Influence of Crop Rotation on the Incidence of *Pythium*- and *Rhizoctonia*-Induced Carrot Root Dieback

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ABSTRACT

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The influence of various crop rotations on population densities of *Pythium* spp. and *Rhizoctonia solani*, subsequent carrot yields, and incidence of carrot root dieback was investigated. Carrots followed crops of alfalfa, barley, carrots, cotton, onions, or fallowed soil in two independent trials. Populations of *Pythium* spp. were greater following alfalfa and barley than other crops in one of the 2 years of the study. Populations of *R. solani* were generally greater following alfalfa and cotton than other crops in each of the 2 years of the study. In 1 year, yields of marketable carrots were reduced following the alfalfa crop; no other cropping pattern influenced carrot yields. The incidence of root dieback, which resulted in mature carrots with misshapen or multiple taproots, was generally greater following alfalfa and barley than other crops in one trial, and greater following alfalfa and cotton in the other trial.

Forking and stubbing of mature taproots reduce the quality of carrots (*Daucus carota* L.) produced in California's Central Valley, where over 22,000 ha are planted annually. Occasionally, the majority of carrots in a field are malformed and unsuitable for the fresh market. Although forking and stubbing of carrots can be caused by any agent that damages the root apex, such as soil compaction or saturation (11,14), these problems have often been attributed to root dieback caused by *Pythium* species (3-5,7). If the root apex is infected and dies when the root is only a few millimeters long, apical dominance is lost and the taproot either fails to elongate (stubbing) or proliferates to form several functional taproots (forking). In severe cases, the root may not recover and the plant dies. In California, *Pythium irregulare* and *P. ultimum* are the principal incitants of root dieback (5), although *Rhizoctonia solani* is occasionally associated with the disorder (R. M. Davis, *personal observations*). Because crop rotation may play an important role in managing soilborne diseases, this study was initiated to assess the influence of cropping patterns on the incidence of root dieback in carrots.

MATERIALS AND METHODS

The experiment was conducted on the University of California, Davis, campus in

Yolo County on Yolo fine sandy loam soil (pH 7.0, organic matter 1%, sand 33%, silt 47%, and clay 20%). The previous crop on both trial sites was corn. Plots (experimental units) were 15 m long and 6.5 m wide (8 rows) with a 5-m buffer (nonfarmed) around each plot. Treatments (rotation crops followed by carrots) were replicated four times. All plots received 170 kg of nitrogen per hectare prior to planting. No pesticides were used in these trials. Weeds were cultivated mechanically or removed by hand. All crops were irrigated with overhead sprinklers as needed. Cotton (*Gossypium hirsutum* cv. Maxxa) was planted at a rate of approximately 24 seeds per m of row on 18 May 1993 and disked under to a depth of approximately 10 cm on 20 September 1993; alfalfa (*Medicago sativa* cv. Moapa 69, 100 seeds per m), barley (*Hordeum vulgare* cv. Briggs, 100 seeds per m), carrots (cv. Six-Pak, 80 seeds per m), and onions (*Allium cepa* cv. South Port White Globe, 80 seeds per m) were planted on 12 November 1993 and were disked under 2 April 1994. All crops were physiologically mature (green) at diskings. Carrots (cv. Six-Pak) were planted at a density of 80 seeds per m in all plots on 3 May 1994. At that time, the incorporated residues from the previous crops were not fully decomposed. Carrots were fertilized and irrigated as described above. On 15 November 1994, all carrots in the center 2 m of the middle two beds in each plot were harvested, weighed, and examined for forked and stubbed roots.

In 1994, the same cultivars of the same crops were planted in a different location on the UC Davis campus. Cotton was planted on 20 May 1994 and disked under 3 October 1994; alfalfa, barley, carrots, and

onions were planted 3 December 1994 and disked under 11 April 1995. Carrots were planted in all plots on 6 May 1995. As in the first trial, the incorporated crop residues were not fully decomposed at the time of planting. On 17 November 1995, carrots were harvested as described above.

