Effect of Extended Crop Rotations on Incidence of Black Dot, Silver Scurf, and Verticillium Wilt of Potato

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Abstract

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Potato tubers were collected and evaluated for symptoms and signs of black dot, silver scurf, and Verticillium wilt to determine the effect of extended crop rotations on disease incidences in the Columbia Basin. Incidence of tubers with black dot collected from storage significantly decreased as the number of years between potato crops increased from 3 to 5 years and beyond and significantly increased as the number of previous potato crops increased to 16. The highest incidence of black dot (range of 73 to 98%) was from fields rotated out of potatoes for 1 to 3 years. The mean incidence of black dot was 56% for fields out of potatoes for 0 to 4 years and 12% for fields out of potatoes 5 and more years. A low incidence (0 to 9%) of black dot was detected at 15 years out of potatoes. Years out of potato and number of prior potato crops accounted for 71% of the variability associated with the incidence of black dot. Severity of black dot on tuber periderm peels significantly increased as incidence of tuber periderm peels with *Colletotrichum coccodes* increased. Coefficient of determination was 0.87 for log severity on regressed on black dot incidence. Incidence of silver scurf was highest from fields out of potatoes for 1 year. Incidence of silver scurf infected tubers significantly increased as the number of previous potato crops increased due to short rotations between potato crops. Incidence of tubers with *Verticillium dahliae* was not related to years between potato crops or number of previous potato crops. The present study confirmed that black dot can be reduced with rotations out of potatoes greater than 5 years.

Potato black dot, a disease common in many potato growing regions of the world, is caused by the fungus *Colletotrichum coccodes*. Tubers, roots, stolons, below- and aboveground stems, and leaves of potato can be infected (1,26,37). Small, black microsclerotia develop on infected plant organs as plants senesce, giving the name black dot to the disease. Tuber surfaces may be blemished with superficial lesions, which often result in a monetary loss, particularly in fresh markets. In addition, tuber yields may be reduced by up to 30% in severe cases (2,23,35,45); however, effects of the disease on tuber yield have been variable (37,40,42).

Foliar symptoms of black dot include chlorosis, stunting, lower leaf abscission, and necrotic leaf lesions (23,25,30). Because foliar symptoms are nondescript and often do not occur until late in the growing season, assessment of black dot during the growing season is often overlooked (2). Roots, stolons, and belowground stems are affected by cortical rot, resulting in a sloughing of the periderm. Lesions on roots may resemble those caused by *Rhizoctonia solani*. Symptoms on tubers are commonly observed at the stem end and lesions appear silvery to brown, depending on cultivar pigmentation, and generally with a poorly defined margin.

Inoculum of *C. coccodes* originates from soil, seed tubers, and water splashed and windblown plants (14,22,25,27,30,32). *C. coccodes* was detected in soil from a majority of commercial fields in a survey in Idaho in 1988, but it was not detected in native vegetation areas (2). Soilborne inoculum generally causes more severe disease symptoms than tuberborne inoculum (32,39). The infection threshold for soilborne inoculum is low in that relatively low levels of soil inoculum cause severe disease (32). Survival of conidia in soil is relatively short and longevity is measured in weeks, whereas microsclerotia survive for more than a year (5). Rotations of 2 years or less with non-susceptible crops are not expected to successfully reduce initial inoculum (14,37).

Planting seed pieces free of *C. coccodes* or treating seeds with fungicides is not expected to decrease severity in plants grown in field soil infested with the pathogen (11). However, tuberborne inoculum is pervasive in that *C. coccodes* progresses over time from infected seed pieces to roots, belowground stems, stolons, and to daughter tubers (22). Airborne inoculum, consisting of microsclerotia or conidia, is likely important in semiarid, sprinkler irrigated regions when foliage of young plants is easily wounded by blowing sand prior to row closure (25,30). Wounds from blowing sand provide entry avenues for the fungus, which develop lesions similar to those of early blight. The pathogen infects plants relatively early in a growing season, spreads internally within stems, and may remain latent until foliar senescence (26,33,37).

Lesions of silver scurf, caused by *Helminthosporium solani*, are generally silver, with a clearly defined margin. *H. solani* is tuberborne and survives in soil for a relatively short duration (16,28). Confirmation of the two diseases often requires examining tubers with a hand lens or microscope to observe the characteristic microsclerotia of black dot or conidia of the silver scurf fungus (16,39). Shrinkage of tubers from water loss can be substantial due to infection by *H. solani* (20).

