, (mulched June 16, emerged June 20,) produced tubers of better type than did the comparable mulched series of the April 10 (1923) plantings. [Table 25, (11) and (6).] In every case, progeny from tubers of the late-planted series of the previous year were superior to those of the early-planted series harvested on the same date. The difference in mean type here, however, was only about half as great as between the mulched and cultivated lots from the ten early-planted series. The yield from the late-planted stock was correlated with the type about as constantly as in the former series. Evidently the delayed planting, resulting in a slightly shorter exposure of the plants to infection, produced tubers containing less spindle-tuber, which as seed tubers were slightly superior to those planted earlier. Insects were much more numerous during June than at any other time, thus probably providing better conditions for transmission among early-planted stock.

These experiments show that when spindle-tuber is present in a lot of potatoes, even in very small quantities, the disease advances less rapidly in the potatoes grown under a straw mulch, also that either early harvesting or late planting seems to be effective in reducing the amount of spindle-tuber. The correlation between tuber type and yield was remarkably constant.

TRANSMISSION OF SPINDLE-TUBER

The infectious nature of spindle-tuber has been established. Transmission of this disease was first reported by Schultz and Folsom (1923). The author suspected transmission of the degeneracy trouble being dealt with in Nebraska and presented data on an experiment conducted in 1921-1922 that indicated quite definitely that field transmission had taken place (Werner and Howard 1923). Some of the earlier

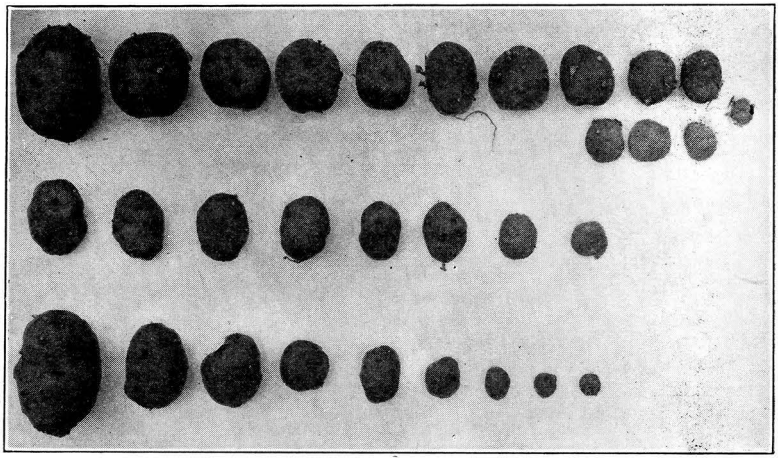


FIG. 22.—Transmission of spindle-tuber by tuber grafts. Upper row, progeny from normal check half, middle row progeny of normal tuber grafted on to spindle-tuber (eyes were removed from spindle-tuber seed piece) and lower row from spindle-tuber check half. Triumph potatoes raised at Scottsbluff in 1923. Data concerning rate of emergence of progeny of these lots in 1924 given in Figure 23.

data reported at the same time indicated that transmission had occurred. A footnote was inserted (Werner and Howard 1923, p. 48) reporting the transmission of spindle-tuber by tuber-grafts made during the winter of 1922-1923.

Much of the data and discussion in the fore part of this bulletin deals to some extent with the matter of transmission. Some experiments more definitely planned for the purpose of securing information upon the extent of transmission and the factors influencing transmission are herein reported.

TRANSMISSION OF SPINDLE-TUBER BY TUBER GRAFTING

As previously reported, spindle-tuber transmission was distinctly evident in the progeny grown from the tubers of

8 out of 11 of the first tuber-grafts (made in December, 1922), when grown in the field in 1923. The tuber type of the progeny from normal checks remained relatively normal. In the case of grafts where transmission was accomplished, the tuber type of the progeny was reduced to type values

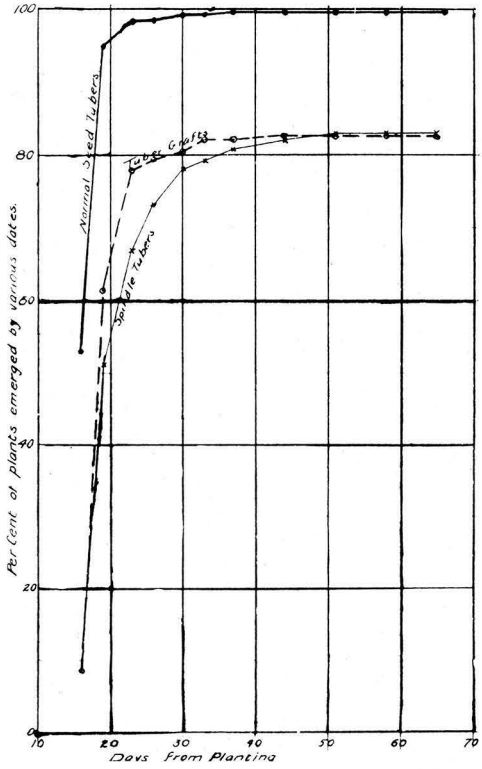


FIG. 23.— Effect of spindle-tuber upon rate of emergence of spindle-tubers and tuber graft progeny as compared with normal tubers, in Scotts Bluff, 1924.

ranging from 7 to 1, most of them 3 to 1. There was a similar decrease in the yield, the production per plant by the progeny of the grafts being 50 per cent to 60 per cent of that from the normal or check lines. (In all cases of tuber-grafting reported on here, the eyes were removed from the spindle-tuber half of the graft so that all plants came from the normal half.)

In the spring of 1923, another set of tuber-grafts was made, involving 15 spindle and normal tubers. These were grown in the field at Scotts Bluff. Each set of 15 plants — that is, normals, grafts, and checks — were planted in separate plats. The grafts were planted in the part of a normal field where very little spindle-tuber transmission was likely to take place.

Spindle-tuber symptoms were very evident in the tuber-grafts during the current season of 1923. This was evident

TABLE 26.—*Transmission of spindle-tubers by tuber-grafts in 1923. Summary of performance of progeny tubers of spindle-tubers, grafts, and normal tubers in 1924.*

Factor considered		Treatment in 1923		
		Normal check	Grafts	Spindle-tuber checks
(1)		(2)	(3)	(4)
Mean weight per seed piece		35.1 grams	25.7 grams	26.9 grams
Number of hills planted		240	235	223
Plants emerged by June 28 (19 days)		95.0%	61.3%	51.1%
Final stand of plants		99.6%	82.6%	83.0%
Spindle-tuber coefficient		13.24%	71.86%	78.84%
Total yield per acre		387.4 bu.	116.2 bu.	100.4 bu.
Per cent in various grades (by weight)	U. S. No. 1 size good type	80.57%	0	0
	U. S. No. 1 size spindle-tubers	14.77%	69.55%	64.75%
	U. S. No. 2	3.86%	25.55%	27.76%
	Culls	0.80%	4.90%	7.50%
100 Representative tubers	Total Weight	43 lbs.	23 lbs.	20 lbs.
	Mean tuber type	6.84	3.34	2.75
	W/L ratio	82.7	68.0	70.7
	T/L ratio	68.9	62.0	63.1

in a decrease in the yield, size of tubers, and tuber type (Fig. 22). The yield of plants in 1923 from normal, graft, and spindle-tubers was 864, 534 and 516 grams respectively.

In 1924, the tubers produced by the 1923 hills were planted in adjacent rows at Scotts Bluff. The plants from the normal checks emerged in practically normal time, whereas those of the graft series were very much delayed, being

practically as slow as those from the spindle-tuber checks (Fig. 23). The final stand of plants of the normal lots was almost perfect, but that of the grafts was only 82.6 per cent and of the spindle-tubers 83.0 per cent (Table 26). The spindle-tuber coefficient of the grafts was almost as high as that of the spindle-tuber checks. (The spindle-tuber coefficient of the normal checks was 13.24 per cent, which of course shows presence of considerable spindle-tuber. This was due to the accidental use in 1923 as normal tubers of 2 tubers that contained spindle-tuber which became more pronounced in 1924 and which was apparently transmitted to some extent to a few other plants, thus showing to a considerable extent in the progeny.)

The grafted tuber-lines produced no marketable sized tubers of good type but they did produce a much greater percentage of little potatoes. The tuber type was distinctly reduced as shown by estimates and W/L ratio (Table 26). In all respects degeneracy was so nearly complete that there was but little difference between the progeny of the grafts and the spindle-tuber checks.

FIELD TRANSMISSION OF SPINDLE-TUBER

In 1923, several sets of experiments were conducted for the purpose of studying the extent to which spindle-tuber transmission took place under field conditions in western Nebraska. These were planned to show the relation of (a) proximity, (b) cultural conditions, (c) date of harvesting, and (d) date of caging to transmission of spindle-tuber.

TRANSMISSION TO ADJACENT ROWS

In 1923, normal Triumph potatoes from a lot of certified seed (Lot F) were planted with severely "run-out" lots of Triumph potatoes on either or both sides. Other lots of the same seed were planted in normal fields given dry-land and irrigation culture and from which diseased plants were rogued. Similar plantings were repeated with Downing potatoes. In 1924, the progeny from these plantings were grown comparatively at Scotts Bluff and results are reported in Table 27.

In both varieties the adjacence of "run-out" plants on both sides of the normal plants (in 1923) increased the amount of spindle-tuber as compared with adjacence on only one side, when determined by the spindle-tuber coefficient [Table 27 (2)]. The amount of spindle-tuber was many times greater than when the lots were rogued in irrigated and

TABLE 27.—*Field transmission of spindle-tuber from row to row in 1923. Progeny planted at Scotts Bluff in 1924 in three adjacent 50-hill rows.*

Treatment in 1923	Triumph					Downing				
			Per cent of total by grades					Per cent of total by grades		
	Spindle-tuber co-efficient	Total yield per cent of check	U. S. No. 1 size spindle tuber	U. S. No. 1 size good type	U. S. No. 2 and culls	Spindle-tuber co-efficient	Total yield per cent of check	U. S. No. 1 size spindle-tuber	U. S. No. 1 size good type	U. S. No. 2 and culls
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
In isolated dry land field, rogued*	5.2	92.7	2.3	95.1	2.6	2.7	100.1	1.1	92.6	7.4
In normal irrigated field, rogued	8.4	93.8	3.5	93.7	2.8	9.8	96.4	5.3	84.3	10.4
One row removed from spindle-tuber plants	.....	.....	.....	.....	.....	35.4	82.6	34.2	45.4	20.4
Adjacent on one side to spindle-tuber plants	47.8	61.8	56.1	32.4	11.5	46.6	74.2	70.3	8.5	21.2
Adjacent on both sides to spindle-tuber plants	60.9	51.3	65.8	16.7	17.5	53.8	70.5	68.8	6.8	24.4
Triumph check, dry land certified	Not read	100.0	1.3	97.0	1.7	Not read	100.0	5.9	90.8	3.3
Bushels per acre from checks	.....	177.7 *Bushels*	.....	.....	.....	.....	248.2 *Bushels*	.....	.....	.....

*Dry land Triumph lot was grown at Bushnell, dry land Downing at Alliance in 1923.

dry land fields. The same relations existed with regard to spindle-tuber in the crop harvested. When compared with the Triumph check the 1924 yield of any lot diminished as the spindle-tuber content increased. The results with the Downing variety were the same as with the Triumph. In addition it was found that less spindle-tuber occurred in the crop from the progeny of the lot grown one row removed from spindle-tubers in 1923, but the amount of spindle-tuber was still very great. Thruout the entire experiment there

TABLE 28.—*Transmission of spindle-tuber to normal plants at varying distances from spindle-tuber plants at Scotts Bluff in 1923.*

1923 treatment	Notes on progeny, July 25, 1924			
	Number of plants	Spindle-tuber coefficient	Per cent of plants apparently normal	Per cent of plants showing spindle-tuber
		Per cent	*Per cent*	*Per cent*
(1)	(2)	(3)	(4)	(5)
Original check, dry land field	364	3.58	82.4	17.6
First row, adjacent to spindle-tubers	286	70.32	1.1	98.9
Second row from spindle-tubers	296	62.37	8.6	91.4
Third row from spindle-tubers	277	53.55	18.4	81.6

was a very definite increase in the percentage of small potatoes as the spindle-tuber content increased. There seemed to have been a trifle more transmission in the normal irrigated field than in the normal dry-land field, but the yields from these stocks differed but slightly.

In 1923 at Scotts Bluff, normal tubers from a certified-seed field were planted in several rows adjacent to several rows of spindle-tubers of all grades.* In 1924, potatoes produced in the first 3 rows were planted for comparison with certified dry-land grown seed from the original field. Spindle-tuber was transmitted very thoroly in these plats in 1923. The plants raised from the tubers produced 3 rows away

* This experiment was conducted by James A. Holden, Superintendent of the Scotts Bluff Experimental Substation. The author made the spindle-tuber readings reported herewith.

