Effect of Sheath Blight on Yield in Tropical, Intensive Rice Production System

R. M. Cu, T. W. Mew, K. G. Cassman, and **P. S. Teng,** Entomology and Plant Pathology Division (EPPD), and Agronomy, Plant Physiology, and Agroecology Division (APPA), International Rice Research Institute, Los Baños, Philippines

ABSTRACT

Cu, R. M., Mew, T. W., Cassman, K. G., and Teng, P. S. 1996. Effect of sheath blight on yield in tropical, intensive rice production system. Plant Dis. 80:1103-1108.

Sheath blight (*Rhizoctonia solani*) of rice (*Oryza sativa*) is associated with intensive and high-input production systems. The effect of sheath blight on yield, the effect of high nitrogen (N) rate on sheath blight incidence, and the stages of crop that are most susceptible to the disease and vulnerable to yield losses were investigated. Grain yield data from a long-term experiment showed a quadratic polynomial curve in response to N input. An initial increase in N supply corresponded to an increase in yield, but at the highest N level, a reduction in yield was observed. Sheath blight incidence also increased with increasing N level. The estimated yield reduction from sheath blight in plots receiving the highest N rate ranged from 20 to 42% in artificially inoculated plots. The highest sclerotial population recorded was only 2.02 sclerotia per 500 g of oven-dried soil or about 1.23 sclerotia per liter of puddled paddy soil. This low sclerotial density in our studies suggested that sclerotia may not be the primary source of inoculum in a tropical lowland rice system. Crop residues colonized by the pathogen may play an important role in sheath blight epidemics in this intensive rice production system. Screenhouse and field experiments indicated significant yield losses when sheath blight infection started at panicle initiation, booting, or flowering. The effect of sheath blight on yield resulted primarily from a reduction in mean seed weight and a lower percentage of filled spikelets. No yield loss or decrease in yield components was observed when infection started at tillering or grain filling.

Sheath blight of rice (*Oryza sativa* L.), caused by *Rhizoctonia solani* Kühn of the anastomosis group AG-1 IA, is a disease associated with an intensive rice production system (26,32). The development of modern varieties that are high yielding, early maturing, semidwarf in stature, and nitrogen (N) responsive has doubled rice production in the tropics and subtropics of Asia. High rates of N fertilizer are applied to achieve high yields, and they in turn promote luxuriant vegetative growth with dense foliar canopies. This type of canopy structure provides a favorable environment for sheath blight development (26,32,34). Moreover, crop intensification, which is made possible by extensive irrigation networks, has increased cropping frequency from one crop per year to two or three crops in a continuous rice production system. This level of crop intensification provides a year-round supply of host plants for the sheath blight pathogen and thus maintains high levels of inoculum in a lowland paddy ecosystem (12). Sheath blight is now considered a major constraint in achieving high yields and contributes to yield variability in many intensive rice-growing domains.

Corresponding author: R. M. Cu
E-mail: rcu@irri.cgiar.com

Accepted for publication 22 May 1996.

Publication no. D-1996-0729-06R

Declining yield trends in intensive rice production systems have been documented in several long-term experiments (5,11). One of the factors that contributes to this decline at some sites is a decrease in the effective soil N supply, which can be reversed by increasing fertilizer N rates (2,5). With increased fertilizer N rates, however, sheath blight control is often required to avoid yield loss from this disease. The purpose of this study was to examine the occurrence of sheath blight in a tropical, intensive rice production system. Specifically, the study aimed to: (i) measure the naturally occurring sheath blight in an intensive rice production system, (ii) quantify the effect of sheath blight on yield in controlled experiments; and (iii) identify the critical stages of crop growth when plants are vulnerable to yield loss.

MATERIALS AND METHODS

Sheath blight in intensive production system. The long-term, continuous cropping experiment (LTCC) at the IRRI research farm in Los Baños, Philippines, started 30 years ago and now represents the most intensive rice production system in Asia (16). LTCC was, therefore, selected as the site where naturally occurring sheath blight can be monitored for three consecutive cropping seasons. Rice cultivars, including IR 72, were grown continuously with high pesticide inputs and four rates of fertilizer N ranging from 0 to more than 200 kg N/ha. The experiment covered a 3,200 m^2 area, and N was applied to plots of 200 m^2 in a randomized complete block design. The experiment had four replicates. Actual N rates varied from year to year and from season to season. Rates of N in the 1993 wet season were 0, 36, 72, and 108 kg/ha. Fertilizer N was split-applied, with half broadcast-incorporated before transplanting and the other half at panicle initiation. In the 1994 dry season, rates of N were 0, 72, 144, and 216 kg/ha. Fertilizer N was divided equally in four parts and applied before transplanting by basal incorporation, and top-dressed at midtillering, panicle initiation, and booting stages. In the 1994 wet season, rates of N were 0, 39, 78, and 117 kg/ha. Fertilizer N was divided equally in three parts and applied at midtillering, panicle initiation, and flowering. Differences in quantity and timing of N application depended on soil and leaf N content of the crop (4,28) as well as the cropping season. Phosphorus and potassium were applied in sufficient quantities to be nonlimiting. Fungicide (benomyl at 500 g a.i. in 160 liters of water per ha) sprays were applied at panicle initiation and flowering stages during 1993 and 1994 wet seasons, and at tillering, panicle initiation, and flowering stages during the 1994 dry season.

