Rice Residue Disposal Influences Overwintering Inoculum Level of *Sclerotium oryzae* and Stem Rot Severity

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ABSTRACT

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The influence of rice residue removal, burning, or soil incorporation on inoculum (sclerotia) level of *Sclerotium oryzae* and stem rot severity was studied over 3 yr. In continuous rice cropping, greatest inoculum level increases and stem rot severities occurred in treatments where residue was incorporated into the soil by chopping and disking or where rice was cut 20–30 cm above the ground at harvest and the straw baled and removed, with the residue incorporated by disking. Treatments where straw was burned in the fall or spring followed by stubble-disking destroyed inoculum and had the lowest inoculum level increases and stem rot severities. Where rice was cut 0–7 cm above the ground (below the site of infection) at harvest and the straw baled and removed, however, inoculum was removed from the field and inoculum increases and stem rot severities were not significantly different from those with the burning treatments. Simulated introduction of rice residue infested with *S. oryzae* into field soil resulted in continued production of sclerotia in the residue after incorporation. Inoculum level and stem rot severity can be minimized by complete destruction or removal of rice straw infested with *S. oryzae*.

Additional key words: cultural control, *Magnaporthe salvinii.*

Stem rot, a serious disease of rice (*Oryza sativa* L.), occurs in most rice-producing countries (3,9–12). It is widespread in California and is most prevalent in the northern areas of the state (15). The causal organism, *Magnaporthe salvinii* (Catt.) Krause & Webster, is best known for its sclerotial state, *Sclerotium oryzae* Catt. The conidial state has been referred to as *Nakataea sigmoidea* (Cav.) Hara, *Vakrabeeja sigmoidea* (Cav.) Sub., and *Helminthosporium sigmoidium* Cav. (6).

S. oryzae overwinters as sclerotia either free in the soil or in association with plant residues. In water-sown rice, sclerotia float to the water surface from the seedbed when fields are flooded and serve as primary inoculum to infect emerging plants, inducing small dark lesions on the leaf sheath at the water line. Death and sloughing of the infected sheaths are followed by penetration of the culm by the fungus. Sclerotia form abundantly on or in infected sheaths and culms as rice plants near maturity and become scattered on the soil surface or remain in crop debris after harvest. High positive correlations among inoculum level (germinable sclerotia) carried over in the seedbed, stem rot severity, and reductions in yield have been shown (6,13). In California, measurements of yield losses have ranged from 8 to 24% (4,6,14).

Efforts to control stem rot have been directed toward manipulating sclerotial populations by various residue management practices. Open field burning of rice straw has been the best method of residue disposal for minimizing carry-over sclerotial populations under continuous rice cropping (14,17). Possible future restrictions on agricultural burning may necessitate developing other means for disposal of the rice residue. This 3-yr study was done to compare the effects of burning, incorporating into the soil, or baling and removing rice residue on the inoculum level of *S. oryzae*, stem rot severity, and yield.

MATERIALS AND METHODS

A 4.6-ha field trial was established 4.25 km north of Biggs, CA. Rice had been grown continuously on Stockton clay adobe soil for several years at the experimental site, and *S. oryzae* had established naturally in the field. Cultural practices were standard, and residue was burned every fall.

The experimental area was divided into 36 individual plots 14.5 × 85 m. Each plot was provided with a separate water system to preclude the exchange of soil, water, and residue between treatments. A separate water supply ditch was established to preclude contamination from adjoining fields.

Four basic residue management treatments were compared: No. 1, residue burned; No. 2, tillers cut at 0–7 cm (low) above the ground at harvest and straw baled and removed; No. 3, residue chopped and incorporated into the soil; and No. 4, tillers cut at 20–30 cm (high) above the ground at harvest and straw baled and removed. Fall disking was compared with spring disking for each basic treatment, and there was a spring moldboard plowing variable for treatment 2. The nine initial residue management treatments (Table 1) were placed in a randomized complete block design with four replications.

In May of the first year (1975), the individual levees and water systems were established after tillage of the experimental area. Final seedbeds were prepared, the plots were flooded, and the S-6 rice cultivar was sown. All cultural practices and fertilizer and pesticide applications were those of conventional production of a rice crop in California (7,8). At the end of the growing season, the nine residue management treatments were carried out.

For the second season (1976), all plots were treated similarly during seedbed preparation, following the specific differences outlined. Seedbed preparation, fertilizer and pesticide applications, and crop management practices were those of conventional production of rice in California (8).

For the third season (1977), fall (1976) and spring (1977) residue management practices were repeated as described for the first and second seasons. Thus, data obtained during this season resulted from effects of two consecutive years of residue management.

