VASCULAR DISCOLORATION OF IRISH POTATO TUBERS

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INTRODUCTION

The exact significance of vascular discoloration in the stem-end tissues of Irish potato tubers has never been fully determined. Various types of both flesh and vascular necrosis are recognized, some of which are associated with the presence of Fusaria of various species or with *Verticillium albo-atrum*. Others, however, at least in the initial stages, yield no organisms when subjected to culture, nor does the microscope reveal the presence of organisms. It is also recognized that a superficial necrosis may develop in the stem tissues of apparently perfectly normal stock. There is no such perfect natural abscission of the potato tuber from the stolon as is common with fruits. Moreover, they are frequently harvested before the plants are mature, and the tubers are then broken off from green stolons. It has been assumed that suberization of the wound thus made normally follows in two or three days, so that not more than a few layers of dead cells should appear unless some aggressive parasite gains entrance to the wound. A popular impression has prevailed that any except the most superficial stem-end discoloration might be taken as a trustworthy indication of the presence of Fusarium, or, at least, that the stock was grown on vines affected with Fusarium or Verticillium.

Somewhat extensive preliminary observations and cultural studies, made by the writer both at the time of harvest and during or at the close of the rest period, on stock grown in sections where Fusarium blight and wilt do not occur, as well as in sections where they are known to be general, show that, while Fusarium and Verticillium undoubtedly do cause vascular discoloration of potato tubers, discoloration can not be accepted as proof of the presence of Fusarium or, indeed, of any other organism, nor can the absence of discoloration be confidently accepted as proof of the sterility of the vessels near the stolon attachment. There seems to be reason to think that vascular necrosis may often arise from purely physiological causes and that it need not necessarily be seriously abnormal, though frequently it is. A more complete discussion of this question must await the outcome of studies at present incomplete, but it seems advisable to present some available data regarding the fungous flora of potato stem ends.

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OUTLINE OF METHODS AND WORK

The general plan followed in the work may be outlined briefly as follows: Material for experimental plantings, involving about 4 acres of plots, was secured from various sources, as reported below. It was treated 30 minutes in 1 to 1,000 mercuric chlorid solution and allowed to dry, after which each tuber was examined for vascular discoloration by removing with a flamed and cooled scalpel a shallow cone of tissue with the stolon attachment at the center of its base. A record was made of the presence or absence of discoloration and of the general character of the discoloration when present, as slight, medium, brown, dark, etc. When discoloration was found, the depth to which it penetrated in the tuber was determined by removing a wedge of tissue. When browning was confined to a shallow area around the removed cone it was designated by recording the symptom A. If the discoloration extended to a greater depth, involving up to one-fourth the length of the tuber, symptom B was recorded. A deeper discoloration was designated by C. Discolored tubers were submitted to culture. In general one planting of tissue was made from each region involved in discoloration. As a rule, therefore, one planting was made from tubers showing symptom A, two from those showing symptom B, three from tubers showing symptom C, and none from those showing no discoloration. In the actual prosecution of the work, however, certain deviations from the general rule were introduced, either to check the dependability of results or to secure additional information. The tubers of each lot were weighed and numbered consecutively in the order of their respective weights, which were recorded. With the exception of lot No. 3, the tubers of each lot weighing less than 3 ounces were divided into two groups, one comprising all the even numbers and the other all the odd numbers. Those weighing 3 ounces or more were halved from stem to apex, one half being placed with the small tubers of even number and the other half with the small tubers of odd number. When the half tubers weighed 3 ounces or more they were cut into stem and apex portions. In a few cases the half tubers were so large as to yield stem, middle, and apex pieces, or even stem, two middle, and apex pieces—four in all from each half. The minimum seed piece for cut tubers was 1½ ounces.

The two lots of seed stock were planted and grown in widely separated regions and under distinctly different environmental conditions of soil and climate, one lot being planted on a light, sandy soil, under rainfall, at Waupaca, Wis., and the other on a heavy clay loam under irrigation at Greeley, Colo. The identity of each plant was preserved, and frequent records were made by the same observers in rotation in each and in both regions to secure all the data possible regarding the influence of the seed piece and environment and of the interrelations of these upon individual plant performance, with special reference to the development of pathological conditions.

DESCRIPTION OF MATERIAL

The material may be divided advantageously for consideration into three groups, each containing several lots. The first group comprises stock affected with tuber-borne diseases of undetermined origin; the second lot is from healthy parentage; and the third is from diseased parentage where the malady is regarded as of parasitic origin. For brevity in presentation many lots which were held separate during the investigation have been combined, so as to appear as a unit, whenever their origin and performance made such treatment feasible.

A brief description and index of the lots presented in the tables follows.

A.—Obscure disease group.

1. Thirty-four seedling varieties originated by Prof. Wm. Stuart, of the Department of Agriculture, and originally regarded as promising but ultimately discarded because of the persistent reappearance of destructive but imperfectly understood hereditary diseases. This material had been grown at Jerome, Idaho, in 1913 and 1914, in the pathological plots there.

2. The progeny of 31 hills of Western Peach Blow, grown at Greeley, Colo., which were suspected of Fusarium infection. This stock is now known to be affected also with leafroll and mosaic and is therefore placed in this group.

