Yield and Water Relations of Pearl Millet Genotypes under Irrigated and Nonirrigated Conditions[1]

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ABSTRACT

Drought resistance in pearl millet [(*Pennisetum americanum* (L.) Leeke] makes it an important food crop in arid and semiarid regions, but research is limited on drought resistance and physiological responses to water stress. To study the relationship of pearl millet yield to physiological characteristics, 10 pearl millet genotypes were grown under irrigated and nonirrigated conditions on a silt loam soil (fine-silty, mixed mesic, Pachic Haplustoll). Leaf diffusion resistance of adaxial (LDR_{ad}) and abaxial (LDR_{ab}) surfaces, leaf water potential (ψ_L), leaf osmotic potential ($\psi_{\pi L}$), and stem osmotic potential ($\psi_{\pi s}$) of genotypes were recorded in both treatments in the afternoon (1200 to 1700 h) when the crop was water-stressed. Leaf diffusion resistance (LDR) for a leaf was calculated as $LDR = (LDR_{ad} \times LDR_{ab})/(LDR_{ad} + LDR_{ab})$. LDR_{ad}, LDR_{ab}, LDR, ψ_L, $\psi_{\pi L}$, and $\psi_{\pi s}$ observed for each genotype were averaged over the stress period and correlated with yields and yield ratios (nonirrigated yield/irrigated yield) of genotypes. Majority of genotypes studies did not differ significantly ($P<0.05$) in average afternoon LDR_{ab}, ψ_L, $\psi_{\pi L}$, $\psi_{\pi s}$, and water use (WU) in both the treatments except that genotypic differences were significant in average afternoon LDR_{ad} and LDR in the nonirrigated treatment. Grain yield was significantly correlated with LDR_{ab} in both irrigated ($r = -0.90$) and nonirrigated ($r = -0.72$) treatments, suggesting that high LDR_{ab} of genotypes is associated with low grain yield. Grain yield ratio was significantly correlated with LDR_{ab} ($r = 0.71$) and LDR ($r = 0.66$) in the irrigated treatment and with $\psi_{\pi L}$ ($r = 0.64$) and $\psi_{\pi s}$ ($r = 0.78$) in the nonirrigated treatment. Average afternoon ψ_L did not correlate with grain yield or grain yield ratio. It is concluded that average afternoon LDR_{ab} could be used to rank pearl millet genotypes for their grain yield in both stressed and nonstressed environment.

Additional index words: **Drought resistance, Leaf water potentials, Leaf osmotic potentials, Stem osmotic potentials, Water use, *Pennisetum americanum* (L.) Leeke, Drought screening.**

PEARL millet [*Pennisetum americanum* (L.) Leeke], extensively grown in arid and semiarid regions of the world, is gaining renewed attention as a crop to meet the food needs of the increasing population in these areas. It is considered to be one of the most drought-resistant cereals, but to date research on drought resistance in pearl millet or its physiological responses to water stress has been insufficient.

Various physiological indices have been used in the past to differentiate genotype response to water stress. For example, O'Toole and Moya (1978) observed significant differences among rice (*Oryza sativa* L.) genotypes for leaf water potentials. They reported that two visual scoring techniques, one based on leaf firing and the other on leaf drying, were highly correlated with leaf water potential. Quarrie and Jones (1979) reported genotypic differences in wheat (*Triticum aestivum* L.) leaves in the rate of water potential decrease. Blum (1974b) attempted to distinguish between water-saturation deficit and leaf water potential as a measure of drought avoidance among sorghum (*Sorghum bicolor* L.) genotypes. He found genotypic differences in average water-saturation deficit increase per unit decrease in leaf water potential. In other studies, wheat genotypes did not differ significantly in their maintenance of leaf water potential under stress (Fischer and Sanchez, 1979) and leaf water potentials did not correlate with yields (Kaul, 1969; Kaul and Crowle, 1971 and 1974; Jones, 1977).

Water deficit in plants has been shown to induce a lowering of osmotic potential in some species and cultivars, which contributes to the maintenance of cell turgor at low leaf water potentials. This osmotic adjustment helps the plant in the maintenance of stomatal opening, photosynthesis, and more water uptake from the soil. Genotypic differences in osmotic adjustment have been reported in wheat by Morgan (1977) and Fischer and Sanchez (1979); in sorghum by Ackerson et al. (1980); and in pearl millet by Henson et al. (1982). However, Jones and Turner (1978) and Turner et al. (1978) did not observe osmotic adjustment among sorghum or soybean (*Glycine max* L.) cultivars.

