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L. W. NIELSEN

AGRICULTURAL EXPERIMENT STATION  
of the  
UNIVERSITY OF IDAHO

Moscow, Idaho

**VERTICILLIUM WILT**  
of  
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by  
**L. W. Nielsen**

## VERTICILLIUM WILT OF POTATOES IN IDAHO

L. W. NIELSEN 1/

A wilt disease has been affecting Idaho potato plants for a number of years. Due to the premature death of vines, growers refer to it as "early dying." In many cases the intermountain leafhopper, *Empoasca filamenta* DeLong, has been suspected of being responsible for this early plant death. Research work, however, has shown that this insect is not involved (16) 2/. The disease has also been referred to as Fusarium wilt, because the symptom complex is similar to that disease (13, 23).

To determine the existence of a causal pathogen isolations were made during the summer of 1945, and an organism identified as *Verticillium albo atrum* R. and B. 3/ was predominately isolated. Data reported herein summarize the findings of three years' investigation on Verticillium wilt of potatoes in Idaho.

### Symptoms of Verticillium Wilt

Foliage and tuber symptoms of the disease have been previously described for Idaho conditions (13, 23). It is a typical wilt disease in its early stages of development. Chlorosis and wilting usually start in the basal leaves on one side of the plant and progress upward. In time most lower leaves wilt and die. Green stems with tufts of apical leaves may stand for sometime, but these ultimately succumb to the disease. All tubers do not show vascular discoloration. The browning of the vascular tissue usually penetrates the stem end of the tuber not more than one-quarter of an inch. Except for reducing size there is no other external visible effect of the disease on the tuber.

### Review of Literature

Pratt (20) was perhaps the first to describe a wilt disease of potatoes in Idaho. In his preliminary report in 1916, he concluded that *Fusarium oxysporum* is present in virgin soils of southern Idaho. For these experiments he obtained disease-free seed stock by macroscopically examining externally and internally seed tubers for evidence of disease. Pratt found that 29.3 percent of the plants grown on virgin land had vascular infection; whereas, 26 percent of the plants grown on previously cultivated land were affected.

In a subsequent paper (21) on experiments conducted in 1916 through southern and eastern Idaho, Pratt again reported relatively

1/ Formerly, Associate Horticulturist, Idaho Agricultural Experiment Station, Aberdeen, Idaho.

2/ Figures in parenthesis refer to literature cited.

3/ The writer is indebted to Dr. W. W. Ray, Oklahoma Agricultural and Mechanical College, Stillwater, Oklahoma, and the late Dr. H. L. Blood, Utah State Agricultural College, Logan, Utah, for confirming the identity of the organism.



high percentages of vascular infection in tubers grown on virgin land from macroscopically disease-free seed. Isolations from affected tubers yielded a variety of organisms including *Fusarium radiculicola*. No mention is made of isolating *F. oxysporum* in these studies.

There is some question as to whether *F. oxysporum* from virgin land was causing the vascular infection and wilt noted by Pratt. His observation: "In all of the desert-land plots the plants presented a sickly appearance as compared with the plants in the alfalfa and grain land plots. There were indications in each of the desert-land plots of light yields and of a diseased product," can be interpreted quite differently in light of present knowledge concerning desert soils. These soils are now known to be low in organic matter and nitrogen (2). A nitrogen deficiency may have caused the "sickly appearance." In neither paper did Pratt present data demonstrating the pathogenicity of the various *Fusarium* spp. isolated from vascular tissues of stems and tubers. Various *Fusarium* spp. have been isolated from discolored vascular tissue of potato stems and tubers (5, 7, 17, 18, 22), but many of them may be nonpathogenic when inoculated into growing plants (5, 22). If *Fusarium* wilt was the disease involved, some of the diseased plants could have developed from infected seed stock. Although every known precaution was taken to eliminate infected seed stock, it has since been demonstrated that the elimination of stem-ends of seed tubers, and freedom from vascular discolorations do not assure elimination of a vascular pathogen from seed tubers (7, 17, 18).

Pratt cultured five *Verticillium* spp. from Idaho soils (21). One of these species was also isolated from the vascular tissue of a tuber grown near Aberdeen. Pathogenicity tests were not made with any of the *Verticillium* spp. Edson also isolated *Verticillium* spp. from potato tubers grown at Jerome, Idaho, in 1914 (7). Here again no pathogenicity tests were made with the *Verticillium* spp. isolated. *Verticillium* wilt is a disease of economic importance in other intermountain and Pacific Coast states (3, 17, 24, 26).