3. A miscellaneous collection of 21 lots from the pathological collection of the field station at Presque Isle, Me. Both seedling and commercial varieties affected with leafroll, mosaic, and dwarfing diseases were included. This lot was grown only at Greeley, Colo., and the tubers were either planted whole, or, if they weighed over 3 ounces, they were cut once crosswise into stem and apex halves.

B.—Healthy group.

4. A representative commercial lot of the variety Late Ohio, grown at Greeley, Colo., in 1914 and obtained from the grower.

5. An exceptionally good commercial strain of the variety Pearl, grown in Greeley, Colo., in 1914, obtained from the grower and collected from the field at harvest time.

6. A fine commercial strain of the variety Pearl, grown at Crandon, Wis., in 1914 and reported to be free from wilt, leafroll, and similar diseases.

7. Wisconsin certified seed potatoes, variety Pearl, secured from the grower.

8. Culls from two lots of Maine-grown stock of the variety Pearl. One of these lots was reported healthy and the other as diseased with leafroll. There was no difference in the performance of the two lots in either locality where they were grown, and disease was absent. They are therefore grouped together as healthy.

9. Certified seed potatoes of the variety Rural New Yorker, grown at Boss Lake, Wis. A second lot of similar, though uncertified, material of the same variety but from another grower near Racine, Wis.

10. A small lot of Wisconsin-grown stock of the variety Pearl, composed of tubers on the stolons of which Colletotrichum pycnidia were developing.

11. Four so-called types of commercial stock of the variety Rural New Yorker, supplied by a local grower of Greeley, Colo., who had used his own home-grown seed for a series of years. These types were really only rather imperfectly established size grades, evidently obtained by bin selection from the general field run of his stock.

C.—PARASITIC DISEASE GROUP.

12. The progeny of representative hills from a typical "Fusarium-blight" field of the variety Early Ohio, grown at Greeley, Colo., in 1914, dug in August and stored in a mass lot.

13. Ten hill lots of the variety Early Ohio, grown at Greeley, Colo., in 1914. The physical condition of the soil of the field was poor, and the plants were small and dwarfed.

14. A representative lot from a field of choice stock of the variety Sir Walter Raleigh, grown in 1914 on a field at East Lansing, Mich., which was heavily infected by Fusarium. Every plant in the field, with the exception of about one-quarter of 1 per cent, wilted and died three or four weeks before frost.

15. Sixty-one hill lots of the variety Pearl, grown in Wisconsin in 1914. The hills selected were from vines with more or less rolled foliage and a brown discoloration of the vascular tissue of the stems. Cultures from the discolored stem tissue failed to yield Fusarium.

16. Eighteen hill lots of the variety Pearl, grown from Wisconsin seed at Greeley, Colo., in 1914. Cultural tests at digging time showed unusual infection of the vines with *Fusarium oxysporum*.

17. Six hill lots of the variety Red McClure, grown at Greeley, Colo., in 1914 on vines shown by isolations to be infected with *Fusarium oxysporum*.

18. Forty hill lots of the variety Rural New Yorker, grown on diseased vines at Waupaca, Wis., in 1914. Cultural tests of the vines for Fusarium at digging time yielded a Fusarium and a Colletrotrichum culture in about equal numbers, but these did not appear to be general.

19. Twenty-five hill lots of the variety Rural New Yorker, grown at Greeley, Colo., in 1914 on vines infected with *Fusarium oxysporum*, as shown by isolation tests from the vascular tissue of the stems at digging time.

PRESENTATION OF RESULTS

VASCULAR DISCOLORATION

The number of tubers in each lot of material and the number having discolored vascular bundles, grouped according to the relative depth of penetration below the stolon attachment, are shown in Table I. A column for miscellaneous symptoms is included to provide for a variety of incidental occurrences, such as net necrosis, decay, mechanical injury, and the like; and following this, the number of tubers of each lot with no vascular discoloration is shown.

It has already been stated that, in general, tubers with stem-end vascular tissue of normal appearance were not submitted to culture and that one, two, or three cultures were made from tubers with discolored vessels, the actual number being determined by the depth of the necrosis. No regular procedure was adopted with respect to the tubers belonging to the miscellaneous group. The figures in the column marked "theoretical," under "number of cultures," have been obtained by adding the number of shallow discolorations, twice the number of deep discolorations, three times the number of very deep discolorations, and whatever number the notes show to be correct to provide the cultures made from tubers with miscellaneous symptoms. The actual number of cultures made and reported upon follows in the next column. Under "duplicates" are included the number of cultures made from discolored tubers in excess of the number theoretically required. The number of cultures made from tubers with no discoloration of the stem-end tissue is next recorded, and last of all is given the number of cases in which a culture was theoretically called for but was not reported. In some cases, for one reason or another, these cultures were not made, while in others they were made and discarded before being studied. because of broken tubes, loss of identifying label, and similar accidents. If the number given in the last column is subtracted from the sum of the numbers in the two preceding columns and the difference is added to the theoretical number of cultures, the actual number is obtained.

