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Scleroti oryzae (the cause of stem rot) overwinters either in rice residue or free in the soil. Previous studies have shown that burning of rice residue is more effective in limiting carry-over and increases in inoculum levels than soil incorporation. A three year study was carried out to compare the effects on inoculum levels of straw removal by fall and spring burning as compared to soil incorporation. When rice was harvested at 0-3", straw baled and removed, followed by stubble-disk plowing in the fall or spring or mold-board plowing in the spring, inoculum levels and stem rot disease severity did not differ significantly from treatments where straw was burned in fall or spring. Treatments resulted in 2- to 5-fold increases in inoculum levels accompanied by increases in stem rot disease severity and losses in yield. The results indicate that harvest of straw at or near ground level followed by removal of residue as completely as possible is as effective in minimizing stem rot inoculum levels as is fall or spring burning under conditions of continuous rice cropping.

The effects of incorporating infested rice straw or free sclerotia on carry-over inoculum levels are described and discussed.

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EFFECTS OF VARIOUS METHODS OF RICE STRAW DISPOSAL ON THE EPIDEMIOLOGY OF RICE STEM ROT

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Abstract

Effects of Various Methods of Rice Straw Disposal on the Epidemiology of Rice Stem Rot

Sclerotium oryzae, the cause of stem rot overwinters either in rice residue or free in the soil. Previous studies have shown that burning of rice residue is more effective in limiting carry-over and increases in inoculum levels than soil incorporation. A three-year study to compare effects of removal of straw with fall and spring burning and incorporation on inoculum levels was carried out. When rice was harvested at 0-3", straw baled and removed followed by stubble-disk plowing in the fall or spring or mold-board plowing in the spring, inoculum levels and stem rot disease severity did not differ significantly from treatments where straw was burned in fall or spring. Treatments where rice was harvested 9-12" followed by soil incorporation or baling and removal, resulted in 2- to 5-fold increases in inoculum level accompanied by increases in stem rot disease severity and losses in yield. The results indicate that harvest of straw at or near ground level followed by removal of residue as completely as possible is as effective in minimizing stem rot inoculum levels as is fall or spring burning under conditions of continuous rice cropping.

The effects of in orporating infested rice straw or free sclerotia on carry-over inoculum levels are described and discussed.

This report was submitted in fulfillment of standard agreement No. 9077 by Robert K. Webster and W. W. Bockus, Department of Plant Pathology, University of California under partial sponsorship of the California Air Resources Board. Work was completed as of February 1, 1978.

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Conclusions

1. *Sclerotium oryzae* inoculum levels in treatments where rice was harvested at or near ground level, the residue baled and removed, were similar to those resulting in treatments where residue was burned either in the spring or fall.
2. When residue infested with *S. oryzae* is incorporated into soil, new sclerotia are produced and the inoculum level increases. Therefore, if removal of residue is adapted, harvest below the water level (site of stem rot infection) would be necessary to limit *S. oryzae* inoculum levels.
3. Incorporation of residue either in fall or spring resulted in increases in *S. oryzae* inoculum, stem rot disease severity and reductions in yield.
4. Free sclerotia (not associated or included in residue) are poor competitors in soil and probably do not contribute to increases in inoculum level.
5. Complete spring burning was as effective as fall burning in minimizing *S. oryzae* inoculum levels.
6. Moldboard plowing as primary tillage following removal of residue was more effective than stubble-disk plowing in minimizing *S. oryzae* inoculum levels.
7. Stubble disking as primary tillage following removal of residue was as effective in the spring as in fall in minimizing *S. oryzae* inoculum levels.
8. Complete removal of residue is a more satisfactory alternative than soil incorporation if open field burning cannot be continued when considering effects on the epidemiology of stem rot disease of rice.

RECOMMENDATIONS

1. Any recommendations resulting in a major change in the California Rice culture system, i.e. residue removal in lieu of burning, are apparent in the conclusions regarding potential influence on stem rot disease.
2. Studies on efficacy of fungicides for stem rot control under conditions of burning, residue incorporation or removal should be carried out.
3. Although complete removal of residues is a satisfactory alternative to open field burning, considering the effects on epidemiology of stem rot disease of rice, there does not exist at this time a usable method of disposing of the residues once they are removed.

Introduction and Background

Stem rot, a serious disease of rice (*Oryzae sativa* L.) occurs in most rice-producing countries of the world (2, 13, 14, 15, 17, 18). The disease is widespread in California being most prevalent in the northern rice-producing areas of the state (24). The causal organism, *Magnaporthe salvinii* (Cattaneo) Krause and Webster (8) is best known for its sclerotial state, *Sclerotium oryzae* Catt. The conidial state has been referred to as *Nakatea sigmoidea* (Cav) Hara, *Vakrabeeja sigmoidea* (Cav.) Sub., or *Helminthosporium sigmoideum* Cav.

The sclerotial state, *S. oryzae*, overwinters from one season to the next as sclerotia either free in the soil or in association with plant residues (5, 6, 9, 21). In water-sown rice, sclerotia float to the surface from the seed bed when fields are flooded and provide the primary inoculum as plants emerge from the water. Initial infection of rice plants occurs at the water line and is first apparent as small dark lesions on the leaf sheath. Disease progression is characterized by the death and sloughing of the infected sheaths followed by penetration of the entire culm. When the culm is infected, panicle size, grain weight and quality are reduced. When infection occurs early in the season, tillers are either killed or fail to produce panicles. Additional losses in yield often result from increased lodging of infected plants resulting in reduced harvester efficiency. Actual loss estimates as high as 75% have been reported in Arkansas (3) and areas of the Punjab (16) with annual losses ranging from 5-10% throughout the rest of the rice-growing world. In California, we have observed losses as high as 50%. Experimental measurements of losses over the past 8 years have ranged from 8 to 24% in a large number of fields in the Northern Sacramento Valley (4, 7, 21).

Sclerotia of *S. oryzae* are formed abundantly on or in infected rice plants as they approach maturity and for as long after harvest as moisture and temperature conditions remain favorable for growth of the fungus. They become scattered on the soil surface or remain in crop debris after harvest. Extensive studies (7, 19, 20) have revealed a high positive correlation between inoculum levels carried over in the seed bed (sclerotial counts) and stem rot disease severity and reduction in yield the following year. This finding has been observed consistently for inoculum levels ranging between 0.1 and 0.8 viable sclerotia per gram of soil in the surface of seed beds. When inoculum increases to levels higher than this, correlations become sporadic due to the fact that essentially all plants become infected.

