Netherlands Journal of Agricultural Science 41 (1993) 1-11

Field evaluation and simulation of frost tolerance in Syrian durum wheat landraces

A. ELINGS[1], M. M. NACHIT

International Center for Agricultural Research in the Dry Areas (ICARDA), Aleppo, Syria

[1] Present address: DLO-Centre for Agrobiological Research, P.O. Box 14, NL 6700 AA Wageningen, Netherlands

Received 26 March 1992; accepted 16 September 1992

Abstract

Syrian durum wheat landraces were evaluated for early- and late-season frost tolerance. Populations appear to be tolerant to early frosts in January, but late frosts in March can severely damage foliage. Locally evolved germplasm presumably is well adapted to usual environmental conditions such as limited early frosts. Late frost tolerance of foliage appears to be related to minimum winter temperatures in the regions of origin, with populations from coastal regions showing highest sensitivity. In simulation studies, foliar damage within the range of observed rates, did not reduce final grain yield, whereas additional floret damage caused reduced grain yield, in combination with a similar increase in straw yield. Therefore, it appears important to give the effects of late frosts on the apex priority over the customary scoring for foliar damage.

Keywords: Triticum turgidum var. *durum*, durum wheat, agro-ecology, frost tolerance, landraces, simulation

Introduction

Low temperature is an environmental factor that may limit dry matter production of plants. Although there appears to exist a wide temperature range for optimum photosynthetic performance, Van keulen & Seligman (1987) hypothesize that average daytime temperatures below 10 °C (and above 25 °C) reduce maximum gross assimilation rate. Below 0 °C, plant growth ceases (Kirby & Appleyard, 1987). The rate of leaf initiation and appearance on the main culm are linearly related to the temperature of the shoot meristem (White et al., 1990), and therefore low temperatures will result in lower development rates and delay future development stages. Temperatures below 0 °C may have a detrimental effect on cell structures, if morphological, physiological and biochemical adaptation is insufficient (Levitt, 1980).

Low temperature tolerance is a desirable plant characteristic for autumn-sown cereals in continental and mountainous areas of the Mediterranean region, which are characterized by winter and unpredictable late frosts in spring. Stapper & Harris (1987) call the occurrence of frost the main uncertainty in the thermal regime in Syria. Landraces are a source for cold tolerance in cereal breeding, since some possess a wide genetic variation for this character.

In this paper, results are reported of an evaluation for frost tolerance of durum wheat landraces from Syria, with regard to their geographical origin. On the basis of simulation of plant growth and development at two locations characterized by different moisture availability, effects of late frosts on final grain and straw yield are discussed.

Materials and methods

Collection missions in the Syrian Arab Republic in 1987 and 1988, conducted in collaboration between the ICARDA Genetic Resources Unit and the Genetic Resources Unit of the Agricultural Research Centre, Douma, resulted in a collection of