## EXPERIMENTAL STUDIES

### Isolations

In all isolation studies, potato dextrose agar was used. In some cases it was acidified by aseptically adding 1 drop of 50 percent lactic acid to each 15 cc of medium. Isolations were made from plants and tubers. For plants, underground stems were used in all cases. They were thoroughly washed in tap water and disinfested by immersing in 1:1000 bichloride of mercury solution for 10 to 15 minutes. The bark was aseptically peeled from the underlying affected xylem tissue and two samples of discolored tissue were taken from each stem. All tissue plantings in petri plates were held at approximately 70 degrees F. Isolations from tubers were carried out in essentially the same manner, except that the tubers were classified in two categories; those showing definite browning, and those with no vascular discoloration. In some cases tubers had either a pronounced yellowing, or only a slight yellowing of the vascular tissue. These were arbitrarily placed in either

of the two classes, depending on the intensity of the coloration. Vascular tissue was aseptically removed from the stem-end of tubers by slicing sufficiently deep to eliminate stolon connections and then removing the vascular tissue with sterile forceps. The tissue selected was that showing the most pronounced discoloration, or the most evident xylem tissue in the clear tuber. Two cultures were made from each tuber. After about 2 weeks the cultures were microscopically examined in situ for the presence of *V. albo atrum*. A positive reading was recorded when either verticillate conidiophores and microsclerotia, or heavy-walled mycelia were present. In a majority of cases both structures were present. In the presence of contaminating bacteria or fungi one or the other structure was sometimes suppressed, and a positive reading was based upon the presence of one of the characteristic structures. Microsclerotia were the dominant type of resting mycelium encountered.

Over the three-year period diseased stems were collected from fields in the potato areas roughly delimited by Twin Falls and Jerome on the south to Ashton and the Teton Basin to the northeast. The isolation data are summarized in Table 1.

Table 1. Isolation of *V. albo atrum* from underground stems of potato plants affected with early dying during the growing seasons of 1945, '46, and '47.

Area from which plants collected	Number of plants collected			Number of plants from which <i>V. albo atrum</i> was isolated		
	1945	1946	1947	1945	1946	1947
Aberdeen .....	41	31	60	31	27	56
Ashton .....		8	4		0	0
Buhl .....		8			4	
Burley .....		8			1	
Eden .....	5	10	16	5	9	14
Idaho Falls .....		9	52		4	42
Jerome .....		34	6		24	1
Kimberley .....		9	9		1	9
Lewisville .....			19			15
Murtaugh .....		18	8		9	7
Parker .....		44	30		29	28
Rexburg .....		41	26		24	26
Rupert .....		10	6		10	5
Shelley .....	23	24	19	21	16	17
Twin Falls .....		16	9		12	8
Totals .....	69	270	264	57	170	228
Percent with <i>V. albo atrum</i> .....				82.6	62.9	86.4

For the years 1945 and 1947, *Verticillium albo atrum* was isolated from more than 80 percent of the diseased plants. In 1946 it was isolated from only 62.9 percent of the affected plants. It is possible that a part of this discrepancy was due to inexperience on the part of one of the persons making isolations that year. This survey covered that portion of southern and eastern Idaho that produces about 90 percent of the table stock shipped from the state. The disease was found uniformly distributed throughout this area. Seed-producing areas of eastern Idaho (Ashton and Teton Basin areas) were also surveyed for



Verticillium wilt. A few plants found in the Ashton area presented a symptom complex similar to that of Verticillium wilt. However, the organism was not isolated in cultures prepared from these plants. No plants having symptoms of the disease were found in the Teton Basin seed area.

Isolations were made from potato tubers grown on infested land at the Aberdeen Station. The results are summarized in Table 2.

Table 2. Isolation of *V. albo atrum* from tubers produced by plants affected with Verticillium wilt.

Year	Tubers with vascular discoloration					Tubers with no vascular discoloration				
	Total	<i>V. albo atrum</i>	Fusarium species	Other fungi	Bacteria	Total	<i>V. albo atrum</i>	Fusarium species	Other fungi	Bacteria
1946	48	15	0	12	4	61	0	0	2	17
1947	64	21	0	5	6	47	3	0	0	14

Isolations were made from approximately 100 tubers of the 1946 and 1947 crops. In 1946 *V. albo atrum* was isolated only from those tubers having vascular discoloration. It grew from 13.7 percent of the tubers studied. In 1947, it grew from 21.6 percent of the tubers studied. In this case, *V. albo atrum* was found in some tubers having no obvious vascular discoloration. It is apparent from these isolation studies that seed stock produced on infested land carries the organism, as has been previously shown (1, 5, 17, 24). Use of such seed stock would facilitate the distribution of the pathogen throughout the potato-growing areas. This is especially true since "one-year out" a/ seed stock is used for planting much of the table stock acreage. This procedure has been satisfactory for adequately controlling virus diseases and is a more economical source of seed stock for the table stock growers. "One-year out" seed stock may carry an appreciable amount of *V. albo atrum* because soils on many farms in the table stock area are infested with the organism, and it is not uncommon for a table stock grower to sell "one-year out" seed to his neighbors or to neighboring communities.

## Pathogenicity Tests

Pathogenicity of *V. albo atrum* isolates was studied in the greenhouse. Six isolates from the three areas sampled in 1945 were tested by direct stem inoculation and soil infestation. During the winter of 1945-46 stem inoculations were made by twisting a piece of sterile cotton on the point of a dissecting needle, saturating it with the desired spore suspension and forcing it into the stem just below the soil surface. The varieties Pontiac and Sebago were thus inoculated February 27. On March 9, 1946, the first symptoms of yellowing and wilting appeared in a few plants of both varieties. As time progressed, all cultures of *V. albo atrum* caused the symptoms wilting and yellowing to develop. Symptoms usually appeared first on one side of the plant, but generally the whole plant ultimately succumbed to the disease.

a/ "One-year out" seed stock is that grown from certified seed potatoes on table stock farms to be used as seed stock the following year. It is not certified.

