Vertical Distribution and Survival of Sclerotium oryzae Under Various Tillage Methods

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This study was funded by the California State Rice Research Board.
Accepted for publication 16 July 1975.

ABSTRACT

The effects of various residue management practices were examined on vertical distribution, survival, and availability of sclerotia of *Sclerotium oryzae* under continuous rice culture. Open field-burning of residue was the most effective method for minimizing inoculum levels. When residue was incorporated into soil, moldboard plowing resulted in burying a high percentage of the surviving inoculum, rendering it unavailable for infection of water-sown rice. A differential survival of sclerotia at various soil depths was observed between tillage methods compared.

Phytopathology 66:97-101

Additional key words: stem rot of rice, cultural control.

Sclerotium oryzae Catt., the cause of stem rot of rice overwinters from one season to the next as sclerotia either free in the soil or in association with plant residues. In water-sown rice, sclerotia float to the surface when fields are flooded and provide the primary inoculum as plants emerge from the water (7). Direct observation and results of others (7) have shown that additional sclerotia become dislodged and rise to the water surface as soil clods in the flooded seedbed disintegrate or by any factors, such as wave action due to wind that disturb the surface layers during the growing season. A positive correlation between inoculum level in the seedbed, disease severity, and yield loss was demonstrated (4, 10).

Lack of high levels of resistance and acceptable chemical control procedures have indicated that efforts toward controlling stem rot should be directed toward cultural practices. The burning of rice residue has been employed with considerable success in minimizing inoculum levels (10); however, the present and probable future restrictions on agricultural burning suggest the need for seeking alternatives to burning for control.

Sclerotia of *S. oryzae* have been reported to survive under experimental conditions for long periods of time. Park and Bertus (8) reported viability after 190 days on air-dry soil in the laboratory; after 133 days buried in moist paddy soil; after 319 days submerged in tap water, and after 525 days in a corked specimen tube. Nisikado and Hirata (6) reported that sclerotia remained viable for 3 years at 20 C, 10-13 months at 25 C, and 4 months at 35 C. Tullis and Cralley (9) reported that a portion of sclerotia associated with straw, when buried 10- to 15-cm deep in soil, remained viable for up to 6 years. Persistance of sclerotia in soil and essential monoculture, due to unsuitability of many rice soils for other crops, reduce the potential of crop rotation as a control measure. Conversely, methods of culture which result in an unavailability or decreased viability of inoculum may be beneficial. Recently, Keim and Webster (1, 2) described biotic and abiotic factors which markedly reduced viability of *S. oryzae* sclerotia. This paper presents information on the vertical distribution of sclerotia at various soil depths and on their survival under different methods of residue management.

MATERIALS AND METHODS.—*Tillage treatments.*—For all practical purposes a rice crop utilizes only the top 30-cm of soil during its growing season. Therefore, tillage practices employed during the present study were limited to that depth or less. The choice to survey only the top 20-cm was further justified since, in water-sown rice, inoculum for infection of rice plants must rise through the flood water from the finished seedbed which involves primarily the surface and that encompassed by disintegrating soil clods. The site selected for study is located in Butte County, California, where rice has been grown continuously for several years on Stockton clay adobe soil. The following residue management and tillage treatments, some currently used by growers (5), were compared: (i) straw and stubble were burned and stubble was disk-plowed to a depth of 15-20 cm in the fall; (ii) crop residue was not burned but residue and soil were disk-plowed together to a depth of 15-20 cm in the fall; (iii) residue was not burned, but residue and soil were disk-plowed in the spring to a depth of 15-20 cm; (iv) residue was not burned, and residue and soil were moldboard-plowed in the fall to a depth of 25-30 cm; (v) residue was not burned, and residue and soil were moldboard-plowed in the spring to a depth of 25-30 cm; and (vi) residue was not burned, and residue and soil were tilled in the fall after harvest with a Howard rotovator which simultaneously chopped the straw and blended it uniformly in the top 15-cm of soil. The stubble-disk plow which was used opened the soil with a slicing action and distributed the crop residue vertically through the soil. The moldboard plow inverted 25- to 30-cm deep strips of soil and residue. The effectiveness of inversion depended on soil moisture conditions and was more complete in the spring than in the fall operations. Each treatment was replicated four times; each plot was 14.5 × 155 meters separated by levees and provided with individual water systems that precluded the exchange of soil and water

TABLE 1. Total number of *Sclerotium oryzae* sclerotia and viable sclerotia per gram soil in finished seedbeds (top 5 cm) observed under tillage practices compared for three consecutive years of rice cropping