Leaf conductance or leaf permeability to water loss have also been used by various workers to compare cultivar response to water stress. Genotypic differences in leaf conductance have been reported in wheat (Jones, 1977; Kaul and Crowle, 1971 and 1974; Shimshi and Ephrat, 1975; Fischer and Sanchez, 1979); in sorghum (Henzell et al., 1975; Blum, 1974a); and in soybean (Dornhoff and Shibles, 1970). Since most of the variation in gas exchange under stress in plants is due to stomatal conductance, net photosynthesis or stomatal conductance could serve as techniques for selecting high yielding cultivars under water stress (Kaul and Crowle, 1974).

From this discussion, it should be evident that physiological differences exist among genotypes under stress, though some conflicting results have been reported. A few attempts have been made to relate changes in physiological characteristics to plant productivity or yield stability (nonirrigated yield/irrigated yield) under stress. Pearl millet was studied in the 1980 summer season with the following objectives: (1) to determine differences among pearl millet genotypes in their leaf water potential, leaf and stem osmotic potentials, leaf diffusion resistance, and water use under both irrigated and nonirrigated conditions: (2) to correlate genotypic differences in all those characteristics in both environments to crop yields and yield stability of genotypes.

MATERIALS AND METHODS

Six pearl millet cultivars (HMP 600, HMP 1700, Serere-3A, HMP 550, Senegal Bulk, and HMP 559) and four hybrids (2221 × 7024, 2221 × 4104, 2094 × 4104, and 2094 ×

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7024) were planted on 22 May 1980 at Ashland Agronomy Research Farm, Evapotranspiration Site, 14 km southwest of Manhattan, Kans. The pearl millet genotypes studied differed particularly in plant height (Table 1). The soil was a fine-silty, mixed mesic, Pachic Haplustoll that held about 250 mm of available water in the top 180 cm of soil profile. The experimental design was randomized complete block in a split plot layout with three replications. The main treatments were irrigation and no irrigation. Each main treatment area was divided into 10 equal subplots to which 10 genotypes of pearl millet (subtreatments) were randomly assigned. Each plot (7 × 10 m) had eight rows 76 cm apart. Plants within a row were thinned to 10 cm. Prior to planting, 68 kg N ha^{-1} was applied. Total rainfall received during the crop-growth period in the 1980 season was 15.6 cm (Fig. 1). Plots of the irrigated treatment were irrigated whenever slight wilting of leaves was observed. These plots received a total of 37.9 cm of irrigation split in six irrigations (Fig. 1).

Leaf water potentials (ψ_L) were estimated with a pressure chamber (Scholander et al., 1965). Two fully expanded top leaves per plot were sampled and then enclosed in a polyethylene bag containing a small piece of damp paper towel and transported to a nearby air-conditioned room where potential measurements were made. Leaf water potentials were made on all replications.

Table 1. Characteristics of pearl millet genotypes as observed in the irrigated treatment.

Genotypes	Plant height (cm)	Maximum LAI observed	Days to 50% flowering after emergence	Days to maturity after emergence
Cultivars				
HMP 600	135† ± 18*	2.9† ± 0.9*	46	76
HMP 1700	86 ± 1	4.3 ± 1.4	49	76
Serere-3A	181 ± 9	4.0 ± 1.0	52	84
HMP 550	98 ± 7	4.7 ± 1.6	46	84
Senegal Bulk	123 ± 9	4.2 ± 0.5	57	91
HMP 559	219 ± 31	5.6 ± 1.3	52	86
Hybrids				
2221 × 7024	77 ± 3	4.1 ± 0.8	46	76
2221 × 4104	105 ± 4	3.6 ± 0.2	49	84
2094 × 4104	95 ± 9	5.1 ± 1.5	52	84
2094 × 7024	82 ± 9	4.5 ± 1.0	47	84

* Standard deviation (n = 3).
† Mean over replications (n = 3).

Both adaxial and abaxial surfaces of fully expanded top leaves were measured for Leaf diffusion resistance (LDR) with a steady-state porometer (Model LI 1600[3], LI-COR, Inc., Lincoln Nebr.). These measurements were taken on two leaves per plot in all replications. The LDR for a leaf was calculated from the following relationship:

$$1/LDR = 1/LDR_{ad} + 1/LDR_{ab},$$

where LDR_{ad} and LDR_{ab} are adaxial and abaxial resistance of a leaf, respectively.

