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Seasonal Drought Response of Selected Wheat Cultivars[1]

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ABSTRACT

The relationship between seasonal plant water status and final yield as affected by cultivar is not well documented in wheat. In a 2-year field experiment, plant water status measurements were used to compare the drought response of selected wheat cultivars. Yield, xylem pressure potential (Ψ_x), adaxial leaf diffusive resistance (R_s), and soil water content (Θ) were monitored. Twelve cultivars of *Triticum aestivum* L. em Thell and *T. durum* Desf., and two of *Tritosecale* wittmack were used. Genotypes with lower seasonal Ψ_x generally had higher percent yield reduction, when yield was expressed as a percent of irrigated controls. Water use during the observation period in the second season was similar for all droughted treatments and cultivars (about 17 cm H_2O) which was less than half that of the irrigated controls (44 cm H_2O). Late in the second season, Ψ_x decreased to as low as −47 bars in some treatments. Correlation between midday Ψ_x and yield (absolute or percent of control) for individual cultivars were highly significant. The importance of full night Ψ_x recovery to near zero was apparent since for three cultivars studied intensively, 80% of the yield difference between nonstressed controls and stressed treatments had already accrued when presunrise Ψ_x decreased to −7 bars. Further reduction of predawn Ψ_x to −38 bars was associated with only an additional 20% of the yield loss. Observations of R_s proved relatively insensitive to cultivar differences in these severely arid conditions.

Additional index words: Plant water potential, Diffusive resistance, Yield, Drought, *Triticum aestivum*, *Triticum durum*.

A variety of approaches have been developed and reviewed to identify drought resistance in cereals (6, 7, 8, 17, 18, 21, 26, 28, 32). However, these can involve tedious procedures that may have limited applicability for field comparisons involving numerous entries. The pressure chamber (9, 27) provides a tool for rapid field surveys of xylem pressure potential (Ψ_x) in plants. It has been shown by various workers (1, 2, 5, 15, 16) that total plant water potential (Ψ_T) is approximately equal to Ψ_x under most conditions. There are only a few reports of field experiments relating Ψ_x to yield as an index of drought resistance among cultivars (12, 13, 19).

We took this approach in a 2-year field study to initially survey 14 cultivars for differences in drought response as determined primarily by Ψ_x and adaxial

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Table 1. Genotypic descriptions, with observations of 50% heading for each cultivar for stress treatment, height, and general maturity type.

	Julian date of 50% heading						Height	Awns	Maturity type	Year used	Remarks
	1973		1974								
	C†	M	C	L	M	S					
Bread wheats											(*T. aestivum* L. em. Thell)
Yecora 70	65	--	61	56	63	75	S‡	*	E-M§	1, 2	Mexican triple dwarf
7 Cerros 66	73	--	63	57	67	77	M	*	M-L	1, 2	Mexican double dwarf
Pitic 62	75	--	--	--	--	--	M	*	M-L	1	Mexican single dwarf
Gabo	75	--	62	55	62	76	T		M	1, 2	Australian tall variety
T64-2W	76	--	63	55	65	76	T		L	1, 2	Tunisian winter × spring cross using Etoile de Choisy as winter parent. Pedigree: K338-EdeChx Koudiat 17-Kt-Y T64 2W
Ciano 67	60	--	54	41	54	66	M	*	E	1, 2	Mexican double dwarf
Cajeme 71	76	--	70	61	64	81	S	*	L	1, 2	Mexican triple dwarf
Kloka	79	--	--	--	--	--	T		M-L	1	German tall variety
Nainari 60	79	--	--	--	--	--	T	*	M-L	1	Mexican tall variety
Durum wheats											(*T. durum* Desf.)
Cocorit 71	64	--	61	55	62	73	M	*	M	1, 2	Mexican double dwarf
Jori 69	69	--	--	--	--	--	M	*	M	1	Mexican double dwarf
D67-3	61	--	55	45	55	66	M	*	E	1, 2	Tunisian selection of dwarf stature and very erect leaves. Pedigree: D67-3-IM-OB-2Y-Om
Triticales											(*Tritosecale* Wittmack)
Armadillo	69	--	63	57	64	77	T	*	M	1, 2	Tall CIMMYT Mexican line Pedigree: X308-6Y-2M-100Y
Maya II	--	--	62	58	63	76	M	*	M	2	Semi-dwarf CIMMYT Mexican line. Pedigree: X2802-58N-2M-ON

† For stress treatment C = control, L = light, M = moderate, and S = severe.
‡ For height S = short, M = medium, and T = tall.
§ For maturity type E = early, M = medium, and L = late.

