Quantitative Relationships Between Sweet Corn Yield and Common Rust, *Puccinia sorghi*

J. K. Pataky

Assistant professor, Department of Plant Pathology, University of Illinois, Urbana 61801.

Research supported by a grant from the University of Illinois Research Board and by the Illinois Agricultural Research Station, University of Illinois, Urbana 61801.

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I thank John Gantz, John Headrick, Suparyono, Jon Olson, Lauri Powers, and Jeff Ediger for technical support; Harris Moran Seed Co., Illinois Foundation Seeds, Inc., and Stokes Seed, Ltd., for seed; and Ciba-Geigy Corporation, Mobay Chemical Corporation, and Rohm and Haas Company for fungicides.

Accepted for publication 22 January 1987 (submitted for electronic processing).

ABSTRACT

Pataky, J. K. 1987. Quantitative relationships between sweet corn yield and common rust, *Puccinia sorghi*. Phytopathology 77:1066-1071.

The quantitative relationships between sweet corn yield and common rust (*Puccinia sorghi*) were studied for three hybrids, Florida Staysweet, Gold Cup, and Stylepak, in 1984, 1985, and 1986. Variation in sweet corn yield was best explained by regression models in which the independent variable was rust severity assessed approximately 1 wk before harvest. The effects of rust on primary and secondary ears varied by hybrid and environment partly due to the number of secondary ears produced by a hybrid in an environment. General models were derived over environments for total ear weight (Florida Staysweet and Stylepak) and for total number of marketable ears (Florida Staysweet and Gold Cup). These models estimated that yield reduction due to rust was 6% of the maximum total ear weight and 6.5% of the maximum total number of marketable ears for each 10% rust severity.

Additional key words: crop loss assessment, *Zea mays*.

Common leaf rust, caused by *Puccinia sorghi* Schw., can reduce corn (*Zea mays* L.) yields. The majority of yield loss estimates for common rust have compared yields from severely rusted plots to yields from relatively rust-free plots (2,4–6,8,11–13).

Various studies have compared the yields of genotypes that did or did not possess race-specific rust resistance (4,5,12). Hooker (4) observed a yield reduction of approximately 6% when rust severity was about 30% on the field corn hybrid B14 × Oh41 compared with no rust on B14A × Oh41, which possessed the Rp_1^d gene. When rust severity ranged from 50 to 75%, Russell (12) reported yield reductions that ranged from 15 to 24% when B14 was compared with B14A in hybrid combination with three susceptible testers, R168, Oh7K, and Oh41. Kim and Brewbaker (5) observed yield reductions that ranged from 6 to 75% and averaged 35% for comparisons among 10 pairs of doublecross hybrids that were genotypically similar except for the Rp_1^d gene.

The effects of common rust on yield also have been estimated by comparing fungicide protected and unprotected corn (2,6,7,9,11,13). Townsend (13) observed ear weight of sweet corn to be reduced by about 15% due to rust and northern corn leaf blight (*Exserohilum turcicum* (Pass.) Leonard & Suggs) in unsprayed plots. Martinez (6) reported yield losses of about 17% when rust severity was approximately 25–30% in unsprayed plots of the flint corn hybrid P465 × L256 as compared with rust severity of approximately 2% in plots sprayed with mancozeb. Mederick and Sackston (7) measured reductions of corn fodder weight of up to 50% in rust-inoculated plots compared with plots that were protected with zineb sprays. Paulus et al (9) observed ear weight reductions of about 7% in unsprayed plots of the sweet corn hybrid Silver Queen and plant height reductions of about 25% in unsprayed plots of the sweet corn hybrid Jubilee. Groth et al (2) estimated the effect of common rust on fresh weight yield of sweet corn by comparing mancozeb sprayed and unsprayed plots of 28 sweet corn hybrids that varied in partial rust resistance. Yield losses ranged from 0 to nearly 50% and generally were related to the level of partial rust resistance displayed by a genotype. For example, yield losses for a moderately rust resistant (Sugar Loaf), an intermediate (Jubilee), and a rust susceptible (Stylepak) hybrid were 18, 26, and 49%, respectively, in late-season plantings when rust was severe. The linear regression of percentage yield loss on rust index was significant, although not a particularly close fit. Consequently, Groth et al (2) concluded that a more precise estimation of the relationship between sweet corn yield and rust severity would require additional experimentation. In a preliminary report, Teng and Montgomery (14) found that response surface models were satisfactory for explaining yield loss in sweet corn as a function of rust severity and host growth stage. Randle et al (11) observed that common rust also affected sweet corn quality factors: ear length, ear diameter, percentage of moisture, and percentage of Brix, which is a measure of soluble solids in the kernel.

