Yield Losses in Winter Barley Resulting from a New Race of *Puccinia hordei* in North America

C. A. GRIFFEY, Assistant Professor, and M. K. DAS, Research Associate, Department of Crop and Soil Environmental Sciences, Virginia Polytechnic Institute and State University, Blacksburg 24061; and R. E. BALDWIN, Plant Pathologist, and C. M. WALDENMAIER, Research Specialist, Eastern Shore Agricultural Experiment Station, Painter, VA 23420

ABSTRACT

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Leaf rust resistance, derived from the barley cultivar Cebada Capa, has been effective in the southeastern United States since 1950, when it was first used in the Virginia barley breeding program. In 1990, races of *Puccinia hordei* virulent to barleys that possess the resistance gene *Rph7* were identified for the first time in North America. This research assessed the potential impact of *Rph7*-virulent races of leaf rust on grain yield and quality in winter barley. Natural epidemics of leaf rust occurred in cultivar trials at Painter and Warsaw, Virginia, in 1991 and 1992. Mean leaf rust severities for barley lines observed over three environments ranged from 10% for the moderately resistant line VA 90-42-45 to 76% for the susceptible cultivar Barsoy. Significant negative correlations between grain yield and leaf rust severity were obtained for three of the four environments. Based on regression analysis over barley genotypes, an average grain yield loss of 0.42% (31.3 kg/ha) for each 1% increment of leaf rust severity on the upper two leaves at the early dough stage of plant development was determined. The susceptible cultivar Barsoy had an average yield loss of 32%, while the average loss for all genotypes was between 6 and 16%. Test weights were reduced by an average of 4.3 kg/hl at Painter in 1991 and 10.5 kg/hl at Warsaw in 1992. Whereas in the past 40 years, barley leaf rust was of little economic importance, it may become a disease of greater importance in regards to losses in grain yield and quality.

Leaf rust, caused by *Puccinia hordei* G. Otth, is widespread geographically but was not considered an economically important disease of barley (*Hordeum vulgare* L.) until the 1970s (2). Prior to the release of James barley (CI 10659) in 1961, most commercial barley cultivars were susceptible to leaf rust, and epidemics frequently occurred in the southeastern United States during the two decades preceding 1960 (C. W. Roane, *personal communication*). Clifford (2) cited reports of yield losses due to leaf rust as high as 31% in nontreated vs. fungicide-treated barley plots (8), and losses ranged from 10 to 20% in commercial fields. Yield losses as high as 40% have been reported by Jenkins et al (4) and Teng (15). Lim and Gaunt (6) studied the effects of powdery mildew and leaf rust on grain yields of barley and concluded that these diseases can cause significant losses. While leaf rust has not caused severe losses in barley over a widespread area or on a yearly basis, it is a potentially damaging disease, particularly in temperate regions (2).

Several methods and models have been used to estimate grain yield loss based on disease severity assessments (1). For each 1% increment of barley leaf rust assessed on the flag leaf at growth stage (GS) 75 (17), a potential yield loss of 0.60% (5) to 0.77% (8) was predicted. Similarly, for each 1% increment of leaf rust on the penultimate leaf or on whole plants, corresponding yield losses of 0.40% (5) and 0.60% (16), respectively, were predicted.

Leaf rust resistance in the cultivar Cebada Capa (CI 6193) is governed by a single dominant gene *Rph7* (9,11). In addition, three to four minor genes that confer a longer latent period also have been identified in this cultivar (10). Cebada Capa has been one of the most effective sources of resistance worldwide (2). Cebada Capa was first used in the Virginia barley breeding program in the early 1950s and has been the primary source of leaf rust resistance since that time. The cultivar Hanover (CI 13197), released in 1968, was the first Virginia barley with leaf rust resistance derived from Cebada Capa (13). Subsequently, all cultivars released in Virginia except one have leaf rust resistance derived from Cebada Capa (C. W. Roane, *personal communication*).

