Heritability of Resistance and Repeatability of Clone Reactions to Sugarcane Smut in Louisiana

C. P. Chao, J. W. Hoy, A. M. Saxton, and F. A. Martin

Former graduate assistant and associate professor, Department of Plant Pathology and Crop Physiology; associate professor, Department of Experimental Statistics; and professor, Department of Agronomy, Louisiana Agricultural Experiment Station, Louisiana State University Agricultural Center, Baton Rouge 70803. Present address of first author: Taiwan Banana Research Institute, P.O. Box 18, Chiuju, Pingtung 90403, Republic of China.

Approved for publication by the director of the Louisiana Agricultural Experiment Station as manuscript number 89-38-3407.

We thank L. B. Grelen for technical assistance.

Accepted for publication 24 January 1990 (submitted for electronic processing).

ABSTRACT

Chao, C. P., Hoy, J. W., Saxton, A. M., and Martin, F. A. 1990. Heritability of resistance and repeatability of clone reactions to sugarcane smut in Louisiana. Phytopathology 80:622-626.

Heritability of resistance to sugarcane smut caused by *Ustilago scitaminea* was estimated by comparing percentages of shoot smut infection of parents and offspring from 18 biparental crosses involving resistant, moderately susceptible, and highly susceptible clones. Frequencies of resistant offspring were highest in resistant × resistant crosses. Narrow-sense heritability estimates, determined by mid-parent-offspring regressions in plant cane (first-season crop) and first ratoon (second-season crop) were 0.41 ± 0.08 and 0.38 ± 0.11, respectively. Estimated genetic gains in resistance ranged from 5 to 13% depending upon the assumed selection intensity. Estimates of repeatability of smut reactions of parents in two plant cane crops and from plant cane to first ratoon were 0.60 ± 0.10 and 0.75 ± 0.07, respectively. The repeatability estimate for offspring from plant cane to first ratoon was 0.62 ± 0.08. Disease reactions of experimental cultivars in breeding program smut inoculation tests also were moderately repeatable between plant cane and first ratoon and subsequent plant cane or first ratoon crops. Repeatability estimates for clones rated as resistant, moderately susceptible, or highly susceptible to smut in plant cane were moderate for resistant and highly susceptible clones and low for moderately susceptible clones in two populations between plant cane and first ratoon. Smut resistance ratings assigned to clones were significantly correlated between crops and in different years. The results suggest that the proportion of resistant progeny can be increased by minimizing the use of susceptible parents and that plant cane infection ratings from multiple inoculation tests are needed to accurately assess sugarcane clone smut susceptibility.

Smut, caused by *Ustilago scitaminea* Syd., is an important disease in many sugarcane-growing regions worldwide (2,6,16,19,20). The characteristic symptom of sugarcane smut is the production of a long, whiplike sorus at the apex of an infected stalk on which billions of teliospores are produced (2,23). Severely infected sugarcane plants produce grasslike, small-diameter shoots. Yield losses usually increase in successive ratoon crops and can be severe in susceptible cultivars (23). After the appearance of smut in a sugarcane-growing region, susceptible cultivars typically must be replaced with resistant cultivars.

Sugarcane is vegetatively propagated, and individual cultivars are clones from single seedlings. Modern sugarcane cultivars are interspecific hybrids between *Saccharum officinarum* L. and *S. spontaneum* L., *S. barberi* Jesw., or *S. robustum* Brandes & Jesw. ex Grassl (4). Sugarcane hybrids typically are polyploid, and chromosome numbers vary due to aneuploidy. Seedling offspring of crosses between species or hybrids are very heterogeneous, and offspring with resistance to smut can be identified in cultivar selection programs. An estimate of the heritability of resistance to smut is needed to determine the best breeding strategy for producing resistant cultivars.