Leaf osmotic potential ($\psi_{\pi L}$) of fully expanded top leaves was observed. One leaf per plot was sampled. A 5-cm midsection of the leaf blade was immediately wiped with a moist paper towel (moistened in distilled water) and then enclosed in a disposable plastic syringe. Both ends of the syringe were sealed. These samples were frozen over dry ice for at least 24 h to rupture cell membranes. The samples were then thawed at room temperature and squeezed with a syringe plunger to release cell contents. Filter-paper discs were saturated with the cell sap and transferred to a psychrometer (Wescor C-51 Sample Chamber[3], Wescor, Inc., Logan, Utah). Leaf osmotic potential was determined after giving sufficient time for equilibrium in the chamber. After every 10 observations on leaf samples, $\psi_{\pi L}$ measurements were calibrated against standard sodium chloride solutions. To determine stem osmotic potentials ($\psi_{\pi s}$), 1-cm long stem sections were taken from the internode between third and fourth leaf from

[3] Mention of a trade mark or proprietary product does not imply approval by the Kansas Agric. Exp. Stn. to the exclusion of other products that may also be suitable.

Table 2. Day of observation and number of observations averaged to calculate various stress indices.

Stress index	Day of observation (days after emergence)	No. of observations averaged
Average afternoon LDR_{ad}	51(3)†,58,59(2),66(2),73(2)	10
Average afternoon LDR_{ab}	51(3),58,59(2),66(2),73(2)	10
Average afternoon LDR	51(3),58,59(2),66(2),73(2)	10
Average afternoon ψ_L	42,43,51(3),56,58,59(2),64,66(2),73(2)	14
Average afternoon $\psi_{\pi L}$	51(3),59,66	5
Average afternoon $\psi_{\pi S}$	51(3),59,66	5

† One observation per day was recorded between 1200 to 1700 h unless specified in parenthesis.

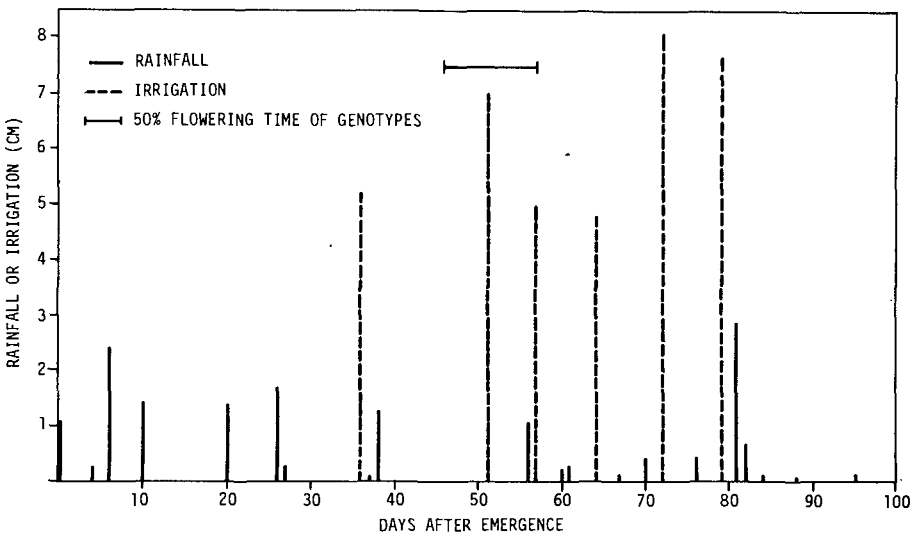

Fig. 1. Rainfall during the crop growth period and amounts of irrigation applied to the irrigated treatment plots during the 1980 season.

Table 3. Mean squares from analysis of variance for grain yield, total yield, average afternoon LDR_{ad}, LDR_{ab}, LDR, ψ_L, $\psi_{\pi L}$, $\psi_{\pi S}$, and water use.

		Mean squares								
Source of variation	Degrees of freedom	Grain yield	Total yield	LDR_{ad}	LDR_{ab}	LDR	ψ_L	$\psi_{\pi L}$	$\psi_{\pi S}$	Water use
Block	2	0.44	17.84	1.48	0.40	0.16	0.20	0.13	0.01	150.31
Irrigation	1	40.90*	1441.87**	132.08**	24.09*	11.78*	2.91	0.53**	1.51*	9146.41*
Error A	2	1.49	7.48	2.50	0.67	0.26	0.16	0.01	0.06	130.11
Genotype	9	1.53**	28.79**	6.14**	1.06**	0.38**	0.04**	0.12**	0.17**	82.79
Genotype × irrigation	9	1.00**	16.96	1.34	0.17	0.04	0.02	0.02	0.03	41.54
Error B	36	0.32	8.69	1.88	0.29	0.10	0.01	0.03	0.04	51.84

*,** Significant at 5 and 1% levels of probability, respectively.