A soil-infesting test was conducted with naturally infested soils from two farms. These soils were placed in 12-quart galvanized buckets, and 4 buckets of each soil were held as non-treated controls. The remaining buckets of soil, 14 in one case and 10 in the other, were disinfested in an autoclave for 2 hours at 15-pounds pressure. Four buckets of disinfested soil from each farm were held as treated controls and the remaining buckets of soil were reinfested with spore suspensions prepared from *Verticillium* isolates, representing the 3 locations sampled in 1945. One previously cut and disinfested seedpiece was planted in each bucket of soil from one farm on January 2 and from the other on January 9. The variously treated and planted buckets of soil were held on a bench previously washed with water and 1:1000 bichloride of mercury solution. The buckets were spaced about 8 inches apart and caution was taken when watering to avoid splashing water and soil from bucket to bucket. The greenhouse thermostat was set at 70 degrees F., but higher temperatures sometimes developed during the daytime.

On March 7, the first wilt symptoms appeared in a plant growing in artificially infested soil. At this time the plants were about 10 inches high and had 9 or 10 leaves. By April 16, all plants in naturally infested soils were dead or dying. Those in disinfested soils were alive and showed no evidence of yellowing or wilting. Most of those in the reinfested soils were either dead or showing early symptoms of *Verticillium* wilt. The disease developed more uniformly in the naturally infested soils than in those reinfested with the various isolates. This may have been due to a non-uniform distribution of inoculum in the soil or to a difference in virulence of the respective isolates.

Pathogenicity tests were also made during the winter of 1946 and 1947, using 5 cultures isolated in 1946 and one isolated in 1945. In these tests only direct stem inoculations were made. A spore suspension of each isolate was injected into stems at the ground level with a hypodermic syringe and needle. The following varieties and selections were inoculated February 19, 1947; Pontiac, U.S.D.A. Seedling 47105, Sequoia, Norkota, Sebago, Menominee, Charles Downing, Potomac, Teton, and Russet Burbank. Inoculated plants were held in a greenhouse where the thermostatic controls were set at 70 degrees F. Wilt symptoms were generally developing 14 days following inoculation. Isolations were made April 5 and 6 from 34 diseased plants including representative specimens of the several varieties. *V. albo atrum* grew from 28 of these thus demonstrating that the organism isolated from diseased field plants is pathogenic when inoculated into healthy plants.

## Effect of Temperature on *Verticillium* Wilt

The effect of temperature on the development of *Verticillium* wilt has been studied previously. Reviews of these investigations (9, 15, 24) indicate that the cardinal temperatures for wilt development are, minimum, 54 to 60 degrees F.; optimum, 70 to 75 degrees F.; and maximum, 82 to 86 degrees F. No controlled experiments have been conducted to demonstrate the role played by temperature under Idaho



conditions. However, a study of the climatological data and the date of appearance of verticillium wilt from 1945 to 1947 inclusive, suggests the importance of the temperature factor. The average daily temperature calculated on the basis of 10-day intervals from May 1 to August 18 for the 3 years are graphically presented in Figure 1.

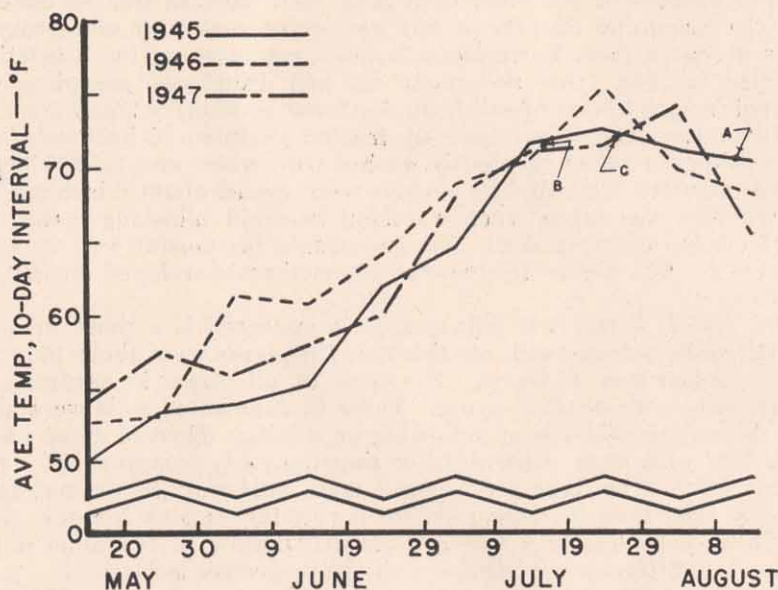


Figure 1. Average early summer temperatures at the Aberdeen Branch Station for the years 1945, 1946 and 1947. Curves plotted from data based upon 10 day averages. Points A, B and C are the dates that wilt first appeared in 1945, 1946 and 1947, respectively.

An inspection of these data shows that the early growing season of 1945 was comparatively cool, while that of 1946 was decidedly warmer and 1947 was roughly intermediate. For these years the disease was first detected at the Aberdeen Station on the following dates, 1945, August 14; 1946, July 17; and 1947, July 27. In 1945 the disease appeared late and was of minor importance. In 1946, the disease developed generally and in epiphytotic proportions, and the vines in numerous potato fields were dead by September 1. For these years the date of appearance and severity of Verticillium wilt was correlated with early summer temperatures.