Sheath blight incidence was measured as the number of infected tillers relative to the total number of tillers of 20 randomly selected plants in each plot. Incidence of sheath blight was assessed at panicle initiation, booting, flowering, grain filling, and maturity. Area under the disease progress curve (AUDPC) was also computed (30). AUDPC and sheath blight incidence were used in regression analysis to assess the effect of sheath blight on yield.

Other diseases that were also assessed were brown spot (*Helminthosporium oryzae* Breda de Haan), narrow brown spot (*Cercospora oryzae* Miyake), stem rot (*Leptosphaeria salvinii* Cattaneo), tungro (rice tungro bacilliform virus and rice tungro spherical virus), and blast (*Pyricularia grisea* (Cooke) Sacc.). Grains were harvested by hand and mechanically threshed. Grain yields, adjusted to 14% moisture, were determined from a 5 m^2 harvest area at the center of each plot.

Soil samples for determination of sclerotial density were collected systematically from each plot. Composite soil samples of about 2 liters were collected from each plot before transplanting of the 1993 wet season

crop and after harvest of each cropping season. Soil samples were subsampled for moisture and weight determination. Sclerotia were collected by wet sieving subsamples through a 0.355-mm mesh screen using the procedure described by Weinhold (33). Collected sclerotia were plated on acidified potato-dextrose agar and incubated at 25°C for 36 h. Young vegetative hyphae were examined under the microscope for typical characteristics of *R. solani* based on the current species concept (27). Briefly, *R. solani* hyphae are brown or any shade of brown. Branching occurs near the distal septum of a cell, and branches have constriction in the hypha and a septum near the point of origin. The septum is of the dolipore type, and cells in vegetative hyphae are multinucleated. Sclerotia that germinated exhibiting the characteristics of *R. solani* were counted. The number of sclerotia per plot was adjusted to the number of sclerotia per 500 g of oven-dried soil.

Sheath blight and other diseases were monitored and measured as they occurred in the LTCC experiment. Sheath blight incidence at various crop stages, N rate, and the quadratic effect of N rate were used in stepwise regression with the significance level for the regressor to enter the model (SLE) and the significance level for the regressor to stay in the model (SLS) set at 95%. Analysis of variance (ANOVA) and Duncan's new multiple range test (DMRT) for mean separation were used on data for sclerotial density. Regression and ANOVA were performed using SAS (SAS Institute, Cary, NC).

Sheath blight effect on yield. A field experiment with a split plot design was conducted at the IRRI farm in the 1993 dry season and repeated in the 1994 dry season to assess the effect of sheath blight on grain yield of cultivar IR72. The experiment was replicated four times. Main plots were three levels of fertilizer N (0, 100, and 200 kg N/ha), and subplots had plants that were either infected (IN) or uninfected (UIN) by sheath blight. Fertilizer N in the main plots was divided equally into four parts and applied by basal incorporation before transplanting, and top-dressed at midtillering, panicle initiation, and booting stages. Subplots were 208 m^2 in area. Plants in the IN plots were inoculated at the early booting stage by evenly broadcasting 25 cm^3 of inoculum per plant. The inoculum consisted of a rice hull and rough rice mixture (2:1, vol/vol) with actively growing mycelia of *R. solani* (21,22). Plants in the UIN plots were not inoculated and received prophylactic treatment with benomyl at 500 g a.i./ha. All plots received a basal addition of 25 kg P/ha, 50 kg K/ha, and 7.5 kg Zn/ha, which were broadcast-incorporated before transplanting. Plants were transplanted at 20-cm spacing in the first week of January in both years and harvested in April. Floodwater depth was kept at 5 to 10 cm until 7 to 10 days before maturity, and insect pests and weeds were controlled as required to avoid yield loss. Incidence of sheath blight was assessed in the same manner as in the LTCC experiment. AUDPC was calculated from assessments of disease incidence at panicle initiation, booting, flowering, early grain filling, and maturity. Grain yields from 5 m^2 harvest area in the center of each plot were adjusted to 14% moisture. Analysis of variance and Fisher's protected least significant difference using SAS (SAS Institute) was used to compare grain yield, sheath blight incidence at maturity, and AUDPC in IN and UIN plots.

