Assessment of Cultivar Performance and Disease Impact on Cereals in Morocco

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ABSTRACT

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Lines and cultivars of barley, bread, and durum wheats were seeded at nine sites in 1984 and 12 sites in 1985 and 1986 in all cereal-growing regions of Morocco to build a data base on regional performance and disease effects. Disease assessments were made four times annually at each site at the same growth stage. Area under the disease progress curve (AUDPC) values were calculated for foliar and root diseases, viruses, and barley stripe. Barley and bread wheat yield losses were most severe along the Atlantic coast (Rharb and Sidi Allal Tazi). All barley and all bread wheat cultivars except Tegey 32 had severe disease loss in at least one location. No yield loss occurred with durums. There were significant cultivar effects for AUDPC by severity among barleys and bread wheats but not among durums. Some barley lines had good resistance to net blotch, the most prevalent disease, but were susceptible to spot blotch. Conversely, all barley cultivars were susceptible to net blotch, but Rabat 071 and 895 were resistant to spot blotch development. Bread wheat line 1723 and cvs. Jouda, Tegey 32, and Merchouch 8 had lower total AUDPC values (by severity) than the popular cvs. Nesma and Siete Cerros. Generally, breeding lines were more resistant than cultivars to leaf rust, but all were equally susceptible to Septoria leaf blotch. AUDPC values for durum wheats were consistently lower than values for bread wheats to all diseases except bacterial leaf streak, which was observed only on durums. Disease was much less at Merchouch, the principal site for cultivar selection, than at Rharb and Sidi Allal Tazi. Selection for resistance to wheat leaf rust and to Septoria leaf blotch could be made at Tangier and Sidi Allal Tazi, respectively, without severe interference from other foliar diseases.

Morocco is situated on the northwest corner of Africa and cereals are grown on about 4.5 million ha (11) in environments that differ markedly in rainfall. Cereal regions along the north Atlantic coast and the Mediterranean receive an average of 1,050 mm of rain annually, while the Souss region in southern Morocco receives about 250 mm (1). Morocco has a long history of cereal culture and cultivar improvement, but until 1984 cultivar development was done primarily by expatriates who spent only 2-7 yr in the country. Assumptions regarding breeding strategies and the importance of stress factors often changed with the arrival of a replacement. Consequently, breeding programs suffered from a lack of continuity. As well, the absence of a reliable data base on disease distribution and intensity and on yield loss from disease has permitted certain misconceptions to be perpetuated regarding the relative importance of cereal diseases (3). For example, net blotch (caused by *Pyrenophora teres* Drechs.) on barley (*Hordeum vulgare* L.) was considered a minor threat principally because disease was evaluated at anthesis when heavily infected lower leaves often had senesced before the flag and penultimate leaves became severely infected. Therefore, susceptible lines were rated as moderately resistant and retained in the breeding program. Only after yield loss was shown to be associated with early infection was *P. teres* recognized as a major constraint to barley production (4).

Selection for disease resistance is done principally at Merchouch, where annual rainfall is about 400 mm. Advanced line testing is done at Tadla, a rain-fed, arid environment with about 300 mm of rainfall per year, and at Tessaout which is arid (about 250 mm of rainfall per year) but irrigated. These principal testing sites are located within major climatic zones where cereals are grown (1), yet the extent to which they provide adequate disease stress for cultivar selection, relative to other locations, and the extent to which they represent the range of disease environments in Morocco is undocumented. For example, the regions of Settat, Tessaout, and the Souss, like Tadla, receive about 250-300 mm of rainfall per year, yet there are marked and consistent regional differences in yield, disease stress, and pathogen virulence (6).

The present study was done to build a data base on disease distribution, intensity, and yield loss among regions because those data are not available for Morocco. The study also was intended to compare disease intensity among sites in order to evaluate the adequacy of sites currently used for disease resistance screening and to examine the adaptability of new, promising cereal lines and the progress made in cultivar improvement. A brief summary of this work has been reported (2).

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MATERIALS AND METHODS

Entries of standard cultivars and selected, advanced lines of barley, bread (*Triticum aestivum* L.), and durum wheat (*T. turgidum* L.) from the Moroccan national program, CIMMYT (Centro Internacional de Mejoramiento de Maiz y Trigo-Mexico City, Mexico), ICARDA (International Center for Agricultural Research in the Dry Areas-Aleppo, Syria), and ACSAD (Arab Center for the Study of Aridzones and Drylands-Damascus, Syria) were seeded at nine locations in the cereal-growing regions of Morocco in November of 1984 and at 12 locations in 1985 and 1986 (Fig. 1). Barleys were six-row cvs. Rabat 071 and 905 (Arig 8); two-row cv. 895 (Brasserie Maroc); six-row lines Acsad 60, Acsad 176, NK 1272 (Northrup-King Co., Woodland, CA), and Z-28 (Moroccan barley improvement program); and two-row line ER/APM (ICARDA). Parents of ER/APM, Early Russian and APAM, are six-row cultivars so obviously the line used in our study was misnamed. We have retained the name ER/APM, however, as that is the name for the seed source used by the Moroccan Cereal Improvement Program and by ICARDA. Bread wheats were the cvs. Nesma, Siete Cerros, Merchouch 8, Tegey 32, and Jouda and the lines 1723, 1724, 1725, and Acsad 67. Durum wheats were the cvs. Kyperounda (2777), Cocorit, Karim, and Marzak and the lines 1718 and Acsad 65.

Cultivars and lines were arranged randomly in 2 × 3 m plots and seeded at 100 kg/ha. Row spacing was 20 cm with 1 m of bare space between cultivars. During 1984-1985 (year 1) and 1985-1986 (year 2), plots were arranged in two blocks, treated and untreated, with fungicides for control of foliar diseases in a completely random design without replications. In year 1, flutriafol (Impact) was used at 125 g a.i./ha; in year 2, propiconazole 125 (TILT) was used at 130 g a.i./ha. During 1986–1987 (year 3), cultivars and lines were seeded in a split-plot arrangement with fungicide treatment (propiconazole 125 at 130 g a.i./ha) as main plots and cultivars as subplots. There were three replicates in a randomized complete block design. Fungicides were applied at pseudostem elongation (growth stage [GS] 30 based on Zadok's scale [14]) and heading (GS 58). If disease was severe, a third application was made at grain filling (GS 65).

A visual assessment of disease intensity was made on all plants in each plot at four crop growth stages: 1) pseudostem elongation (GS 30); 2) heading (GS 58); 3) grain filling (GS 65); and 4) soft dough (GS 83). Severities of most foliar diseases were recorded as the proportion (0–1) of laminar tissue showing symptoms. Incidence of root rot (caused by *Cochliobolus sativus* (Ito and Kuribayashi) Drechs. ex Dastur, and *Fusarium* Link:Fr. spp.) was assessed once before heading by examining all culms per cultivar and giving a general rating as the proportion of stunted culms with lesions on the lowest internode. At heading, grain filling, and soft dough, assessments were based on the proportion of culms with premature whiteheads without signs or symptoms of the wheat stem maggot (*Meromyza* sp. Fitch). Incidences of barley yellow dwarf virus (BYDV), barley yellow striate mosaic virus (BYSMV), and barley stripe (caused by *Pyrenophora graminea* S. Ito and Kuribayashi) were recorded as the proportion of plants per plot showing symptoms.