Verticillium dahliae, the principle cause of Verticillium wilt of potato, has a wide host range including over 200 dicotyledonous species (24). Inoculum can be carried internally in potato seed tubers, infest soil carried with seed tubers, and be soilborne (12,24). Microsclerotia are produced abundantly in infected, susceptible potato cultivars and extended crop rotations have been ineffective in reducing disease incidence (6,13,44).

The primary objective of this study was to quantify the effect of extended crop rotations of more than 5 years out of potatoes on incidence of black dot in the Columbia Basin. The bases for the objective were an observed association in commercial fields between high levels of black dot and relatively short rotations out of potatoes. The hypothesis was that black dot incidence would be reduced with rotations out of potato for more than 5 years. Data were also collected for silver scurf and Verticillium wilt. Infection of progeny tubers was used as a measure of disease incidence for the three diseases.

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Materials and Methods

Tubers of the short season cultivar Russet Norkotah from commercial fields with different rotation times out of potato were assessed from 2008 to 2011. The tubers were assessed during the growing season and in storage for incidence of black dot (*C. coccodes*), silver scurf (*H. solani*), and for infection by *V. dahliae*. Rotational crops were alfalfa, bean, grass seed, onion, pea, sweet corn, and winter wheat. All fields were located north of Pasco, WA, consisted of a sandy to sandy loam soil, fumigated with metam sodium prior to planting potato, irrigated by center pivot systems, at least 51 ha in size, and were managed by personnel from one farm in 2008 through 2011. Cultural practices were uniform among fields within the farm.

Fields were treated with azoxystrobin (Quadris Flowable) at planting at 163 g ai/ha and/or on foliage of fully emerged plants by chemigation at 112 g ai/ha. Fields that were treated at planting were none in 2008, four of seven in 2009, and six of six fields in each of 2010 and 2011. Fields that were treated at full emergence were four of five in 2008 (the exception was U5W), seven of seven fields in 2009, and six of six fields in each of 2010 and 2011.

Four to five tubers per plant from 10 randomly selected plants in each field (40 to 50 tubers per field) were sampled approximately every 2 weeks from mid-June to late August. Plants for tuber collection were selected along transects from the outer edge of a circular shaped field to the pivot center. Distance between sampled plants was at least 22 m. Different transects were used on each assessment date. Four to five collections were made during each of the growing seasons. Sampled fields varied by rotation sequence and time out of potatoes. Numbers of fields sampled during the growing seasons were zero in 2008, four in 2009, four in 2010, and two in 2011, for a total of 10 fields. Samples of 50 tubers were additionally collected from storage during October 26 to November 20 of tuber lots from five fields in 2008, seven in 2009, and six fields each in 2010 and 2011, for a total of 24 fields (Table 1). The 10 fields sampled during the growing season were included with the fields whose tuber lots were sampled from storage.

Tubers sampled from fields after each collection date and from storage in the fall were transported to the laboratory and assayed for pathogenic fungi. Periderm peels from tubers were placed on moistened filter paper to detect *C. coccodes* and *H. solani* and the stem ends of tubers containing vascular tissue were plated on a nutrient medium to detect *V. dahliae* and *C. coccodes* (27). Periderm peels were done by cutting a periderm slice (consisting of periderm and cortex tissues) from the lateral surface of tubers that was approximately 60 mm long, 40 cm wide, and 3 mm thick and placed on moistened filter paper in a 90 mm diameter petri plate. The stem ends of tubers were plated by cutting a slice of periderm and medulla tissue about 1 cm in diameter and 3 mm thick from the stem end of each tuber and placing on modified potato dextrose agar in petri plates (27). Plated tuber stem ends and periderm peels were incubated at 21 to 23°C on a laboratory bench for 11 to 14 days and then viewed with a stereo zoom scope for fungal growth.

Table 1. Number of fields and total number of collections over the growing season (n) that tuber samples were collected from commercial fields and the number of tuber lots from storages that tuber samples were collected to determine incidence of tubers infected with *Colletotrichum coccodes*, using two assay methods, over 4 years

	Commercial fields during the growing season				Storage	
	Stolon end		Periderm		Stolon end	Periderm
Year	No. fields	n	No. fields	n	No. lots	No. lots
2008	0	0	0	0	0	5
2009	4	19	0	0	0	7[a]
2010	4[b]	18[b]	4[a]	18[a]	6[b]	6[a]
2011	2[b]	10[b]	2[a]	10[a]	6[b]	6[a]

[a] Tubers also assessed for *Helminthosporium solani*.
[b] Tubers also assessed for *Verticillium dahliae*.

