Interactions between cultivar characteristics and environmental conditions limit the spread and increase of smut in Louisiana. Growth of fall-planted and harvested sugarcane and disease development are interrupted then synchronized by winter. Sorus production does not begin until May, increases sharply during June, and continues at a lower rate through October. Aerial teliospore concentrations increase with sorus production and are affected by rainfall and distance from a spore source. Numbers of teliospores deposited on the soil within the crop are highest below and adjacent to sori then decrease rapidly with increasing distance. Most disease spread occurs within 15 m of an inoculum source. Winter severity and growing season rainfall affect disease gradients and rates of disease increase. Survival rates are lower for smut-infected than smut-free plants, and rates of smut recurrence in previously infected plants are low following severe winters. Teliospores are not long-lived in soil when moisture is present, and viable spores were not detected after 6-9 weeks. As a result, soilborne inoculum is not present when sugarcane is tillering in the spring.

Key words: *Ustilago scitaminea*, interactions, environment.

**INTRODUCTION**

Sugarcane smut, caused by *Ustilago scitaminea* Syd., was first observed in Louisiana in 1981 (Koike *et al.*). At that time, 79% of the acreage was planted with cultivars susceptible to smut, so the appearance of the disease caused considerable alarm in the industry. The spread of smut to all of the sugarcane growing areas of the state was confirmed by field surveys conducted during 1984 (Hoy *et al.*). However, disease incidence in individual fields was usually low. Research on the epidemiology of smut was initiated to determine the factors that affect the increase of smut and the extent of the threat posed to the Louisiana industry by the disease. The results of this project are reviewed here.

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MATERIALS AND METHODS

Sorus production was monitored in smut inoculation tests conducted as part of the breeding program. Sori were counted and tagged at 1 wk intervals. Clones were separated into resistant and moderately and highly susceptible categories based on the number of sori produced by the end of July.

Aerial teliospores were collected in three, 7-day, drum-spore samplers. One sampler was operated near the center of the test field, and the two others were placed 15 and 135 m outside the field. Sampler tapes were cut into seven, 24-hour segments, placed on microscope slides, and spores were counted with a microscope. Spore numbers per m$^3$ of air were calculated for 24 h periods and 2 h intervals during 24 h periods. Precipitation, relative humidity, temperature, and wind speed data were collected.

Teliospore deposition was studied by placing silicone jelly-coated microscope slides beneath smut-infected plants and at the base of plants at distances of 1.8, 3.6, 5.4, 7.2, 9.0, 10.8, 12.6, and 14.4 m across rows in two directions. Thirteen experiments were conducted. Slides were left in the field for one wk. Spores were then counted, and the number deposited per cm$^2$ per day was calculated.

Smut infection data were collected from fields of three cultivars: CP 65-357, CP 74-383, and CP 76-331 in plant cane and first and second ratoons. Data recorded included number of plants infected, number of sori per plant, number of plants with recurrent smut in subsequent crops, number of new smut-infected plants, and the total number of sori per year. In addition, smut-infected plants were mapped during plant cane. All new infections during first ratoon were also mapped. Distances between ratoon and plant cane infections were measured, and composite disease gradients were determined for each field. Freezing air temperature and rainfall data were collected each year.

Teliospore longevity was determined for spores on the surface of saturated soil or mixed in soils with different moisture contents. Germination percentages were determined for spores in soil by removing 0.1 g soil, mixing in 10 ml deionized water, plating on water agar, and counting total numbers of spores and the number germinated after 8 h at 32°C.

RESULTS

Sorus production began during May. Mean dates for initial emergence of sori for moderately susceptible and resistant clones respectively, were one and three weeks later than for highly susceptible clones. Sorus production increased sharply during June then continued at a lower rate through October (Figure 1). Smaller
peaks in production occurred in highly susceptible clones during August and October. Additional evidence for secondary infection cycles was indicated by the late season production of sori in noninoculated plots.

Concentrations of teliospores per m³ of air per day determined from sampler counts were variable (Figure 2). Spore concentrations increased as sorus production increased. Lower spore concentrations detected from July to September were associated with increased precipitation. Spore numbers were reduced on average by 53±7% and 99±0.3% at distances of 15 and 135 m respectively. Spore concentrations for 2-h intervals during individual days were variable, but 2-h interval means indicated that spore numbers increased during the afternoon (Figure 3). This spore release pattern was associated with increases in temperature and wind speed and a decrease in relative humidity.
FIGURE 2. Smut teliospore concentrations per m$^3$ of air above the canopy of a sugarcane crop (0.4 ha) compared with daily rainfall data.

Numbers of teliospores deposited on the soil within the crop were highest below and adjacent to plants containing sori (Figure 4). Numbers of deposited spores then decreased rapidly with increasing distance. Prevailing coastal winds in several experiments resulted in high numbers of spores being deposited beneath and downwind from sori.

