Effects of *Pyrenophora teres* and Weeds on Barley Yield and Yield Components

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ABSTRACT

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Combinations of location and fungicide treatments were used to create epidemics of *P. teres* that had common onset times yet differed in area under the disease progress curve (AUDPC). Regression analysis showed that yield was inversely related to AUDPC when AUDPC ranged from 0.1 to 28.4. When yield decreased with AUDPC so did number of ears and kernel weight. Most of the variation in number of ears and kernel weight was explained by AUDPC and AUWGC (area under weed growth curve) for the growth intervals tillering to booting and tillering to mid-anthesis, respectively. Exponential curves with lower asymptotes at 70 g and 20 ears best expressed the relationships between yield and AUDPC and between number of ears and AUDPC, respectively, while grain weight was a linear function of AUDPC. Weeds also affected yield by reducing number of ears and kernel weight.

Barley (*Hordeum vulgare* L.) is the predominant cereal grown in Morocco and occupies about 2 million hectares (13). Net blotch, caused by *Pyrenophora teres* Drechs., is the most prevalent disease, but its impact on yield and yield components is not well documented for dry, Mediterranean climates like that of Morocco. In temperate, humid regions, however, *P. teres* is known to reduce barley yields in experimental plots by 9–37% (4–6,11,12,15), primarily by reducing grains per ear (6,12) and kernel weight (2,5,6,15).

Net blotch is a major limiting factor to winter barley production in Great Britain, where the climate is favorable for disease development (7). Morocco, however, has a relatively dry climate and net blotch has been considered unimportant; therefore, selection for resistance has not had high priority. However, between emergence and anthesis, the disease often is severe on lower leaves, most of which senesce before selection. Flag and penultimate leaves often have little disease; consequently, susceptible lines are often retained in the breeding program, thus perpetuating susceptibility in Moroccan barleys. Grain number/ear and kernel weight are determined during shoot elongation to milk (31–73) and milk to hard dough (73–87) growth stages, respectively (18). Therefore, selection for resistance after anthesis is reasonable if yield loss is due primarily to reductions in grain number and weight and if those components are affected by disease during grain formation.

Weeds also are a common pest in Moroccan barley fields. Weeds reduce numbers of tillers and yield as a function of species density (3) and the time of weed emergence in relation to crop emergence (10). However, the effect of weeds on Moroccan barley culture is complicated by their nutritional and sociological roles. In rural areas, cereal fields are used as a source of certain weed species (primarily members of the families Gramineae and Papilionaceae) to supplement livestock diets. Consequently, some weeds are perceived as useful even though they may limit barley yields.

This study was prompted by the observation that *P. teres* is ubiquitous in Moroccan barleys, particularly from emergence to anthesis and by the knowledge that in selection for resistance, early infection has not been considered as a criterion for rejection. Also, early weed infestations are permitted to remain in competition with barley, often until anthesis, when they are harvested for livestock feed. Therefore, the purpose of this study was to examine the effects of *P. teres* and weeds on barley yield and yield components in a rainfed Mediterranean environment. Results would either support the management practices currently given to these pests or provide evidence for increased awareness and more timely attention to crop management.

MATERIALS AND METHODS

Thirty plots of the susceptible two-row barley Brasserie Maroc were planted at El Koudia and Merchouch in 1983. Plots were drilled (20-cm row spacing) at 110 kg/ha and fertilized at seeding with 40 kg/ha of nitrogen as ammonium sulfate. The treatment design consisted of a split plot arrangement with two weed treatments (subplots) and five fungicide treatments (whole plots) in a randomized complete block design with three replications per location. Each subplot was 5 × 5 m and separated by 5 m of wheat plus 4 m of bare ground. Subplots designated W1 were unweeded, while those designated W2 were hand-weeded twice when barley was at tillering and at heading. Epidemics developed from natural infection and were modified by fungicide treatments to obtain different areas under the disease progress curve (AUDPC). Whole plots, designated D1, were untreated with fungicides. Those designated D2 were treated with thiophanate-methyl at 2.11 kg/ha and 1 kg/ha at the four-tiller and stem elongation growth stages, respectively. Whole plots D3 and D4 were treated with 3 kg/ha of thiophanate-methyl at the four-tiller growth stage and with 3 kg/ha of Propiconizole at the seven-tiller growth stage. Whole plots D5 were treated with 3 kg/ha of thiophanate-methyl at the four-tiller stage plus Propiconizole at 3 and 1 kg/ha at the seven-tiller and stem elongation stages, respectively.