leaf diffusive resistance (R_s). Three cultivars were studied intensively — 'Yecora 70' and 'Gabo' (*T. aestivum* L. em Thell), and 'Cocorit 71' (*T. durum* Desf.). The remaining entries were surveyed less frequently. As shown previously (3, 30) Ψ_x and R_s remain essentially constant on diurnal response curves for several hours around solar noon on clear, calm days. Thus, with adequate replication and random sampling, many midday measurements can be made and compared for several hours each day of measurement. Daily and weekly averages can subsequently be compared and related to yield to determine relative treatment and cultivar response to stress. Measurements of Ψ_x made before sunrise can also be made to determine and compare maximum diurnal recovery from stress.

MATERIALS AND METHODS

Studies were conducted in the winter and spring of 1972-1973 and 1973-1974, at the Centro Investigaciones Agricolas Noroeste (CIANO) Station of the Instituto de Investigaciones Agricolas, Secretaria de Agricultura, Mexico, field station in Ciudad Obregon, Sonora, Mexico, in cooperation with Centro Internacional de Mejoramento de Maiz y Trigo (the International Maize and Wheat Improvement Center (CIMMYT)).

The soil (not classified) was reddish and high in montmorillonitic clay (> 50%). The soil cracked deeply upon drying and slight texture changes (coarser) and calcium carbonate accumulation occurred from the 95 to 100-cm depths, suggesting this soil might be a chromoxerert or a vertic camborthid.

Bulk density (ρ_b) and water retention were determined. During the first year, neutron-probe monitoring of Yecora 70, Gabo, and Cocorit 71 was attempted, however, instrumentation failure at this remote location prevented data collection. In the second year, these same cultivars were instrumented with soil psychrometers in all treatments, and with mercury scale tensiometers in the control (well-irrigated) plots, and monitored periodically. Soil water content of the surface 25 cm was determined gravimetrically. Soil water content and soil water potential were computed from the individual calibration curves of each psychrometer and from the soil water retention curves and ρ_b expressed in equation form as

$$\Theta = a\Psi_s^{\,b} \qquad [1]$$

Theta (Θ) is volumetric water content, Ψ_s is soil water potential in bars, and a and b are constants. Available soil water (−0.3 to −15 bar) was estimated to be 14.4 cm in the surface 1 m.

Descriptions of cultivars are presented in Table 1. The cultivars, Gabo, Yecora 70, and Cocorit 71, were observed more intensely than the others. These three represent a range of drought response determined by yield in earlier field studies (14).

Both years employed a split plot design in a Latin square. Three stress levels were created by varying planting dates while holding the date of final irrigation constant; therefore, plants matured later with respect to the last irrigation in each progressively severe treatment. Control plots were watered periodically throughout the season, giving four soil-water levels which were replicated four times. Prior to the last irrigation (treatment initiation), cool weather prevailed both years and all plots were well watered. Irrigation and cultural data for the two seasons are briefly summarized below:

1972-73

Treatment	*Planted*	*Irrigated*
1. Control	9 Dec.	9, 25 Dec.; 24 Jan.; 10 Feb.; 13, 31 Mar.; 18 Apr.
2. Light Stress	24 Nov.	24 Nov.; 20 Dec.; 24 Jan.; 10 Feb.
3. Mod. Stress	9 Dec.	8, 26 Dec.; 24 Jan.; 10 Feb.
4. Severe Stress	20 Dec.	22 Dec.; 24 Jan.; 10 Feb.

Genotype subplots were nine 30-cm spaced rows, 2.5 m in length. Rows were in north-south alignment. Seeding rate was at 80 kg/ha. Fertilization was 100 kg/ha N (ammonium nitrate) and 80 kg/ha P_2O_5 (triple phosphate). In addition to

Table 2. Mean seasonal Ψ_x for pre-sunrise and midday observations. Each value in the first year's data is the mean of four or 10 dates for pre-sunrise and midday observations, respectively, with four replicates per date. Each value in the second year's data is the mean of six or nine dates for pre-sunrise and midday observations, respectively, with four replicates per date.