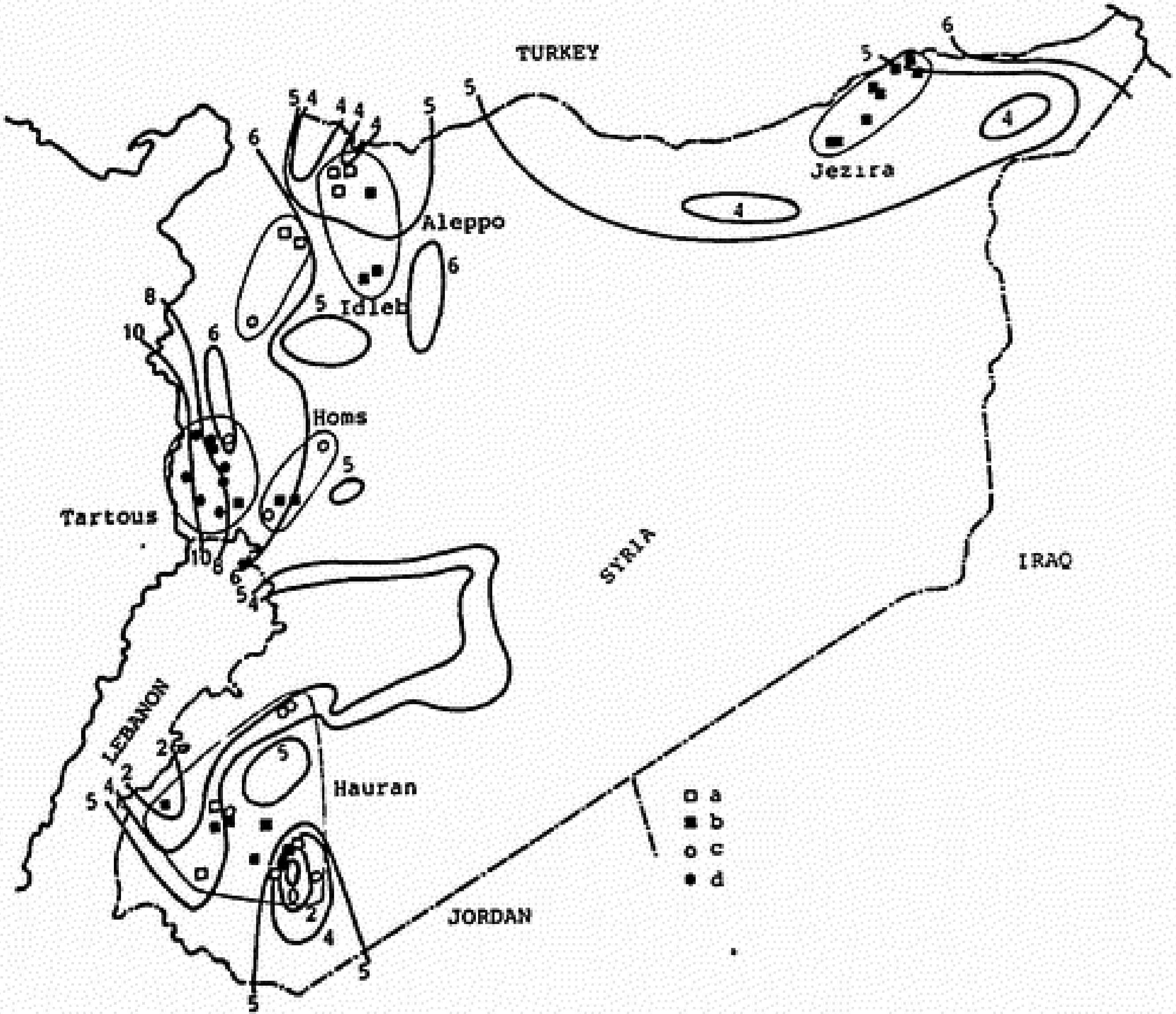

Figure 1. Sites and regions of collection, degree of foliar damage due to late-season frosts in March, and isotherms of mean minimum March temperature (°C). Collection sites are represented by letters indicating different frost damage scores: a = score 0-1.0; b = score 1.1-2.0; c = score 2.1-4.0; and d = score 4.0 or more. Isotherms (thick solid lines) of mean minimum temperatures of winter months show comparable patterns. Collection regions are indicated by thin solid lines.

durum wheat [*Triticum turgidum* L. var. *durum* (Desf.) MK] landraces (Van Slageren et al., 1989). Forty-nine populations, with their putative origin at or in the vicinity of their 45 collection sites (Fig. 1), were considered representative for their respective environments (Elings & Nachit, 1991). These were subjected to agronomic evaluation during the 1989-90 crop cycle at ICARDA's principal experimental station, located at Tel Hadya, Syria. Thirty-eight of these were also sown at the Homs Agricultural Research Station. These locations represent a low and a high yielding environment with long-term average precipitations of 330 and 425 mm, respectively (Table 1).

At both locations, the landrace populations were sown at two levels of nutrient availability. Natural fertility represented one level, the other level was created through additional nitrogen and phosphorus application. Nitrogen at a rate of 40 kg ha^{-1} for Tel Hadya and 60 kg ha^{-1} for Homs was split-dressed in equal amounts at sowing and at end of tillering, and phosphorus at a rate of 40 kg ha^{-1} for both locations was applied at sowing. The different nitrogen application levels were used to eliminate nitrogen deficiencies and achieve for the areas representative production levels, which is higher for the high rainfall site Homs.

Two replicates were sown per location, both in a randomized complete block design with landrace population and nutrient level as factors. Three control varieties were included in the experiment: Haurani-27, a local landrace; Cham 1, a variety suitable for high intput conditions; and Cham 3, a more stress tolerant variety than Cham 1. Dates of sowing and harvest are given in Table 1.

Table 1. Geographical coordinates, dates of sowing and harvest, observed precipitation, simulated crop transpiration, and observed average grain and straw yield (dry matter) for the season 1989-90, for Tel Hadya and Homs. Between brackets are given the observed average grain and straw yields on the basis of all 49 populations sown at Tel Hadya. Information is given for two levels of nutrient availability. Tel Hadya and Homs are a low and high yielding location, respectively.