TABLE 29.—*Transmission of spindle-tuber to a normal strain of seed potatoes (grown as check among varying lots of seed in 1923), as determined by progeny performance in 1924. Scotts Bluff.*

1923 lot No.	1923 History				1924 Spindle-tuber symptoms and yield					
	Tuber type of seed tubers produced in 1923		Tuber type of lots in adjacent rows in 1923		Plants showing different degrees of spindle-tuber, July 25, 1924			Tuber type		Total per acre yield
	Estimated type	W/L ratio	Lot to north	Lot to south	Mild	Medium	Severe	Estimated type	W/L ratio	
		Per cent			*Per cent*	*Per cent*	*Per cent*		*Per cent*	*Bushels*
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Lots grown in irrigated field in 1923										
K13	7.4	95.3	5	1.6	20	40	15	4.3	70.7	220.8
K15	7.3	92.7	5	1.6	.....	50	50	3.0	69.3	157.5
K17	7.2	89.9	5	4.0	10	20	50	3.9	73.4	133.2
K19	7.4	90.1	3.5	7.1	15	45	40	2.7	70.4	176.2
K21	7.9	91.0	4.0	5.0	20	40	30	4.1	74.3	210.8
K55	8.7	100.7	Commercial field not rogued		10	10	.....	7.1	87.8	253.3
K70	8.6	93.9	Commercial field rogued		10	5	.....	7.3	92.1	426.6
Lots grown in dry-land field in 1923										
EE2	6.6	89.1	1.0	6.8	40	25	20	5.8	83.3	254.2
EE6	5.7	85.7	3.4	4.5	15	5	45	6.1	81.9	298.3
EE19	6.6	88.1	1.5	8.5	5	15	35	5.9	84.5	288.2
EE22	6.8	86.1	1.5	8.5	15	15	15	5.7	80.6	332.5

from spindle-tuber plants had a ST coefficient of 53.55 per cent (Table 28). However, that of the adjacent row was 70.32 per cent. Evidently in a season such as 1923, spindle-tuber was transmitted to plants located at a considerable distance, tho the extent of the transmission decreased with the distance.

In 1923, a lot of Triumph potatoes (lot H) that contained practically no spindle-tuber was used as a check lot in the Scotts Bluff experimental plantings. These check lots were generally among spindle-tubers of varying degrees in both dry-land and irrigated plats, as well as among normal plants. In the fall, 30 representative tubers from each lot were saved and calibrated. The effect of the spindle-tuber environment was then already apparent in the tuber type [Table 29 (2)]. The tuber type of the dry-land lot was not as good as of the irrigated lots. In 1924, all these lots showed spindle-tuber symptoms. Those among the worst plants in 1923 were the most seriously affected. The tuber type of the lots among spindle-tuber in the irrigated plat was only about 50 per cent as good as in 1923. However, the stock from normal, commercial, irrigated fields was almost as good as in 1923 [K55 and K70, (9)]. These lots were far superior in type (9), shape (10), and yield (11) to the lots that had been exposed to infection.

While the dry-land lots in 1923 were adjacent to rows of plants much more severely affected, the 1924 type was reduced only slightly and was much better than was that of the tubers from the irrigated lots. The yield was also greater. Some of the adjacent spindle-tuber lots on dry land in 1923 were so very degenerate that the plants were very small and the stand was poor, thus actually reducing somewhat the chance of infection.

Spindle-tuber was very readily transmitted from diseased to healthy plants in adjacent rows and in rows some distance away. The extent of transmission decreased with the distance from the spindle-tuber stock. Transmission took place on dry land but apparently not as easily or extensively as in the irrigated plats (see also pages 54 to 67, Tables 18, 19, Figs. 11, 17, 19). Stock produced from normal unrogued irrigated fields contained only a small amount of spindle-tuber. Seed-stock grown in irrigated rogued plats was practically as good as dry land rogued stock and far superior to dry land or irrigated unrogued stock grown in the vicinity of spindle-tuber plants.

TRANSMISSION TO ALTERNATE PLANTS; CHECKED BY CAGED PLANTS

In a previous publication (Nebr. Research Bulletin 24, pp. 50-51), the authors reported an experiment that indicated that spindle-tuber (the degeneracy trouble) had been transmitted to alternate plants, but the data were not entirely conclusive because of the absence of sufficient proper checks.

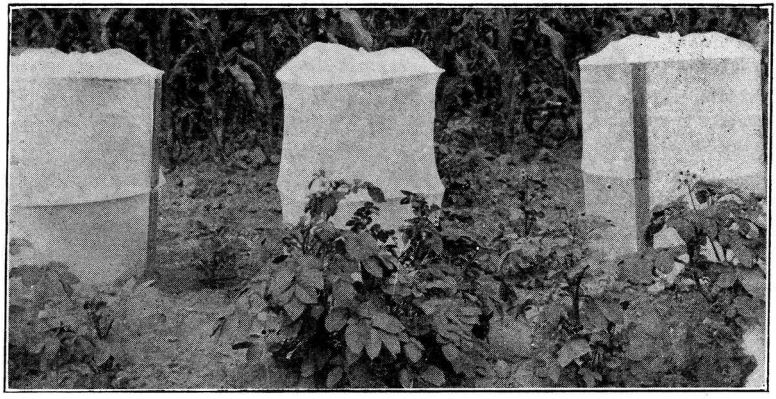


FIG. 24.— Method of alternately planting normal and spindle-tuber plants in 1923. Cheese-cloth cages covered normal plants in background. Results from this series shown in Figure 25 and Tables 30 and 31.

TABLE 30.—*Effect of alternate planting with spindle-tuber plants upon tuber type of normal plants, during the current season, Scotts Bluff, 1923. Progeny of nine seed tubers planted in four sets.*

Treatment in 1923		Number of tubers	Ratio of W/L
(1)	(2)	(3)	*Per cent* (4)
Alternated with spindle-tuber	Caged all season	49	90.41 ± 1.34
	Open all season	106	83.37 ± 0.97
Grown in normal fields	Irrigated field	66	93.48 ± 1.40
	Dry land field	81	93.25 ± 0.86

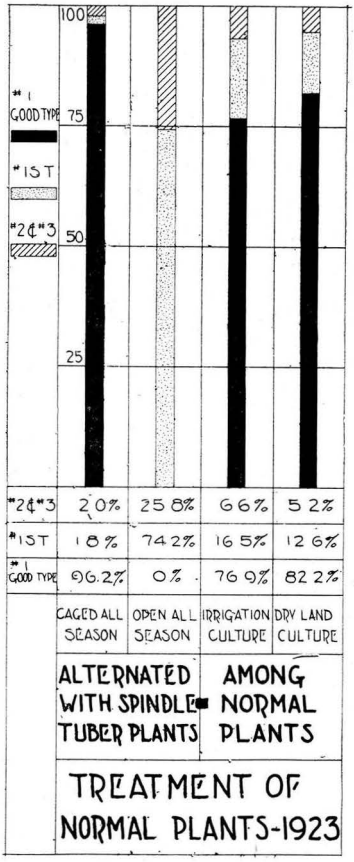


FIG. 25.—Transmission of spindle-tuber when normal plants were alternated with spindle-tubers in 1923, as shown by per cent of spindle-tubers produced from tuber planted in 1924, with checks grown under cages and in normal isolated dry land and irrigated plats. (See also Tables 30 and 31.)

In 1923, 10 normal tubers were divided into 4 pieces for planting 4 sets. In two sets the normal plants were planted alternately in the row with spindle-tubers, but in one set the normal plants were protected from infection by insect proof (fine cheesecloth) cages placed in position before the plants emerged (Fig. 24). These sets were in adjacent rows in an irrigated plat in which about 50 per cent of the plants

were affected with spindle-tuber. The other two sets were used as further checks and were planted among supposedly normal plants in dry-land and irrigated plats. During the growing season spindle-tuber was detected in the surrounding plants of the latter two plats. These plants were removed as soon as discovered. Apparently, however, they were the source of some infection as were also the supposed normal plants from two of the experimental tubers. The plants from these tubers were discarded and results from only 8 tubers were considered. These conditions resulted in more exposure to infection than was desirable in the checks. In 1924, 20 seed pieces were planted from each 1923-hill, in adjacent rows. Thus in 1924 each 1923 treatment was represented by 160 hills.

Spindle-tuber was transmitted to the alternate normal uncaged (open) plants sufficiently early in the season for the symptoms to be distinctly evident in the tubers, which had a W/L tuber ratio 7.04 per cent lower than that of the adjacent caged series (Table 30 and Fig. 25). There was little difference in the tuber type of the other series.

The completeness of the transmission in the case of the unprotected normal plants was shown (Table 31) by the high per cent of the plants infected, the retarded emergence, the increased spindle-tuber coefficient, the severely reduced total yield, the absence of any good type No. 1 size tubers, the production of an excessive quantity of small potatoes (Fig. 25), and very poor mean tuber types as shown by a low W/L ratio. The caged plants produced only normal progeny. The slight amount of spindle-tubers produced by this group (1.8 per cent) may have resulted from infection during 1924. Some infection took place in the open, dry-land, and irrigated,— supposedly normal plats, which resulted in a proportionate expression of symptoms and decrease in yield, all of which were slight, however, in comparison with the "open alternated" lot.

Some inconsistencies appear in the results with the dry-land grown lots which we are unable to explain. It is apparent, however, that culture was a very minor factor as compared with the presence or absence of plants seriously affected with spindle-tuber.

These results further emphasize the great rapidity with which spindle-tuber spreads and how, when present in quantity or allowed to become established, it can practically ruin a strain in one season.

TABLE 31.—*Transmission of spindle-tuber in 1923, accomplished by alternate plantings of normal and spindle-tuber Triumph plants. Checks provided by caging the growing plants in relatively isolated dry-land and irrigated fields. Data from crop of progeny raised in 1924.*

Treatment of plants in 1923 (from normal seed)		Spindle-tuber symptoms in plants July 25		Per cent of plants emerging by June 28 (18 days)	Total yield in pounds per 160 hill plat (8-20 hill units)	Distribution of total production by grades			Production in bushels per acre			Tuber type in 1924 from 20 hills grown from third plant (1923) of each group		
		Per cent of plants showing symptoms	Spindle-tuber coefficient			No. 1 grade good type	No. 1 grade good spindle-tuber	No. 2 and No. 3 grades	Total yield	No. 1 grade good type	No. 1 grade spindle-tuber type	No. of tubers	Type index	W/L ratio
(1)	(2)	*P.Ct.* (3)	*P.Ct.* (4)	*P.Ct.* (5)	*Lbs.* (6)	*P.Ct.* (7)	*P.Ct.* (8)	*P.Ct.* (9)	*Bushels* (10)	*Bushels* (11)	*Bushels* (12)	(13)	(14)	*P.Ct.* (15)
Alternated with spindle-tuber plants	Open all season	97.0	66.7	44.4	89.6	0	74.2	25.8	93.3	0	69.2	90	2.61	74.6
	Caged all season	0	0	71.3	383.5	96.2	1.8	2.0	399.5	384.2	7.2	108	7.87	91.2
Grown in normal fields	Irrigated field*	28.0	16.7	68.1	334.9	76.9	16.5	6.6	348.9	268.3	57.6	105	8.28	89.9
	Dry land field*	42.0	35.3	83.1	340.4	82.2	12.6	5.2	354.6	291.5	44.7	112	7.90	90.0

* In 1923 the dry land plat was located only several rows away from a plat of plants which later was found to contain a high percentage of spindle-tuber plants. Consequently the dry land stock was exposed to more infection than was the irrigated stock.