Residue and tillage treatment	Sclerotia per gram soil					
	1971		1972		1973	
	Number	Viable	Number	Viable	Number	Viable
Residue burned, fall-disked	2.91[z]	0.28 a	2.06	0.26 a	2.27	0.32 a
Residue not burned, fall-disked	3.46	0.52 b	2.48	0.55 c	3.72	1.15 c
spring-disked	3.37	0.56 b	2.54	0.62 c	2.84	1.08 c
fall-plowed	3.39	0.46 b	2.11	0.47 b	2.39	0.69 b
spring-plowed	2.55	0.42 b	2.06	0.47 b	2.08	0.51 b
fall and spring rotovated	3.08	0.48 b	2.57	0.46 b	2.81	1.01 c

[z]Values represent means of four replicates with 18 subsamples per replicate. Values with common letters do not differ statistically ($P = 0.05$) for each column.

TABLE 2. Vertical redistribution during seedbed preparation of sclerotia of *Sclerotium oryzae* after initial tillage treatments and overwintering

Residue and tillage treatment	Sample depth (cm)	Sclerotia (no. per gram of soil)			
		After initial treatments and overwintering-April 1		After seedbed preparation April 20	
		Total number	Number viable	Total number	Number viable
Burned-fall disked	1-5	2.16[y]	.29	2.06	0.26 a
	5-10	1.25	.08	- - -[z]	
	10-20	.16	.004	- - -	
Not burned - fall disked	1-5	4.83	.79	2.46	0.55 c
	5-10	4.29	1.02	- - -	
	10-20	1.01	.16	- - -	
Not burned - spring disked	1-5	5.65	.97	2.54	0.62 c
	5-10	1.46	.31	- - -	
	10-20	.17	.09	- - -	
Not burned - fall plowed	1-5	2.45	.27	2.11	0.47 b
	5-10	1.47	.17	- - -	
	10-20	.28	.05	- - -	
Not burned - spring plowed	1-5	4.70	1.16	2.06	0.47 b
	5-10	.71	.09	- - -	
	10-20	.22	.01	- - -	
Not burned - fall and spring rotovated	1-5	5.92	1.05	2.57	0.46 b
	5-10	4.44	.98	- - -	
	10-20	1.57	.13	- - -	

[y]Values represent means of four replicates with 18 subsamples per replicate. Values with common letters do not differ significantly at the $P = 0.05$ level.

[z]Physically not available as inoculum for present crop.

between plots. After the initial residue management and tillage practices, all remaining operations were those of normal production of a rice crop in California (5), including final tillage in the spring to prepare the soil for seeding. These operations mainly affected the top 10-15 cm and resulted in considerable mixing of soil and residue.

Collection of samples.—Samples of approximately 30-40 g of soil were collected with a standard soil core sampler, placed in paper bags, and held at 1 C until extraction of sclerotia. The time of sampling in relation to tillage practices and the depth of the sample are presented where appropriate in the Results section. The methods for recovering sclerotia from soil samples and determining their viability are presented elsewhere (3).

RESULTS.—*Vertical distribution of inoculum.*—Seedbed inoculum levels in the top 5-cm were observed for 3 years consecutively and were used as a basis to make comparisons between treatments. The fall-burn, disk treatment was most effective in minimizing inoculum level increases under continuous rice cropping (Table 1). Current interest in air quality control, however suggests that burning of residue may be excluded as a step in the present California rice culture system. Consequently, the effect of alternate methods for disposing of residue on survival of inoculum at different