To measure the population densities of *Pythium* spp. and *R. solani*, randomized soil samples (each consisting of 10 pooled subsamples) were collected each year from each plot prior to planting the first rotation crop (cotton), during midseason of the rotation crop, and immediately prior to planting the subsequent carrot crop. The samples were collected with a 2.54-cm-diameter soil sampler (0 to 20 cm deep). Population densities of fast-growing *Pythium* spp. were determined by soil dilution and plating on a selective medium containing pimarin, pentachloronitrobenzene, ampicillin, penicillin, and rifampicin (5). Identification of *Pythium* spp. was made from morphological characteristics of cultures on potato-carrot agar and on blades of sterilized grass in water (12). Population densities of *R. solani* were determined in 150-g subsamples by plating the organic matter fraction onto water agar (13). The moisture content of each soil sample was determined gravimetrically.

To identify the fungi associated with root dieback, about 200 carrot seedlings outside the area in each plot targeted for yield data were gently lifted by hand 3 weeks after planting. In the laboratory, the seedlings were washed in water and examined for root lesions or rotted taproots. About 80 symptomatic root systems from each trial were surface-disinfested for 1 min or less in a 0.5% solution of sodium hypochlorite and plated on water agar and the selective medium described above to isolate fungi.

All data were analyzed with the MSTAT-C statistical program (Version 1.42, Michigan State University, East Lansing) for analysis of variance. Means were separated by Duncan's multiple range test.

RESULTS AND DISCUSSION

The mean population densities of *Pythium* spp. and *R. solani* in all plots prior to planting any crop in 1993 were 28.4 CFU/g of dry soil and 1.5 CFU/100 g of dry soil, respectively; in 1994, the initial means for *Pythium* spp. and *R. solani* were 45.6 CFU/g of dry soil and 1.4 CFU/100 g

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of dry soil. There were no significant differences in population densities of either fungus among treatments in midseason (*data not presented*). Immediately prior to planting carrots in 1994, populations of *Pythium* spp. were significantly greater in plots planted to barley and alfalfa than in the other plots (Table 1). In 1995, there were no significant differences in *Pythium* population densities among treatments. In both trials, populations of *R. solani* were greater following alfalfa or cotton than following fallow, onion, or barley. Population densities in continuous carrots were variable.

In the first trial, the incidence of carrot forking and stubbing was generally greater following a crop of alfalfa or barley than following other cropping patterns (Table 2). In 1995, the incidence of forking and stubbing was greater in crops following cotton or alfalfa than following other rotations. Carrot yields were decreased following alfalfa in one trial; otherwise, there was no effect of crop rotation on carrot yields (Table 2).

Pythium spp. or *R. solani* was recovered from 80% of the symptomatic seedlings in the first trial (82% *Pythium* spp. and 18% *R. solani*) and from 68% of the seedlings in the second trial (90% *Pythium* spp. and 10% *R. solani*). *P. ultimum* accounted for about 60% of all fast-growing *Pythium* spp.; *P. irregulare* accounted for most of the remaining isolates. *P. aphanidermatum* was occasionally isolated. Isolates of *R. solani* were assigned to anastomosis group 4 using the cellophane method by pairing isolates with "tester" strains (from E. E.

Butler, UC Davis) and observing hyphal fusion (1).

In California's Central Valley, growers plant carrots year-round in rotation with a variety of crops, often utilizing short intercropping periods. Cropping history has been observed to influence carrot quality, especially in regards to *Pythium*- and *Rhizoctonia*-induced carrot root dieback, which results in forking and stubbing. In one trial in this study, the incidence of root dieback and populations of *Pythium* spp. were increased following barley relative to disease incidence and populations of *Pythium* spp. following onion, cotton, or a fallow field. In contrast with these results, growers who typically use small grains in rotation with carrots do not experience reduced carrot quality. The short interval between disking the barley crop and planting carrots in this experiment did not allow complete decomposition of the barley tissue. The large amount of organic matter in the soil apparently stimulated growth of *Pythium* spp. and *R. solani* and may have encouraged root infections. An increase in populations of *P. ultimum* by saprophytic utilization of plant nutrients after soil incorporation of fresh crop residues and the importance of partly decomposed plant residues as the base for propagules of *R. solani* have been described in other cropping systems (2,8,9,13). It has also been demonstrated that disease caused by *P. ultimum* substantially decreases with increasing time between soil amendment and planting due to competition from other soil microbes stimulated by crop residues (6).