Sheath blight inoculation at different crop stages. A screenhouse experiment with three replicates consisted of 2.88 m^2 plots that were planted every 7 to 14 days

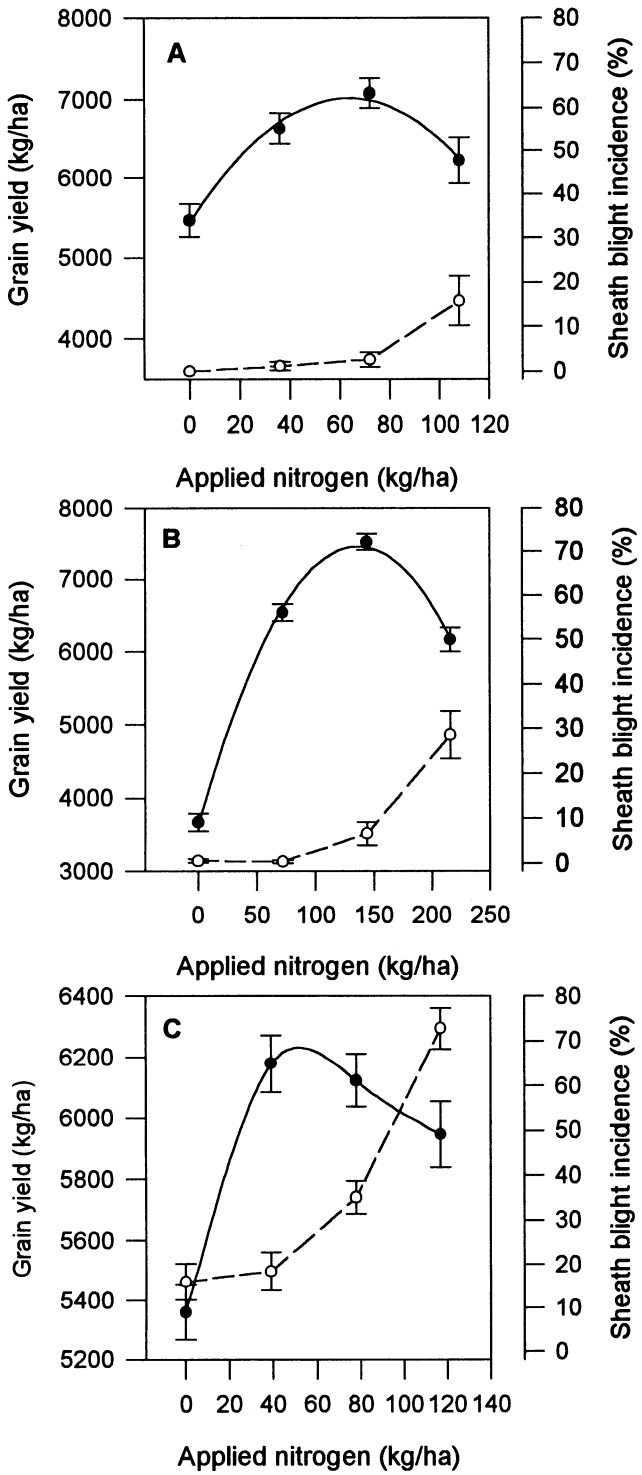

Fig. 1. Effect of nitrogen on grain yield in solid line, and effect of nitrogen on sheath blight incidence (%) in broken lines for **(A)** 1993 wet season, **(B)** 1994 dry season, and **(C)** 1994 wet season. Sheath blight incidence was measured at maturity. Data points represent the means, and vertical bars correspond to standard errors of the means.

with cultivar IR72 to obtain plants at different growth stages. Plants were spaced 20 cm apart and received basal applications of 40, 26, and 50 kg/ha of N, P, and K, respectively, which were broadcast-incorporated before transplanting. Another 80 kg N/ha was top-dressed in equal splits at maximum tillering and booting stages. Planting on a 7- to 14-day interval continued until such time when plots with plants at about midtillering, panicle initiation, booting, flowering, and grain filling can be selected from among plots planted sequentially. On the day when plants in different plots were at about midtillering, panicle initiation, booting, flowering, and grain filling, each plot was divided into subplots. One subplot was untreated to provide a disease-free control. The other subplot was inoculated uniformly with 25 cm^3 per plant of rice hull and rice grain mixture (2:1, vol/vol) containing actively growing mycelia of *R. solani*. Thus, inoculation occurred at the same time on plants at different growth stages. Incidence of sheath blight was determined at maturity. Grains were harvested and threshed by hand, and yield was calculated from six plants in the center of each subplot at 14% moisture.