It is evident that manipulation of sclerotial populations or inoculum level provides the most logical approach to controlling stem rot. Consequently factors that affect their survival and increases or decreases from one season to the next have been studied extensively. Information on survival at various depths in soil (21), effects of various biotic and abiotic factors on viability (5, 6) and the saprophytic ability of S. oryzae is now available (1).

The effects that various culture practices used by the growers themselves in producing a rice crop may have on the epidemiology of stem rot disease is of particular importance in relating results of laboratory studies to actual occurrence of the disease in the field. The nature of the disease cycle and the prominent role of sclerotial populations made a consideration of residue management the logical point of attack in minimizing inoculum level and resultant disease.

At the onset of our studies it was not known if the common practice of open field burning of rice residue was beneficial in minimizing inoculum levels of S. oryzae. It was well known that the majority of California rice growers traditionally burned rice residue mainly due to the need to eliminate the large volumes of straw and stubble from interferring with preparation of fields for continuous rice culture. At the same time public opposition toward the continuance of agricultural burning increased. Furthermore, the effects of soil incorporation (a most likely alternative to burning at the time) of large volumes of residue (often infected with S. oyrzae) on the severity of stem rot were (1) not known. It was for this purpose that long-term trials comparing the effects of burning vs. various methods of total residue incorporation were established (19, 23).

Studies comparing the effectiveness of moldboard plowing and stubble-disk plowing as initial tillage practices both in the fall and spring with open field burning in minimizing inoculum levels were carried out for 4 consecutive years at one site (site I) and 5 years (site II) at another. At site I, S. oryzae initially occurred at a very low level (.06 viable sclerotia/gram soil) and stem rot disease was not an economic factor. At site II, S. oryzae inoculum levels ranged between 0.2 and 0.3 viable sclerotia/gram soil and significant levels of disease were observed. Inoculum levels in seed beds in all treatments other than burning increased significantly with each subsequent year of residue incorporation while burning of residue resulted in no increase over the original level at each site. Moldboard plowing in the fall, moldboard plowing in the spring, stubble-disk plowing in the fall, and stubble-disk plowing in the spring in this order followed burning in effectiveness in minimizing inoculum levels (19, 21, 23).

Increases in disease severity were correlated with inoculum level increases and were accompanied by decreases in yield. Open field burning of residue in the fall was clearly the most effective method tested for minimizing loss to stem rot disease. The average yield over 5 years study when residue was burned was 59.3 cwt/acre as compared to 55.1 cwt/acre where residue was incorporated. In addition to actual yield losses due to disease, the comparative cash costs for preparation of seed beds following burning vs. incorporation were $93.67 when burned and $107.27 for incorporated treatments (25). These figures do not include costs of straw size reduction and additional grower and equipment time required when residue incorporation reduced operating efficiency.

The demonstration that burning rice residue is not only the most efficient and economical approach to continuous rice culture, but that it also effectively minimizes stem rot in areas where it is well established should not overshadow the finding that burning also prevented the buildup of the disease where it was not a problem (site I). This latter fact is as important to the rice grower attempting to maintain his land in top condition as concern for preventing soil contamination by any other pollutant that would reduce the capacity to produce by that field.

It is apparent from the above that open field burning of rice residue after harvest has provided an invaluable form of stem rot disease control. The unavailability of high levels of disease resistance in our present varieties and lack of a registered chemical control emphasize the role of burning in minimizing losses to stem rot.

At the present time, the feasibility of removing rice straw from fields for utilization and as an alternative to burning is being investigated. In addition, proposals to limit acreages burned in the fall, which result in increased spring burning, are being adapted. This project was designed to determine the potential effects of these proposed changes in our present rice culture system on the epidemiology of rice stem rot disease.

Specific Objectives:

(1) Determine the effects of removing rice residue by baling on *S. oryzae* inoculum levels. This aspect assumed rice would be harvested at a normal height and would probably result in leaving most of the *S. oryzae*-infested residue in the field.

(2) Determine the effect of harvesting at different heights followed by baling and removal of straw on *S. oryzae* inoculum levels. Normal harvest heights when rice is not lodged would be above the water level, thus leaving the majority of the infested residue in the field. In this phase a treatment of harvesting at ground level (3") or below the infection site on the plant was studied. Barring the dislodging of sclerotia from residue by equipment this was expected to be effective in removing existing inoculum from the field plus the potential for inoculum buildup on infested residue during overwintering.

(3) Compare the effectiveness of fall vs. spring burning on minimizing *S. oryzae* inoculum levels. Efficiency or cleanliness of spring burns is often variable.

(4) Compare the effectiveness of stubble-disk or moldboard plowing as primary tillage methods following the removal of residue, and

(5) Obtain comparative data on inoculum levels, disease incidence and severity, and rice yield in each of the residue management regimes listed above.

Procedures and Methods

A. Experimental location, design, and set-up:

An agreement was made with the California Cooperative Rice Research Foundation in Butte County to establish the experimental area required to carry out the study. The trial area was located 4.25 kilometers north of Biggs, California. Rice had been grown continuously for several years at the site. Soil type was Stockton Clay Adobe. *Sclerotium oryzae* was established in the field and losses to stem rot had occurred in previous years. Culture practices were standard and the practice of burning residue in the fall had been followed. The total experimental area of 5.75 hectares was divided into 45 separate plots, each 14.5 x 85 meters. 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.

A randomized complete block design with nine treatments and five replications was utilized. The experimental design and treatments compared are illustrated in Figure 1. Replication V was discontinued in 1976 due to a washed out levee.

B. 1975 Season

The individual levees and water systems were established after initial tillage of the experimental area in May of 1975. Following this, final seed beds were prepared, the plots were flooded and variety S-6 rice was sown. All culture practices, fertilizer and pesticide applications were those of normal production of a rice crop in California (10, 12). Following the growing season and harvest the initial residue management treatments were carried out as follows:

Treatments to be compared:

1. Straw spread from harvester, residue burned in fall, stubble-disked once in the fall and allowed to overwinter. Chiseled in the spring to facilitate drying prior to seed bed preparation, (HFBFD).