First year seasonal Ψ_x for three cultivars

Cultivar	Pre-sunrise Ψ_x (−bars) Treatment Control	Pre-sunrise Moderate	Midday Ψ_x (−bars) Treatment Control	Midday Moderate
Yecora 70	3.6 a*	9.8 c	16.9 e	25.6 g
Cocorit 71	2.5 ab	6.1 d	15.2 f	23.9 gh
Gabo	2.1 b	4.7 d	14.2 f	21.8 h
Mean**	2.7	6.9	15.4	23.8

Second year seasonal Ψ_x for three cultivars

Pre-sunrise Ψ_x (−bars)

Cultivar	Treatment Control	Light	Moderate	Severe
Yecora 70	2.0 a	13.8 b	12.6 c	9.8 d
Cocorit 71	1.7 a	17.2 b	13.2 c	12.0 d
Gabo	2.4 a	14.0 b	12.1 c	6.8 e
Mean	2.1	15.0	12.6	9.5

Midday Ψ_x (−bars)

Cultivar	Treatment Control	Light	Moderate	Severe
Yecora 70	16.5 a	32.2 b	32.1 d	31.7 f
Cocorit 71	17.6 a	38.3 c	35.7 e	36.1 g
Gabo	17.2 a	33.1 b	33.4 de	30.4 f
Mean	17.1	34.5	33.8	32.7

* Numbers in the same column followed by the same letter are not different at the 5% level of probability as determined by Duncan's Multiple Range Test.

** Means of controls differed from stressed means both years at the 1% level of probability or better as determined by F-test.

irrigation, light rain, totaling 45 mm, was recorded between planting and the cutoff of irrigation on 10 February, followed by significant rainfall 20 to 21 February (37 mm), 13 March (8 mm), and 6 April (15 mm).

1973-74

Treatment	*Planted*	*Irrigated*
1. Control	6 Dec.	6 Dec.; 19 Jan.; 4, 23 Feb.; 16, 29 Mar.
2. Light Stress	24 Nov.	24 Nov.; 19 Jan.; 4 Feb.
3. Mod. Stress	6 Dec.	6 Dec.; 19 Jan.; 4 Feb.
4. Severe Stress	18 Dec.	18 Dec.; 10 Jan.; 4 Feb.

In the second year, row length was increased to 3 m and seeding rate reduced to 60 kg/ha. Fertilization was 50 kg/ha N (ammonium nitrate) and 60 kg/ha P_2O_5 (triple phosphate). Only 1.4 mm of measureable precipitation was recorded in this year on 20 March. Detailed meteorological data are available elsewhere (29). In the second season, the amount of water applied to controls was estimated from tensiometer data and soil water release curves to be 13 to 15 cm per irrigation. This estimate is similar to one derived earlier at a nearby site in a study which also indicated that drainage in this high clay content soil is negligible (31).

Roots were sampled in the 1973-1974 trial from 7.6 cm diameter soil cores. Washed roots were collected on fine-mesh screens, removed, dried, and weighed.

Plant water status measurements included xylem pressure potential (Ψ_x) and adaxial diffusive resistance (R_s) of flag leaves. Techniques were outlined in detail in a previous paper (30). The diffusion porometer (LICOR instruments model LI205)[3] was similar to one described by Kanemasu et al. (20).

[3] Mention of product names is for description only, and does not imply any endorsement.

Table 3. Seasonal R_s for three cultivars in the second year. Each value is the mean of four midday observation dates with four replicates per treatment per date. Each replicate is the mean of two observations.

Cultivar	Control	Light	Moderate	Severe
	s/cm			
Yecora 70	14.1 ab*	33.0 c	32.3 d	35.7 e
Cocorit 71	13.3 b	54.5 c	34.1 d	38.0 e
Gabo	16.9 a	36.3 c	31.4 d	27.1 e
Mean**	14.8	41.3	32.6	33.6

* Numbers in the same column followed by the same letter are not different at the 5% level of probability as determined by Duncan's Multiple Range Test.

** Means of controls differed from stressed means both years at the 1% level of probability or better as determined by F-test.

It was calibrated over a range of temperatures on porous plates with known diffusive resistances. All values of Ψ_x and R_s reported in this paper were made following achievement of full canopy cover. More detailed descriptions of canopy development are available elsewhere (29).

RESULTS AND DISCUSSION

Intensive Study of Three Cultivars

Except for Yecora 70, complete cultivar comparisons were only made for control and moderate stress treatments in the first season. Rain interfered with the earlier planted (light stress) treatment and delayed maturity of the severe stress treatment. Control Ψ_x and R_s were highly statistically different (1% level or better) than the moderate treatment (Table 2). Due to the large difference between controls and the stressed treatment, each treatment was analyzed separately for greater sensitivity, using dates of observations as an additional factorial in determining cultivar significance within each treatment. In the first season, mean Ψ_x of Gabo was highest, Yecora 70 was lowest, and Cocorit 71 was intermediate (Table 2). This ranking existed both in control and in stressed treatments, whether measured before sunrise or during midday.