Severe epidemics of common rust have occurred on sweet corn in the midwestern United States in the past 10 yr. Rust has been extremely severe on several of the most popular sweet corn hybrids, especially hybrids with the shrunken-2 (sh_2) endosperm mutation for high levels of kernel sugars (8). Fungicides have been applied to these highly susceptible genotypes to control rust. Various levels of partial rust resistance also have been observed among commercial sweet corn hybrids (1,8). Fungicide sprays and partial resistance effectively reduce rust severity. However, to determine the level of disease control that optimizes economic returns on control investments, the quantitative relationships between sweet corn yield and rust severity must be defined more precisely. Therefore, the objective of this study was to more accurately determine the relationships between sweet corn yield and rust severity.

MATERIALS AND METHODS

The experiments were done at the Agronomy/Plant Pathology South Farm in Urbana, IL. Planting dates were 1 June 1984, 7 May 1985, and 5 May 1986. Each of three sweet corn hybrids, Gold Cup, Stylepak, and Florida Staysweet, were grown as separate experiments in each year. Gold Cup is a moderately rust resistant, midseason maturing hybrid primarily grown for fresh market. Stylepak is a rust susceptible, midseason hybrid primarily grown for processing. Florida Staysweet is a rust-susceptible, full-season hybrid grown primarily for fresh market, but it also can be grown for processing and carries the sh_2 gene for high levels of kernel sugar. Experimental units consisted of four-row plots about 3 m wide and 6 m long. Plant populations were about 57,400 per hectare.

Normal production practices were followed each year. Soil types were a Flannigan silt loam, a Drummer silty clay loam, and a Proctor silt loam for fields in which trials were done in 1984, 1985, and 1986, respectively. The 1984 and 1986 fields had been in alfalfa for 3 yr before these experiments. The 1985 field was in a corn-soybean rotation. Soil tests for all fields were done in the fall of 1984 and indicated pH of 6.4, 6.1, and 6.5; P_1 of 61, 68, and 120; and K of 284, 194, and 362, for the 1984, 1985, and 1986 fields, respectively. Fertilizer was applied in the fall of 1983 (0-295-278) and spring of 1984 (134-0-199) for the 1984 trial, in the spring of 1985 (94-0-180) for the 1985 trial, and in the spring of 1986 (198-0-0) for the 1986 trial.

Each experiment included six replicates of six treatments arranged in a randomized complete block experimental design. Treatments were designed to generate a range of rust severity levels. In 1984, all plants were inoculated on 15 June, except for the control. Plants in the control plots were sprayed five times with triadimefon (48 ml/ha) on 22 June; 6, 16, and 28 July; and 3 August. Plants in four inoculated treatments also were sprayed one, two, three, or four times with triadimefon beginning 6 July. In 1985, two treatments were inoculated two or four times on 12 and 16 June or on 30 May, and 12, 16, and 24 June, respectively; one treatment was not inoculated or sprayed; one treatment was sprayed four times with propiconazole 3.6 E (48 ml/ha) on 12 and 24 June and 5 and 18 July; and two treatments were sprayed four or six times with mancozeb (1.12 kg/ha) on 12 June and 1, 12 and 18 July or on 12 and 24 June and 1, 5, 12, and 18 July, respectively. In 1986, two treatments were inoculated two or four times on 24 June and 1 July or on 2, 16, and 24 June and 1 July, respectively; one treatment was not inoculated or sprayed; one treatment was sprayed two times with propiconazole on 23 June and 9 July; and two treatments were sprayed two or four times with mancozeb on 16 June and 1 July or on 16 and 23 June and 1 and 9 July, respectively. Inoculations were done using urediniospore suspensions of *P. sorghi* (approximately 3 g of urediniospores in 36 L of water and 5 ml of Tween 80) sprayed directly into plant whorls. Urediniospores were originally collected in 1983 from infected corn leaves at various locations in Illinois. Inoculum was increased in the greenhouse and field.

