Spread and Increase of Sugarcane Smut in Louisiana

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ABSTRACT

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Disease gradients from inoculum point sources and rates of disease increase between seasons were studied in fields of sugarcane naturally infected with smut during a 4-yr period. Sugarcane stools showing smut whips were counted and mapped during plant cane (first-season crop) and subsequent ratoon crops in fields of three cultivars beginning in different years. Smut incidence increased in ratoon crops in some crop cycles but decreased in others. Infections occurring in plant cane were treated as inoculum point sources, and distances from the nearest plant-cane infection to new infections in first ratoon determined disease gradients. Spread of disease occurred to 11.1–16.5 m. Regression analysis of disease incidence on distance from an inoculum source indicated that log-log and log-linear disease spread models fit the data. Smut spread and increase were affected by an interaction of cultivar infection characteristics, such as the smut recurrence rate in ratoon stools infected as plant cane, the number of smut whips produced by infected stools in each crop-cycle year, the heights of smut whips in relation to the crop canopy, and environmental factors possibly including winter temperatures and rainfall during the infection period.

Additional keywords: *Ustilago scitaminea*.

Severe epidemics of smut, caused by *Ustilago scitaminea* Syd, have occurred in numerous sugarcane growing areas around the world (1,10). This culmicolus smut infects buds of sugarcane, *Saccharum* interspecific hybrids (1,10), and becomes established in meristematic tissues. After a latent period of 4–7 mo, the shoot apex is converted into a long unbranched structure, known as a whip, from which airborne spores are passively released (15). A smut whip may release 10^8–10^9 spores/day and produce 10^{11} spores during an infectious period that lasts up to 3 mo (15).

Smut-infected shoots often grow at a faster rate than normal shoots, and this results in the emergence of smut whips above the crop canopy (15). Smut spores were detected 1.5 m above ground level up to 40 m from an infected field (14). Spore deposition was monitored in and outside a smut-infected field of 10-mo-old plants, and deposition was light at ground level inside the crop but heavy on plant parts and on bare ground 10 m outside the crop (15). In Florida, the disease gradient was determined during a first-season or plant-cane crop, and primary disease spread from a line source of inoculum was observed for 25–30 m (12,13).

Epidemics resulting in serious yield losses have occurred following the first appearance of smut in regions in which a large portion of the land area was planted with susceptible cultivars (1,10,15). Sugarcane smut was first observed in Louisiana in 1981 (8) when 78% of the acreage was planted with susceptible cultivars. During 1987, 35% of the acreage was planted with susceptible cultivars; however, disease severity in infected fields has rarely reached economic levels of yield reduction (6). Smut incidence and severity increased in ratoon crops of susceptible cultivars in many regions (1,10), but, in Louisiana, field observations and a survey (5) indicated that, in some years, the highest levels of infection occurred in plant cane.

In tropical areas and in Florida, more than one disease cycle can occur per growing season (1,12). In Louisiana, sugarcane is grown near the northern limit of its cultivation range, and the active growth period only lasts 7–9 mo (11). Because of the short growing season and the long latent period, most secondary infections are not expressed until the following season.

In Louisiana (5), the incidence of smut observed in first ratoon (second-season crop) following a severe winter was lower than that which occurred during plant cane in single fields of two cultivars. Lower winter survival rates for smut-infected plants and the recovery from infection of some stools in first ratoon contributed to the reduction in amount of infection.

In this study, natural smut disease gradients and rates of disease increase were determined in commercial sugarcane fields. Preliminary results have been reported (4).

MATERIALS AND METHODS

Disease increase. Smut infection data were collected from a portion of plant-cane fields of three sugarcane cultivars: CP 65-357 (0.15 ha) during August 1984; CP 65-357 (0.55 ha) and CP 74-383 (0.22 ha) during August 1985; and CP 76-331 (0.40 ha) during September 1986. These cultivars were rated as moderately susceptible to smut on the basis of infection levels observed in breeding program tests. A sugarcane plant (stool) was considered to be infected with smut if it contained one or more stalks showing a smut whip. Data collected from each field included number of smut-infected stools, number of smut whips per stool, and total number of smut whips in the surveyed area.

The same fields were surveyed again the following year in first ratoon. Data recorded included number of stools infected as plant cane with recurrent smut, number of new smut-infected stools, number of whips per stool, total number of smut-infected stools, and total number of smut whips. These data were compared with the plant-cane data from each field.