The tuber peels were estimated for percent surface area with lesions containing microsclerotia of *C. coccodes* and percent surface area with conidiophores and conidia of *H. solani*. Agar surrounding tissue pieces from tuber stem ends were evaluated for colonies of *C. coccodes* and *V. dahliae*. Maximum area of affected periderm peel was 20% for *C. coccodes* and 40% for *H. solani* and incidence, whether or not periderm or stem ends were infected, was used to analyze data.

Periderm peels were assayed for *C. coccodes* from samples collected in fields during the growing seasons in 2010 (four fields, *n* or number of collections = 18) and 2011 (two fields, *n* = 10) and from samples from 24 tuber lots collected from storage the four years, 2008 to 2011 (Table 1). Tuber stem ends were plated for *C. coccodes* from samples collected in fields during the growing season in 2009 (four fields, *n* = 19), 2010 (four fields, *n* = 18), and 2011 (two fields, *n* = 10). Black dot severities and incidences on tuber periderm were assessed from tubers collected from lots in storage in 2009 (*n* = 6) and 2011 (*n* = 6). Both assays were done on samples from fields during the growing season in 2010 (four fields, *n* = 18) and 2011 (two fields, *n* = 10).

H. solani was assessed on tuber periderm from lots out of storage (*n* = 19) that were assessed for *C. coccodes* in 2009, 2010, and 2011. *V. dahliae* was assessed in the stem end assays from the same samples from the field (*n* = 28) and storage lots (*n* = 12) as *C. coccodes* in 2010 and 2011 (Table 1).

Data analysis. Regression analyses with incidence of diseased tubers for black dot, silver scurf, or Verticillium wilt (dependent variables) by days after planting (DAP), years out of potatoes for a field, and number of potato crops for a field (independent variables) were conducted using PROC REG in SAS (Version 9.1, SAS Institute Inc., Cary, NC). Multicollinearity between the independent variables of years out of potatoes and number of potato crops was examined by variance inflation factors and variance proportions (3) using the VIF and COLLINOIT options in PROC REG, SAS statistical software. The association for incidences of detection of *C. coccodes* on tuber peels and stem end assays was investigated using Pearson's correlation by PROC GLM and PROC CORR in SAS statistical software. Data were used from six fields and included 28 collection samples in 2010 and 2011. Data for black dot severity on tuber periderm peels and incidence of tuber on which *C. coccodes* was detected on either the tuber periderm peel (number of tuber lots = 17 for tubers sampled in 2009, 2010, and 2011) or the stolon end assay (number of tuber lots = 12 for tubers sampled in 2010 and 2011) were analyzed by regression. Tuber lot sample number differed between the two analyses because the two assays were not always done for all samples.

Results

C. coccodes was first obtained from the stolon end of tubers at 103 DAP on July 16 in 2009, at 84 DAP on June 18 in 2010, and 109 DAP on July 29 in 2011. Either the intercept on the y-axis or the slope of the regression lines differed the three years (Fig. 1). The fungus was first obtained from periderm of tubers collected in fields at 102 DAP on July 20 in 2010, and at 109 DAP on July 27 in 2011. Slopes of the regression lines differed the two years (Fig. 2). Incidence of infected tubers in commercial fields was low between 100 and 130 DAP and then sharply increased after 140 DAP (Fig. 2). Disease symptoms of blemishes and lesions of black dot were not present on tubers collected from the fields, but the fungus was detected in tuber periderm and at the tuber stem end, indicating that the tubers were latently infected. Disease symptoms were later observed on tubers in storage.

Incidence of tubers infected with *C. coccodes* from storage significantly decreased as the number of years between potato crops increased from 3 to 5 years and beyond (Fig. 3), and significantly increased as the number of previous potato crops increased to 16 (Fig. 4). The highest incidences of black dot (73, 74, and 98%) were observed from fields rotated out of potatoes for 1 to 3 years (Fig. 3). A noticeable drop in incidence of black dot was observed at 7 (13%) and 8 (5 and 26%) years out of potatoes. A low incidence of black dot (two fields at 0% and two fields at 8 and 9%, respectively) was detected at 15 years out of potatoes (Fig. 3). The mean incidence of black dot was 56% for fields out of potatoes for 0 to 4 years and 12% for fields out of potatoes 5 and more years. Years out of potato and number of prior potato crops accounted for 71% of the variability associated with incidence of black dot on tubers. The two variables were not collinear.

