Verticillium dahliae Infects Specific Rotational Crops of Potato in the Columbia Basin, WA

David L. Wheeler and Dennis A. Johnson
Department of Plant Pathology, Pullman, WA.

ABSTRACT:

Certain rotational crops of potato may potentially reduce Verticillium wilt, caused by *Verticillium dahliae,* however inconsistent results suggest that specific rotational crops may be infected by *V. dahliae*. Experimental inoculations and field surveys were used to test the hypothesis that selected rotational crops of potato are asymptomatically infected by *V. dahliae* in the Columbia Basin, WA. Rotational crops including mustards, grasses, and Austrian winter pea, and susceptible crops peppermint, native mint, and potato were planted in soil infested with eight isolates of *V. dahliae* from various hosts. The isolates represented two vegetative compatibility groups, both mating types, and distinct genotypes. Crops were grown to senescence and assayed for *V. dahliae* on semi-selective media. Despite no disease expression, at least one *V. dahliae* isolate was detected from the stems, roots and soil of all the rotational crops tested. The isolate of the mating type detected least frequently in nature (*MAT*1-1) was detected at greater (P<0.05) colony forming unit/g (CFU/g) of stems from four of seven crops than isolates of the other mating type (*MAT*1-2). Less CFU/g of stems were detected from the grasses inoculated with seven of eight isolates than potato, Austrian winter pea and arugula. Several *V. dahliae* isolates were detected from the seed of arugula and Austrian winter pea. Differences in soil population densities between crops were detected in soils infested with four of eight isolates. Interactions between rotational crops and *V. dahliae* isolates suggest that crops should be screened against a collection of *V. dahliae* isolates before being planted to avoid infections resulting in inoculum production. Results were validated by collecting stem samples of rotational crops grown in fields with a history of Verticillium wilt of potato in the Columbia Basin, WA. *V. dahliae* was detected in stems of rotational crops in four of six fields and stem incidence varied from 0% in arugula, to 2% in millet and wheat and, 6-63% in white and brown mustards. Results indicate that certain rotational crops of potato can be asymptomatically infected by different isolates of *V. dahliae*. The distribution, pathogenicity, and genotypes of *V. dahliae* isolates infecting rotation crops needs to be determined.

INTRODUCTION:

Verticillium dahliae infects a diversity of plant species, causing Verticillium wilt symptoms in hundreds of dicotyledonous species (19) and no disease symptoms in various other species. Disease expression varies across symptomatic hosts and generally includes stunting, wilting, and premature senescence (1). In the Pacific Northwest, potato (*Solanum tuberosum*) and mint (*Mentha*) production systems, which may occur in rotation which each other, sustain yield losses due to *V. dahliae* of up to 50% in potato (4).

V. dahliae persists in soil for more than 10 years (25) as multicellular, melanized microsclerotia. Microsclerotia germinate in response to plant root exudates (10,17) and infect roots, resulting in a continuum of host-fungus interactions (15, 21). Upon infection of host xylem tissue, conidia are produced and translocated apically through the xylem vessels where they occlude perforation plate apertures, restrict evapo-transporation, and incite symptom expression (10, 3). Symptomatic host infections culminate in disease expression whereas asymptomatic infections do not (15). Microsclerotia are produced during host senescence in symptomatic and may be produced in asymptomatic host tissues (6, 15, 16) and are returned to the soil by cultivation and decomposition of infested plant debris.

Control of Verticillium wilt of potato has depended on soil fumigation, host resistance, cultural practices, and crop rotations (12). Despite the wide host range and persistence of *V. dahliae* in soils (25) crop rotation is being actively investigated as a potential disease control tactic (2, 9, 13, 11, 14, 20, 23). Mixed reports indicate that crop rotations can increase yields (14, 18, 22) and reduce or impart no effects on disease incidence (14, 22, 24) and *V. dahliae* soil population densities (7,14, 22, 24).

In the Columbia Basin of WA, brown (*Brassica juncea*) and white (*Sinapis alba*) mustards, and several grasses, including sudangrass (*Sorghum bicolor sudanense*), corn (*Zea mays*), and millet (*Panicum milliaceum*) are planted in rotation with potato. After sowing, rotational crops are either tilled into the soil as green manure crops or grown until harvest for seed. Green manure crops can contribute to soil quality, subsequent crop yields (18), and disease suppression (5) and have therefore been planted by growers in the Columbia Basin (Figure 1).