Areas under the disease progress curve (AUDPC) were calculated for each disease (12) by using disease severity and incidence and days from date of planting that coincided with the growth stage on the date of assessment. Only AUDPC values of 0.01 and greater are reported. AUDPC values were summed for all diseases assessed by severity and by incidence to express total disease development by an individual cultivar or line and by site. AUDPC was used to express disease development rather than terminal severity because our observations showed that some diseases, such as powdery mildew (caused by *Erysiphe graminis* DC. f. sp. *hordei* Em. Marchal) and bacterial leaf streak (caused by *Xanthomonas campestris* pv. *transluscens* (Jones, Johnson, and Reddy) Dye), commonly occurred early in the season but did not infect flag and penultimate leaves. Therefore, terminal severities often were nil, yet the diseases were present from stem elongation to heading.

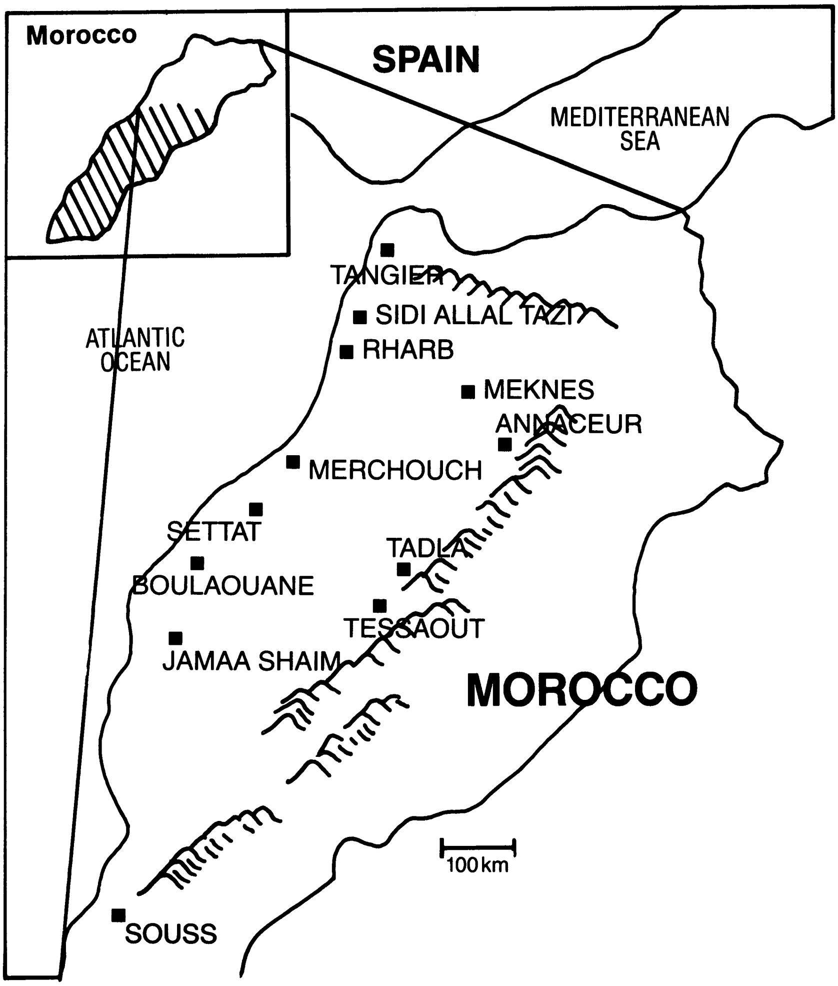

Fig. 1. Location of experimental sites in Morocco where cultivar nurseries were seeded to monitor pathogen development and to assess cultivar performance during 1984–1987.

Table 1. Means for barley yield, yield loss, and area under the disease progress curve (AUDPC) for eight diseases on eight cultivars and lines from 10 locations in Morocco over a 3-yr period

Cultivar or line	Yield[v]		Yield loss (%)		AUDPC										
					By severity							By incidence			
	g/m²	No.[w]	Max.[x]	Mean	NB[y]	PM	LR	SR	SB	SC	Total	No.	BYDV	BS	Total
Rabat 071	328 a[z]	23	82.0	12.6 a	10.90 a	0.50 b	0.10 a	0.01 a	0.10 c	0.00 a	11.61 ab	27	0.00 a	0.03 a	0.03 a
905	372 a	23	72.0	7.9 a	2.50 c	1.50 ab	2.20 a	0.09 a	2.39 abc	0.00 a	8.68 ab	27	0.00 a	0.08 a	0.08 a
895	311 a	22	75.0	10.6 a	7.00 b	0.30 b	0.60 a	0.01 a	1.20 bc	0.00 a	9.11 ab	27	0.40 a	0.01 a	0.41 a
Acsad 60	333 a	22	35.0	4.2 a	1.31 c	0.40 b	0.20 a	0.00 a	4.55 a	0.00 a	6.46 bc	27	1.80 a	0.06 a	1.86 a
Acsad 176	367 a	23	54.0	8.9 a	0.34 c	2.30 a	0.90 a	0.00 a	3.56 a	0.32 a	7.42 bc	27	0.28 a	0.02 a	0.30 a
NK 1272	342 a	22	34.0	3.3 a	0.37 c	0.30 b	0.03 a	0.01 a	3.25 ab	0.00 a	3.96 c	27	0.01 a	0.20 a	0.21 a
Z-28	315 a	22	56.0	12.3 a	11.60 a	0.60 b	0.50 a	0.01 a	0.50 c	0.00 a	13.21 a	27	0.00 a	0.04 a	0.04 a
ER/APM	381 a	21	42.0	1.9 a	0.13 c	0.40 b	0.30 a	0.02 a	3.43 ab	0.31 a	4.59 c	27	0.00 a	0.09 a	0.09 a

[v] Yield from fungicide-treated plots.
[w] Number of observations.
[x] Maximum yield loss observed during 3-yr study.
[y] NB = net blotch, PM = powdery mildew, LR = leaf rust, SR = stem rust, SB = spot blotch, SC = scald, BYDV = barley yellow dwarf virus, BS = barley stripe.
[z] Means within a column followed by the same letter are not significantly different ($P = 0.05$) according to the FLSD test.

At maturity, an area of 1 m^2 was harvested from each plot and threshed by hand or by machine if available at the site. The grain was air-dried for 2 wk and then weighed. Percent of yield loss was calculated as $(Yt - Ynt/Yt) * 100$, where Yt is yield in g/m^2 for fungicide-treated plots and Ynt is untreated plot yield.

AUDPC, yield, and yield loss data were analyzed by mixed model ANOVA for an unbalanced design using years as replications because we were interested primarily in site and cultivar effects. An unbalanced design was used to accommodate in the ANOVA an unequal number of cultivars and sites among years as some cultivars were seeded only 2 of 3 yr, and the sites Meknes, Rharb, and Sidi Allal Tazi were used in years 2 and 3 but not in year 1. AUDPC was used as a covariate in ANOVA of yield and yield loss data after first testing for interactions between the covariate and the independent variables, cultivar, and location. Yield of individual barley, bread wheat, and durum wheat cultivars was regressed on an environmental index (EI), which was the mean yield of all cultivars and lines for each cereal group among sites and among years (5,7). The homogeneity of regression coefficients was tested (13) by Student's t test ($P = 0.05$) to determine if cultivars and lines differed in their response rate to improved environments. Confidence limits were calculated for predicted cultivar yields at minimum, mean, and maximum EI values (8). Standard errors of the estimate ($Sy.x$) were used to compare (by F test) the yield variability of cultivars among environments.