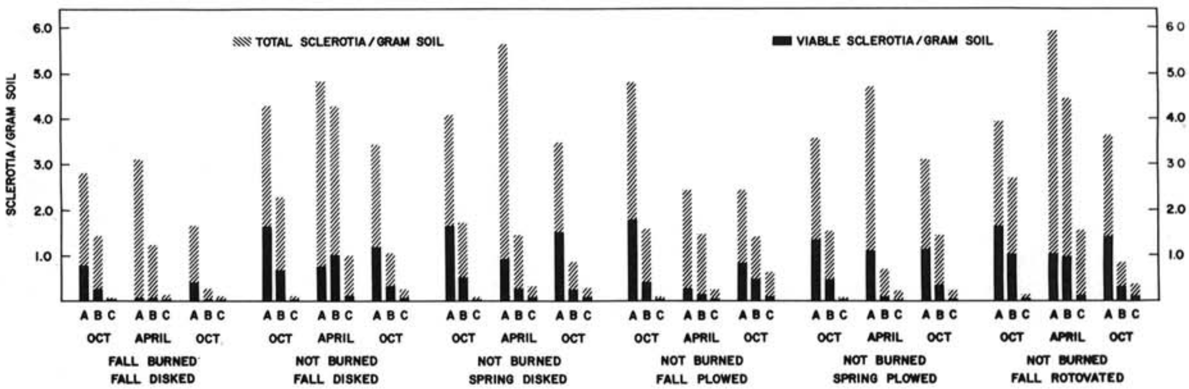

Fig. 1-(A to C). Comparison between total numbers of sclerotia and viable sclerotia/gram soil in different residue management treatments at three vertical depths; **A)** 0-5 cm, **B)** 5-10 cm, and **C)** 10-20 cm at three separate sample dates spanning the production of a rice crop (cultivar Calrose). October 1971 samples taken after harvest, but prior to initial fall treatments; April 1972 samples taken after all initial treatments, but prior to final seedbed preparation. October 1972 samples taken after harvest of the 1972 crop, but prior to tillage treatments.

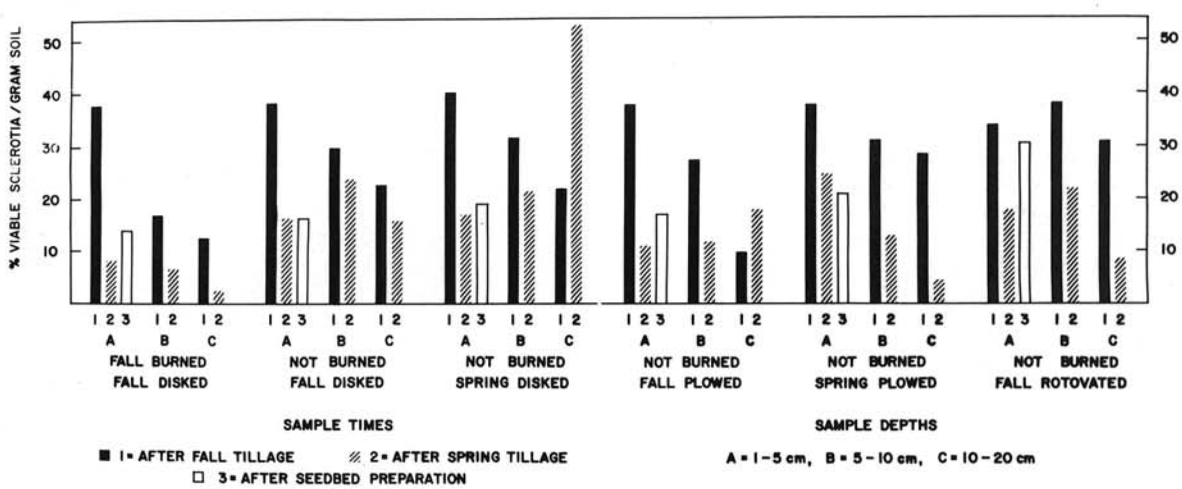

Fig. 2. Percentage viability of sclerotia at different depths at three sample times for the six basic treatments compared. 1. After harvest before fall tillage treatments, 2. After fall tillage, overwintering and spring tillage but prior to seedbed preparation, 3. After final seedbed preparation just prior to planting in the spring. A = 1-5 cm, B = 5-10 cm, and C = 10-20 cm.

depths, and also on redistribution of inoculum into future seedbeds, was determined in October 1971, April 1972, and October 1972. Samples in October (1971), taken immediately after harvest of the current crop provided inoculum levels just prior to initial treatments. Samples taken in April (1972) provided inoculum status following initial fall- and spring-tillage treatments, but prior to final seedbed preparations. Results of the October 1972 sampling after a season of the treatments revealed substantial increases in inoculum level at the 5-cm depth in all treatments over that observed in seedbeds at the 5-cm depth. This would be expected since the crop sustained considerable stem rot disease during the growing season and many sclerotia were deposited on the soil surface due to the agitation of infected plants during the harvesting operation. The vertical distribution of inoculum observed at the other sample times at the various depths is consistent with that expected in relation to the depths affected by the various tillage methods.

Physical redistribution of inoculum due to tillage necessary for satisfactory seedbed preparation, following the basic treatments for the (Spring 1972) season, is compared in Table 2. Seedbed preparation included: Treatment 1, (Burned, fall-disked); disk harrowed twice, spike-tooth harrowed once, H-Iron-flotation to level once, and one additional disk harrowing; Treatments 2 (not burned, fall-disked), 3 (not burned, spring-disked), 4 (not burned, fall moldboard-plowed), and 5 (not burned, spring moldboard-plowed), stubble disk plowed three times, disk harrowed once, spike-tooth harrowed once, leveled with H-Iron-flotation twice, and disk harrowed once at final preparation; and treatment 6 (not burned, rotovated) disk harrowed once, stubble disk plowed twice, disk harrowed once, spike-tooth harrowed once, H-Iron-flotation for leveling once, and disk harrowed for final preparation. There was considerable redistribution of inoculum and it occurred consistently with the nature and depth of the tillage operations required for satisfactory seedbed preparation (Table 2).