Soil inoculum levels. Each year soil samples were collected from the top 10 cm of finished seedbeds just before flooding. Each plot was subdivided into four equal areas approximately 20 × 14.5 m. Eight to 10 200–250-g samples were collected at random from each subplot and bulked into one sample per subplot to provide four bulk samples per plot. The bulk samples were air-dried and run through a soil grinder to reduce clod size and facilitate even mixing of the

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sample. Three 50-g samples were taken at random from each of the bulk samples from the subplots, and the number of sclerotia was determined as described previously (5).

Percentage germination of sclerotia was tested by placing 50 sclerotia from each 50-g sample on water agar plates containing streptomycin sulfate and penicillin G, each at 3,000 ppm. Plates plus sclerotia were incubated at 24 ± 2 C under white fluorescent lights (about 690 lux) for 12 days. Germinated sclerotia produced the conidiophores and conidia of *N. sigmoidea* (5).

Disease severity. Disease severity was determined just before draining fields in preparation for harvest for each growing season. Samples of tillers were collected at random in each plot from areas corresponding to those from which soil samples were collected. At least 300 individual tillers per plot were rated for stem rot severity at each sample time as described previously (6).

Simulation of residue incorporation. To determine whether rice straw infested with *S. oryzae* supported production of sclerotia after incorporation into soil, four 3 × 3 m plots, each surrounded by a 30-cm high levee, were established in an area where rice had never been grown and *S. oryzae* did not occur. Mature rice plants infested with *S. oryzae* (2.51 disease index rating) (6) were collected from four equivalent areas (3 × 3 m) of a rice field and incorporated with hand shovels into the experimental basins to a depth of 18 cm.

In California, rice soil usually remains wet between the time fields are drained and the time the fall rains come. Thus, fall tillage practices incorporate rice residue into moist soil. For this reason, the experimental field was sprinkler-irrigated to provide moisture. After incorporation of the infested residue, soil samples were taken periodically from the field and the number of sclerotia per 100 g of soil was determined (5). At each sampling, 60 soil cores (1.8 cm in diameter and 15 cm deep) were taken from each basin with a standard soil-core sampler, bulked into a paper bag, and air-dried. Each dry soil sample was mixed, and the sclerotia in four 100-g subsamples were extracted and counted (5).

RESULTS

Yield determination. Yields of paddy rice, at 14% seed moisture, were determined for each plot each year. Drought conditions occurred in 2 yr of the study (1976 and 1977), and there was little decomposition of rice residue during the overwintering period. Thus, for treatments where large volumes of rice straw were incorporated into the soil, the accumulation of residue resulted in "trashy" seedbeds. Stand establishment was less uniform in these treatments than in those that had seedbeds with less residue (burning treatments). Therefore, the differences in yield data were not necessarily indicative of loss from stem rot and are omitted. However, correlations between yield loss due to stem rot and either inoculum level of *S. oryzae* or stem rot disease severity have been shown (6,13).

Effect of treatments on inoculum levels. The range of initial inoculum levels was 32–98 germinable sclerotia per 100 g of soil. There were no statistically significant differences between treatments, however, with the exception of the fall burn, fall disk (32/100 g) and the tillers cut low, straw baled and removed, spring disk (98/100 g) treatments (treatments 1A and 2C). This difference in initial inoculum levels was probably due to uneven distribution of *S. oryzae* in the large field.

The increases in germinable sclerotia per 100 g of soil between years for the various treatments are shown in Table 2. There were no significant differences in increases between treatments differing only in time of tillage (fall vs. spring); between basic treatments 1 (residue burned) and 2 (tillers cut low and straw baled and removed); and between basic treatments 3 (residue chopped and incorporated) and 4 (tillers cut high and straw baled and removed). Some increases were significantly lower in treatments 1 and 2 than in treatments 3 and 4, however.

Effect of treatments on disease severity. Mean stem rot severity ratings of the various residue management treatments for the 3 yr are given in Table 3. In both the second and third years, there were no significant differences in disease severity between treatments differing only in time of tillage (fall vs. spring); between basic treatments 1 (residue burned) and 2 (tillers cut low and straw baled and removed); and between basic treatments 3 (residue chopped and incorporated) and 4 (tillers cut high and straw baled and removed). Some disease ratings for the second and third years were significantly lower in treatments 1 and 2 than in treatments 3 and 4, however.