A range in estimates for heritability of resistance to sugarcane smut has been reported. In Hawaii, narrow-sense heritability values of 0.56 and 0.75 were estimated by variance components from 8 × 8 diallel crosses with cultivars highly resistant and highly susceptible to smut race A (26,27). Narrow-sense heritability estimates of resistance to races A and B, determined by parent-offspring regression on a family mean basis, were 0.51 and 0.47, respectively (25). Broad-sense heritability estimates of resistance to races A and B, determined by variance components, were 0.96 and 0.91, respectively (25). Estimates from mid-parent-offspring and female parent-offspring regressions in Barbados were between 0.17 and 0.49 for biparental crosses and between 0.12 and 0.24 for polycrosses (22). The Barbados and Hawaii estimates were restricted to only plant cane (first-season crop) in Barbados and first ratoon in Hawaii. In Louisiana, sugarcane is grown at the northern limit of its cultivation range, and the breeding population is different from those of Barbados and Hawaii.

After the first report of smut in Louisiana in 1981 (16), emphasis was given to breeding and selection for clones resistant to smut. Smut reactions of sugarcane clones determined in inoculation tests have been demonstrated to vary between experiments (17) and between plant cane and ratoon crops within experiments (24). Smut resistance ratings assigned on a 1–9 scale were reported to vary for some clones between plant cane experiments in Louisiana (11). An estimate of clone smut reaction repeatability under Louisiana conditions is needed to develop procedures to accurately assess resistance in experimental cultivars.

The objective of this study was to estimate the heritability of resistance to smut and repeatability of clone smut reactions in the Louisiana sugarcane breeding population. A portion of the results was reported previously (9).

MATERIALS AND METHODS

Estimation of smut resistance heritability. Offspring of 18 crosses involving 17 sugarcane clones selected from the Louisiana Agricultural Experiment Station (LAES) sugarcane breeding program were chosen to study heritability of resistance to smut. Each offspring was a clone derived from a true seed. Sixteen parent clones were from crosses made at the U.S. Sugarcane Field Station, Canal Point, FL, and selected at the U.S. Sugarcane Research Unit, Houma, LA, and L 65-69 was from the LAES sugarcane breeding program. Eight parent clones, CP 65-357, CP 67-412, CP 70-330, CP 72-356, CP 72-370, CP 73-351, CP 74-383, and L 65-69, were commercial cultivars; five clones, CP 66-346, CP 72-355, CP 73-308, CP 76-340, and CP 77-310, were elite lines; two clones, CP 77-407 and CP 77-413, were advanced, unreleased lines; and two clones, CP 60-16 and CP 61-39, were breeding lines.

Eighteen stalks of each parent and offspring were cut, the tops were removed below the growing point, the leaf sheaths were stripped, and the samples were divided into three replicates of six stalks each. Stalks were inoculated by dipping for 10 min in a freshly prepared smut spore suspension containing 5×10^6 viable spores/ml of water. Spores used for inoculation were from a composite collection obtained during the current growing season from different cultivars and locations. Offspring and parents then were planted 18 September 1985 in a randomized complete block design in single-row plots, 2.7 m in length and 0.9 m in width, with a 0.9-m alley between plots at the LAES Citrus Experiment Station, Port Sulphur, LA.

Smut infection levels of parents and offspring were determined in the plant cane and first ratoon crops during late July of 1986 and 1987, respectively. Individual plants were difficult to distinguish, and clones varied in the number of infected (exhibiting a smut sorus) and apparently healthy stalks that were produced per plant. As a result, the percentage of smut-infected stalks in relation to total stalks was determined for each offspring and parent in each replicate each season. The overall smut infection percentage for each offspring and parent was the mean infection percentage of the three replicates.

Clones in breeding program smut inoculation tests are rated as resistant (R), moderately susceptible (MS), or highly susceptible (HS) based on the observed infection levels relative to infection levels of a series of clones of known smut reactions: CP 72-356 (R), CP 65-357 (MS), and CP 73-351 (HS). A resistant rating was assigned to a clone if the infection percentage ranged from 0 to 11%; a moderately susceptible rating was assigned if the infection level ranged from 11.1 to 22%; and a highly susceptible rating was assigned if the infection level was greater than 22%.