Disease assessments were made at 7–10-day intervals until harvest beginning 16 July 1984, 8 July 1985, and 3 July 1986. Rust severity was estimated by two evaluators as the relative percentage of the total leaf area infected using a modified Peterson scale (10). Measured with the "relative" Peterson scale, rust severity was 100% when 37% of the total leaf area was covered by uredinia. The two disease assessments were averaged at each rating date. Area under the disease progress curve (AUDPC) was determined from the first to last evaluation.

Primary and marketable secondary ears were harvested by hand at fresh market maturity (approximately 19 days after midsilk) from 20 plants in the middle two rows of each plot. Weight of husked ears from 20 plants, total number of marketable ears, and ear widths were measured in all 3 yr. Marketable ears were subjectively determined based on general fresh market standards. Marketable ears were well-filled to within 2 to 3 cm of the tip and relatively all the same size. Ear length, tip fill, and butt fill also were measured in 1984 and 1985. Percentage of Brix was measured using a hand-held refractometer in 1984 for eight subsamples from four ears in each plot. Harvest dates were 9 August 1984, 30 July 1985, and 21 July 1986 for Gold Cup; 14 August 1984, 1 August 1985, and 24 July 1986 for Stylepak; and 16 August 1984, 3 August 1985, and 28 July 1986 for Florida Staysweet.

Linear, quadratic, and cubic ordinary-least-squares regression models to predict yield as a function of disease were evaluated for all rust severity assessments and for AUDPC. *F*-statistics were examined to compare overall significance ($P < 0.05$) of models and significance of polynomial terms. Coefficients of determination (r^2) estimated the proportion of the variation in yield explained by disease assessment. Residuals were plotted on

TABLE 1. Means and ranges of rust severity approximately 1 wk before harvest, ear weight, and number of marketable ears for sweet corn hybrids evaluated in 1984, 1985, and 1986

Hybrid and year	Rust severity (%)		Ear weight (kg/ha × 1,000)[a]						Marketable ears (per ha × 1,000)					
			Total		Primary		Secondary		Total		Primary		Secondary	
	$\bar{x}$	range	$\bar{x}$	range	$\bar{x}$	range	$\bar{x}$	range	$\bar{x}$	range	$\bar{x}$	range	$\bar{x}$	range
Florida Staysweet														
1984	38	5–63	16.6	12.8–21.3	13.1	11.5–15.2	3.5	1.1–7.0	64.6	57.4–86.1	57.4	57.4–57.4	7.2	0–28.7
1985	27	7–55	15.1	11.5–20.1	13.1	11.2–14.6	1.9	0–5.7	62.0	48.8–83.2	54.1	45.9–57.4	7.9	0–25.8
1986	10	1–25	9.7	8.5–12.1	9.5	8.3–11.3	0.3	0–1.8	52.0	43.0–68.9	49.6	43.0–54.5	2.4	0–14.4
Gold Cup														
1984	39	20–60	16.0	12.8–19.1	10.4	9.6–11.1	5.7	2.0–8.7	81.7	62.2–105.2	57.4	57.4–57.4	24.3	4.8–47.8
1985	28	7–50	14.3	11.2–17.9	11.4	10.6–12.1	3.0	0.4–6.9	62.7	48.8–86.1	54.7	43.0–57.4	8.1	0–28.7
1986	5	1–20	12.6	10.1–14.3	11.3	10.1–12.0	1.3	0–3.0	61.6	48.8–74.6	54.1	45.9–57.4	7.6	0–17.2
Stylepak														
1984	40	24–68	16.2	12.6–20.0	13.3	11.3–15.0	2.9	1.3–5.6	58.0	57.4–67.0	57.4	57.4–57.4	6.4	3.2–9.6
1985	27	7–50	12.5	9.5–14.3	12.5	9.5–14.3	0	0–0	48.8	40.1–57.4	48.8	40.1–57.4	0	0–0
1986	5	1–17	14.1	12.2–16.0	14.1	12.2–16.0	0	0–0	52.9	45.9–57.4	52.9	45.9–57.4	0	0–0

[a] Ear weight and number of marketable ears based on plant populations of approximately 57,400 plants per hectare.

disease assessments to determine homogeneity of variance, linearity of the model, and occurrence of outliers.