Simulation of residue incorporation. Soil samples collected immediately after incorporation of the infested rice residue (3 October 1977) contained 36 sclerotia of *S. oryzae* per 100 g of soil (Fig. 1). These propagules had already formed in the stem rot-

TABLE 1. Rice residue management treatments

1. Residue burned[a]	2. Tillers cut low at harvest and straw baled and removed	3. Residue chopped and incorporated into the soil	4. Tillers cut high at harvest and straw baled and removed
A. Tillers cut high (20–30 cm) Straw spread by harvester Residue burned in fall Plot stubble-disked in fall Plot overwintered Plot chiseled in spring to dry Seedbed prepared	Tillers cut low (0–7 cm) Straw windrowed at harvest Straw baled and removed Plot overwintered Plot chiseled in spring to dry Plot moldboard plowed in spring Seedbed prepared	Tillers cut high (20–30 cm) Straw windrowed at harvest Straw chopped to aid soil incorporation Plot subble-disked in fall Plot overwintered Plot chiseled in spring to dry Seedbed prepared	Tillers cut high (20–30 cm) Straw windrowed at harvest Straw baled and removed Plot stubble-disked in fall Plot overwintered Plot chiseled in spring to dry Seedbed prepared
B. Tillers cut high (20–30 cm) Straw spread by harvester Plot overwintered Residue burned in spring Plot chiseled in spring to dry Plot stubble-disked in spring Seedbed prepared	Tillers cut low (0–7 cm) Straw windrowed at harvest Straw baled and removed Plot stubble-disked in fall Plot overwintered Plot chiseled in spring to dry Seedbed prepared	Tillers cut high (20–30 cm) Straw windrowed at harvest Straw chopped to aid soil incorporation Plot overwintered Plot chiseled in spring to dry Plot stubble-disked in spring Seedbed prepared	Tillers cut high (20–30 cm) Straw windrowed at harvest Straw baled and removed Plot overwintered Plot chiseled in spring to dry Plot stubble-disked in spring Seedbed prepared
C.	Tillers cut low (0–7 cm) Straw windrowed at harvest Straw baled and removed Plot overwintered Plot chiseled in spring to dry Plot stubble-disked in spring Seedbed prepared		

[a]Four basic residue management treatments were used, with fall disking compared with spring disking and a spring moldboard plowing variable for treatment 2.

infected tissues before the straw was collected and incorporated into the experimental field. During the 7 wk following incorporation, there was a threefold increase in the number of sclerotia per 100 g of soil (Fig. 1).

DISCUSSION

Previous studies (14,16,17) have shown that burning rice residue minimizes stem rot more effectively than incorporating it into the soil. In those studies, burning residues in continuous rice culture for several consecutive years resulted in maintaining the population of *S. oryzae* at a level corresponding to the inoculum level at the beginning of the experiment. In our study, on the other hand, germinable sclerotia per 100 g of soil increased between years for the burning treatments. This would be expected, since the study was carried out during drought years for California. Throughout the dry overwintering period, there was probably little degradation of soilborne sclerotia (1) to offset the input of sclerotia dislodged by the harvesting operation or surviving the fire. Burning rice residue, however, is more effective than incorporating it into the soil in minimizing stem rot during drought years.

Since stem rot lesions generally occur on rice tillers at the water line about 15 cm above the soil surface, cutting at the normal height (20–30 cm) results in most of the stem rot lesions and accompanying sclerotia remaining in the field, where they are subsequently incorporated into the soil. Simulated introduction of infested rice residue into the soil indicates that production of sclerotia of *S. oryzae* in infested tissues can continue after incorporation into the soil. Significant numbers of sclerotia are produced as a result of the continued activity of *S. oryzae* mycelium in soilborne lesions, since the competitive saprophytic ability of *S. oryzae* is restricted in soil (2). Thus, treatments in which straw was cut high, baled, and removed or in which residue was incorporated not only introduced sclerotia already formed in the tissues into the soil but also made possible further increases in sclerotia numbers in infested tissues after residue incorporation into the soil. Such increases in inoculum level during the overwintering period would result in increased stem rot severity and yield loss the following year (13).

Cutting straw as low to the ground as possible followed by baling and removing rice residue from the field was the best alternative to

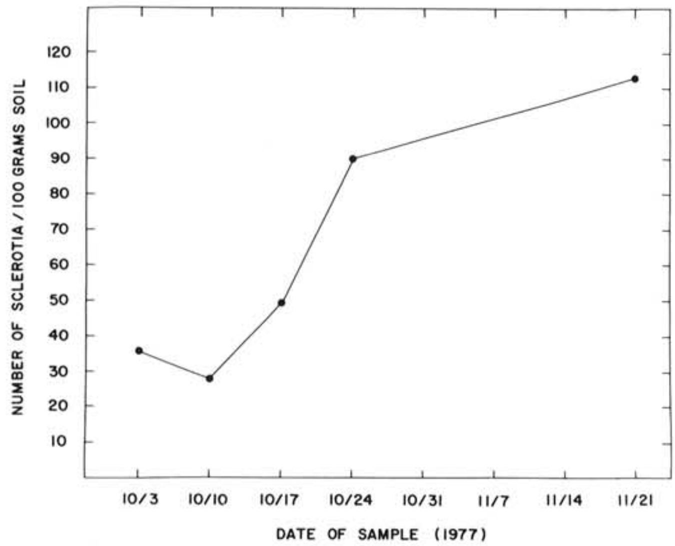

Fig. 1. Change in numbers of sclerotia per 100 g of soil after rice residue infested with *Sclerotium oryzae* was incorporated into an experimental field on 3 October 1977. The value for each sample date represents the mean number of sclerotia extracted from 16 100-g soil samples.