Isolates of *P. hordei* that could overcome the resistance conferred by *Rph7* were identified in North America for the first time in 1990 (12,14). Since then, such isolates have been identified in rust collections from California, Pennsylvania, and Virginia. Natural epidemics of barley leaf rust occurred in breeding nurseries at several locations in Virginia and North Carolina in 1990 and 1991 (3). No commercial barley cultivar evaluated in Virginia was immune to *Rph7*-virulent races (Table 1). In 1990, barley leaf rust was found on volunteer barley plants near breeding nurseries at Blacksburg, Virginia, in November. The rust fungus overwintered, and the level of disease reached epidemic proportions prior to the heading stage of barley development. These nurseries were abandoned due to complete devastation of the crop. From observations made in Virginia during the past 3 yr, it is apparent that races of *P. hordei* with *Rph7* virulence can cause severe damage. The purpose of this study was to assess the impact of leaf rust races possessing virulence to *Rph7* on disease development, grain yield, and test weight in barley.

MATERIALS AND METHODS

Ten winter barley cultivars and 11 experimental lines from the Virginia barley breeding program were grown at Warsaw and Painter, Virginia, in 1990–91 and 1991–92. The soils at Warsaw and Painter are Suffolk fine-loamy, siliceous, thermic Typic Hapludults and Bojac coarse-loamy, mixed, thermic Typic Hapludults, respectively. Fertilizer (N-P-K) was applied at the time of land preparation using the recommended rates of 34-90-90 and 28-56-90 kg/ha at Warsaw in 1991 and 1992, respectively, and 28-56-56 and 28-0-56 kg/ha at Painter in 1991 and 1992, respectively. The barley genotypes were seeded at a rate of 130 kg/ha during late October. Additional nitrogen was applied to test plots at Warsaw in early March at rates of 95 and 101 kg/ha in 1991 and 1992, respectively. At Painter, additional nitrogen was applied in a split application in both years at a rate of 67 kg/ha in early March and 34 kg/ha in early April.

Experimental units (plots) were 2.78 m in length and comprised six rows at Warsaw and seven rows at Painter with a 0.18-m spacing between rows. The experiments were arranged in randomized complete blocks with four replications. In 1991, leaf rust severity was assessed in only two of the four replicates at Warsaw; subsequently, only data from these two replicates were used in analyses for this particular test.

The percentage of leaf area infected with leaf rust was assessed according to

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the scale of Melchers and Parker (7) in each plot at Warsaw and Painter between the late milk (GS 77) and soft dough (GS 85) stages of crop development. Average rust severity for each plot was based on disease ratings on the upper two leaves of five or more arbitrarily selected tillers per plot in all tests, except the 1992 Painter test, where average severity was based only on flag leaf assessments.

Plots were harvested at maturity with a small-plot combine. Grain yield, corrected to 13.5% moisture, and test weight were determined for each plot. Mean test weights obtained for cultivars grown in the absence of leaf rust at Holland, Virginia, in 1991 and 1992 and at Blackstone, Virginia, in 1992 are representative of test weights normally obtained for these cultivars, and were used as a standard for making comparisons. Analyses of variance were performed on grain yield, test weight, and leaf rust severity. Correlations of leaf rust severity with grain yield and with test weight were determined for each test. Yield loss was calculated as b_1/b_0 from regression equations of grain yield and leaf rust severity as described by King and Polley (5).

RESULTS

Natural epidemics of leaf rust developed in 1991 and 1992 at Warsaw and Painter as a result of infection by *P. hordei* isolates with virulence to *Rph7*. In 1991, leaf rust severities of 15 and 90% were observed on susceptible cultivars in the early to soft dough stages of development at Warsaw and Painter, respectively. Leaf rust severities as high as 15% were observed on susceptible cultivars in the late boot stage at Warsaw in 1992, and severities of 50% were observed on cultivars in the soft dough stage at Painter in 1992.