For each trial, yields were converted to the percentage of the maximum yield of that trial. The intercept (b_0) of the regression equation of yield on disease assessment was considered the best estimate of maximum yield for individual trials. Percentage of maximum yield was then regressed on disease assessments for trials and hybrids.

RESULTS

Treatments were effective at achieving various levels of rust. Rust severity approximately 1 wk before harvest ranged from 5 to 68, 7 to 55, and 1 to 25% in 1984, 1985, and 1986, respectively (Table 1). Ranges and overall mean rust severity were about the same for all three hybrids within years although Gold Cup is more rust resistant than Stylepak and Florida Staysweet.

In general, yields were highest in 1984 (Table 1). Total ear weight averaged approximately 16,300, 14,000, and 12,100 kg/ha in 1984, 1985, and 1986, respectively. Total number of marketable ears averaged approximately 68,100, 57,800, and 55,500 in 1984, 1985, and 1986, respectively. The number of marketable secondary ears and secondary ear weight was greatest in 1984 and least in 1986. In each year, total number of marketable ears was greatest for Gold Cup and least for Stylepak because of greater production of marketable secondary ears for Gold Cup and few or no marketable secondary ears for Stylepak. Total ear weight was greatest for Florida Staysweet in 1984 and 1985, but least for this hybrid in 1986. In 1986, plots of Florida Staysweet were located next to an alfalfa (*Medicago sativa* L.) field, whereas plots of Gold Cup and Stylepak were bordered by sweet corn.

Variation in total yield and its components was best explained when the independent variable of regression models was rust severity measured approximately 1 wk before harvest. Rust severity at harvest and AUDPC models also adequately explained variation in yield (Table 2), but coefficients of determination, patterns of residuals, and similarity of models between years and hybrids were better for models that used rust assessments 1 wk before harvest. Models that used earlier rust assessments generally explained less of the variation in yield.

TABLE 2. Regression coefficients[a] and coefficients of determination for regressions of percent total ear weight on rust severity at harvest and area under disease progress curve (AUDPC) for sweet corn hybrids Florida Staysweet, Gold Cup, and Stylepak

	Severity at harvest			AUDPC		
Year and hybrid	b_1	b_2	r^2	b_1	b_2	r^2
Florida Staysweet						
1984	−0.60	···	0.72	−0.0255	0.00222	0.78
1985	−1.32	0.0117	0.70	−0.1446	0.00013	0.77
1986	−1.37	···	0.40	−0.1085	···	0.28
Gold Cup						
1984	−0.58	···	0.70	−0.0242	···	0.74
1985	−0.60	···	0.58	−0.0318	···	0.55
1986	···	···	ns	···	···	ns
Stylepak						
1984	−0.65	···	0.50	−0.0242	···	0.71
1985	−0.42	···	0.56	−0.0451	···	0.54
1986	−0.79	···	0.30	−0.0591	···	0.29

[a] Intercept coefficients (b_0) were statistically within 100% for all regressions.