Nine severity estimates based on the proportion of leaf area showing typical net symptoms were made visually at approximately weekly intervals from tillering (growth stage 23) to soft dough (growth stage 85) on 10 tillers per plot. Before weeding, all weed species were identified and from each subplot aboveground portions of all weeds were taken from 0.1-m^2 sites selected randomly on three occasions when barley was at tillering, heading, and dough growth stages. Weeds were oven dried at 90 C for 12 hr and then weighed. Dry weight of all weeds per sample was used as a measure of infestation and to calculate area under the weed growth curve (AUWGC).

Yield components were recorded as tiller numbers per 0.1 m^2 and number of ears per 0.1 m^2. Number of grains per ear and total spikelets per ear also were recorded from five randomly selected ears per plot. At maturity, 1 m^2 was harvested from each plot for grain yield per square meter and grain weight per 500 grains.

Areas under progress curves for *P. teres* (AUDPC) and for weed dry weight (AUWGC) were calculated according to the procedure of Shaner and Finney (14). Disease was expressed as a proportion (0–1) and weeds as gram weight. Time was expressed on the two-digit growth scale (0–99) of Zadoks et al (21). AUDPC was calculated for four growth intervals: tillering to booting (23–41), tillering to heading (23–50), tillering to mid-anthesis (23–65), and mid-anthesis to soft dough (65–85). Those intervals correspond to the growth stages when number of spikelets, number of tillers, number of ears and grains per ear, and grain weight are formed, respectively (18). AUWGC values were calculated for growth stage intervals stem elongation to mid-anthesis (30–65) and mid-anthesis to soft dough (65–85). Total area from tillering to soft dough (23–85) also was calculated for AUDPC, whereas the total area from stem elongation to soft dough (30–85) was calculated for AUWGC.

AUDPC and AUWGC for the intervals 23–85 and 30–85, respectively, were subjected to analysis of variance (ANOVA) to test for disease and weed treatment differences. Data from El Koudia and Merchouch were pooled and analyzed as a split-split plot with location as the main plot and AUDPC or AUWGC within disease treatments as subplots and AUDPC or AUWGC within weed treatments as sub-subplots.

Scatter diagrams of untransformed data pooled from both locations suggested a nonlinear relationship between AUDPC, AUWGC (independent variables), and certain yield components (dependent variables). Consequently, data from individual plots were fitted to exponential, second degree polynomial, and asymptotic curves with asymptote values obtained by iteration. As well, linear approximations were made to determine if they were adequate estimators of the functional XY relationship. The F test, the coefficient of determination (R^2), and the standard error of the estimate ($Sy.x$) were used to evaluate models.

RESULTS

Location effect on AUDPC. AUDPC treatment means from El Koudia and Merchouch ranged from 7.2 to 24.7 and from 0.3 to 7.1, respectively (Table 1). There were significant location and significant treatment differences, as well as a significant location × disease treatment interaction. There was no significant location × disease treatment × weed treatment interaction. With the exception of the difference between D3 and D5 treatment mean differences in AUDPC at El Koudia were significant ($p \leq 0.05$), while at Merchouch treatments D1 and D2 were different from D3, D4, and D5, but all other combinations of treatment differences were nonsignificant.

AUWGC treatment means from El Koudia and Merchouch were 202.8 (W1) and 34.6 (W2) and 73.3 (W1) and 25.6 (W2), respectively (Table 1), but means within a location were significantly different ($P \leq 0.05$) only at El Koudia. As with AUDPC, there was a significant location difference and a significant location × weed treatment interaction. The weed populations at El Koudia and Merchouch were composed of 14 species from nine families and of eight species from seven families, respectively (Table 2). Species belonging to the families Gramineae and Papilionaceae are used for forage so five of fourteen species and three of eight at El Koudia and Merchouch, respectively, would not be regarded as weeds by many Moroccan farmers.