Despite the widespread adoption of rotational crops, reductions in *V. dahliae* soil population densities (7, 14) following rotational crops are not always observed, indicating that some of these crops may be infected by *V. dahliae*. Controlled experimental inoculation and field surveys were used to test the hypothesis that several rotational crops of potato are infected with *V. dahliae.*

MATERIALS AND METHODS:

Experimental inoculations: Two brown mustards (*Brassica juncea* ISCI '199' and *B. juncea* 'Pacific Gold') , white mustard (*Sinapis alba* 'Martigena'), sudangrass (*Sorghum bicolor sudanense* 'Piper'), sweetcorn (*Zea mays* 'Marvel*'),*wheat *(Triticum aestivum* 'Alpowa'), peppermint (*Mentha x piperita* 'Black Mitchum'), native mint (*M. spicata)*, and potato (*Solanum tuberosum* 'Norkotah') were planted in potting media artificially infested with 30 CFU/g of *V. dahliae* isolates from potato (653) or mint (111), in one repeated trial. Arugula (*Eruca sativa* 'Nemat'), Austrian winter pea (*Pisum sativum* subsp. *arvense*), sudangrass (*Sorghum bicolor sudanense* 'Piper'), sweetcorn (*Zea mays* 'Marvel*'),* barley (*Hordeum vulgare* 'Baroness'), peppermint (*Mentha x piperita* 'Black Mitchum'), and potato (*Solanum tuberosum* 'Norkotah') were planted in sand-based media artificially infested with 10 CFU/g of eight *V. dahliae* isolates from various hosts, in a second trial. The isolates represented two vegetative compatibility groups, both mating types, and distinct genotypes (Table 1) (8). Plants were arranged in a randomized complete block design and grown under greenhouse conditions.

Crops were harvested and stems, roots, seed and soil were assayed for *V. dahliae* on semi-selective media upon senescence. Stems were subsequently incubated and observed for development of microsclerotia. Vine senescence and yield data were also collected. Analysis of variance was performed with PROC GLM in SAS (version 9.2; SAS Institute, Cary, NC). Log-transformations of stems, roots, and soil data were necessary to satisfy the assumption of homogeneous variances. Raw data are presented with mean separation letters assigned after logtransformation. Trials within the first experiment were combined since no significant (P<0.05) trial by host or isolate interactions were observed.

Field Survey: A stratified-random sampling technique was used to collect stems of rotational crops, including arugula (*Eruca sativa* ‘Nemat’), sunflower (*Helianthus annuus*), brown mustard (*B. juncea* ISCI 199), white mustard (*S. alba* ‘Martigena’), wheat (*T. aestivum*), and millet (*Panicum milliaceum* ‘Proso’), during 2013 in 6 fields with a history of Verticillium wilt of potato in the Columbia Basin. Stems were assayed for *V. dahliae* on semi-selective media.

RESULTS:

Experimental inoculations: Both *V. dahliae* isolates were detected from the stems of potato ‘Norkotah’, brown mustards ‘Pacific Gold’ and ISCI 199, and white mustard ‘Martigena’, while only *V. dahliae* 111 was detected from the stems of wheat ‘Alpowa’ (Table 2), in the first trials (Table 2). Greater stem incidence (P<0.05) of both *V. dahliae* isolates were detected from potato ‘Norkotah’ stems than from the mustards and wheat ‘Alpowa,’ except within *V. dahliae* 111 where basal stem incidence of brown mustard ‘Pacific Gold’ was not significantly different from other crops. Greater root incidence (P<0.05) of both *V. dahliae* isolates was detected from potato ‘Norkotah’ roots than from other crops, except within *V. dahliae* 111 where root incidence of wheat ‘Alpowa’ was not significantly different from potato ‘Norkotah.’ Greater CFU/g of soil (P<0.05) of both *V. dahliae* isolates were detected from soil where mints were grown relative to potato ‘Norkotah,’ wheat ‘Alpowa,’ and sudangrass ‘Piper.’ A significant interaction (P<0.05) between rotational crops and *V. dahliae* isolates was observed where greater CFU/g of soil of *V. dahliae* (111) were detected in soils where all crops were grown, except sweetcorn where greater CFU/g of soil of *V. dahliae* (653) were detected.

