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ARTICLE TITLE:	Approaches to control of potato early dying caused by Verticillium dahliae
ARTICLE AUTHOR:	
VOLUME:	62
ISSUE:	4
MONTH:	
YEAR:	1985
PAGES:	177-185
ISSN:	0003-0589
OCLC #:	
CROSS REFERENCE ID:	[TN:1318026][ODYSSEY:206.107.42.72/PUL]
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APPROACHES TO CONTROL OF POTATO EARLY DYING CAUSED BY *VERTICILLIUM DAHLIAE*

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Abstract

Potato early dying disease, caused by *Verticillium dahliae,* may be either suppressed or controlled by a variety of procedures. These methods include the growing of resistant cultivars, attention to cultural management, utilization of pesticides, and solar heating of soils. The greatest successes in control of Verticillium wilt have been achieved with the use of either soil fumigants or clonal resistance, but these approaches have been restricted. Widespread use of fumigants has been limited by cost, and the lack of commercial acceptance has often restricted the utilization of resistant potato cultivars. The Katahdin and Targhee cultivars are currently available with resistance and/or tolerance to this disease. The Russet Burbank potato also possesses a limited degree of resistance to the fungus, and with this resistance, the disease appears to be suppressed by optimal growing conditions. In potato fields that have been cropped for several years, disease suppression in Russet Burbank was found to be related to methods of irrigation and increased nitrogen availability. It is suggested that improved utilization of resistant germplasm and effective use of biological control strategies may ultimately lead to economical control of this disease.

Resumen

La enfermedad de la muerte prematura de la papa, causada por *Verticillium dahliae,* puede ser eliminada o controlada por varios procedimientos. Estos métodos comprenden el cultivo de cultivares resistentes, atención prestada al manejo del cultivo, utilización de insecticidas y fungicidas y el calentamiento solar de los suelos. Los más grandes éxitos en el control de la marchitez por Verticillium se han logrado mediante el uso de fumigantes de suelos o resistencia clonal, pero estos métodos han sido restringidos. La aplicación amplia de fumigantes ha sido limitada por el costo y, a menudo, la falta de aceptación comercial ha restringido la utilización de cultivares resistentes de papa. Los cultivares Katahdin y Targhee están actualmente disponibles con resistencia o tolerancia a esta enfermedad, o con la combinación de ambas. Russet Burbank también tiene un grado limitado de

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KEY WORDS: Potato early dying, *Verticillium dahliae,* crop rotation, inoculum density, fumigation, resistance

resistencia al hongo y, con esta resistencia, la enfermedad parece ser vencida mediante condiciones óptimas de cultivo. En los campos de papa que han sido cultivados durante varios años, se encontró que la eliminación de la enfermedad en Russet Burbank estuvo relacionada con los métodos de irrigación y un aumento en la disponibilidad de nitrógeno. Esto sugiere que una utilización mejor del germoplasma resistente y el uso efectivo de las estrategias del control biológico pueden finalmente llevar a un control de esta enfermedad, que sea económico.

Potato early dying disease (Verticillium wilt) may be caused by either of two soilborne fungal species—*Verticillium dahliae* Kleb. (microsclerotial form) or *Verticillium albo-atrum* Reinke and Berthold (dark mycelial form). In Idaho and other arid growing regions of the western United States, this disease is caused by *V. dahliae.* Surveys of field isolates have demonstrated a uniformity of strain type in Idaho and this strain is similar to the nondefoliating strain (SS4) found in cotton (2). Recently Puhalla and Hummel (18) compared this strain with *V. dahliae* isolates from a worldwide collection and characterized Idaho isolates as belonging to the genetic population P-4. To date, P-4 has only been identified in the Pacific Northwest and Wisconsin and is different from European isolates. Because of this difference between isolates from the U.S. and Europe, results support the view that *V. dahliae* of potato may not have been introduced with European seed as is commonly believed.

Verticillium wilt is one of the most severe diseases of potato in the western U.S. Depending on severity, time of occurrence and growing season, potato yields and tuber size may be substantially reduced. Yield losses of 5.6 to 11.2 metric T/ha (50-100 cwt/A) are not uncommon (2), and losses of up to 46% have been documented in southeastern Idaho (7). With these losses, the need to develop control procedures is great, and to achieve this control the need also exists to evaluate the effect of treatments on *V. dahliae.*

Disease symptoms on potato are not reliable for purposes of diagnosis. Isaac and Harrison (12) state that "the only true characteristic symptom, that of unilateral chlorosis and necrosis, is morphologically indistinguishable from senescence symptoms, and is not produced until maturity of the host (the potato), and then often a week or so before normal senescence." Thus, the possibilities for incorrect diagnosis are many. This being the case, there is a vital need to determine the degree of *V. dahliae* colonization in potato tissue if the effects of treatments for disease control (e.g., pesticide, cultural practices, cultivars) are to be accurately evaluated. Since 1974, our investigations in Idaho have routinely utilized such a procedure (5) and have attempted to quantify the colonization of *V. dahliae* in potato stem tissue and inoculum levels in soil with both disease severity and yield.