Analyses of variance for the tests at Painter and Warsaw showed significant ($P \leq 0.01$) differences among cultivars for grain yield, test weight, and leaf rust severity in both years. Significant ($P \leq 0.01$) negative correlations between grain yield and leaf rust severity were observed for Warsaw in 1992 and for Painter in both years; subsequently, data from these three environments were analyzed over environments. Cultivar effects and cultivar $\times$ environment interactions were significant for grain yield, test weight, and leaf rust severity over environments. Mean data for disease severity, grain yield, and test weight for the 21 barley genotypes evaluated over three environments are presented in Table 1. Pertinent data for each of the four individual environments are presented below.

Disease severity and yield loss in 1991. Leaf rust severity means among cultivars varied from 24% (5–90%) at Painter to 43% (2–90%) at Warsaw. Based on regression analyses, 15 and 31% (R^2 = coefficient of determination) of the variability in grain yield was attributed to leaf rust at Warsaw and Painter, respectively. A significant negative correlation between grain yield and leaf rust severity was observed at Painter (Fig. 1) but not at Warsaw. Yield loss calculated as b_1/b_0 from regression analysis over all barley genotypes was 0.40% (21.4 kg/ha) for each 1% increment of rust severity at GS 83 for Painter. Six barley lines had estimated yield losses lower than 5% (95–217 kg/ha), and Barsoy had a yield loss of 36% (1,229 kg/ha). Other diseases present in the 1991 tests included scald (*Rhynchosporium secalis* (Oudem.) J.J. Davis) at Painter and barley yellow dwarf and powdery mildew (*Blumeria graminis* DC. ex Mérat f. sp. *hordei* Em. Marchal) at Warsaw. Based on correlations, only powdery mildew had a significant effect on grain yield. Of the 21 barley genotypes evaluated, only Barsoy, Boone, and Mulligan are susceptible to powdery mildew. Therefore at Warsaw, some of the yield loss observed for these cultivars could be attributed to powdery mildew.

Disease severity and yield loss in 1992. At Warsaw, leaf rust severity for the upper two leaves ranged from 20 to 100%, and over cultivars averaged 79%. At Painter, rust severity for the flag leaf varied from 1 to 38%, and over cultivars averaged 11%. Significant ($P \leq 0.01$) negative correlations were observed between grain yield and leaf rust severity at both locations (Figs. 2 and 3). Based

Table 1. Leaf rust reaction type, field severity, grain yield, yield loss, and test weight for 21 winter barley genotypes evaluated in Virginia in 1991 and 1992[a]

	Leaf rust			Grain yield	Yield loss		Test weight[g] (kg/hl)	
	Seedling reaction[b]		Severity					
Genotype	Race 8[c]	Race 30[d]	(%)	(kg/ha)	kg/ha(%)[e]	kg/ha(%)[f]	Normal	Disease
Barsoy	S	S	76	4,497	1,500 (33)	1,445 (32)	67.6	63.5
VA 90-42-9	S	S	60	5,935	1,426 (24)	1,520 (26)	63.2	58.8
Sussex	S	S	54	5,805	426 (7)	1,333 (23)	64.3	59.2
Boone	MR	S	51	5,102	239 (5)	1,099 (22)	67.1	57.7
VA 90-42-47	R	MS	50	5,388	346 (6)	1,151 (21)	63.6	59.6
VA 90-42-14	R	S	48	6,069	467 (8)	1,243 (20)	65.7	61.7
VA 90-42-64	S	S	45	6,414	494 (8)	1,223 (19)	68.2	65.5
Wysor	R	MS	45	6,159	28 (1)	1,174 (19)	66.7	60.8
Mollybloom	S	S	43	5,662	0 (0)	1,020 (18)	66.2	59.9
VA 89-41-1	MS	S	42	6,311	269 (4)	1,126 (18)	66.2	62.4
Mulligan	MR	S	41	5,541	169 (3)	972 (18)	67.1	60.1
Pamunkey	MR	S	36	7,104	245 (3)	1,081 (15)	69.5	66.8
VA 90-41-10	R	S	35	6,593	263 (4)	966 (15)	65.0	61.7
VA 90-41-9	R	S	33	6,432	333 (5)	888 (14)	65.7	62.5
VA 90-42-26	R	S	31	6,661	306 (5)	870 (13)	64.9	62.0
VA 90-42-22	I	MS	30	6,750	91 (1)	858 (13)	64.9	62.0
Nomini	MR	MS	24	7,068	0 (0)	714 (10)	64.2	62.4
VA 90-41-14	MS	MS	20	6,916	274 (4)	579 (8)	66.5	65.5
Starling	I	I	16	6,773	0 (0)	459 (7)	65.1	61.2
Pennco	S	MS	13	6,240	0 (0)	348 (6)	64.0	61.1
VA 90-42-45	R	MR	10	6,580	730 (11)	283 (4)	65.2	61.3
Mean			38	6,190	362 (6)	969 (16)	65.8	61.7
LSD (0.05)			5	445			1.4	1.3