Incidences of detection of *C. coccodes* on the tuber peels and stem end assays were positively and significantly ($P < 0.001$) correlated for data from the six fields where both assays were completed in 2010 and 2011. Correlation coefficient was 0.85. Severity of black dot on tuber periderm peels significantly increased ($P < 0.0001$) as incidence of tuber periderm peels with *C. coccodes* increased for 17 seed lots collected from storage in 2009, 2010, and 2011. Coefficient of determination was 0.87 for log severity on regressed on black dot incidence. Severity of black dot on tuber periderm peels also significantly ($P = 0.012$, $R^2 = 0.49$) increased as incidence of detection of *C. coccodes* from the stolon end of tubers.

Incidence of tubers with *H. solani* from storage ranged from 0 to 100%. Incidence of silver scurf was highest from fields out of potatoes for 1 year (Fig. 5). Silver scurf incidence decreased ($P = 0.016$) as years out of potatoes increased with 5 years out of potatoes being a threshold after which the disease dropped to near undetectable levels. Silver scurf was present at a low incidence (2% each) from two fields rotated out of potato for 15 years (Fig. 5). Incidence of silver scurf significantly increased ($P = 0.036$) as the number of previous potato crops increased; however, fields with 10 or more potato crops and silver scurf incidence greater than 20%, except for one field, also had rotations out of potatoes for 1 and 2 years (Fig. 6). The exception was a 3 year rotation out of potatoes with 14 potato crops and 38% incidence of silver scurf.

V. dahliae was first detected in tubers from field samples at 96 DAP. The incidence of infected daughter tubers increased substantially after 135 DAP (Fig. 7). Incidence of tuber with *V. dahliae* from storage was not related to years between potato crops (Fig. 8) or number of previous potato crops (Fig. 8).

Discussion

Extended crop rotations between potato crops substantially reduced the incidence of black dot on daughter tubers. Incidence of black dot was significantly reduced to a mean of 12% in commercial fields when out of potatoes for 5 or more years. A peak in black dot incidence occurred 2 years out of potato production, presumably allowing time for microsclerotia to be dislodged and distributed within soil from decomposing plant material. In a previ-

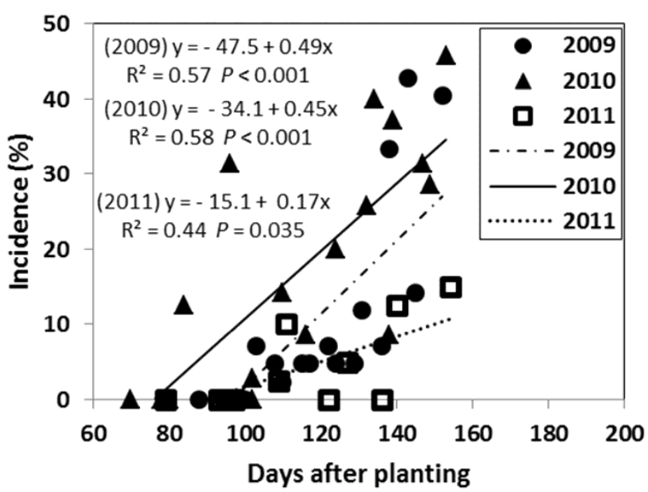

Fig. 1. Incidence of detection of *Colletotrichum coccodes* at the stolon end of Russet Norkotah tubers collected during the growing season from 10 fields from 2009 to 2011 north of Pasco, WA.

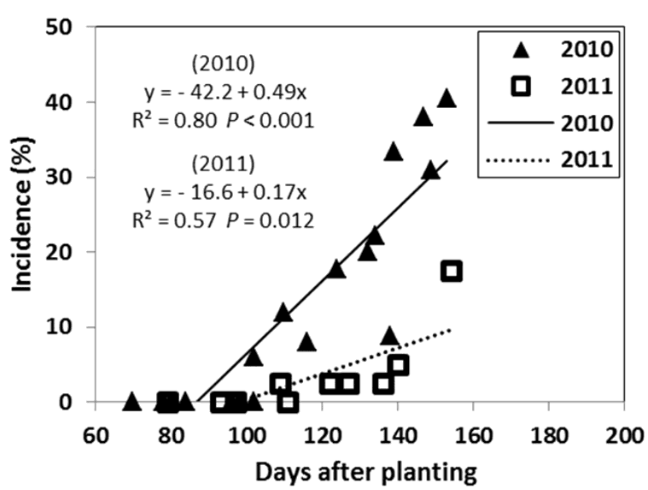

Fig. 2. Incidence of detection of *Colletotrichum coccodes* on the periderm of Russet Norkotah tubers collected during the growing season from six fields from 2010 to 2011 north of Pasco, WA.