Heritability estimates were determined by regressing the infection percentage for each replicate of 5 to 11 (generally 10) randomly chosen offspring from each of the 18 crosses on the mid-parent infection percentage (the average smut infection percentage of the two parents for each cross) for each replicate (3,10). Narrow-sense heritability (h^2) of smut resistance was estimated by mid-parent-offspring regressions (3,10) in plant cane and again in first ratoon.

The h^2 values estimated by mid-parent-offspring regression were used to estimate genetic gains of smut resistance with parent selection levels of 30 and 70% in plant cane and in first ratoon. The formula used for calculating expected genetic gain was standard selection intensity (i) $\times$ h^2 $\times$ phenotypic standard deviation (1,15).

Estimation of repeatability of clone smut reactions. Repeatability analysis measures the amount of variation that does not vary over time. Estimates of repeatability for smut reactions of parents and offspring between plant cane and first ratoon and standard errors were calculated from variance components (3,10,14). The infection percentages of parents or offspring in all three replicates were used for estimation of smut reaction repeatability.

On 11 September 1986, 18 stalks of each of the 17 parent clones were inoculated with smut spores and planted at the same location as described previously. The smut infection percentages of parents in three replicates in the 1986 and 1987 plant cane crops then were used to determine variance components and estimate parent smut reaction repeatability.

Estimates of smut reaction repeatability also were determined for clones in two experimental cultivar (breeding line) inoculation tests. Clones were inoculated and planted as described previously at the LAES Citrus Research Station on 9 October 1985 and at the LAES St. Gabriel Experiment Station, St. Gabriel, LA, on 11 September 1986. Infection percentages were determined in late July. Repeatability estimates were determined for smut reactions of 37 clones between two subsequent plant cane crops and between plant cane and first ratoon in 1986 and 1987 and similarly for 42 clones between plant cane in 1987 and plant cane or first ratoon in 1988. A repeatability estimate also was determined for 21 clones in subsequent first ratoons in 1987 and 1988. In addition, all clones in the inoculation tests were rated as described previously during plant cane and separated into R, MS, and HS groups. Smut reaction repeatability was estimated for clones in each group in the two experiments between plant cane and first ratoon in 1986 and 1987, respectively, and in 1987 and 1988, respectively. Repeatability estimates were determined for 56 R, 13 MS, and 11 HS clones between 1986 and 1987 and for 41 R, 73 MS, and 20 HS clones between 1987 and 1988.

Numerical smut resistance ratings typically are assigned to clones for each year of each inoculated experiment as described previously on a scale of 1–9 in which 1–3 = resistant, 4–6 = moderately susceptible, and 7–9 = highly susceptible. Spearman's correlation analysis for ranked data (18) was used to determine whether ratings were correlated between different crop years and the same crop stage in different years.

TABLE 1. Percent smut infection for sugarcane parents and F_1 progeny from 18 crosses in plant cane (PC) and first ratoon (FR)