2. Straw spread from harvester, allowed to overwinter, residue was burned in the spring, chiseled to facilitate drying of soil and stubble-disked, (HSBSD).

3. Straw wind-rowed from harvester, chopped to reduce particle size to facilitate soil incorporation and stubble-disked once and allowed to overwinter. Chiseled in the spring to facilitate drying prior to seed bed preparation, (HNBFD).

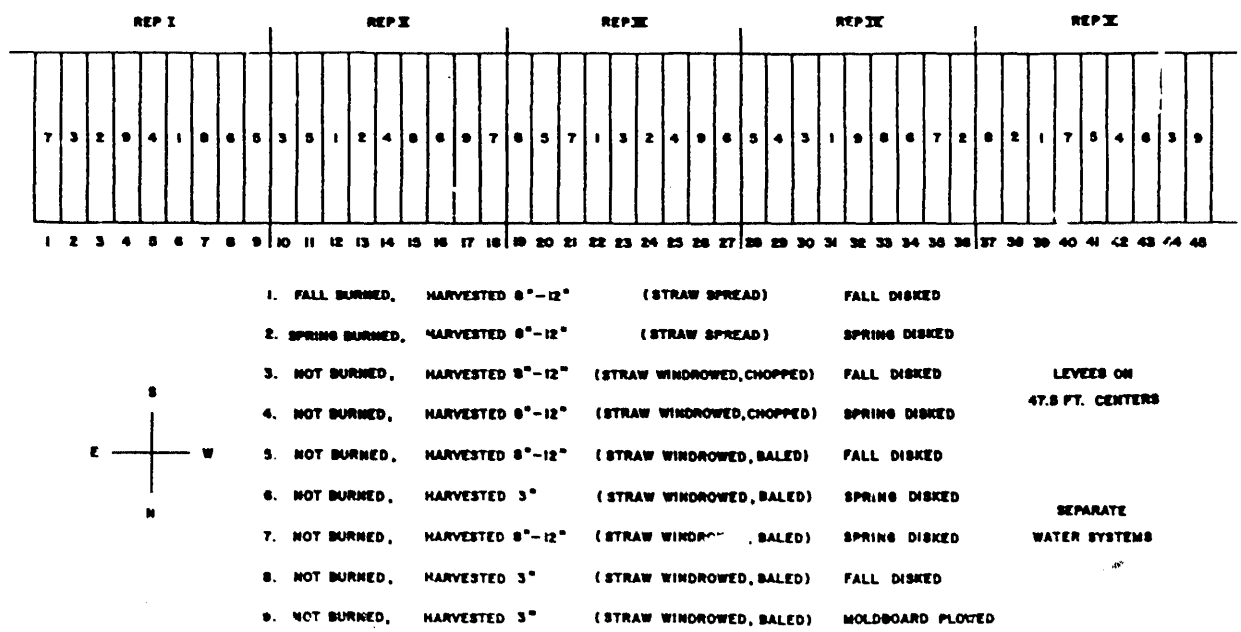

Fig. 1. Experimental design and treatments compared

4. Straw wind-rowed from harvester, chopped to reduce particle size to facilitate soil incorporation and allowed to overwinter. Chiseled in the spring to facilitate drying and stubble-disked once prior to seed bed preparation, (HNBSD).

5. Straw harvested at 8-12" from the ground and wind-rowed from the harvester. Rows of straw were baled and removed, the plot was stubble-disked and allowed to overwinter; chiseled in the spring to facilitate drying prior to seed beed preparation, (HRFD).

6. Straw harvested at 0-3" from the ground and wind-rowed from the harvester. Rows of straw were baled and removed. After overwintering the plot was chiseled to facilitate drying and stubble-disked, (LRSD).

7. Straw harvested at 8-12" from the ground and wind-rowed from the harvester. Rows of straw were baled and removed and allowed to overwinter. Chiseled in the spring to facilitate drying and stubble-disked, (HRSD).

8. Straw harvested at 0-3" from ground and wind-rowed from the harvester. Rows of straw were baled and removed, the plot was stubble-disked and allowed to overwinter, chiseled in the spring to facilitate drying, (LRFD).

9. Straw harvested at 0-3" from the ground and wind-rowed from the harvester. Rows of straw were baled and removed, the plot was moldboard plowed and allowed to overwinter; chiseled in the spring to facilitate drying, (LRSP).

C. 1976 Season

All plots were treated similarly during seed bed preparation following the specific differences outlined above. Seed bed preparation, fertilizer, pesticide and crop management practices were those of normal production of a rice crop in California (10).

D. 1977 Season :

Fall (1976) and Spring (1977) residue management practices were repeated as described for the 1975 and 1976 seasons. Thus results obtained during this season resulted from effects of two consecutive years of residue management as outlined.

E. Observations:

1. Determination of soil inoculum levels:

Sclerotia of *S. oryzae* which survive various culture practices and exist in the surface of the seed bed prior to flooding and planting constitute the inoculum that will be effective in causing stem rot disease in the present rice crop (7, 21). Inoculum level is expressed as viable sclerotia per gram soil. Methods for soil sampling and inoculum level determination have been described in detail (9).

A brief summary of the application of these methods to the present study follows:

(a) Collection of soil samples: All soil samples analyzed for the present study were collected from the top 4 inches of finished seed beds just prior to flooding. Each plot was subdivided into four equal areas approximately 20 x 14.5 meters. Eight to 10, 200-250 gr samples were collected at random from each subplot and bulked into 1 sample per subplot. This resulted in four bulk samples per plot. The bulk samples were then run through a soil grinder to reduce clod size and insure, as much as possible, an even mixing of the sample.