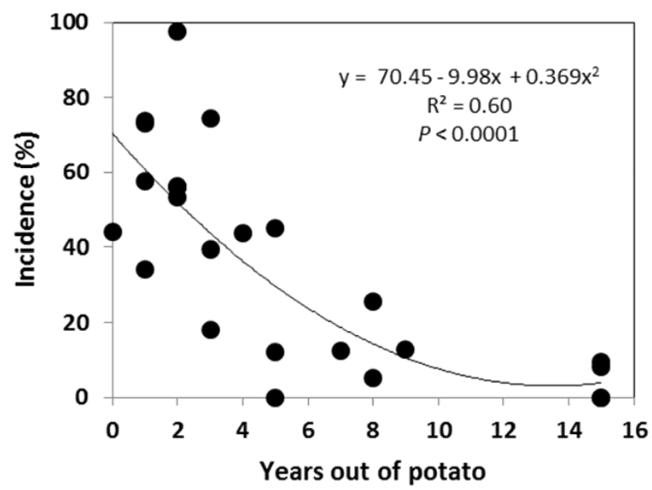

Fig. 3. Incidence of detection of *Colletotrichum coccodes* on the periderm of Russet Norkotah tubers collected from storage relative to the number of years a field was out of potato production for 24 from fields located in the Columbia Basin of WA from 2008 to 2011.

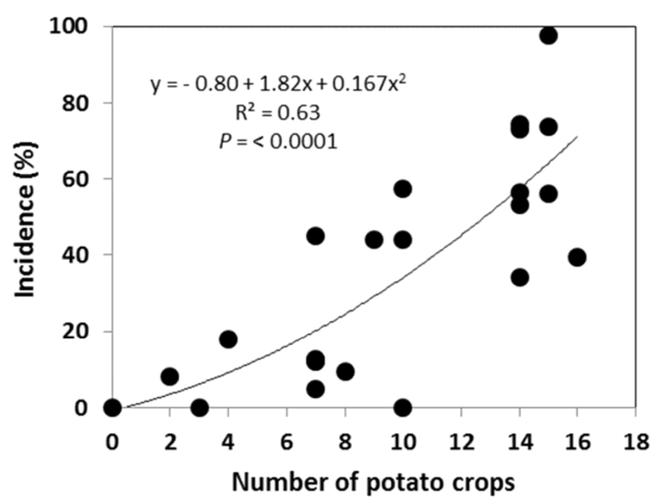

Fig. 4. Incidence of detection of *Colletotrichum coccodes* on the periderm of Russet Norkotah tubers collected from storage relative to the number of potato crops grown in a field for 23 fields located in the Columbia Basin of WA from 2008 to 2011.

ous study (19), severity of black dot on stems and tubers of cv. Desiree was not affected by previous cropping but was less severe in a field that had not grown potatoes for 7 years compared with plots with shorter rotations. A 5-year rotation or longer out of potato production may initially be considered as not economically feasible for many growers, but may be economical when considering the benefits from reducing the negative effects of *C. coccodes* and other soilborne pathogens, maintaining tuber quality, and reducing potential fungicide use. Selection and suitable economic returns from rotational crops would improve the economic feasibility of rotating 5 and more years out of potato production.

Incidence of black dot increased as the number of prior potato crops for a field increased, which likely reflected a buildup of inoculum in soil with subsequent potato crops. *C. coccodes* was not detected from tubers collected from a field with 10 prior potato crops, but the field also had been rotated out of potato for 5 years, which would partially account for the low incidence of black dot (Fig. 4). The two variables, years between potato crop and number of potato crops, were not collinear and when analyzed together accounted for 71% of the variation for tuber infection.

