Influence of Crop Rotation on Survival of Verticillium albo-atrum in Soils

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This research was supported in part by Cotton, Incorporated, California Planting Cotton Seed Distributors, and California Processing Advisory Board. We appreciate the assistance of D. M. Harper and H. L. Andris.

Accepted for publication 23 January 1976.

ABSTRACT

HUISMAN, O. C., and L. J. ASHWORTH, JR. 1976. Influence of crop rotation on survival of Verticillium albo-atrum in soils. Phytopathology 66:978-981

Inoculum density of *Verticillium albo-atrum* was followed in soil of eight variously cropped commercial fields at about monthly intervals for 3.5-4.0 years. High inoculum densities (20-60 microsclerotia/g soil) persisted under continuous susceptible crop (cotton) culture in infested fields. The inoculum usually increased rapidly following 1 year of a susceptible crop, with a higher inoculum density often occurring the second year regardless of whether the subsequent crop was a nonsusceptible or a susceptible host. Once soils were infested, the rate of decrease in inoculum, even in the presence of immune crops, was very low, and seasonal decreases in inoculum in continuous susceptible crop culture were similar to seasonal decreases during immune crop culture. Immune-host culture has little influence on *V. albo-atrum* survival in soils and the pathogen's rate of attrition is too low to make short-term rotations of value for wilt control.

Additional key words: Gossypium hirsutum, soil-borne pathogens, epidemiology.

Several workers have reported on the long persistence of *Verticillium albo-atrum* R. & B. (*V. dahliae* Kleb.) in soils. Nielson (24) reported that in *V. albo-atrum*-infested fields in Idaho, severe wilt infections occurred in potatoes following a 4- to 7-year interval of nonsusceptible-crop culture. In 1960, Guthrie (13) confirmed that wilt was still a serious problem in infested potato fields in spite of crop rotations involving 5- to 7-year intervals of nonhost culture. Nelson (23) reported similar observations for this pathogen in mint fields in Michigan. In one test, where mint plants were grown in soil taken from a field after 12 years of fallow and nonhost cropping, 90% of the plants became infected with *V. albo-atrum*. Similarly, Lucas et al. (18) found that rotations of 2-4 years were not sufficient to reduce the disease in mint fields to a point of economic control.

Other reports indicate that crop rotations with nonhost crops were successful in reducing Verticillium wilt in infested fields. McKay (20), in Oregon, reported that 3- to 4-year rotations drastically reduced the wilt disease in subsequent potato crops. In the midwestern USA, Green (11) reported that with mint, wilt infections were reduced and yields improved following 3- to 5-year rotations with nonhost crops. Marked reductions in wilt incidence for cotton with 2- to 3-year rotations have been reported by Hinkle and Fulton (14). Similarly, Ranney (25) and Leyendecker et al. (17) have observed improved yields and/or reduced wilt infections following short-term rotations. Reports from Russian workers (22) also indicated beneficial effects of crop rotation for Verticillium wilt of cotton.

A similarly confusing picture has been reported for the Verticillium wilt diseases in California. Wilhelm (27) reported that *Verticillium* was readily recoverable from an infested tomato field after 8 years of grain and pasture cropping. After 14 years of nonhost cropping, the fungus was still present in this field, although at reduced levels. George et al. (10) observed no effect of short-term rotations on Verticillium wilt of cotton. In contrast, Smith and Garber (26), George et al. (9), McCutcheon (19), and Butterfield et al. (7) reported reductions in wilt infections and/or increased yields for cotton resulting from short-term (2- to 3-year) rotations with nonhost crops.

In view of these conflicting reports, it seemed desirable to determine the effect of crop rotations on survival of *V. albo-atrum* in soils. The availability of a quantitative assay (5, 15) enabled direct monitoring of the pathogen in the soil and thus avoided interference by other possible agronomic effects of the rotations on crop yield and host infection.