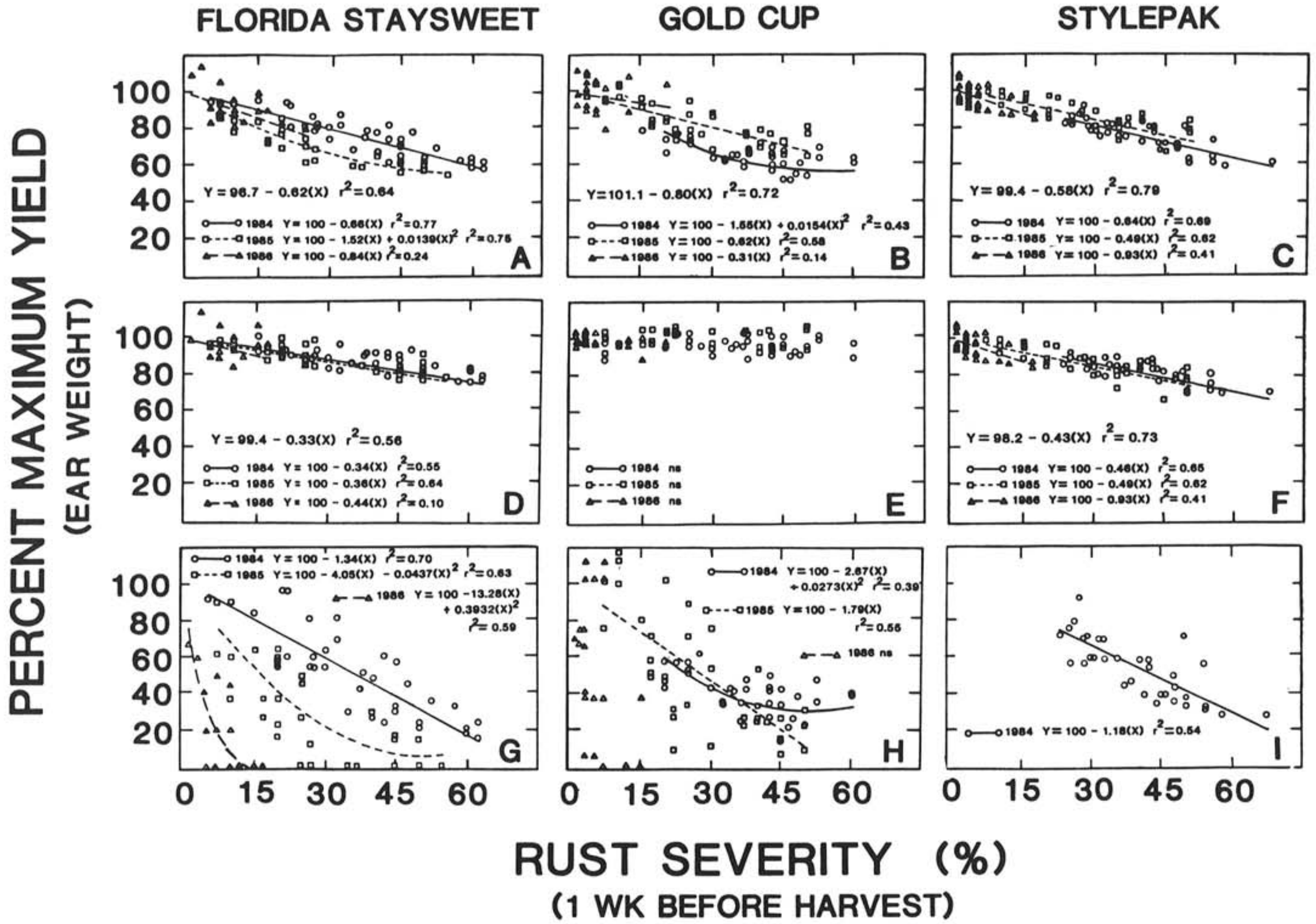

Fig. 1. Regressions of percent maximum sweet corn ear weight on rust severity 1 wk before harvest for the hybrids Florida Staysweet, Gold Cup, and Stylepak evaluated in 1984, 1985, and 1986: **A–C,** Total ear weight; **D–F,** Primary ear weight; and **G–I,** Secondary ear weight. Equations in larger type are for regressions over all years.

Ear weight decreased as a function of rust severity 1 wk before harvest (Figs. 1 and 2). Rust decreased the weight of primary ears of Florida Staysweet and Stylepak but had no effect on primary ear weight of Gold Cup (Fig. 1D–F). For all three hybrids, the effect of rust on primary ear weight was similar in each year. Rust decreased the weight of marketable secondary ears for all three hybrids (Fig. 1G–I); however, the effect of rust on secondary ear weight differed among years. Total ear weight response to rust severity was similar between years for Stylepak and relatively similar between years for Florida Staysweet (Fig. 1A and C).

A single model derived from data for Stylepak and Florida Staysweet in all 3 yr indicated that the total ear weight was reduced approximately 6% for each 10% rust severity 1 wk before harvest (Fig. 2). For Gold Cup, the negative yield-rust relationship based on total ear weight was linear like that of the Stylepak–Florida Staysweet model, but the effect of rust was greater on Gold Cup when data were analyzed over years ($b_1 = -0.80$). Therefore, because rust did not affect primary ear weight of Gold Cup, because the effect of rust on total ear weight was more severe on Gold Cup, and because Gold Cup is almost entirely grown for fresh market, the data for Gold Cup were not included in the combined analysis of yield based on ear weight.