Relatively high levels of *C. coccodes* were detected in soil of commercial fields where potatoes were grown every third or fewer seasons. Populations of soil pathogens potentially build up in soil with frequent growth of the crop host or presence of alternative weed hosts. Currently used soil fumigants fail to substantially reduce *C. coccodes* (26,43). In the Netherlands, potato yield decreased as the frequency of growing potato as part of the rotation increased. Soil disinfection with methyl bromide or pasteurization eliminated the rotation effect on yield, suggesting that it was caused by a complex of microbial pathogens. Organisms thought to belong to the complex were *C. coccodes*, *Fusarium tabacinum*, and *V. dahliae.* In soil that had never carried a potato crop before, *V. dahliae* decreased the yield of susceptible potato cultivars, and *C. coccodes* may have caused damage only late in the growing season in weakened plants. In a highly susceptible cultivar, Amethyst, yield loss by *V. dahliae* was almost doubled in the presence of *C. coccodes* (42).

Rotational crops may aid in decreasing, maintaining, or increasing soil populations of *C. coccodes*. The fungus was isolated from yellow mustard, spring canola, soybean, alfalfa, and oat, with significantly lower frequencies obtained from alfalfa and oat than yellow mustard, spring canola, or soybean in a previous study (34). *C. coccodes* was not obtained from wheat, barley, maize, and rye,

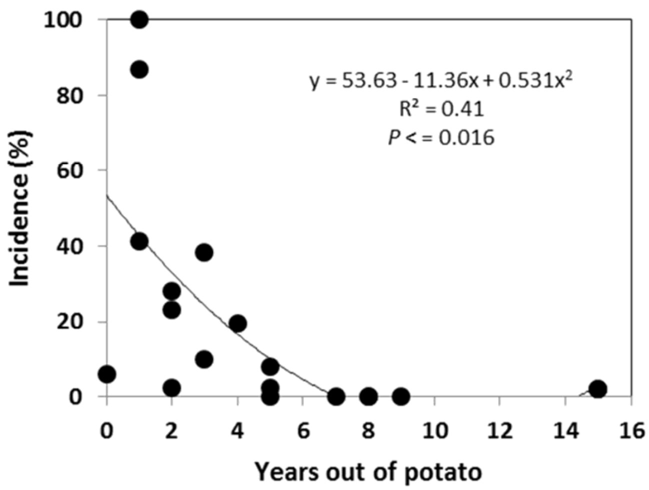

Fig. 5. Incidence of detection of *Helminthosporium solani* on periderm of Russet Norkotah tubers collected from storage relative to number of years a field was out of potato production for 19 fields located in the Columbia Basin of WA from 2009 to 2011.

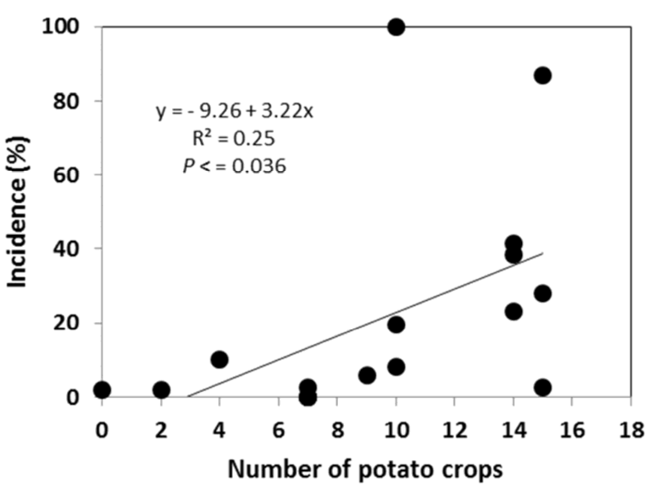

Fig. 6. Incidence of detection of *Helminthosporium solani* on periderm of Russet Norkotah tubers collected from storage relative to the number of potato crops grown on a field for 18 fields located in the Columbia Basin of WA from 2009 to 2011.

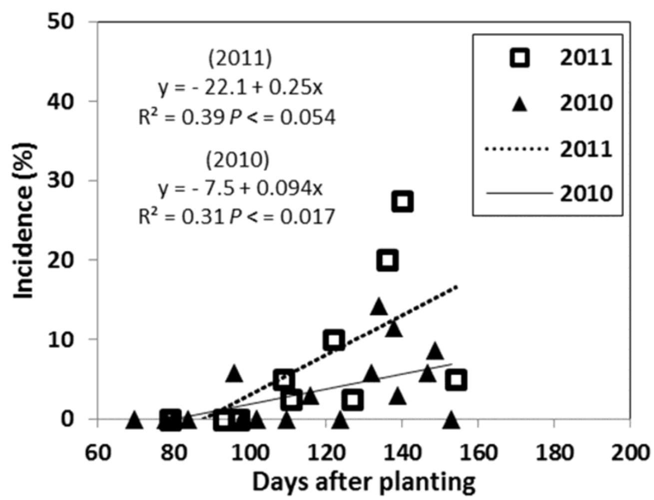

Fig. 7. Incidence of detection of *Verticillium dahliae* at the stolon end of Russet Norkotah tubers collected during the growing season from six fields north of Pasco, WA, from 2009 to 2011.