AUDPC and AUWGC effects on yield. Regression analysis of data pooled from both locations ($N = 60$) showed that an asymptotic curve best expressed the relationship between AUDPC and yield (Fig. 1). AUDPC from subplots (values ranged from 0.1 to 28.4) explained 76% of the variation in yield (Table 3) when yield

TABLE 1. Mean areas under the *Pyrenophora teres* disease progress curve (AUDPC) and under the weed growth curve (AUWGC) for disease (D) and weed (W) treatments at El Koudia and Merchouch, Morocco, in 1983

	AUDPC[a]					AUWGC[b]	
Location	D1	D2	D3	D4	D5	W1	W2
El Koudia	24.7	21.4	8.3	11.7	7.2	202.8	34.6
Merchouch	6.5	7.1	1.5	1.6	0.3	73.3	25.6

[a] LSD 0.05 for differences in AUDPC at same location = 2.17.
[b] LSD 0.05 for differences in AUWGC at same location = 108.20.

TABLE 2. Weed species present (+) in plots at El Koudia and Merchouch, Morocco, in 1983

Family	Species	El Koudia	Merchouch
Caryophyllaceae	*Polycarpon tetraphyllum* L.	+	···
	Silene gallica L.	+	+
	Spergularia purpurea Pers.	+	···
Chenopodiaceae	*Chenopodium murale* L.	+	···
Compositae	*Chrysanthemum coronarium* L.	+	···
	Cichorium endivia L.	···	+
Cruciferae	*Diplotaxis catholica* (L.) Dc.	+	···
	Raphanus raphanistrum L.	+	···
Gramineae	*Avena sterilis* L.[a]	+	···
	Avena sterilis L. spp. *macrocarpa* (Moench.) Briq.	···	+
	Phalaris minor L.[a]	+	···
	Phalaris paradoxa L.[a]	···	+
	Lolium rigidium Gaud.[a]	+	···
Papilionaceae	*Medicago hispida* Gaertn[a]	+	···
	Trifolium isthmocarpum Brot.[a]	+	···
	Vicia sativa L.[a]	···	+
Papaveraceae	*Papaver hybridum* L.	+	···
Polygonaceae	*Emex spinosa* (L.) Campd.	+	···
Primulaceae	*Anagallis foemina* L.	···	+
Scrophulariaceae	*Antirrhinum orontium* L.	···	+
Umbelliferae	*Ridolfia segetum* Moris.	···	+

[a] Used as forage.

was transformed as $\ln(y - c)$ where y = grain weight per square meter and $c = 70$ (lower asymptote). Weeds explained 27% of the variation in yield, whereas AUDPC and AUWGC together accounted for 81% of the yield variability (Table 3). An F test of partial correlation coefficients (16) showed that AUWGC explained variation in yield not explained by AUDPC ($F = 46.33$ with 1 and 57 df).

AUDPC and AUWGC effects on tiller, spikelet, grain, and ear numbers. Number of tillers, number of spikelets per ear, and number of grains per ear were not significantly ($P \leq 0.05$) correlated with either AUDPC or with AUWGC. As with yield, an asymptotic curve best expressed the relationship between number of ears per 0.1 m^2 and AUDPC (Fig. 2). Together, the independent variables AUDPC calculated for the growth interval tillering to booting (23–41) and AUWGC calculated for the growth interval stem elongation to mid-anthesis (30–65) explained 51% (Table 3) of the variability in ear number when ear number was transformed as $\ln(y - c)$ where y = ear number per 0.1 m^2 and $c = 20$. An F test of partial correlation coefficients (16) showed that AUWGC explained variation in ear number not explained by AUDPC ($F = 34.78$ with 1 and 57 df). A reduction in grain weight also was associated with an increase in AUDPC for the growth interval