Table 2. Maximum terminal disease intensity (proportion) by severity and by incidence for diseases observed during a 3-yr study on barley, bread wheats, and durums at 12 sites in Morocco

Crop Cultivar or line	Maximum terminal disease intensity (proportion)									
	By severity							By incidence		
	LR[a]	SLB	SR	YR	PM	TS	BLS	RR	BYDV	BYSMV
Durum wheat										
Kyperounda	0.40	0.00	0.10	0.05	0.20	0.20	0.00	0.05	0.10	0.99
Cocorit	0.10	0.90	0.01	T[b]	0.05	0.60	0.00	0.10	0.00	0.90
Karim	0.10	0.02	T	T	T	0.70	0.05	0.01	0.00	0.80
Marzak	0.05	0.60	0.25	T	0.01	0.05	T	0.01	0.00	0.01
1718	0.60	0.99	0.10	T	0.01	0.50	T	0.02	0.00	0.80
Acsad 65	0.60	0.99	0.01	0.01	0.00	0.20	0.40	0.25	0.00	0.60
Bread wheat	LR	SLB	SR	YR	PM	TS		RR		
Nesma	0.80	0.99	0.50	0.10	0.05	0.01		0.00		
Siete Cerros	0.80	0.99	0.90	0.10	T	T		0.05		
Merchouch 8	0.80	0.99	0.30	0.00	0.05	0.10		T		
Tegey 32	0.90	0.10	0.60	0.90	0.00	0.10		T		
Jouda	0.00	0.99	0.05	0.05	T	0.05		T		
1723	0.01	0.90	0.05	0.05	0.00	T		0.00		
1724	0.01	0.99	0.01	0.05	T	0.05		0.01		
1725	0.02	0.99	0.01	0.10	0.02	0.05		0.01		
Acsad 67	0.99	0.99	T	0.50	0.10	0.02		0.00		
Barley	NB[c]	PM	LR	SR	SB	SC		BYDV	BS	
Rabat 071	0.99	0.02	0.80	0.01	0.05	T		0.00	0.01	
905	0.99	0.20	0.80	0.10	0.99	T		T	0.05	
895	0.99	T	0.80	0.01	0.99	T		0.50	T	
Acsad 60	0.99	0.25	0.60	T	0.99	T		0.50	0.30	
Acsad 176	0.20	0.50	0.80	T	0.99	0.50		0.50	0.01	
NK 1272	0.50	0.10	0.80	0.01	0.99	T		0.00	0.30	
Z-28	0.99	0.50	0.80	0.10	T	0.00		0.00	0.01	
ER/APM	0.10	0.05	0.80	0.05	0.99	0.60		T	0.01	

[a] LR = leaf rust, SLB = Septoria leaf blotch, SR = stem rust, YR = stripe rust, PM = powdery mildew, TS = tan spot, BLS = bacterial leaf streak, RR = root rot, BYDV = barley yellow dwarf virus, BYSMV = barley yellow striate mosaic virus.
[b] T = trace (< 0.01).
[c] NB = net blotch,, SB = spot blotch, SC = scald, BS = barley stripe.

RESULTS

Barley. Barley cultivars and lines did not differ significantly for yield when treated with fungicides for control of foliar diseases even though there was an 18% difference between the highest and lowest yields (Table 1). Differences in mean yield loss were also nonsignificant. Average yield loss for cultivars and lines over all sites and years did not exceed 13%, although the maximum loss observed on each cultivar indicated that all might be damaged by one or more diseases. Development of net blotch as measured by AUDPC was greater on cvs. Rabat 071 and 895 and line Z-28 than on 905 and on lines ER/APM, Acsad 60, Acsad 176, and NK 1272, even though all lines and 905 were subject to infection by *P. teres* (Table 2).

The opposite was true for development of spot blotch (caused by *C. sativus*).

Table 3. Means for barley yield, yield loss, and area under disease progress curve (AUDPC) by location in Morocco for eight diseases on eight cultivars and lines over a 3-yr period

Location	Yield[u]		Yield loss (%)		AUDPC										
					By severity							By incidence			
	g/m^2	No.[v]	Max.[w]	Mean	NB[x]	PM	LR	SR	SB	SC	Total	No.	BYDV	BS	Total
Tangier	...[y]	...	...	...	3.90 bcd[z]	0.19 bc	7.82 a	0.00 b	0.00 c	0.09 a	12.00 b	24	0.00 a	0.23 a	0.23 a
Sidi Allal Tazi	449 ab	16	48.0	20.5 ab	15.00 a	1.31 a	0.01 b	0.00 b	7.10 a	0.10 a	23.52 a	16	0.00 a	0.04 a	0.04 a
Rharb	302 de	15	82.0	25.3 a	10.50 a	0.10 c	0.00 b	0.00 b	3.30 b	0.45 a	14.35 b	16	0.00 a	0.00 a	0.00 a
Meknes	422 abc	16	0.0	0.0 e	0.20 d	0.40 bc	0.00 b	0.00 b	0.00 c	0.01 a	0.61 d	16	0.00 a	0.12 a	0.12 a
Annaceur	...	...	...	...	0.00 d	0.15 c	0.00 b	0.00 b	0.00 c	0.00 a	0.15 d	24	0.00 a	0.57 a	0.57 a
Merchouch	377 bcd	16	44.0	6.5 cd	4.20 bc	1.06 ab	0.21 b	0.00 b	0.00 c	0.36 a	5.83 c	24	0.00 a	0.03 a	0.03 a
Settat	188 f	18	25.0	4.2 d	4.50 bc	1.03 abc	2.36 b	0.00 b	2.30 b	0.00 a	10.19 b	24	1.77 a	0.00 a	1.77 a
Tadla	246 ef	16	12.0	2.1 de	2.99 bcd	1.51 a	0.00 b	0.00 b	4.42 b	0.00 a	8.92 b	24	0.93 a	0.19 a	1.12 a
Boulaouane	310 de	24	54.0	13.4 bc	3.20 bcd	0.84 abc	1.38 b	0.00 b	7.80 a	0.00 a	13.22 b	24	0.00 a	0.02 a	0.02 a
Tessaout	495 a	16	0.0	0.0 e	0.20 d	1.04 abc	0.00 b	0.00 b	0.00 c	0.00 a	1.24 cd	24	0.00 a	0.15 a	0.15 a
Jamaa Shaim	372 cd	23	56.0	8.0 cd	5.50 b	0.22 bc	1.23 b	0.01 b	0.00 c	0.00 a	6.96 c	24	0.00 a	0.04 a	0.04 a
Souss	300 de	18	0.0	0.0 e	0.50 cd	0.20 bc	0.15 b	0.15 a	0.00 c	0.00 a	1.00 d	24	0.01 a	0.05 a	0.06 a

[u] Yield from fungicide-treated plots.
[v] Number of observations.
[w] Maximum yield observed during 3-yr study.
[x] NB = net blotch, PM = powdery mildew, LR = leaf rust, SR = stem rust, SB = spot blotch, SC = scald, BYDV = barley yellow dwarf virus, BS = barley stripe.
[y] No yield data.
[z] Means within a column followed by the same letter are not significantly different ($P = 0.05$) according to the FLSD test.

AUDPC for spot blotch was greater on Acsad 60, Acsad 176, NK 1272, and ER/APM than on Rabat 071, 895, and Z-28 (Table 1), but all cultivars and lines were susceptible to infection by *C. sativus* (Table 2). AUDPC values for spot blotch on 895, Rabat 071, Z-28, and 905 were not significantly different. Powdery mildew, leaf rust (caused by *Puccinia hordei* G. Otth), BYDV, and stem rust (caused by *P. graminis* Pers.:Pers. f. sp. *tritici* Eriks. & E. Henn.) developed on most cultivars, but AUDPC values for those diseases usually were considerably lower than AUDPC values for net blotch and spot blotch. Barley scald (caused by *Rhynchosporium secalis* (Oudem.) J. J. Davis) was observed on most cultivars and lines but only on Acsad 60 and ER/APM did severities exceed 0.01 (Table 2) and AUDPC values exceed 0.01 (Table 1). AUDPC for all diseases assessed by severity on NK 1272 and on ER/APM were significantly less than AUDPC on Rabat 071, 905, 895, and Z-28. AUDPC values for diseases assessed by incidence (BYDV and barley stripe) were not significantly different among cultivars and lines (Table 1), although both diseases were observed on all cultivars except Rabat 071 and on most lines (Table 2).