TABLE I.—*Appearance of vascular tissue and origin of cultures*

Lot No. and designation.	Number of tubers.	Nature of discoloration.					Number of cultures.				
		Shallow.	Deep.	Very deep.	Miscellaneous.	None.	Theoretical.	Actual.	Duplicate.	From tubers not discolored.	Theoretically required but lacking.
OBSCURE DISEASE GROUP											
1 Id	1,731	474	26	4	5	1,222	544	590	44	57	55
2 WPB	387	159	1	1	2	224	164	162	8	13	23
3 Me	636	206	2	0	10	418	217	215	6	14	22
HEALTHY GROUP											
4 CLO	335	233	21	2	9	70	290	373	85	5	7
5 PC	957	563	0	0	2	392	564	572	19	11	22
6 PW	537	80	0	1	5	451	84	89	1	12	8
7 PSW	65	10	0	0	0	55	10	9	0	0	1
8 PMc	133	14	0	0	0	119	14	16	0	2	0
9 RW	360	58	0	0	1	301	58	59	2	5	6
10 RWColl.	7	0	0	0	7	0	7	7	0	0	0
11 CRC	664	262	3	0	2	397	269	280	13	9	11
PARASITIC DISEASE GROUP											
12 AEO	212	132	17	0	0	63	166	181	24	2	11
13 EO	69	17	1	1	0	50	22	22	1	1	2
14 M	546	289	6	1	1	249	305	298	10	8	25
15 DPW	391	85	0	0	3	303	88	80	1	7	16
16 DPC	152	88	0	0	0	64	88	106	16	5	3
17 RMc	47	14	0	0	0	33	14	16	1	2	1
18 DRW	222	51	0	0	0	171	51	55	0	5	1
19 DRC	145	61	3	0	0	81	67	73	8	3	5
Total	7,596	2,796	80	10	47	4,663	3,022	3,203	239	161	219

ISOLATION AND IDENTIFICATION OF FUNGI

Isolations were made by transferring a small piece of tissue removed under aseptic conditions from the region of discoloration directly to a test tube containing sterilized nutrient material prepared in the usual way. Melilotus stems, potato cylinders, and steamed rice were used, the number of each diminishing in the order named. Identifications were made direct from the original tube in some cases, while subcultures were resorted to in others. Except in part of the Fusarium cultures, no attempt was made to identify the species. Two hundred and ninety-one out of the 718 cultures of Fusarium secured were identified as *F. discolor* var. *sulphureum* or *F. oxysporum*, but it is not to be supposed that the remaining 499 cultures were all of other species. Indeed, it is probable that *F. oxysporum* and *F. radicicola* predominated among the cultures reported as *Fusarium* spp. The summarized results of the cultural studies are presented in Table II. Two columns of figures appear under each genus reported. In the first column is given the number of instances when the culture was either pure or so nearly so as not to give

visible evidence of the presence of other organisms at the time of identification. In the second column is recorded the number of times the genus in question was found in a tube associated with some other organism. Each tube containing a mixed culture is reported twice, once for each organism. In no case were more than two organisms identified from a single tube. The total number of identifications reported is therefore the sum of all the columns marked "pure" plus the sum of all the columns marked "mixed," while the total number of plantings reported is the sum of all the columns marked pure plus one-half the sum of all the columns marked "mixed."

One very significant thing shown in Table II is the fact that out of 3,203 plantings, all but 161 of which were made from discolored tissue, 1,352 gave no growth. There is good reason to believe that in the great majority of these cases the tubes yielded no growth because the tissue transplanted was sterile, or at least free from filamentous fungi. These results are in entire accord with those obtained by the writer in numerous other cases where cultural tests of discolored vascular tissue of potatoes have been carried out. In some instances the discoloration may be a response to parasitic attack on some other portion of the plant, though the tissues of the tuber are not actually attacked. In such cases it may be regarded as a parasitic phenomenon of a secondary character. From the physiological point of view, however, it matters little whether a lethal dose of toxin diffuses from some point in the stem back of the stolon or from a point within the tuber itself. Likewise, the result is the same whether the tissue is killed by the action of fungi, primary or secondary, or through the operation, directly or indirectly, of malign environment of whatever nature. Conclusions based on field experiments with many factors uncontrolled must not be accepted without reserve, but the writer has secured deep vascular discoloration which he believes to be the direct result of too rapid respiration induced in the soil at high temperatures such as prevail during the summer months in the vicinity of Washington and which are occasionally experienced at more northern and western points. This was the case with stock grown at Arlington Farm during the summer of 1917, in which vascular discoloration was universal and pronounced, extending throughout the tuber in most cases. While certain lots of this material yielded Fusarium or other fungi from a certain portion of the plantings, other lots yielded only an occasional saprophytic growth out of hundreds of plantings. The results were confirmed by repeated trials, which gave uniformly identical results.

There seems, therefore, to be good reason to regard some of the stem-end browning of vascular tissue as physiological, even in the cases in which it extends well into the tubers.