The two CP 65-357 and single CP 74-383 fields were surveyed in first ratoon during August. The CP 76-331 field was surveyed twice in first ratoon, once during June, and again in September. In the September survey, any smut-infected stool containing whips actively releasing spores, which was not detected in June, was considered to be an infection caused by inoculum produced during first ratoon.

Three fields were surveyed again in second ratoon (third-season crop). The total number of smut whips was determined in the CP 65-357 field surveyed as plant cane during 1984. The total number of smut-infected stools, the total number of smut whips, and the number of whips per stool were determined in the CP 65-357 and CP 74-383 fields surveyed as plant cane in 1985.

Determination of disease gradients. Smut-infected sugarcane stools were mapped in each of the four plant-cane fields. During first ratoon, the recurrence or recovery from smut was determined for each stool that had been infected in plant cane, and all new infections were mapped. Each stool showing a smut infection in plant cane was considered a point source of inoculum, and the distance to the nearest plant-cane infection was determined for each new infection expressed in first ratoon. Any plant-cane smut-infected stools occurring directly adjacent to each other on the same row were treated as a single inoculum point source. New first-ratoon smut infections were grouped into distance categories measured as concentric rings increasing by radial distances based on row-center intervals. Row centers were 1.8 m apart in all experimental fields. The first distance interval included plants to the outside edge of the row adjacent to the inoculum point source or all plants occurring within a radius of 2.1 m. New infections were grouped as occurring within rings with intervals 0–2.1, 2.11–3.9, 3.91–5.7, 5.71–7.5, 7.51–9.3, 9.31–11.1, 11.11–12.9, 12.91–14.7, 14.71–16.5, and 16.51–18.3 m from an inoculum point source. New first-ratoon infections in each distance interval then were totaled for all inoculum point sources, and the percentage in each interval determined the disease gradient.

The relationship of disease incidence to distance from an inoculum source was examined for each field using log-log (3) ($Y = aD^{-b}$) and log-linear (7) ($Y = ae^{-bD}$) models for disease spread, in which Y = percent disease, D = distance from a point source of inoculum, and a and b are parameters.

Determination of smut whip and crop canopy heights. Smut whip and crop canopy heights were measured in the experimental fields of CP 65-357, CP 74-383, and CP 76-331 once during June 1987. In the CP 65-357 field, height measurements were taken from 97 whips in 56 smut-infected stools, and canopy height was estimated 28 times. In the CP 74-383 and CP 76-331 fields, 140 and 110 whips were measured in 56 and 53 stools, respectively. The CP 74-383 canopy height was estimated 37 times, and the CP 76-331 canopy height was estimated 53 times.

Weather data collection. Freezing air temperature data for the three winters and rainfall data for the four growing seasons during the study period were obtained from a weather station at the U.S. Sugarcane Research Unit, Houma, LA.

RESULTS

Disease increase. Smut increase data determined over the course of a 3-yr crop cycle in a field of CP 65-357 beginning in 1984 and single fields of CP 65-357 and CP 74-383 beginning in 1985 and a 2-yr cycle in a field of CP 76-331 beginning in 1986 are compared in Tables 1 and 2.

The smut recurrence rate in first ratoon of stools showing an infection during plant cane was only 17% (10 of 57) for first-ratoon CP 65-357 during 1985, whereas the smut recurrence rate for first-ratoon CP 65-357 during 1986 was 55% (30 of 55) (Table 1). The smut recurrence rates in first ratoon for stools previously infected in plant cane were 20 (14 of 69) and 75% (66 of 88) for first-ratoon CP 74-383 during 1986 and first-ratoon CP 76-331 during 1987, respectively (Table 1). The winter survival rates for smut-infected stools were 75 (44 of 57), 95 (52 of 55), 96 (66 of 69), and 100% (88 of 88) in the same first-ratoon fields, respectively.

The number of new smut-infected stools observed in first ratoon for each plant-cane infected stool was 0.8 for first-ratoon CP 65-357 during 1985, 5.1 for first-ratoon CP 65-357 during 1986, 2.1 for first-ratoon CP 74-383 during 1986, and 1.9 for first-ratoon CP 76-331 in 1987. The overall change in smut incidence or change in number of smut-infected plants from plant cane to first ratoon was a 4% decrease in first-ratoon CP 65-357 in 1985, a 562% increase in first-ratoon CP 65-357 in 1986, a 233% increase in first-ratoon CP 74-383 in 1986, and a 264% increase in first-ratoon CP 76-331 in 1987 (Table 1). Decreases in the total number of smut-infected plants of 9 and 23% occurred from first ratoon to second ratoon during 1987 for fields of CP 65-357 and CP 74-383 (Table 1).