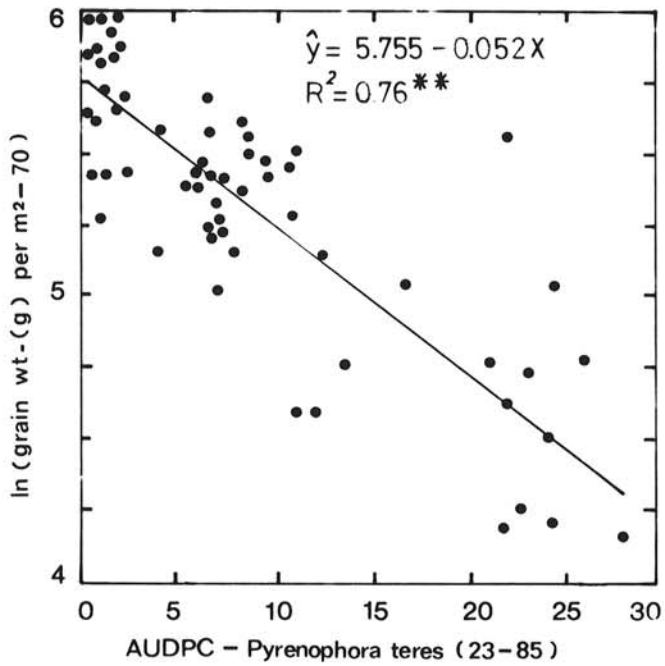

Fig. 1. Regression of ln(grain weight) on area under the disease progress curve from tillering (growth stage 23) to soft dough (growth stage 85) for *Pyrenophora teres* and grain weight of barley per square meter transformed as $\ln(y - c)$ where y = grain weight per square meter and $c = 70$ at El Koudia/Merchouch.

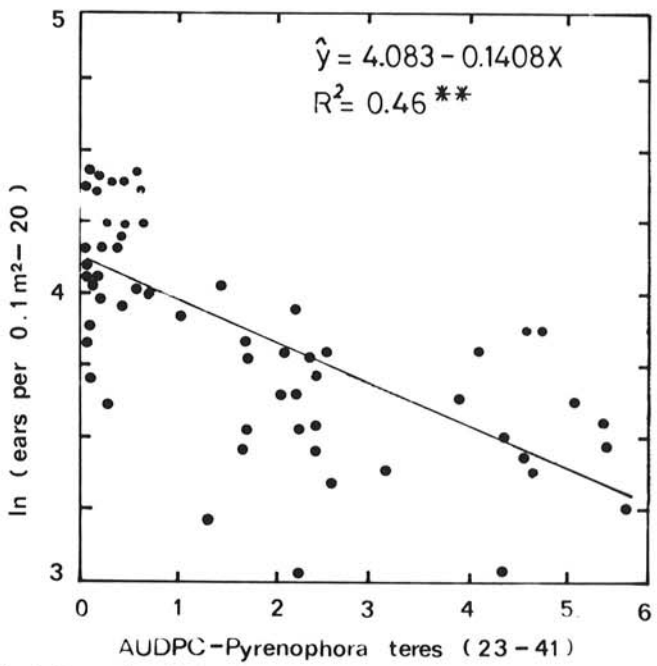

Fig. 2. Regression of ln(ears) on area under the disease progress curve from tillering (growth stage 23) to booting (growth stage 41) for *Pyrenophora teres* and number of barley ears per 0.1 m^2 transformed as $\ln(y - c)$ where y = number of barley ears per 0.1 m^2 and $c = 20$ at El Koudia/Merchouch.

TABLE 3. That portion of the progress curve for *Pyrenophora teres* and for weed growth that gave the largest F and R^2 and the smallest standard error of the estimate ($Sy.x$) when regressed on yield and on those yield components of barley significantly ($P \leq 0.05$) affected by disease and by weeds, Merchouch and El Koudia, Morocco, 1983

Dependent variable	Independent variables						
	N[a]	AUDPC[b]	AUWGC[c]	F (AUDPC)[d]	F (AUWGC)	$Sy.x$[e]	R^2[f]
Yield[g]	60	23-85	···	187.89	···	0.25	0.76
	60	···	30-85	···	21.80	0.41	0.27
	60	23-85	30-85	233.14	14.97	0.21	0.81
Number of ears[h]	60	23-41	···	49.06	···	0.27	0.46
	60	···	30-65	···	15.36	0.32	0.21
	60	23-41	30-65	53.08	5.76	0.26	0.51
Grain weight[i]	60	23-41	···	72.21	···	0.67	0.55
	60	···	30-65	···	10.46	0.93	0.15
	60	23-41	30-65	73.51	2.05	0.67	0.57