TABLE II.—*Number of isolations from stem-end tissue*

Lot No.	*Alternaria* spp.		*Bacterium* spp.		*Colletotrichum* spp.		*Fusarium discolor sulphurium.*		*Fusarium oxysporum.*		*Fusarium* spp.		*Penicillium* spp.		*Rhizoctonia* spp.		*Verticillium* spp.		Miscellaneous.		No growth.	Total.	
	Pure.	Mixed.	Pure.	Mixed.	Pure.	Mixed.	Pure.	Mixed.	Pure.	Mixed.	Pure.	Mixed.	Pure.	Mixed.	Pure.	Mixed.	Pure.	Mixed.	Pure.	Mixed.		Pure.	Mixed.
OBSCURE DISEASE GROUP																							
1	59	3	26	6	0	1	11	0	8	0	25	6	20	0	3	1	6	5	18	0	403	579	22
2	62	3	17	0	1	0	4	1	1	0	14	2	13	0	0	0	9	1	4	1	33	158	8
3	30	6	2	0	4	6	1	0	0	0	3	1	6	1	0	0	0	0	7	0	155	208	14
HEALTHY GROUP																							
4	25	9	7	4	1	0	4	0	29	0	185	13	2	1	0	0	2	1	5	0	99	359	28
5	183	19	31	4	8	4	12	0	6	0	11	5	47	1	1	0	67	18	12	1	168	546	52
6	12	1	36	2	0	2	1	0	6	1	10	4	0	0	1	0	1	0	1	0	16	84	10
7	1	0	0	6	0	0	0	0	2	2	0	4	0	0	0	0	0	0	0	0	0	3	12
8	3	1	1	0	2	0	0	0	0	0	2	0	0	0	1	0	0	0	0	1	6	15	2
9	7	0	6	7	2	2	1	0	14	1	6	8	0	0	1	0	0	0	3	0	10	50	18
10	0	0	0	2	1	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	4	5	4
11	11	3	24	3	1	0	8	1	8	1	57	2	4	0	2	0	7	1	9	1	143	274	12
PARASITIC DISEASE GROUP																							
12	90	15	3	1	0	0	3	0	8	0	40	14	1	0	0	0	1	0	1	2	18	165	32
13	1	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	1	0	0	0	18	22	0
14	0	0	2	3	8	44	1	0	59	43	0	3	0	0	1	0	8	1	18	0	154	251	94
15	13	0	19	5	2	0	2	0	23	0	0	5	0	0	0	0	2	0	0	0	14	75	10
16	43	3	6	1	2	0	1	0	0	0	2	0	4	0	1	0	1	2	2	0	41	103	6
17	2	1	0	0	0	0	0	0	0	0	0	0	2	0	0	0	5	1	1	0	5	15	2
18	5	0	12	1	0	0	0	0	26	0	0	1	0	0	0	0	0	0	0	0	11	54	2
19	3	1	4	0	0	0	1	0	0	0	2	1	1	1	0	0	6	1	0	0	54	71	4
Total	550	65	196	45	32	59	51	2	190	48	358	71	100	4	11	1	116	31	81	6	1,352	3,037	332
Total for genus	.....	615	.....	241	.....	91	.....	53	.....	238	.....	429	.....	104	.....	12	.....	147	.....	87	1,352	.....	3,369

Another striking thing brought out in Table II is the frequency with which Alternaria was recovered from the vascular tissue. Almost 20 per cent of the discolored tubers carried this genus, in most instances unmixed with other fungi. This proportion is so high as to suggest that it may possess some significance hitherto unsuspected or at least undiscovered. Similar results have frequently been secured with other material. As high as 50 per cent of some lots of tubers have yielded Alternaria in cultural tests, even from stock presenting an attractive appearance on superficial examination.

FIELD STUDIES

The general manner in which the stock was handled in planting has already been indicated (p. 277–278). In taking notes in the field a full description of each plant was recorded at each reading, including such matters as size, habit, character, color, and orientation of stems and foliage, as well as the general appearance as to vigor. At least three sets of notes, and in the case of some lots more, were made on each plant during the season. Successive sets of notes were taken by different members of the staff, and no reference to the previous notes was made while preparing the new set. In the preparation of the present article the writer has endeavored to translate these descriptions into the expressions "diseased" and "healthy." Every plant has been placed in one group or the other, even though in some cases the assignment had to be more or less arbitrary. Consistency has been maintained, however, and the writer has been able to bring to his aid thorough familiarity with the appearance of the material throughout the season. One of the three principal sets of notes is his own.

Plants whose description at any given note taking indicates probable suspicion in the mind of the observer of the presence of disease have been recorded as diseased, even though at previous or subsequent note takings they may be recorded as healthy. It is certain that many cases of recorded disease at the first note taking represent only delayed germination, but as this may be correlated with reduced vitality or fungous attack on the sprout or tuber, it seems important to record it. Records of recovery as well as of disease have been made and will be considered later, but it is of interest first to inquire into the general relation of vascular discoloration to fungous invasion and the correlation of these within the tuber with disease in the plants produced. For the purpose of this consideration plants once reported as diseased have been counted as diseased whether later reported as diseased or healthy.