Changes in disease intensity, expressed as whips per hectare, in each field during the crop cycle are shown in Table 2. Changes in disease intensity were similar to changes in the incidence of smut-infected plants in each field. However, a decrease in number of smut whips per infected plant was observed in each subsequent year of the crop cycle in each field (Table 2). Yearly decreases in the number of whips per stool resulted in a greater decrease or smaller increase in number of whips per hectare than occurred in the number of smut-infected plants. There was a decrease of 29% in smut whips per hectare compared to a decrease of 4% in smut-infected plants in first-ratoon CP 65-357 in 1985. Smut-whips-per-

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

Sugarcane cultivar[a]	Plant-cane year	No. of plant-cane stools with smut[b]	First-ratoon stools with smut: Recurrent smut[c]	First-ratoon stools with smut: New infections	First-ratoon stools with smut: Total stools	Second-ratoon: Second-ratoon stools with smut
CP 65-357	1984	57	10	45	55	...
CP 65-357	1985	55	30	279	309	281
CP 74-383	1985	69	14	147	161	124
CP 76-331	1986	88	66	167	233	...

[a]Study areas for cultivars 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 that 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

Sugarcane cultivar[a]	Plant-cane year	Number of smut whips/ha: Plant cane	Number of smut whips/ha: First ratoon	Number of smut whips/ha: Second ratoon	Number of whips/stool: Plant cane	Number of whips/stool: First ratoon	Number of whips/stool: Second ratoon
CP 65-357	1984	1,687	1,193	6,306	4.4	3.2	...
CP 65-357	1985	402	2,033	1,444	4.0	3.6	2.8
CP 74-383	1985	3,536	5,691	2,841	11.2	8.5	5.0
CP 76-331	1986	980	2,065	...	4.5	3.5	...

[a]Study areas for cultivars 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.

hectare increases of 506, 161, and 211% were observed in first-ratoon CP 65-357 and CP 74-383 in 1986 and CP 76-331 in 1987, respectively, compared to smut-infected-plant increases of 562, 233, and 264%, respectively. A smut-whips-per-hectare increase of 528% was observed in second-ratoon CP 65-357 during 1986.

Disease gradients. Smut disease gradients determined in first ratoon for the four fields are shown in Figure 1. The steepest gradient occurred in CP 65-357 in 1985. Spread from a point source of inoculum was limited to the first four distance intervals (7.5 m) (Fig. 1A). The spread of smut over the greatest distance occurred in CP 65-357 in 1986. Disease spread in this field was limited to the first nine distance intervals (16.5 m) (Fig. 1B). Disease gradients for smut in CP 74-383 and CP 76-331 were similar, with new smut infections occurring over the first six intervals (11.1 m) (Fig. 1C and D).

The average number of new first-ratoon smut infections occurring within the first two distance intervals was determined for plant-cane inoculum point sources with or without recurrent smut in first ratoon for each field. The averages then were compared to estimate the extent to which smut infections produced during first ratoon represented current season disease spread and increase. The average numbers of new first-ratoon smut infections occurring within the first distance interval (2.1 m) of inoculum sources with recurrent smut were 2.5, 0.6, and 0.7 for CP 65-357 in 1986, CP 74-383 in 1986, and CP 76-331 in 1987, respectively. In comparison, the average numbers of new smut infections within the first interval of inoculum sources with nonrecurrent smut in the same fields were 2.4, 0.9, and 0.9, respectively. The average numbers of new infections within the first two distance intervals combined (3.9 m) for inoculum sources with recurrent smut in the