	Tel Hadya		Homs	
	natural soil fertility	additional fertilizer applied	natural soil fertility	additional fertilizer applied
Longitude	36°56'E		36°43'E	
Latitude	36°01'N		34°45'N	
Date of sowing	28/11/89		11/12/89	
Date of harvest	4/ 6/90		11/ 6/90	
Long-term average precipitation (mm)	330		425	
Seasonal precipitation (mm)	234		218*	
Seasonal crop transpiration (mm)	89	89	211	213
Grain yield (kg ha^{-1})	338 (314)	267 (239)	1156	1276
Straw yield (kg ha^{-1})	1597 (1579)	1706 (1681)	4992	5180
Total dry matter production (kg ha^{-1})	1935 (1893)	1973 (1920)	6148	6456

* Residual soil moisture assumed.

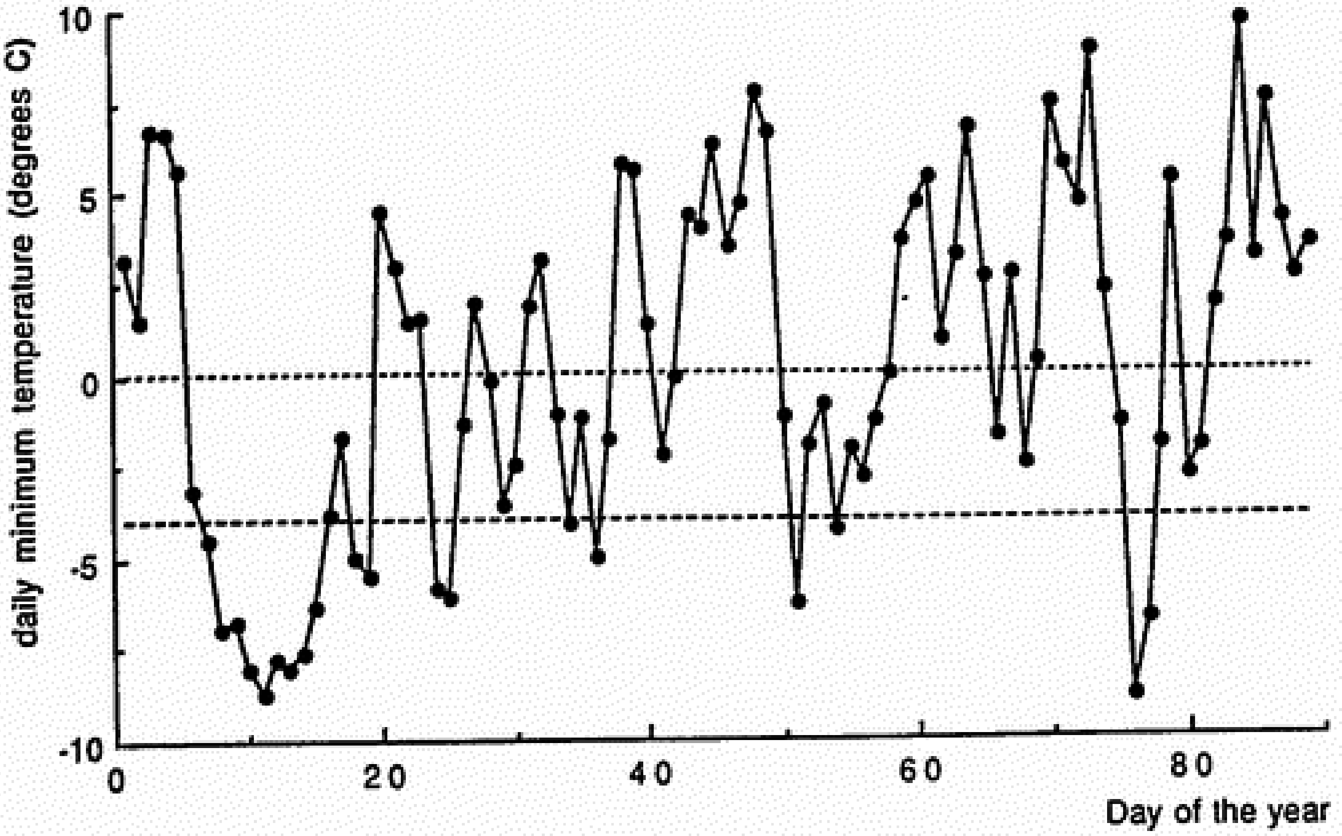

Figure 2. Daily minimum temperature at Tel Hadya, Syria, for January, February and March 1990. Horizontal lines indicate 0 °C and -4 °C, respectively.