RELATION OF VASCULAR DISCOLORATION TO FUNGOUS INVASION AND DISEASE

Table III is designed to show the performance in the field of all the tubers studied, arranged according to the character of the tubers. The tubers are grouped under four headings:

1. Tubers with vascular discoloration yielding a culture.
2. Tubers with vascular discoloration yielding no culture.
3. Tubers without vascular discoloration yielding no culture.
4. Tubers without vascular discoloration yielding a culture.

The tubers under each heading are arranged in two columns, according as they yielded plants which were healthy or diseased. In case a tuber was cut into two or more pieces at least one of which produced a diseased plant, the tuber has been reported in the disease column. As is to be expected, most of the plants in the progeny of the lots carrying obscure tuber-borne diseases are diseased. The results presented in the remaining two groups, however, seem to indicate that vascular discoloration does not necessarily imply fongous invasion; nor is either of these in the tuber a guarantee of disease in the plant, or their absence a guarantee of health.

TABLE III.—*Number of healthy and diseased plants from tubers examined*

Lot No.	Discoloration; fungus present.		Discoloration; fungus absent.		No discoloration; fungus absent.		No discoloration; fungus present.		Total.
	Healthy.	Diseased.	Healthy.	Diseased.	Healthy.	Diseased.	Healthy.	Diseased.	
OBSCURE DISEASE GROUP									
1	15	147	23	324	86	1,124	0	12	1,731
2	22	90	14	37	42	171	2	9	387
3	8	46	22	142	73	339	2	4	636
Total	45	283	59	503	201	1,634	4	25	.....
HEALTHY GROUP									
4	128	65	53	19	55	10	4	1	335
5	263	118	131	53	261	122	6	3	957
6	28	33	12	13	249	190	8	4	537
7	5	4	1	0	22	33	0	0	65
8	8	0	6	0	114	3	2	0	133
9	19	25	6	9	151	146	2	2	360
10	3	0	0	4	0	0	0	0	7
11	82	46	74	65	216	175	5	1	664
Total	536	291	283	163	1,068	679	27	11	.....

TABLE III.—*Number of healthy and diseased plants from tubers examined*—Continued

PARASITIC DISEASE GROUP

Lot No.	Discoloration; fungus present.		Discoloration; fugus absent.		No discoloration; fungus absent.		No discoloration; fungus present.		Total.
	Healthy.	Diseased.	Healthy.	Diseased.	Healthy.	Diseased.	Healthy.	Diseased.	
12	113	18	16	2	52	9	2	0	212
13	2	5	4	8	34	15	1	0	69
14	76	62	76	83	133	113	2	1	546
15	20	39	7	22	115	182	0	6	391
16	17	43	10	18	29	31	2	2	152
17	3	6	3	2	12	20	1	0	47
18	17	25	4	5	93	74	1	3	222
19	5	12	23	24	29	50	0	2	145
Total	253	210	143	164	497	494	9	14	.....
Grand total	834	784	485	830	1,766	2,807	40	50	7,596

INFLUENCE OF ENVIRONMENT

Influence of environment upon the development of disease and recovery is a subject of much interest and importance. Table IV brings out some interesting facts regarding the development of disease in Wisconsin and in Colorado in cut and uncut seed. It should be borne in mind that the plants grown in the two States from cut seed are from the same individual, since, as has already been stated, the tubers were halved lengthwise and one half was planted in each place. The seed under 3 ounces was not cut but was divided into two approximately equal portions for planting. For the cut seed the total number of tubers cut and the total number of seed pieces appear in each line. One-half the number of seed pieces is the number planted in each State, except from lot 3. This lot was planted in Colorado only, and it was halved crosswise into stem and apex pieces instead of lengthwise.

The third and fourth columns give the number of diseased plants developing in Wisconsin and Colorado, respectively, and the following column gives the number of cases in which corresponding portions of a given tuber yielded diseased plants in both places. These plants are referred to as pairs. In No. 3 only, the pairs are from stem and apex halves of the same tuber. Of the 197 diseased plants recorded, 106 were from stem-end seed pieces and 91 were from apex or seed ends. As shown in the table, 79 pairs occurred.

For the uncut seed the number of tubers planted in each State and the number developing disease in each State appear.

TABLE IV.—*Distribution of diseased plants*

Lot No.	Cut seed.					Whole seed.			
	Number of tubers.	Number of seed pieces.	Number of diseased plants in Wisconsin.	Number of diseased plants in Colorado.	Number of diseased pairs.	Number of tubers in Wisconsin.	Number of diseased plants in Wisconsin.	Number of tubers in Colorado.	Number of diseased plants in Colorado.
OBSCURE DISEASE GROUP									
1	757	1,636	729	698	650	483	432	491	454
2	11	22	8	9	7	194	181	182	116
3	143	286	.....	197	79	.....	.....	493	414
Total	911	1,944	737	904	736	677	613	1,166	984
HEALTHY GROUP									
4	184	376	52	45	25	75	12	76	11
5	631	1,552	105	201	42	163	24	163	42
6	482	1,076	177	141	62	27	4	28	3
7	46	114	17	35	12	9	3	10	3
8	10	20	0	0	0	60	1	62	2
9	300	718	104	153	64	30	11	30	5
10	7	14	3	2	1	0	0	0	0
11	84	202	10	73	8	290	82	290	142
Total	1,744	4,072	468	650	214	654	137	658	208
PARASITIC DISEASE GROUP									
12	23	46	1	2	0	96	13	93	13
13	5	10	0	1	0	34	13	30	14
14	484	1,136	113	197	52	30	11	32	8
15	125	272	56	74	41	121	75	145	91
16	28	56	19	17	14	63	41	62	31
17	15	30	10	4	3	17	13	15	4
18	96	214	40	37	17	52	25	74	25
19	61	150	31	45	23	45	14	39	26
Total	837	1,914	270	377	150	458	205	490	212
Grand total	3,492	7,930	1,475	1,931	1,100	1,789	955	2,315	1,404