[a] Number of observations.
[b] Area under progress curve for *P. teres* calculated by method of Shaner and Finney (14), using disease proportion (0-1) and growth stage (1-99) according to Zadoks et al (21). 23-85 refers to AUDPC between tillering and soft dough and 23-41 is AUDPC between tillering and booting.
[c] Area under growth curves for weed dry weight in grams calculated as above. 30-85 is AUWGC between stem elongation and soft dough; 30-65 is AUWGC between stem elongation and mid-anthesis.
[d] F values from regression analysis used to test significance of regression coefficients.
[e] Standard error of estimate.
[f] Coefficient of determination.
[g] Yield in grams per square meter and transformed as $\ln(y - c)$ where y is grain weight and $c = 70$.
[h] Number of ears per 0.1 m^2 and transformed as $\ln(y - c)$ where y is number of ears and $c = 20$.
[i] Grams per 500 grains.

23–41 (Fig. 3). Linear regression explained 55% (Table 3) of the variability in grain weight, whereas AUDPC (23–41) with AUWGC (30–65) together accounted for 57% of the variation. Here, an F test (16) of partial correlation coefficients showed that the additional variation in grain weight explained by AUWGC was nonsignificant ($F = 1.51$ with 1 and 57 df). Ratios of standard, partial regression coefficients (independent of original units of measurement) for AUDPC/AUWGC were 3.32, 2.45, and 5.22 for yield, ear number, and grain weight, respectively. These ratios indicate that AUDPC was two to five times more useful than AUWGC in estimating yield components and, therefore, that *P. teres* was relatively more important than weeds in affecting yield.

DISCUSSION

Through combinations of location effects and fungicide treatments, we obtained epidemics of *P. teres* that differed in AUDPC, usually in a systematic manner (Table 1); nevertheless, there was considerable variation within treatments. Generally, AUDPC decreased as the dose and frequency of fungicide treatments increased. Neither thiophanate-methyl or Propiconizole applied to uninfected barley showed any phytotonic effects.

Weed treatments (W1 and W2) were designed to be superimposed on *P. teres* treatments to create a range of weed/disease combinations for regression analysis of AUDPC and AUWGC on yield and yield components. ANOVA of AUWGC showed that there were significant treatment differences only at El Koudia (Table 1), but marked differences in AUWGC at Merchouch served to expand the range of values used in regression.

Location differences for AUDPC and a significant location × AUDPC interaction were expected as El Koudia is near the Atlantic coast where rainfall is relatively greater and temperatures more favorable for *P. teres* than inland, where Merchouch is located.

According to our data, *P. teres* reduces yield in dryland environments (Fig. 1) primarily by reducing ear number (Fig. 2) and kernel weight (Fig. 3), and most of the variation in those yield components was explained by AUDPC and AUWGC for the growth intervals tillering to booting (23–41) and tillering to mid-anthesis (30–65), respectively. Commonly, in Morocco, barley seedlings are infected and disease intensifies rapidly, so it was not surprising to find ear number reduced, as it is a yield component subject to constraint during the growth interval of emergence to anthesis (18). Tiller numbers were not correlated with AUDPC, indicating that *P. teres* reduced the number of ear-bearing tillers per plant but did not affect tiller production. Similar results were reported by Jordan et al (8) on hydroponically grown barley. These results are not unique to *P. teres*. *Erysiphe graminis* DC. ex Mérat f. sp. *hordei* Em. Marchal and *Puccinia hordei* Otth also reduce ear numbers in barley (9), and, as we found with *P. teres*, ear reduction was related to early epidemics, which expressed their ear-reducing effect during the boot stage.