Smut increase over 2 or 3 year crop cycles in three cultivars is compared in Tables 1 and 2. Disease gradients determined for four fields between plant cane and first ratoon are shown in Figure 5. The number of freezes with temperatures low enough to kill sugarcane buds during the 1984-1985, 1985-1986, and 1986-1987 winters were 4, 7, and 0 respectively. The minimum temperatures for the 1984-1985 freezes were -10.6, -5.0, -4.4, and -3.9°C, and -6.1°C for the 1985-1986 freeze. Rainfall from May-October for 1984, 1985, and 1986 was 688, 723, and 469 cm respectively. Compared with a 50-year average, rainfall for these years were 92 and 127 cm above normal and 126 cm below normal respectively. The percentage of sori produced above the canopy in different cultivars also may affect smut spread and increase.
FIGURE 4. Average smut teliospore deposition gradient at the soil surface within a sugarcane crop determined from 22 gradients. Data points are means, with standard error bars, for percentages of the number of spores deposited per cm² per day below smut sori that were detected at increasing distances from a spore point source.

The survival rates of completely smut-infected plants were lower compared with smut-free plants following the severe 1984-1985 winter. Survival rates for smut-infected compared with smut-free plants were 53% compared to 89% for CP 65-357 and 22% compared with 86% for CP 74-383. The smut recurrence rates for all previously infected plants were only 17 and 3% for CP 65-357 and 65 CP 74-383 plants, respectively, and the average number of sori per infected plant decreased from 4.4 to 3.2 and from 7.8 to 5.0 respectively. The ratio of smutted to non-smutted shoots per plant varied among cultivars.

In experiments to determine the longevity of teliospores on saturated soil, spore germination was strongly affected by fungistasis and averaged only 0.6%. Percent spore germination after transfer and incubation on water agar was initially
FIGURE 5. Sugarcane smut disease gradients between plant cane and first ratoon in naturally infected fields of: A, Cultivar CP 65-357 in first ratoon during 1985; B, CP 65-357 in first ratoon during 1986; C, CP 74-383 in first ratoon in 1986; and D, CP 76-331 in first ratoon during 1987. Gradients represent the incidence (%) of new first-ratoon smut infections over distance intervals based on row centers (1.8 m) from an inoculum point source.

Percent germination in the incubated treatment then decreased with time, and no viable spores were detected after four weeks. In experiments with spores mixed in different soils containing different amounts of moisture, soils and soil moisture levels generally did not affect spore longevity, and viable spores were not detected after 6-9 weeks. Spores also lost viability in sterile soil treatments and when maintained at ambient relative humidity. Variation in spore longevity was observed for different spore collections mixed in dry soils or maintained under dessication. The results of one experiment are shown in Figure 6.
TABLE 1. Change in number of smut-infected stools from plant cane through first ratoon and second ratoon determined in three sugarcane cultivars over a 4-yr period in Louisiana.

<table>
<thead>
<tr>
<th>Sugarcane cultivar(a)</th>
<th>Plant cane year</th>
<th>No. of plant cane stools with smut(b)</th>
<th>First ratoon stools with smut(c)</th>
<th>Recurrent Smut Infections</th>
<th>New Infections</th>
<th>Total stools with smut</th>
<th>Second ratoon stools with smut</th>
</tr>
</thead>
<tbody>
<tr>
<td>CP 65-357</td>
<td>1984</td>
<td>57</td>
<td>10</td>
<td>45</td>
<td>55</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>CP 65-357</td>
<td>1985</td>
<td>55</td>
<td>30</td>
<td>279</td>
<td>309</td>
<td>281</td>
<td></td>
</tr>
<tr>
<td>CP 74-383</td>
<td>1985</td>
<td>69</td>
<td>14</td>
<td>147</td>
<td>161</td>
<td>124</td>
<td></td>
</tr>
<tr>
<td>CP 76-331</td>
<td>1985</td>
<td>88</td>
<td>66</td>
<td>167</td>
<td>233</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

\(a\) Study areas for cvs CP 65-357 (1984), CP 65-357 (1985), CP 74-383 (1985) and CP 76-331 (1986) were 0.15, 0.55, 0.22 and 0.40 ha respectively.

\(b\) Smut infection determined from observation of at least one stalk in a sugarcane stool showing a smut whip.

\(c\) Number of first ratoon sugarcane stools showing smut whips which had previously shown smut whips in plant cane.

TABLE 2. Changes in smut whip intensity from plant cane through first ratoon and second ratoon detected in three sugarcane cultivars over a 4-yr period in Louisiana.

<table>
<thead>
<tr>
<th>Sugarcane cultivar(a)</th>
<th>Plant cane year</th>
<th>Number of smut whips/ha</th>
<th>Number of whips/stool</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Plant cane</td>
<td>First ratoon</td>
</tr>
<tr>
<td>CP 65-357</td>
<td>1984</td>
<td>1687</td>
<td>1193</td>
</tr>
<tr>
<td>CP 65-357</td>
<td>1985</td>
<td>402</td>
<td>2033</td>
</tr>
<tr>
<td>CP 74-383</td>
<td>1985</td>
<td>3536</td>
<td>5691</td>
</tr>
<tr>
<td>CP 76-331</td>
<td>1986</td>
<td>980</td>
<td>2065</td>
</tr>
</tbody>
</table>

\(a\) Study areas for cvs. CP 65-357 (1984) CP 65-357 (1985) CP 74-383 (1985) and CP 76-331 (1986) were 0.15, 0.55, 0.22 and 0.40 ha respectively.