Other cropping patterns also affected carrot quality. In one of the 2 years of this experiment, the incidence of forking and stubbing of carrots after a crop of cotton was greater than after carrots, onion, barley, or a fallow field. Populations of *R. solani* in plots planted with cotton were also among the highest recovered. Although *R. solani* was recovered infrequently from symptomatic seedlings compared with the frequency of recovery of *Pythium* spp., it may contribute to the overall incidence of forking and stubbing. The incidence of forking and stubbing in a carrot-carrot rotation was intermediate relative to other cropping patterns. Growers typically avoid back-to-back carrots to reduce the risk of damaging levels of leaf blights (*Alternaria dauci* or *Xanthomonas campestris* pv. *carotae*) or root-knot nematodes (*Meloidogyne* sp.). Onions and a fallow field prior to a carrot crop did not increase the incidence of forking and stubbing or pathogen populations relative to other cropping patterns.

In this study, the incidence of root dieback (and subsequently forking and stubbing) was increased following alfalfa relative to a fallow field or other rotation crops. This is consistent with our observations that carrot culls are sometimes excessive in grower fields after alfalfa is removed (*personal observations*). In one trial in this study, populations of *Pythium* spp. were greater following alfalfa; and in both trials, *R. solani* populations were greater in alfalfa relative to other crops. In addition to decreasing root quality, marketable yields were reduced following alfalfa in one trial. Alfalfa is also a host to *Pythium violae*, the cause of cavity spot of carrot (10). Hence, alfalfa should be used cautiously in rotation with carrot.

Table 1. Effect of cropping sequence on populations of *Pythium* spp. and *Rhizoctonia solani* immediately prior to planting carrots

Cropping sequence	<i>Pythium</i> spp. (CFU/g dry soil)		<i>R. solani</i> (CFU/100 g dry soil)	
	1994	1995	1994	1995
Fallow-carrots	22.2 a ^z	16.2 a	1.4 a	1.5 a
Carrots-carrots	34.5 a	26.3 a	2.2 ab	1.8 ab
Onion-carrots	15.5 a	18.9 a	1.7 a	1.3 a
Barley-carrots	133.5 b	53.2 a	1.0 a	1.2 a
Alfalfa-carrots	112.0 b	36.6 a	3.9 b	3.4 c
Cotton-carrots	43.6 a	51.2 a	3.4 b	2.6 bc

^z Means in each column followed by the same letter are not significantly ($P = 0.05$) different according to Duncan's multiple range test (four replications).

Table 2. Incidence of forking and stubbing (culled roots) and yields of carrots following various crop rotations

Cropping sequence	1994		1995	
	Culled roots (%)	Marketable yields (kg/4 m)	Culled roots (%)	Marketable yields (kg/4 m)
Fallow-carrots	2.0 a ^z	44.4 a	3.3 a	43.3 a
Carrots-carrots	4.9 ab	39.5 a	3.8 a	38.8 a
Onion-carrots	1.4 a	44.5 a	2.5 a	41.0 a
Barley-carrots	8.4 bc	38.9 a	2.4 a	35.6 a
Alfalfa-carrots	9.0 c	27.1 b	8.8 b	41.8 a
Cotton-carrots	1.2 a	40.7 a	7.9 b	38.7 a

^z Means in each column followed by the same letter are not significantly ($P = 0.05$) different according to Duncan's multiple range test (four replications of 250 to 350 plants per experimental unit).

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