The screenhouse experiment was conducted in the 1994 dry season and was repeated as a field experiment in the 1994 wet season with cultivar IR 72. Uniform applications of 50 kg N/ha, 26 kg P/ha, and 50 kg K/ha were broadcast-incorporated before transplanting. Another 100 kg N/ha was top-dressed in equal splits at maximum tillering and booting. Eighteen 1 m^2 quadrats were placed at random in the field during early tillering stage. Three replicate quadrats were inoculated with mycelia of *R. solani* grown in rice grain–hull medium (2:1, vol/vol) at midtillering, panicle initiation, booting, flowering, and mid-grain-filling. A sixth set of three quadrats that was not inoculated served as the control. Unlike the screenhouse experiment in which plants were planted sequentially and inoculation occurred on the same day, the field experiment was planted at one time and inoculation occurred sequentially when the crop reached different growth stages. Sheath blight incidence was determined at maturity. Harvested plants from six center plants of the quadrat were sampled to measure grain yield at 14% moisture. The 1,000-grain weight, spikelet per m^2, filled grain per m^2, and percent filled grain were measured.

RESULTS

Sheath blight in intensive production system. Sheath blight incidence measured at maturity negatively correlated with yield better than incidence measured at other stages or AUDPC. Sheath blight incidence at maturity was therefore used in regression analysis. Grain yield followed a quadratic polynomial curve in response to N input (Fig. 1, Table 1). An increase in N corresponded to an increase in yield, but at the highest N level, a reduction in yield was observed. Sheath blight incidence also increased with increasing N level. The sheath blight effect on yield in the 1993 wet season was not significant by regression analysis (Table 1). However, sheath blight had a significant negative effect on yield in the 1994 dry and wet seasons. Grain yield was increased by N rate, reduced by the quadratic effect of N rate, and further reduced by the occurrence of sheath blight (Table 1). Brown spot, narrow brown spot, stem rot, tungro, and blast were below 1% incidence. Despite two to three applications of fungicide, sheath blight incidence was as high as 16, 29, and 73% incidence in the 1993 wet season, 1994 dry season, and 1994 wet season, respectively (Fig. 1). Sclerotial density in soil ranged from 0.21 to 2.02, 0.14 to 0.61, and 0.29 to 0.83 sclerotia per 500 g of oven-dried soil in the 1993 wet season, 1994 dry season, and 1994 wet season, respectively. No significant differences in sclerotial density between N rates at each cropping season were observed, and no significant differences were observed in sclerotial density between cropping seasons by analysis of variance ($P = 0.05$).

Sheath blight effect on yield. A significant yield reduction in IN plots was observed with 100 and 200 kg N/ha in the 1993 and 1994 dry season experiments. No yield reduction was observed at 0 kg N/ha in both years. Mean yield of UIN treatments increased from 7,783 with 100 kg N/ha to 9,074 kg/ha with 200 kg N/ha in 1993, whereas yields leveled off in these N treatments from IN plots. In the 1994 experiment, there was a significant yield reduction of about 2,600 kg/ha in IN treatments with 100 kg N/ha compared to UIN plots at the same N rate; at 200 kg N/ha, UIN plots had a 3,664 kg/ha yield advantage compared with IN plots. Incidence of sheath blight at maturity and the AUDPC were significantly higher in IN plots at any N rate (Table 2). Yield loss due to sheath blight ranged from 8 to 20% in the 1993 dry season and from 30 to 42% in the 1994 dry season.

Sheath blight inoculation at different crop stages. Results from the screenhouse experiment indicated that the rice crop was most sensitive to yield loss from sheath blight when infection occurred at panicle initiation. The relative yield loss from sheath blight was 24% when infection started at panicle initiation, 17% with infection at booting, and 13% with infection at flowering (Table 3, screenhouse). Yields from plots that were inoculated at midtillering or grain filling were not significantly lower than yields from the disease-free plots. Sheath blight incidence was high when inoculation started at panicle initiation, booting, or flowering stages, and significantly lower with inoculation at tillering and grain filling stages. Although plots were inoculated on the same day so that climatic conditions above the leaf canopies were similar, differences in leaf area among plots with plants at different growth stages would probably affect microclimates within these canopies.

The study of sheath blight infection at various growth stages of the crop was repeated in the 1994 wet season, and yield losses from sheath blight were observed when inoculation occurred from panicle initiation to flowering stage (Table 3, field). Yield losses at panicle initiation, booting, and flowering were 34, 33, and 26%, respectively. Sheath blight reduced mean seed weight and percentage of filled spikelets (Table 4). No yield loss was observed when inoculation occurred at tillering or grain filling. Inoculation in this study occurred on different dates in the same field with a uniformly managed crop, and there were differences in both canopy development and weather conditions on each inoculation date. Generally, infections were apparent 3 to 6 days following inoculation. Despite these potential influences on infection and disease progression, the relationship between yield loss and time of infection was similar to the pattern observed in the screenhouse experiment with inoculation of plots at different growth stages on the same day.