Disease Initiation

Controversy still exists over the possible introduction of *V. dahliae* with seed. Although it is commonly accepted that potato seed is the primary source of *V. dahliae* in virgin soils (13), Hoyman (10) reported intratuber infection of Norgold Russet seed by *V. dahliae* to be of no consequence to development of the disease in the current season. Data from Idaho would tend to support this hypothesis. Although certified seed potatoes from certain regions of Idaho have consistently been shown to be heavily infected with *V. dahliae* (2), reports of problems with Verticillium wilt during the first year of cropping on virgin soils have not appeared. Similarly, when seed potatoes were planted in virgin ground and inoculated heavily with *V. dahliae,* no disease problem was observed the first year (Davis, unpublished). In many instances, the causal organism can exist as a part of the natural flora of the soil and may only require the introduction of a susceptible host crop to bring about a serious plant disease problem (9, 17, 19).

The burning of potato vines may be of value (8) by delaying the buildup of inoculum. This is particularly true on "new" potato ground and ground that has been recently fumigated with an effective fungicide (e.g., chloropicrin, metham-sodium).

Rotation

After several successive potato crops, the level of soilborne inoculum is generally sufficient to cause severe wilt. This inoculum is long-lasting in soil and with grain rotations, the minimum time period to effectively reduce inoculum in moderately-infested land generally requires at least 5 to 10 years. In "old" potato ground, the short rotation practices commonly used (2 to 3 years) are ineffective (2, 4). The use of rotation, as presently practiced, does not result in effective control of *V. dahliae.*

Inoculum Density and Association with Cultural Practices

The results of soil assays for *V. dahliae* suggest that an inoculum density (ID) of 10 cfu/gm of air-dried soil approximates the threshold density needed to cause an economically significant problem in Idaho. Using a similar procedure for soil assay determinations, Nnodu and Harrison (15) estimated the threshold ID to lie between 18 and 23 cfu of *V. dahliae*/gm of soil in Colorado. Davis, *et al.* (7) reported yield increases (>46%) of the Russet Burbank potato when *V. dahliae* ID was reduced by soil solarization from 9.7 to 0.3 cfu/gm in the upper 15 cm of the soil profile. Since these yield responses were negatively correlated with both the incidence of wilt and *V. dahliae* stem colonization, this yield response was attributed to reduction of soilborne *V. dahliae* ID.

From 1975 through 1978, surveys of soilborne populations of *V. dahliae* were made from 159 potato fields in Idaho. Collections were uniformly made from potato fields that had been planted on similar dates with the Russet Burbank potato. The most impressive fact to evolve from these investigations was the lack of a consistent relationship between inoculum levels and disease severity (3). Even with high inoculum levels (> 100 cfu/gm of air-dried soil), the symptoms of Verticillium wilt did not always correlate with the amount of soilborne inoculum. Instead, cultural management practices that involved irrigation and plant nutrition were found to closely correlate with the incidence of Verticillium wilt and with the colonization of *V. dahliae* in potato stem tissue. The method of irrigation correlated with both wilt severity and *V. dahliae* stem colonization. When compared with sprinkler irrigation, the disease was most severe with gravity-flow, furrow irrigation. These data support earlier investigations by McMaster (14), who compared the effects of sprinkler irrigation with gravity irrigation in replicated plots. His investigations demonstrated a significant suppression of Verticillium wilt when plots were irrigated by sprinkler. Although the reason for this relationship is not known, it has been suggested (2) that the difference may be related to N availability. With gravity-flow irrigation, N accumulates within the upper 7.5-15.0 cm of the soil profile. In contrast, N may be more uniformly distributed throughout the soil with sprinkler irrigation. When N is less available to roots because of leaching and poor distribution, the disease becomes more severe (2).

A wide range of cultural factors in addition to irrigation method has also been associated with Verticillium wilt. In southeastern Idaho, field surveys have shown close relationships between the electrical conductivity (EC) of soil, NO_3, K, and P levels in petioles (collected early in the growing season prior to mid-July) with *V. dahliae* colonization in potato stems. These cultural variables explained 71% of the field variability related to *V. dahliae* colonization in stems of Russet Burbank potato (3).