The figures given in Table IV indicate no conspicuous relation between the character of the tuber used for seed and the occurrence of disease, since the number of pairs of diseased plants is only equal to from one-half to one-third the total number of diseased plants in either locality. It is to be noted that in general the Colorado conditions resulted in more disease than did those of Wisconsin, particularly when cut seed was used, and this, too, notwithstanding the fact that the cut tubers were well suberized when planted.

These results seem to indicate that the soil and not the tubers should be considered the most potent source of disease, a fact substantiated for the Greeley section by the more recent studies of Dr. MacMillan. Additional indication of this probability is given in Table V, where the behavior of stem and apex seed pieces is presented and the number of diseased plants per tuber is shown. The obscure disease group, of course, shows a majority of cases in which all the plants from a tuber were diseased, when any of them were; but the combined results from the healthy and the parasitic disease groups show that out of 283 quartered tubers yielding diseased plants, 123 yielded 1 such plant only, 99 yielded 2, 33 yielded 3, while only 28 yielded 4.

TABLE V.—*Number of tubers yielding diseased plants*

Lot No.	From stem pieces.	From apex pieces.	From both stem and apex pieces.	Total number of tubers.	Total number of tubers yielding diseased plants.	Number of tubers yielding 1 diseased plant.	Number of tubers yielding 2 diseased plants.	Number of tubers yielding 3 diseased plants.	Number of tubers yielding 4 diseased. plants.
OBSCURE DISEASE GROUP									
1	51	51	49	[a] 57	53	3	5	3	42
2	.....	.....	.....	0	.....	.....	.....	.....	.....
3	106	91	79	[b] 143	118	39	79	.....	.....
HEALTHY GROUP									
4	1	1	0	[c] 4	2	1	1	0	0
5	71	33	27	[d] 141	77	44	20	5	8
6	48	25	23	[c] 56	50	17	18	12	3
7	11	9	9	[c] 11	11	1	6	1	3
8	.....	.....	.....	0	.....	.....	.....	.....	.....
9	46	23	21	59	48	20	14	11	3
10	.....	.....	.....	0	.....	.....	.....	.....	.....
11	16	13	12	[c] 17	17	5	12	0	0
PARASITIC DISEASE GROUP									
12	.....	.....	.....	0	.....	.....	.....	.....	.....
13	.....	.....	.....	0	.....	.....	.....	.....	.....
14	41	26	18	[c] 84	49	24	16	3	6
15	9	7	6	11	10	2	6	0	2
16	.....	.....	.....	0	.....	.....	.....	.....	.....
17	.....	.....	.....	0	.....	.....	.....	.....	.....
18	6	3	3	11	6	2	3	0	1
19	9	10	6	[c] 14	13	7	3	1	2

[a] Two tubers were cut into eight pieces each. All yielded diseased plants. Other tubers were cut into four pieces each.
[b] Tubers were cut into two pieces each.
[c] Tubers were cut into four pieces each.
[d] Four tubers were cut into six pieces each. All produced healthy plants, except one stem and one middle piece from the same side of one tuber. These are both recorded as stem plants. Other tubers were cut into four pieces.

It appears further from the data given on the second and third groups in Table V that a tuber from healthy parentage or from fungous-invaded parentage is more likely to yield a diseased plant from a stem-end seed piece than from the apex. Two hundred and fifty-eight tubers yielded diseased plants from stem ends and 150 yielded diseased plants from apex ends. One hundred and twenty-five of these tubers yielded diseased plants from both stem and apex. The ratios, therefore, of stem, apex, and pairs were approximately 10:6:5. The fact that the proportion of diseased stem plants to diseased apex plants is slightly higher in the healthy group than in the parasitic disease group is not inconsistent with other data presented in this paper.

The facts seem to indicate that the greater liability of stem-end plants to disease results not because the vascular tissue of the seed piece is more often infected by fungi but because it is more often endowed with less physiological resistance.

DISEASE AND RECOVERY

Data dealing with disease and recovery are presented in Table VI. The total number of plants reported at the first note taking as diseased is recorded in the first column. Following this is recorded the number of these plants which subsequently appeared to recover and to remain healthy. The next column gives the number of additional plants reported diseased at the second note taking, followed similarly by the number of those which subsequently recovered. The next column records the number of hitherto healthy plants which appeared to be diseased at the third note taking.