Diffusive resistances (analyzed in the same fashion) within treatments were not significantly different between cultivars in the first season. The mean resistances were ranked as would be expected, however, in the light of Ψ_x observations. Mean resistance values for Yecora 70, Cocorit 71, and Gabo were 6.6, 6.4, 6.3 and 12.5, 11.9, 11.9 s/cm, respectively, for the control and moderate treatments. No additional statistical significance was achieved by treating individual observations as conductance ($1/R_s$). The seasonal mean for the three cultivars the first year are the average of five midday observation dates with four replicates per treatment per date. Each replicate was the average of two observations per replicate.

In the second season, differences between the controls and the three stress treatments were again highly statistically significant (1% level or better) for Ψ_x and R_s (Tables 2 and 3). Again, controls and each individual stress treatment were analyzed separately to determine the variation due to cultivar in each treatment. Cocorit 71 (rather than Yecora 70) had the lowest mean Ψ_x. In all three stress treatments, Ψ_x of Cocorit 71 was more negative than that of either ships) had no rust damage occurred (Table 4).

Cultivars with shallow slopes (and thus good yield maintenance) were Gabo, T64-2W, and Ciano. T64-2W and Gabo are tall, awnless cultivars that develop a waxy cuticle on abaxial flag leaf surfaces, stems, and spikes under stress. With severe stress, flag leaves curl in soda-straw fashion and become nearly vertical, with the abaxial surface of higher diffusive resistance (30) exposed. Ciano, however, "escapes" drought through earliness, maturing before onset of prolonged serious stress. In related work, Fischer and Maurer (13) concluded that tall bread wheats and barleys were the

Table 5. Mean Ψ_x from extensive survey of cultivars in bars. Each value is the mean of four replicates per date and six or three dates for Year 1 or 2, respectively.

Cultivar	Year 1†		Year 2‡			
	Controls	Moderate	Controls	Light	Moderate	Severe
Yecora 70	17.0 d*	28.4 g	17.3 hi	31.4 j	32.0 n	30.9 pqr
7 Cerros	15.1 bc	25.1 efg	16.6 h	32.8 jk	30.6 n	28.4 p
Pitic 62	16.2 cd	27.5 fg				
Gabo	13.8 ab	24.0 ef	17.7 hi	32.1 j	32.1 n	28.1 p
T64-2W	12.7 a	22.1 e	16.4 h	31.1 j	30.9 n	26.9 p
Ciano 67	16.6 cd	25.8 efg	19.8 i	31.1 j	32.1 n	32.8 qr
Cajeme 71	17.2 d	26.3 fg	17.3 hi	32.8 jk	32.8 n	29.8 pqr
Kloka	15.0 bc	25.3 efg				
Cocorit 71	14.8 bc	26.6 fg	18.2 hi	37.8 m	34.3 n	33.6 r
Nainari 60	14.8 bc	24.4 efg				
Jori 69	13.7 ab	25.5 efg				
D67-3	14.8 bc	25.7 efg	18.7 hi	30.3 j	33.8 n	33.4 r
Armadillo	13.4 ab	27.7 fg	18.6 hi	36.9 km	33.1 n	26.0 p
Maya II			17.3 hi	37.3 m	33.6 n	28.0 pq
Mean**	15.0	25.7	17.8	33.3	32.5	30.0

* Numbers in the same column followed by the same letter are not different at the 5% level of probability as determined by Duncan's Multiple Range Test.
** Means of controls differed from stressed means both years at the 1% level of probability or better as determined by F-test.
† Mean of six dates.
‡ Mean of three dates.

Table 6. Mathematical relationships for least squares best fit for Fig. 2.

Cultivar	First year				Second year			
	Y = (eqn)	A	B	R^2	Y = (eqn)	A	B	R^2
Yecora 70	A+BX	11.04	−0.14	1.000‡	A+BlnX	22.62	−5.16	0.955
7 Cerros	$A+X^B$	50.61	−0.64	1.000	A+BX	7.52	−0.11	0.973
Pitic 62	A+BX	7.79	0.10	0.992				
Gabo	A+BX	6.63	−0.08	0.995	A+BX	8.48	−0.12	0.854
T64-2W	$A+X^B$	10.08	−0.28	1.000	A+B/X	0.44	98.81	0.778
Ciano 67					A+BX	10.13	−0.17	0.889
Cajeme 71	A+BX	11.90	−0.18	0.978	A+B/X	−0.71	149.84	0.939
Kloka	A+B/X	1.34	74.41	0.941				
Cocorit 71	A+BlnX	21.89	−4.67	1.000	A+B/X	−4.63	332.37	0.966
Nainari 60	A+BX	7.61	−0.10	1.000				
D67-3†					A+BX	9.50	−0.14	0.883
Jori 69	A+BX	7.47	−0.08	0.994				
Armadillo	A+B/X	2.34	41.06	0.983	A+B/X	0.06	93.62	0.707
Maya II					A+B/X	0.40	97.28	0.838

† D67-3 is deleted from the first year's analysis because of abnormally low yield in the controls.
‡ Note: The R^2 of unity results from rounding in the fourth decimal place.