The number of marketable ears decreased as a function of rust severity 1 wk before harvest (Figs. 3 and 4). Rust did not affect the number of marketable primary ears of Gold Cup in any year, of Florida Staysweet in 1984 and 1986, or of Stylepak in 1986 (Fig. 3D–F). However, the number of marketable secondary ears was decreased by rust for Florida Staysweet and Gold Cup (Fig. 3G and H). Generally, this was due to poor kernel fill on one side or on the tip end of an ear. Thus, for Gold Cup and Florida Staysweet, the effect of rust on total number of marketable ears was principally due to the effect of rust on secondary ears. In contrast, Stylepak produced few secondary ears and rust affected the number of marketable primary ears (Fig. 3F). Although the effect of rust on marketable secondary ears varied among years for Florida Staysweet and Gold Cup (Fig. 3G and H), the number of marketable secondary ears also differed between years (Table 1), so that the effect of rust on the total number of marketable ears was similar between years for Gold Cup and relatively similar between years for Florida Staysweet (Fig. 3A and B).

A single model derived from data for Florida Staysweet and Gold Cup in all 3 yr indicated that the total number of marketable

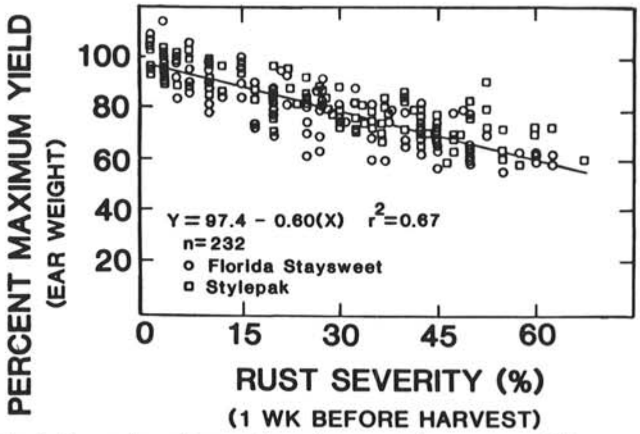

Fig. 2. Regression of percent maximum sweet corn ear weight on rust severity 1 wk before harvest for combined data of Florida Staysweet and Stylepak evaluated in 1984, 1985, and 1986 field trials.