At least one of eight *V. dahliae* isolates were detected from the stems, roots and soil of each crop, in the second trial (Table 3). Isolate 461 of one mating type (*MAT*1-1) was detected at greater CFU/g of stem from stems of five of seven rotational crops than isolates of the other mating type (*MAT*1-2) (data not shown). Isolate 461 was also the only isolate detected from sudangrass (*S. bicolor sudanense* ‘Piper’) stems while *V. dahliae* 381 was the only isolate detected from sweetcorn (*Z. mays* ‘Marvel’) stems. Greater CFU/g were detected from potato stems and arugula roots inoculated with five and four of eight *V. dahliae* isolates than other crops, respectively. An interaction (P<0.0001) was observed between rotational crops and *V. dahliae* isolates where greater CFU/g of stem of *V. dahliae* were detected in stems of potato, except in isolates 155, and VMD-4 where greater CFU/g of stem were detected from arugula and Austrian winter pea, respectively. Two and five of eight *V. dahliae* isolates were detected from the seed of arugula and Austrian winter pea, respectively. Five of eight *V. dahliae* isolates were detected from the progeny tubers of potato. No differences in soil population densities were detected between soils where crops were grown vs. the non-planted fallow.

Field Survey: *V. dahliae* was detected in stems of sunflower (*Helianthus annuus*), brown (*B. juncea* ISCI 199) and white (*S. alba* ‘Martigena’) mustards, wheat (*T. aestivum*), and millet (*Panicum miliaceum* ‘Proso’) from four of six surveyed fields (Figure 2). In each field stem incidence varied from 0% in arugula ‘Nemat,’ to 2% in wheat and millet ‘Proso,’ 16% in sunflower, and 6-63% in white ‘Martigena’ and brown ISCI 199 mustards, respectively. Additionally, microsclerotia were observed on the stems of the mustards and grasses in greenhouse experiments and field surveys (Figure 3, d-f).

CONCLUSION:

Both experimental inoculations and field surveys demonstrated that specific rotational crops of potato can be asymptomatically infected by *V. dahliae* (Tables 2-3; Fig. 2). This is the first report of asymptomatic infections of white mustard (*S. alba* 'Martigena'), brown mustard (*B. juncea* 'Pacific Gold' and *B. juncea* ISIC 199), arugula (*E. sativa* 'Nemat'), sweetcorn (*Z. mays* 'Marvel'), and sudangrass (*S. bicolor* sudanense 'Piper') by *V. dahliae* to our knowledge.

Additionally, *V. dahliae* isolates from various susceptible hosts, VCGs, both mating types, and distinct genotypes (Table 1) differentially infect selected rotational crops. Specifically, *V. dahliae* 461 of the mating type detected least frequently in nature (*MAT*1-1) was generally detected at greater CFU/g of stem than isolates with the other mating type (*MAT*1-2). Isolates 461 and 381 were also the only isolates detected from the stems of sudangrass (*S. bicolor sudanense* 'Piper') and sweetcorn (*Z. mays* 'Marvel'), respectively. Interactions between rotational crops and *V. dahliae* isolates suggest that candidate rotational crops should be screened against a representative collection of *V. dahliae* isolates before being planted to avoid infections resulting in significant production of microsclerotia.

Despite infections of rotational crops, greater CFU/g of stem were detected in potato 'Norkotah' stems than stems of rotational crops in five of seven *V. dahliae* isolates (Table 3). Together with abovementioned experimental and anecdotal evidence that rotational crops reduce Verticillium wilt, this suggests that these infections may not significantly contribute to soilborne inoculum and future Verticillium wilt epidemics.

Evidence that specific rotational crops of potato can be infected by certain *V. dahliae* isolates under greenhouse and field conditions was presented. Although preliminary data suggests that these infections may not contribute to future epidemics, it is not known if these infections represent stable forms of tolerance that may be sustained through time or if *V. dahliae* is adapting to these rotational crops. In the former case, growers may plant rotational crops indefinitely. In the latter case, caution should be exercised when planting rotational crops and appropriate crop rotations should be designed to minimize the risk of host adaptation and the emergence of a new Verticillium wilt. To assess the effects of these infections on Verticillium wilt epidemics, the distribution, pathogenicity on potato, and genotypes of *V. dahliae* isolates infecting rotational crops needs to be determined.