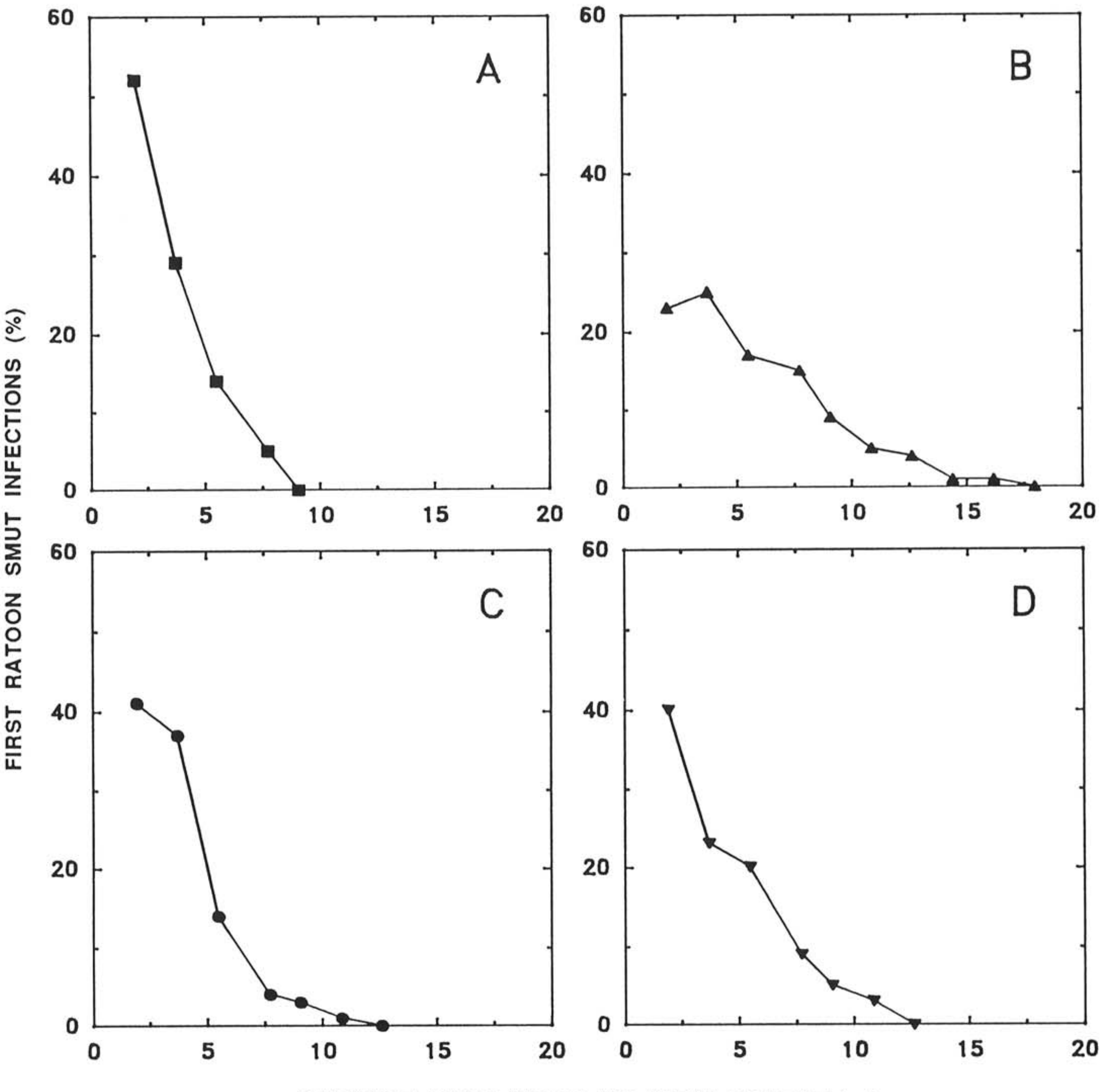

Fig. 1. Sugarcane smut disease gradients between plant cane and first ratoon in naturally infected fields of: **A,** Cultivar CP 65-357 in first ratoon during 1985; **B,** CP 65-357 in first ratoon during 1986; **C,** CP 74-383 in first ratoon during 1986; and **D,** CP 76-331 in first ratoon during 1987. Gradients represent the incidence (%) of new first-ratoon smut infections over concentric distance intervals based on row centers (1.8 m) from an inoculum point source.

same fields were 3.4, 1.0, and 0.4 compared with averages of 3.2, 1.0, and 0.5, respectively, for inoculum sources with nonrecurrent smut.