Table 7. Mathematical relationships for least squares best fit for Fig. 3.

Cultivar	First year				Second year			
	Y = (eqn)	A	B	R^2	Y = (eqn)	A	B	R^2
Yecora 70	A+BX	1.50	1.01	0.896	1/(A+BX)	0.44	−0.05	1.000
7 Cerros	$A+X^B$	−0.95	1.37	0.972	A+BX	1.15	0.68	0.988
Pitic 62	A+BX	−0.18	0.98	0.833				
Gabo	A+BX	−0.18	0.85	0.749	A+B/X	6.47	−8.99	0.993
T64-2W	$A+X^B$	6.78	−13.21	1.000‡	A+BX	0.38	0.85	0.982
Ciano 67	A+BX	3.78	0.20	0.136	A+BX	8.14	−13.43	0.997
Cajeme 71	A+BX	15.46	−44.23	0.917	A+BX	−1.99	1.48	0.994
Kloka	A+B/X	−0.65	0.93	0.870				
Cocorit 71	A+B/X	13.46	−36.01	0.932	A (BX)	0.76	0.40	0.983
Nainari 60	A+BX	−0.49	1.00	0.908				
D67-3†					A+BlnX	−1.06	4.25	0.994
Jori 69	A+BX	−1.81	1.32	0.564				
Armadillo	A+BX	1.11	0.60	0.571	A+BX	0.08	0.70	1.000
Maya II					A+BX	−0.64	1.02	0.993

† D67-3 is deleted from the first year's analysis because of abnormally low yield in the controls.
‡ Note: The R^2 of unity results from rounding in the fourth decimal place.

using 44 cm H_2O between the last common irrigation and harvest (17 February to 8 April), while the stressed treatments averaged 17 cm H_2O loss.

The importance of full Ψ_x recovery to near zero values by dawn is seen in Fig. 1. Plotting an average of each cultivar's pre-sunrise Ψ_x observations for the season against yield, one can see that most of the yield loss (irrigated yield minus stress yield) resulting from drought treatment had occurred when a pre-sunrise Ψ_x of -7 bar has been experienced. The sensitivity of yield to pre-sunrise Ψ_x probably relates to reattainment of insufficient cell turgor to induce cell expansion and growth. The -7 bar Ψ_x has been shown (22, 29, 30) to correspond with a relative turgidity of only 90% for Yecora 70. The apparent decrease in sensitivity of yield to further increased water stress has also been recognized before (13).

Extensive Survey

Midday Ψ_x was determined on selected dates each season across the entire collection of cultivars (Table 5). Statistical treatment was the same as for the previously discussed Ψ_x data. It is immediately apparent that only a few cultivars perform significantly different from the overall collection. Furthermore, the magnitude of differences are not large. The unusual cultivars are either particularly prone or resistant to stress. The data in Tables 4 and 5, when combined, demonstrate the nature of the relationships between stress and yield. Figure 2 and Table 6 present actual yield vs. lowest observed Ψ_x for each season. Strong correlations are evident. Correlations are nearly equally as strong when percent control yields or actual yield loss are used to express yield, or when mean seasonal Ψ_x is used to characterize plant water status. In Fig. 3, relative cultivar yield is presented as the least squares best fit (Table 7) of each cultivar vs. the mean of all cultivars for that treatment in a manner similar to that shown by Easton and Clements (11). Genotypes prone to yield loss are detected by slopes greater than one. The curvilinear fits indicate that sensitivity to drought varies with treatment severity for each cultivar.