A two-week period of below-zero daily minimum temperatures was recorded at the beginning of 1990 (Fig. 2). During the remainder of January and February a number of shorter periods with night-frosts of decreasing severity occurred. In March a one-week period of frosts occurred, with two sequential days with minima of -8.9 °C and -6.8 °C, respectively. Whereas early season frosts are characteristic for the climate at Tel Hadya, the probability of such severe frosts after mid-March may be as low as once in a century (W. Göbel, ICARDA, personal communication). The January frost period coincided with early tillering (phenological stages 21 and 22; Zadoks et al., 1974), and the March frosts occurred just before plants reached first node stage (phenological stage 31). This temperature pattern provided an opportunity to evaluate tolerance in locally evolved landrace germplasm to both early and late season frosts.

The percentage foliage damaged due to frosts was visually scored at 21 January and 21 March (day number 21 and 80, respectively). An effect of time in January was difficult to observe due to the very low levels of damage, whereas in March, the period of severe frost was too short (viz. 2 days). Frost damage was measured on a 0-9 scale: 0 = no damage, 9 = 90 % or more of the foliage damaged. One score per plot was given; herewith ignoring phenotypic variation within the genotypically heterogeneous landrace populations.

Frost damage was related to mean minimum temperatures of winter months in the regions of collection (Fig. 1), and to a classification in landrace groups (Elings & Nachit, 1991). Data on the duration of cold periods were not available. A landrace group is a subgroup within the Syrian durum wheats, as identified by farmers. Each group is characterized by some morphological traits, and by a specific geographical distribution pattern.

Reduction of grain and straw yield due to frost damage could not be determined experimentally, because of absence of a control not subjected to frost. Instead, yield reduction was estimated using a crop growth model for spring wheat (Van Keulen & Seligman, 1987) that was modified to take into account dry matter distribution between main shoot and tillers, and with respect to post-anthesis senescence as a consequence of water shortage. This model has proved to simulate a recognizable durum wheat crop and reproduce in a consistent way genotype × environment interactions and their effects on yield (Elings & van Keulen, in preparation).

Plant were assumed to possess tolerance to moderate frosts between 0 °C and -4 °C. The effect of damage due to more severe frosts was described by a fractional decline in green leaf weight and area (relative frost damage rate, FDR), for each day with a minimum temperature below -4 °C. Frost damage presumably increases with decreasing temperature. However, as temperatures below -9 °C were not observed and experimental data were insufficient to relate frost damage to temperature, FDR was assumed constant between -4 °C and -9 °C.

Growth was simulated for Tel Hadya and Homs, where 11 and 4 days, respectively, with minimum temperatures below -4 °C occurred between days 5 and 20. For both locations, late frost damage was simulated at days 76 and 77. Grain and straw yield were estimated for both levels of nutrient availability, and for increasing values of FDR, using average plant genotype data.

Whereas early in the season the apex is below the soil and protected against low temperatures, damage may occur later on. Therefore, January frosts only damage foliage, whereas in March, additional damage to florets can be expected. For January, only foliar damage was simulated. For March, the consequences of both foliar damage and additional floret damage were estimated. However, as damage to florets had not been observed, this was assumed equal to foliar damage. In the case of Tel Hadya, estimates were compared with observed yields.

Results

The January frosts caused little apparent foliar damage, viz. below 5 % in all populations. As at Tel Hadya, 11 days with severe frosts occurred between days 5 and 20, FDR values were less than 0.005. This FDR leads to similar simulated grain yield and a simulated straw yield reduction of 3 % in comparison with no frost damage. For Homs, where 4 days with severe frosts occurred in January, no grain and straw yield reduction was simulated with FDR = 0.005 for early season frosts.

With respect to foliar damage due to late season frosts in March at Tel Hadya, populations without and with additional fertilizer scored on average 2.0 and 2.5, respectively. However, this negative fertilizer effect was not significant at $P = 0.01$, and therefore all four observations per population were averaged to one population mean (Table 2). The overall average and maximum damage scores were 2.3 and 6.5, respectively. Foliar damage of 23 % and 65 % over two days imply an average and maximum FDR of 0.122 and 0.408, respectively.

Table 2. Foliar damage due to late-season frosts in March to landrace populations and control varieties. Landraces are classified per region of collection and landrace group.

	Number of populations	Frost damage*	
		mean	range
Regions of collection			
Tartous	10	4.9	2.0-6.5
Homs	6	2.1	1.3-4.3
Hauran	14	1.8	1.0-3.0
Jezira	10	1.4	0.8-1.8
Aleppo	6	1.1	0.3-1.8
Idleb	3	1.1	0.3-1.8
Landrace groups			
Baladi	14	4.0	1.0-6.5
Sheirieh	1	2.0	–
Hamari	3	1.8	1.3-2.3
Nab el Jamal	3	1.7	0.3-4.3
Haurani	18	1.6	0.8-3.0
Bayadi	5	1.5	1.3-1.8
Sweidi	4	1.5	1.0-2.3
Shihani	1	1.5	–
Overall mean	49	2.3	
Control varieties			
Haurani-27		1.5	
Cham 1		4.9	
Cham 3		3.5	

* Measured on a 0-9 scale: 0 = no damage, 9 = 90 % or more of foliage damaged.