Relationship of tillage method and vertical distribution to survival of sclerotia.—A redistribution of sclerotia from one vertical position to another during tillage operations was suggested (Fig. 1, Table 2). Further, observed viability of sclerotia recovered from the soil surface (38-49%) and standing stubble and straw (76-92%) immediately after harvest was higher than that for sclerotia recovered from soil. Consequently, the effect of residue incorporation on numbers of sclerotia at different depths and times in the soil (either free or associated with residue) must have a direct bearing on the final inoculum levels in seedbeds.

Viability of sclerotia at different depths under the various treatments after harvest in the fall but prior to fall tillage were compared with those observed in the spring after fall treatments, overwintering, and initial spring treatments, but prior to seedbed preparation. Percentage viability of sclerotia at the end of the cropping season is quite uniform in the top 5-cm of soil (Fig. 2, A-1) and differences between the treatments became larger with increases in depth (Fig. 2-B and C). The reduction in percent viability of sclerotia observed at the various depths (5-10 and 10-20 cm) in the spring sampling (Fig. 2-2 and 3) are substantial and could be due either to a redistribution of nonviable sclerotia from the lower horizons during tillage, to a loss of viability during the overwintering period, or to both of these factors. The higher percentage viable sclerotia in the not burned spring disked, not burned fall disked and not burned rotovated treatments at the 5- to 10-cm depth in the spring sampling is probably due in part to redistribution from the upper layers as are the increases in percent viability in the not burned spring disked and not burned spring plowed treatments at the 10- to 20-cm depth. The decreases in percentage viability between the 5- to 10-cm depth and the 10- to 20-cm depth in treatments not burned fall disked, not burned rotovated, not burned spring plowed and burned fall disked, indicate the redistribution is accompanied by a differential survival of sclerotia at different depths (Fig. 1 and 2). This is probably related to enhanced contact of sclerotia with physical and biological factors in soil known to affect viability of sclerotia (1, 2). This is of particular interest when comparing the various treatments. For example, percentage viability of sclerotia in the top layer of fall samples, immediately after production of a crop are quite uniform but marked differences in percentage viability were observed as sample depth increased with the exception of the not burned spring plowed and not burned rotovated treatments (Fig. 1 and 2). The spring sampling revealed lower percentage viability in the top two sample depths, but differences between sample depths were not as pronounced as in the fall sampling. This difference may