(b) Determination of viable sclerotia per gram soil: The method used to determine inoculum levels is based on the facts that *S. oryzae* sclerotia are hydrophobic, bouyant and of uniform size ($\bar{X}$ dia 270 μ). In addition, upon germination on water agar the sclerotia produce characteristic conidiophores and conidia of the conidial state, *N. sigmoidea*. Three, 50 gram samples were taken at random from each of the bulk samples from the subplots and placed in 400-ml beakers and covered with water. After soaking overnight, the samples were blended for 10-15 seconds in a Waring Blendor with approximately 250 ml of water. Each sample was then washed through a 20-mesh (Tyler Standard Scale) screen, stacked on a 100 mesh (Tyler Standard Scale) screen. The material collected on the 100 mesh screen was then washed into a 400 ml beaker with a wash bottle and water added to make approximately 300 ml. After 10-15 minutes the sclerotia from the sample floated to the surface and the heavier soil particles settled. The sclerotia were then vacuumed from the surface of the water into a vacuum flask and filtered onto a 15-cm #1 Whatman filter paper disc in a Buchner funnel. The filters bearing the sclerotia were air-dried and the sclerotia brushed into petri dishes for counting with a dissecting microscope.

Viability was tested by placing 50 sclerotia from each sample on water agar plates containing streptomycin sulfate and penicillin G each at 3000 ppm, and incubating the plates plus sclerotia at room temperature

(24 ± 2 C) under white fluorescent light for 12 days. Sclerotia that produced the conidiophores and conidia of *N. sigmoidea* were considered viable.

Seed beds of all plots were sampled and viable sclerotia per gram soil determined as described above for each year of the study. The values obtained for 1975 were considered the "base" or starting point. Values obtained for succeeding years (1976, 1977) were considered indicative of the effects the various residue managements had on inoculum level of *S. oryzae*.

2. Determination of stem rot disease severity

(a) Collection of plant samples: Samples of tillers were collected at random from areas corresponding to those from which soil samples were collected in each plot. At least 300 individual tillers per plot were rated for disease severity at each sample time.

(b) Disease ratings: Stem rot disease is most evident on plants nearing maturity. At this stage severity ranges from small lesions inflicting little damage through various stages of penetration of the culm with the extreme infections resulting in dead tillers that failed to produce panicles. For the most part this range of damage is determined by the time during the growing season that the initial infection of a tiller occurs. Because of this, percent infection observed at harvest time is not as reliable in estimating disease loss as is disease severity. Studies over the past several years support this conclusion (7, 20). The weighted disease severity rating system used here allows for accurate determination of the actual damage caused by stem rot during the growing season.

The disease index used consisted of dividing healthy and infected tillers into five categories based on the amount of disease as follows:

(i) healthy, no symptoms of stem rot; (ii) lightly infected with symptoms on the outer leaf sneaths only; (iii) mildly infected with discoloration and infection through the inner leaf sheaths, culm still green;

(iv) infection progressed through the leaf sheath into the culm; interior of the culm not infected internally; (v) tiller severely infested, infection progressed through and internally infecting the culm with mycelium and sclerotia present. Culm may or may not be collapsed.

Each category was weighted and the disease index calculated as follows:

$$DI = \frac{1(H^n)+2(L^n)+3(M^n)+4(M^{*n})+5(S^n)}{\text{Total number of tillers examined}}$$

where: H^n = number of healthy tillers, (class i), L^n = number of lightly infected tillers (class ii); M^n = number of mildly infected tillers (class iii), M^{*n} = number of moderately infected tillers (class iv), and S^n = number of severely infected tillers (class v). Therefore, a DI of 1.00 represents all healthy tillers, and a DI of 5.00 all severely infected tillers.

Disease index as recorded here is most indicative of actual damage when determined just prior to draining fields in preparation for harvest. Consequently all values for Disease Index were determined at that time for each of the three growing seasons covered in this study.

3. Yield determinations:

Yields in paddy rice were determined for comparison with inoculum level, disease severity data and residue treatment effects. Entire plots were harvested with commercial equipment (John Deer 105 Harvester) and yield for each determined. Samples were collected from each plot for moisture determination. Weights were adjusted to 14% moisture for standardization.

4. Nutritional status:

All plots received preplant applications of fertilizers consistent in rate required for maximum rice growth and yield production in the experimental area. Since it was not known if the various residue management treatments being compared would differentially affect the nutritional status of plants, leaf samples were collected from each plot for analysis of nitrogen, phosphorous and potassium by standard methods (11, 12).

5. Data analysis:

Analysis of variance and mean separation by Duncan's Multiple Range tests were carried out on all data. Statements noting significant differences refer to the 5% level of significance.

Results

A. Effects of residue management treatments on *S. oryzae* inoculum levels.

The inoculum levels of viable sclerotia per gram soil in seed beds determined in the spring (1975) of the first year served as a base or starting point to measure effects of the various treatments on sclerotial populations during the following years. Fig. 2 shows the mean inoculum levels for each treatment over the three seasons studied. The data show that beginning inoculum levels were quite different between treatments compared. This would be expected in a field trial as large as this and was reflected in the statistical analysis where blocks or replications differed significantly. In order to see more clearly the actual effects of treatments between years and the cumulative effect over the entire experimental period the percent change in sclerotial populations is presented in Table 1. Statistical analysis revealed a highly significant difference between years for all treatments. Numbers of sclerotia and changes resulting from various treatments are summarized in Table 2.