Continuous soil temperature data are not available for the potato soils of southern and eastern Idaho. Periodic soil temperatures were recorded in 1939 at the Aberdeen station. Air temperature data indicate that 1939 was a relatively warm season similar to 1946. Soil temperatures taken at roughly 4 to 5 inches below the soil surface and to the side of the potato ridge (row) reached 71.8 degrees F. July 27 and 28 b/. The average air temperature for those dates was 74.5 and 75

b/. Data recorded by Mark R. Kulp, formerly Irrigationist, Idaho Agricultural Experiment Station, Moscow, Idaho.



degrees F. This soil temperature is at the optimum for the development of Verticillium wilt (9, 15, 24) and considerably below the optimum soil temperature reported for *Fusarium oxysporum* wilt (82 to 86 degrees F. (10, 19)).

These circumstantial soil temperature data are within the optimum range for Verticillium wilt development, and the correlation between early summer temperatures and the appearance and relative severity of Verticillium wilt from year to year offers an explanation for the yearly fluctuation in severity of Verticillium wilt. The failure to find Verticillium wilt in the seed producing areas covered in this study may be directly related to the soil temperature factor. These seed areas have an elevation of about 1 mile and the growing season is shorter and cooler than that found in the upper Snake River Valley where the disease is prevalent. Soil temperatures at these higher elevations may not be warm enough for Verticillium wilt to develop.

## The Effect of Soil Fertility on Verticillium Wilt

That the use of nitrogen fertilizers favorably increases yields of potatoes grown on wilt infested land has been reported for Idaho conditions (12, 13). This also applies to other practices that might increase soil fertility of infested land, and can be illustrated by an experiment performed in 1946. The infested land was relatively low in fertility, and 1946 was its fourth year of crop production since being plowed from alfalfa. Barnyard manure was applied to a portion of the land at the rate of about 40 tons per acre in contrast to no fertilization. As the crop developed it was evident that top growth in fertilized plots was more rapid than in non-fertilized plots. The top-growth response was measured by weighing the yield of dry tops before harvest. The comparative yields of dry vines and tubers are summarized in Table 3.

The heavy application of barnyard manure significantly increased the total yield of potatoes. Verticillium wilt developed in both the fertilized and non-fertilized plots at the same time. As the disease progressed, wilt appeared to be more severe in plants growing on land of low fertility, the smaller plants succumbing more rapidly. It is reported that starved plants are more susceptible to attack by *V. albo atrum* (24). All plants in the fertilized plots ultimately died from the disease. In this experiment fertilizer seemed to benefit the crop by increasing the rate of early summer growth, making it possible for plants to approach full top growth before the disease developed. Such plants have a better chance of producing a crop of potatoes even

Table 3. Effect of heavy application of barnyard manure to soils infested with *V. albo atrum* on top growth and total yield of Russet Burbank potatoes.

Treatment	Dry weight of tops per 50-foot plot	Total yield per acre
	pounds	sacks
Non fertilized.....	20.46	180.75
Fertilized.....	34.54	215.42
L. S. D. 1 percent.....	6.53	14.90

though they are ultimately killed by the disease. Barnyard manure is believed to propagate the organism in the soil (24). No data relative to this problem were recorded.

## The Effect of Planting Date on Severity of Verticillium Wilt

No detailed experiments testing the effect of planting date on the incidence and severity of Verticillium wilt have been made. The disease is reported as being more severe in early planted potatoes, and by planting later fewer plants develop symptoms and possibly fewer tubers become affected (1). Observations under Idaho conditions suggest that these reported data are correct for seed production; but for the table stock producer where maximum tonnage is the main objective, growers have found that late planting is not practical. One of the most severely infested areas in the state is the Egin Bench country west of St. Anthony. Soils in this section are sandy and are subirrigated. Subirrigation furnishes a uniform supply of water to growing plants, and thus makes it possible for these growers to produce crops having a high percentage of U. S. Number One Grade. Consequently, potatoes have been their primary cash crop for many years. Some fields have produced as many as 20 consecutive potato crops. Verticillium wilt is a major production problem in this section and the growers have found from experience that late planting is definitely unprofitable. In this section the crop is planted the latter part of April or early May (about 1 month earlier than most table stock), and vine growth is practically complete by mid-July or early August when the disease first makes its appearance. By using this early planting practice, these growers are able to produce around 200 sacks c/ per acre even though the disease appears every year. In other sections where the disease is becoming more prevalent, the growers are gradually shifting over to earlier planting dates in order to escape the losses that result from late planting.

## Crop Rotation

Under Oregon conditions, a crop rotation, including clover for two years preceding potatoes, largely eliminated *V. albo atrum* from infested soils (18). This practice does not seem to hold for southern and eastern Idaho, where it is a common rotation practice to grow alfalfa for 2 to 4 years or red clover preceding a potato crop. This is illustrated in Table 4. Verticillium wilt developed very extensively in each of these fields when planted to potatoes in 1946 or 1947. Fields 2b and 2c had essentially the same rotations between potato crops, and Verticillium wilt was prevalent in the potato crops planted in 1946 and 1947, respectively. The 1947 potato crop produced in Field 6d was the first crop of potatoes in that field for 8 years and here again Verticillium wilt affected most of the plants by the end of the growing season.

c/ Sack as used in this paper means the conventional commercial package of 100 pounds of potatoes.