[a] Mean leaf rust severity, grain yield, and yield loss data over three environments.
[b] Seedling reaction: R = resistant, MR = moderately resistant, I = intermediate, MS = moderately susceptible, and S = susceptible.
[c] Race 8 virulence/avirulence formula: *Rph*1,4,8/*Rph*2,3,5,2+6,7,9,Triumph.
[d] Race 30 virulence/avirulence formula: *Rph*1,2,4,2+6,7,8/*Rph*3,5,9,Triumph.
[e] Yield loss estimated from regression equations for each genotype over three environments.
[f] Yield loss based on $Y = 7{,}386 - 31.3 \times$ regression equation over all genotypes.
[g] Normal = mean test weights over three environments in 1991 and 1992 in the absence of leaf rust, and disease = mean test weights of entries evaluated for leaf rust at Painter and Warsaw, Virginia, in 1991 and 1992.

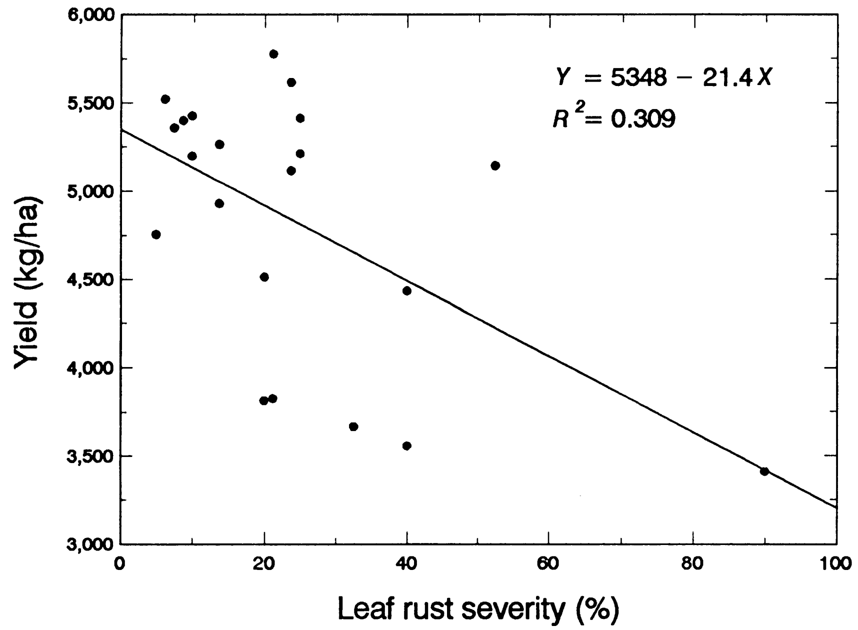

Fig. 1. Relationship between grain yield and leaf rust severity assessed at the early dough stage on the upper two leaves for 21 barley genotypes evaluated at Painter, Virginia, in 1991.