Cajeme 71, Yecora 70, and Cocorit 71 have steeper slopes in Fig. 2 and 3 indicating a greater fraction of their control yield is lost to drought (particularly in going from control to the light stress) than for other cultivars. It has been suggested (4, 10) that cultivars selected exclusively under well-irrigated conditions may not perform well under water stress. One study suggested there is no relationship between height and drought resistance (19). Since the semi-dwarfs were selected for high yield under irrigation, however, the shorter cultivars may be associated with poor yield under drought for this reason. In the second season, the percent yield losses of Yecora 70, Ciano, and Cajeme were even slightly worse than immediately apparent since control yields would have been slightly higher (thus increasing the slope of these relation-

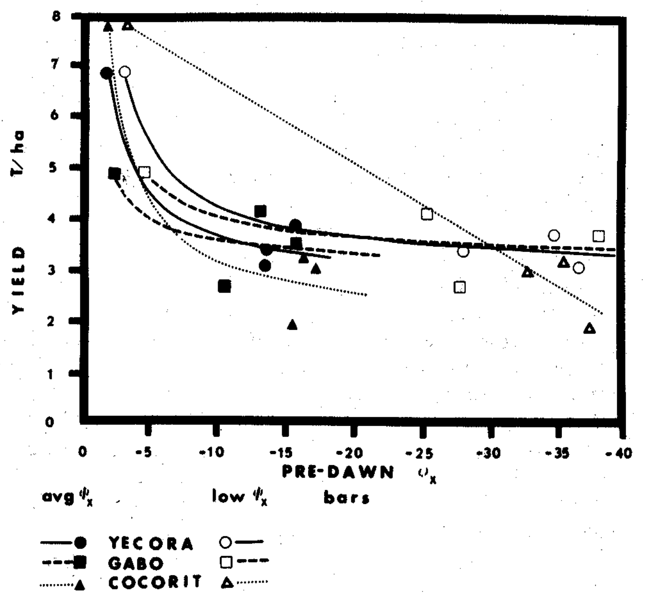

Fig. 1. Sensitivity of yield in the second season to predawn Ψ_x. Best fit of Cocorit 71 low Ψ_x in the form $y = A + Bx$ was only slightly better than the form $y = A + (B/x)$ used for other plots. The R^2 for average Ψ_x or low Ψ_x fits were: 0.973 and 0.980, 0.948 and 0.975, and 0.516 and 0.572 for Yecora 70, Cocorit 71, and Gabo, respectively. Each point is the mean of four replicates.

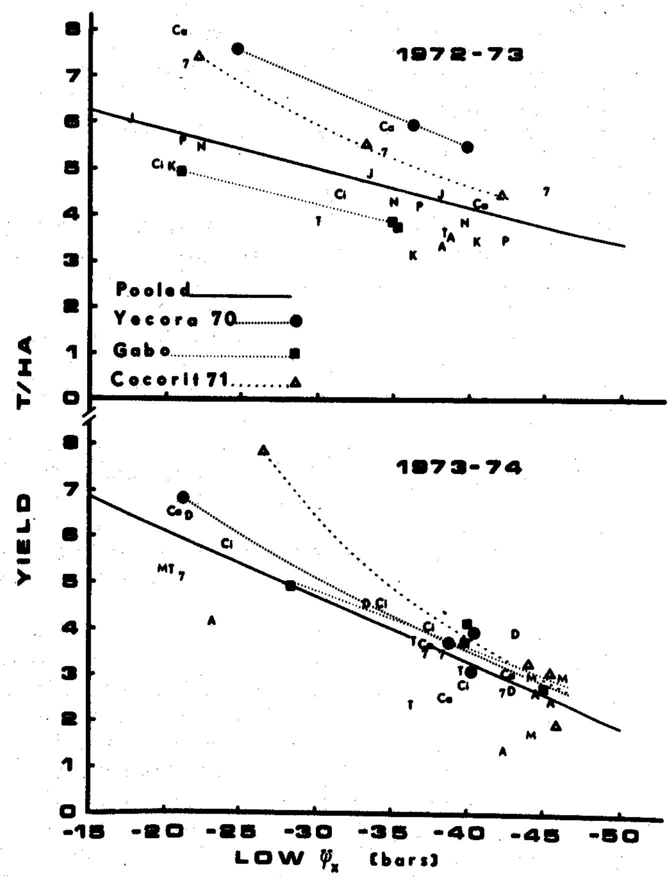

Fig. 2. Yield as a function of lowest observed midday Ψ_x. Mean R^2 for the best fit of each cultivar are 0.989 and 0.877 for the two seasons, respectively. Letter symbols A, Ca, Ci, D, J, K, M, N, P, T, and 7 represent cultivars Armadillo, Cajeme 71, Ciano 67, D67-3, Jori 69, Kloka, Maya II, Nainari 60, Pitic 62, T64-2W, and 7 Cerros 66, respectively. Each point is the mean of four replicates.