Among cultural factors considered, the relation of N has been most frequently associated with Verticillium wilt of potato. A separate survey that was conducted in the Egin Bench area of Idaho during 1978 exemplifes this relationship. This region is an area with unusually high ID levels (32-452 cfu/gm of air-dried soil) and with a method of irrigation that is different from most other regions in Idaho (sub-irrigation). With this investigation, 21 variables were studied (e.g., nematode populations, populations of *Colletotrichum atramentarium* in soil and stems, nutritional factors, and *V. dahliae* populations in soil). From these variables (in a region where soilborne inoculum was not a limiting factor), the availability of N was found to be the most closely related to the degree of colonization of plant tissue by *V. dahliae.* As the availability of N increased, *V. dahliae* colonization in plant tissue was least. Colonization of *V. dahliae* in potato stem tissue was found to be most closely related to both yield and tuber size—with increased *V. dahliae* colonization, yield and size were least. Even with extremely high ID levels (> 250 cfu/gm of soil), however, disease development in some fields was not always severe and in certain instances, yields were even acceptable (> 30.1 metric T/ha). These fields were characterized by petiole NO_3-N levels on 6 July that exceeded 21,000 ppm.

Chemical Control

Verticillium wilt may be controlled by a variety of fumigation treatments that have fungicidal activity [Telone C (dichloropropene and chloropicrin), chloropicrin, Vapam (metham-sodium), Vorlex (methyl isothiocyanate and chlorinated hydrocarbons), Terr-o-cide D (mixtures of ethylene dibromide and chloropicrin)] (13, 16), but cost is a limiting factor for the widespread application of these products. To a limited degree, nematicides [e.g., D-D, Telone (dichloropropenes), Temik (aldicarb)] have also suppressed Verticillium wilt, but these products have not been shown to have a direct effect on soil populations of *V. dahliae.*

Table 1 summarizes the effects of fumigation treatments over a 4-year period at Ft. Hall, Idaho where the Russet Burbank potato has been continuously cropped on the same ground. After 4 years of continuous cropping, the mean maximum yield benefit to be obtained from these treatments was 6.5 metric T/ha (57 cwt/A). Yield was inversely related to severity of Verticillium wilt (higher yields with less wilt). Although treatments were only significantly effective if applied every year, significant differences were observed between soil population levels of *V. dahliae* a year after the final treatment (into 1975).

TABLE 1. — *Effects of fumigation treatments on yield and soil populations of* Verticillium dahliae *with annual cropping of potato-Ft. Hall, Idaho.*

Treatment	Yield (1971-1974)[1] Treated each year Total	Treated each year U.S. #1	Treated every other year Total	Treated every other year U.S. #1	Cfu *V. dahliae*/ gm of soil 1-yr after treatment-1975
Untreated	30.4X[2]	16.5A[3]	31.3[4]	17.5[4]	67BC[3]
Dichloropropene (DP)					
281 L/ha	33.8XY	19.1AB	32.3	17.3	123A
DP + 15% picfume 187 L/ha	36.1Y	21.2B	34.2	19.6	72BC
DP + 15% picfume 281 L/ha	36.9Y	21.8B	34.4	20.4	21CD
DP + 30% picfume 187 L/ha	34.9Y	20.1B	34.4	20.3	21CD
DP + 30% picfume 281 L/ha	35.7Y	20.3B	35.1	20.4	15D

[1]Metric T/ha (equal to 8.9 cwt/A).
[2]Different letters within a column indicate significant differences at P = 0.01 level.
[3]Different letters within a column indicate significant differences at P = 0.05 level.
[4]Differences not significant.

Data from replicated field plots (Table 2) indicate that significant interactions can occur between soil fumigation treatments (dichloropropene and 15% chloropicrin at 281 L/ha) and N availability. With a deficiency of N, Verticillium wilt in the Russet Burbank potato was found to be most severe. As the availability of N approached the optimum for highest yield, the severity of the disease was less and this relationship was inversely related with yield. In contrast, this same relationship has not been found to occur with Norgold Russet, which is a more determinant growth type (Davis, unpublished). These observations suggest a genotypic relationship to the N response.

TABLE 2. — *Relationships of nitrogen and fumigation treatments to Verticillium wilt severity and yield of Russet Burbank potato.*

Treatments		Percent total N in petioles[1]	Percent petioles with *V. dahliae*[2]	Percent stems with visible wilt[3]	Yield (metric T/ha)
kg N/ha	Fumigation				
0	Untreated	1.85ab[4]	13a[4]	62a[4]	18.7a[4]
0	DP[5] + 15% chloropicrin	1.76a	7b	31b	25.6ab
168	Untreated	2.18c	4bc	42b	25.1ab
168	DP + 15% chloropicrin	2.40d	1c	10c	36.8c
336	Untreated	2.43d	3bc	34b	24.0ab
336	DP + 15% chloropicrin	2.54d	1c	17c	28.9b

[1]Petioles collected 3 July.
[2]Mean values based on results of isolations from 300 petioles/treatment collected 5 August.
[3]> 75% of stem with symptoms ranging from severe yellowing to death.
[4]Different letters within columns denote significant differences at P = 0.05.
[5]Dichloropropene.