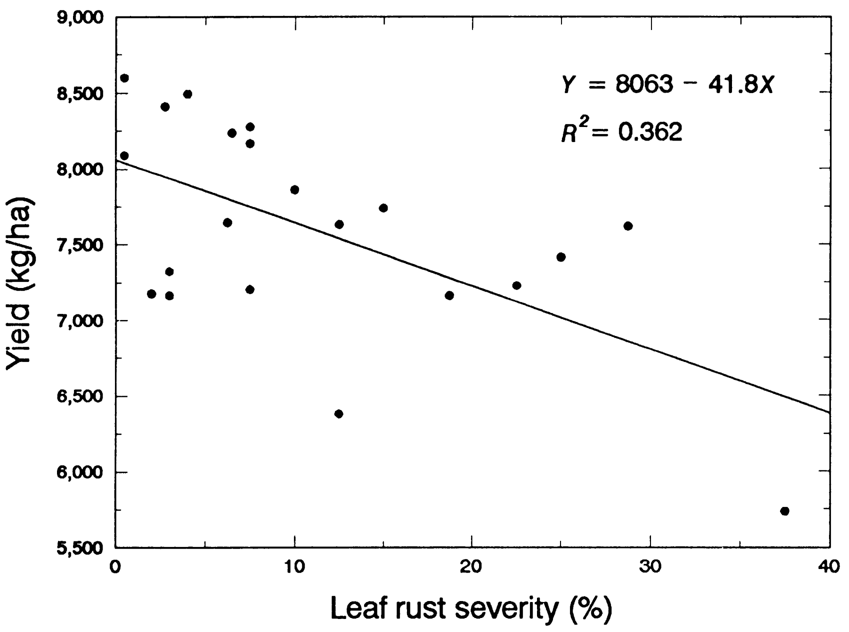

Fig. 2. Relationship between grain yield and leaf rust severity assessed at the early dough stage on flag leaves for 21 barley genotypes evaluated at Painter, Virginia, in 1992.

on R^2 values, 48% of the variability in grain yield at Warsaw and 36% at Painter were due to leaf rust. Yield losses of 0.27% (21.2 kg/ha) at Warsaw and 0.52% (41.8 kg/ha) at Painter for each 1% increment of rust severity at GS 83 were calculated as b_1/b_0 from regression analyses over all barley genotypes. Using these formulas, estimated yield losses at Warsaw varied from 5% (349 kg/ha) for experimental line VA 90-42-45 to 27% (1,175–1,685 kg/ha) for nine of the 21 lines evaluated. At Painter, the barley lines VA 90-42-45, VA 90-41-14, and Pennco had yield losses of 1% or less (21–74 kg/ha), and Barsoy had a 19% (1,115 kg/ha) yield loss. Other diseases present in the 1992 tests were Septoria leaf blotch (*Septoria passerinii* Sacc.) at Painter, and powdery mildew, barley yellow dwarf, and net blotch (*Pyrenophora teres* Drechs.) at Warsaw. Correlations between grain yield and severity data obtained for these diseases were significant only for powdery mildew.

Disease severity and yield loss over three environments. Leaf rust severity ranged from 10% for experimental line VA 90-42-45 to 76% for the cultivar Barsoy (Table 1). A significant ($P \leq 0.01$) correlation ($r = -0.76$) between grain yield and leaf rust severity was observed; thus, 58% of the variability in grain yield was explained by leaf rust (Fig. 4). A yield loss of 0.42% (31.3 kg/ha) for each 1% increment of leaf rust severity at GS 83 was calculated as b_1/b_0 from the regression analysis of all genotypes over three environments. This estimate of yield loss is based on the premise that the effect of leaf rust on yield is similar for all barley genotypes. Based on this assumption, five barley lines had yield losses of 10% or less, and the remaining genotypes had losses ranging from 13 to 32%. Yield loss also was calculated as b_1/b_0 from regression analyses for individual genotypes across the three environments. Based on these equations, 14 barley lines had yield losses of 5% or less, and the remaining lines had losses ranging from 6 to 33%. Estimated yield losses for VA 90-42-9 and Barsoy were 24 and 33%, respectively, while the remaining barley genotypes had losses ranging from 0 to 11%.