In the lower portion of the table the Rural New Yorker and the Pearl varieties have been summarized in juxtaposition for purposes of convenient comparison. The outstanding feature of this table is the remarkable degree of recovery shown, particularly in Colorado. This is especially noticeable with the Pearl stock in Colorado. It is, possibly, the ability of the Pearl to recuperate in that section which accounts for the popularity of this variety in the Greeley region.

A summary of the data on disease and on recovery for the entire experiment in total and by States is given in Table VII. Table VIII shows percentage data figured from information shown in Tables IV and VII. Attention is directed to the figures in Tables IV and VII in connection with the percentage averages in Table VIII, because percentage figures may be misleading when the numbers from which they are computed are small. A striking example of this is shown in Table VIII, where one plant in Wisconsin was diseased and did not recover, while two were diseased in Colorado and both recovered. This appears in the respective columns on recovery as 0 and 100 per cent. In the larger groups and in the aggregates, however, reduction to percentage gives a clearer presentation of the facts.

TABLE VI.—*Disease and recovery*

OBSCURE DISEASE GROUP

Lot No.	Number of diseased plants.	Wisconsin.					Colorado.					Number not recovered.	
		Number in first note taking.		Number added in second note taking.		Number added in third note taking.	Number in first note taking.		Number added in second note taking.		Number added in third note taking.		
		Diseased.	Recovered.	Diseased.	Recovered.	Diseased.	Diseased.	Recovered.	Diseased.	Recovered.	Diseased.	Wisconsin.	Colorado.
1	2,313	943	67	170	31	48	824	97	263	24	65	1,063	1,031
2	314	15	1	112	15	62	93	73	32	32	0	173	20
3	611	.....	.....	.....	.....	.....	372	41	237	29	2	.....	541
Total	3,238	958	68	282	46	110	1,289	211	532	85	67	1,236	1,592
HEALTHY GROUP													
4	120	34	11	19	3	11	53	23	0	0	3	50	33
5	372	29	14	54	16	46	177	113	28	14	38	99	116
6	325	67	18	13	5	101	127	50	13	8	4	158	86
7	58	2	1	18	13	0	32	12	5	3	1	6	23
8	3	0	0	1	0	0	2	2	0	0	0	1	0
9	273	55	26	51	41	9	135	74	22	18	1	48	66
10	5	2	1	0	0	1	2	2	0	0	0	2	0
11	307	3	1	75	62	14	208	182	4	3	3	29	30
Total	1,463	192	72	231	140	182	736	458	72	46	50	393	354
PARASITIC DISEASE GROUP													
12	29	14	12	0	0	0	5	3	9	6	1	2	6
13	28	1	1	9	0	3	3	3	1	1	11	12	11
14	329	26	8	87	63	11	184	143	12	4	9	53	58
15	296	25	2	65	3	41	35	22	125	101	5	126	42
16	108	35	1	6	0	19	34	13	8	3	6	59	32
17	31	1	0	22	7	0	2	2	6	3	0	16	3
18	127	20	4	44	35	1	43	24	16	16	3	26	22
19	116	6	0	38	12	1	55	49	2	1	14	33	21
Total	1,064	128	28	271	120	76	361	259	179	135	49	327	195
Healthy Pearl	758	98	33	86	34	147	338	177	46	25	43	264	225
Diseased Pearl	404	60	3	71	3	60	69	35	133	104	11	185	74
Total	1,162	158	36	157	37	207	407	212	179	129	54	449	299
Healthy Rural New Yorker	585	60	28	126	103	24	345	258	26	21	4	79	96
Diseased Rural New Yorker	243	26	4	82	47	2	98	73	18	17	17	59	43
Total	828	86	32	208	150	26	443	331	44	38	21	138	139

TABLE VII.—*Summary of disease and recovery*

OBSCURE DISEASE GROUP

Lot No.	Colorado and Wisconsin.				Wisconsin.			Colorado.		
	Number of tubers.	Number of seed pieces.	Number of diseased plants.	Number of recovered plants.	Number of seed pieces.	Number of diseased plants.	Number of recovered plants.	Number of seed pieces.	Number of diseased plants.	Number of recovered plants.
1	1,731	2,610	2,313	219	1,301	1,161	98	1,309	1,152	121
2	387	398	314	121	205	189	16	193	125	105
3	636	779	611	70	.....	.....	.....	779	611	70
Total	2,754	3,787	3,238	410	1,506	1,350	114	2,281	1,888	296

HEALTHY GROUP

4	335	516	120	37	263	64	14	264	56	23
5	957	1,878	372	157	939	129	30	939	243	127
6	537	1,131	325	81	565	181	23	566	144	58
7	65	133	58	34	66	20	14	67	38	15
8	133	275	3	1	70	1	0	72	2	2
9	360	778	273	159	389	115	67	389	158	92
10	7	14	5	3	7	3	1	7	2	2
11	664	782	307	248	391	92	63	391	215	185
Total	3,058	5,507	1,463	720	2,690	605	212	2,695	858	504