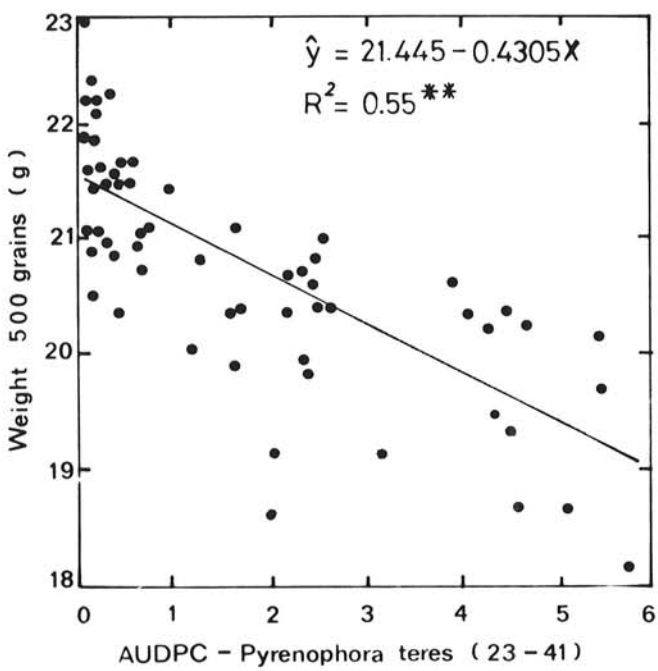

Fig. 3. Regression of grain weight on area under the disease progress curve from tillering (growth stage 23) to booting (growth stage 41) for *Pyrenophora teres* and weight of 500 grains (g) of barley at El Koudia/Merchouch.

Early disease development also explained a significant portion of the variability in kernel weight, a yield component normally thought to be subject to constraint from grain filling to dough. AUDPC for the interval 65–85 explained 38% of the variation in kernel weight, while AUDPC for the interval 23–41 explained 55%. Appropriate F tests of partial correlation coefficients (16) showed that AUDPC (65–85) did not give information about kernel weight in addition to that given by AUDPC (23–41). Nevertheless, the ratio of standard, partial regression coefficients for AUDPC (23–41)/AUDPC (65–85) was 12.8, indicating that AUDPC (23–41) is 12.8 times more important than AUDPC (65–85) in predicting kernel weight. That is, the association of AUDPC (23–41) to kernel weight may suggest a causal relationship in addition to that understood to exist between kernel weight and disease stress at the time of grain filling.

As with *P. teres*, weed infestations during stem elongation to mid-anthesis (30–65) also explained a small but significant amount of the variability in ear number but not in kernel weight. Appropriate F tests showed that AUWGC explained variation not explained by AUDPC in yield, and in number of ears but not in grain weight. Nevertheless, ratios of standard, partial regression coefficients indicate that AUDPC is a better predictor of yield, ear number, and grain weight than AUWGC.

Reduction in ear number appears to be a phenomenon related to reduced carbohydrate production as *P. teres* and weed development are most closely associated with ear numbers during the period of ear formation. The accumulation of dry matter in grains, however, does not appear to be a uniquely source-limited process as reported by others (19,20). Our data suggest that grain weight is affected by disease/weed stress during spikelet formation, even though spikelet number/ear and grain number/ear are not affected. It appears, therefore, that the inherent capacity of individual grains to accumulate carbohydrate is altered by disease early in the season.

The relationship between yield and AUDPC/AUWGC was best expressed by an exponential curve with a lower asymptote at 70 g of grain weight per square meter. That is, as AUDPC and AUWGC increase, yield will approach 70 g/m^2. The yield/disease/weed relationship described here is for only one cultivar (Brasserie Maroc) in two locations; however, we have observed a similar relationship between yield and *P. teres* along on six-row barleys, so the relationship we describe here might infer a general relationship between *P. teres*, weeds, and barley yield in dryland environments. In Morocco, we have observed *P. teres* primarily on leaves and only occasionally on leaf sheaths and peduncles. Consequently, materials assimilated for grain filling in infected plants could come from ears, leaf sheaths, and peduncles. In fact, Watson et al (20) have reported that 26% of grain dry matter in barley is derived from the ear, 59% from the flag-leaf lamina, sheath, and peduncle, and 15% from the penultimate leaf. Infected plants with ears, then, could produce grain even though leaves were dried by disease. Therefore, an asymptotic-like relationship could exist between *P. teres* and barley yield in an environment where disease development occurred primarily on leaves.

An asymptotic-like relationship between cereal yield and weed density is implied by the results of Bowden and Friesen (1) and of Swan and Furtick (17), but disease loss studies seldom cover a sufficient range of intensities to demonstrate the occurrence of an asymptote. We had 60 plots and a range of AUDPC values from

0.1 to 28.4 (Fig. 1), all with the same disease onset time. We think that the broad array of epidemics enabled us to demonstrate the presence of an asymptote-like relationship within the range of AUDPC values observed. An asymptotic curve also best expressed the relationship between AUDPC and ear number (Fig. 2).