Disease severity and test weight. Negative but nonsignificant ($P \geq 0.05$) correlations between test weight and leaf rust severity were observed in all tests, where 0.4–15% of the variability in test weight was explained by leaf rust. In the 1992 tests, barley diseases accounted for approximately 10–15% of the variability in test weight.

Mean test weights among cultivars evaluated in three environments in the absence of leaf rust (normal) were 4.1 kg/hl higher than those obtained at Painter and Warsaw under rust epidemics in 1991 and 1992 (Table 1). Within cultivar, differences in test weight between normal and disease (leaf rust) environments varied from 1.5% for experimental line VA 90-41-14 to 14.0% for Boone barley. Test weights at Warsaw in 1992 were severely reduced, and the average test weight among cultivars was 55.3 kg/hl compared with a 66 kg/hl test weight mean at Blackstone, Holland, and Painter. Based on regression analyses, leaf rust and net blotch had an equal effect on test weight reductions at Warsaw in 1992. Leaf rust resulted in a considerable loss in test weight, even when considering that only half of the reduction observed in Table 1 was due to leaf rust infection.

DISCUSSION

Leaf rust epidemics and grain yield losses were most severe at Painter in 1991 and at Warsaw in 1992 primarily due to the establishment of rust on cultivars prior to growth stage 75. Calpouzos et al (1) reported that the magnitude of yield loss is directly related to the plant stage at which rust epidemics are initiated. Lim and Gaunt (6) found that leaf rust epidemics occurring after GS 75 had little effect on grain yield. This may partially explain the lack of significant correlation between rust severity and grain yield observed at Warsaw in 1991. Significant negative correlations between grain yield and leaf rust severity were obtained in three environments, where 31–48% of the variability in grain yield was explained by leaf rust. Udeogalanya and Clifford (16) found significant negative correlations between grain yield and leaf rust severity for each assessment taken on three dates between anthesis and the mid-milk stage (GS 75) of plant development. Likewise, Melville et al (8) reported that a significant relationship existed between grain yield and leaf rust severity at GS 75. Estimated yield losses based on regression equations from analyses over all barley genotypes ranged from 0.27% to 0.52% for each 1% increment of leaf rust severity at GS 83 for three of the four tests in the current study. These predicted yield losses were slightly lower than most of those reported by King and Polley (5), Melville et al (8), and Udeogalanya and Clifford (16). Variability among environments and in plant growth stages at which rust epidemics were initiated and disease severity assessed likely accounted for these differences.

Yield loss based on regression of leaf rust severity against yield over all genotypes may have overestimated yield loss of some genotypes, because this estimate is based on the premise that leaf rust has the same effect on all genotypes. Based on this supposition, yield losses ranged from 4 to 32%, with an average loss of 16% over three environments. When separate regression equations were calculated for each genotype over the three environments, an average yield loss of 6% was obtained. Predicted yield losses for the susceptible cultivar Barsoy and experimental line VA 90-42-9 were similar for both methods. Estimated yield losses attributed to leaf rust for Barsoy varied from 19 to 36%, with an average loss of 32% over tests. Lim and Gaunt (6), and Udeogalanya and Clifford (16) reported yield losses of 20% resulting from barley leaf rust. Pennco and Starling barley cultivars and experimental line VA 90-42-45 had the highest levels of field resistance to barley leaf rust in the current study.

While a significant negative correlation between leaf rust severity and test weight was not observed for any test, the data presented in Table 1 suggest that leaf rust caused a reduction in test weight. Consistent negative correlations between leaf rust severity and kernel weight were reported by Udeogalanya and Clifford (16). In studies by King and Polley (5), and Melville et al (8), reductions in grain weight were associated with leaf rust infection.

Few commercial barley cultivars in North America possess a satisfactory level of resistance to races of leaf rust with virulence to *Rph7*. In many cases, two or more fungicide applications are needed for effective control of leaf rust (8,16). Since the average price of feed barley in Virginia over the past 5 yr was $85 per tonne, economical application of commercial fungicides to control barley leaf rust would probably be limited to a single application (8). Therefore, until resistant barley cultivars are available commercially, barley leaf rust is likely to be a serious source of loss in grain yield and quality.