Cross		Parental smut ratings[a]		Smut infection (%)									
				Maternal parent		Paternal parent		Mid-parent		F_1 progeny mean		Cross progeny mean[b]	
Maternal parent	Paternal parent	PC	FR	PC	FR	PC	FR	PC	FR	PC	FR	PC	FR
CP 60-16	× CP 77-310	R × R	R × R	0	0	0	4	0	2	22	19	19	21
CP 72-356	× CP 66-346	R × R	R × R	0	2	2	0	1	1	26	31		
CP 72-370	× CP 66-346	R × R	R × R	1	0	2	0	2	0	8	12		
CP 65-357	× CP 67-412	MS × R	MS × R	12	14	1	8	7	11	18	19	18	25
CP 72-370	× CP 73-351	R × HS	R × HS	1	0	31	67	16	34	18	24	28	29
CP 77-310	× CP 77-407	R × HS	R × R	0	0	37	7	19	4	38	25		
CP 65-357	× CP 77-407	MS × HS	MS × R	12	14	37	7	25	10	33	21	33	
CP 61-39	× CP 70-330	HS × R	HS × R	38	23	0	1	19	12	19	23	35	30
CP 74-383	× CP 77-310	HS × R	HS × R	57	38	0	4	29	21	42	37		
CP 76-340	× CP 72-355	HS × R	MS × R	43	20	5	3	24	12	43	36		
CP 77-407	× CP 67-412	HS × R	R × R	37	7	1	8	19	8	34	22		
CP 65-357	× L 65-69	MS × MS	MS × R	12	14	17	1	15	8	40	26	35	
CP 65-357	× CP 77-413	MS × MS	MS × HS	12	14	21	35	17	24	34	48		44
CP 73-308	× CP 77-413	MS × MS	R × HS	21	6	21	35	21	20	31	33		
CP 76-340	× CP 77-413	HS × MS	MS × HS	43	20	21	35	32	28	33	39	34	
CP 77-407	× CP 73-308	HS × MS	R × R	37	7	21	6	27	6	34	18		
CP 74-383	× CP 77-407	HS × HS	HS × R	57	38	37	7	47	22	42	29	41	
CP 76-340	× CP 77-407	HS × HS	MS × R	43	20	37	7	40	14	40	21		

[a] R = resistant, MS = moderately susceptible, and HS = highly susceptible.
[b] Means for each observed cross type are presented on the first line in which a given cross type is listed.

TABLE 2. Number of offspring with resistant (R), moderately susceptible (MS), and highly susceptible (HS) smut infection reaction types and the percentage of resistant offspring in plant cane (PC) and first ratoon (FR)

Cross		Parental smut ratings		No. offspring with each smut reaction type						Resistant offspring (%)			
				R		MS		HS		Within cross		Cross type	
Maternal parent	Paternal parent	PC	FR	PC	FR	PC	FR	PC	FR	PC	FR	PC	FR
CP 60-16	× CP 77-310	R × R	R × R	6	6	0	1	4	3	60	60	51	43
CP 72-356	× CP 66-346	R × R	R × R	3	2	1	3	6	5	30	20		
CP 72-370	× CP 66-346	R × R	R × R	7	3	3	1	1	6	64	30		
CP 65-357	× CP 67-412	MS × R	MS × R	4	3	1	3	5	4	40	30	40	24
CP 72-370	× CP 73-351	R × HS	R × HS	3	3	1	0	1	2	60	60	40	35
CP 77-310	× CP 77-407	R × HS	R × R	2	3	1	3	7	4	20	30		
CP 65-357	× CP 77-407	MS × HS	MS × R	2	2	2	4	5	3	22	22	22	
CP 61-39	× CP 70-330	HS × R	HS × R	5	4	3	2	3	5	45	36	19	23
CP 74-383	× CP 77-310	HS × R	HS × R	1	1	0	1	9	8	10	10		
CP 76-340	× CP 72-355	HS × R	MS × R	0	1	2	4	8	5	0	10		
CP 77-407	× CP 67-412	HS × R	R × R	2	5	2	0	6	2	20	49		
CP 65-357	× L 65-69	MS × MS	MS × R	1	4	3	1	6	5	10	40	17	
CP 65-357	× CP 77-413	MS × MS	MS × HS	2	1	2	3	5	5	22	11		6
CP 73-308	× CP 77-413	MS × MS	R × HS	2	1	0	1	8	8	20	10		
CP 76-340	× CP 77-413	HS × MS	MS × HS	1	0	3	3	5	6	11	0	12	
CP 77-407	× CP 73-308	HS × MS	R × R	1	7	2	1	4	3	14	70		
CP 74-383	× CP 77-407	HS × HS	HS × R	1	2	0	2	8	5	11	22	6	
CP 76-340	× CP 77-407	HS × HS	MS × R	0	2	1	4	9	4	0	20		

TABLE 3. Expected sugarcane population genetic gain in smut resistance for two parent selection intensities for plant cane and first ratoon

Crop	Population smut infection mean (%)	Expected genetic gains[a] at two selection intensities	
		30%	70%
Plant cane	31 ± 28	13	6
First ratoon	26 ± 26	11	5

[a] Subtract the genetic gain value at each selection intensity from the current population smut infection percentage mean to determine the expected mean of the population resulting from crosses among selected clones.