Grouping of populations into regions of collection and landrace groups, on the basis of damage scores in March, gave in both cases a bimodal distribution. Severe foliar damage due to late frosts occurred to landrace populations originating from the coastal region of Tartous and the western littoral mountains; average scores for these and other regions were 4.9 and 1.1 to 2.1, respectively (Table 2 and Fig. 1). This corresponds with the geographical distribution pattern of the Baladi landrace group, which was collected mainly from the coastal region of Tartous, and which showed an average damage score of 4.0. Other landrace groups originated in general from other parts of the country, and scored an average of 1.5 to 2.0.

Plant growth at Tel Hadya was limited by a low seasonal precipitation of 234 mm, whereas a similar amount of 218 mm at Homs was compensated by residual soil moisture of the previous season (Table 1). Differences in moisture availability reflected in higher yield levels for Homs. Observed average grain and straw yields for Tel Hadya and Homs are given in Table 1.

Nutrient availability had a significant effect at $P = 0.01$ on grain and straw yield. Therefore, yield levels were related to frost damage separately for both nutrient conditions. FDR's derived from observed foliar damage due to March frosts, and observed grain and straw yields at Tel Hadya, for both nutrient conditions, are related in Figs. 3a and b. Linear regression on the basis of all populations (Table 3, Figs. 3a and b) indicate for both nutrient conditions a grain yield decrease and a straw yield increase with higher values of FDR. Observed yields, however, represent different populations and thus comprise a genotype and a genotype × environment interaction component, which causes wide variation.

Simulated grain and straw yield for different values of FDR due to March frosts, assuming only foliar damage, and assuming both foliar and floret damage, for the