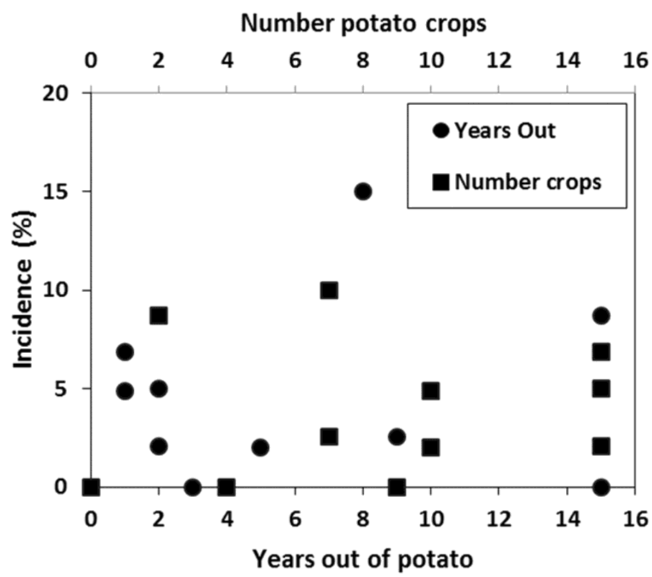

Fig. 8. Incidence of detection of *Verticillium dahliae* at the stolon end of Russet Norkotah tubers collected from storage relative to the years a field was out of potato production (12 fields) and number of previous potato crops on a filed (11 fields) from the Columbia Basin of WA in 2010 and 2011.

and these crops should aid in reducing soil populations of *C. coccodes* in rotations with potato (34). Weeds such as *S. nigrum* (black nightshade) and *S. triflorum* (cutleaf nightshade) can be common in potato fields and may serve as alternative hosts for *C. coccodes*. These may account for long term persistence of *C. coccodes* and *V. dahliae* in the soil.

Infections of tuber periderm by *C. coccodes* were latent in the commercial fields. The black dot fungus was first detected between 84 and 109 DAP, dependent on the year, and increased as the growing season progressed. Disease symptoms of blemish lesions and disease signs of sclerotia became evident only in storage. The variation in first detection of the pathogen and slopes of regression lines of disease incidence on DAP was likely due to differences in years such as ambient temperature and inoculum levels in soil and seed tubers. The assay of the stolon end of tubers would have been a measure of both tuberborne and soilborne inocula, while the assay of the periderm would have been a measure of mostly soilborne inoculum (22).

The impact of black dot on potato yield and incidence of *C. coccodes* in soil has been difficult to assess because obvious symptoms may not develop or symptoms mimic those caused by other diseases and disorders. Consequently, disease level has been difficult to assess in the field. Bioassays of potato roots from minitubers and microplants in infested soil were reliable in a previous study (8). Assessing severity of infection on daughter tubers proved a reliable method of assessing levels of *C. coccodes* and *H. solani* inoculum in the commercial fields in this study. Assessing root infection was a sensitive and reliable method for detecting soil infestations by *C. coccodes* and assessing infections of minitubers were sensitive in detecting *H. solani* in a previous study (8). Assessment of root colonization has also been suggested as a useful technique quantifying potato cultivar response to *C. coccodes* (1). An advantage of plant bioassays is that relatively low amounts of inoculum can be detected (8).

Severity of lesions with microsclerotia of *C. coccodes* on tubers was expected to be significantly associated with incidence of tubers with lesions and microsclerotia. Eighty-seven percent of the variation of lesion severity was explained by disease incidence, justifying the use of disease incidence as a measure of disease (7). Severity and incidence of silver scurf lesions were highly related in a previous study (16).