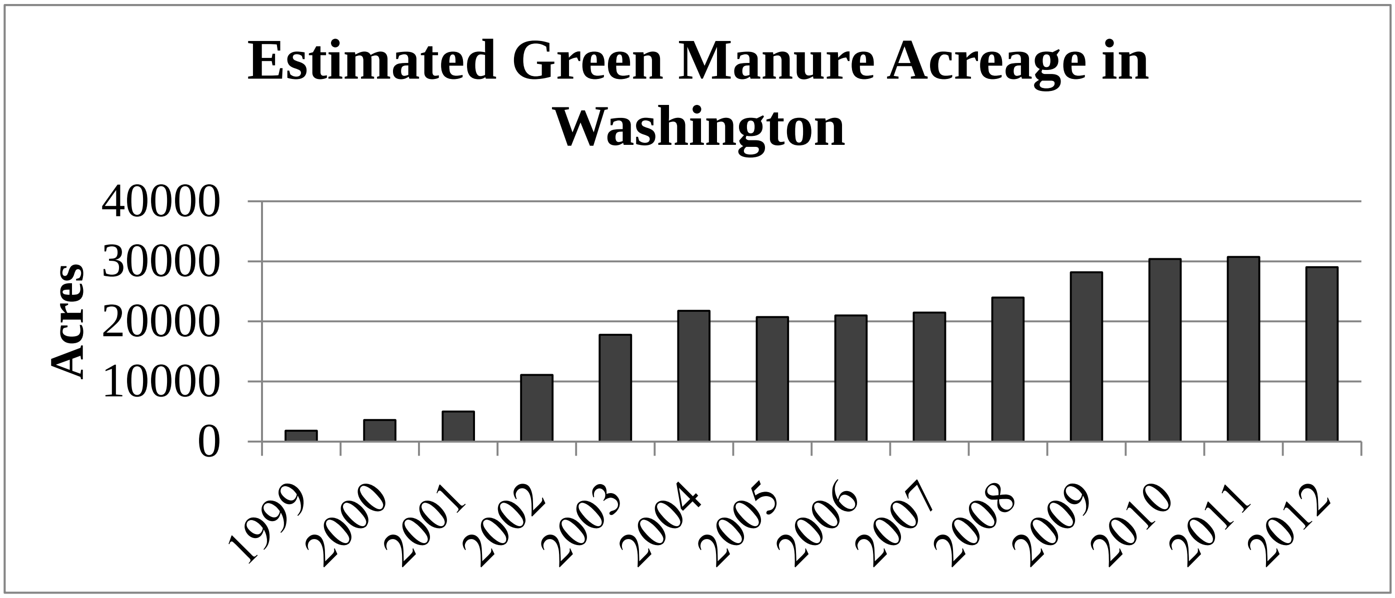

Figure 1. Estimated green manure acreage in Washington from 1999-2012. Modified from estimates by Andy McGuire based on mean seeding rate of 10 lbs./ acre.

Table 1. *Verticillium dahliae* isolates (8) from various hosts, vegetative compatibility groups (VCG), genotypes, and mating types used in experimental inoculations.

V. dahliae isolate	Host	VCG	Multilocus haplotype	MAT idiomorph
111	Peppermint	2B	H02	*MAT1-2*
653	Potato	4A	H04	*MAT1-2*
155	Peppermint	4A	H04	*MAT1-2*
VD5VSP699	Spinach	2B(4B	H07	*MAT1-2*
49.B.2010	Potato	4B	H07	*MAT1-2*
381	Watermelon	2A/B	H24	*MAT1-2*
461	Tomato	2	H37	*MAT1-1*
VMD-4	Tomato	2A/B	H38	*MAT1-2*

Table 2. Stem and root infections, soil population densities, and area under the senescence progress curve (AUSPC) of crops grown in soil infested with 30 CFU/g of *Verticillum dahliae* isolates from potato (653) and peppermint (111).