DISCUSSION

The LTCC experiment was managed intensively with two to three fungicide sprays and three insecticide sprays. Insect

Table 1. Regression statistics and parameter estimates for grain yield of IR72 in a long-term continuous cropping experiment

Cropping season and year	Parameter estimate[y]				Standard error				r^2 (%)[z]	CV (%)[z]	Prob>F
	α	N	N^2	ShB	α	N	N^2	ShB			
1993 wet season	5435.27*	49.58*	–0.38*	–1.92 ns	171.56	7.88	0.08	16.51	73.83	5.53	0.001
1994 dry season	3660.25*	54.39*	–0.19*	–13.44*	121.22	2.83	0.01	6.86	92.47	7.23	0.001
1994 wet season	5549.21*	30.28*	–0.22*	–8.57*	61.06	3.13	0.04	1.22	53.15	6.08	0.001

[y] The parameter estimates α, N, N^2, and ShB correspond to the intercept (kg/ha), nitrogen rate (kg N/ha), square of nitrogen rate, and sheath blight incidence (%) at maturity. An asterisk indicates that the *t* statistic of the parameter estimate was significant ($P < 0.05$).

[z] Coefficients of determination (r^2) were adjusted for degrees of freedom. CV = coefficient of variation.

pests and most diseases were controlled. The incidences of brown spot, narrow brown spot, tungro, stem rot, and blast were below 1%, but sheath blight, despite the fungicide applications, reached levels that significantly affected yields in treatments with high N rates. Sheath blight in the LTCC experiment occurred from natural infection. The yield-reducing effect of sheath blight was small relative to the incremental effect of N fertilizer, and in all three seasons the highest yields were achieved at N rates lower than the maximum rate used in the experiment (Fig. 1). At these lower N rates with highest yield, sheath blight incidence was low. The effect of sheath blight on yield was discernible only at the highest N level. The interactions of yield, N, and sheath blight highlight the need for precise N management or strategies to avoid excess N and disease problems when high rice yields are targeted.

Table 2. Grain yield and sheath blight assessment at various levels of nitrogen[v]

Season, N rate, infection status[w]	Sheath blight incidence (%)[x]	AUDPC (%-days)[y]	Grain yield (kg/ha)[z]
1993 dry season			
0 kg N/ha			
Inoculated (IN)	23.3 a	474.4 a	4631.4 a
Uninoculated (UIN)	0.0 b	0.0 b	4713.0 a
CV	(40.2)	(47.9)	(13.6)
100 kg N/ha			
Inoculated (IN)	46.7 a	1298.2 a	7113.3 b
Uninoculated (UIN)	0.0 b	0.0 b	7783.4 a
CV	(28.2)	(23.4)	(4.4)
200 kg N/ha			
Inoculated (IN)	65.2 a	1926.0 a	7227.0 b
Uninoculated (UIN)	0.0 b	0.0 b	9073.9 a
CV	(18.1)	(21.9)	(1.9)
1994 dry season			
0 kg N/ha			
Inoculated (IN)	57.5 a	1975.6 a	4854.3 a
Uninoculated (UIN)	0.9 b	24.8 b	5530.3 a
CV	(11.2)	(15.6)	(16.9)
100 kg N/ha			
Inoculated (IN)	65.1 a	2465.5 a	6065.5 b
Uninoculated (UIN)	0.6 b	38.8 b	8701.4 a
CV	(4.9)	(7.6)	(6.9)
200 kg N/ha			
Inoculated (IN)	71.1 a	2650.9 a	5129.8 b
Uninoculated (UIN)	1.6 b	51.3 b	8793.6 a
CV	(11.9)	(8.9)	(7.1)

[v] Means with the same letter in a column at each N rate are not significantly different using LSD (P = 0.05). CV = coefficient of variation.
[w] Plants were inoculated at early booting stage with rice hull and grain mixture (2:1, vol/vol) containing actively growing mycelium of *Rhizoctonia solani.*
[x] Sheath blight incidence at maturity.
[y] Area under disease progress curve (AUDPC) was calculated from sheath blight incidence measured at panicle initiation, booting, flowering, grain filling, and maturity.
[z] Grain yield (kg/ha) was estimated from a 5 m^2 harvest area and adjusted to 14% moisture.

Table 3. Yield and sheath blight incidence in plots inoculated with *Rhizoctonia solani* at different growth stages of the crop[v]

	Growth stage at inoculation[w]				
Cropping season, yield, disease	Midtillering	Panicle initiation	Midbooting	Early flowering	Grain filling
1994 dry season (screenhouse)					
Yield in IN[x]	3,664 a	2,891 b	2,667 b	4,440 b	3,990 a
Yield in UIN[x]	3,823 a	3,824 a	3,215 a	5,103 a	4,100 a
CV[y]	(16.2)	(10.9)	(9.8)	(7.1)	(3.5)
ShB ± SE[z]	11 ± 2	32 ± 8	44 ± 9	80 ± 7	22 ± 2
1994 wet season (field experiment)					
Yield in IN[x]	4,360 a	3,097 b	3,047 b	3,458 b	4,235 a
Yield in UIN[x]	4,676 a	4,676 a	4,676 a	4,676 a	4,676 a
CV[y]	(14.5)	(8.5)	(4.3)	(10.4)	(6.9)
ShB ± SE[z]	9 ± 2	70 ± 3	77 ± 6	72 ± 3	70 ± 2

[v] Means of grain yield (kg/ha) within each column and experiment followed by the same letter are not significantly different (P = 0.05).
[w] Plants were inoculated at various crop stages with rice hull and grain mixture (2:1, vol/vol) containing actively growing mycelium of *R. solani.*
[x] Grain yield (kg/ha) at 14% moisture in IN or plots with infected plants and UIN or plots with uninfected plants.
[y] CV = coefficient of variation for grain yield.
[z] ShB = Sheath blight incidence (%) measured at maturity in IN plots. No sheath blight was observed in the UIN plots. SE = standard error of the mean.