TABLE 32.—*Relation of time of caging normal plants (in spindle-tuber field) in 1923 to spindle-tuber transmission as shown by progeny in 1924. (1923 planting on June 10.) Triumph potatoes—Scotts Bluff.*

Factors noted in 1924		Treatment of plants in 1923						
		In spindle-tuber field					In normal field	
		Date of caging plants						
		Before emergence	July 10	July 30	August 20	September 10	Caged all season	Open all season
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Spindle-tuber symptoms in plants July 25	Per cent of plants showing symptoms	9.0%	96%	93%	96%	100%	4.0%	25%
	Spindle-tuber coefficient	1.0%	55.1%	50.7%	64.7%	80.6%	1.0%	8.2%
Per cent of plants emerging by June 28 (18 days)		75%	65.6%	63.8%	41.2%	31.2%	87.5%	83.7%
Total yield in pounds per 80 hills (4-20 hill plats)		174.7 lbs.	88.1 lbs.	90.7 lbs.	65.3 lbs.	42.5 lbs.	223.2 lbs.	222.8 lbs.
Per cent of total production by grades	No. 1 size good type	92.0%	30.3%	16.0%	7.6%	0	96.3%	84.6%
	No. 1 size spindle-tuber type	5.8%	56.1%	71.7%	74.6%	64.5%	2.6%	13.3%
	No. 2 and culls	2.2%	13.6%	12.3%	17.8%	35.5%	1.1%	2.1%
	Total yield	364.0 bu.	183.5 bu.	189.0 bu.	136.0 bu.	88.5 bu.	465.0 bu.	464.1 bu.
Yield in bushels per acre	No. 1 size good type	334.9 bu.	55.6 bu.	30.3 bu.	10.3 bu.	0	447.8 bu.	392.7 bu.
	No. 1 size spindle-tuber type	21.1 bu.	103.0 bu.	135.5 bu.	101.5 bu.	57.1 bu.	12.0 bu.	61.8 bu.
Tuber type in 1924 from 20 hills grown from 4th plant of each group	No. of tubers	32	87	100	90	51	76	120
	Type index	7.88	2.67	2.57	2.38	2.61	8.03	7.90
	W/L ratio	89.0	72.5	73.4	72.5	81.2	90.7	88.8

SEASON OF TRANSMISSION; DETERMINED BY SUCCESSIVE CAGING

In the course of making careful observations of experimental plats and for seed potato certification, it has been the experience of the author that in western Nebraska spindle-tuber symptoms cannot be distinguished in the plants nearly as well early in the season as during August and September. Also that the symptoms are more distinct in the warmer seasons. This condition has a very serious

FIG. 26

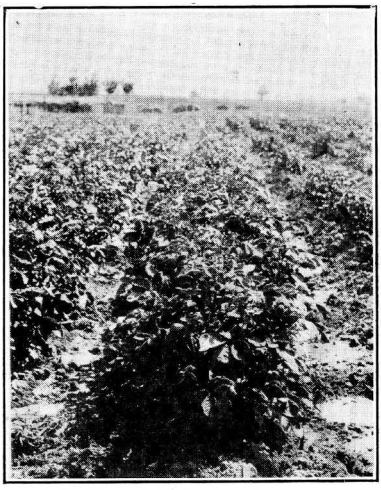


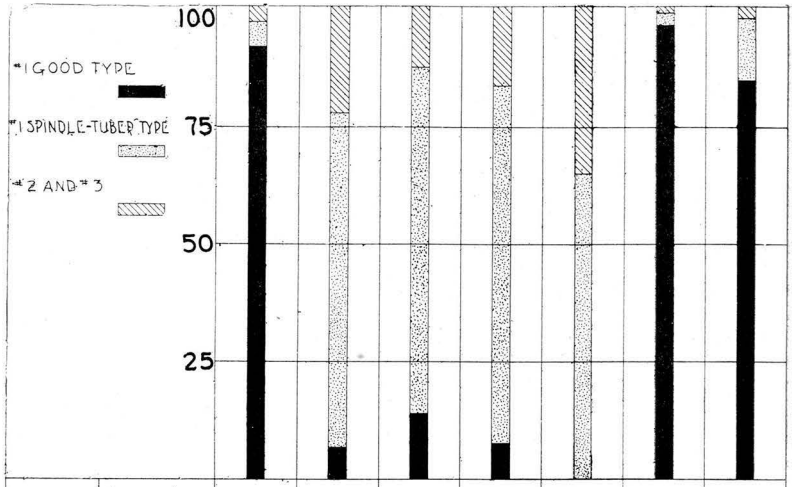
FIG. 27

Vine grown in July, 1924, from seed tubers produced in 1923 from plants grown in a field with 50 per cent spindle-tuber plants. Plants raised in 1923 were from the same seed tuber. At left — Figure 26 — Parent plant of 1923 was caged on July 30. This insect-proof cage was left over the plant the entire season. The 1923 parent plant of those at the right (Figure 27) was caged all season. Infection took place during the first ten days the plants were above ground in 1923.

practical bearing. It is important to know just how early infection takes place and therefore how early roguing must be done in order to be effective. In 1923, a series of caging experiments was conducted to determine the facts in this matter.

In 1923, 5 supposedly normal tubers were each divided into 7 pieces for planting that many plats, in which the plants were to be caged at different dates (see Table 32). All except two plats were planted in one of the irrigated fields

containing over 50 per cent of serious spindle-tuber plants. In this experiment, all normal plants were adjacent in the row but spindle-tubers were in adjacent rows. As in the alternate planting experiment (Table 31), early in the growing season it was discovered that one tuber had had mild spindle-tuber. The plants from this tuber were all removed on July 28. (The difficulty of detecting with certainty the very mild symptoms of spindle-tuber in the tubers and also in plants made it very difficult to find suitable tubers for checks which would also be free from mosaic.)



PER CENT IN EACH GRADE								
	"2 AND "3	22	222	124	178	355	11	21
	"1 SPINDLE-TUBER TYPE	58	710	737	746	645	26	133
	"1 GOOD TYPE	920	68	139	76	0	963	846
TREATMENT IN 1923		BEFORE EMERGENCE	JULY 10	JULY 30	AUG 20	OPEN ALL SEASON	CAGED ALL SEASON	OPEN ALL SEASON
		DATE OF CAGING PLANTS						
		NORMAL PLANTS AMONG SPINDLE-TUBER PLANTS					NORMAL PLANTS AMONG NORMAL PLANTS	

FIG. 28.— Spindle-tuber transmission took place early in the season in 1923 as shown by 1924 comparative tests of progeny of lots caged at various dates. Caging all season or isolation among normal plants was effective in avoiding spindle-tuber infection. As spindle-tuber increased per cent of small tubers also increased. For character of plant see Figures 26 and 27, also see Table 31. (Triumph variety in Scotts Bluff.)

Infection took place very early during the 1923 season. This was evident in the reduced type and W/L ratio in 1923 of all lots exposed to infection in comparison with the caged or isolated lots. Plants caged on July 10, that had emerged between June 28 and July 1 and were thus exposed to infection only 12 days or less when plants were very small, had received sufficient infection to cause serious degeneration in 1924 [Table 32 (4), Figs. 26, 27, and 28]. Plants caged at 20-day later intervals received a greater amount of infection as shown in 1924 (Table 32) by the delayed emergence, the per cent of plants infected, the increased ST coefficient, the reduced yield, the increased percentage of spindle-tuber potatoes harvested, and the increase in the percentage of small potatoes. Lots caged all season in 1923, produced very high yields and contained but a very small amount of spindle-tuber in 1924. Probably this small amount of spindle-tuber was acquired during the 1924 season. The plants growing unprotected in the normal field were exposed to some spindle-tuber infection (as previously explained, page 88). The similarity of the performance of this lot [Table 32 (9)] and the similar lots in the other series [Table 31 and Table 33 (8)] is quite significant.

These data indicate very definitely that, since infection may take place very early in the season, spindle-tuber plants should be rogued out as early as possible. Deferring roguing for a few weeks may result in such general infection as to ruin the strain for seed purposes. Such was the history of lots BE and CB reported in Fig. 11. Furthermore, if a strain contains a very high percentage of spindle-tuber it is doubtful if it is practical or possible to reclaim it as a good seed strain. The masking of spindle-tuber symptoms in cool weather makes early identification difficult. Therefore, the best plan is to keep it out of the seed plat as much as possible.

SEASON OF TRANSMISSION; DETERMINED BY VARIOUS HARVESTING DATES

An experiment, complementary to the date-of-caging experiment, in which potatoes exposed to spindle-tuber infection were harvested at different dates, was conducted in 1923. Schultz and Folsom (1923 b) reported a greater amount of disease present in lots harvested progressively later in the season and that this was correlated with a greater number of aphids. They also reported the incubation period (p. 61) for spindle-tuber as being " usually over 25 days." Knowing

TABLE 33.—*Relation of date of harvesting normal Triumph plants (1923) to the extent of transmission of spindle-tuber, as shown by the progeny in 1924. (Normal plants were alternated with spindle-tubers in 1923.)*

Factors noted in 1924		Treatment given parent plants in 1923					
		Normal plants alternated with spindle-tuber plants. Date when harvested					Check grown in normal field. Harvested October 10
		August 20	August 30	September 10	September 30	October 10	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Spindle-tuber symptoms in plants July 25	Plants showing symptoms	65%	72%	89%	96%	99%	32%
	Mean degree of severity	22.9	36.3	48.1	66.7	63.8	12.0
Per cent of plants emerging by June 28 (17 days)		59.9%	51.4%	49.4%	50.6%	61.2%	81.2%
Total yield in pounds per 160 hills (8-20 hill plats)		297.0 lbs.	231.1 lbs.	190.3 lbs.	137.8 lbs.	157.0 lbs.	364.4 lbs.
Per cent of total production by grades	No. 1 size good type	30.6%	25.0%	5.2%	11.2%	0	82.7%
	No. 1 size spindle-tuber	60.0%	61.7%	81.3%	68.2%	79.9%	13.2%
	No. 2 size and culls	9.4%	13.3%	13.5%	20.6%	20.1%	4.1%
Yield in bushels per acre	Total	309.4 bu.	240.7 bu.	198.2 bu.	143.5 bu.	163.5 bu.	379.6 bu.
	No. 1 size good type	94.7 bu.	60.2 bu.	10.3 bu.	16.1 bu.	0 bu.	314.0 bu.
	No. 1 size spindle-tuber	185.6 bu.	148.5 bu.	161.1 bu.	97.9 bu.	130.6 bu.	50.1 bu.
Tuber type in 1924 from 20 hills	No. of tubers	115	92	110	No. 5 hills destroyed in 1923 accidentally	61	115
	Type index	5.62	2.98	2.93		2.62	9.43
	W/L ratio	78.2%	73.6%	71.8%		74.0%	90.9%

that relatively few aphids were present in western Nebraska, it was deemed advisable to determine the merits of early harvesting.

Ten tubers were divided and planted in 6 plats. In each case spindle-tuber seed pieces were planted alternately with

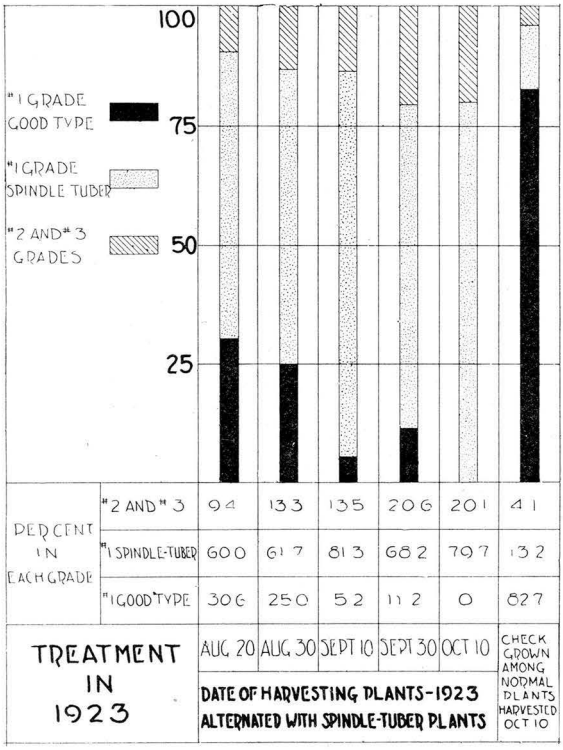


FIG. 29.— Progeny from tubers harvested early in 1923 from normal plants in a spindle-tuber field produced a slightly higher percentage of good type tubers and lower percentage of spindle-tubers than did progeny from late harvested lots. This was a very ineffective method for controlling spindle-tuber in comparison with protection among normal plants in an isolated plat. (See Table 33.)

the normal stock as in the experiments reported in Table 31. The first lot was harvested on August 20, which was the earliest possible date because of the small size of the tubers prior to that date. The tubers were held in cold storage from about 5 days after harvesting till about two weeks

before planting in the spring of 1924. Progeny of the last 2 of the hills of 2 plats were accidentally lost in the course of the experiment, so results are presented here for but the first 8 tuber-lines.

Least infection occurred in the check lot grown in the normal field, which lot also produced the greatest yield in 1924 [Table 33 (8) and Fig. 29]. Among the lots exposed to infection, the one harvested very early (August 20, 1923) contained the least infection and produced the highest yield [Table 33 (3) and Fig. 29]. With progressively later harvesting, the percentage of infected plants increased, the spindle-tuber coefficient increased, the yield decreased as did the percentage of good type No. 1 size tubers, but the percentage of spindle-tubers and small tubers increased. There was a corresponding decrease in the tuber-type on the basis of tuber type index and W/L ratio. Evidently, more infection took place as the season advanced and infection did not reach all the early harvested tubers before they were dug in 1923. The spindle-tuber content of the lots harvested September 30 and October 10 [Table 33 (6) and (7)] was very similar to that of the lot adjacent all season to spindle-tuber plants reported upon in Table 31. The chance for infection was very great in this plat, as 50 per cent of the plants were infected and normal plants were exposed on all sides. In a field containing 5 per cent or so of spindle-tuber, early harvesting might be more efficacious.

It is of passing interest here to note that with the alternately planted spindle-tubers harvested on the same dates, the disease also increased in severity as the season advanced. In 1924, the total yield from the August 20 lot (1923) was 125 bushels per acre, while that of the September 30 lot was 86.8 bushels and of the October 10 lot 50.5 bushels. Apparently the severity increased or more of the disease was acquired from other plants.