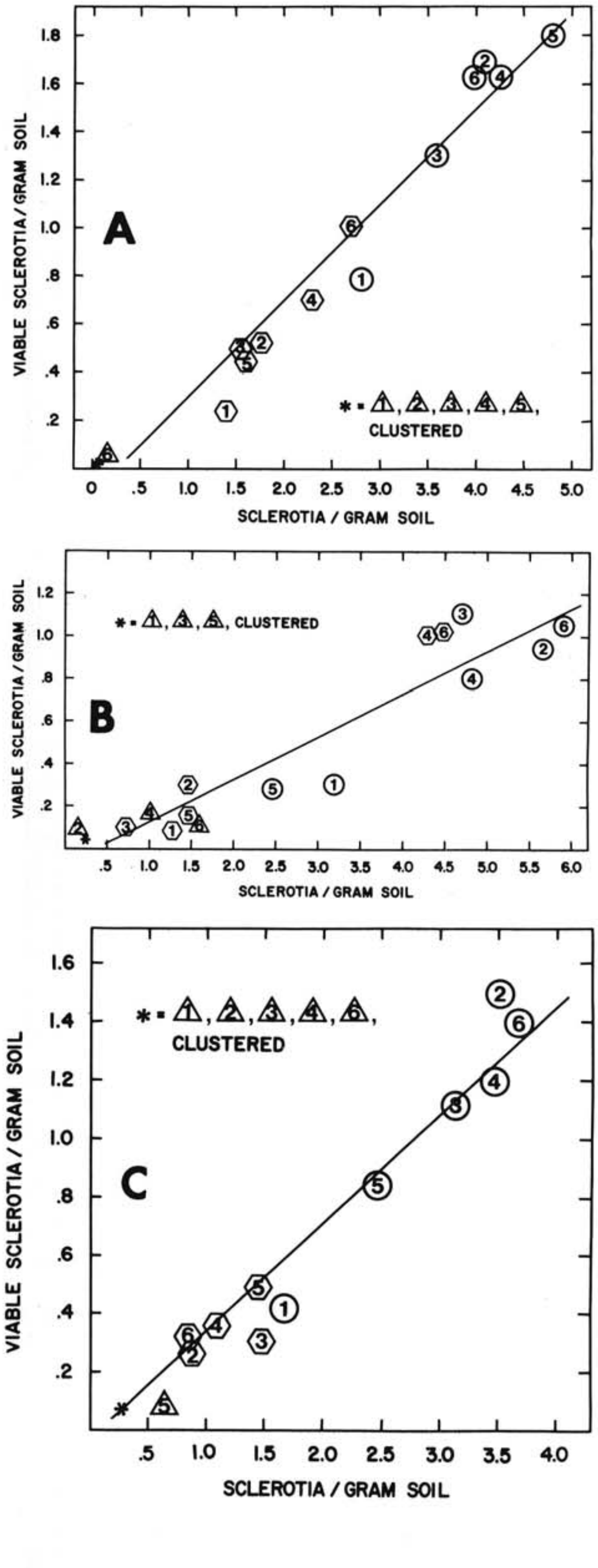

Fig. 3-(A to C). Linear regression of viable sclerotia per gram soil on total sclerotia per gram soil recovered from treatments compared at three sample depths and times. **A**) Fall 1971 sampling, **B**) Spring 1972 sampling, and **C**) Fall 1972 sampling. Legend: 0 = 0-5 cm; ⬡ = 5-10 cm; △ = 10-20 cm. 1 = Residue burned, fall disked; 2 = Residue not burned, fall disked; 3 = Residue not burned, spring disked; 4 = Residue not burned, fall moldboard plowed; 5 = Residue not burned, spring moldboard plowed and 6 = Residue not burned, fall and spring rotovated. A: Standard Error of Regression = .118, $P = .001$. B: Standard Error of Regression = 1.75; $P = .30$. C: Standard Error of Regression = .477; $P = .001$.

reflect the fact that the fall samples had been submerged beneath 10-15 cm of water during the crop year for nearly 5 months while during overwintering. Although the plots received nearly 90 cm of rainfall, the soil surface varied in texture and degree of saturation depending on the tillage practice.

Regression coefficients for total sclerotia and viable sclerotia per gram of soil at the various sample depths were determined. The relation between effect of treatment and vertical distribution on viability of sclerotia is shown in Fig. 3A-C.

DISCUSSION.—Results of tests presented here indicate that the practice of burning residue followed by stubble disk plowing is the most effective method for minimizing inoculum available for infecting subsequent rice crops. When residue is not burned, the most effective means for minimizing inoculum levels is moldboard plowing. This results in depositing the majority of sclerotia in the soil at a depth beyond that reached by the implements used to prepare finished seedbeds. In this case, the viability of the sclerotia is not a factor since they do not reach the surface of the paddy water, which is the site of infection under the cultural system used for rice in California.

The data indicate that in addition to exclusing sclerotia from effective horizons, the deeper tillage treatments (moldboard plowing) also result in a higher percentage loss of viability during the overwintering period. On the other hand, tillage by rotovating did not show this effect. This is likely due to the fact that rotovation results in the most uniform distribution of residue throughout the soil zone affected by tillage, and also in a more open and uniformly aerated soil tilth.

Longevity of *Sclerotium oryzae* in soil has been studied by other authors (6, 8, 9); however, they did not report the numbers of surviving sclerotia after various periods of time under various conditions. Such information is essential since recent studies relating inoculum levels and their correlation with disease severity and losses in yield (10) were reported.

Recently Keim and Webster (1, 2) reported that alternate wetting and drying, and biotic soil factors significantly reduce percentage viability of populations of sclerotia in rice soils. These factors may have played a role in the lower inoculum levels observed in the moldboard plow treatments and the lower horizons sampled in the other treatments of the present study. This is because tillage by moldboard plowing results in a more complete burying and subsequent exposure of sclerotia and infested residue to direct soil contact.

These and other studies (1, 2, 10) have shown that a high percentage of sclerotia in soil lose viability within a relatively short period of time. Our data do not distinguish whether sclerotia observed at specific sample dates were those produced on the infected crop, or whether new sclerotia were generated on the residue, either on the soil surface or in that incorporated into the soil by the various treatments. Information regarding this possibility, and whether one or more of the treatments compared here favor or discourage inoculum increases during overwintering, is being sought.

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