No single management tactic will sufficiently reduce the effects of black dot on potato growth. Therefore, several tactics must be integrated to successfully manage the disease. Lengthening the time between potato crops reduces the effect of soilborne inoculum and may be a helpful disease management tactic. Data from the current study suggest that more than 5 years out of potatoes are needed to appreciably reduce the effects of the disease from soilborne inoculum. Incidence of black dot was lower in early seed tuber generations than in older generations. The younger generations were grown in fields with fewer potato crops and at wider rotation intervals out of potato (31).

An application of a strobilurin based fungicide at 40 to 62 DAP significantly reduced black dot microsclerotia in upper and lower stems and tubers (9) and may prove beneficial when coupled with intermediate and long rotations out of potato. However, black dot levels were not reduced when azoxystrobin was applied at planting in a previous study (9) and incidence of black dot was observed not to be affected with an application at planting in the present study. All fields except one in this study were treated with azoxystrobin at full emergence. The one exception, field U5W, was rotated out of potatoes for 15 years and had a black dot incidence of 9%. Three other fields that were rotated out of potatoes for 15 years and were treated with azoxystrobin at full emergence had black dot incidences of 0, 0, and 8%, respectively. Reductions in black dot levels were inconsistent when azoxystrobin was applied by chemigation in a previous study (21) and were inconclusive in this study. Valid comparisons on the effect of azoxystrobin on silver scurf could not be made in the current study and azoxystrobin has not reduced the incidence of *V. dahliae* in potato in previous trials (unpublished data).

Severity of black dot has been associated with plant stress (43), and reducing plant stress is an important management tactic for black dot. In recent experiments, significantly more disease occurred on plants stressed from an imbalance of either nitrogen or potassium than when optimum levels of each nutrient were available to plants (4,18). Severity of black dot was also greater when plants were stressed by excessive irrigation water than when plants were optimally watered (10). Not only does water-saturated soil favor spread and development of *C. coccodes*, but oxygen is displaced in the soil, which is needed by roots for oxidative respiration. Other causes of plant stress include coinfection with other pathogens, especially *V. dahliae*, and blowing sand, which may increase incidence of foliar infections. Short rotations between potato crops may also increase crop stress from various factors. As expected, a holistic management approach is needed for growing a healthy potato crop and managing potato black dot.

Crop rotation standards for seed potato production systems, with respect to transmissible tuber blemish diseases, should be higher than those for potatoes grown for wholesale markets. Incidence of black dot was demonstrated to be high in rotations out of potato for 3 years and less. Consequently, relatively short rotations should be especially discouraged when producing potato seed tubers when either black dot or silver scurf is a concern.

H. solani was infrequently detected on tubers in fields with rotations out of potatoes more than 3 years. This was expected because previous research demonstrated that *H. solani* does not survive more than a year in field soil (28). An increase in incidence of silver scurf with an increase in the number of potato crops was explained by the fact that fields having 10 or more potato crops also had short rotations between potato crops. The coefficient of determination indicated that only 25% of the variation in incidence of silver scurf was explained by the number of potato crops. Silver scurf incidence was affected by location despite the same tuber seed source in a previous study (17). The level of *H. solani* on seed tubers used in the current study was not determined and consequently, the effect of infected seed tubers cannot be determined by these data. However, the source of infection in fields rotated out of potatoes for 3 or more years was likely infected seed tubers, whereas the source for fields rotated out every 2 or fewer years was inoculum from soil, seed tubers, or both. Because of the prominence of seed tuber inoculum, clean seed tubers, fungicide seed tuber treatments, and post-harvest fungicides and treatments are essential for management of silver scurf (15–17,19,29).

The lack of association between incidence of tubers infected with *V. dahliae* and years out of potato production is likely due to the extended longevity of microsclerotia in soil and an influence of prior fumigation of each sampled field with metam sodium. Soil fumigation with metam sodium kills a certain percentage of the soil microsclerotia, but not all of them (24). Thus, a residual level of microsclerotia of *V. dahliae* would persist in soil and potentially infect growing susceptible plants. The relatively high incidence of *V. dahliae* detected in fields 7 and 8 years out of potato (Fig. 7) may be due to soilborne inoculum being introduced with tare dirt (12).

In summary, the present study confirmed that black dot can be reduced with rotations out of potato greater than 5 years. The economic viability needs to be assessed of integrating such long rotations into a broad-spectrum disease management strategy for commercial production systems. Incidence of silver scurf was highest from fields out of potatoes for 1 year. Infected seed tubers likely accounted for silver scurf in rotations out of potato for more than 3 years. Level of progeny tubers infected with *V. dahliae* remained constant in relation to years out of potatoes and number of previous potato crops.

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