RESULTS

The narrow-sense heritability estimates for smut resistance obtained by mid-parent-offspring regressions were 0.41 ± 0.08 for plant cane and 0.38 ± 0.11 for first ratoon.

In plant cane, the F_1 progeny of 15 of 18 crosses had a higher infection percentage mean than the mid-parent value (Table 1). The lowest smut infection means for F_1 progeny in plant cane, 18 and 19%, were observed for progeny of MS × R and R × R cross types, respectively. The infection percentage means for F_1 progeny of R × R, MS × MS, and HS × HS cross types were 19, 35, and 41%, respectively (Table 1). The proportion of resistant offspring produced from R × R, MS × MS, and HS × HS crosses in plant cane were 51, 17, and 6%, respectively (Table 2). These results indicate that resistance genes occurred at a higher frequency in progeny of R × R crosses than in progeny of MS × MS and HS × HS crosses.

Using the parent infection percentages from first ratoon to determine cross types, only five cross types were represented in the 18 crosses (Table 1). Infection percentage means for F_1 progeny in first ratoon were higher than the mid-parent infection value for 17 of 18 crosses (Table 1). MS × MS and HS × HS cross types did not occur during first ratoon. Comparing the five cross types that did occur, R × R crosses had the lowest overall progeny smut infection percentage (21%) (Table 1) and the highest proportion of resistant offspring (43%) (Table 2), whereas MS × HS crosses had the highest progeny infection percentage (44%) and the lowest proportion of resistant offspring (6%).

Expected genetic gains in smut resistance for progeny populations in plant cane and first ratoon for parent selection intensities of 70 and 30% are shown in Table 3.

Smut reactions of parents for plant cane in two subsequent years and for plant cane and first ratoon were moderately to highly repeatable (Table 4). Progeny reactions in plant cane and first ratoon also were moderately repeatable (Table 4). The clone effect and year × clone interaction were significant in all three analyses (Table 4).

Repeatability estimates for smut reactions for experimental cultivars ranged from 0.41 to 0.61 (Table 5). The clone effect on smut reaction was significant in the analyses of all five experiments (Table 5).

Repeatability estimates of smut reactions of R, MS, and HS clones between plant cane and first ratoon ranged from 0.14 to 0.62 and from 0.09 to 0.30 in two experimental cultivar inoculation tests (Table 6). Repeatability estimates were moderate for R and HS clones and low for MS clones in both experiments.

The smut resistance ratings assigned to experimental cultivars in each year of three experiments were significantly correlated (Table 7).

DISCUSSION

The results of the mid-parent-offspring regressions suggest that smut resistance is a moderately heritable trait in the Louisiana sugarcane breeding population under prevailing environmental conditions. Environmental and gentoype × environment covariances between parents and offspring may bias h^2 estimates (7,21). However, estimates of h^2 determined by mid-parent-offspring regression based on smut infection percentages of parents and offspring within the same or in different replicates in plant cane and first ratoon in the same year were similar and also indicated that smut resistance is moderately heritable (8). In addition, estimates of moderate heritability for smut resistance were determined by mid-parent-offspring regressions based on smut infection percentages of parents and offspring in replicates in different years (8). These results indicate that environmental and genotype × environment covariances between parents and offspring did not bias the pooled h^2 estimates.