Thus, it appears that 5 years of a legume (alfalfa) in the crop rotations employed in Idaho does not eliminate the pathogen from the soil. This long survival of the pathogen in field soils has nullified all attempts at artificially infesting field soils and demonstrating seed transmission of the disease, as all fields selected for these experiments later proved to be infested.

In 1947 an experiment was performed in Field 6d, Table 4, to demonstrate seed transmission of the disease. It was assumed that the soil might be free from the pathogen, and the following treatments were made. Stem-end pieces were cut from certified seed grown in one of the apparently wilt-free seed areas. Stem-ends were also cut from "one-year out" seed stock that possibly carried a small percentage of *V. albo atrum*. A third treatment using this same stock was planted and the plants themselves inoculated with *V. albo atrum* on July 21. The fourth treatment consisted of stem-end pieces showing vascular discoloration from seed stock grown in wilt land in 1946. A study of the yield data showed no significant difference between the several treatments. The disease made its appearance the latter part of July and early August and developed uniformly in all plots.

From these observations and data, it should not be concluded that crop rotations, including 2 to 4 years alfalfa, are not beneficial. The nitrogen and organic matter added to the soils by this practice are of great benefit and make it possible to produce a fairly high yield of potatoes, even though the disease organism is present in the soil.

The best indication available of the economic importance of Verticillium wilt is a comparison of yields from fields grown the same year on land infested to various intensities with the pathogen. A field classified as having moderate infestation and one known to be heavily

Table 4. Field cropping practices used on three fields at the Aberdeen Station in which Verticillium wilt developed in the most recent potato crop.

Year	CROPPING SEQUENCE		
	Field 2b	Field 2c	Field 6d
1940	Potatoes	Red Clover	Barley
1941	Potatoes	Red Clover	Barley
1942	Barley	Potatoes	Alfalfa
1943	Alfalfa	Wheat	Alfalfa
1944	Alfalfa	Alfalfa	Alfalfa
1945	Alfalfa	Alfalfa	Alfalfa
1946	Potatoes	Alfalfa	Alfalfa
1947		Potatoes	Potatoes

infested with the organism were planted in 1947. The latter field had grown a previous crop of potatoes and was fertilized with barnyard manure for the 1947 crop. Menominee and Russet Burbank were planted in both fields. Each variety was randomized and replicated 4 times in plots 3 x 45 feet. Yield data of these varieties are summarized in Table 5.

In making this comparison it must be conceded that the two fields varied in soil fertility and perhaps other factors than inoculum potential. The difference in these factors may possibly be measured by the relative yield of Menominee in the two fields. Menominee appears to

have field resistance to *Verticillium* wilt. On the moderately infested field there was no significant difference in the total yields of Russet Burbank and Menominee. However, on the heavily infested soil Menominee yielded more potatoes than Russet Burbank; and for 1947 *Verticillium* wilt possibly reduced the yield of Russet Burbank in this field about 40 sacks per acre. In years such as 1946, when the disease appeared in epiphytotic proportions, the reduction in yield is much more pronounced. A similar comparison can be made for 1946. In fields planted with certified seed, heavily infested soil produced from 150 to 180 sacks per acre of small potatoes, while land carrying a low infestation of the organism produced in excess of 300 sacks per acre. As previously indicated, losses from the disease are dependent upon temperature during the early part of the growing season and vary from year to year. These observations are in agreement with those reported by McKay (18).

Table 5. Comparative average yields of Russet Burbank and Menominee when grown on land heavily and moderately infested with *V. albo atrum*. Same seed source used for each planting.

Variety	TOTAL YIELDS		
	Moderate soil infestation sacks /A.	Heavy soil infestation sacks /A.	Difference between fields sacks /A.
Russet Burbank	294.86	223.79	71.07
Menominee	312.65	286.41	26.24
L. S. D. 1-percent	N.S.	33.65	

## Resistance to *Verticillium* Wilt

There is little evidence of pronounced resistance to *Verticillium* wilt in any of the older potato varieties (24). Russet Burbank is very susceptible. In many fields of Russet Burbank potatoes it is evident that variants are present. These variants are most apparent during the latter part of the growing season and are conspicuous for their large vines and late bloom. When grown on wilt-infested soil, the variants are easily distinguished from regular Russet Burbank as they remain green while surrounding plants wilt and die. These variants suggested a resistant strain of Russet Burbank and were selected from four commercial plantings (14), increased and tested under field conditions. These large-vine types are probably similar to those tested under California conditions (26).

The Russet Burbank selections have been maintained relatively free of virus diseases by growing them in tuber unit plots accompanied with roguing. Of the newer potato varieties, Sebago and Menominee appear to have resistance to *Verticillium* wilt under field conditions. U.S.D.A. Seedling 47105 also carries resistance to this disease, but its tubers have a very low specific gravity and are susceptible to scab, thus making it an undesirable sort. The Russet selections, Sebago and Menominee were grown on wilt infested land in 1946 and 1947. Yield data from these trial plantings are summarized in Table 6. In none



Table 6. Yield of Russet Burbank selections and varieties on land infested with *V. albo-atrum*. Data recorded as 100-pound sacks per acre.