A comparison of the data in Tables 32 and 33 shows that less spindle-tuber was transmitted to the tubers produced in 1923 when the lots were harvested August 30 than when the plants were caged on July 10. Thruout these two experiments early harvesting apparently was more effective in reducing infection than early or medium early caging.

The data presented in Table 25, dealing with Early Ohio potatoes grown at Lincoln in 1923 and harvested at different dates, also show a definite decrease in tuber type and yield

(of the crop from the progeny) with progressively later harvested lots, when grown both with and without a straw mulch.

Thus for the seed grower, early harvesting could be expected to give better returns than late roguing. Furthermore, since it is also evident in Table 33 that infection of tubers continues to increase after September 10, it will evidently be a desirable practice, of some merit in controlling spindle-tuber, for the grower to harvest the seed plat ahead of the main crop. This has an additional advantage in that late-harvested stock (October 15 and later) is frequently field-frosted.

DISCUSSION OF FIELD TRANSMISSION

These various experiments show that without doubt spindle-tuber can be transmitted artificially from tuber to tuber and that under field conditions prevailing in all parts of Nebraska it is transmitted from plant to plant. It appears that cultural and climatic conditions provide environments which are of considerable importance in favoring or retarding spindle-tuber development or transmission. Thus transmission seems to occur more readily in eastern than in central and western Nebraska. When spindle-tuber is present, degeneracy seems to occur more rapidly in irrigation than in dry-land fields in the west, and in eastern Nebraska more rapidly in cultivated than in a straw mulched stock.

Transmission occurs early in the season and continues as long as the plants are growing. Hence early and continuous roguing are imperative if spindle-tuber is present. Delayed harvesting will tend to result in an increased tuber infection.

That spindle-tuber is transmitted in western Nebraska is very conclusively shown by all these data. The specific manner in which it is transmitted, i.e., the transmitting agent, is still very doubtful. It has been repeatedly shown by other American workers that aphids are very active agents in transmitting all virus diseases. Some of these workers have reported definitely as being unable to secure transmission by other insects common on potato plants such as flea beetles and Colorado potato beetles (Schultz and Folsom 1923 b). Working in Ireland, Murphy (Murphy 1923) reports having secured transmission of leaf roll by means of capsid bugs (*Calocoris bipunctatus*), jassids (*Typhlocyba ulmi*), flea beetles (*Psylliodes affinis*), and froghoppers (*Philaneus spumarius*). He also reported transmission among sprouted potatoes by peach aphids (*Myzus Persica*). This opens up

a new field of investigation not touched upon in this bulletin. Flea beetles are present in all potato regions in Nebraska and are especially abundant in some localities. In the early summer of 1923, the potato cellars of western Nebraska contained myriads of minute insects which were working on the tubers. The identity of these was not established; but considering their numbers and the great increase in spindle-tuber in some commercial lots noticed early in 1923, it is possible that these insects acted as a carrying agent.

The 1923 season was abnormal, in that the temperature was lower and the humidity higher than the average for the region. Thus the 1923 climate was relatively more favorable than most seasons for aphid activity. However, very few aphids were present in western Nebraska fields, only a few, 2 to 5, being found on several plants in a hundred. Consequently it is believed either that the few aphids present were extremely active and the disease very infectious or that it is transmitted by some other insects or other means not yet understood.*

INFLUENCE OF ENVIRONMENTAL CONDITIONS UPON SEVERITY OF SYMPTOMS

Environmental factors, such as temperature, soil, and moisture, have a very decided effect upon the type of vine growth and the tuber type, but such variations are only temporary. If the strain is normal and diseases are not present, these variations are not reproduced the following year if the strain is then grown under more favorable conditions. If a virus disease is present, environment will frequently exert some influence in increasing the severity and spread of the disease (perhaps by providing more optimum conditions for the disease or by providing better conditions for a transmitting agent). Data are presented to show the effect of temperature, soil type, and soil moisture as individual factors or in combination. These conditions are provided by growing potatoes in widely separated places and also by different planting dates.

RELATION OF SOIL TEMPERATURE TO TUBER TYPE

It is generally understood that tubers formed at high temperatures are more elongated than those produced at lower temperatures. Definite results to this effect were re-

* See note on knife transmission (as determined by Goss) pages 127-128.

ported by Jones *et al.* (1922). On the basis of field observations, the author suspected a similar effect with spindle-tubers, so in 1923 an experiment was conducted in which spindle-tubers were produced at controlled temperatures.

GREENHOUSE EXPERIMENTS, 1923-1924

From October, 1923, to February, 1924, normal and spindle-tuber plants were grown in the greenhouse at various soil temperatures. The plants were grown in water-tight cans 9 inches in diameter and 24 inches deep. These cans were sunk into tanks of water to the same depth as was the soil inside the cans. There were 6 cans in each tank. The temperature of the water was regulated by means of steam

TABLE 34.—*Relation of soil temperature to tuber type. Normal and spindle-tuber Triumph potatoes produced in greenhouse, Lincoln, October, 1923—February, 1924. (Optimum soil moisture maintained, 6 plants in each set.)*

Normal tubers			Spindle-tubers		
Mean soil temperature	Number of tubers	W/L ratio mean	Mean soil temperature	Number of tubers	W/L ratio mean
°F.		*Per cent*	°F.		*Per cent*
(1)	(2)	(3)	(4)	(5)	(6)
56.2°	15	127.7	55.7°	9	113.3
69.4°	9	103.7	69.8°	8	89.6
71.5°	15	97.0	.....	.....	.....
85.0°*	.....	.....	85.0°	.....	.....

*This temperature caused the death of the plants before tuberization.

and cold water supplies. The temperature seldom varied over 5° F. in the course of 24 hours. The tanks were insulated with mineral wool (between the double walls). The soil surface was insulated by a mineral wool covering of 2 inches. A circular sheet of galvanized iron with a one and one-half inch hole in the center was placed between the soil and mineral wool to insure the development of the tubers in the desired temperature region below the insulation rather than in it, as otherwise frequently results. Water was supplied thru a pipe opening into a reservoir at the bottom of each can, made by inverting a 4-inch clay pot and surrounding it with 2 inches of gravel. Water was kept at a depth of 2 inches in this reservoir. All cans were filled with the

same amount of soil, composed of composted sod (2 parts by weight), manure (1 part), and sand (1 part). Temperatures were checked by reading the water temperature three times daily and further, in 2 tanks, by a soil thermograph located in the center of one of the cans.

Cans in four tanks were planted with normal tubers and in three with spindle-tubers. Temperatures maintained and results secured are reported in Table 34. These temperatures were maintained after the plants emerged. Before that time the temperature was the same in all lots, so as to secure

TABLE 35.—*Relation of soil texture and moisture to shape of tubers, with both normal and spindle-tuber stocks. Triumph variety grown in greenhouse at Lincoln, October, 1923 to February, 1924.*

Soil moisture content	Per cent of sand in soil—by moist weight	Normal tubers		Spindle tuber	
		No. of tubers	W/L ratio mean	No. of tubers	W/L ratio mean
(1)	(2)	(3)	*Per cent* (4)	(5)	*Per cent* (6)
High	80% sand	24	102.4	6	90.5
	40% sand	15	93.3	3	86.6
Low	No sand	18	82.1	6	83.2
	40% sand	28	109.5	4	94.5

uniform emergence. The air temperature was kept under 70° F. and averaged close to 65° F.

As the temperature increased, the tubers, both normal and spindle-tubers, became more elongated. The spindle-tubers produced at 55.7 ° were of better type than were the normal tubers produced at 69.4 °. Thus, in regions or seasons with high temperatures during tuber production period the normal tubers will be more elongated than when temperatures are lower. This same relation would hold with spindle-tubers. Spindle-tuber symptoms at low temperature could be distinctly distinguished in only the eyes of many of the tubers. Potatoes grown in different regions with different temperatures will not exhibit spindle-tuber symptoms of the same

TABLE 36.—*Relation of soil texture to tuber type of normal and spindle-tuber Triumph potatoes at Scotts Bluff in 1924. (All tubers measured weighed more than 15 grams.)*

Tuber and can number	W/L parent tubers	Character of soil					
		Heavy		Intermediate		Light	
		No. of tubers	W/L of progeny	No. of tubers	W/L of progeny	No. of tubers	W/L of progeny
(1)	*Per cent* (2)	(3)	*Per cent* (4)	(5)	*Per cent* (6)	(7)	*Per cent* (8)
			Spindle-tubers				
1	70	3	65.7	9	87.2	5	74.9
2	69.5	3	55.8	4	58.8	8	89.0
3	73.3	3	59.2	3	67.4	6	80.4
4	70.7	4	54.3	5	79.8	9	86.5
5*	77.9	6	70.4	4	75.6	.....	.....
6	57.5	7	77.9	9	80.5	4	97.9
7*	66.6	3	77.6	3	65.9	.....	.....
8	75.7	3	62.1	2	72.8	1	95.8
Mean* W/L	69.5	.....	62.9	.....	75.8	.....	84.8
Total number of tubers	.....	23	.....	32	.....	33	.....
			Normal tubers				
1	92.9	4	85.3	3	95.8	11	64.5
2	83.3	4	81.3	7	95.5	7	100.3
3	97.2	7	69.7	5	85.4	4	74.3
4	86.6	9	78.5	8	88.6	6	66.2
5	83.4	9	74.9	9	84.3	9	91.7
6	92.8	6	77.3	6	87.5	9	83.8
7	120.0	7	83.5	11	89.2	9	100.0
8	98.5	4	60.3	13	75.6	8	95.8
Mean W/L	94.3	.....	76.0	.....	86.5	.....	83.9
Total number of tubers	.....	50	.....	62	.....	63	.....

*Mean of spindle-tubers based on 6 hills because 5 and 7 in sand series were destroyed by insects.

degree. This is illustrated and discussed more fully on pages 105–109. (Further data on effect of temperature on normal tubers in Tables 37 and 41.)

RELATION OF SOIL TEXTURE TO TUBER TYPE

It is generally understood that a light, fairly loose soil is necessary for the development of tuber type approaching

the ideal and that elongated tubers are produced in heavy or compact soils. Much tuber elongation undoubtedly due to spindle-tuber has frequently been attributed to the heavy or compact nature of the soils.

SOIL EXPERIMENTS IN GREENHOUSE, 1923-1924

During the winter of 1923-1924, normal and spindle-tubers were planted in built-up soils of varying composition. Screened river sand was mixed with composted sod (grown on silt soil). The proportions are given in Table 35. Moisture was maintained at the maximum amount for plant growth by means of a reservoir in 3 inches of gravel, in the bottom of each can, which was supplied with moisture thru a tube from an earth jar in which water was maintained at a constant level. Cans 2 feet deep and 1 foot in diameter were used as soil containers.

With both normal and spindle-tubers the tuber type decreased as the percentage of sand decreased. The difference was more with normal than with spindle-tubers. Spindle-tubers grown in a very sandy soil (80 per cent) were of better type than normal tubers grown in a soil containing no sand.

SOIL EXPERIMENTS AT SCOTTS BLUFF IN 1924

In the summer of 1924, normal tubers and spindle-tubers (Triumph variety) were grown in three types of soil. One seed piece was planted from each seed tuber in one of the 8 cans in each soil series. The heavy soil was a silt that had accumulated in a low place; the intermediate soil type was the ordinary soil type found on the Scotts Bluff Experimental Farm, which is described by the soil survey as Tripp very fine sandy loam (Skinner 1913); and the light soil was drift sand secured along the roadside. The cans used were 2 feet deep, 16 inches in diameter at the top and 14 inches at the bottom. The soil was packed as the cans were filled. Water was supplied on the surface and thru a pipe that extended into an inverted clay pot in the bottom of the can. The spindle-tuber and normal lots were isolated so that the normal plants would not become infected. The parent spindle-tubers were only of the slight and medium type, and no severe spindle-tubers were used.

The data presented in Table 36 show that the spindle-tuber progeny had the best shape in the lightest soil [Table 36 (8)] and that the shape was more elongated in the heavier soils. The same general tendency prevailed with the normal seed-stock. The light soil was so infertile and had such a

very low water holding capacity that it was difficult to maintain good, uniform plant growth. This is undoubtedly the cause of the inconsistencies shown with the normal seed stock (8).

With soils of varying texture, shape alone is not a safe index of spindle-tuber. However, in all these experiments the characteristic shallow eyes developed in all spindle-tuber lots.

RELATION OF SOIL MOISTURE TO TUBER TYPE

The soil moisture is directly and indirectly a factor in tuber development. Some of the direct relations to tuber type are that (a) when deficient the soil becomes more compact, thereby impeding normal tuber enlargement; (b) when variable in amount the tuber growth may be checked and later renewed, resulting in elongation, cracks, knobs, etc. Some indirect relations of soil moisture to tuber development are: (a) an increase in the amount of soil moisture results in a decrease in soil temperature (shown to be favorable to better type) and reduces the fluctuations of the soil temperature; (b) the amount of soil moisture very largely governs the rate of growth of the plant. Experimental data on the relation of soil moisture to tuber type will be gleaned from several experiments for this discussion.