Moderate to high narrow-sense heritability for smut resistance was indicated by h^2 estimates determined by biparental crosses in Barbados (22) and Hawaii (25–27). Parents in the breeding programs at Barbados, Hawaii, and Louisiana are products of recurrent selection programs conducted under very different conditions. Variation in the h^2 estimates determined in different regions may arise from differences in tested sugarcane breeding populations, environments, isolates of *U. scitaminea*, experimen-

TABLE 4. Repeatability of smut reactions for sugarcane parents in two plant cane crops and plant cane:first ratoon and for progeny in plant cane: first ratoon

	Parents				F_1 progeny	
	Plant cane: plant cane		Plant cane: first ratoon		Plant cane: first ratoon	
Source of variation	df	MS	df	MS	df	MS
Year	1	0.03	1	0.03	1	0.38**[a]
Rep	2	0.04	2	0.01	2	0.13
Year × rep	2	0.06	2	0.01	2	0.14**
Clone	16	0.19**	16	0.17**	169	0.28**
Year × clone	16	0.06**	16	0.14**	169	0.05**
Error	64	0.02	64	0.01	662	0.03
Repeatability	0.60 ± 0.10		0.75 ± 0.07		0.62 ± 0.08	

[a] ** $P \leq 0.01$.

TABLE 5. Repeatability of smut reactions for sugarcane clone populations in two plant cane (PC) crops, plant cane and first ratoon (FR), or two first ratoons in 1986–1987 or 1987–1988

	1986-1987				1987-1988					
	PC:PC		PC:FR		PC:PC		PC:FR		FR:FR	
Sources of variation	df	MS	df	MS	df	MS	df	MS	df	MS
Year	1	0.530**[a]	1	0.021	1	0.260**	1	0.548**	1	0.029
Rep	2	0.001	2	0.002	2	0.003	2	0.003	2	0.004
Year × rep	2	0.012	2	0.009	2	0.006	2	0.004	2	0.002
Clone	36	0.071**	36	0.055**	41	0.085**	41	0.056**	36	0.060**
Year × clone	36	0.036	36	0.018*	41	0.035**	41	0.021**	36	0.017**
Error	113	0.020	82	0.010	122	0.015	122	0.012	113	0.008
Repeatability	0.41 ± 0.08		0.55 ± 0.08		0.52 ± 0.07		0.47 ± 0.08		0.61 ± 0.07	

[a] * $P \leq 0.05$, and ** $P \leq 0.01$.

TABLE 6. Repeatability of smut reactions for sugarcane clones rated in plant cane as resistant (R), moderately susceptible (MS), or highly susceptible (HS) between plant cane and first ratoon in 1986 and 1987 or 1987 and 1988

	1986-1987						1987-1988					
	R		MS		HS		R		MS		HS	
Sources of variation	df	MS	df	MS	df	MS	df	MS	df	MS	df	MS
Year	1	0.001	1	0.004	1	0.002	1	0.010	1	2.080**[a]	1	0.485**
Rep	2	0.001	2	0.061	2	0.071	2	0.001	2	0.007	2	0.003
Year × rep	2	0.008	2	0.002	2	0.003	2	0.001	2	0.027	2	0.028
Clone	56	0.014**	12	0.033	10	0.075	40	0.007**	72	0.033*	19	0.111*
Year × clone	56	0.010**	12	0.019	10	0.095*	40	0.004	72	0.015	19	0.040
Error	114	0.004	26	0.019	22	0.037	115	0.003	190	0.022	50	0.038
Repeatability	0.62 ± 0.06		0.14 ± 0.17		0.43 ± 0.16		0.28 ± 0.08		0.09 ± 0.06		0.30 ± 0.11	

[a] * $P \leq 0.05$, and ** $P \leq 0.01$.

TABLE 7. Spearman's rank correlation coefficients between smut resistance ratings assigned on a 1–9 scale to sugarcane clones in plant cane (PC) or first ratoon (FR) of experimental cultivar inoculation tests

Crop/year	PC/1987	PC/1988	FR/1987	FR/1988
PC/1986	0.34*[a]	0.41*	0.56**	0.59**
PC/1987		0.46**	0.33*	0.65**
PC/1988			0.49*	0.40*
FR/1987				0.39*

[a] ** $P \leq 0.01$, and * $P \leq 0.05$.

tal design, and interactions among these factors. Despite differences in these factors, results indicate that resistance to smut is a moderately heritable trait in the breeding populations in Barbados, Hawaii, and Louisiana. Variations in pathogenicity or virulence within the Louisiana population of *U. scitaminea* have not been observed.