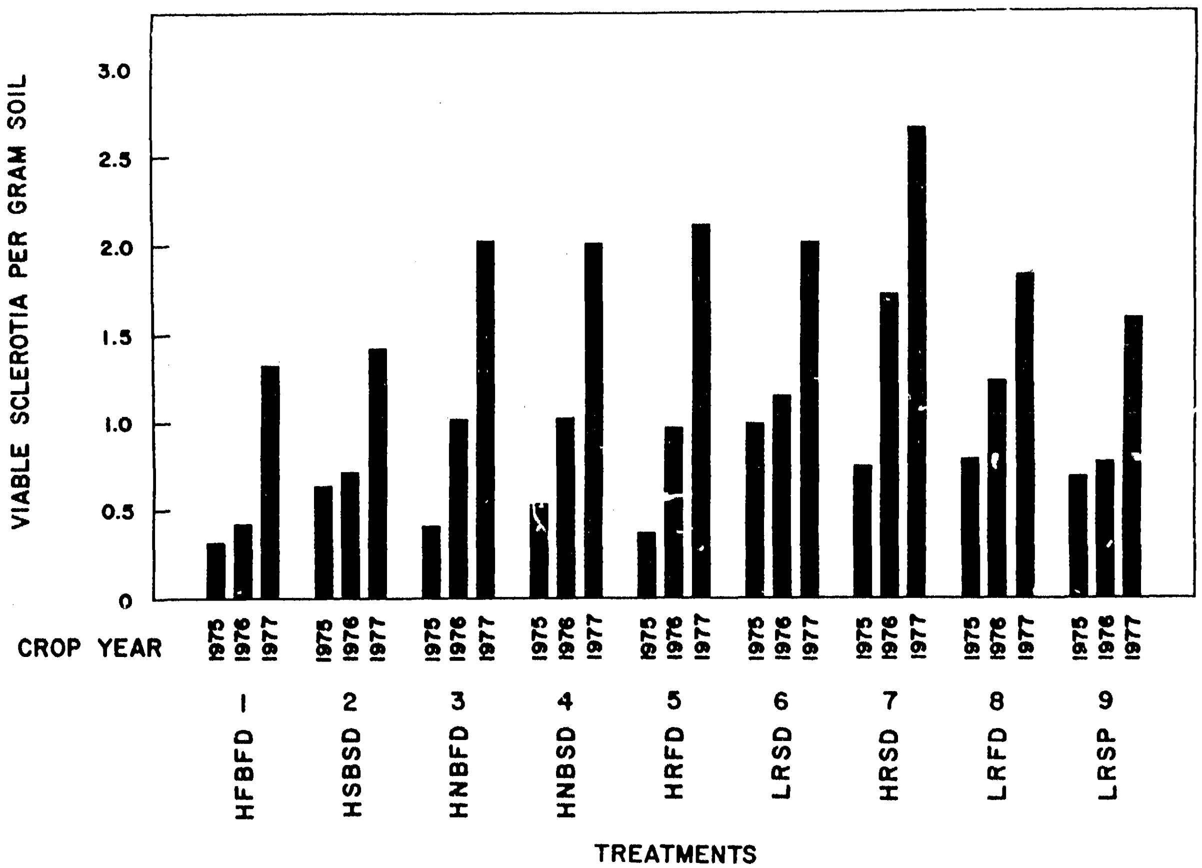

Fig. 2. Mean inoculum levels of Sclerotium oryzae in residue treatments compared for 3 consecutive years

TABLE 1

Percent change in stem rot inoculum between residue disposal treatments after 3 consecutive years of rice cropping

	Viable sclerotia/gram soil		
	Percent change between seasons		Cumulative
Residue Management Treatments	1975-1976	1976-1977	1975-1977
(1) Harvested 8-12", Straw spread; fall burned and fall stubble disked (HFBFD)	+ 22	+144	+137
(2) Harvested 8-12", straw spread spring burned; spring stubble disked (HSBSD)	- 22	+101	+121
(3) Harvested 8-12", straw wind-rowed and chopped, fall stubble disked (HNBFD)	+170	+ 93	+419
(4) Harvested 8-12", straw wind-rowed and chopped, spring stubble disked (HNBDS)	+ 54	+ 93	+279
(5) Harvested 8-12", straw wind-rowed, baled and removed, fall stubble disked (HRFD)	+121	+131	+500
(6) Harvested 3", straw wind-rowed, baled and removed, spring stubble disked (LRSD)	+ 17	+ 68	+111
(7) Harvested 8-12", straw wind-rowed baled and removed, spring stubble disked (HRSD)	+210	+153	+255
(8) Harvested 3", straw wind-rowed, baled and removed, fall stubble disked (LRFD)	+ 13	+ 48	+130
(9) Harvested 3", straw wind-rowed baled and removed, spring moldboard plowed (LRSP)	- 13	+106	+128

Values represent relative percent differences between means of treatments with seasonal variation removed.

TABLE 2

Actual change in number of viable sclerotia/gram between residue disposal treatments after three consecutive years of rice cropping

	Viable sclerotia/gram soil		
	No. sclerotia increased		Cumulative
Residue Management Treatments	1975-1976	1976-1977	1975-1977
(1) Harvested 8-12", straw spread; fall burned and fall stubble disked (HFBFD)	0.10 a	0.90 cd	1.00 ef
(2) Harvested 8-12", straw spread spring burned; spring stubble disked (HSBSD)	0.07 a	0.71 cd	0.78 e
(3) Harvested 8-12", straw wind-rowed and chopped, fall stubble disked (HNBFD)	0.68 ab	1.02 cd	1.70 fgh
(4) Harvested 8-12", straw wind-rowed and chopped, spring stubble disked (HNBSD)	0.51 ab	0.98 cd	1.49 efgh
(5) Harvested 8-12", straw wind-rowed baled and removed, fall stubble disked (HRFD)	0.59 ab	1.26 d	1.84 gh
(6) Harvested 3", straw wind-rowed baled and removed, spring stubble disked (LRSD)	0.25 ab	0.85 cd	1.10 efgh
(7) Harvested 8-12", straw wind-rowed, baled and removed, spring stubble disked (HRSD)	0.98 b	0.92 cd	1.90 h
(8) Harvested 3", straw wind-rowed, baled and removed, fall stubble disked (LRFD)	0.44 ab	0.59 c	1.03 efg
(9) Harvested 3", straw wind-rowed, baled and removed, spring moldboard plowed (LRSP)	0.08 a	0.82 cd	0.90 ef

Values represent mean of 4 replications. Values with common letters do not differ significantly within years at the 5% level as determined by Duncan's Multiple range test. LSD (P = 0.05) = 0.72 for first to second year increase, and 0.76 for first to third year increase.

B. Stem rot disease incidence and severity

Disease ratings were determined for each plot just prior to draining of water in preparation for harvest. The values presented in Table 3 represent the relative percent differences in disease severity between treatments with seasonal variation (between years) removed. Mean disease severity differed significantly (5%) between all three years of the study with the most severe disease experienced in the third year. This is not surprising since overall inoculum levels increased correspondingly. Lowest disease levels generally corresponded to lowest inoculum levels (Fig. 2, Table 3) with the exception of treatment LRFD.

C. Yield determinations:

Yield was determined for each plot by harvesting the entire area and adjusting to standard moisture content for comparison. Yields shown in Table 4 are expressed as percent increase or decrease between seasons of the treatments compared. Relative yields increased significantly in both fall and spring burn treatments and decreased significantly in the treatments HNBFD, HRFD, and LRFD with LRFD significantly lower than all treatments. In spring tillage, treatments HNBSD, LRSD, HRSD, LRSP yield was less affected than in comparable treatments with fall tillage, (HNBFD, HRFD and LRFD).