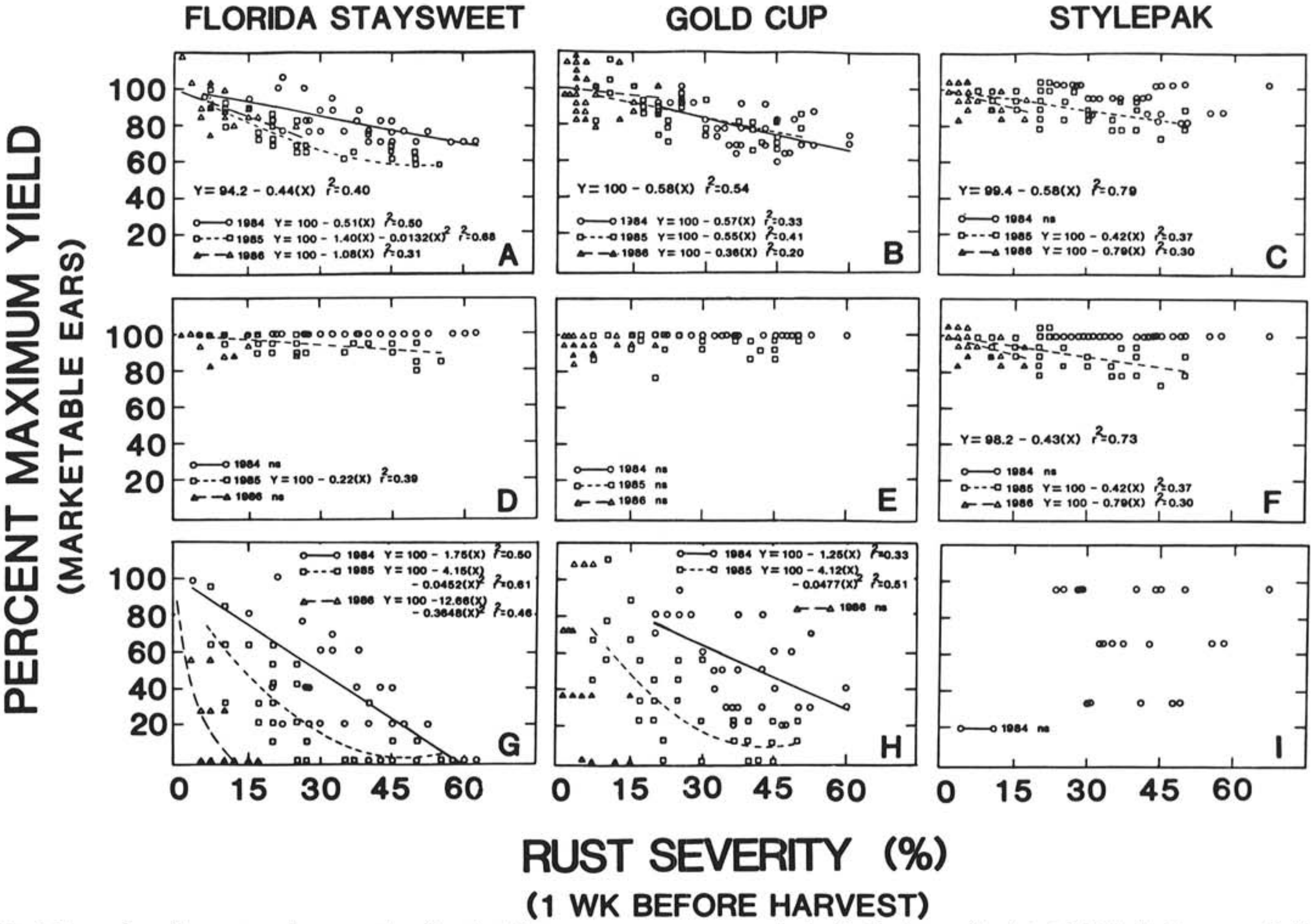

Fig. 3. Regressions of percent maximum number of marketable sweet corn ears on rust severity 1 wk before harvest for the hybrids Florida Staysweet, Gold Cup, and Stylepak evaluated in 1984, 1985, and 1986: **A–C**, Total marketable ears; **D–F**, Marketable primary ears; and **G–I**, Marketable secondary ears. Equations in larger type are for regressions over all years.

ears was reduced approximately 6.5 for each 10% rust severity 1 wk before harvest (Fig. 4). For Stylepak, the yield-rust relationship based on marketable ears was similar ($b_1 = -0.58$), but data for Stylepak were not included in the combined analysis because very few secondary ears were produced on this hybrid, and Stylepak is usually not grown for fresh market.

Tip fill, butt fill, and percent Brix of marketable ears were not affected by rust although number of marketable ears was reduced by poor fill. Ear diameter and ear length were reduced slightly by rust for all three hybrids although variation in ear diameter and length was not explained well by regressions on rust severity ($r^2 < 0.35$).

DISCUSSION

The quantitative relationships between sweet corn yield and common leaf rust were best explained by regression models in which the independent variable was rust severity assessed approximately 1 wk before harvest.

The responses to rust varied by hybrid and by environment. For example, rust did not affect primary ear weight or number of marketable primary ears of Gold Cup, but there was an effect of rust on primary ears of Stylepak, a hybrid that produced few or no secondary ears. Similarly, the effect of rust on secondary ears of Florida Staysweet and Gold Cup varied among years partly because secondary ear production varied among years. Thus, general models of yield-rust relationships (rust damage functions) may not accurately estimate primary and secondary ear yields of specific hybrids and environments. Groth et al (2) made similar conclusions based on the poor fit of regressions of percent yield loss on rust index for 28 sweet corn hybrids. They suggested that yield loss-rust relationships may not be applicable to hybrids not included in the study from which the relationships are derived. In our study however, while there was considerable variation in the effect of rust on primary and secondary ears, models describing the effects of rust on percent maximum total ear weight and percent maximum total number of marketable ears were similar. Differences in slope coefficients (b_1) for individual hybrids and years were largely due to the range of rust severity over which yields were evaluated. For example, slope coefficients were most varied and coefficients of determination were lowest in 1986 when the range of rust severity was relatively small. Thus, random variation accounted for a greater amount of the total variation (lower r^2) and slope coefficients were less stable. However, the plots of data for total ear weight and total number of ears did not differ greatly among years, and, thus, general models were derived.