Selection or variety	Year, location, growth period, and yield*					
	1946			1947		
	Aberdeen 125 days	Caldwell 119 days	Shelley 138 days	Aberdeen 122 days		
	No. 1's	Total	No. 1's	Total	No. 1's	Total
Russet Burbank	111.22	229.40	113.93	158.17	111.15	223.79
Selection 1**	51.40	238.10	73.28	171.43	90.28	184.48
Selection 2	54.30	248.87	54.98	170.17	82.11	195.29
Selection 3	59.82	227.38	56.43	170.95	87.12	195.00
Selection 4	53.43	230.87	57.30	164.75	89.84	202.81
Sebago	207.63	242.77			190.57	223.86
Menominee	180.92	251.48			219.61	286.41
L.S.D. 5%	31.94	N.S.	21.00	N.S.	23.81	25.08
1%	42.98		29.14		31.98	33.65

\* U. S. Number One commercial grade and total yield.

\*\* Station designation of these selections. Selection 1, G 17; Selection 2, G 109; Selection 3, Large Hege; Selection 4, Large Type.

of the 1946 plantings did the Russet selections yield as many U. S. Number 1 tubers as did the Russet Burbank, but the total yields were not different. The smaller yield of Russet Burbank Number 1 potatoes, in comparison with Sebago and Menominee, was due to the numerous malformed tubers produced by this variety under unfavorable moisture conditions. The failure of the Russet selections and the varieties to produce a greater total yield in 1946 was of considerable interest because all of them lived until killing frost, while Russet Burbank was killed by *Verticillium* wilt during the latter part of August. In all cases, these experimental plantings were made in commercial table stock fields. On the basis of records kept of the planting at Aberdeen, it appears that the failure of these selections and varieties to outyield regular Russet Burbank was associated with the irrigation practices employed. When it was obvious to the grower that commercial Russet Burbank plants were dying, irrigations were stopped and the resistant sorts did not have adequate moisture to make potatoes during the last of August or the first of September.

In the 1947 planting at Aberdeen, an attempt was made to correct this error. In this test the potatoes were irrigated until the time of killing frost. Russet Burbank yielded approximately the same in 1947 as in 1946 at Aberdeen. The several selections yielded a greater proportion of marketable tubers, but they did not yield as many Number One tubers as Russet Burbank and their total yield tended to be smaller. Menominee yielded more potatoes than Russet Burbank.

Additional plantings of these selections and varieties have been made on land relatively free of *V. albo atrum* and in a high state of fertility. In Table 7 are summarized yield data from plantings made during the three years. On fertile and lightly or moderately infested land Russet Burbank has yielded as well as Sebago and Menominee. In no case have the large-vine selections yielded more than the Russet Burbank, and in most cases their yield of marketable potatoes (U.S. No. 1) has been less. Yields at Burley for the 1947 planting were all low due to an accidental irrigation during the growing season which greatly reduced plant vigor and ultimate yield. Due to this accident the standard deviation in the analysis of data was very large, making the total yields insignificant, even though an inspection of the data suggests a real difference. From studies made thus far, it appears that the selections from Russet Burbank require a longer growing season than is commonly found in the potato growing sections of Idaho. However, it may be possible to increase their yield of marketable potatoes by modifying cultural practices.

An experiment was made in 1947 with Selections 1 and 3, in which the seedstock was warmed for various periods, and the seedpieces planted at two spacings in the row to see if these factors might increase the yield of marketable tubers. Seedstock of each Selection was warmed by holding it for 36 days and 16 days respectively at temperatures ranging from 55 to 80 degrees F. It was then cut into pieces, averaging 1-1/2 to 2 ounces, and planted at spacings of 8 and 12 inches in 36-inch rows. Data from the randomized experiment are summarized in Table 8.



Table 7. Yield of Russet Burbank selections and other varieties on land plowed from alfalfa or clover. Data recorded as 100-pound sacks per acre.

Selection or variety	Year, location, growth period, and yield*				Total	1945		1946		1947	
	No. 1's	Aberdeen 114 days	Total	No. 1's	Aberdeen 107 days	No. 1's	Total	No. 1's	Burley 110 days	No. 1's	Total
Russet Burbank	170.17		224.48	194.28			254.01	62.43			125.16
Selection 1	148.10		216.05	133.15			225.64	87.84			161.46
Selection 2	131.55		200.08	140.12			238.77	93.65			175.69
Selection 3	159.72		224.77	146.07			222.94	70.42			155.94
Selection 4	135.04		196.02	128.12			209.52	89.30			175.69
Sebago	199.79		214.89	201.54**			225.64**	143.02			173.66
Menominee	191.66		227.38	193.12**			219.25**	110.35			179.47
L.S.D. 5%	35.92		27.35	38.65			40.16	37.61			N.S.
1%	47.71		36.35	52.21			54.25	50.47			

\* U. S. Number One commercial grade and total yield.

\*\* These data from variety experiment grown on land contiguous with that used for the selections. Same cultural practices applied to all. L.S.D. values are only approximate for these yields.