Hosts	Stems[a] (% stem incidence) Basal	Stems[a] (% stem incidence) Apical	Roots[a] (CFU 60 cm^{-1} of root)	Soil[b] (CFU g^{-1} of soil)	AUSPC[a]
Verticillium dahliae potato pathotype (653)					
Potato 'Norkotah'	0.8 a	0.8 a	9.5 a	31.0 cd	90.7 a
Peppermint	0.0 c	0.0 c	0.2 b	168.3 ab	26.8 b
Native Mint	0.0 c	0.0 c	0.4 b	255.8 a	.
White mustard 'Martigena'	0.2 bc	0.1 bc	0.9 b	42.7 abcd	.
Brown mustard 'Pacific Gold'	0.2 bc	0.1 bc	0.1 b	127.0 abc	.
Brown mustard ISCI 99	0.3 b	0.3 b	0.1 b	51.3 bcd	.
Sweetcorn 'Marvel'	0.0 c	0.0 c	0.1 b	105.3 abc	.
Wheat 'Alpowa'	0.0 c	0.0 c	0.8 b	8.3 d	.
Sudangrass 'Piper'	0.0 c	0.0 c	0.1 b	6.3 d	.
L.S.D	0.2	0.2	3.1	130.3	42.5
Verticillium dahliae mint pathotype (111)					
Hosts	Stems[a] (% stem incidence) Basal	Stems[a] (% stem incidence) Apical	Roots[a] (CFU 60 cm^{-1} of root)	Soil[b] (CFU g^{-1} of soil)	AUSPC[a]
Potato 'Norkotah'	0.7 a	0.7 a	11.5 a	73.6 de	83.5 a
Peppermint	0.0 c	0.0 b	0.1 c	294.3 a	54.5 a
Native Mint	0.0 c	0.0 b	1.5 bc	260.0 a	.
White mustard 'Martigena'	0.3 b	0.3 b	0.6 c	155.0 ab	.
Brown mustard 'Pacific Gold'	0.2 bc	0.2 b	1.1 bc	311.7 a	.
Brown mustard ISCI 99	0.4 ab	0.2 b	0.2 c	96.3 abc	.
Sweetcorn 'Marvel'	0.0 c	0.0 b	0.2 c	17.3 e	.
Wheat 'Alpowa'	0.0 c	0.1 b	2.5 ab	60.3 bcd	.
Sudangrass 'Piper'	0.0 c	0.0 b	0.4 c	56.7 cd	.
L.S.D	0.2	0.3	6	132.9	52.9

[a]Mean separation letters were assigned within stems, roots, and AUSPC with Fisher's protected least significance difference. Means that share the same letter are not significantly different (P<0.05).
[b]Mean separation letters from log-transformed data were assigned to raw soil data with Fisher's protected least significance difference. Means that share the same letter are not significantly different (*P*<0.05).

Table 3. Stem, seed, and root infections, soil population densities and area under the senescence progress curve (AUSPC) of crops grown in soil infested with 10 CFU/g of eight *Verticillium dahliae* isolates.

Verticillium dahliae potato pathotype (653)

Hosts	Stems[a] (CFU g⁻¹)	Seed[a] (% infested)	Roots[a] (CFU g⁻¹)	Soil[a] (CFU g⁻¹)	AUSPC[b]
Potato 'Norkotah'	976.2 a	0.0 a	13.8 d	17.0 a	6361.5 a
Peppermint 'Black Mitchum'	2.4 cd	0.0 a	138.6 ab	39.8 a	5.5 b
Arugula 'Nemat'	60.4 b	0.0 a	377.6 a	26.4 ab	.
Austrian Winter Pea	121.2 b	0.02 a	93.2 b	15.0 ab	.
Sweetcorn 'Marvel'	0.0 d	0.0 a	93.0 b	22.6 ab	.
Barley 'Baroness'	3.6 c	0.0 a	19.2 cd	25.4 ab	.
Sudangrass 'Piper'	0.0 d	0.0 a	63.9 bc	10.6 b	.
Fallow	.	.	.	12.4 ab	.
L.S.D	99.9	0.04	82.5	28.6	844.2

Verticillium dahliae mint pathotype (111)