Flutriafol controlled powdery mildew and leaf rust and gave partial control of net blotch, but it was ineffective for spot blotch. Its effectiveness against stem rust and scald was not tested because those diseases occurred only in trace severities during year 1 when flutriafol was used. Propiconazole effectively controlled all important foliar diseases. Because of the ineffectiveness of flutriafol against spot blotch, there were no yield loss data for susceptible barley cultivars for Boulaouane in year 1.

There was no significant location × cultivar interaction for barley yield, so yields were averaged across all cultivars for each location (Table 3). Barley yield and yield loss varied significantly with location. Yields from irrigated regions (Tessaout) and from coastal (Sidi Allal Tazi) and inland areas where annual rainfall normally exceeds 400 mm (Meknes and Merchouch) were greater than yields from Tadla and Settat, where annual rainfall ranges from 200 to 400 mm. Exceptions occurred in the Souss, which is an irrigated area in southern Morocco, and in the Rharb, which is on the Atlantic coast in a region receiving 400–600 mm of rainfall annually. In the Souss and Rharb, yields were less than at Tessaout and Sidi Allal Tazi (similar to Rharb in annual rainfall and temperature). Yield loss significantly greater than zero was noted at six of 10 sites where yield data were taken during the 3-yr study, but only at Sidi Allal Tazi, Rharb, and Boulaouane did the mean yield loss for all cultivars exceed 8%. No yield loss attributable to disease occurred at Meknes, Tessaout, and Souss, and the loss measured at Tadla (2.1%) was not significantly greater than zero. The mean yield losses on Rabat 071, a barley cultivar widely grown in Morocco, were 28.5, 55.0, 22.0, 12.6, and 17.3% at Sidi Allal Tazi, Rharb, Merchouch, Jamaa Shaim, and Boulaouane, respectively. Losses were nil at all other sites.

Net blotch was observed at all sites except Annaceur and was the dominant barley disease at Sidi Allal Tazi, Rharb, Merchouch, Settat, Jamaa Shaim, and Souss (Table 3). Spot blotch was the predominant disease at Tadla and Boulaouane and second in importance at Sidi Allal Tazi and Rharb. Leaf rust and powdery mildew were the predominant diseases at Tangier and at Tessaout, respectively, while AUDPC for all diseases was <1 at Meknes and Annaceur. Stem rust was observed only at Jamaa Shaim and Souss and AUDPC values were <1. Scald occurred at several sites, but like stem rust, AUDPC values were always <1. BYDV occurred at Settat, Tadla, and Souss and mean AUDPC values were 1.77 or less. Barley stripe was noted at all sites except Rharb and Settat, but mean AUDPC values were 0.57 or less.

When yields of fungicide-treated cultivars were regressed on the EI, the regression coefficient for cv. 905 was significantly greater than coefficients for cv. Rabat 071 and lines Acsad 60, Acsad 176, NK 1272, and Z-28 (Table 4). These data suggest that in the absence of disease, 905 responded with greater yield to improved environments more rapidly than did Rabat 071, Acsad 60, Acsad 176, NK 1272, and Z-28. When yields from untreated plots were regressed on EI, however, regression coefficients for both 905 and ER/APM were greater than coefficients for all other cultivars and lines. Confidence limits at minimum EI values overlapped for treated and for untreated barleys (*data not shown*), indicating that all cultivars and lines perform similarly in relatively poor environments. Among cultivars and lines, confidence limits at mean and maximum EI values generally overlapped for treated barleys, but for untreated barleys, confidence limits for 905 and ER/APM were different than limits for cvs. 895 and Rabat 071 and for line Z-28. Therefore, in the absence of disease, there was usually no yield advantage among cultivars and lines regardless of environment; however, when disease was a factor in EI, 905 and ER/APM gave higher yields than cvs. Rabat 071 and 895 and line Z-28 in improved environments, probably because of their resistance to development of net blotch (Table 1). There were no significant cultivar and line differences for standard errors of the estimate (*data not shown*). That is, all barleys showed similar heterogeneity in yield among environments.

Bread wheat. There were no significant yield differences among bread wheats treated for foliar disease control (Table 5). Cultivar differences in yield loss over all sites and years were nonsignificant and mean yield loss did not exceed 5.6%. Nevertheless, with the exception of Tegey 32, cultivars and lines were susceptible to damage by foliar diseases, as maximum loss ranged from 26 to 65%.

Flutriafol gave good control of leaf rust, stem rust, and powdery mildew. Septoria leaf blotch, stripe rust, and tan spot were not severe during year 1 when flutriafol was used. Propiconazole controlled all major foliar disease during years 2 and 3.

All bread wheats except Jouda were susceptible to leaf rust (caused by *Puccinia recondita* Roberge ex Desmaz. f. sp. *tritici* [Table 2]), although development, as measured by AUDPC, on lines 1723, 1724, and 1725 was significantly less than development on cvs. Siete Cerros, Merchouch 8, and Tegey 32 and line Acsad 67. Interestingly, AUDPC for leaf rust on Nesma was not different from 0 even though it is a susceptible cultivar. Septoria leaf blotch (caused by *Mycosphaerella graminicola* (Fuckel) Sanderson) was observed on all cultivars and lines, but only for

Table 4. Regression coefficients (b_1) and confidence limits for barley yield (g/m^2) from plots treated and untreated for control of foliar diseases at mean and maximum values of an environmental index (EI) constructed from the mean yield of cultivars and lines at 10 sites in Morocco

Cultivar or line	Treated b_1	Treated Mean EI (341)		Treated Maximum EI (610)		Untreated b_1	Untreated Mean EI (275)		Untreated Maximum EI (463)	
Rabat 071	0.968 bc[z]	357	295	659	513	0.833 b[z]	288	225	484	343
905	1.186 a	399	349	741	645	1.456 a	378	308	672	565
895	1.057 ab	326	272	648	519	0.890 b	295	236	502	364
Acsad 60	0.991 b	364	302	671	529	0.948 b	342	279	553	424
Acsad 176	0.959 bc	384	336	694	552	1.070 b	364	297	593	470
NK 1272	0.992 b	368	318	666	554	1.082 b	373	299	608	471
Z-28	0.752 c	346	284	605	430	1.049 b	292	233	516	403
ER/APM	1.126 ab	407	337	748	602	1.681 a	435	350	771	646

[z]Values in a column followed by the same letter are not significantly different ($P = 0.05$) according to Student's t test.

Merchouch 8 and Tegey 32 was AUDPC significantly less than for Nesma and Siete Cerros, the dominant cultivars in Morocco. There were no cultivar differences in AUDPC for stem rust, stripe rust (caused by *P. striiformis* Westend.), powdery mildew, tan spot (caused by *Pyrenophora tritici-repentis* (Died.) Drechs.), and root rot. Total AUDPC by severity was significantly less on cvs. Merchouch 8, Tegey 32, and Jouda and line 1723 than on cvs. Nesma and Siete Cerros and line Acsad 67.

There was no significant location × cultivar interaction for bread wheat yield, so yields were averaged across all cultivars for each location (Table 6). Bread wheat yield and yield loss varied significantly with location. Mean yield loss over all cultivars and all years exceeded 10% only at Sidi Allal Tazi and Rharb. No loss from disease was measured at Meknes, Merchouch, Settat, Tadla, Boulaouane, Tessaout, Jamaa Shaim, and Souss. Mean yield losses on the popular cultivar Nesma, however, were 33.0, 16.5, and 2.7% at Sidi Allal Tazi, Rharb, and Boulaouane, respectively. Yield loss on Nesma was zero at all other sites.