Both the log-log and log-linear models provided significant fits to the data for each field. However, the log-linear model gave a better fit to the smut data in all four fields (Fig. 2). The coefficients of determination for the log-log model were 0.92, 0.72, 0.86, and 0.88 compared with 0.98, 0.90, 0.96, and 0.98 for the log-linear model for the 1985 first-ratoon CP 65-357, the 1986 first-ratoon CP 65-357 and CP 74-383, and the 1987 first-ratoon CP 76-331, respectively. Prediction line slopes for each of the four fields for the log-log model were −1.63, −1.51, −2.14, and −1.44, respectively. Plots of residuals from data points to predicted values indicated that both models overestimated the incidence of new infections near an inoculum point source and in the furthest distance intervals and underestimated incidence in the middle distance intervals. This pattern was more pronounced with the log-log model.

Comparison of smut whip and crop canopy heights. Smut infections in CP 65-357 and CP 76-331 resulted in the production of whips at or above the crop canopy height, whereas the majority of whips produced by smut-infected plants of CP 74-383 developed within the canopy (Table 3). A highly significant difference was indicated by a *t* test between smut whip and canopy heights in CP 65-357 and CP 76-331, whereas no significant difference was detected between whip and canopy height measurements in CP 74-383.

Weather data. During the 1984–1985 winter, 10 freezes were recorded with a total duration of 110 hr. Eleven freezes with a total duration of 63 hr and five freezes with a duration of 20 hr were recorded during the 1985–1986 and the 1986–1987 winters,