MATERIALS AND METHODS

This investigation was conducted in commercially cropped fields of the San Joaquin Valley of California. After an initial survey of 16 fields in 1971, eight were selected because of differences in crop history and inoculum levels of the Verticillium wilt fungus. The inoculum levels in these loam to clay loam soils thereafter were determined at about monthly intervals for 3.5-4.0 years. The soil-sampling pattern for fields was an inverted horseshoe beginning at the point of entry into a field. Ten cores taken 0-30 cm deep and 10 steps apart were bulked into a composite sample for each side of the horseshoe pattern. The soil samples were air-dried 2 days at 21-24 C, ground in a soil mill to pass a 2-mm screen, and mixed well (1). By using the procedures reported earlier (5, 15), an assay was made on each of the three composite samples per field at each sampling date. When appropriate, assay samples were treated for 10 seconds with sodium hypochlorite and desorbed with potassium hydroxide to overcome dormancy of microsclerotia (2).

RESULTS

In our original survey, high inoculum levels of *Verticillium* in soils usually were associated with fields having an intensive cotton-cropping history (Table 1, last four entries). However, in many fields (Table 1, first 12 entries) there appeared to be little correlation between *Verticillium* inoculum levels and previous cropping history (e.g., field 30 vs. 72).

To evaluate further the influence of crop rotation on pathogen survival, eight fields were selected for continuous monitoring over an extended period. Changes in inoculum densities from month to month generally were gradual whether they were ascending or descending in response to cropping practices, as illustrated in the preceding report (2). Maximum annual inoculum densities, determined in July-September, for eight fields with different cropping histories are presented in Fig. 1. The excellent agreement between month-to-month assay results [see Fig. 1 in (2)] assured us that the values given in Fig. 1 represent seasonal inoculum changes rather than sampling error. In fields repeatedly cropped to a susceptible crop (cotton), high inoculum densities (20-60 microsclerotia/g soil) are built up and persist, as seen in field 89 and the 1971 value for field 77 (Fig. 1). Inoculum density increased rapidly following only 1 year of a susceptible crop with the increase appearing in the year following this crop. This delayed increase occurred regardless of whether the subsequent crop was susceptible (Fig. 1, fields 88, 42A, and 77) or nonsusceptible (Fig. 1, fields 42, 79, and 86). Once soils were infested, the rate of decrease in inoculum, even in the presence of immune crops, was low (Fig. 1, fields 42, 77, 86, and 86A). Seasonal decreases in inoculum in continuous susceptible culture (Fig. 1, fields 42A and 88) were equal to any seasonal decreases in immune-crop culture (Fig. 1, fields 42, 77, 79, and 86).

DISCUSSION

Microsclerotia are the principal persistent propagules of *Verticillium* spp. in soil (12, 16, 21). That these microsclerotia originate in infested host tissue was suggested (6, 8) and confirmed (16). The finding that the rapid buildup of *V. albo-atrum* in soil does not become evident until the year following the planting of a susceptible crop (Fig. 1) is consistent with this view. Infested host tissue first must be incorporated in the soil and decomposed before the inoculum buildup is detectable (3, 21). This time lag in inoculum release must be taken into consideration in any efforts to manipulate pathogen populations in soils.

Our data suggest that *V. albo-atrum* can survive in soils for long periods. An extrapolation of attrition rates in fields 77, 86, and 86A (Fig. 1) indicates that from 10 to over 20 years are required for the pathogen population to drop to near zero. These estimates agree with the findings of others (13, 23, 24, 27) that *Verticillium* spp. persist in soils for many years and can induce severe wilt in susceptible crops even after 6-12 years of nonhost cropping.

The rapid buildup and slow attrition of propagules of *V. albo-atrum* in soil limits the value of crop rotation for controlling this soil-borne pathogen. Within 1-2 years the fungus can increase to 30-40 microsclerotia/g soil in fields with initially relatively low (1-5 microsclerotia/g soil)

TABLE 1. Inoculum densities of *Verticillium albo-atrum* in variously cropped soils of the San Joaquin Valley of California