Observations from the LTCC experiment were consistent with results from the sheath blight inoculation experiment. The yield reduction due to sheath blight was detectable only at high N levels. Unusually high mean daily temperatures of 28 to 29°C and high relative humidity with cyclic dry and wet periods from panicle initiation to flowering contributed to higher sheath blight incidence in the 1994 dry season. This finding was also consistent with the work of Hashiba (12), who identified the range of high temperatures and humidity that were conducive for sheath blight development. The more recent information from Savary et al. (29) emphasized that canopy wetness rather than relative humidity is one of the driving variables for focal expansion. Cyclic dry and wet periods were shown to be conducive for sheath blight development, whereas continuous wet or dry conditions even at high relative humidity are inhibitory (17).

Grain weight, known to be a conserved and stable varietal character (23), is one of the yield components affected by sheath blight. Sheath blight infection from panicle initiation to flowering resulted in yield loss by reducing the mean grain weight and the number of filled grains. When infection started at the tillering stage, the disease failed to progress beyond the infected tillers because the canopies were not fully developed and the microclimate within the canopies was apparently not conducive to disease development. Plant compensation by producing new tillers may explain why infection in early vegetative stages fails to influence yield. When infection started at grain filling, disease may not have enough time to progress as in the screenhouse test or the disease may progress rapidly if the weather conditions are extremely favorable for disease development as in the field test (Table 3). Yield was not affected in either case because sheath blight had only a short period of time to affect yield components. Since yield loss from sheath blight occurred only when infection started at panicle initiation to flowering, fungicide treatments against sheath blight should therefore be timed during these critical stages when the crop is susceptible to the disease and vulnerable to yield loss.

R. solani produces sclerotia on plant surfaces and on crop residues. Sclerotia are considered the survival structures of the pathogen and are believed to be the pri-

mary source of initial infection in temperate and subtropical rice-growing regions (13,18,19,26). In the tropics, however, sclerotia are also found in soil and on plant debris, but sclerotial densities are lower than those reported in temperate and subtropical areas (9,18). The highest density of sclerotia was only 2.02 sclerotia per 500 g of oven-dried soil, found in the 1993 wet season in plots with the highest N input. This represents about 1.23 sclerotia per liter of saturated paddy soil, compared with values of 27 to 87 sclerotia per liter of soil reported by Lee (18). The low sclerotial densities in our studies suggest that sclerotia may not be the dominant source of initial inoculum in tropical lowland rice. Instead, mycelia of *R. solani* in plant residues may play a more important role in sheath blight epidemics in this intensive rice production system. The density of mycelia in plant debris is difficult to quantify and was not assessed in this study.

The failure to manage sheath blight effectively in the LTCC could be due either to the inefficacy of the fungicide that was used or to the ineffectiveness of the application method. Benomyl, the fungicide used to control sheath blight in the long-term experiment, was reported ineffective against sheath blight if used alone (15). Moreover, benomyl is ineffective against stem rot of rice (14). Benomyl was also found ineffective against other diseases due to development of resistant strains (10,20). The efficacy of benomyl against strains of *R. solani* found in an intensive rice production system should be evaluated for possible occurrence of resistant isolates, and alternative fungicides for effective sheath blight management should be explored.