**DISCUSSION**

The results presented here represent a summary of research on the epidemiology of smut in Louisiana. More complete results and discussion have been published by Chao et al.\(^1\), Hoy and Grisham\(^3\), Hoy et al.\(^4\), Hoy et al.\(^5\).
FIGURE 6. Longevity of teliospores of *Ustilago scitaminea* in two nonsterile and sterile field soils containing different amounts of moisture.

Sugarcane is grown at the northern limit of its cultivation range in Louisiana. Freezing temperatures typically kill above-ground growth several times during winter, and the growing season only lasts 8-9 months. The spread and increase of smut are limited when plant growth and disease development are interrupted and then synchronized by the winter. Tillering occurs until July, then the number of shoots begins to decline. Average percentages of tillers produced by May (before sorus emergence) were 32 and 72% for plant cane and ratoon crops respectively, and 87 and 94% by the end of June (Ricciaul and Landry*). Teliospores are not long-lived in soil when moisture is present, so soilborne inoculum is not present during the spring tillering period. As a result, many potential infection sites (germinating buds) escape exposure to spores. In addition, the short growing season limits the number of infection cycles.
Rates of disease increase and disease gradient slopes are affected by interactions between cultivar characteristics and environmental factors. Winter severity, in particular, affects disease increase. This effect is reflected in the lower survival rates of smut-infected plants, the low rates of smut recurrence in previously infected plants, and the lower survival and expression rate of secondary infections following a severe winter.

The epidemiology research findings have resulted in the formulation of disease management recommendations that will allow farmers to continue to grow moderately susceptible cultivars without suffering significant yield losses. The factors limiting smut development in Louisiana may be similar in some other subtropical areas in which sugarcane is grown.

REFERENCES

ETUDES EPIDEMIOLOGIQUES DE LA MALADIE DU CHARBON DE LA CANNE À SUCRE EN ZONE SOUS TROPICALE EN LOUISIANE

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RESUME

Des interactions entre les variétés et les conditions environnementales limitent la dissemination et l’incidence du charbon en Louisiane. La croissance de champs, plantés ou récoltés en automne et le développement de la maladie sont interrompus puis synchronisés par l’hiver. La production de sores ne reprend qu’à partir du mois de mai, augmente considérablement en juin et se poursuit à un très faible taux en octobre. Les concentrations de téliospores dans l’atmosphère augmentent avec la production des sores et sont affectées par la précipitation et la distance de la source de spores. Le nombre de téliospores déposées sur le sol dans un champ est plus élevé sous et dans les sites adjacents aux sores et décroît rapidement à mesure que la distance des sores augmente. La dissémination de la maladie se fait jusqu’à 15 m à partir d’une source d’inoculum. La rigueur de l’hiver et la précipitation enregistrée au cours des mois de croissance ont une incidence sur les gradients de la maladie et le taux d’augmentation de l’infection. Le taux de survie est plus faible dans les plants infectés de charbon que dans ceux qui sont sains tandis que le taux de resurgence du charbon dans les plants précédemment affectés est faible après des hivers rigoureux. Les téliospores ne survivent pas longtemps dans le sol en présence d’humidité et leur viabilité disparaît après 6 à 9 semaines, avec pour résultat l’absence du charbon dans le sol au moment du tallage de la canne au printemps.

Mots clés: Ustilago scitaminea, interaction, environnement.
LA EPIDEMIOLOGÍA DEL CARBON DE LA CAÑA DE AZÚCAR BAJO LAS CONDICIONES SUBTROPICALES DE LOUISIANA

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RESUMEN

Las interacciones entre las características del cultivar y las condiciones ambientales limitan el esparcimiento y aumento del carbón en Louisiana. El crecimiento de la caña de azúcar sembrada en el otoño y cosechada, y el desarrollo de la enfermedad son interrumpidos y luego sincronizados por el invierno. La formación de soros no comienza hasta mayo, aumentando drásticamente durante junio y contínuos hasta fines de octubre. Las concentraciones de teliosporas aéreas aumentan con la producción de soros y son afectadas por la lluvias y la distancia de la fuente de esporas. El número de teliosporas depositadas sobre el suelo dentro del cultivo son mayores debajo y cerca a los soros, luego decrece rápidamente al aumentar la distancia. La mayor dispersión de la enfermedad sucede dentro de 15 m de la fuente de inóculo. La severidad del invierno y las lluvias en la época de desarrollo del cultivo afectan la gradiente y el grado de incremento de la enfermedad. La supervivencia es menor para plantas infectadas con carbón que para las plantas libres de carbón y los grados de recurrencia del carbón en plantas infectadas previamente son bajas después de inviernos severos. Las teliosporas no viven por largo tiempo cuando el suelo está húmedo y no se encuentran esporas viables después de 6-9 semanas. Como resultado de esto, no hay inoculación proveniente del suelo cuando la caña de azúcar empieza a macollar en primavera.

Palabra claves: Ustilago scitaminea.