In the absence of individual models for specific hybrids and environments, a general model gave the best available estimate of damage due to rust. For hybrids that are usually grown for fresh market and for which yield is measured by the number of marketable ears, the best estimate of yield reduction due to rust was approximately 6.5% for each 10% rust severity. For hybrids that are grown for processing and for which yield is measured by ear weight, the best estimate of yield reduction due to rust was approximately 6% for each 10% rust severity.

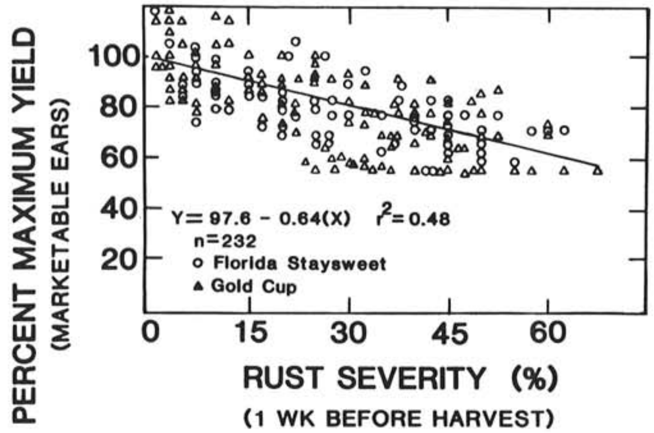

Fig. 4. Regression of percent maximum number of marketable sweet corn ears on rust severity 1 wk before harvest for combined data of Florida Staysweet and Gold Cup evaluated in 1984, 1985, and 1986 field trials.

The effect of rust on primary and secondary ears was hybrid dependent. For fresh market hybrids that may produce two ears per plant, the effect of rust was primarily on the secondary ear as previously observed by Groth et al (2). Rust had very little effect on the number of marketable primary ears of Florida Staysweet and Gold Cup, even though primary ear weight of Florida Staysweet was reduced by rust. Thus, under severe rust epidemics, primary ears of Florida Staysweet would be smaller but usually would be marketable, whereas primary ears of Gold Cup would not be affected by rust. Also, the relationship between percent total number of marketable ears and rust severity was consistent over environments for Gold Cup, but rust had a slightly greater effect on the percentage of total number of marketable ears of Florida Staysweet in 1985 and 1986 when yields were lower. It would, however, be premature to infer from this data that rust always has a greater effect on yield under low yield environments. Likewise, it would be premature to infer that yields and rust severity are highest under similar environments although both were highest in 1984. In 1984, all plants except controls were inoculated, whereas in 1985 and 1986 only plants in two treatments were inoculated. For this same reason, comparison of fungicidal controls between years is not appropriate.

For hybrids grown for processing, the effect of rust on ear weight may result from reductions of primary and secondary ear weights. Although the effect of rust on primary ear weight was slightly greater for Stylepak than for Florida Staysweet, the effect of rust on total ear weight was about the same.

Rust damage functions can be used to improve disease management decisions. For example, when rust is particularly severe in late-season *sh*$_2$ sweet corn crops, the economic benefit of multiple fungicide applications that are used to reduce rust severity (9) can be evaluated by determining the reduction in rust severity that results from fungicide applications and by using rust damage functions to convert differences in rust severity to differences in percent yield. Similarly, the value of planting a partially rust-resistant hybrid can be evaluated by converting the difference in rust severity among resistant and susceptible hybrids to percent yield. Data are available for these analyses for over 100 commercial sweet corn hybrids for which rust severity near harvest has been assessed under severe epidemics initiated by inoculations (8). Likewise, the value of adult plant resistance that retards rust development as plants age (3) and the value of incorporating an *Rp* gene for rust resistance into highly susceptible hybrids could be evaluated in a similar manner.

As additional studies of sweet corn rust generate more data, the functions derived from this study can be improved and validated. In particular, data on the effects of high- and low-yield environments with respect to the effects of rust on secondary ears, and data for other one- and two-eared hybrids are needed. Until these data are collected and models are developed for specific genotypes and environments, the best estimates of the effects of rust on sweet corn yield are the regression models derived from this study.

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