Disease Resistance

Russet Burbank possesses a degree of resistance to *V. dahliae* (2, 5) and proper cultural management (e.g., irrigation and fertility) can enhance this resistance in some cultivars. The relationship between N level and tolerance to *V. dahliae* was demonstrated with three potato genotypes (Table 3). Wilt symptoms of two susceptible cultivars (Butte and Russet Burbank) were suppressed with increased N availability. With wilt suppression, yields were increased and the percentage of undersized potatoes was reduced. These results emphasize the importance of N fertility level on foliar wilt development and indicate the need for maintaining low to moderate N levels when comparing cultivars for wilt resistance.

Although Russet Burbank possesses a moderate degree of field resistance to *V. dahliae,* Targhee and Katahdin are more resistant. Hunter, *et al.,* (11) concluded that Katahdin may give rise to a large percentage of tolerant lines upon selfing and that this cultivar may possess recessive genes for resistance. Krikun and Orion (13) indicate that Katahdin is a common ancestor of Israeli genotypes with tolerance to Verticillium wilt.

TABLE 3. — *Increased tolerance to Verticillium wilt in three susceptible potato clones with increased nitrogen availability.*

Nitrogen rate applied	Mean ppm[1] NO_3-N in petioles	Percent stems with severe Verticillium symptoms[2]			Yield (metric T/ha)[3]			
		Butte	Burbank	A66107-51	Total	U.S. 1	<4 oz	Mal
112 kg/ha	10,903A[4]	26A[4]	18A[4]	0A	29.3A[4]	18.0A[4]	9.3A[4]	2.0A[4]
224 kg/ha	17,014B	20A	10AB	0A	32.8B	21.5B	8.3B	2.9B
336 kg/ha	19,347C	7B	7B	0A	32.6B	22.2B	7.2C	3.3C

[1]Petioles were collected 16 July and represent mean values among all three potato clones.
[2]Symptoms were determined on 30 August. Wilt symptoms were highly correlated with *V. dahliae* colonization of apical stems ($r = 0.413$, $P = 0.01$).
[3]Mean yield values for all potato clones.
[4]Different letters within columns denote significant differences at $P = 0.05$.

For over 25 years, the potato breeding program at Aberdeen, Idaho has been breeding for Verticillium wilt resistance. Potato clones with high levels of resistance are available. Extensive testing of these clones indicates that true resistance to colonization of stem tissue by *V. dahliae* has been combined with desirable characteristics of vine and tuber that are similar to those of Russet Burbank. Among clones that have been found to possess a high degree of resistance are A66107-51 (-51) and A68113-4 (-4). Although Katahdin is a common ancestor of both clones, they also derive resistance from the Jubel cultivar. These clones have been studied extensively and have been found to possess many desirable characters. The rate of maturity (defined by vine growth/tuberization ratios) of these clones is similar to that of Russet Burbank (1) and with Verticillium wilt resistance these clones possess a high yield potential. When five potato clones of differing resistance to *V. dahliae* were cropped for 5 consecutive years on the same ground, the potato genotypes with the highest degree of *V. dahliae* resistance were -51 and -4 (6). With each year of continuous cropping, the relative Verticillium wilt severities of the two highly resistant clones (-51 and -4) have remained negligible (< 1.0%) while that of the more susceptible cultivars (Russet Burbank and Butte) have consistently exceeded 39%. During this 5-year project, yields of -51 have ranged from 26 to 110% higher than Russet Burbank, while yield increases of -4 have ranged from 38 to 142% higher.

Conclusion

Verticillium wilt of potato can be controlled with resistant genotypes, but market acceptance of these cultivars has not been widespread. We can also control this disease by a variety of fumigation treatments, but these treatments are commonly too expensive to be justified for *V. dahliae* control alone. We can suppress Verticillium wilt of Russet Burbank with cultural practices that involve soil solarization, irrigation and nutrition. The utilization of optimal growing conditions may currently provide us with one of the most viable solutions to the Verticillium wilt problem in Russet Burbank.

For the future, the improved utilization of resistant germplasm may ultimately provide the means to manage and conquer this disease. The possibilities for success are many. Identification and characterization of microflora with beneficial effects on plant growth and/or disease suppression may also provide viable solutions. It is possible that biological control techniques may ultimately provide the most lasting economic approach for suppression of Verticillium wilt of potato. If soils can be rendered suppressive through the addition of biological competitors, the influence of fumigants may be extended and the cost reduced. With an understanding of pathogen suppression, the need for pesticides may be reduced and/or eliminated.

Acknowledgments

Much of the work described herein was supported by the Idaho Potato Commission.

Idaho Agricultural Experiment Station Research Paper No. 84711. Department of Plant, Soil and Entomological Sciences, University of Idaho, Aberdeen, ID 83210.

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