As measured by AUDPC, leaf rust was the predominant disease at Tangier, Settat, Tessaout, Jamaa Shaim, and Souss (Table 6), while Septoria leaf blotch predominated at Sidi Allal Tazi, Rharb, Merchouch, and Boulaouane. AUDPC values for stripe rust were negligible and consistently lower than for other foliar diseases except at Meknes and Tadla. Only in the Souss did development of stem rust approach that of other foliar diseases. Powdery mildew and tan spot were observed at two and three sites, respectively, but as with stripe rust, AUDPC values were negligible. Root rot and BYSMV were noted only at Jamaa Shaim and Annaceur, respectively, and AUDPC values for disease incidence were <1.

When yield of individual bread wheats treated for control of foliar pathogens was regressed on EI, regression coefficients for the lines 1723, 1724, 1725, and Acsad 67 and cv. Tegey 32 were significantly greater than coefficients for Nesma and Merchouch 8 (Table 7). Regression coefficients for cvs. Jouda and Siete Cerros were significantly greater than the coefficient for Nesma but not significantly different from coefficients for Merchouch 8, Tegey 32, and all lines studied. In the absence of disease, therefore, Nesma and Merchouch 8 did not respond to improved environments as rapidly as did the lines and Tegey 32. Regression coefficients were greater for the untreated bread wheats Jouda and 1724 than for Nesma and Acsad 67 but not different from coefficients for other cultivars and lines. When disease was a factor in EI, the recently released cultivar

Table 5. Means for bread wheat yield, yield loss, and area under the disease progress curve (AUDPC) for seven diseases on nine cultivars and lines from 10 locations in Morocco over a 3-yr period

Cultivar or line	Yield[v]		Yield loss (%)		AUDPC								
					By severity							By incidence	
	g/m²	No.[w]	Max.[x]	Mean	LR[y]	SLB	SR	YR	PM	TS	Total	No.	RR
Nesma	335 a[z]	24	48.0	3.9 a	1.24 bc	5.60 a	0.60 a	0.11 a	0.01 a	0.00 a	7.56 a	27	0.00 a
Siete Cerros	360 a	24	65.0	5.6 a	1.75 ab	4.80 ab	0.40 a	0.10 a	0.00 a	0.00 a	7.05 a	27	0.00 a
Merchouch 8	342 a	24	26.0	1.8 a	2.26 ab	1.40 cd	0.08 a	0.00 a	0.11 a	0.05 a	3.90 b	27	0.00 a
Tegey 32	373 a	13	0.0	0.0 a	1.86 ab	0.15 d	0.43 a	1.04 a	0.00 a	0.00 a	3.48 b	17	0.00 a
Jouda	388 a	24	46.0	2.9 a	0.00 c	2.99 abcd	0.03 a	0.05 a	0.01 a	0.00 a	3.08 b	27	0.00 a
1723	434 a	20	28.0	1.4 a	0.01 c	1.76 bcd	0.02 a	0.02 a	0.00 a	0.00 a	1.81 b	20	0.00 a
1724	418 a	20	34.0	1.7 a	0.02 c	4.59 abc	0.01 a	0.04 a	0.07 a	0.01 a	4.74 ab	20	0.01 a
1725	404 a	20	56.0	4.2 a	0.05 c	4.48 abc	0.00 a	0.08 a	0.14 a	0.00 a	4.75 ab	20	0.01 a
Acsad 67	356 a	12	59.0	3.5 a	3.30 a	4.67 abc	0.00 a	0.53 a	0.21 a	0.00 a	8.71 a	16	0.00 a

[v] Yield from fungicide-treated plots.
[w] Number of observations.
[x] Maximum yield loss observed during 3-yr study.
[y] LR = leaf rust, SLB = Septoria leaf blotch, SR = stem rust, YR = stripe rust, PM = powdery mildew, TS = tan spot, RR = root rot.
[z] Means within a column followed by the same letter are not significantly different ($P = 0.05$) according to the FLSD test.

Table 6. Means for bread wheat yield, yield loss, and area under disease progress curve (AUDPC) by location in Morocco for eight diseases on nine cultivars over a 3-yr period

Location	Yield[u]		Yield loss (%)		AUDPC										
					By severity							By incidence			
	g/m²	No.[v]	Max.[w]	Mean	LR[x]	SLB	SR	YR	PM	TS	Total	No.	RR	BYSMV	Total
Tangier	...[y]	...	...	...	4.00 a[z]	0.21 d	0.00 b	0.00 a	0.00 b	0.29 a	4.50 cde	22	0.00 a	0.00 a	0.00 a
Sidi Allal Tazi	482 b	16	65.0	24.6 a	0.14 cd	17.05 a	0.00 b	0.00 a	0.00 b	0.11 ab	17.30 a	16	0.00 a	0.00 a	0.00 a
Rharb	272 cd	15	60.0	11.1 b	0.01 cd	11.71 b	0.00 b	0.00 a	0.00 b	0.00 b	11.72 b	16	0.00 a	0.00 a	0.00 a
Meknes	305 c	16	0.0	0.0 c	0.01 cd	0.01 d	0.00 b	0.46 a	0.00 b	0.00 b	0.48 e	16	0.00 a	0.00 a	0.00 a
Annaceur	...	...	...	...	0.00 d	0.00 d	0.00 b	0.00 a	0.01 b	0.27 a	0.28 e	21	0.00 a	0.86 a	0.86 a
Merchouch	484 b	14	0.0	0.0 c	1.66 bcd	2.34 cd	0.00 b	0.00 a	0.00 b	0.00 b	4.00 cde	21	0.00 a	0.00 a	0.00 a
Settat	211 d	22	0.0	0.0 c	2.63 ab	2.41 cd	0.07 b	0.00 a	0.00 b	0.00 b	5.11 cd	22	0.00 a	0.00 a	0.00 a
Tadla	433 b	16	0.0	0.0 c	0.04 cd	0.32 d	0.00 b	0.76 a	0.00 b	0.00 b	1.12 e	22	0.00 a	0.00 a	0.00 a
Boulaouane	328 c	22	14.0	1.0 c	1.50 bcd	5.09 c	0.04 b	0.00 a	0.00 b	0.00 b	6.63 c	22	0.00 a	0.00 a	0.00 a
Tessaout	682 a	16	0.0	0.0 c	0.94 bcd	0.00 d	0.20 b	0.54 a	0.00 b	0.00 b	1.68 de	22	0.00 a	0.00 a	0.00 a
Jamaa Shaim	277 cd	22	0.0	0.0 c	1.95 bc	0.55 d	0.34 b	0.00 a	0.00 b	0.00 b	2.84 de	22	0.01 a	0.00 a	0.01 a
Souss	419 b	22	0.0	0.0 c	1.56 bcd	0.00 d	1.07 a	0.00 a	0.49 a	0.00 b	3.12 cde	22	0.00 a	0.00 a	0.00 a

[u] Yield from fungicide-treated plots.
[v] Number of observations.
[w] Maximum yield loss observed during 3-yr study.
[x] LR = leaf rust, SLB = Septoria leaf blotch, SR = stem rust, YR = stripe rust, PM = powdery mildew, TS = tan spot, RR = root rot, BYSMV = barley yellow striate mosaic virus.
[y] No yield data.
[z] Means within a column followed by the same letter are not significantly different ($P = 0.05$) according to the FLSD test.

Jouda and the line 1724 responded with greater yield more rapidly than Nesma to improved environments.