TABLE 2. Increases in germinable sclerotia of *Sclerotium oryzae* per 100 g of soil between years for various rice residue disposal treatments

Treatment		Increase between first and second years[z]	Increase between first and third years
1A	Residue fall burned, fall stubble-disked	1 c	100 ef
1B	Residue spring burned, spring stubble-disked	7 c	78 e
2A	Tillers cut at 0–7 cm, straw baled and removed, spring moldboard plowed	8 c	90 ef
2B	Tillers cut at 0–7 cm, straw baled and removed, fall stubble-disked	44 cd	103 efg
2C	Tillers cut at 0–7 cm, straw baled and removed, spring stubble-disked	25 cd	110 efgh
3A	Residue chopped, fall stubble-disked	68 cd	170 fgh
3B	Residue chopped, spring stubble-disked	51 cd	149 efgh
4A	Tillers cut at 20–30 cm, straw baled and removed, fall stubble-disked	59 cd	184 gh
4B	Tillers cut at 20–30 cm, straw baled and removed, spring stubble-disked	98 d	190 h

[z]Averages of four replications. Values with common letters do not differ significantly at the 5% level as determined by Duncan's multiple range test. LSD ($P = 0.05$) = 72 for first to second year increase and 76 for first to third year increase.

TABLE 3. Stem rot disease severity ratings for 3 yr of continuous rice cropping under different residue management practices

Treatment		Disease index[y]		
		First year	Second year	Third year
1A	Residue fall burned, fall stubble-disked	2.20[z] ab	1.84 c	2.18 e
1B	Residue spring burned, spring stubble-disked	2.24 ab	1.98 cd	2.21 ef
2A	Tillers cut at 0–7 cm, straw baled and removed, spring moldboard plowed	2.16 ab	1.96 cd	2.20 ef
2B	Tillers cut at 0–7 cm, straw baled and removed, fall stubble-disked	2.37 b	1.90 cd	2.39 efg
2C	Tillers cut at 0–7 cm, straw baled and removed, spring stubble-disked	2.03 a	1.98 cd	2.39 efg
3A	Residue chopped, fall stubble-disked	2.12 ab	2.03 cd	2.53 g
3B	Residue chopped, spring stubble-disked	2.22 ab	2.06 d	2.42 fg
4A	Tillers cut at 20–30 cm, straw baled and removed, fall stubble-disked	2.19 ab	2.07 d	2.43 g
4B	Tillers cut at 20–30 cm, straw baled and removed, spring stubble-disked	2.24 ab	2.06 d	2.48 g

[y]Disease index = $1(H^n) + 2(L^n) + 3(M^n) + 4(M^{*n}) + 5(S^n)$ divided by the total number of tillers examined, where H^n = number of healthy tillers, L^n = number of lightly infected tillers, M^n = number of mildly infected tillers, M^{*n} = number of moderately infected tillers, and S^n = number of severely infected tillers (6).

[z]Averages of four replications with at least 300 tillers rated per replication per year. Values with common letters do not differ significantly at the 5% level as determined by Duncan's multiple range test. LSD ($P = 0.05$) = 0.24 for first year, 0.19 for second year, and 0.20 for third year. In the disease severity range of 1.8–2.5, there is an approximately 2% yield reduction due to stem rot for each increase of 0.1 units (R. K. Webster, *unpublished*).

burning in minimizing *S. oryzae* inoculum level increases and stem rot severities. In contrast to a high cut of tiller, a low (0–7 cm) cut results in eliminating most lesions and associated sclerotia from the field when residue is baled and removed. Removal or destruction of lesions and inoculum by the low cut and straw baled and removed and the burning treatments reduced the potential for further production of sclerotia by *S. oryzae* in soilborne infested tissues as well as the direct input of sclerotia into soil.

Other studies (1,2) have shown that sclerotia free of residue in the soil do not increase saprophytically and in fact decline in numbers during the overwintering period. Thus, infested rice residue is a major factor in maintaining and/or providing increase of *S. oryzae* inoculum levels in field soil.

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