Hosts	Stems[a] (CFU g⁻¹)	Seed[a] (% infested)	Roots[a] (CFU g⁻¹)	Soil[a] (CFU g⁻¹)	AUSPC[b]
Potato 'Norkotah'	1022.4 a	0	14.6 c	7.4 a	6440.0 a
Peppermint 'Black Mitchum'	5.8 d	0	86.6 ab	16.2 a	0.0 b
Arugula 'Nemat'	60.0 c	0	190.0 a	11.9 a	.
Austrian Winter Pea	149.6 b	0	40.8 b	7.8 a	.
Sweetcorn 'Marvel'	0.0 e	0	12.4 c	13.3 a	.
Barley 'Baroness'	2.8 d	0	12.6 c	5.5 a	.
Sudangrass 'Piper'	0.0 e	0	10.0 c	2.4 a	.
Fallow	.	.	.	7.7 a	.
L.S.D	93.8	0	35.9	17	603.9

Verticillium dahliae from peppermint (155)

Hosts	Stems[a] (CFU g⁻¹)	Seed[a] (% infested)	Roots[a] (CFU g⁻¹)	Soil[a] (CFU g⁻¹)	AUSPC[b]
Potato 'Norkotah'	17.4 b	0	5.7 bc	3.4 a	6918.0 a
Peppermint 'Black Mitchum'	0.4 d	0	31.8 ab	7.1 a	17.5 b
Arugula 'Nemat'	86.0 a	0	108.0 a	7.3 a	.
Austrian Winter Pea	50.4 b	0	36.4 cd	3.7 a	.
Sweetcorn 'Marvel'	0.0 d	0	17.8 bc	2.9 a	.
Barley 'Baroness'	4.2 c	0	0.0 d	7.9 a	.
Sudangrass 'Piper'	0.0 d	0	5.6 cd	1.9 a	.
Fallow	.	.	.	2.2 a	.
L.S.D	44.3	0	43.6	7.3	454.1

Verticillium dahliae from spinach (VD5)

Hosts	Stems[a] (CFU g⁻¹)	Seed[a] (% infested)	Roots[a] (CFU g⁻¹)	Soil[a] (CFU g⁻¹)	AUSPC[b]
Potato 'Norkotah'	1014.2 a	0	28.3 b	2.1 a	6355.0 a
Peppermint 'Black Mitchum'	0.0 e	0	6.8 c	2.6 a	49.0 b
Arugula 'Nemat'	93.0 c	0	224.8 a	1.0 a	.
Austrian Winter Pea	306.4 b	0	38.0 b	1.4 a	.
Sweetcorn 'Marvel'	0.0 e	0	10.4 c	1.4 a	.
Barley 'Baroness'	4.6 d	0	0.0 d	2.0 a	.
Sudangrass 'Piper'	0.0 e	0	0.60 d	2.6 a	.
Fallow	.	.	.	4.1 a	.
L.S.D	144.3	0	21.7	4.7	653

Verticillium dahliae from potato (49.B)

Hosts	Stems[a] (CFU g⁻¹)	Seed[a] (% infested)	Roots[a] (CFU g⁻¹)	Soil[a] (CFU g⁻¹)	AUSPC[b]
Potato 'Norkotah'	1014.8 a	0.0 a	27.9 b	2.9 ab	5923.5 a
Peppermint 'Black Mitchum'	5.4 d	0.0 a	74.8 b	3.9 ab	47.5 b
Arugula 'Nemat'	77.2 c	0.01 a	231.2 a	0.8 b	.
Austrian Winter Pea	412.0 b	0.02 a	94.0 b	9.7 a	.
Sweetcorn 'Marvel'	0.0 e	0.0 a	8.8 c	6.0 ab	.
Barley 'Baroness'	3.4 d	0.0 a	5.8 c	10.2 ab	.
Sudangrass 'Piper'	0.0 e	0.0 a	18.6 c	2.0 ab	.
Fallow	.	.	.	1.8 ab	.
L.S.D	248.3	0.05	63.7	9	1105.4

Verticillium dahliae from watermelon (381)

Hosts	Stems[a] (CFU g⁻¹)	Seed[a] % infested)	Roots[a] (CFU g⁻¹)	Soil[a] (CFU g⁻¹)	AUSPC[b]
Potato 'Norkotah'	425.6 a	0.0 a	63.9 bc	30.6 ab	6412.0 a
Peppermint 'Black Mitchum'	1.0 d	0.0 a	165.6 abc	47.8 a	0.00 b
Arugula 'Nemat'	54.0 b	0.004 a	213.6 ab	28.7 ab	.
Austrian Winter Pea	606.4 a	0.1 a	330.8 a	16.2 b	.
Sweetcorn 'Marvel'	0.8 d	0.0 a	80.2 c	17.1 b	.
Barley 'Baroness'	2.4 c	0.0 a	5.0 d	13.6 ab	.
Sudangrass 'Piper'	0.0 d	0.0 a	18.8 d	9.3 b	.
Fallow	.	.	.	20.1 ab	.
L.S.D	198.5	0.1	58.3	30.6	312.4