Another possible reason for fungicide inefficacy against sheath blight is the application method. The current practice involves spraying with a nozzle that produces a fine mist over the canopy, with about 160 liters of spray solution per ha. Fine droplets are deposited on leaves, mostly in the upper and middle portions of the canopy. The protective and curative effects of the fungicide spray is therefore limited to the upper half of the canopy. The crop may be protected from secondary spread of the disease within the upper canopy. However, infection from initial inoculum starts on the lower sheaths near the water level (13,26,32), so that sheath blight could spread within the lower canopy even after fungicide application. Benomyl, although systemic, is not transported through basipetal movement (6,31) to protect the lower portions of the plants. Directing the spray at the basal portions of the plants, where primary infections start, may increase the efficacy of the fungicide, but this is difficult to achieve in dense leaf canopies like those in treatments receiving high N fertilizer rates. Sheath blight is currently a disease associated with intensive rice production systems, where high N is required to achieve high yields. High N input results in conditions favorable for sheath blight development, which could reduce grain yield by as much as 42% in the tropics, as shown in this study. This is the nitrogen–sheath blight dilemma that farmers must deal with in making management decisions. In some cases, rice yields continue to respond significantly to increasing N rates up to 225 kg N/ha when sheath blight incidence is low (3,16). The need to apply high N to achieve higher yields implies the need to control sheath blight to prevent yield loss when disease pressure is high and weather conditions are conducive to disease development. Since there is no commercially available cultivar in the tropics with an acceptable level of resistance, sheath blight management must largely rely on fungicide application. Computer-assisted advisory programs that can identify conditions favorable for disease development could help improve the timing of fungicide sprays and may reduce the frequency of sprays required. Advisory programs for other crops have been used on a commercial scale with some success (7,8). It may also be possible to minimize the need for fungicide control of sheath blight by improving the congruence between crop N demand and the N supply from soil and applied N fertilizer (4). Supply of N in excess of crop demand in the vegetative stage leads to the development of a dense leaf canopy at panicle initiation stage, with greater leaf area than required to achieve high yields. Such canopies provide a more conducive environment for sheath blight infection. Opportunities to achieve more synchronous N supply in rice systems involve better balance between the rate of applied N and the N supplying capacity of the soil (2), and improved N fertilizer timing based on nondestructive monitoring of plant N status (28). The use of biological control agents that can manipulate the soil microflora or affect the sheath blight inoculum directly (24,25), as well as the use of transgenic plants with chitinase genes (1) that may provide protection against infection or disease progression of sheath blight, are promising disease-control strategies that are currently under investigation.

Table 4. Relationship between crop growth stages at the time of inoculation with *Rhizoctonia solani* and components of yield in a field experiment during the 1994 wet season

Growth stage at disease onset	Components of yield				ShB incidence (%)
	1,000 grain weight (g)	Spikelets per m²	Filled grain per m²	Filled grain (%)	
Tillering	26.1	28,068	21,613	76.9	9*[z]
Panicle initiation	24.9*	22,816	16,810*	73.7*	70*
Booting	25.2*	23,956	17,010*	71.0*	77*
Flowering	26.0	25,329	17,506*	68.9*	72*
Grain filling	26.5	26,060	20,481	78.5	70*
Uninfected check	26.3	26,391	22,421	81.7	0

[z] Means in a column with asterisks were significantly different from the uninfected check according to Dunnett's test ($P < 0.05$). ShB = sheath blight incidence at maturity.

ACKNOWLEDGMENT

We thank Joven Alcantara, Sammy Liboon, and Gerard Maningas for technical assistance in crop management, yield determination, and disease assessments.

LITERATURE CITED

1. Broglie, K., Chet, I., Holliday, M., Cressman, R., Biddle, P., Knowlton, S., Mauvais, J., and Broglie, R. 1991. Transgenic plants with enhanced resistance to the fungal pathogen *Rhizoctonia solani.* Science 254:1194-1197.
2. Cassman, K. G., De Datta, S. K., Olk, D. C., Alcantara, J. M., Samson, M. I., Descalsota, J. P., and Dizon, M. A. 1995. Yield decline and the nitrogen economy of long-term experiments on continuous, irrigated rice systems in the tropics. Pages 181-222 in: Soil Management: Experimental Basis for Sustainability and Environmental Quality. R. Lal and B. A. Stewart, eds. Lewiston Publishers, CRC Press, Boca Raton, FL.
3. Cassman, K. G., Kropff, M. J., Gaunt, J., and Peng, S. 1993. Nitrogen use efficiency of rice reconsidered: What are the key constraints? Plant Soil 155/156:359-362.
4. Cassman, K. G., Kropff, M. J., and Yan, Z. D. 1994. A conceptual framework for nitrogen management of irrigated rice in high-yield environments. Pages 81-96 in: Hybrid Rice Technology: New Developments and Future Prospects. S. S. Virmani, ed. International Rice Research Institute, Los Baños, Philippines.
5. Cassman, K. G., and Pingali, P. L. 1995. Extrapolating trends from long-term experiments to farmers field: The case of irrigated rice systems in Asia. Pages 63-84 in: Agricultural Sustainability in Economic, Environmental, and Statistical Terms. V. Barnett, R. Payne, and R. Steiner, eds. John Wiley & Sons, Ltd., London.
6. Chatrath, M. S., Lyda, S. D., and Lauchi, A. 1972. Translocation of 2-(4-thiazolyl) benzimidazole in maturing cotton plants. Phytopathology 62:1410-1414.
7. Cu, R. M., and Line, R. F. 1994. An expert advisory system for wheat disease management. Plant Dis. 78:209-215.
8. Cu, R. M., and Phipps, P. M. 1993. Development of a pathogen growth response model for the Virginia peanut leaf spot advisory program. Phytopathology 83:195-201.
9. Damicone, J. P., Patel, M. V., and Moore, W. F. 1993. Density of sclerotia of *Rhizoctonia solani* and incidence of sheath blight in rice fields in Mississippi. Plant Dis. 77:257-260.
10. Delp, C. J., ed. 1988. Fungicide Resistance in North America. American Phytopathological Society, St. Paul, MN.
11. Flinn, J. C., and De Datta, S. K. 1984. Trends in irrigated-rice yields under intensive cropping at Philippine research stations. Field Crops Res. 9:1-15.