Field	County	Inoculum density[a] 1971	Crop histories 1971	1970	1969	1968	1967	1966
81	Merced	0.03	cot[b]	wh-mi	cot	fal	fal	cot
82	Merced	0.03	cot	alf	alf	alf	alf	. . .
83	Merced	0.05	cot	cant	cot	cant	cot	. . .
36	Kings	0.08	cot	ba-wh	alf	alf	alf	ba-co
88	Merced	0.20	cot	alf	alf	alf	cot	cot
30	Kings	0.48	cot	cot	cot	cot	alf	alf
80	Madera	0.93	cot	cot	corn	cot	corn	. . .
87	Merced	1.15	cot	ba	cot	wh	tom	alf
73	Kings	3.50	cot	wh	wh	cot	cot	alf
72	Tulare	3.90	cot	b.e.	s.b.	cot	alf	alf
78	Kings	4.10	cot	cot	wh	cot	cot	. . .
42	Kings	4.70	cot	cot	corn	cot	cot	cot
74	Tulare	24.60	cot	s.b.	cot	cot	cot	cot
75	Tulare	28.00	cot	cot	cot	cot	cot	cot
89	Merced	38.10	cot	cot	cot	cot	alf	alf
77	Tulare	47.00	cot	cot	cot	cot	alf	alf

[a]Microsclerotia per gram dry soil.

[b]Abbreviations for crops: cotton, cot; wheat-milo, wh-mi; fallow, fal; alfalfa, alf; cantaloupe, cant; barley-wheat, ba-wh; barley-corn, ba-co; barley, ba; blackeye cowpea, b.e.; sugar beet, s.b.

population levels (Fig. 1, fields 42A, 86, and 88). These values are over 10-fold the level (about four microsclerotia/g soil) needed to cause 100% infection in a cotton crop (4). Although attrition occurs during nonsuscept culture (Fig. 1), the observed rate is far too slow to make short-term crop rotation meaningful as a control measure. In field 86A (Fig. 1) microsclerotia of *V. albo-atrum* had not dropped sufficiently after 6 years of nonhost cropping to make it safe again for cotton.

Crop rotations, however, can be useful under certain circumstances. If the rotation is initiated when the inoculum is close to the minimum level needed for 100% infection in a susceptible crop, the attrition could be sufficient to drop the inoculum to a level where disease incidence in a subsequent susceptible crop would be reduced significantly. This situation is evident in field 79 (Fig. 1). However, such a situation would probably be the exception in the San Joaquin Valley since the inoculum buildup is so rapid. This also may explain some of the conflicting reports on the results of crop rotation in controlling *Verticillium* spp. Depending on inoculum level of an experimental field when a rotation regime was initiated, the attrition rate may or may not be sufficient to reduce disease incidence. Thus, it is important to know inoculum levels in experimental fields. The occasional large decreases in inoculum level observed in most fields (Fig. 1) also may figure in the conflicting reports on crop rotation, in that their unpredictable and short-term nature would necessarily lead to inconsistent results.

In most rotation studies, pathogen attrition has not been measured. Since inoculum buildup in continuous host culture progresses steadily while that in rotation plots is disrupted during the nonhost cycle, a direct plot comparison at the end of the rotation sequence may be misleading. With the possible exception of the report by McKay (20), crop rotations, when data permit evaluation, have not caused a reduction of the wilt pathogen. Although disease incidence was lower in rotation plots than in continuous cotton plots in the rotation trials of Hinkle and Fulton (14), at best no reduction in disease incidence occurred whereas in almost all cases Verticillium wilt incidence was significantly higher in each plot at the end of the 5th year than at the start of the trial. A similar situation is observable in data reported by George et al. (9). In reports of shorter studies, the observed differences in wilt incidence between continuous host and rotation plots have not been drastic (7, 17, 26). This suggests that rotations merely stretch out the time involved in inoculum buildup, but are unable to avert it. In California where wilt reductions have been reported in crop rotation studies with cotton (7, 9, 19, 26), the corresponding yield increases have averaged only 10% (our own calculations of reported data).