Confidence limits for yields at the minimum EI value were not different among bread wheats treated or untreated for foliar disease control (*data not shown*). Confidence limits for treated Jouda, 1723, and 1724 at mean and maximum EI values were different from confidence limits for Nesma but overlapped with confidence limits for Siete Cerros. The confidence limits for untreated 1723 were different from Nesma at mean and maximum EI values; untreated 1724 was different from Nesma only at maximum EI. These data support results from the analysis of regression coefficients by showing that in the absence of disease, Jouda and lines 1723 and 1724 possess a clear yield advantage over Nesma in improved environments, but when disease is a factor in EI, only line 1723 is distinct from Nesma and that probably is because of its resistance to development of Septoria leaf blotch. No line had a yield advantage over Siete Cerros, another widely grown cultivar, regardless of environment.

Standard errors of the estimate for treated Nesma, Jouda, and 1724 were significantly less than the *Sy.x* value for Acsad 67 but not different from *Sy.x* values from all other cultivars and lines (Table 7). Among untreated cultivars and lines, only the *Sy.x* for Nesma was significantly less than the value for Acsad 67. Clearly, Acsad 67 showed the most yield variability among cultivars and lines tested.

Durum wheat. Durum cultivars and lines differed significantly in yield when treated for control of foliar diseases (Table 8). The popular cv. Kyperounda yielded significantly less than all other cultivars and lines. No significant yield loss to disease was measured. There were no significant cultivar differences in AUDPC for leaf rust, Septoria leaf blotch, stem rust, stripe rust, powdery mildew, root rot, and BYDV. However, development of bacterial leaf streak was greater on Acsad 65 than on other cultivars and lines, and AUDPC for tan spot on Karim was greater than on Kyperounda and Marzak. There were no differences in total AUDPC by severity and incidence among cultivars and lines.

There was no location × cultivar interaction for durum yield, so yields were averaged across all cultivars for each location (Table 9). Durum wheat yield and AUDPC differed significantly with location. Higher yields occurred in irrigated and coastal areas than in rainfed, inland areas. Bacterial leaf streak was the dominant disease at Jamaa Shaim and was observed only there and at Rharb. BYSMV was putatively identified (9) at Annaceur where it caused severe stunting and 100% yield loss in 1987. Tan spot was the predominant disease in the Rharb and ranked second in AUDPC (by severity) at Sidi Allal Tazi. At most other sites, tan spot either was not observed or was of minor importance. Leaf rust and Septoria leaf blotch were present at nine and six sites, respectively, but AUDPC values were <2 with the exception of Septoria leaf blotch at Sidi Allal Tazi. Stem rust, stripe rust, powdery mildew, root rot, and BYDV were observed at a few locations, but again, AUDPC values were always <1.

When yields of individual durums treated and untreated for control of foliar diseases were regressed on EI, the regression coefficients for Kyperounda were significantly less than coefficients for other cultivars and lines, indicating that it did not respond as rapidly to improved environments as did the other durums (Table 10). Confidence limits for yield among treated and untreated durums at the minimum EI overlapped (*data not shown*), but at mean and

Table 7. Regression coefficients (b_1) and confidence limits for bread wheat yields from plots treated and untreated for control of foliar diseases at mean and maximum values of an environmental index (EI) constructed from the mean yield of cultivars and lines at 10 sites in Morocco and standard errors of the estimate (*Sy.x*) from the regression of yield on EI

Cultivar or line	Treated b_1	Treated Mean EI (365)		Treated Maximum EI (741)		Treated *Sy.x*	Untreated b_1	Untreated Mean EI (333)		Untreated Maximum EI (573)		Untreated *Sy.x*
Nesma	0.757 c[y]	359	309	696	542	58 a[z]	0.874 cd[y]	331	287	563	474	52 a[z]
Siete Cerros	1.025 ab	388	330	815	677	68 ab	0.980 abcd	341	295	596	510	54 ab
Merchouch 8	0.918 bc	375	307	777	598	81 ab	0.975 abcd	385	319	648	524	77 ab
Tegey 32	1.098 a	410	283	913	608	110 ab	0.923 bcd	369	248	648	412	108 ab
Jouda	1.025 ab	413	361	836	711	62 a	1.102 ab	366	298	655	538	79 ab
1723	1.119 a	449	382	910	765	72 ab	1.091 abc	409	337	697	572	77 ab
1724	1.099 a	426	372	873	754	58 a	1.122 a	378	320	668	568	63 ab
1725	1.111 a	416	354	872	736	67 ab	0.972 abcd	360	292	623	495	72 ab
Acsad 67	1.171 a	389	228	937	563	134 b	0.855 d	376	245	652	380	113 b

[y]Values in a column followed by the same letter are not significantly different ($P = 0.05$) according to the Student's *t* test.
[z]Values in a column followed by the same letter are not significantly different ($P = 0.05$) according to the *F* test.

Table 8. Means for durum wheat yield, yield loss, and area under the disease progress curve (AUDPC) for nine diseases on six cultivars and lines from 10 locations in Morocco over a 3-yr period

Cultivar or line	Yield[w] g/m²	No.[x]	LR[y]	SLB	SR	YR	PM	BLS	TS	Total	No.	RR	BYDV	Total
			AUDPC by severity								AUDPC by incidence			
Kyperounda	232 b[z]	24	0.46 a	0.00 a	0.11 a	0.08 a	0.02 a	0.06 b	0.03 b	1.21 a	27	0.04 a	0.38 a	0.42 a
Cocorit	366 a	20	0.14 a	1.30 a	0.01 a	0.00 a	0.08 a	0.16 b	0.95 ab	2.68 a	20	0.04 a	0.00 a	0.04 a
Karim	390 a	20	0.14 a	0.02 a	0.00 a	0.00 a	0.01 a	0.31 b	1.13 a	1.62 a	20	0.01 a	0.00 a	0.01 a
Marzak	384 a	14	0.20 a	0.82 a	0.22 a	0.00 a	0.10 a	0.20 b	0.00 b	1.55 a	18	0.01 a	0.00 a	0.01 a
1718	375 a	24	0.72 a	1.05 a	0.08 a	0.00 a	0.01 a	0.26 b	0.42 ab	2.55 a	27	0.01 a	0.00 a	0.01 a
Acsad 65	354 a	24	0.88 a	1.04 a	0.01 a	0.01 a	0.01 a	1.25 a	0.11 ab	3.40 a	27	0.10 a	0.00 a	0.10 a

[w]Yield from fungicide-treated plots. No significant yield losses occurred.
[x]Number of observations.
[y]LR = leaf rust, SLB = Septoria leaf blotch, SR = stem rust, YR = stripe rust, PM = powdery mildew, BLS = bacterial leaf streak, TS = tan spot, RR = root rot, BYDV = barley yellow dwarf virus.
[z]Means within a column followed by the same letter are not significantly different ($P = 0.05$) according to the FLSD test.

maximum EI values, confidence limits for all cultivars and lines except Marzak and Acsad 65, respectively, were different from confidence limits for Kyperounda. Line 1718 and cvs. Cocorit and Karim, therefore, have a distinct yield advantage over the popular cv. Kyperounda in all but the relatively poor environments whether in the presence or absence of disease. Standard errors of the estimate for all durums except Marzak were not different, indicating that yield variability over environments was similar among most cultivars and lines.

DISCUSSION

The importance of disease to cereal production in Morocco has been based largely on incidence and severity but not on yield loss. Common diseases, such as Septoria leaf blotch and leaf rust on wheat and powdery mildew on barley, were assumed to cause yield loss because they are ubiquitous and sometimes severe. Importance was often based on a single disease severity estimate made in breeders' nurseries located along the Atlantic coast (such as in Rharb) where foliar diseases commonly are serious but where cereals do not predominate. Other studies made in principal inland cereal areas (e.g. Merchouch, Meknes, and Tessaout) were designed to select for disease resistance and earliness and not to determine the impact of diseases on yield.