12. Hashiba, T. 1984. Forecasting model and estimation of yield loss by rice sheath blight disease. JARQ 18:92-98.
13. Hashiba, T., and Mogi, S. 1975. Developmental changes in sclerotia of the rice sheath blight fungus. Phytopathology 65:159-162.
14. Jackson, L. F., Webster, R. K., Wick, C. M., Bolstad, J., and Wilkerson, J. A. 1977. Chemical control of stem rot of rice in California. Phytopathology 67:1155-1158.
15. Jones, R. K., Belmar, S. B., and Jeger, M. J. 1987. Evaluation of benomyl and propiconazole for controlling sheath blight of rice caused by *Rhizoctonia solani.* Plant Dis. 71:222-225.
16. Kropff, M. J., Cassman, K. G., Peng, S., Mathew, R. B., and Setter, T. L. 1994. Quantitative understanding of yield potential. Pages 21-38 in: Breaking the Yield Barrier: Proc. Workshop Rice Yield Potential Favorable Environ. K. G. Cassman, ed. International Rice Research Institute, Los Baños, Philippines.
17. Leaño, R. M., Castilla, N. P., Lapis, D. B., and Savary, S. 1993. A simple methodology for analyzing rice sheath blight epidemiologic processes under semi-controlled conditions. Int. Rice Res. Notes 18:42-43.
18. Lee, F. N. 1980. Number, viability, and buoyancy of *Rhizoctonia solani* sclerotia in Arkansas rice fields. Plant Dis. 64:298-300.
19. Lee, F. N., and Rush, M. C. 1983. Rice sheath blight: A major rice disease. Plant Dis. 67:829-832.
20. Littrell, R. H. 1974. Tolerance in *Cercospora arachidicola* to benomyl and related fungicides. Phytopathology 64:1377-1378.
21. Marchetti, M. A. 1983. Potential impact of sheath blight on yield and milling quality of short-statured rice lines in the southern United States. Plant Dis. 67:162-165.
22. Marchetti, M. A., and Bollich, C. N. 1991. Quantification of the relationship between sheath blight severity and yield loss in rice. Plant Dis. 75:773-775.
23. Matsushima, S. 1976. High-yielding rice cultivation. University of Tokyo, Tokyo, Japan.
24. Mew, T. W., and Rosales, A. M. 1986. Bacterization of rice plants for control of sheath blight caused by *Rhizoctonia solani.* Phytopathology 76:1260-1264.
25. Mew, T. W., Rosales, A. M., and Elazegui, F. A. 1980. Ecology of the rice sheath blight pathogen: Saprophytic survival. Int. Rice Res. Notes 5(4):15.
26. Ou, S. H. 1985. Rice Diseases. Commonw. Mycol. Inst., Kew, Surrey, England.
27. Parmeter, J. R., Jr., and Whitney, H. S. 1970. Taxonomy and nomenclature of the imperfect state. Pages 7-19 in: Biology and Pathology of *Rhizoctonia solani.* J. R. Parmeter, Jr., ed. University of California, Berkeley.
28. Peng, S., Laza, R. C., Garcia, F. V., and Cassman, K. G. 1995. Chlorophyll meter estimates of leaf area-based nitrogen concentration for rice. Comm. Soil Sci. Plant Anal. 26:927-934.
29. Savary, S., Castilla, N. P., Elazegui, F. A., McLaren, C. G., Ynalvez, M. A., and Teng, P. S. 1995. Direct and indirect effects of nitrogen supply and disease source structure on rice sheath blight spread. Phytopathology 85:959-965.
30. Shaner, G., and Finney, R. E. 1977. The effect of nitrogen fertilization on the expression of slow-mildewing resistance in Knox wheat. Phytopathology 67:1051-1056.
31. Siegel, M. R. 1973. Distribution and metabolism of methyl 2-benzimidazole carbamate, the fungitoxic derivative of benomyl, in strawberry plants. Phytopathology 63:890-896.
32. Webster, R. K., and Gunnell, P. S., eds. 1992. Compendium of Rice Diseases. American Phytopathological Society, St. Paul, MN.
33. Weinhold, A. R. 1977. Population of *Rhizoctonia solani* in agricultural soils determined by a screening procedure. Phytopathology 67:566-569.
34. Yu, C. M., Ling, K. C., and Ou, S. H. 1976. Effect of nutritional and microclimatic conditions on the development of sheath blight disease of rice. Plant Prot. Bull. (Taiwan) 18:261-267.