Although we do not wish to detract from the agronomic benefits of crop rotation, we conclude that rotations per se have little effect on *V. albo-atrum*

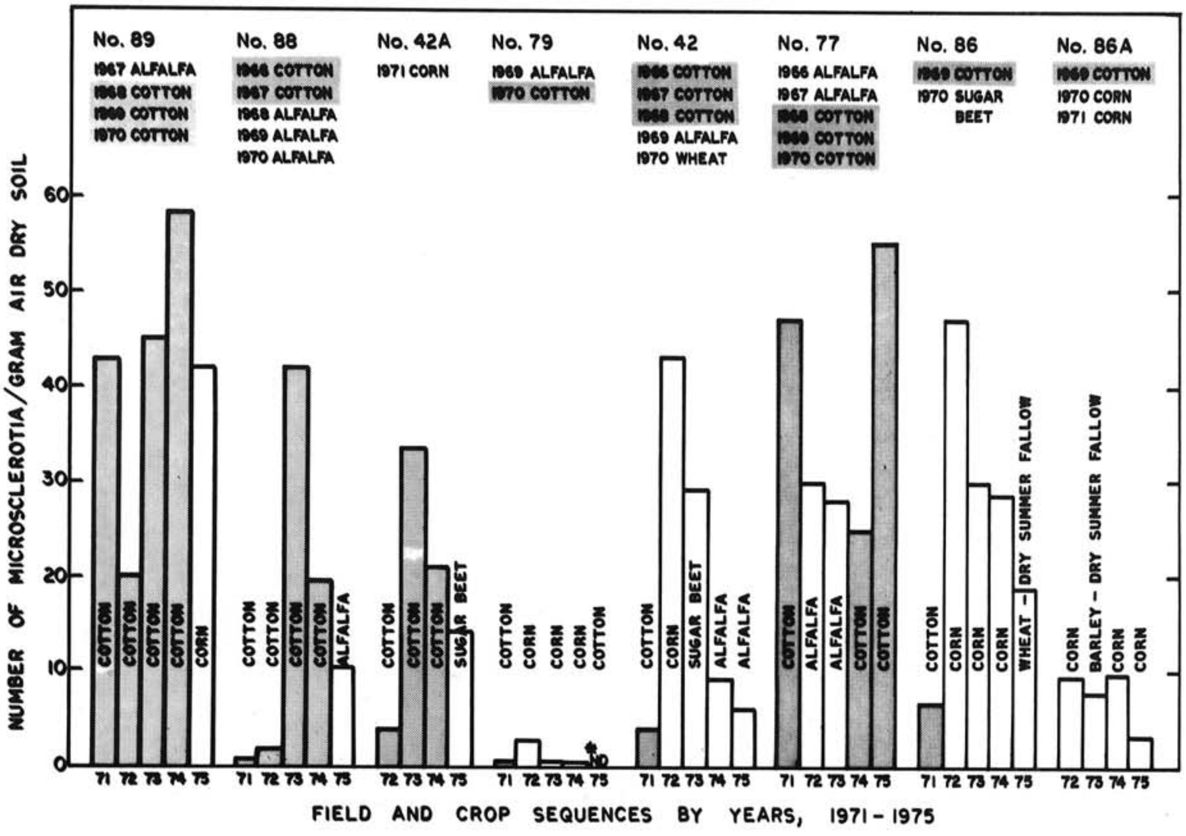

Fig. 1. Influence of cropping sequences on inoculum densities of *Verticillium albo-atrum*. Shading indicates a *Verticillium*-susceptible crop.

survival in soils and are ineffective in the long run as control measures for this important soil-borne pathogen.

Of particular importance is our observation that significant attrition of microsclerotia does occur in field soils. However, such attrition occurs independently of the crop grown. Since reduction in inoculum in continuous, susceptible culture was equal to any seasonal decreases in immune-crop culture, reductions in fields 42, 77, 79, and 86 (Fig. 1) cannot be attributed to the presence of sugar beets, alfalfa, or corn. Apparently factors independent of the crop grown are involved in these reductions in inoculum density. It is important to identify the variables both for understanding the biology of this pathogen in the soil and for developing control measures. Preliminary data indicate that soil temperature-moisture interactions are important in survival of the fungus.

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