The frequency of resistant offspring obtained from Hawaiian R × R, R × S, S × R, and S × S crosses averaged 60% (26). In contrast, only 26 and 29% of the offspring from all crosses were found to be resistant to smut in Louisiana in plant cane and first ratoon, respectively (8). It appears that, in the Louisiana sugarcane breeding population, a high frequency of resistant offspring may only be reliably obtained from R × R crosses.

Expected genetic gain calculations indicate that high selection intensity would be necessary to obtain a low smut infection percentage mean in the next generation. This is not feasible because breeding program parental selection considers many traits, some of equal or greater importance than smut resistance. However, by identifying susceptible clones and minimizing their use as parents, the proportion of smut-resistant offspring in the cultivar selection program can be increased.

Smut reactions of parents and offspring in the resistance heritability study were moderately to highly repeatable. Clone smut reactions between years were significantly affected by genotype and the genotype × environment interaction. Evidence of these effects is seen in the changes in infection levels of parent clones between plant cane and first ratoon which caused several cross types to change. Analysis of variance of smut infection percentages of individual parent clones indicated significant differences in five of 17 (29%) clones between plant cane and first ratoon (8). Significant differences were detected in one MS clone and four HS clones.

Smut reactions of experimental cultivars in inoculation tests also were moderately repeatable between crops within experiments and the same crop stage in different years. The analyses indicate that genotype, environment, and the genotype × environment interaction significantly affect clone smut reaction repeatability. Clone smut reactions between plant cane and first ratoon were apparently more repeatable than in Barbados, where clone smut reactions in plant cane and first ratoon were poorly correlated (24).

Repeatability of R, MS, and HS clone smut reactions varied in two experiments. However, the results suggest that smut reactions of R and HS clones are more repeatable than reactions of MS clones. As in the other experiments, repeatability was significantly affected by genotype, environment, and the genotype × environment interaction.

Smut resistance ratings are assigned to experimental cultivars in inoculation tests to attempt to minimize the effects of smut infection level variability between years. Ratings were significantly correlated between years and crop stages. However, the degree of correlation suggests that a mean of multiple ratings is needed to achieve accuracy.

Epidemiology studies indicated that environmental conditions affect smut infection and severity within and between seasons (5,12,13). The repeatability analyses suggest that sugarcane clone smut reactions in inoculated tests in Louisiana are influenced considerably by the environment. Clone smut infection levels in first ratoon are affected by environmental conditions over two seasons, and changes in infection levels between plant cane and first ratoon are affected by the level of infection occurring in plant cane (J. W. Hoy, *unpublished*). These results imply that plant cane smut infection data from multiple, annual inoculation tests are needed to accurately assess the smut susceptibility of sugarcane clones in Louisiana.