SOIL MOISTURE EXPERIMENTS IN GREENHOUSE, 1923-1924

In the greenhouse experiments (1923-24), a decrease in the amount of moisture maintained in a soil containing 40 per cent sand resulted in a marked improvement in the tuber type (shape) of both normal and spindle-tuber (Triumph) potatoes (Table 35). The tuber type in the dry soil was better than in any of the moist soils of the soil texture series. In the case of the dry soil, only enough water was supplied to the plant to prevent serious wilting.

SOIL MOISTURE EFFECT ON NORMAL AND SPINDLE-TUBERS IN CANS AT SCOTTS BLUFF, 1923

In 1923, normal and spindle-tuber Triumph potatoes were grown in cans, with different amounts of soil moisture. The soil used was uniform thruout. The cans used were 2 feet deep, with a diameter of 16 inches at the top and 14 inches at the bottom. A 4-inch layer of gravel was placed in the bottom of all cans. In the cans that were to be kept at the high soil moisture rate, pipes were placed so that they opened into an inverted clay pot in the center of the bottom

of the can. In these cans, a 3-inch water table was maintained at all times, thereby maintaining enough soil moisture for optimum growth. In the case of the cans that were to receive only a small amount of moisture, the pipes opened into inverted clay pots in the center of the soil mass. This was for the purpose of insuring better distribution of the small amount of moisture supplied. With these low moisture lots, enough water was supplied to keep the plants growing

TABLE 37.—*Effect of relative amount of soil moisture on tuber type Triumph potatoes grown in cans at Scotts Bluff in 1923.*

Character of field in which plants were grown	Relative soil moisture content			
	High		Low	
	No. of tubers	Mean W/L ratio	No. of tubers	Mean W/L ratio
(1)	(2)	*Per cent* (3)	(4)	*Per cent* (5)
Tubers from normal plants				
Normal field	4	91.3	7	101.6
Spindle-tuber field	9	92.0	10	104.8
Mean of tubers from normal plants in both fields	13	91.8	17	103.5
Tubers from spindle-tuber plants				
Spindle-tuber fields	11	57.6	9	89.2

and to prevent serious midday wilting. All cans were covered with a lid, sloping in all directions from the center, and with a hole in the center for the plant and the watering pipe. All cans were sunk in the soil to within one inch of the top of the cans. Some of the plants were surrounded by normal plants and others by spindle-tuber plants. Data on the crop produced are reported in Table 37.

The normal tubers produced in the low-moisture cans were of the best type [Table 37 (5) compared with (3)]. Likewise, low-moisture spindle-tubers (5) were much less elongated than spindle-tubers from high-moisture cans (3). Spindle-tubers produced with the low amount soil moisture with a mean W/L ratio of 89.2 per cent had a shape almost

as good as that of the normal tubers from the high-moisture cans with a W/L ratio of 91.8 per cent. Soil temperature readings were not made; but since the cans were all surrounded by the same soil and were all covered with lids, the temperature of the soils in the cans with different amounts of moisture probably did not vary as much as in open fields. Evidently relatively high amounts of soil moisture cause elongation of both normal and spindle-tubers, whereas low amounts of soil moisture result in less elongated or better type tubers. The best shaped tubers were produced with an amount of moisture barely sufficient to support growth. This is the case when the temperature is the same with all degrees of moisture. Generally, however, the soil temperature will increase as the soil moisture decreases, so that on any given soil some of the disadvantages of high-moisture may be partly overcome by the lower temperature in so far as the tuber type is concerned.

RELATION OF TIME OF PLANTING TO TUBER TYPE

The time of planting is another important factor influencing tuber type, because it largely determines the period during which tuber formation and development takes place.

OBSERVATIONS OF FIELDS CONTAINING SPINDLE-TUBER, 1924

During the 1924 season, several similar instances were observed. In Dawes County the same lot of seed was used to plant 2 commercial fields during early June on a heavy soil and 2 were planted in late June on a lighter soil. The bin inspection in October * revealed 3.0 per cent mild and 3.5 per cent severe spindle-tubers in the potatoes from one of the early-planted fields and 4.0 per cent severe spindle-tuber from the other early field, whereas potatoes from the field planted in late June showed a total of only 1 per cent spindle-tuber. The difference in spindle-tuber content shown here is probably the result of difference in manifestation of symptoms as influenced by the soil and temperature conditions.

In the case of another grower, who planted three parts of one field with the same strain but at different dates during the month of June, the bin inspection revealed 4.0 per cent of distinct spindle-tuber in the potatoes from the earliest planting, 2.5 per cent in those from the second and 0.9 per cent in those from the third planting.

* Data used here concerning the 1926 inspections were supplied by William Morrow, Jr., Certification Manager of the Nebraska Certified Potato Growers, Co-operative.

TABLE 38.—*Effect of environment in western Nebraska and northern Maine upon spindle-tuber symptoms in 1923 and 1924. Triumph variety.*

Tuber lot numbers	Mean W/L ratios of tubers produced							Mean estimated tuber type of tubers						
	1923 crop raised from western Nebraska grown seed			1924 crop raised in western Nebraska			1924 crop grown in Maine from seed grown in West. Nebr. in 1923	1923 crop raised from western Nebraska grown seed			1924 crop grown in western Nebraska			1924 crop grown in Maine from seed grown in West. Nebr. in 1923
				From seed grown in		Maine grown seed greater than Nebr.					From seed grown in		Maine grown seed greater than Nebr.	
	West. Nebr.	North. Maine	Maine greater than Nebr.	West. Nebr.	North. Maine			West. Nebr.	North. Maine	Maine greater than Nebr.	West. Nebr.	North. Maine		
	P.Ct.	*P.Ct.*	*P.Ct.*	*P.Ct.*	*P.Ct.*	*P.Ct.*	*P.Ct.*							
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
4	78	98	20	75	80	5.	.....	4.0	8.8	4.8	3.8	3.9	0.1	....
5	81	90	9	78	74	—4.	94.8	3.1	8.2	5.1	3.9	3.6	—0.3	7.7
6	75	111	36	77	81	4.	92.0	2.8	9.0	6.2	3.6	3.7	0.1	7.3
7	77	107	30	77	76	—1.	.....	4.7	9.0	4.3	3.1	3.2	0.1	....
8	77	107	30	84	78	—6.	.....	4.0	8.9	4.9	3.4	3.5	0.1	....
9	88	106	18	77	85	8.	.....	3.3	9.0	5.7	3.3	3.5	0.2	....
10	80	94	14	81	77	—4.	90.6	4.5	8.4	3.9	3.7	3.4	—0.3	7.6
11	83	98	15	75	73	—2.	86.6	4.4	8.0	4.4	3.4	3.6	0.2	7.7
Lots 4 to 11 Mean.....	79.9	101.4	21.5	78.0	78.0	0	.....	3.85	8.66	4.81	3.52	3.54	0.02	....
Lots 4 to 11 Total number of tubers calibrated	48	45	.....	160	153	.....	.....	48	45	160	160	153	.....	....
Lots 5, 6, 10 and 11 Mean.....	79.8	98.3	18.5	77.2	76.0	1.2	91.0	3.7	8.4	4.7	3.65	3.57	0.08	7.6
Lots 5, 6, 10 and 11 Total number of tubers calibrated	30	22	.....	80	76	.....	35	30	22	.....	80	76	.....	35

Thus, time of planting has a very definite bearing upon commercial seed production, in that the tuber type of normal tubers is altered and certain diagnosis of the presence or extent of spindle-tuber is made more difficult. It is also quite possible that when spindle-tuber is present more transmission occurs in the early plantings as shown in experiments reported.

SPINDLE-TUBER SYMPTOMS UNDER WESTERN NEBRASKA AND NORTHERN MAINE CONDITIONS

In 1923, 15 Triumph spindle-tubers, that had been produced in western Nebraska in 1922, were split lengthwise into equal halves. One-half of each tuber was planted at Presque Isle, Maine, by Dr. Donald Folsom. The other half was grown in an irrigated field at Scotts Bluff in western Nebraska. The tubers produced from each tuber half were harvested separately at both places. Tuber measurements were secured from 8 tubers grown at each place.

In 1923, the Maine-grown spindle-tubers were of much better shape and type than were those grown in Nebraska, [Table 38 (2-4) and (9-11)]. The Maine tubers were blocky and flat, with normal red color but somewhat shallow eyes, whereas the Nebraska tubers were elongated, cylindrical with a pointed seed end, numerous shallow eyes and the typically pink spindle-tuber color. The Maine-grown spindle-tuber potatoes were of better shape than many western Nebraska-grown normal potatoes, and if mixed in with a western Nebraska-grown lot of normal potatoes many of them would hardly have been suspected of harboring spindle-tuber. There was no doubt about the presence of spindle-tuber in the Nebraska-grown progeny.

The reason for the great difference in shape is undoubtedly very largely the result of temperature conditions. The mean monthly temperatures for July to September during 1923 at the two points were as follows:

Presque Isle, Maine: July 62.4 ° F.; August 58.8 ° F.; September 54.4 ° F.

Scotts Bluff, Nebr.: July 74.7 ° F.; August 69.5 ° F.; September 62.1 ° F.

The mean temperature for the three months during which tuber development took place was 58.5 ° F. at Presque Isle, Maine, and 68.7 ° F. at Scotts Bluff, Nebraska. The soil used

in Maine was Caribou loam; that used in Nebraska was Tripp very fine sandy loam.

The conditions in Maine and Nebraska affected only the expression of the spindle-tuber symptoms as seen in the tubers. The conditions in Maine did not decrease the amount or severity of the spindle-tuber disease. In 1924, 8 hills from each 1923 hill from both Nebraska- and

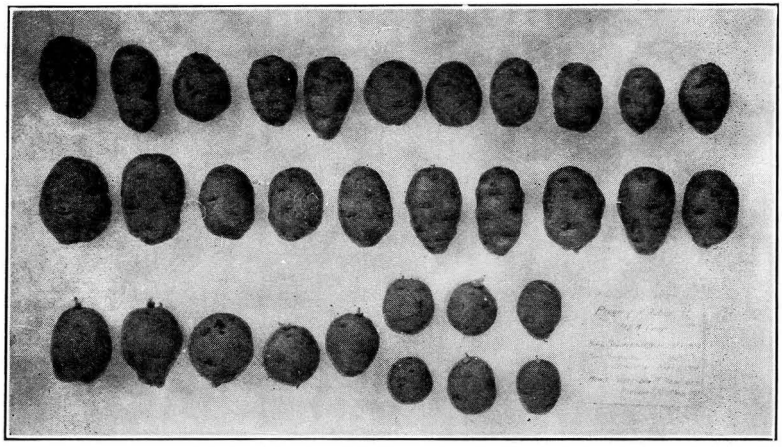


FIG. 30.— Effect of environment on spindle-tuber type. Triumph potatoes, 1924 progeny of one spindle-tuber (No. 11) grown from seed produced in Nebraska (upper row) and Maine (middle row) in 1923 and in same field in Scotts Bluff, Nebraska, in 1924; also progeny of 1923 Nebraska stock grown at Presque Isle, Maine, in 1924 (lower row). Tubers in upper and lower rows were raised from seed tubers that were produced in the same hill in western Nebraska in 1923. (For data see Table 38.)

Maine-grown stock were planted at Scotts Bluff. In the fall of 1924, calibrations of 20 tubers from each 8-hill group showed that spindle-tuber was present to an equal extent in both Maine- and Nebraska-grown stock [Table 38 (5-7)], for the mean W/L ratio of both was exactly the same, 78.0 per cent, which was less than the 1923 Nebraska ratio of 79.9 per cent. The estimated tuber type of both lots was also practically the same [Table 38 (12-14)]. These lots had acquired a slight infection of mild mosaic in Maine in 1923 but they did not lose any of the spindle-tuber disease even tho the tuber type was temporarily improved.

The vine vigor of both lots was about the same in 1924 and the yield apparently should have been very similar. Yield data are not reported because the yield of one of the groups suffered severely, due to competition with a vigorously-growing check lot.

In 1924, potatoes were again grown in Maine from 4 of the tuber lines that were raised in western Nebraska in 1923. The tuber type of these tubers grown in Maine [Table 38 (8) (15)] in 1924 was not as good as the tuber type of the same

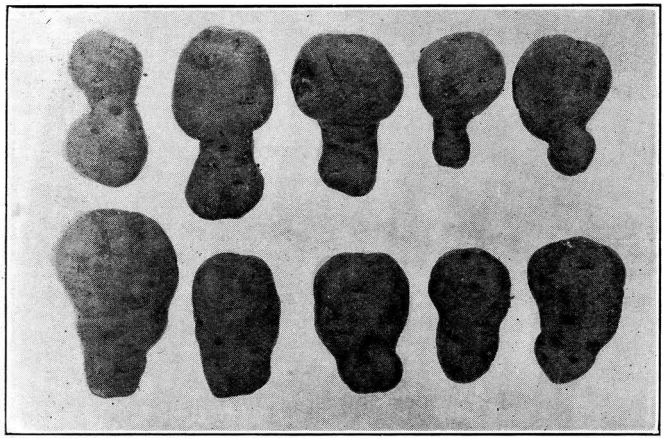


FIG. 31.—Tubers of irregular shape, due to soil moisture conditions causing variable rates of growth. These tubers produced a crop practically the same as that produced by normal shaped tubers. Tubers of this type should not be confused as spindle-tubers.

lines produced in Maine in 1923, but it was distinctly superior to the tuber type of the stock grown in Nebraska in 1923. It was also superior to the 1924 Nebraska crop raised from the same units of Nebraska- and Maine-grown seed (1923) (Fig. 30). Part of the decline in the type of the 1924 Maine-grown stock was probably due to the gradual increase in the severity of the disease as shown in the lots grown in Nebraska in 1924.