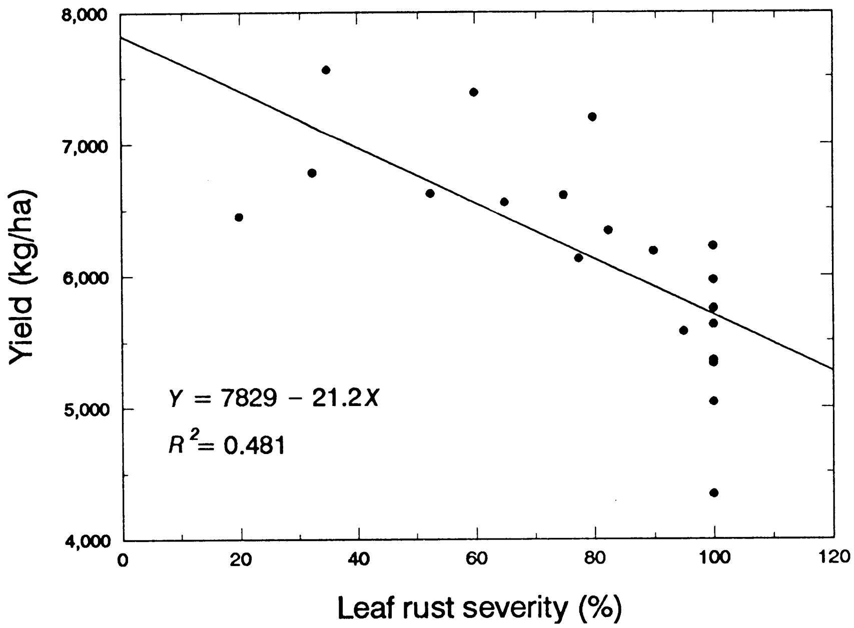

Fig. 3. Relationship between grain yield and leaf rust severity assessed at the early dough stage on the upper two leaves for 21 barley genotypes evaluated at Warsaw, Virginia, in 1992.

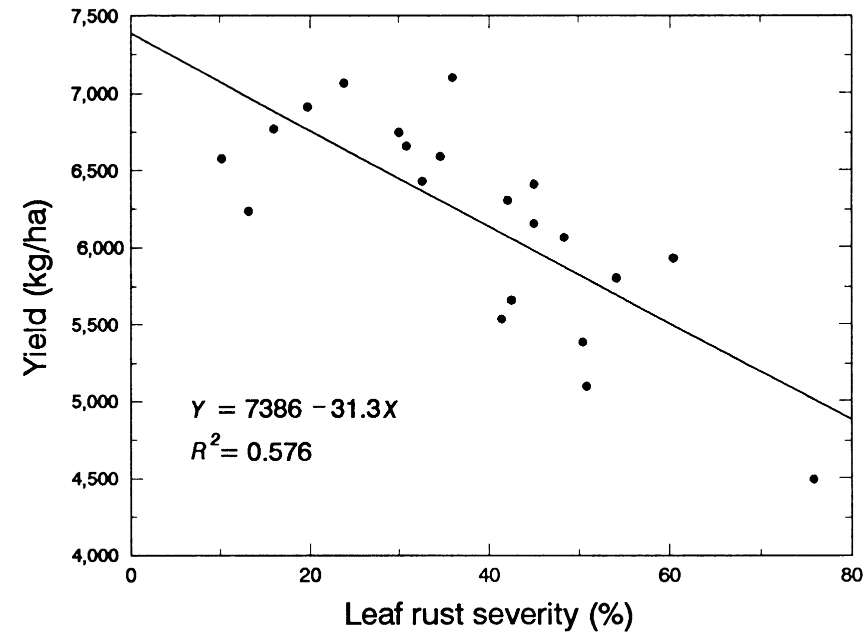

Fig. 4. Relationship between grain yield and leaf rust severity assessed at the early dough stage on the upper two leaves for 21 barley genotypes evaluated over three environments in Virginia.