Verticillium dahliae from tomato (461)

Hosts	Stems[a] (CFU g^{-1})	Seed[a] (% infested)	Roots[a] (CFU g^{-1})	Soil[a] (CFU g^{-1})	AUSPC[b]
Potato 'Norkotah'	1197.6 a	0.0 a	52.2 c	22.2 a	6789.0 a
Peppermint 'Black Mitchum'	2.4 e	0.0 a	169.4 b	42.2 a	15.9 b
Arugula 'Nemat'	158.4 c	0.0 a	505.6 a	18.5 a	.
Austrian Winter Pea	539.2 b	0.07 a	244.8 b	34.4 a	.
Sweetcorn 'Marvel'	0.0 f	0.0 a	261.6 b	31.4 a	.
Barley 'Baroness'	8.0 d	0.0 a	61.0 c	38.6 a	.
Sudangrass 'Piper'	3.0 e	0.0 a	95.8 c	17.8 a	.
Fallow	.	.	.	34.8 a	.
L.S.D	119.9	0.2	132.5	28.6	827.6

Verticillium dahliae from tomato (VMD-4)

Hosts	Stems[a] (CFU g^{-1})	Seed[a] (% infested)	Roots[a] (CFU g^{-1})	Soil[a] (CFU g^{-1})	AUSPC[b]
Potato 'Norkotah'	10.8 b	0.0 a	0.2 cd	0.2 ab	6752.5 a
Peppermint 'Black Mitchum'	0.0 c	0.0 a	1.8 b	0.2 ab	5.5 b
Arugula 'Nemat'	2.0 bc	0.0 a	46.4 a	0.04 ab	.
Austrian Winter Pea	30.4 a	0.02 a	1.2 bc	0.1 ab	.
Sweetcorn 'Marvel'	0.0 c	0.0 a	0.8 bcd	0.4 a	.
Barley 'Baroness'	0.2 c	0.0 a	0.0 d	0.0 b	.
Sudangrass 'Piper'	0.0 c	0.0 a	0.0 d	0.04 ab	.
Fallow	.	.	.	0.2 ab	.
L.S.D	13.2	0.04	4.9	0.4	497

[a]Mean separation letters from log-transformed data were assigned to raw stem, seed, root and soil data with Fisher's protected least significance difference. Means that share the same letter are not significantly different (P<0.05).
[b]Mean separation letters were assigned to AUSPC with Fisher's protected least significance difference. Means that share the same letter are not significantly different (P<0.05)