When spindle-tuber is present in any lot of seed produced under conditions most favorable for ideal tuber type development (especially low-temperature), spindle-tuber symptoms in the tubers will not be manifested distinctly. Under such conditions when producing seed potatoes, it will be necessary to pay much more critical attention to removal

of spindle-tuber from the field and to be more critical of variations from the normal tuber type than where spindle-tuber symptoms develop more distinctly.

ABNORMAL TUBER TYPE CAUSED BY CLIMATIC CONDITIONS

From the previous discussion it is quite evident that environmental conditions — as temperature, soil moisture, and soil texture — exert a decided influence upon the shape of

TABLE 39.—*Seed value of poorly-shaped Triumph tubers, produced in a dry-land seed field in 1921. (Abnormal tuber type was result of drought—causing second growth.) Trials in 1922.*

Tuber type of seed tubers	Total yield per acre	Per cent of total by grades: U.S.No. 1 size good type	U.S.No. 1 size spindle-tuber type	U. S. No. 2 and culls
(1)	*Bushels* (2)	*Per cent* (3)	*Per cent* (4)	*Per cent* (5)
Scotts Bluff irrigated trials 1922				
Normal	348.3	91.8	0.7	7.5
Poor type or "bottle necks"				
Basal end pieces	336.7	93.6		6.4
Apical end pieces	359.2	90.9	1.1	8.0
Alliance dry-land trials, 1922				
Normal	104.0	72.6		27.4
Poor type or "bottle necks"				
Basal end pieces	96.6	68.0		32.0
Apical end pieces	83.7	63.9	3.9	32.2

normal and spindle-tubers. The experiments reported considered only the general shape and type and did not consider the abnormal tubers frequently encountered and referred to as knobs, second growth, " bottle neck," " dumbbell," etc. Such potatoes are very common in seasons having irregular growing conditions. In the case of the Triumph potatoes on dry land, when the temperature is high and the soil very dry, as is frequently the case during August, when the tubers are developing, growth is very slow and tubers grow slowly or not at all. When more favorable weather follows, due to lower temperature or rainfall, rapid growth

is resumed. In some varieties the tubers then develop knobs or growth cracks, but the Triumph tubers generally continue to grow from the apical end. The new growth takes the form of a large, normal-shaped tuber with the original tuber (formed earlier in the season) as a small knob at the basal end. This gives the appearance of an inverted bottle, hence the name "bottle neck." There are numerous variations of this type, some of the tubers assuming cylindrical shape.

In the fall of 1921, two bushels of such abnormally shaped tubers (similar to those illustrated in Fig. 31) were selected from a commercial field in Kimball County. Tubers showing "run-out" symptoms were not included. One bushel was planted at Scotts Bluff (irrigation) and one at Alliance (dry land) in 1922 in comparison with normal type stock from the same field. The abnormal tubers were cut crosswise and apical and basal pieces were planted in separate rows.

In the irrigated plat the abnormally shaped tubers yielded practically as much as the normal tubers (Table 39). On the dry land the abnormal lots yielded slightly less. The type of tubers harvested from all lots of seed was practically the same. In both plats the abnormal tubers produced a small percentage of spindle-tuber, while none were produced by the normal tubers. Evidently it was impossible to accurately differentiate between spindle-tubers and tubers of abnormal shape because of growing conditions. However, it is evident that poor type due to irregular growing conditions did not exert a permanent effect on the tuber type and that the seed value of such abnormally shaped stock was only slightly impaired. However, if spindle-tuber is present, the use of abnormally shaped tubers for seed is more hazardous because of the difficulty of eliminating the spindle-tubers.

SPINDLE-TUBER CONTROL EXPERIMENTS

Many of the experiments herein reported suggest means of control. A few experiments outlined for the purpose of determining the efficiency of certain measures in controlling spindle-tuber will be reported.

TUBER TYPE SELECTION EXPERIMENT IN SCOTTS BLUFF IN 1922-1923

In the fall of 1922, three grades of tubers were selected from rows of Triumph potatoes (raised from certified seed), in an irrigated field that contained many spindle-tuber units.

TABLE 40.—*Value of seed selection in strains infected with spindle-tuber. Trials at Scotts Bluff, 1923.*

Character of seed	Per cent plants emerged by			Relative vigor	Yield per acre		Relative tuber type
	June 30 (23 days)	July 3 (26 days)	July 27		U. S. No. 1 size	Total	
	Per cent	*Per cent*	*Per cent*		*Bushels*	*Bushels*	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Check—Lot H dry land, 1922	95.0	95.0	95.0	9.2	240.0	258.6	8.5
Lot F, in spindle-tuber field, 1922	47.8	87.7	99.0	5.63	93.9	116.0	5.0
Medium good type	41.8	77.2	93.8	5.41	74.1	108.3	3.7
Culls tubers	30.3	74.8	99.0	4.93	62.5	85.1	3.0
Check—Lot F dry land, 1922	93.8	96.8	99.0	9.35	.....	243.1	7.5

The grades were as follows: (a) best type tubers, (b) tubers of any intermediate type, and (c) the small and poor type tubers that remained. These were planted in the spring of 1923 at Scotts Bluff. The data secured are reported in Table 40.

Considerable spindle-tuber infection had taken place in the irrigated field in 1922. This was shown by the delayed emergence of the plants from all tubers selected from the spindle-tuber field (Table 40, Fig. 32). The poorer the type of tubers planted, the slower was the emergence. The vine

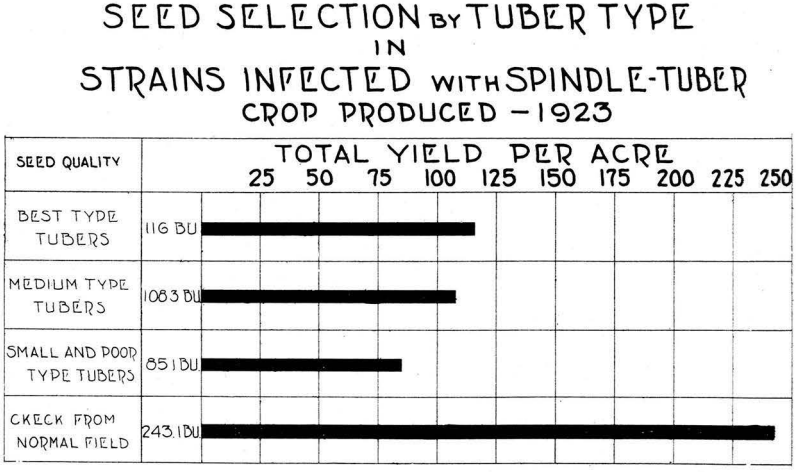


FIG. 32.— In comparison with seed from normal fields (check), selection for type in the same strain, after it becomes infected, is practically valueless in maintaining a productive strain.

vigor also declined with the relative quality of the type of the seed-tubers, as did also the yield and tuber type. However, even tho the best type tubers selected from the lot that contained spindle-tuber were superior to the other tubers, the difference was relatively slight when compared with the superior returns, more than 100 per cent greater yield, secured from both the check lots which were planted with good seed from good fields. Under such conditions, the selection of the better type tubers (for seed) from a lot containing spindle-tubers is not to be recommended. The preferable method is to discard such tubers and then plant a strain that is entirely free (or as nearly as possible) from spindle-tuber. However, the selection of the best type tubers

from a lot of good seed containing only a very small amount of spindle-tuber is a different matter and is sometimes to be recommended.

RESULTS FROM SEED TUBERS CLASSIFIED BY TYPE, 1924

In the fall of 1923, as the tubers from the spindle-tuber plats were being calibrated and tuber type noted, 20 tubers

TABLE 41.—*Relation of tuber type of seed tubers to quality and yield of resulting crops, Triumph variety, Scotts Bluff, 1924. 20-hill plats.*

Relative tuber type of seed tubers planted	Per cent of tubers in each grade				
	U. S. No. 1 grade size				
	Good type tubers	Spindle-tubers	Total U. S. No. 1	U. S. No. 2 grade size	Smaller than No. 2
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*
(1)	(2)	(3)	(4)	(5)	(6)
1	.....	42.9	42.9	52.9	4.2
2	.....	57.2	57.2	31.2	11.6
3	.....	50.7	50.7	40.4	8.9
4	.....	64.3	64.3	27.0	8.7
5	.....	88.2	88.2	9.4	2.4
6	40.4	53.8	94.6	5.4	.4
7	35.7	59.4	95.1	4.2	.7
8	54.5	36.5	91.0	7.9	1.1
9	49.2	45.9	95.1	4.1	.8
10 (check)	79.4	11.5	90.6	6.2	2.9

of each tuber type value were saved. Tubers of type 10 were secured from a commercial lot (lot R) because none were produced by the lots from which the others were selected. In the spring of 1924, one seed piece was planted from each of these tubers of each type value. Thus there were 20 hills from each of the 10 types of tuber type. The data secured from these plats are reported in Table 41.

As the tuber type of the seed improved, (a) the percentage of No. 1 grade, good type tubers increased [Table 41 (2)], (b) the total amount of No. 1 grade size tubers increased (4), (c) the percentage of No. 2 and No. 3 grade tubers decreased (5) and (6), (d) the total yield increased with considerable regularity, and (e) spindle-tuber symptoms decreased in severity.

There was considerable similarity between the type of the seed planted and the type of the tubers harvested. Spindle-tuber was present in all lots, but in lots planted with tuber types 9 and 10 the spindle-tubers were of a very mild type. The yields showed a very severe reduction when poor-type tubers were planted. They are not reported because they are not considered very reliable, due to the variation caused by uneven row competition and the small plats. These conditions would, however, not seriously influence the percentage division of the crop by grades.

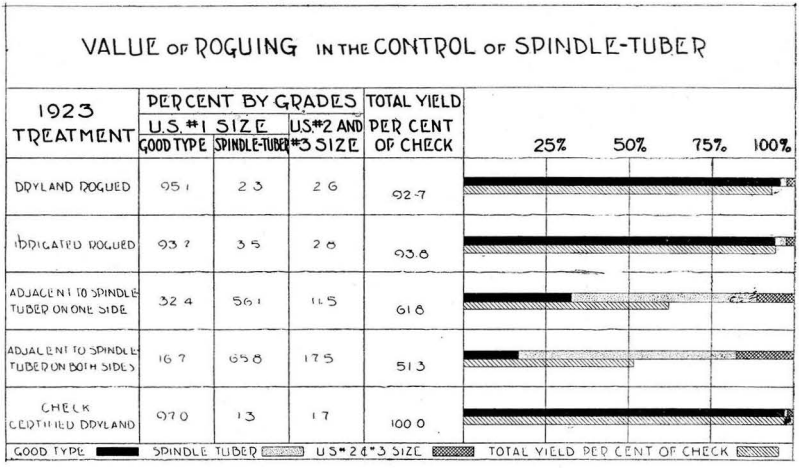


FIG. 33.— Isolation and roguing were effective means of controlling spindle-tuber in either dry land or irrigated fields. (For data see Table 27.)

This experiment emphasizes the results from the previous experiment, i.e., that the selection of good-type tubers from spindle-tuber lots is at best only a rather poor and uncertain method as compared with the use of seed-potatoes from uninfected fields.