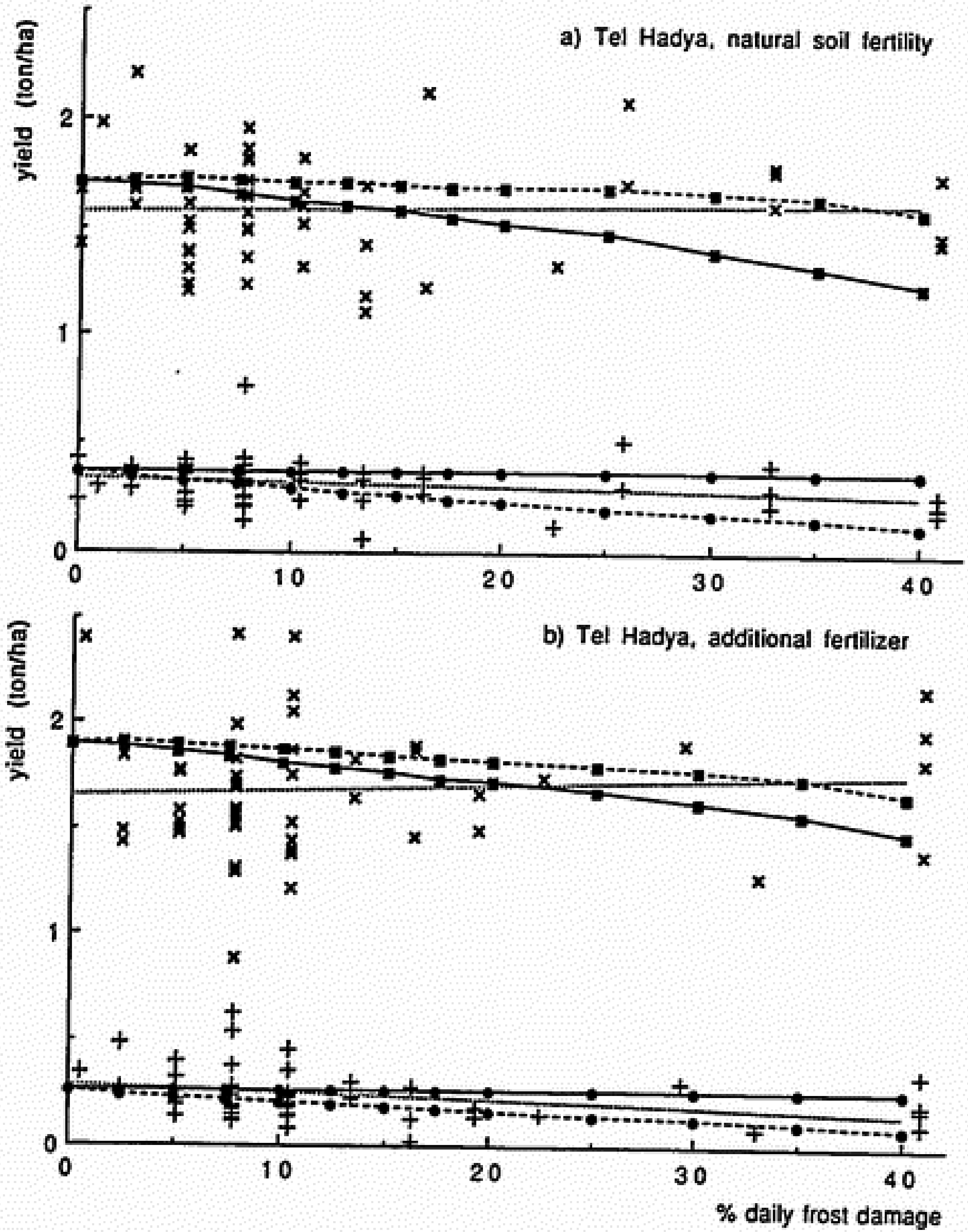

Figure 3. Observed and simulated grain and straw yields at Tel Hadya for the 1989-90 crop cycle, for different levels of daily frost damage, at natural soil fertility (a) and with additional fertilizer (b). Simulations assuming only foliar damage, and both foliar and floret damage are presented. Legend: + = observed grain yield. × = observed straw yield. ● = simulated grain yield. ■ = simulated straw yield. —— = only foliar damage simulated. ----- = both foliar and floret damage simulated. •••• = linear regression line for observed yields.

Table 3. Linear relations between yield and percentage daily frost damage, for the 1989-90 crop cycle at Tel Hadya, for both conditions of nutrient availability, determined on the basis of 49 populations.

Natural soil fertility	
grain yield = 0.3367 - 0.0018 × % daily frost damage	$r^2 = 0.032$
straw yield = 1.5645 + 0.0017 × % daily frost damage	$r^2 = 0.002$
Additional fertilizer	
grain yield = 0.2782 - 0.0031 × % daily frost damage	$r^2 = 0.065$
straw yield = 1.6435 + 0.0029 × % daily frost damage	$r^2 = 0.009$

low yielding location Tel Hadya are given in Figs. 3a and b. Simulated values correspond on the average with observed values. Simulated grain yield assuming only foliar damage is within the range of observed rates of the frost damage (viz. 0 % to 40 % per day) not affected, whereas straw yield decreases. In comparison with only foliar damage, additional floret damage causes grain yield reduction, and an increase in straw yield. This straw yield increase in slightly larger than the grain yield decrease.

For the high yielding location Homs (Figs 4a and b), no observed data on frost damage were available. Simulation of only foliar damage resulted in a small grain yield increase, due to a slightly longer grain filling period as a consequence of a longer green area duration. Straw yield decreased with higher frost damage rates. Additional floret damage caused grain yield reduction, and for both nutrient conditions at low levels of FDR a slight increase in straw yield, caused by reserve carbohydrates not translocated to the grains in combination with a slight decrease in total dry matter production. Straw yield decreased at higher level of FDR.

Discussion

Germplasm evolved in Syria presumably is well adapted to local environmental conditions. Durum wheat, since it evolved in the fifth millennium B.C. in the Fertile Crescent from cultivated emmer (Zohary & Hopf, 1988), has yearly been exposed to local temperature regimes, such as early-season frosts. The low damage caused by the early frosts in January, which were not particularly severe, suggests that prefrost acclimation was sufficient, and that tolerance has evolved naturally.

In January, the apex is below the soil and protected against low temperatures. Syrian barley landraces show variation in rate of apex development; a vernalization requirement results in low initial apex development, which leads to high levels of cold tolerance through low temperature avoidance (E. van Oosterom, ICARDA, personal communication). The same mechanism 'may be found in Syrian durum wheat landraces.