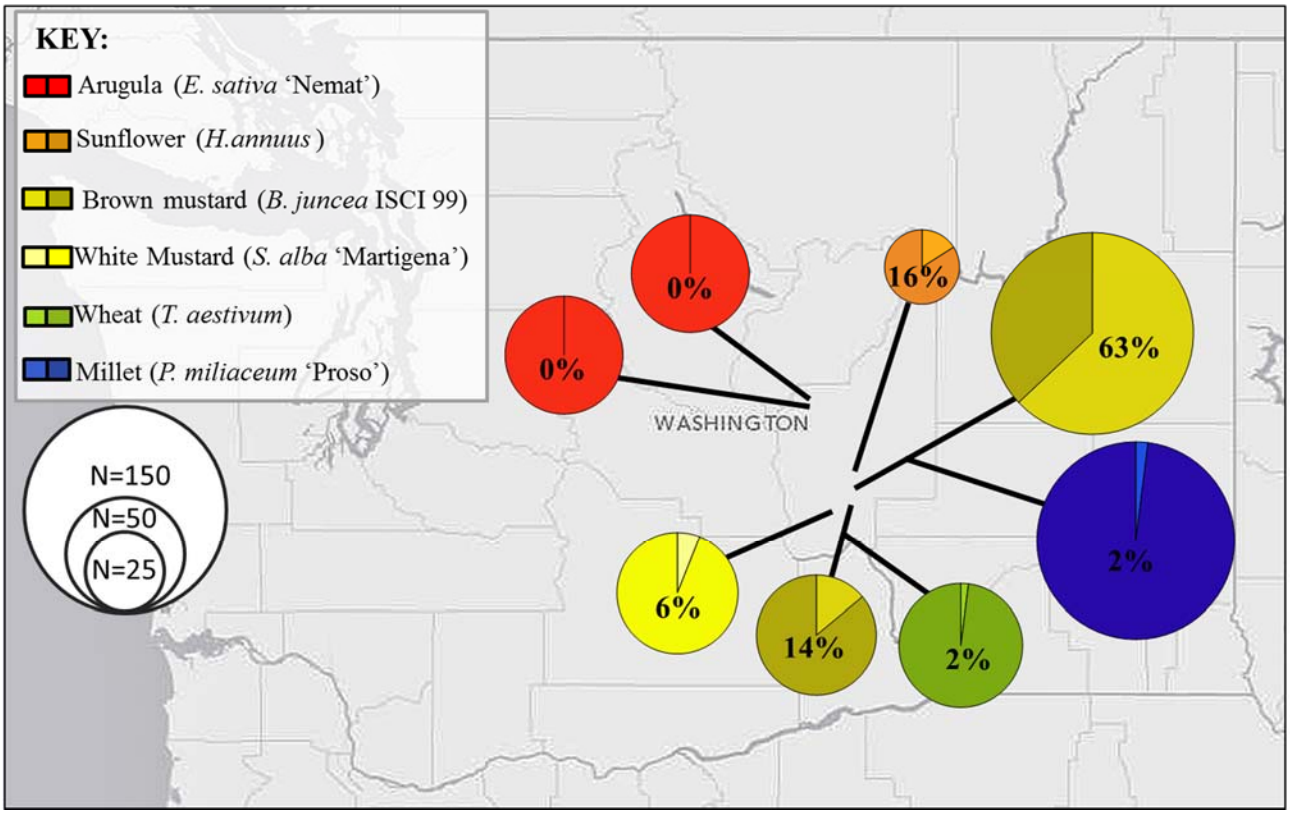

Figure 2. Incidence of *Verticillium dahliae* in stems of rotational crops collected from six fields with a history of Verticillium wilt of potato in the Columbia Basin, WA. Each black line represents a field, each circle represents a crop within each field and the value inside each circle represents *V. dahliae* stem incidence (%).

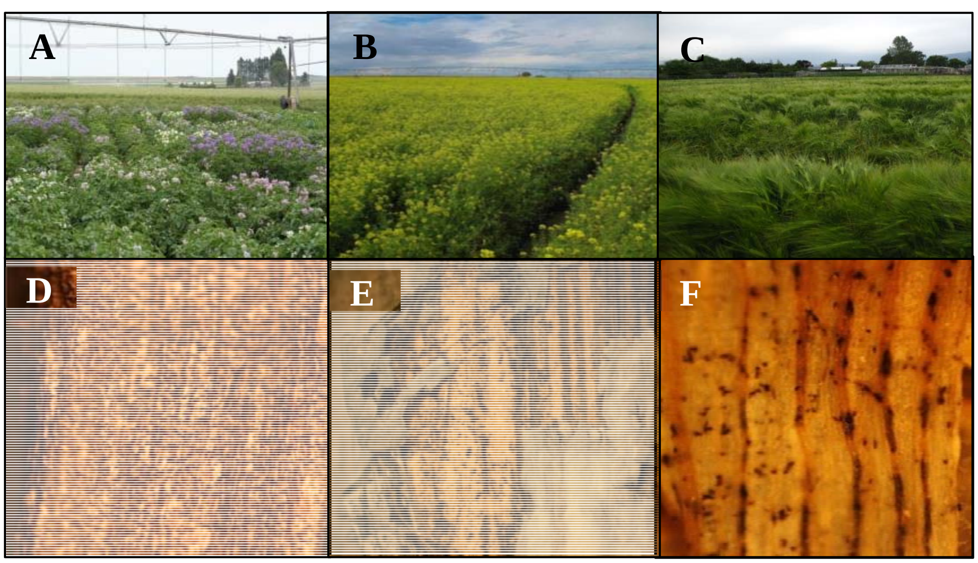

Figure 3. Potato (a), mustard (b) and grass (c) fields with infested stems (d-f).

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