D. Nutritional status:

Nutritional status of rice plants grown under the various treatments was determined by analysis of leaf samples collected from the various treatments. According to Mikkelsen and Hunziker (11) foliar content on a dry weight basis of nitrogen of 2.6-3.2%, phosphorus of 1,000-1,800 ppm and potassium of 1.0-2.2% at 80-85 days from planting is adequate for obtaining maximum yields of field-grown rice. The mean foliar content of each treatment for these nutrients was adequate in all treatments for the 1975 season. Values obtained for 1977 are presented in Table 5. As seen there differences in nitrogen and potassium between treatments were not responsibile for differences observed in yield, indicating the availability of commercial fertilizers applied regardless of possible interactions due to various residue treatments. All treatments had relatively low levels of phosphorous. Treatments HFBD, HSBSD and HRSD were slightly below critical levels and this may have affected yield.

TABLE 3

Percent change in stem rot disease severity between residue disposal treatments after 3 consecutive years of rice cropping

Residue Management Treatments	Stem rot disease severity (1 = healthy, 5 = severe)		
	Percent change between seasons		Cumulative
	1975-76	1976-1977	1975-1977
(1) Harvested 8-12", straw spread; fall burned and fall stubble disked (HFBFD)	- 6.55	- 0.4	- 8.11[a]
(2) Harvested 8-12", straw spread spring burned; spring stubble disked (HSBSD)	- 1.92	- 7.38	- 8.82a
(3) Harvested 8-12", straw wind-rowed and chopped, fall stubble disked (HNBFD)	+ 5.37	+ 5.52	+11.68c
(4) Harvested 8-12", straw wind-rowed and chopped. spring stubble disked (HNBSD)	+ 2.58	- 1.78	+ 1.41 b
(5) Harvested 8-12", straw wind-rowed, baled and removed, fall stubble disked (HRFD)	+ 3.73	- 1.17	+ 3.33[b]
(6) Harvested 3", straw wind-rowed, baled and removed, spring stubble disked (LRSD)	+ 7.01	+ 2.34	+10.61c
(7) Harvested 8-12", straw wind-rowed, baled and removed, spring stubble disked (HRSD)	+ 1.30	+ 2.00	+ 3.38b
(8) Harvested 3", straw wind-rowed, baled and removed, fall stubble disked (LRFD)	-10.36	+ 7.12	- 6.59a
(9) Harvested 3", straw wind-rowed, baled and removed, spring moldboard plowed (LRSP)	+ 0.29	- 6.15	- 5.24a

Values represent percent differences between the means of treatments between years with seasonal variation removed.

TABLE 4

Percent change in yield of paddy rice between residue disposal treatments after 3 consecutive years of rice cropping

Residue Management Treatments	Percent change in yield at 14% moisture		
	Between seasons		Cumulative
	1975-1976	1976-1977	1975-1977
(1) Harvested 8-12", straw spread; fall burned and fall stubble disked (HFBFD)	+ 4.12	+7.71	+12.33
(2) Harvested 8-12", straw spread spring burned; spring stubble disked (HSBSD)	+10.61	-0.9	+ 7.08
(3) Harvested 8-12", straw wind-rowed and chopped, fall stubble disked (HNBFD)	- 6.81	+1.81	- 3.31
(4) Harvested 8-12", wind-rowed and chopped, spring stubble disked (HNBSD)	+ 0.04	-0.66	- 0.72
(5) Harvested 8-12", straw wind-rowed, baled and removed, fall stubble disked (HRFD)	+ 3.78	-5.66	- 3.78
(6) Harvested 3", straw wind-rowed, baled and removed, fall stubble disked (LRSD)	+ 3.26	+3.2	+ 1.04
(7) Harvested 8-12", straw wind-rowed, baled and removed, spring stubble disked (HRSD)	+ 1.42	+0.11	+ 1.23
(8) Harvested 3", straw wind-rowed, baled and removed, fall stubble disked (LRFD)	- 7.06	-6.71	-12.66
(9) Harvested 3", straw wind-rowed, baled and removed, spring moldboard plowed (LRSP)	- 1.42	+1.23	+ 0.29

Values represent the mean of four replications.

TABLE 5

Foliar content of nitrogen, phosphorus and potassium for rice collected 85 days after planting, 1977 season.

Residue management treatments	Foliar content on dry weight basis 86 days after planting		
	Phosphorous ppm	Potassium %	Nitrogen %
(1) Harvested 8-12", straw spread; fall burned and fall stubble disked (HFBFD)	762	1.57	2.48
(2) Harvested 8-12", straw spread spring burned; spring stubble disked (HSBSD)	750	1.57	2.71
(3) Harvested 8-12", straw wind-rowed and chopped, fall stubble disked (HNBFD)	840	1.62	2.64
(4) Harvested 8-12", straw wind-rowed and chopped, spring stubble disked (HNBSD)	840	1.62	2.77
(5) Harvested 8-12", straw wind-rowed, baled and removed, fall stubble disked (HRFD)	797	1.53	2.70
(6) Harvested 3", straw wind-rowed, baled and removed, spring stubble disked (LRSD)	795	1.41	2.87
(7) Harvested 8-12", straw wind-rowed, baled and removed, spring stubble disked (HRSD)	747	1.56	2.61
(8) Harvested 3", straw wind-rowed, baled and removed, fall stubble disked (LRFD)	845	1.48	2.77
(9) Harvested 3", straw wind-rowed, baled and removed, spring moldboard plowed (LRSP)	817	1.47	2.92

Means of 4 replications: Nitrogen of 2.8 - 3.6%, phosphorus at 1000-1800 ppm and potassium of 1.0-2.4% is adequate for obtaining maximum yields of field-grown rice when sampled at 6065 days from planting (11).