ROGUING AND ISOLATION EXPERIMENTS

APPLICATION OF EXPERIMENTAL DATA REPORTED

Experiments reported earlier in this bulletin provide much data showing that the amount of spindle-tuber increased in direct proportion to the exposure to infection and as the chances for infection were decreased by roguing out diseased plants and isolating the seed plats the amount of

TABLE 42.—*Occurrence of spindle-tuber in 1924 crop from lots of seed produced in rogued plats given different cultural conditions in 1923.*

Treatment in 1923				Per cent (by weight) of spindle-tubers of No. 1 size. Harvested from comparative plats in 1924					
				Plat located at Scotts Bluff 3 rows—40 hills each				Plat located at North Platte. 3 rows, 60 hills each	
Place where grown	Planting date	Harvesting date	Culture	Triumph	Downing	Irish Cobbler	Early Ohio	Irish Cobbler	Early Ohio
(1)	(2)	(3)	(4)	*Per cent* (5)	*Per cent* (6)	*Per cent* (7)	*Per cent* (8)	*Per cent* (9)	*Per cent* (10)
Alliance	June 15	Sept. 27	Dry land	1.7	0.8	0.4	.....	1.1	4.4
Bushnell	June 5	Sept. 13	Dry land	1.0	6.3	0.3	6.0	.....	.....
Bushnell	June 5	Oct. 13	Dry land	2.3	9.2	0.9	4.9	2.1	3.9
Scotts Bluff	June 16	Sept. 10	Irrigation	2.5	33.4	9.2	.....	.....	.....
Scotts Bluff	June 16	Oct. 11	Irrigation	1.8	27.7	10.3	.....	.....	.....
North Platte	April 21	Aug. 26	Irrigation	40.5	43.4	45.4	.....	35.5	58.9
North Platte	April 21	Sept. 15	Irrigation	9.7	38.4	3.9	14.6	.....	.....
Union	April 5	Aug. 1	Straw mulch	.....	.....	.....	7.4	.....	7.8
Union	April 5	Aug. 1	Cultivation	.....	.....	.....	25.8	.....	20.1
Union	April 5	Oct. 15	Straw mulch	.....	.....	.....	3.1	.....	6.6
Union	April 5	Oct. 15	Cultivation	.....	.....	.....	10.0	.....	6.9
Union	June 5	Oct. 15	Straw mulch	.....	.....	.....	0.5	.....	0.14
Union	June 5	Oct. 15	Cultivation	.....	.....	.....	1.8	.....	1.36

spindle-tuber was very much less, sometimes actually decreasing.

Attention is specifically directed to several tables containing data pertaining to this matter. With both Downing and Triumph potatoes, spindle-tuber was held down to a very low percentage when seed plats growing on irrigated and dry land were planted among normal stock and diseased plants were rogued out as detected (Table 27). These same lots when adjacent to spindle-tubers degenerated so much that they were almost worthless for the production of a crop of good quality tubers the following year (Table 28).

The distinct superiority of seed stock grown under isolated conditions (provided by geographical isolation or caging), whether growing on dry land or irrigated land, was shown by results reported in Tables 29, 31, 32, and 33.

The importance of prompt early removal of spindle-tuber plants was shown in Table 32.

That early harvesting of seed stock may be desirable if spindle-tuber is present was shown in Table 33. Since environmental conditions have some effect upon the extent to which spindle-tuber is transmitted (as shown by Tables 18, 20, 21, 22, 23, 24, and 25 and Figs. 11, 17, 18, and 19), due consideration should be given to such conditions and practices correspondingly adjusted. Under conditions most favorable for transmission, roguing must be done more promptly and thoroly and isolation is more desirable than when conditions are less favorable.

When spindle-tuber and other diseases were eliminated as factors of degeneracy, seed potatoes grown on dry land and under irrigation were practically of equal value (Tables 27, 29, 30 and 31; also Tables 22 and 23). However, when spindle-tuber was present, transmission was more rapid under irrigation than under dry land conditions (Tables 18, 22, 23, 24, and 29 and Figs. 17 and 19), thereby suggesting the necessity of greater care in roguing irrigated plats.

SEED PLAT EXPERIMENTS, 1923-1924

In 1923, 4 varieties of potatoes were planted in tenth-acre seed plats (tenth-acre of each variety) at 4 places in the state. Climatic and cultural conditions were very different at these various places (Table 42). In addition one variety (Early Ohio) was grown under a variety of conditions at Union, in the extreme eastern part of the state. Supposedly good seed of each variety was planted. However, some of the lots were found to contain some mosaic and considerable

spindle-tuber. The Triumph lot contained less than 2 per cent of spindle-tuber, most of which was mild, while the Downing stock contained about 15 per cent spindle-tuber plants, the Irish Cobbler about 8 per cent, and the Early Ohio about 20 per cent.

At all places the plats containing the various varieties were adjacent to each other. At Alliance, Bushnell, and Union the seed plats were isolated from all other potatoes by at least 500 feet. At Scotts Bluff and North Platte, the plats were located in fields containing other potatoes, some of which were diseased, but at both places the seed potatoes for the following year were selected from rows at least 3 rows removed from the other potato plantings.

In 1923, all of these plats were vigorously rogued at least twice. All plants showing any symptoms of any known disease as well as all suspiciously weak plants were removed. In all of these plats, insects of many kinds were more abundant in 1923 than in most years. They were especially abundant at North Platte during June, when those plats were rogued.

The straw mulch used at Union was applied immediately after planting the potatoes and was about four inches deep.

In the fall of 1923, good type potatoes were selected for seed purposes of all varieties at each of these places. They were stored under uniform conditions and were planted in comparative plats at Scotts Bluff and North Platte in 1924. No plants were removed from these plats in 1924. At harvesting time all potatoes were run over a Boggs sorter before weighing. All spindle-tuber potatoes of No. 1 size (over 1⅞ inches in diameter) that could be detected were sorted out and weighed separately. The percentages of spindle-tubers in the 1924 crop raised from the various lots of seed in the two trial plats are given in Table 42.

Under western dry-land conditions (Bushnell and Alliance) rigid roguing prevented the increase of spindle-tuber in lots containing a relatively low percentage (Triumph and Irish Cobbler) and greatly reduced the percentage of spindle-tuber in those lots that originally contained a relatively large amount (Downing and Early Ohio).

In the irrigated plat at Scotts Bluff, roguing seemed less efficacious. The relative percentage of spindle-tuber was not appreciably reduced, neither did it seem to have increased, except in the Downing where outside infection was suspected.

The results secured at North Platte show that a great

deal of infection occurred before the plats were rogued and that altho the roguing was most severe at this place it was not effective in controlling the spread of spindle-tuber. The author cannot offer any explanation for the inconsistent percentage of spindle-tuber produced by the Triumph and Irish Cobbler seed stocks produced at North Platte in 1923 but harvested at different dates.

At Union, with Early Ohio, the percentage of spindle-tuber decreased considerably in the mulched plats and also to some extent in the cultivated plats. Late planting, in 1923, resulted in a very great reduction in the percentage of spindle-tuber in the following crop. The roguing in all these plats was the same, as nearly as possible.

When considering time of harvesting as a factor in assisting in the control of spindle-tuber in rogued seed plats, the data are not conclusive, as they represent only one year's work and differences are not consistent. The data from Bushnell-grown seed seem to indicate that early harvesting might be slightly advantageous. However, the data from Scotts Bluff, North Platte, and Union, mostly show less spindle-tuber in the late harvested lots, thereby suggesting that there may be little advantage, if any, in early harvesting of rogued plats. The longer storage period necessitated by early harvesting may have weakened the seed stock sufficiently to cause the plants to be more susceptible to infection from diseased plants in the trial plat in 1924.

From these data it appears that roguing if done thoroly, which implies sufficiently early and frequently, is effective in controlling or reducing the amount of spindle-tuber. This method seems to be most effective in the western dry-land regions. Roguing is less effective under conditions more favorable for infection, such as are found in irrigated fields and in the eastern part of the state. Other experiments herein reported showed that under these more unfavorable conditions good stock protected from infection remained vigorous and productive. Thus if seed stock is to be grown under such conditions, good stock containing a minimum amount of spindle-tuber (and other diseases) should be used and this should be kept pure by frequent severe roguing.

THE TUBER INDEX METHOD APPLIED TO SPINDLE-TUBER

During the winter of 1923-1924, about 6000 Triumph tubers were indexed, mostly for the purpose of detecting mosaic. This work was done in a greenhouse in which the temperature was maintained at 55 ° to 65 ° F. Considerable

difficulty was experienced in determining spindle-tuber symptoms at this low greenhouse temperature. The situation was not helped very much by later raising the temperature, because then the plants all tended to become spindling and produced smaller leaves. A number of tubers were eliminated because the plants showed spindle-tuber symptoms. In some plants the symptoms were very distinct, while in others they were vague and the plants were removed mostly on suspicion rather than on definite diagnosis. The tubers considered sound after indexing were planted in isolated seed plats by the 4-hill tuber-unit method at Bushnell and Scotts Bluff in western Nebraska.

TABLE 43.—*Results with the tuber index method as applied to spindle-tuber. (Four strains of Triumph potatoes indexed during the winter of 1923-1924 in greenhouses at Lincoln.)*

Strain lot number	Tubers indexed in greenhouse during winter		Tuber unit field trials of tubers selected after indexing. (Trials at Scotts Bluff and Bushnell)	
	Number of tubers	Per cent of tubers eliminated because of spindle-tuber	Number of tubers	Per cent of tuber units eliminated because of spindle-tuber
(1)	(2)	*Per cent* (3)	(4)	*Per cent* (5)
1	595	15.0	227	100.0
2	347	7.5	140	83.0
3	421	2.4	296	25.0
4	779	1.7	229	3.6

The data presented for four strains most largely used for field plantings are given in Table 43. In lots containing a large amount of spindle-tuber (strain 1), more tubers were rejected by indexing than in lots containing less spindle-tuber (strain 4), but all of the spindle-tubers were by no means eliminated, since a large number of units were rejected in the tuber-unit plats because of it (Table 43). Most of the spindle-tuber encountered was relatively mild and difficult to detect with certainty under field conditions.

The symptoms of spindle-tuber in the greenhouse are not the same and are not as distinctive as those manifested in the field. The leaves are lighter in color and are more pointed and narrow, also more smooth and glossy than normal Triumph leaves. When any curling occurs the leaves seem to curl down rather than roll up, as in the field. The plants also seem to emerge later and seem to grow somewhat slower and less vigorously than normal plants. During the winter of 1924-25, a large per cent of spindle-tuber seed pieces failed to produce sprouts by the end of 6 weeks. All of these were found to have formed small tubers directly without producing plants. * It is evident from this description that with the present knowledge of symptoms, identification under greenhouse conditions is uncertain.

With a more thoro knowledge of symptoms as shown in the greenhouse, it may be possible to index for spindle-tuber more accurately than has been possible heretofore. However, as soil, temperature, and moisture are capable of producing considerable variation in the type of plants and tubers of normal and spindle-tubers, this method may not prove satisfactory for detecting the milder forms of spindle-tuber.

Mosaic was almost completely eradicated from these lots by tuber indexing, as checked by field readings and tuber indexing of the field progeny during the fall of 1924. For spindle-tuber, the greenhouse tuber index method is of less value and requires more expert knowledge and keener observation of slight symptoms.†

GENERAL DISCUSSION

Spindle-tuber is the cause of most of the degeneration occurring in seed potatoes in Nebraska, which has heretofore been ascribed to the effect of environmental conditions in reducing the vitality of the seed stock. It has been shown that this disease manifests very characteristic symptoms in plant tops and tubers and that these symptoms vary in different environments. The symptoms seem to be most conspicuous at high temperatures.

* This peculiarity was called to the attention of the author by Dr. R. W. Goss several days before it was observed in the tuber index stock here referred to. The author is indebted to Dr. Goss for informal co-operation in determining the symptoms here described. Goss and Peltier (1924) report somewhat similar observations.

† With further greenhouse experience during the winter of 1924-25 and 1925-26, the author believes that when one is familiar with the manifestations peculiar to greenhouse conditions, the index method can be effectively applied. Low temperatures and soils rich in organic matter and abundance of soil moisture have been used these last two seasons. See pages 127, 128.

Since spindle-tuber very seriously reduces the yield and injures the commercial quality by the serious distortion of the tuber shape and appearance, it is of more serious consequence than the other virus diseases and is of concern to all who grow or market seed or table potatoes. It is apparently quite generally distributed thruout all the commercial potato-growing regions of the United States. It is very probably the most serious disease of potatoes in Nebraska at the present time.

Spindle-tuber has been shown to be an infectious disease. It has also been shown that it was transmitted from plant to plant, in the various parts of the state where work was conducted. Transmission of spindle-tuber, as indicated by the increase in the amount of spindle-tuber in any stock, has been found to be much more rapid and extensive in the irrigated than in the dry land fields. Possibly this is due to the fact that the vine growth is more succulent and rank in the irrigated fields. The succulent growth provides a more congenial host for insects to work upon and may be a better medium to receive infectious material. The rank growth causes the vines to intermingle and in covering the entire soil surface with vine growth the atmosphere immediately surrounding the plants is more humid and in other respects more favorable as an insect habitat than is the atmosphere of the dry-land fields. Furthermore, due to the close planting and intertwining of the plants, insects need not travel as far to get to another plant as on dry land where plants are generally distinctly separated. Another very important practical factor is, that in irrigated fields spindle-tuber plants may be present in greater number than is generally suspected, because frequently spindle-tuber plants do not emerge until the other plants have become well established. These spindle-tuber plants suffer in competition and do not develop sufficient size to enable them to be seen without careful searching. These plants, altho small, serve as sources for spindle-tuber infection. This is probably why the experiments reported have shown that in lots containing considerable spindle-tuber the percentage of it was not reduced but often increased in irrigated rogued plats whereas on dry land the percentage of spindle-tuber was considerably decreased by roguing. However, other experiments showed that when spindle-tuber was present to only a very small extent, it was controlled by isolation and roguing as well in irrigated as in dry-land plats and the seed stock was about equally productive.