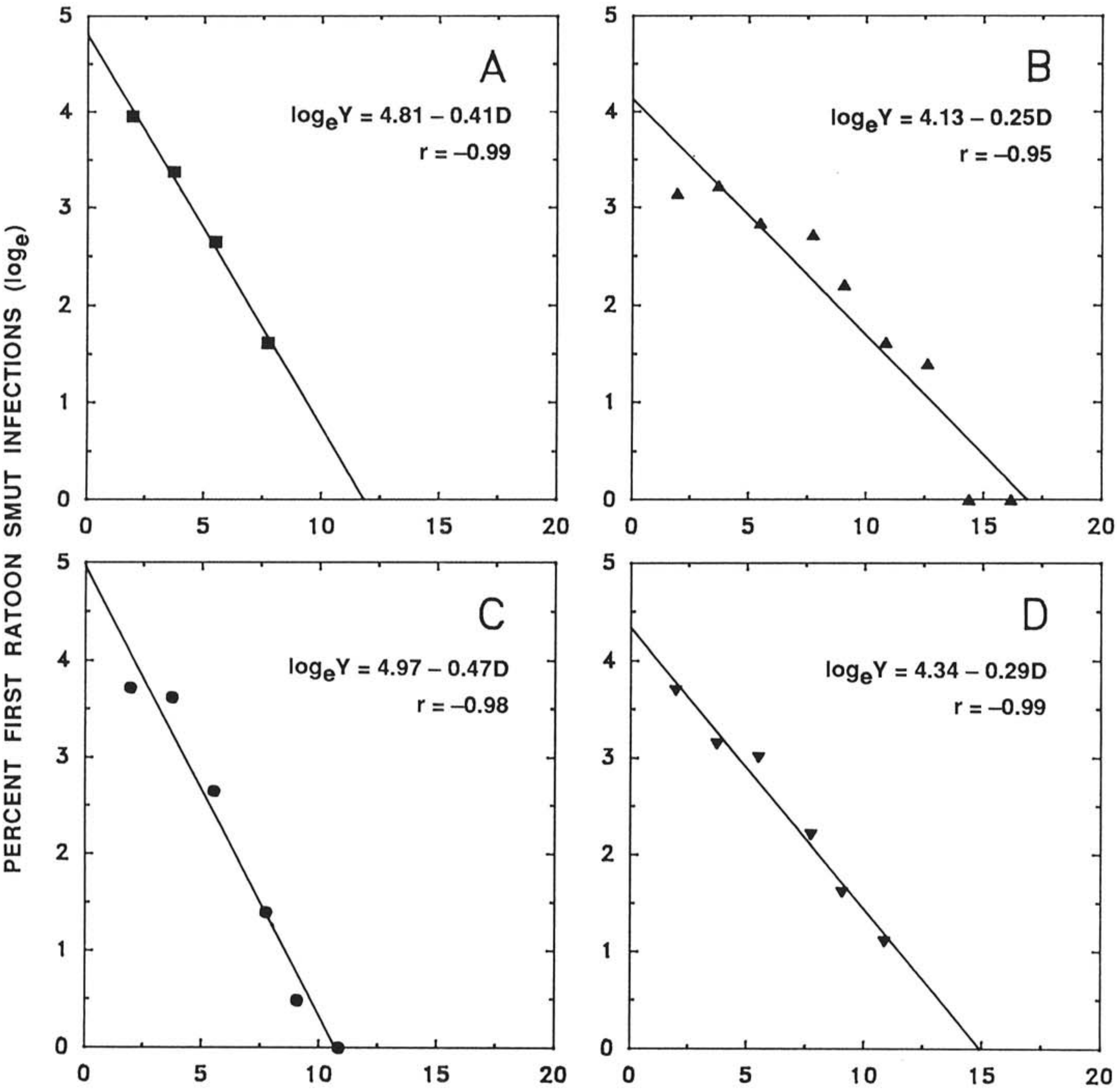

Fig. 2. Transformed disease incidence in relation to distance. Y = the percentage of new first-ratoon smut infections, and D = distance from an inoculum point source. Analyses were for data from four fields. **A,** Cultivar CP 65-357 in first ratoon during 1985. **B,** CP 65-357 in first ratoon during 1986. **C,** CP 74-383 in first ratoon during 1986. **D,** CP 76-331 in first ratoon during 1987.

TABLE 3. Proportion of smut whips produced below, within, or above the crop canopy by smut-infected plants of sugarcane cultivars CP 65-357, CP 74-383, and CP 76-331

Sugarcane cultivar	Number of smut whips	Percentage of smut whips[a]		
		Below canopy	Within canopy	Above canopy
CP 65-357	97	4	39	57
CP 74-383	140	23	63	14
CP 76-331	110	8	43	49

[a] Smut whips with height measurements outside the 95% confidence interval for the crop canopy height mean were considered to be produced below or above the canopy. Heights were determined once during June 1987.

respectively. Ambient air temperatures of −3.5 C or below can kill sugarcane buds (9). The number of freezes with air temperatures of −3.5 C or below during the 1984–1985, 1985–1986, and the 1986–1987 winters were 4, 1, and 0, respectively. The minimum temperatures for the 1984–1985 winter freezes were −10.6, −5.0, −4.4, and −3.9 C, and the minimum temperature for the 1985–1986 winter freeze was −6.1 C.

Rainfall totals for the months when smut spores were produced and conditions favored infection (May through October) for 1984, 1985, and 1986 were 687.6, 723.2, and 469.3 cm, respectively. Compared to a 50-yr average, rainfall from May through October was 91.8 cm above normal during 1984, 127.3 cm above normal during 1985, and 126.5 cm below normal during 1986.

DISCUSSION

Smut incidence changes observed in fields of CP 65-357 and CP 74-383 between plant cane and first ratoon or first ratoon and second ratoon showed a similar pattern. However, no consistent pattern to changes was observed between seasons in different years. Smut incidence decreased in fields between 1984 and 1985, increased in fields between 1985 and 1986, and decreased in fields between 1986 and 1987. CP 74-383 exhibited greater decreases and smaller increases in smut incidence than CP 65-357. Between 1986 and 1987, smut incidence decreased in second-ratoon CP 65-357 and CP 74-383 but increased in first-ratoon CP 76-331. These results suggest that changes in smut incidence over the course of a crop cycle are affected by an interaction between cultivar infection characteristics and environmental factors.

Differences were detected between cultivars in the number of whips per infected stool, the rates of smut recurrence in first-ratoon stools infected as plant cane, and the number of new first-ratoon infected stools per plant-cane inoculum source. Smut recurrence rates were low in CP 74-383 in this study and a previous study (3%) (5), low to moderate in CP 65-357, and highest in CP 76-331. The highest number of new infections per plant-cane inoculum source (5.1) was observed in CP 65-357 during 1986. In comparison, the highest observed ratios for CP 74-383 and CP 76-331 were 2.1 and 1.9, respectively. Smut-infected plants of CP 74-383 consistently produced the highest number of whips per stool.