Sources of tolerance to late season frosts were found especially in Baladi landrace populations from the coastal Tartous region. Possibly, differences in the frequency of severe frosts in March between coastal and inland regions have caused different levels of tolerance. However, as the probability of severe frosts in March is very low,

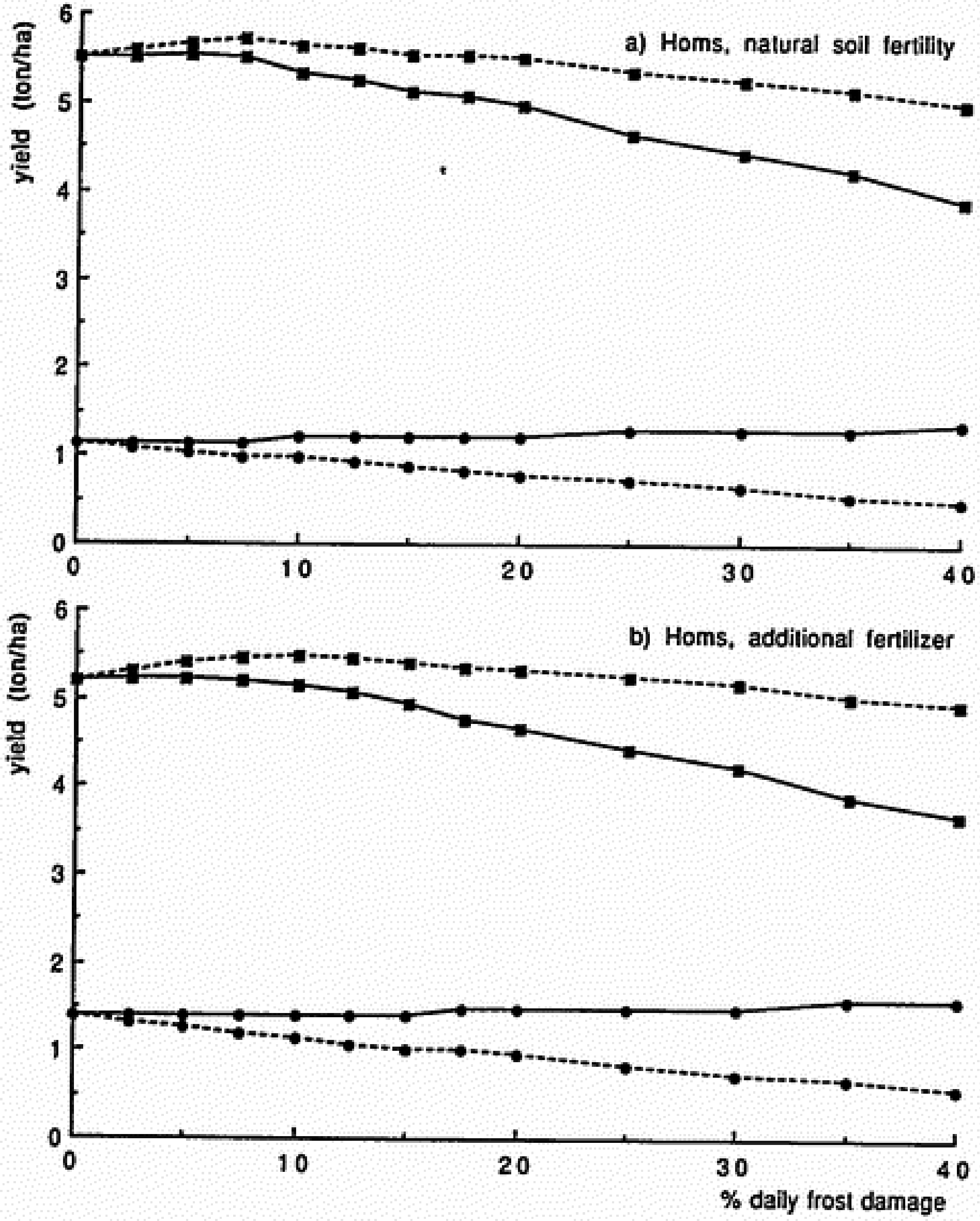

Figure 4. Simulated grain and straw yields at Homs for the 1989-90 crop cycle, for different levels of daily frost damage, at natural soil fertility (a) and with additional fertilizer (b). Simulations assuming only foliar damage, and both foliar and floret damage are presented. For legend see Fig. 3.

it is more probable that tolerance to late season frosts is determined by low temperatures during earlier winter months, which are characteristic for the Syrian climate. During the months November to March, mean minimum temperatures inland are lower than in coastal regions, which could be reflected in higher cold tolerance of germplasm originating from inland regions. Cocks & Ehrman (1987) found similar results when evaluating frost tolerance of annual legumes of Syrian origin.

In the case of Syrian barley, fertilizer application increased tolerance to early frosts (Salahieh & Abd, 1990). However, our experiments showed with respect to foliar damage a lower, but not significant tolerance to late frosts in the fertilized treatment. Also, nutrient availability had only limited influence on the relative changes in straw yield, although grain yield may be affected considerably. In the case of only foliar damage and FDR = 0.122 (the observed average), grain yield remained stable, and straw yield decreased with 3 % to 6 %. Only in the case of Homs with additional fertilizer, grain yield increased with 6 %. In the case of both foliar and floret damage, grain and straw yield changes of -18 % to -24 % and -2 % to +5 %, respectively, were observed.