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	Controls	Moderate	Controls	Light	Moderate	Severe
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7 Cerros	15.1 bc	25.1 efg	16.6 h	32.8 jk	30.6 n	28.4 p
Pitic 62	16.2 cd	27.5 fg				
Gabo	13.8 ab	24.0 ef	17.7 hi	32.1 j	32.1 n	28.1 p
T64-2W	12.7 a	22.1 e	16.4 h	31.1 j	30.9 n	26.9 p
Ciano 67	16.6 cd	25.8 efg	19.8 i	31.1 j	32.1 n	32.8 qr
Cajeme 71	17.2 d	26.3 fg	17.3 hi	32.8 jk	32.8 n	29.8 pqr
Kloka	15.0 bc	25.3 efg				
Cocorit 71	14.8 bc	26.6 fg	18.2 hi	37.8 m	34.3 n	33.6 r
Nainari 60	14.8 bc	24.4 efg				
Jori 69	13.7 ab	25.5 efg				
D67-3	14.8 bc	25.7 efg	18.7 hi	30.3 j	33.8 n	33.4 r
Armadillo	13.4 ab	27.7 fg	18.6 hi	36.9 km	33.1 n	26.0 p
Maya II			17.3 hi	37.3 m	33.6 n	28.0 pq
Mean**	15.0	25.7	17.8	33.3	32.5	30.0

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Cultivar	First year				Second year			
	Y=(eqn)	A	B	R^2	Y=(eqn)	A	B	R^2
Yecora 70	A+BX	11.04	−0.14	1.000‡	A+BlnX	22.62	−5.16	0.955
7 Cerros	$A+X^B$	50.61	−0.64	1.000	A+BX	7.52	−0.11	0.973
Pitic 62	A+BX	7.79	0.10	0.992				
Gabo	A+BX	6.63	−0.08	0.995	A+BX	8.48	−0.12	0.854
T64-2W	$A+X^B$	10.08	−0.28	1.000	A+B/X	0.44	98.81	0.778
Ciano 67					A+BX	10.13	−0.17	0.889
Cajeme 71	A+BX	11.90	−0.18	0.978	A+B/X	−0.71	149.84	0.939
Kloka	A+B/X	1.34	74.41	0.941				
Cocorit 71	A+BlnX	21.89	−4.67	1.000	A+B/X	−4.63	332.37	0.966
Nainari 60	A+BX	7.61	−0.10	1.000				
D67-3†					A+BX	9.50	−0.14	0.883
Jori 69	A+BX	7.47	−0.08	0.994				
Armadillo	A+B/X	2.34	41.06	0.983	A+B/X	0.06	93.62	0.707
Maya II					A+B/X	0.40	97.28	0.838

† D67-3 is deleted from the first year's analysis because of abnormally low yield in the controls.
‡ Note: The R^2 of unity results from rounding in the fourth decimal place.

Table 7. Mathematical relationships for least squares best fit for Fig. 3.

Cultivar	First year				Second year			
	Y=(eqn)	A	B	R^2	Y=(eqn)	A	B	R^2
Yecora 70	A+BX	1.50	1.01	0.896	1/(A+BX)	0.44	−0.05	1.000
7 Cerros	$A+X^B$	−0.95	1.37	0.972	A+BX	1.15	0.68	0.988
Pitic 62	A+BX	−0.18	0.98	0.833				
Gabo	A+BX	−0.18	0.85	0.749	A+B/X	6.47	−8.99	0.993
T64-2W	$A+X^B$	6.78	−13.21	1.000‡	A+BX	0.38	0.85	0.982
Ciano 67	A+BX	3.78	0.20	0.136	A+BX	8.14	−13.43	0.997
Cajeme 71	A+BX	15.46	−44.23	0.917	A+BX	−1.99	1.48	0.994
Kloka	A+B/X	−0.65	0.93	0.870				
Cocorit 71	A+B/X	13.46	−36.01	0.932	A (BX)	0.76	0.40	0.983
Nainari 60	A+BX	−0.49	1.00	0.908				
D67-3†					A+BlnX	−1.06	4.25	0.994
Jori 69	A+BX	−1.81	1.32	0.564				
Armadillo	A+BX	1.11	0.60	0.571	A+BX	0.08	0.70	1.000
Maya II					A+BX	−0.64	1.02	0.993

† D67-3 is deleted from the first year's analysis because of abnormally low yield in the controls.
‡ Note: The R^2 of unity results from rounding in the fourth decimal place.