PARASITIC DISEASE GROUP

12	212	235	29	21	119	14	12	116	15	9
13	69	74	28	5	39	13	1	35	15	4
14	546	1,198	329	218	598	124	71	600	205	147
15	391	538	296	128	257	131	5	281	165	123
16	152	181	108	17	91	60	1	90	48	16
17	47	62	31	12	32	23	7	30	8	5
18	222	340	127	79	159	65	39	181	62	40
19	145	234	116	62	120	45	12	114	71	50
Total	1,784	2,862	1,064	542	1,415	475	148	1,447	589	394
Grand total	7,596	12,156	5,765	1,672	5,611	2,430	474	6,423	3,335	1,194
Healthy Pearl	1,692	3,417	758	273	1,640	331	67	1,644	427	202
Diseased Pearl	543	719	404	145	348	191	6	371	213	139
Total	2,235	4,134	1,162	418	1,988	522	73	2,015	640	341
Healthy Rural New Yorker	1,031	1,574	585	410	787	210	131	787	375	279
Diseased Rural New Yorker	367	574	243	141	279	110	51	295	133	90
Total	1,398	2,148	828	551	1,066	320	182	1,082	508	369

TABLE VIII.—*Summary of disease and recovery in percentage*

OBSCURE DISEASE GROUP

Lot No.	Percentage diseased.						Percentage recovered.	
	Cut seed.		Whole seed.		All seed.			
	Wisconsin.	Colorado.	Wisconsin.	Colorado.	Wisconsin.	Colorado.	Wisconsin.	Colorado.
1	89.12	85.33	89.44	92.46	89.24	88.01	8.44	10.52
2	72.73	81.82	93.30	63.74	92.20	64.77	8.47	84.00
3	.....	66.88	.....	83.98	.....	78.43	.....	11.46
Total	88.90	81.08	90.55	84.39	89.64	82.77	8.44	15.69

HEALTHY GROUP

4	27.66	23.94	16.00	14.47	24.33	21.21	21.88	41.07
5	13.53	25.90	14.72	25.77	13.74	25.88	23.26	52.26
6	32.90	26.21	14.81	10.71	32.04	25.44	12.71	40.28
7	29.82	61.40	33.33	30.00	30.30	56.72	70.00	39.47
8	0.00	0.00	1.67	3.23	1.43	2.78	0.00	100.00
9	28.97	42.62	36.67	16.67	29.56	40.62	58.26	58.23
10	42.86	28.57	0.00	0.00	42.86	28.57	33.33	100.00
11	9.90	72.28	28.28	48.97	23.53	54.99	68.48	86.05
Total	22.99	31.93	20.95	31.56	22.49	31.84	35.04	58.74

PARASITIC DISEASE GROUP

12	4.35	8.70	13.54	13.98	11.76	12.93	85.71	60.00
13	0.00	20.00	38.24	46.67	33.33	42.86	7.69	26.67
14	19.89	34.68	36.67	25.00	20.74	34.17	57.26	71.71
15	41.18	54.41	61.98	62.76	50.97	58.72	3.82	74.55
16	67.86	60.71	65.08	50.00	65.93	53.33	1.67	33.33
17	66.67	26.67	76.47	26.67	71.88	26.67	30.43	62.50
18	37.38	34.58	48.08	33.78	40.88	34.25	60.00	64.52
19	41.33	60.00	31.11	66.67	37.50	62.28	26.67	70.42
Total	28.21	39.39	44.76	43.27	33.57	40.70	31.16	66.89
Grand total	38.59	47.01	53.38	60.65	43.31	51.92	19.51	35.82
Healthy Pearl	21.65	27.30	12.36	19.01	20.18	25.97	20.24	47.31
Diseased Pearl	45.73	55.48	63.04	58.94	54.89	57.41	3.14	65.26
Total	24.21	30.29	33.41	36.60	26.26	31.76	13.98	53.28
Healthy Rural New Yorker	25.05	48.82	29.06	45.94	26.68	47.65	62.38	74.40
Diseased Rural New Yorker	39.01	45.05	40.21	45.13	39.43	45.08	46.36	67.67
Total	28.97	47.77	31.65	45.73	30.02	46.95	56.87	72.64

SUMMARY

In the material studied, vascular discoloration of stem-end tissues of Irish potato tubers was not found to be proof of the presence of parasitic fungi. Discolored bundles were often sterile, and fungi were frequently isolated from tissues which appeared normal.

The organisms recovered, in the order of their greatest frequency, were Fusarium 720, Alternaria 615, bacteria 241, Verticillium 147, Penicillium 104, Colletotrichum 91, Rhizoctonia 12, miscellaneous 87.

Out of 3,203 plantings, all but 161 of which were from discolored tissues, 1,352 gave no growth.

The field trials indicate that neither vascular discoloration nor fungus invasion of the tissues of the mother tuber is a guarantee of disease in the resulting plants, nor is their absence a guarantee of health. The soil and not the tuber appeared to have been the more potent source of disease.

Stem-end seed pieces yielded slightly higher percentages of disease than eye-end pieces, evidently because the stem end is endowed with less physiological resistance.

The plants showed a marked capacity for recuperation, which varied with the variety, with the environment, and with the interaction of the two.