In relation to grain and straw yield, frost tolerance is related to or interacts with other plant characteristics, such as development rate, dry matter distribution and grain filling duration. A vernalization requirement results in a low development rate, less injury to the apex, and limited grain yield reduction; differences in regrowth capacity of damaged foliage will result in different straw yields; and a longer grain fill can compensate for a reduced sink size. Genotypic variation in these characteristics and genotype × environment interaction caused the wide variation in yield for a given frost damage level. The consequences of different levels of frost damage for plant growth were estimated with average plant genotype data, which therefore resulted in average expected yields. This approach was suitable to gain initial understanding of effects of frost damage.

Yield reduction due to late season frost can be an effect of damage to foliage and to florets. However, with the available data, it was difficult to separate these two effects, and as floret damage had not been determined experimentally, simulation results have to be interpreted with care. Floret damage can not be excluded, as the grain fill is influenced by mainly sink-limited factors, and relatively close correlations between grain yield and kernel density have been found (Jenner et al., 1991). Comparison of observed and simulated yields is helpful in explaining the effects of frost damage. Especially simulation results with high levels of FDR indicate that observed grain yield reductions were caused by a combination of both foliar and floret damage. Simulations show that foliar damage reduces total dry matter production, whereas additional floret damage reduces the sink capacity. The decrease in grain weight is about equal to the increase in weight of reserve carbohydrates at the end of te growth cycle, which causes the increase in straw yield in comparison with only foliar damage. A different quantification of the effects of late frost on florets will result in different simulated grain yield, which, however, will not alter the fact that this is reduced by floret damage. It appears that the number of florets per m^2 influences final grain yield, and therefore, it is important to observe the effects of late frosts on the apex, in addition to the customary scoring of foliar damage.

Acknowledgments

The authors kindly acknowledge R. Rabbinge, H. van Keulen, A. C. Zeven, T. Payne, J. Goudriaan, A. van Schoonhoven and E. van Oosterom for suggestions on drafts of the manuscripts.

References

Cocks, P. S. & T. A. M. Ehrman, 1987. The geographic origin of frost tolerance in Syrian pasture legumes. *Journal of Applied Ecology* 24: 673-683.

Elings, A. & M. M. Nachit, 1991. Durum wheat landraces from Syria. I. Agro-ecological and morphological characterization. *Euphytica* 53: 211-224.

Jenner, C. F., T. D. Ugalde & D. Aspinall, 1991. The physiology of starch and protein deposition in the endosperm of wheat. *Australian Journal of Plant Physiology* 18: 211-226.

Kirby, E. J. M. & M. Appleyard, 1987. Development and structure of the wheat plant. In: F. G. H. Lupton (Ed.), Wheat Breeding. Its Scientific Basis, p. 287-311. Chapman and Hall, Cambridge.

Levitt, J., 1980. Responses of Plants to Environmental Stresses. Volume I. Chilling, Freezing and High Temperature Stresses. Academic Press, New York, 497 pp.

Salahieh, H. & R. Abd, 1990. Genotype and management effects on the degree of frost damage to barley in northern Syria. *Rachis* 9: 31-32.

Stapper, M. & H. C. Harris, 1989. Assessing the productivity of wheat genotypes in a Mediterranean climate, using a crop-simulation model. *Field Crops Research* 20: 129-152.

Van Keulen, H. & N. G. Seligman, 1987. Simulation of Water Use, Nitrogen Nutrition and Growth of a Spring Wheat Crop. Simulation Monographs. Pudoc, Wageningen, 310 pp.

Van Slageren, M. W., A. Elings, L. Holly, B. Humeid, A. A. Jaradat & Kh. Obari, 1989. Cereals, food legumes and their wild relatives in Syria and Jordan. *FAO/IBPGR Plant Genetic Resources Newsletter* 80: 5-14.

White, P. J., H. D. Cooper, M. J. Earnshaw & D. T. Clarkson, 1990. Effects of low temperatures on the development and morphology of rye (*Secale cereale*) and wheat (*Triticum aestivum*). *Annals of Botany* 66: 559-566.

Zadoks, J. C., T. T. Chang & C. F. Konzak, 1974. A decimal code for the growth stages of cereals. *Weed Research* 14: 415-421.

Zohary, D. & M. Hopf, 1988. Domestication of Plants in the Old World. Claredon Press, Oxford, 249 pp.