Discussion

Fall burning of rice residue was known to be effective in minimizing carry-over inoculum levels of S. oryzae and subsequent stem rot disease severity from previous studies (19, 21, 22, 23). The results of present experiments confirmed those of earlier studies and extends the conclusion to spring burning and complete removal of residue. For example, inoculum levels in treatments where straw was removed by harvesting at 3", baled and removed followed by fall or spring tillage (LRSD, LRFD, LRSP) did not differ significantly from each other or from the spring and fall burning treatments (HFBFD, HSBSD) but these were significantly lower in inoculum level than all remaining treatments, (HNBFD, HNBSP, HRFD, HRSD). Treatments harvested at 8-12" with straw removed and tilled in the spring (HRSD) differed from identical treatments tilled in the fall (HRFD) in percent inoculum increase, but not in cumulative viable sclerotia. Treatments harvested at 8-12", straw removed and spring stubble disked (HRSD) or fall (HRFD) tillage or straw chopped and incorporated in the fall (HNBFD) or spring (HNBSD) showed the greatest increases in inoculum level over the three year experimental period and did not differ significantly between each other.

It appears that removal of all the straw (3" harvest) that contains the stem rot infections was as effective in minimizing inoculum levels as was fall and spring burning. Support for this conclusion was obtained from a separate study summarized in Appendix A. There it was shown that residue parasitically infested with S. oryzae supports continued production of sclerotia, after soil incorporation during the overwintering period. Since S. oryzae infects rice at the water level and infections are mostly confined to parts of the plant higher than 3", the removal of stubble and straw by either burning or cutting at ground level and baling had similar effects on overwintering inoculum levels.

Other studies have shown that over 96% of sclerotia remaining in burned over stubble are not viable. Thus the potential of the saprophytic ability of sclerotia dislodged by harvesting and removal practices, to survive free from residues in the soil or to germinate and infest organic material during the overwintering period was posed. In an additional study it was shown (Appendix B) that S. oryzae free from residue in the soil is not an aggressive competitor and that overall inoculum level decreased under these conditions.

Thus saprophytic colonization of uninfected rice residue or other organic material in the soil by free sclerotia of S. oryzae is not considered to be an important factor in overwintering inoculum levels.

Correlations between stem rot disease severity and inoculum level are most valid when observed values for each variable occur in the linear phase of the stem rot disease severity vs. inoculum level curve (20). This is essentially linear when inoculum levels range between .05 and .8 viable sclerotia/gram soil. Levels higher than this show positive correlations but at lower statistical significance. In the present study, lowest disease severity occurred in treatments HFBFD, HSBSD, (fall and spring burning) and LRFD (complete removal, fall disked) and LRSP (complete removal, spring moldboard plowed). Spring tillage was more effective in minimizing disease severity than fall tillage in treatments where straw was harvested at 8-12" (HNBFD vs. HNBSD) and incorporated. When straw was harvested at 8-12" and removed by baling, spring and fall tillage by stubble-disking did not differ significantly (HRFD vs. HRSD). When straw was harvested at 3" and removed, fall tillage by stubble-disking resulted in significantly less disease than spring tillage by stubble-disking (LRSD vs. LRFD). When straw was harvested at 3" and removed followed by fall tillage by stubble-disking or spring tillage by moldboard plowing, (LRFD vs. LRSP) disease severity did not differ significantly. There were simple correlations between increases in inoculum level and disease severity but their statistical significance was lower due to the relatively high inoculum levels resulting in some of the treatments.

The trends noted above in inoculum level and disease severity were generally reflected in yield obtained for the various treatments with the exception of treatment (LRFD) Table 4.

Nitrogen and potassium levels were adequate for obtaining maximum yields throughout the study but in the third year, phosphorous levels approached critical levels in some of the treatments (Table 5). Nevertheless, this was lowest in treatments showing the lowest reductions in yield. Any effects of additional phosphorous would most likely have been reflected in increasing yields in treatments, HFBFD, HSBSD, HRFD, LRSP and HRSD. In these cases straw was removed by either burning or baling. It is well known that many fields in the area (11) require the application of phosphorous in normal rice culture. Thus it is not expected that these results will affect any changes in current rice practices but it may be necessary to re-evaluate amounts of phosphorous applied to certain fields under residue practices of burning or removal of straw.

The overall effect of the two drought years during the experimental period on the results of the present study are not known. It was noted that residue persisted throughout the overwintering season to a greater extent than had been observed in past years. This resulted in particularly "trashy" seedbeds in treatments where residue was incorporated and to some extent in treatments harvested at 8-12". It was for this reason the studies summarized in appendices A and B were initiated and included in the project. Results obtained there indicate similar differences in simulated residue conditions but generally resulted in lower inoculum production and survival levels similar to those obtained in studies carried out during years of more normal rainfall.

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Glossary of Terms & Symbols

1. HFBFD Straw spread from harvester, residue burned in fall, stubble-disked once in the fall and allowed to overwinter. Chiseled in the spring to facilitate drying prior to seed bed preparation.
2. HSBSD - Straw spread from harvester, allowed to overwinter, residue was burned in the spring, chiseled to facilitate drying of soil and subble-disked.
3. HNBFD - Straw wind-rowed from harvester, chopped to reduce particle size to facilitate soil incorporation and stubble-disked once and allowed to overwinter. Chiseled in the spring to facilitate drying prior to seed bed preparation.
4. HNBSD - Straw wind-rowed from harvester, chopped to reduce particle size to facilitate soil incorporation and allowed to overwinter. Chiseled in the spring to facilitate drying and stubble-disked once prior to seed bed preparation.
5. HRFD - Straw harvested at 8-12" from the ground and wind-rowed from the harvester. Rows of straw were baled and removed, the plot was stubble disked and allowed to overwinter; chiseled in the spring to facilitate drying prior to seed bed preparation.
6. LRSD - Straw harvested at 0-3" from the ground and wind-rowed from the harvester. Rows of straw were baled and removed. After overwintering the plot was chiseled to facilitate drying and stubble-disked.
7. HRSD - Straw harvested at 8-12" from the ground and wind-rowed from the harvester. Rows of straw were baled and removed and allowed to overwinter. Chiseled in the spring to facilitate drying and stubble-disked.
8. LRFD - Straw harvested at 0-3" from ground and wind-rowed from the harvester. Rows of straw were baled and removed, the plot was stubble-disked and allowed to overwinter, chiseled in the spring to facilitate drying.
9. LRSP - Straw harvested at 0-3" from the ground and wind-rowed from the harvester. Rows of straw were baled and removed, the plot was moldboard plowed and allowed to overwinter; chiseled in the spring to facilitate drying.