P. teres in Morocco causes an early-season disease. Commonly, selection for resistance is made at anthesis when flag and penultimate leaves on once severely infected plants can be relatively free from disease. Consequently, barley lines relatively free from disease at maturity but susceptible to loss from early season infections have been retained in our breeding program. Screening for juvenile plant resistance can be done, but until recently that need has not been fully appreciated.

Our results show that weeds reduce barley yields, but their effects may be obscured by infection from *P. teres*. About two-thirds of the species encountered would not be used as forage, consequently, the current management style for barley in Morocco, which does not recognize the damage potential of *P. teres* and of weeds, appears to need modification.

LITERATURE CITED

1. Bowden, B. A., and Friesen, G. 1967. Competition of wild oats (*Avena fatua* L.) in wheat and flax. Weed Res. 7:349-359.
2. Buchannon, K. W., and Wallace, H. A. H. 1962. Note on the effect of leaf diseases on yield, bushel weight, and thousand-kernel weight of Parkland barley. Can. J. Plant Sci. 42:534-536.
3. Friesen, G., and Shebeski, L. H. 1960. Economic losses caused by weed competition in Manitoba grain fields. I. Weed species, their relative abundance and their effect on crop yields. Can. J. Plant Sci. 40:457-467.
4. Hampton, J. G. 1980. The role of seed-borne inoculum in the epidemiology of net blotch of barley in New Zealand. N. Z. J. Exp. Agric. 8:297-299.
5. Hampton, J. G., and Arnst, B. J. 1978. The relationship between net blotch and yield loss in spring barley. Pages 18-1–18-4 in: Proceedings of the Australian Plant Pathology Society Workshop on Epidemiology and Crop Loss Assessment. Lincoln College, New Zealand.
6. Jordan, V. W. L. 1981. Aetiology of barley net blotch caused by *Pyrenophora teres* and some effects on yield. Plant Pathol. 30:77-87.
7. Jordan, V. W. L., and Allen, E. C. 1984. Barley net blotch: Influence of straw disposal and cultivation on inoculum potential, and on incidence and severity of autumn disease. Plant Pathol. 33:547-559.
8. Jordan, V. W. L., Best, G. R., and Allen, E. C. 1985. Effects of *Pyrenophora teres* on dry matter production and yield components of winter barley. Plant Pathol. 34:200-206.
9. 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. II. Apical development and yield potential. Plant Pathol. 35:54-60.
10. McBeath, D. K., Dew, D. A., and Friesen, H. A. 1970. Competition between barley and wild oats as affected by nitrogen, barban and time of seeding. Can. J. Plant Sci. 50:541-550.
11. McDonald, W. C., and Buchannon, K. W. 1964. Barley yield reductions attributed to net blotch infection. Can. Plant Dis. Surv. 44:118-119.
12. Piening, L., and Kaufman, M. L. 1969. Comparison of the effects of net blotch and leaf removal on yield in barley. Can. J. Plant Sci. 49:731-735.
13. Raki, M. 1985. La place des cereales dans la nouvelle politique agricole. Le Contact Magrhrebin 12:17-21.
14. Shaner, G., and Finney, R. E. 1977. The effect of nitrogen fertilization on the expression of slow mildewing resistance in Knox wheat. Phytopathology 67:1051-1056.
15. Shipton, W. A. 1966. Effect of net blotch infection of barley on grain yield and quality. Aust. J. Exp. Agric. Anim. Husb. 6:437-440.
16. Steel, R. G. D., and Torrie, J. H. 1960. Principles and Procedures of Statistics. McGraw-Hill, New York. 481 pp.
17. Swan, D. G., and Furtick, W. R. 1962. Competition of fiddleneck with wheat. Weeds 10:121-123.
18. Teng, P. S., and Gaunt, R. E. 1980-1981. Modelling systems of disease and yield loss in cereals. Agric. Syst. 6:131-154.
19. Thorne, G. N. 1966. Physiological aspects of grain yield in cereals. Pages 88-105 in: The Growth of Cereals and Grasses. F. L. Milthorpe and J. D. Butterworth, eds. London.
20. Watson, D. J., Thorne, G. N., and French, S. A. W. 1958. Physiological causes of differences in grain yield between varieties of barley. Ann. Bot. (London) 22:321-352.
21. 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.