Based principally on incidence and terminal severity, there is the impression within the cereal-worker community in Morocco that Septoria leaf blotch on bread wheats, root rot on durums, and powdery mildew and BYDV on barley are the most important cereal diseases. For example, powdery mildew is considered a major barley disease in Morocco because it occurs throughout the country, but its impact on yield appears to have been evaluated only on near-isogenic lines (10). Disease severities and yield losses were greater at Rabat (50% terminal severity on flag leaf and 55% yield loss), located along the Atlantic coast where powdery mildew commonly is severe but where cereals are a minor crop, than at Meknes (9% terminal severity on flag leaf and 3% yield loss), which is located in a region where cereals predominate. Our data show that powdery mildew occurred on all barley cultivars and lines, but 3-yr mean AUDPC values were lower than values for net blotch and spot blotch and did not exceed 2.3. Powdery mildew also occurred at all 12 sites but only at Tessaout, Meknes, and Annaceur did AUDPC surpass values for net blotch and spot blotch, and values were usually <1.

BYDV is assumed to be a major constraint to barley production in Morocco, but during our 3-yr study, it did not occur on cv. Rabat 071 and only in trace incidence on cv. 905. Nevertheless, BYDV was observed at three of 12 sites (Souss, Tadla, and Settat) on cv. 895. Tadla and Settat are located in important barley areas, and the 3-yr mean AUDPC on cv. 895 did not exceed 0.4 although the maximum terminal incidence observed was 0.50. Similar maximum terminal incidences were noted on Acsad 176 and Acsad 60, so the potential for severe infection and crop loss existed among selected, advanced lines and the cv. 895.

Stem rust, scald, and barley stripe were observed on several cultivars and lines

Table 9. Means for durum wheat yield, yield loss, and area under disease progress curve (AUDPC) by location in Morocco for 10 diseases on six cultivars and lines over a 3-yr period

	Yield[v]		AUDPC												
			By severity								By incidence				
Location	g/m²	No.[w]	LR[x]	SLB	SR	YR	PM	BLS	TS	Total	No.	BYDV	RR	BYSMV	Total
Tangier	...[y]	...	1.78 a[z]	1.58 b	0.00 a	0.00 a	0.00 b	0.00 b	1.18 ab	4.54 b	15	0.00 a	0.00 b	0.00 b	0.00 b
Sidi Allal Tazi	420 b	11	0.00 d	7.41 a	0.00 a	0.00 a	0.00 b	0.00 b	2.61 a	10.01 a	11	0.00 a	0.00 b	0.00 b	0.00 b
Rharb	211 ef	11	0.06 d	0.88 b	0.00 a	0.00 a	0.00 b	0.44 b	2.30 a	3.68 bc	11	0.00 a	0.28 a	0.00 b	2.80 b
Meknes	279 de	11	0.00 d	0.00 b	0.00 a	0.13 a	0.00 b	0.00 b	0.01 b	0.14 d	11	0.00 a	0.00 b	0.00 b	0.00 b
Annaceur	...	...	0.00 d	0.00 b	0.00 a	0.00 a	0.09 b	0.00 b	0.78 b	0.87 cd	15	0.00 a	0.00 b	2.89 a	2.89 a
Merchouch	419 b	11	0.23 c	0.01 b	0.00 a	0.00 a	0.00 b	0.00 b	0.00 b	0.24 d	15	0.00 a	0.04 b	0.00 b	0.04 b
Settat	164 f	15	1.35 ab	0.11 b	0.00 a	0.00 a	0.00 b	0.00 b	0.00 b	1.46 cd	15	0.00 a	0.00 b	0.00 b	0.00 b
Tadla	396 bc	11	0.04 d	0.00 b	0.00 a	0.02 a	0.00 b	0.00 b	0.00 b	0.06 d	15	0.00 a	0.00 b	0.00 b	0.00 b
Boulaouane	320 bcd	15	1.25 abc	0.33 b	0.02 a	0.00 a	0.00 b	0.00 b	0.18 b	1.78 cd	15	0.08 a	0.00 b	0.00 b	0.08 b
Tessaout	608 a	11	0.17 cd	0.00 b	0.05 a	0.00 a	0.00 b	0.00 b	0.00 b	0.22 d	16	0.00 a	0.00 b	0.00 b	0.00 b
Jamaa Shaim	293 cde	15	0.50 bcd	0.00 b	0.20 a	0.00 a	0.00 b	3.37 a	0.00 b	4.07 bc	15	0.00 a	0.09 b	0.00 b	0.09 b
Souss	419 b	15	0.73 abcd	0.00 b	0.36 a	0.00 a	0.29 a	0.00 b	0.00 b	1.38 cd	15	0.61 a	0.00 b	0.00 b	0.61 b

[v] Yield from fungicide-treated plots. No significant yield losses occurred at any location.
[w] Number of observations.
[x] LR = leaf rust, SLB = Septoria leaf blotch, SR = stem rust, YR = stripe rust, PM = powdery mildew, BLS = bacterial leaf streak, TS = tan spot, BYDV = barley yellow dwarf virus, RR = root rot, BYSMV = barley yellow striate mosaic virus.
[y] No yield data.
[z] Means within a column followed by the same letter are not significantly different ($P = 0.05$) according to the FLSD test.

Table 10. Regression coefficients (b_1) and confidence limits for durum wheat yield (g/m^2) from plots treated and untreated for control of foliar diseases at mean and maximum values of an environmental index (EI) constructed from the mean yield of cultivars and lines at 10 sites in Morocco and standard errors of the estimate ($Sy.x$) from the regression of yield on EI

	Confidence limits												
	Treated						Untreated						
Cultivar or line	b_1	Mean EI (340)		Maximum EI (620)		$Sy.x$	b_1	Mean EI (313)		Maximum EI (561)		$Sy.x$
Kyperounda	0.659 c[y]	274	190	536	297	99 a[z]	0.706 b[y]	262	204	480	336	68 ab[z]
Cocorit	1.142 a	390	329	733	625	65 a	1.007 a	341	285	616	509	61 ab
Karim	1.140 a	418	349	765	641	74 a	1.173 a	376	309	670	548	72 ab
Marzak	1.039 ab	392	298	741	531	85 a	1.162 a	386	269	723	508	104 b
1718	1.142 a	402	346	745	643	65 a	1.103 a	363	329	649	590	39 a
Acsad 65	0.912 b	395	313	697	522	95 a	1.030 a	352	290	635	519	73 ab

[y] Values in a column followed by the same letter are not significantly different ($P = 0.05$) according to Student's t test.
[z] Values in a column followed by the same letter are not significantly different ($P = 0.05$) according to the F test.

and at most locations, but AUDPC values never exceeded 1.0. Their relative importance to barley production appears to be minimal, yet the susceptibility of some lines to scald and barley stripe suggests that the severity/incidence of these diseases might increase with the release of ER/APM, Acsad 176, Acsad 60, and NK 1272. Of eight diseases observed on barley, it is clear that net blotch predominated on the cvs. Rabat 071 and 895 and on the line Z-28, whereas spot blotch was the principal disease on lines ER/APM, Acsad 60, Acsad 176, and NK 1272 even though Acsad 60 and NK 1272 were also subject to severe infection by *P. teres*. It appears, therefore, that the barley improvement program has successfully selected for resistance to net blotch development in some lines being considered for release, but those same lines are susceptible to spot blotch. Spot blotch was observed at five of 12 sites, but two of those (Sidi Allal Tazi and Rharb) are not located in important barley areas, so spot blotch is not yet considered a major threat to barley production. Nevertheless, its presence as the dominant disease at Boulaouane, located in an important barley area, should serve as a warning that spot blotch could become a disease of some importance to barley production in Morocco.