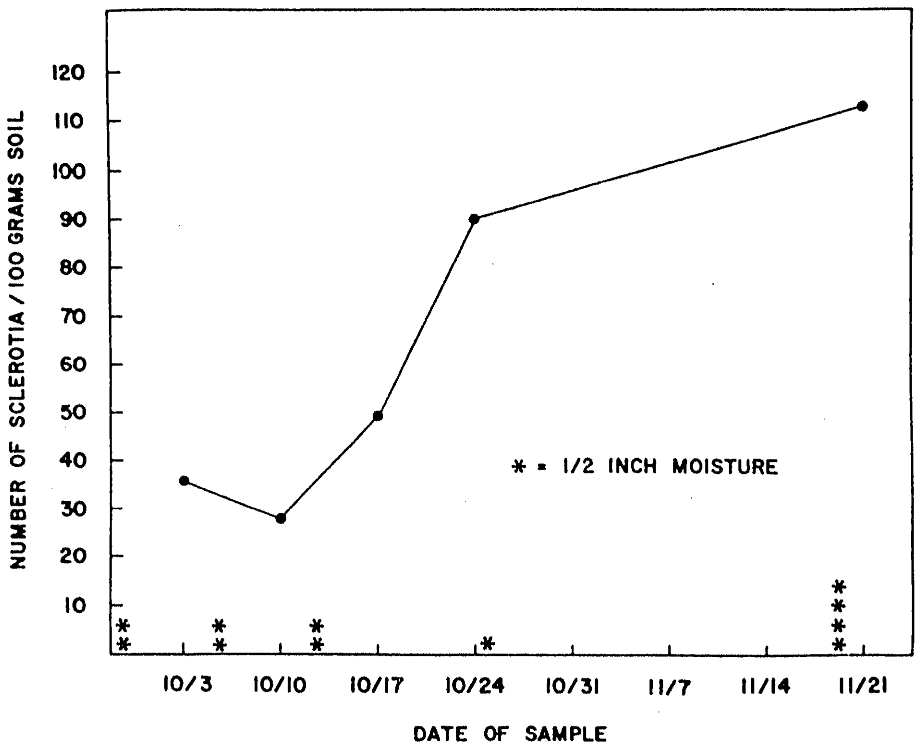
APPENDIX A

PRODUCTION OF SCLEROTIA OF SCLEROTIUM ORYZAE IN STEM ROT-INFECTED RICE TISSUE WHICH HAS BEEN INCORPORATED INTO FIELD SOIL

Soil incorporation is one method of disposing of rice residue. If this procedure should become common practice it would be useful to know if straw-infected with Sclerotium oryzae supports production of sclerotia after incorporation. To test this, mature rice tissue infected with S. oryzae was collected from a field just prior to harvest. The infected rice residue was then incorporated into a field where there were no detectable sclerotia of S. oryzae in the soil. In California rice, soil usually does not dry out between the time the fields are drained and when 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 the introduction of the infected residue soil samples were periodically taken from the field and the number of sclerotia/g soil determined.

Samples taken immediately following incorporation of the rice residue indicated there were 0.36 sclerotia/g soil due to the introduction of sclerotia that had already formed in the infected rice tissue before incorporation (Fig. 1). Seven weeks after introduction of the residue there were 1.13 sclerotia/g soil (Fig. 1). Continued production of sclerotia by S. oryzae in parasitically infected rice tissue resulted in a threefold increase in sclerotia numbers. Not only does incorporation of rice residue into soil introduce sclerotia which have formed in infected tissues but there is the potential for further increases in sclerotia numbers after incorporation. Such increases in inoculum level are expected to result in significant yield losses due to stem rot disease in succeeding rice crops.

PRODUCTION OF SCLEROTIA OF SCLEROTIUM ORYZAE IN STEM ROT INFECTED RICE TISSUE WHICH WAS INCORPORATED INTO FIELD SOIL



APPENDIX B

THE SAPROPHYTIC ABILITY OF SCLEROTIUM ORYZAE DERIVED FROM SCLEROTIA

Sclerotia of Sclerotium oryzae are formed on or in infected rice tissues as the rice plants mature. Harvesting and tillage practices dislodge sclerotia from these tissues and distribute them throughout the soil along with much noninfected rice residue. Thus there is the potential for germination of sclerotia in the soil, colonization of organic material by S. oryzae and the production of additional sclerotia.

To determine the ability of S. oryzae to give rise to new sclerotia saprophytically, radioactive sclerotia (C^{14}) were used to artificially infest soil. New sclerotia produced in the soil as a result of germination of radioactive sclerotia and subsequent saprophytic colonization of organic material were not radioactively labeled and thus distinguishable from the radioactive sclerotia originally placed in the soil. Soil infested with 20 radioactive sclerotia of S. oryzae was placed in petri dishes. Treatments included both autoclaved and nonautoclaved soil, with or without an amendment of dried, healthy rice sheaths. The soil was moistened and the petri dishes incubated for 60 days. All sclerotia were then extracted and each individual sclerotium classified as either radioactive or nonradioactive based upon its counts per minute. Radioactive sclerotia were those which were used to infest the soil at the beginning of the experiment, whereas nonradioactive sclerotia were those produced saprophytically during the incubation period.

Essentially no new sclerotia were produced in treatments where rice sheaths were not added (Table i). In autoclaved soil amended with rice sheaths the radioactive sclerotia germinated, S. oryzae colonized the sheaths and the number of sclerotia increased (Table i). In nonsterile soil amended with rice sheaths the saprophytic ability of S. oryzae is restricted and the data indicate that saprophytic colonization of healthy rice residue is not an important source of sclerotia (Table i).

Table i

Effect of addition of rice sheaths and autoclaving soil on the recovery of radioactive sclerotia and production of new sclerotia of *Sclerotium oryzae*

Treatment	Number of C^{14}labeled sclerotia recovered[a]	Number of nonlabeled sclerotia recovered[b]
Nonautoclaved soil		
Rice sheaths	9.7[c]	1.4
No rice sheaths	13.3	0.1
Autoclaved soil		
Rice sheaths	8.9	28.1
No rice sheaths	16.9	0

[a]Initially 20 radioactive sclerotia of *S. oryzae* introduced in each replication and incubated 60 days.

[b]Sclerotia produced as a result of saprophytic colonization of organic material by *S. oryzae*.

[c]All values are means of 10 replications.