Table 8. The effect of warming seedstock and spacing of seedpieces on plant population and yield of Russet Burbank Selections 1 and 3.

Treatment	Stems per hill	Stems per square foot	Yield sacks No. 1's	/A. Total
Heat period:				
36 days	3.61	1.37	91.15	173.26
16 days	3.41	1.30	96.12	175.58
0 days	2.59	.97	92.56	168.76
L.S.D. 5%	.66	.09	N.S.	N.S.
1 %	.88	.12		
Spacings:				
12 inches	3.23	1.02	88.14	168.61
8 inches	3.17	1.41	98.41	176.42
L.S.D. 5%	N.S.	.08	4.28	N.S.
1 %		.10	5.74	
Selections:				
Number 1	3.18	1.22	93.62	171.26
Number 3	3.22	1.21	92.93	173.77
L.S.D. 5%	N.S.	N.S.	N.S.	N.S.
Interactions:				
Selection x Heat period	N.S.	1%	N.S.	N.S.
Selection x Spacing	N.S.	N.S.	N.S.	N.S.
Heat period x Spacing	N.S.	N.S.	1%	N.S.
Sel. x H.P. x Spacing	N.S.	N.S.	N.S.	N.S.

Two of the undesirable characteristics of Russet Burbank Selections are their traits of producing few stems per hill and knobby tubers. It was suspected that the warming treatment would increase the number of stems produced by each seedpiece and thus increase the yield of marketable potatoes. The closer spacing would have the same effect. It was also suspected that the pre-cutting warm period might affect a more rapid emergence and thereby a longer growing season. For convenience the data are presented on the basis of heat-period, spacing, and selections. The heat periods increased the number of stems per hill about equally, but did not increase the yield of marketable tubers or the total yield. There is a trend to beneficial response from the short heat treatment. The yield of marketable potatoes was affected by spacing. The greater stem population gave the highest yield of marketable tubers. There was no significant difference in the performance of the two selections.

Of the several interactions only two were significant. Selections x Heat period is highly significant when considering stems per square foot of ground area. This suggests that intrinsically the two selections differ, although the data show no difference between them. This difference may be due to a masked virus or some other factor. The other interaction, Heat period x Spacing, with regard to yield of Number Ones is also significant. The heat periods alone did not significantly affect the yield of Number One tubers but when in combination with closer spacing, there is a significant response. None of the treatments affected the total yield. This again suggests that the Russet Selections are possibly too late for a growing season like that found in the irri-



gated potato sections of southern and eastern Idaho, or the particular selections studied lack yielding capacity. This is contrary to the performance of similar selections grown in California (26).

## Chemical Soil Treatment

In 1945, wilt-infested soils were treated with carbon disulphide and chloropicrin d/ to determine whether a soil-borne pathogen might be causing the disease. It was assumed that if such a pathogen were involved that one of the soil fumigants would give a beneficial response. Both chemicals were injected to a depth of 5 to 6 inches, October 12, 1945. Carbon disulphide was injected at the rate of 15 cc. per hole and the holes were arranged 18 inches apart in 18-inch rows. Chloropicrin was injected at the rate of 3 cc. per hole and the holes were 12 inches apart in 18-inch rows. In both cases the injected holes were plugged by stepping on them immediately after injection. The treated land was not worked further until the following spring when it was plowed and prepared for potato planting, May 3, 1946. No attempt was made to prevent reinfestation of the plots by machinery or irrigation water as this was not practicable on the farm where the experiment was performed.

Carbon disulphide appeared to stunt growth of the subsequent potato crop. As the season progressed, it was evident that the chloropicrin treatment was prolonging the life of the plants. There were diseased plants in the chloropicrin plots but as pointed out above, this was possibly due in part to the cultural practices employed after the chemical treatments were made. On September 5, 125 days after planting, approximately 50 percent of the foliage of these plants was still alive; while approximately 15 and 20 percent was alive for the carbon disulphide and control plots, respectively. The harvest data are summarized in Table 9. Carbon disulphide tended to reduce the yield, but the reduction was not significant. Chloropicrin gave a significant increase in yield and more tubers set per hill in these plots. However, the tubers were no larger than those in the other treatments. All the increase in yield from chloropicrin plots may not be due to controlling Verticillium wilt. The larger number of tubers per hill sug-

Table 9. Effect of treating\* soils heavily infested with *V. albo atrum* with fumigants on yield and tuber set of Russet Burbank potatoes.

Soil treatment	Total yield per acre	Tubers per hill	Average tuber weight
	sacks		lb.
No treatment	168.91	3.86	.380
Carbon disulphide	130.91	3.36	.322
Chloropicrin	223.11	5.10	.384
L.S.D. 5%	50.94	.67	N.S.
1%	84.99	1.11	

d/ Supplied gratis by the Innis, Speiden Co., 117 Liberty Street, New York 6, New York.

gests that chloropierin may have controlled Rhizoetonia damage also. Under Idaho conditions it has been observed repeatedly that **Corticium solani** attacks and destroys small tubers as well as severing stolons. This greater set of tubers may be due, in part, to controlling soil-borne Rhizoetonia. It is believed, however, that much of this greater yield was due to controlling Verticillium wilt, but the practice as employed in this test would be economically impractical.