Total AUDPC permits rapid comparison of leaf damage among sites and cultivars. However, similar totals do not necessarily lead to similar yield losses as the impact on yield of different diseases can be unique.

Merchouch, Tadla, and Tessaout are the principal sites for selection in the barley improvement program, yet selection for disease resistance might be more efficient if done at other sites. During years 2 and 3, Sidi Allal Tazi was the single best site for combined net blotch, spot blotch, and powdery mildew development. Tangier and Settat were best for leaf rust, while Tadla was best for BYDV. Yield loss data on Rabat 071 suggest that barley diseases were a constraint to production in several regions of Morocco where barley is cultivated (Boulaouane, Jamaa Shaim, and Merchouch). Severe losses at Sidi Allal Tazi and Rharb do not generate the same concern as losses from other locations as these sites are not important barley growing areas. The ANOVA was unable to detect small yield differences which suggests that refinements in experimental technique might reveal cultivar differences.

This study shows that in relatively poor yield environments, yield of barley cultivars and lines do not differ. As environments improved, however, differences among cultivars emerged and then principally in the presence of disease. When disease was a factor in the EI, cv. 905 and the line ER/APM yielded more than did the principal cvs. Rabat 071 and 895. The advantage of 905 and ER/APM appears to be their resistance to net blotch development even though 905 is susceptible to severe infection late in the season. If the incidence and severity of spot blotch increases, however, that advantage would be lost as both cultivars are susceptible.

Similar standard errors of the estimate among cultivars and lines indicate a certain yield stability across environments (5). That is, among cultivars and lines tested, there appears to be a common genetic elasticity to the environment. However, yield stability as measured by regression coefficients for cultivar yield regressed on EI indicated that ER/APM and 905 responded more rapidly ($b > 1$) than all other cultivars and lines tested in the presence of disease (Table 4) to improved environments, and that characteristic is important to Moroccan farmers. In countries where grain production is seldom in surplus and where long-term storage is not possible, cultivars that yield relatively the same over a range of environments ($b = 1$) would have an advantage over those that perform relatively well under adverse conditions but less well in favorable environments. However, in Morocco, on-farm, long-term storage is possible but surpluses are rare. Cultivars with regression coefficients >1, therefore, would respond to improved environments and favorable seasons.

The impact of diseases on bread wheat production is in marked contrast to the importance of disease to barley yields. All bread wheat cultivars except Tegey 32 and all lines were susceptible to severe yield loss even though mean yield loss was 5.6% or less. As well, there was no yield loss at seven of 10 sites where yield data were taken. Mean yield losses were 24.6 and 11.1% at Sidi Allal Tazi and Rharb, respectively, but as with barley those losses are not indicative of losses in areas where bread wheat is a major crop. Septoria leaf blotch was the dominant disease on bread wheats and occurred on all cultivars and lines and at most sites. Among cultivars there was little difference in AUDPC with only development on Tegey 32 being different from development on cvs. Nesma and Siete Cerros. AUDPC for Septoria leaf blotch exceeded five at only two sites, Sidi Allal Tazi and Rharb, and those sites are located along the Atlantic coast where cereals do not predominate. In the principal cereal areas represented by all other sites, AUDPC was five or less, indicating that Septoria leaf blotch is a disease principally of coastal areas and although found in all but the lowest rainfall areas (Tessaout, Souss, and Annaceur), mean development was negligible during the study. Leaf rust occurred at all sites except Annaceur and was primarily a disease of cultivars. The Moroccan cereal improvement program has successfully selected for resistance to leaf rust as no disease was observed on the new cultivar, Jouda, yet leaf rust development on some promising, advanced lines (1723, 1724, and 1725) was similar to that observed on Nesma, a susceptible cultivar. Other diseases appeared to have a negligible impact on bread wheat production as AUDPC seldom exceeded 1 on any cultivar/line or at any site.

Septoria leaf blotch and leaf rust were more severe at Sidi Allal Tazi and Tangier, respectively, than at Merchouch, the principal site for cultivar selection. By moving the disease resistance program to Sidi Allal Tazi and Tangier, therefore, a more rigorous test of promising lines to disease would be achieved.

In relatively poor environments (minimum EI value), bread wheat cultivars did not differ in yield, but as environments improved, differences among cultivars and lines were noted. In the absence of disease, Jouda, 1723, and 1724 outperformed Nesma, the dominant cultivar, but performed similarly to Siete Cerros, another popular cultivar. Only 1723 was superior to Nesma in the presence of disease, probably because development of Septoria leaf blotch, the principal bread wheat disease, was less on 1723 than on Nesma. No cultivar or line yielded more than Siete Cerros in improved environments, whether disease was present or not. Some success, therefore, has been achieved by the cereal improvement program to raise the performance of bread wheats over the predominant cultivar, Nesma. Nevertheless, Siete Cerros, which has been grown in Morocco since 1967, is equal in yield performance to the recently released cv. Jouda and to lines being considered for release, in spite of its susceptibility to leaf rust and to Septoria leaf blotch.

Diseases had no impact on durum yield during the 3-yr study even though cultivars and lines were susceptible to most pathogens observed. Leaf rust and Septoria leaf blotch developed less on durums than on bread wheats, whereas, bacterial leaf streak, tan spot, and root rot appear to be primarily diseases of durums. Development of bacterial leaf streak and tan spot was less on Kyperounda than on Acsad 65 and Karim, respectively, cultivars considered as replacements for Kyperounda.

Selection for cereal disease resistance in Morocco is done entirely in the field, and our results show that more efficient selection could be done at Sidi Allal Tazi, Tangier, and Jamaa Shaim rather than at sites commonly used for cultivar selection (Merchouch, Tadla, and Tessaout). Disease, as measured by total AUDPC (by severity), was greatest at Sidi Allal Tazi where Septoria leaf blotch and tan spot predominated. Tangier appears suitable for selection to leaf rust resistance as development there was significantly greater than at Merchouch, Tadla, and Tessaout. The unique development of bacterial leaf streak at Jamaa Shaim and Rharb and BYSMV at Annaceur suggest that selection for resistance to those diseases could only be conducted there.

Cultivars and lines, regardless of disease, yielded more than the popular Kyperounda in improved environments but were similar in yield to Kyperounda in relatively poor environments. Obviously, some advancement by the cereal improvement program has been achieved to increase yield over Kyperounda, yet neither the recently released cultivar Karim nor the promising line 1718 were superior to Cocorit, a common durum cultivar in Morocco.

It is evident that Moroccan barleys and bread wheats are subject to severe yield loss from disease, but our data indicate that severe losses occur principally in areas along the Atlantic coast where crops other than cereals predominate. Where cereals predominate, mean losses were negligible to nil, suggesting that the impact of diseases on cereal production for the country was also negligible during the study. Observations made by the authors and by others suggest that weed competition (4) and Hessian fly were more serious threats to cereal production than diseases. Nevertheless, the widespread presence of several diseases prompts caution in assuming that selection for disease resistance is unimportant. On the contrary, the yield advantage of promising barleys is attributable to their resistance to net blotch development. New lines of bread wheat have good resistance to leaf rust, but those lines are just as susceptible to Septoria leaf blotch as the current popular cultivars. Consequently, because Septoria leaf blotch is the dominant bread wheat disease, there is little yield advantage of new lines over cultivars in the presence of disease. However, in improved environments, and in the absence of disease, several lines yielded more than Nesma. In contrast, all durum cultivars and lines tested gave higher yields than the standard, Kyperounda, in all but poor environments. Our data suggest that selection for disease resistance for all cereals be moved to Sidi Allal Tazi and Tangier rather than be retained at Merchouch and Tessaout.

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