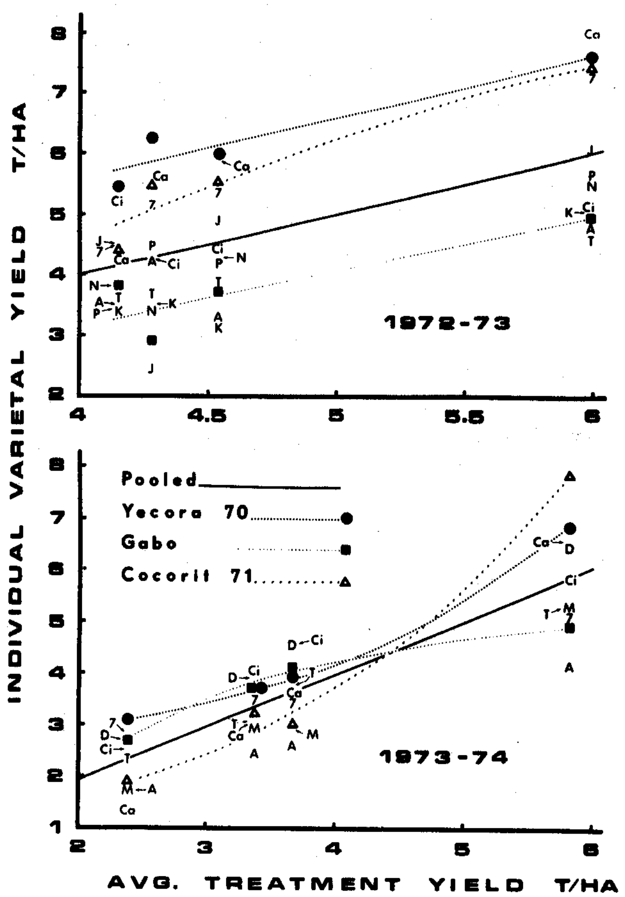

Fig. 3. Best fit of individual cultivar yield as a function of mean cultivar yield for each treatment. The pooled response best fit and the 1 to 1 response line were statistically identical. Letter symbols A, Ca, Ci, D, J, K, M, N, P, T, and 7 are the same as Fig. 2. Each point is the mean of four replicates.

most drought resistant entries, dwarf bread wheats were intermediate, and durum wheats and triticales were the most susceptible to drought. These conclusions strongly parallel the above findings.

T64-2W was unique in the selection. Its pedigree includes a spring-winter cross. Speculation on the mechanism of winter hardiness in wheat has led some researchers to hypothesize that osmotic adjustment prevents frost damage by lowering the freezing point of tissue (23, 24, 25). Osmotic adjustment may conceivably double as a drought resistance mechanism.

CONCLUSION

Wheat cultivars vary in their response to water stress. There is a high correlation between a cultivar's seasonal plant water status (Ψ_x) and its yield, which is unique to each cultivar. The slopes of these relationships at a given stress level indicate the degree of yield sensitivity (percent yield loss) to drought, and may help identify cultivars particularly prone to or resistant to yield loss from drought. Data for Yecora 70, Gabo, and Cocorit 71 are consistent with diurnal observation (30) and are relatively consistent between seasons. The cultivars Gabo and T64-2W, which maintain high Ψ_x under stress, were not semi-dwarfs, unlike most other entries. Cocorit 71, which produced the lowest Ψ_x, was a semi-dwarf. Absolute yields of the semi-dwarfs were, however, usually higher under stress than the above mentioned taller cultivars, though their percent yield loss under stress was often greater. The Mexican semi-dwarfs were probably best suited to such local factors as day length, temperature regime, specific pathogens and pests, and local soil properties since they were developed at CIANO. It must be recognized that the given traits of any one cultivar which result in a high yield potential are likely to be expressed over a large range of environmental conditions and thus produce a high baseline yield under drought. This high baseline must not, however, be confused with drought resistance. Drought resistance is better defined as the ability to minimize yield loss in the absence of optimal soil water availability. The challenge of applying these findings lies in transferring the ability to maintain percent yield under stress to cultivars with higher absolute yield levels.

Seasonal means of Ψ_x observed before sunrise were consistent in ranking with those observed at midday. The relationship observed between pre-sunrise Ψ_x and yield indicates the importance of achieving diurnal recovery to near-zero potentials. Even relatively small stresses (failure to recover to near zero Ψ_x) result in large yield losses.

The relative insensitivity of flag leaf adaxial diffusive resistance to cultivar differences under stress would seem to rule it out as a screening tool for water stress resistance in cereals. Finally, the performance of T64-2W in this experiment stimulates interest in the possible relationship between winter hardiness and drought resistance.

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