## DISCUSSION

The findings of this research are contrary to the earlier reports and beliefs as to the cause of the early dying in Idaho potatoes. Although there was some uncertainty as to the causal pathogen involved, the disease was most generally believed to be *Fusarium* wilt. When first observed by the writer in 1945, it was recorded as *Fusarium* wilt, but **V. albo atrum** was the dominant organism from diseased plants. Since the disease has frequently been diagnosed as *Fusarium* wilt careful notes were made of all isolations to ascertain the prevalence of **Fusarium spp.** that grew in culture from tissue plantings. From those isolations made in 1945, Table 1, 3 **Fusarium spp.** were cultured; in 1946, 30 were cultured; and in 1947, 2. No **Fusarium spp.** grew from the vascular tissue of tubers. In many cases these organisms were associated with **V. albo atrum** in the same plant. One of those isolated in 1945, and 15 of those isolated in 1946 grew from plants that were infected with **V. albo atrum**. On the basis of culture characters and the prevalence of micro- and macroconidia there were at least 4 or 5 species represented in the cultures of 1946. Due to the heterogeneous nature of the *Fusarium* isolates, and their infrequent appearance in culture, no pathogenicity tests were made with them. Raeder and Kraus reported testing the pathogenicity of 55 single spore *Fusarium* isolates cultured from potatoes and found that 5 caused the **oxysporum**-type wilt and 2 the **eumartii**-type wilt (22). This suggests that a majority of the **Fusarium spp.** isolated from Idaho potatoes may not be pathogenic.

In 1943 soil at the Aberdeen Experiment Station was infested with a culture of **Fusarium oxysporum** (22). The artificially infested land was then arranged into a rotation experiment\*for controlling *Fusarium* wilt. In that portion of the rotation devoted to continuous cropping with potatoes, 10 plants affected by wilt were collected in each of the years 1946 and 1947 and isolated. **V. albo atrum** grew from 18 of the 20 diseased plants, and only one culture of a **Fusarium spp.** developed from the 20 plants studied. In this experiment it appears that **V. albo atrum** introduced by earlier potato crops was the pathogen causing wilt and not **Fusarium oxysporum** used for artificially infesting the soil in 1943.

During the progress of these investigations, it has been apparent that **V. albo atrum** grows more slowly on potato-dextrose agar than do various **Fusarium spp.** This is also evident from the data presented by Edson and Shapovlov for these genera (8). It was also noticed that plants in advanced stages of wilt, or that were held for 4 to 7 days



under humid conditions prior to isolation frequently yielded a variety of organisms (including *Fusarium* spp.), and it was difficult to establish the presence of *V. albo atrum* in such plants. The sundry organisms that developed in culture from such plants were considered as secondary and no attempt was made to segregate or test their pathogenicity. The slower rate of growth of *V. albo atrum* plus the prevalence of secondary organisms in plants held several days before isolation, may partially explain the failure to previously establish this organism as the causal pathogen of early plant death.

Two plant samples from western and northern Idaho were studied. Isolations were made from a sample of 7 stems from Latah County (northern Idaho) and a *Fusarium* spp. grew from 4 of them. A sample of plants from Parma, Idaho, also gave only a *Fusarium* spp. when cultured. The pathogenicity of these isolates was not tested. At these lower altitudes with longer growing seasons and warmer summer temperatures, it is possible that *Fusarium* wilt may be a factor in causing early death of potato vines. However, for the past 3 years, *V. albo atrum* has been the primary cause of early dying at the higher elevations in southern and eastern Idaho.

It is reported that *V. albo atrum* is more virulent to eggplant in alkaline soils (10) than in acid soils. Acid soils seem to favor wilt diseases produced by *Fusarium* spp. (9). Potato soils of southern and eastern Idaho are practically all above pH 7.0 and many of them will test 8.0 to 8.5, further suggesting that this soil factor is favorable for the development of Verticillium wilt.

The large-vine Russet Burbank Selections are probably only tolerant to Verticillium wilt. *V. albo atrum* has been isolated from these plants in the late growing season when affected plants had a small amount of yellowing and wilting of the basal leaves. Similar observations were made in California (26), yet most of these plants live until killing frost, even though grown on land of low fertility and heavily infested. The field resistance of Sebago and Menominee is also of interest. Both of these varieties when grown in the greenhouse and directly inoculated, developed typical symptoms and were killed by the disease. USDA Seedling 47105 on the other hand, apparently carries a different resistance factor as it has survived direct stem inoculations in the greenhouse; however, some wilting of inoculated plants did develop.

## SUMMARY

1. Early dying of potatoes in southern and eastern Idaho is primarily caused by *V. albo atrum* R. and B.
2. The time of appearance and severity of the disease are dependent upon early summer temperatures.
3. Under Idaho conditions, the pathogen has survived 7 years in soils cropped with barley and alfalfa.
4. Highly fertile soils resulting from rotations using alfalfa or clovers, heavy applications of barnyard manures, or commercial nitrogen fertilizers, reduce yield losses.

5. Resistant or tolerant selections from the Russet Burbank variety appear to be too late for growing conditions found in southern and eastern Idaho and have proven unsatisfactory in yield tests when grown on infested and relatively non-infested soils.

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