LITERATURE CITED

1. Calpouzos, L., Roelfs, A. P., Madson, M. E., Martin, F. B., Welsh, J. R., and Wilcoxson, R. D. 1976. A new model to measure yield losses caused by stem rust in spring wheat. Univ. Minn. Agric. Exp. Stn. Tech. Bull. 307.
2. Clifford, B. C. 1985. Barley leaf rust. Pages 173-205 in: The Cereal Rusts. Vol. II, Diseases, Distribution, Epidemiology, and Control. A. P. Roelfs and W. R. Bushnell, eds. Academic Press, New York.
3. Griffey, C., and Price, A. 1991. Barley leaf rust epidemics in Virginia. Pages 98-99 in: Barley Newsletter 35. K. W. May, ed. American Malting Barley Association, Milwaukee, WI.
4. Jenkins, J. E. E., Melville, S. C., and Jemmett, J. L. 1972. The effect of fungicides on leaf diseases and on yield in spring barley in south-west England. Plant Pathol. 21:49-58.
5. King, J. E., and Polley, R. W. 1976. Observations on the epidemiology and effect on grain yield of brown rust in spring barley. Plant Pathol. 25:63-73.
6. Lim, L. G., and Gaunt, R. E. 1986. The effect of powdery mildew (*Erysiphe graminis* f. sp. *hordei*) and leaf rust (*Puccinia hordei*) on spring barley in New Zealand. I. Epidemic development, green leaf area and yield. Plant Pathol. 35:44-53.
7. Melchers, L. E., and Parker, J. H. 1922. Rust resistance in winter wheat varieties. U.S. Dep. Agric. Bull. 1046.

8. Melville, S. C., Griffin, G. W., and Jemmett, J. L. 1976. Effects of fungicide spraying on brown rust and yield in spring barley. Plant Pathol. 25:99-107.
9. Nover, I., and Lehmann, C. O. 1974. Resistenzeigenschaften im Gerstenund Weizensortiment Gatersleben 18. Prufung von Sommergersten auf ihr Verhalten gegen Zwergrost (*Puccinia hordei* Otth). Kulturpflanze 22:25-43.
10. Parlevliet, J. E., and Kuiper, H. J. 1977. Resistance of some barley cultivars to leaf rust, *Puccinia hordei*; polygenic, partial resistance hidden by monogenic, hypersensitivity. Neth. J. Plant Pathol. 83:85-89.
11. Roane, C. W., and Starling, T. M. 1970. Inheritance of reaction to *Puccinia hordei* in barley. III. Genes in the cultivars Cebada Capa and Franger. Phytopathology 60:788-790.
12. Roelfs, A. P., Long, D. L., Steffenson, B. J., Jin, Y., Hughes, M. E., and Casper, D. H. 1990. Barley rusts in the United States in 1990. Pages 73-74 in: Barley Newsletter 34. R. D. Horsley, ed. American Malting Barley Association, Milwaukee, WI.
13. Starling, T. M., Roane, C. W., and Camper, H. M. 1970. Registration of Hanover barley. Crop Sci. 10:456.
14. Steffenson, B. J., Jin, Y., and Griffey, C. A. 1993. Pathotypes of *Puccinia hordei* with virulence for the barley leaf rust resistance gene *Rph7* in the United States. Plant Dis. 77:867-869.
15. Teng, P. S. 1978. System modelling in plant disease management. Ph.D. thesis. Lincoln College, New Zealand.
16. Udeogalanya, A. C. C., and Clifford, B. C. 1982. Control of barley brown rust, *Puccinia hordei* Otth, by benodanil and oxycarboxin in the field and the effects on yield. Crop Prot. 1:299-308.
17. Zadoks, J. C., Chang, T. T., and Konzak, C. F. 1974. A decimal code for the growth stages of cereals. Weed Res. 14:415-421.