Winter severity as determined by the occurrence of freezing air temperatures sufficient to damage or kill sugarcane buds (9) appeared to affect changes in disease incidence between seasons. First-ratoon smut recurrence rates and the numbers of new smut infections per plant-cane infection were less than one for both CP 65-357 and CP 74-383 (5) following the severe 1984–1985 winter, and decreases in disease incidence and intensity resulted. Smut recurrence rates and ratios of new infection per plant-cane infection were higher following the mild 1985–1986 winter, and disease increased in both cultivars. Most secondary smut infections probably occur near the soil surface and would be affected by ambient air temperatures. The differences in number of new infections per plant-cane inoculum source observed in both cultivars following severe or mild winters suggest that severe winters reduce the survival of unexpressed, secondary infections as well as primary infections expressed during plant cane.

Changes in disease incidence observed following two mild winters were not consistent. Following the 1985–1986 winter, disease incidence increased in first-ratoon CP 65-357 and CP 74-383 and the second-ratoon CP 65-357. Following the 1986–1987 winter, a twofold increase in disease incidence was observed in first-ratoon CP 76-331, but a decrease was observed in second-ratoon CP 65-357 and CP 74-383. A comparison of rainfall data with smut incidence in Kenya (2) suggested that high disease incidence resulted from high rainfall conditions during the growing season. In this study, differences in the amount of rain during the growing season may have affected disease incidence changes observed in ratoon crops following the two mild winters. Rainfall during the 1985 infection period was 127.3 cm above normal and 126.5 cm below normal during the 1986 infection period. Thus, it appears that the amount of rainfall during the infection period also affects the increase of sugarcane smut in Louisiana possibly by affecting the number of secondary infections that occur.

The disease gradients recorded in these experiments reflected the interaction of cultivar infection characteristics with environmental factors. A steep gradient was observed in CP 65-357 following the severe 1984–1985 winter, whereas the flattest gradient was observed in CP 65-357 following the mild 1985–1986 winter. The short range spread of disease occurred in all fields over distances of 7.5 to 16.5 m. In Florida, secondary disease spread was detected during plant cane and occurred over a distance of 30 m (12,13). One difference between the two studies, which might have affected disease spread, was that a line source of inoculum was used in Florida.

In Kenya, smut whips were observed to develop above the crop canopy (15). In Louisiana, field observations indicated that some smut whips were produced above the canopy at the time of their emergence. Then as the season progressed, normal shoots continued to elongate and grew up around the smut whips. The proportion of smut whips produced above the canopy appeared to vary among cultivars. Measurements of whip heights in different cultivars confirmed this. The majority of smut whips produced in CP 65-357 developed above the canopy, whereas most whips produced in CP 74-383 were within the canopy. Disease spread occurred over a greater distance in CP 65-357 than in CP 74-383 between 1985 and 1986, and the probability of a new infection occurring within the first three distance intervals was 0.65 for CP 65-357 compared with 0.92 for CP 74-383. Apparently, the height of smut whips produced by infected plants of a cultivar is another factor that can affect the disease gradient and thus disease increase.

The approach used in these experiments was to use naturally occurring smut infections as inoculum point sources to study disease gradients and increase. The accuracy of the interpretations of the results depends on three assumptions: smut whips were not produced by secondary infections during the current growing season; there was no significant overlap of individual gradients; and inoculum from outside sources did not cause significant numbers of new infections. The development of very similar numbers of new first-ratoon smut infections within the first two distance intervals of plant-cane infections that had recurrent or nonrecurrent smut in first ratoon and the failure to detect new smut infections late in the season that had not been observed early in the season suggest that the number of secondary infections expressed during the season was low. Some overlap between individual gradients was inevitable; however, plant-cane smut-infected plant densities based on a conservative estimate of five plants per meter of row were 1.4, 0.4, 1.1, and 0.8% for 1984 CP 65-357, 1985 CP 65-357, 1985 CP 74-383, and 1986 CP 76-331, respectively. The disease gradient slopes predicted by the log-log model were all in the −1 to −2 range. Gregory (3) suggested that slope values in this range are common for field experiments on disease gradients and that values close to zero indicate secondary spread or contamination from outside inoculum sources.

The spread and increase of sugarcane smut in Louisiana is complex and represents an interaction of environmental factors and cultivar infection characteristics. These experiments suggest that conditions in Louisiana do not favor high rates of disease increase in the smut-susceptible cultivars currently being grown. If the initial incidence of disease is low, then the development of smut epidemics causing significant yield losses in ratoon crops of these cultivars is unlikely.

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