LITERATURE CITED

1. Allard, R. W. 1964. Principles of Plant Breeding. John Wiley & Sons, New York. 485 pp.
2. Antoine, R. 1961. Smut. Pages 326-354 in: Sugarcane Diseases of the World. Vol. 1. J. P. Martin, E. V. Abbott, and C. G. Hughes, eds. Elsevier Science Publishers B. V., Amsterdam. 542 pp.
3. Becker, W. A. 1984. Manual of Quantitative Genetics. 4th ed. Academic Enterprises, Pullman, WA. 190 pp.
4. Blackburn, F. 1984. Sugar-Cane. Longman Group Inc., New York. 414 pp.
5. Bock, K. R. 1964. Studies on sugar-cane smut (*Ustilago scitaminea*) in Kenya. Trans. Br. Mycol. Soc. 47:403-407.
6. Byther, R. S., and Wismer, C. A. 1971. New sugarcane disease reported in Hawaii. Sugarcane Pathol. Newsl. 7:18-21.
7. Casler, M. D. 1982. Genotype × environment interaction bias to parent-offspring regression heritability estimates. Crop Sci. 22:540-542.
8. Chao, C. P. 1988. Nature and heritability of resistance to sugarcane smut caused by *Ustilago scitaminea*. Ph.D. thesis. Louisiana State University, Baton Rouge. 101 pp.
9. Chao, C. P., and Hoy, J. W. 1987. Estimation of heritability of sugarcane smut resistance in Louisiana. (Abstr.) Phytopathology 77:1723.
10. Falconer, D. S. 1981. Introduction to Quantitative Genetics. 2nd ed. The Longman Press, London. 340 pp.
11. Grisham, M. P., and Breaux, R. D. 1987. Varietal smut ratings in sugarcane before and after mid-season ratooning and between replicated and nonreplicated tests. J. Am. Soc. Sugar Cane Technol. 7:65-68.
12. Hoy, J. W., and Grisham, M. P. 1988. Spread and increase of sugarcane smut in Louisiana. Phytopathology 78:1371-1376.
13. Hoy, J. W., Grisham, M. P., and Benda, G. T. A. 1987. Effect of Louisiana growing conditions on the overwintering of smut-infected sugarcane. Sugar Cane 3:11-15.
14. Kang, M. S. 1981. Clonal and individual repeatability of agronomic traits in sugarcane. J. Am. Soc. Sugar Cane Technol. 1:22-27.
15. Kang, M. S., Miller, J. D., and Tai, P. Y. P. 1983. Genetic and phenotypic path analysis and heritability in sugarcane. Crop Sci. 23:643-647.
16. Koike, H., Fontenot, D., Damann, K., and Schlub, R. 1981. Smut of sugarcane in Louisiana: A first report. Plant Dis. 65:1018.
17. Prasadarao, K. K., Sarma, M. N., Satyanarayana, Y., and Achutarama Rao, M. 1979. Assessment of sugarcane varietal reaction to smut—A new approach. Sugarcane Pathol. Newsl. 23:1-7.
18. SAS Institute, Inc. 1987. SAS/STAT Guide for Personal Computers. Version 6 ed. Cary, NC. 1028 pp.
19. Todd, E. H. 1978. Sugarcane smut in Florida. Sugar J. 41:23.
20. Villalon, B. 1982. Sugarcane smut (*Ustilago scitaminea* Syd.) in the lower Rio Grande valley of south Texas. Plant Dis. 66:65-66.
21. Vogel, K. P., Gorz, H. J., and Haskins, F. A. 1981. Heritability estimates for forage yield, in vitro dry matter digestability, crude protein, and heading date in indiangrass. Crop Sci. 21:35-38.
22. Walker, D. I. T. 1980. Heritability of smut resistance. Sugar Cane Breed. Newsl. 43:19-23.
23. Waller, J. M. 1969. Sugarcane smut (*Ustilago scitaminea*) in Kenya. I. Epidemiology. Trans. Br. Mycol. Soc. 52:139-151.
24. Whittle, A. M., and Walker, D. I. T. 1982. Interpretation of sugarcane smut susceptibility trials. Trop. Pest Manage. 28:228-237.
25. Wu, K. K., Heinz, D. J., and Hogarth, D. M. 1988. Association and heritability of sugarcane smut resistance to races A and B in Hawaii. Theor. Appl. Genet. 75:754-760.
26. Wu, K. K., Heinz, D. J., and Meyer, H. K. 1983. Heritability of sugarcane smut resistance and correlation between smut grade and yield components. Crop Sci. 23:54-56.
27. Wu, K. K., Ladd, S. L., Heinz, D. J., and Meyer, H. K. 1977. Combining ability analysis in sugarcane smut resistance. Sugar Cane Breed. Newsl. 39:59-62.