The agency transmitting spindle-tuber in western Nebraska is not definitely known. It seems that aphids are not the carriers because of their comparative absence. Transmission takes place very early in the season. Early harvested potatoes have been found to contain less spindle-tuber than those harvested late, but the difference is not great enough to warrant its recommendation. Late planting gave better results in reducing the amount of spindle-tuber than those harvested early, but the difference is not great enough to warrant its recommendation. Late planting gave better results in reducing the amount of spindle-tuber in rogued seed stock.

In eastern Nebraska, straw-mulched seed stock has quite consistently produced a smaller amount of spindle-tuber than has the cultivated stock. The lower soil temperature and smaller vine growth of the mulched plats may have some connection with this result. The greater amount of transmission occurring in central and eastern Nebraska is probably due to the large number of insects present in those localities.

In view of the fact that soil temperature, texture, and moisture all cause a modification of tuber type in normal and spindle-tubers, frequently causing spindle-tubers grown under very ideal conditions to be of better type than normal tubers under less favorable conditions, it is very necessary to determine the specific nature of the symptoms under these varying conditions.

It has been shown that when spindle-tuber plants are not removed the disease becomes progressively worse until by the end of 3 or 4 years a lot of potatoes may be worthless for seed purposes with 100 per cent spindle-tuber altho it may originally have had only a small amount. It has also been shown that tuber type selection, or tuber-unit line selection work, was of little or no avail for accomplishing seed improvement or spindle-tuber control if the stock was already infected. It has also been shown that roguing of strains containing a considerable amount of spindle-tuber was found to be inadequate in reducing or preventing the increase of spindle-tuber in all except western dry-land plats.

On the other hand it has been shown that when good strains, free or relatively free from spindle-tuber, were planted in isolated plats or protected from infection by caging, the amount of spindle-tuber did not increase; also, that when disease was not present as a factor, dry-land and irrigated seed stock were of about equal value.

On the basis of these findings the best recommendation that can be made at the present time for the control or elimination of spindle-tuber is: That good seed stock, free from spindle-tuber (if such stock can be obtained), be secured and planted in an isolated seed plat and that this seed plat be thoroly and frequently rogued of all plants showing symptoms or suspected of containing spindle-tuber.

BIBLIOGRAPHY

Albrecht, W. A.
1922. Nitrate Accumulation Under Straw Mulch, Soil Science, Oct., 1922, p. 299.

Christensen, Axel.
1921. Experimental Results with Potatoes at the Torrington, Wyoming, Substation, Nebr. Potato Imp. Assoc., 3rd Annual Report, p. 24–26.

Edmundson, W. C.
1922. Report of Colorado Potato Experiment Station, Nebr. Potato Imp. Assoc., 4th Annual Report, p. 38–44.

Elmer, O. H.
1922. Mosaic Cross Inoculation and Transmission Studies. Science, Vol. 56 (1922), No. 1448, p. 370–372.

Emerson, R. A.
1914. Home Mulched vs. Northern Seed Potatoes for Eastern Nebraska, Nebr. Bul. 146, Dec., 1914.

Fitch, C. L.
1914. Identification of Potato Varieties, Iowa Ext. Bul. 20, April, 1914.

Folsom, Donald.
1923. Potato Spindle-Tuber, Maine Agr. Exp. Sta., Bul. 312, Aug., 1923.

Folsom, Donald, and Schultz, F. S.
1924. The Importance and Natural Spread of Potato Degeneration Diseases, Maine Agr. Exp. Sta. Bul. 316, Jan., 1924.

Goss, R. W.
1924. Effect of Environment on Potato Degeneration Diseases, Nebr. Agr. Exp. Station, Res. Bul. 26, March, 1924.

Goss, R. W., and Peltier, G. L.
1925. Further Studies on the Effect of Environment on Potato Degeneration Diseases, Nebr. Res. Bul. 29, Jan., 1925.

Goss, R. W.
1925 and 1926. From Appendix.

Jones, L. R., McKinney, H. H., and Fellows, H.
1922. Influence of Soil Temperature on Potato Scab, Wisconsin Research Bul. 53, July, 1922.

Kiesselbach, T. A.
1917. Studies Concerning the Elimination of Experimental Error in Comparative Crop Tests, Nebr. Agr. Exp. Sta., Research Bul. 13, pp. 53–60.

Krantz, F. A.
1922. Permanence of Variety in the Potato, Jour. Agr. Res. 23, 947–961.

Krantz, F. A., and Bisby, B. R.
1921. Relation of Mosaic to Running Out of Potatoes in Minnesota, Minn. Agr. Exp. Sta., Bul. 197, Sept., 1921.

Martin, W. H.
1922. "Spindle-Tuber," a New Potato Trouble, Hints to Potato Growers, N. J. State Potato Assn., Vol. 8, Dec., 1922.

Murphy, Paul A.
1923. Investigation of Leaf Roll and Mosaic Diseases of the Potato, Jour. Dept. of Agriculture, Ireland, Vol. XXIII, No. 1, pp. 20–34.

Murphy, Paul A.
1923. On the Cause of Rolling in Potato Foliage; and on Some Further Insect Carriers of the Leaf-Roll Disease, Sci. Proc. Roy. Dublin Soc. (N. S.) 17:163–184.
1924. Vol. XXIII, No. 4, Feb., 1924.

Salaman, Radcliffe N.
1922. Degeneration of Potatoes, Report of the International Potato Conference, London, 1921, p. 79.

Sandsten, E. P.
1921. Potato Production in Colorado, Nebr. Potato Imp. Assoc., 3rd Ann. Rpt., Dec., 1921.

Sheldon, Phil.
1920. Seed Quality of Potatoes Planted in Scotts Bluff County as Determined by Comparative Trials, Nebr. Potato Improvement Association, 2nd Ann. Rpt., pp. 18–23.

Schultz, E. S., and Folsom, Donald.
1923. A "Spindling Tuber" Disease of Irish Potatoes, Science, Vol. 57, No. 1466, Feb. 2, 1923, p. 149.

Schultz, E. S., and Folsom, Donald.
1923. Transmission, Variation, and Control of Certain Degeneration Diseases of Irish Potatoes, Jour. Agr. Res., Vol. 25, No. 2, July 14, 1923.
1925. Infection and Dissemination Experiments with Degeneration Diseases of Potatoes. Observations in 1923. Jour. of Agr. Research, Vol. 30, No. 6, March, 1925, pp. 493–528.

Skinner, L. T., and Beck, M. W.
1913. Soil Survey of Scotts Bluff County, Nebraska, Field Operations of the Bureau of Soils.

Stuart, W. A.
1915. Group Classification and Varietal Description of Some American Potatoes, U. S. D. A., Bul. 176, March, 1915.

Stuart, W. A.
1920. Testing Northern Grown Seed Potatoes in the South, 2nd Ann. Rpt. Nebr. Potato Imp. Assoc., pp. 52–57.

Stuart, W. A.
1923. The Potato, Lippincott Pub. Co.

Werner, H. O.
1920. Irrigation as a Factor in Seed Potato Production, Proceedings of the American Society of Horticultural Science, pp. 133–138.

Werner, H. O.
1920. Seed Potato Investigations with Western Nebraska Potatoes, Nebraska Potato Improvement Association, 2nd Ann. Rpt., pp. 31–52.

Werner, H. O.
1921. Results of Experiments with Potatoes in Western Nebraska During 1921, Nebr. Potato Imp. Assoc., 3rd Ann. Rpt., pp. 65–71.

Werner, H. O.
1922. Varieties of Potatoes for Nebraska, Nebr. Exp. Sta., Bul. 182, Nov., 1922.

Werner, H. O., and Howard, R. F.
1923. Seed Potato Investigations, Nebr. Agr. Exp. Sta., Research Bul. 24, Dec., 1923.

Whipple, O. B.
1919. Degeneration in Potatoes, Montana Agr. Exp. Sta., Bul. 130, April, 1919.

Whipple, O. B.
1920. Line Selection Work with Potatoes, Journal of Agr. Research, Vol. 19, No. 11, Sept., 1920.

APPENDIX

Since the original manuscript was sent to the press the writer has secured additional information concerning the symptoms of spindle-tuber under winter greenhouse conditions. The spindle-tuber plants herein considered showed distinct symptoms, for we still find it very difficult to detect the very mild forms.

Leaf measurements were made January 5, 1926, with normal and spindle-tuber plants grown in 5½-inch pots for tuber index work. The average length of the terminal leaflets of 14 spindle-tuber plants was found to be 83.4 per cent of the average of similarly placed leaflets of 14 normal plants of the same age. (Jan. 5, 1926.) The spindle-tuber leaflets were more elongated than those of normal ones as shown by Table 44.

TABLE 44.—*Comparison of measurements of spindle-tuber and Triumph plants. Jan. 5, 1926, in greenhouses at Lincoln. Mean of 14 plants.*

Character of plants	Height	Diameter of stem at base	Position of leaf from top of plant			
	Mm.	Mm.	1st	2nd	3rd	4th
(1)	(2)	(3)	(4)	(5)	(6)	(7)
			Mean length of terminal leaflets in millimeters			
Normal	186.2	10.25	70.9	84.4	88.2	95.8
Spindle-tuber	162.9	7.04	59.9	69.0	75.3	78.6
			Mean ratio of width to length of terminal leaflets			
Normal			74.9%	86.1%	97.2%	111.6%
Spindle-tuber			72.3%	74.1%	84.4%	91.1%

The spindle-tuber leaflets are more elongated than the leaflets of normal plants (Fig. 34). Spindle-tuber leaves do not seem to be as thick as normal leaves. Actual measurements were not made, but when 50 leaf areas (one square centimeter each) were taken from both types of plants, on the basis of the dry matter, the normal leaves were found to average 9.73 per cent heavier than the spindle-tuber leaves. In young plants spindle-tubers develop more lateral leaflets than normal plants.

Dr. R. W. Goss (working independently at this station) found that secondary tuberization was very common with spindle-tubers planted during the early part of their dormant period. (Goss 1925.) He also found that spindle-tubers produced with high soil moisture are much more elongated than with low soil moisture, thus further corroborating the findings reported on pages 98, 103-105. (Results by Goss not yet published.)

On page 122 the author states that aphids were present in insufficient numbers to warrant the assumption that the transmission occurring was due to insects entirely, but that transmission was evidently taking place in some unknown way. Dr. Goss (1926) has shown conclusively that spindle-tuber is transmitted by contact of cut seed pieces and by

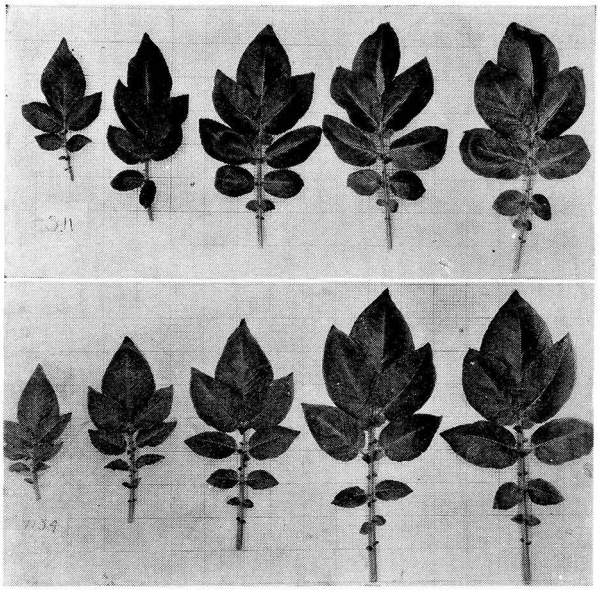


FIG. 34.— Leaves of spindle-tuber plant (at top) and normal plant (at bottom) in greenhouse, January 5, 1926. These were plants about 6 weeks old, grown at low temperatures. In each case they represent the 5 top leaves of the plant. Note the smoother leaf surface and less distinct venation of spindle-tuber leaves, also conspicuous midribs. Spindle-tuber leaves were so thin that they curled and wilted as shown, in the few minutes necessary for photographing.

means of the cutting knife. Undoubtedly some of the transmission and some of the rapid increase of spindle-tuber reported in this bulletin resulted from such contact transmission. These results by Goss suggest that spindle-tubers should be very carefully sorted out of a lot of seed potatoes before cutting. It also points to the need for information concerning the value of treating seed potatoes after cutting as a means of controlling spindle-tuber.

Goss, R. W.
1925. Effect of the Spindle-Tuber Disease on Sprouting. Potato News Bulletin, Vol. 2, No. 7, July 1925, pp. 261-264.
Goss, R. W.
1926. Transmission of Potato Spindle-Tuber Disease by Cutting Knives and Seed Piece Contact. Phytopathology (Abstracts), Vol. 16, January 1926, p. 6.

* Yield data in Bul. 24 as reported there are erroneously interchanged.