Table 4. Mean grain yield and total yield of pearl millet genotypes in irrigated and nonirrigated treatments.

	Grain yield (t ha^{-1})			Total yield (t ha^{-1})		
Genotypes	Irri.	Non-irrig.	% Reduction	Irrig.	Non-irrig.	% Reduction
HMP 600	2.62 b*	1.86 a	28.8	16.49 d	10.71 b	35.0
HMP 1700	3.75 a	1.89 a	49.5	20.18 bcd	10.93 b	45.8
Serere-3A	2.52 c	1.20 a	52.2	22.82 abc	12.69 ab	44.4
HMP 550	3.25 abc	1.81 a	44.4	18.37 cd	10.85 b	40.9
Senegal Bulk	3.24 abc	1.33 a	59.2	26.92 a	11.30 b	58.0
HMP 559	1.28 d	1.09 a	14.2	22.79 abc	17.24 a	24.4
2221 × 7024	3.93 a	1.54 a	60.7	20.63 bcd	9.18 b	55.5
2221 × 4104	3.34 abc	1.92 a	42.4	20.96 bcd	12.90 ab	38.5
2094 × 4104	3.59 ab	1.38 a	61.6	23.97 ab	13.79 ab	42.5
2094 × 7024	4.30 a	1.27 a	70.5	25.60 ab	11.08 b	56.7

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

Table 5. Average afternoon LDR_{ad}, LDR_{ab}, and LDR of pearl millet genotypes in irrigated and nonirrigated treatments.

	LDR_{ad} (sec cm^{-1})		LDR_{ab} (sec cm^{-1})		LDR (sec cm^{-1})	
Genotypes	Irrig.	Non-irrig.	Irrig.	Non-irrig.	Irrig.	Non-irrig.
HMP 600	3.4 a	6.7 abc	1.9 ab	2.9 b	1.2 ab	2.0 bc
HMP 1700	2.9 a	5.9 bc	1.7 ab	2.6 b	1.1 ab	1.8 c
Serere-3A	4.2 a	8.9 a	2.3 ab	3.4 b	1.5 ab	2.5 ab
HMP 550	3.2 a	6.8 abc	1.8 ab	2.7 b	1.2 ab	1.9 bc
Senegal bulk	2.8 a	4.6 bc	1.5 ab	2.7 b	1.0 ab	1.7 c
HMP 559	4.1 a	6.8 abc	2.5 a	4.4 a	1.5 a	2.6 a
2221 × 7024	2.1 a	6.0 bc	1.5 ab	3.0 b	0.9 b	2.0 bc
2221 × 4104	3.1 a	4.9 bc	1.5 b	2.8 b	1.0 ab	1.8 c
2094 × 4104	2.3 a	4.2 c	1.7 ab	3.0 b	1.0 ab	1.8 c
2094 × 7024	4.2 a	7.1 ab	1.4 b	3.0 b	1.0 ab	2.1 abc

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

the top of a plant. The stem osmotic potentials ($\psi_{\pi s}$) were determined in the same manner as $\psi_{\pi L}$.

Neutron probe access tubes were installed within a plant row in the middle of each plot. Soil moisture measurements were made every week with a neutron probe (Troxler Model 380) from 15 to 165-cm depths at 15-cm depth increments. Soil moisture in the top 15-cm soil layer was determined gravimetrically. Water use by genotypes was computed by the water-balance method. No surface runoff occurred during the season.

Various indices of water stress (see Table 2) were calculated from the observations on LDR_{ad}, LDR_{ab}, LDR, ψ_L, $\psi_{\pi L}$, and $\psi_{\pi s}$. For example, average afternoon LDR_{ad} is the average of 10 LDR_{ad} observations between 1200 and 1700 h on selected days (from 51 to 73 days after emergence) during the stress period. To determine grain and total yields 9 m^2 area was harvested from the middle of each plot. Data were analysed using analysis of variance and means were separated by the Duncan's Multiple Range Test. Simple correlations of yields and yield ratios with various stress indices were calculated using treatment means.

RESULTS AND DISCUSSION

Crop Yields

Water stress in plants occurred from boot to hard dough growth stage of genotypes that significantly reduced their grain and total yields (Tables 3 and 4). Hybrids that yielded relatively high in the irrigated treatments yielded 42.4 to 70.5% less grain in the nonirrigated treatment, whereas yields of cultivars were reduced by 28.8 to 52.5%. This suggests that high-yielding genotypes undergo greater percent reduction in grain yield when stressed than low yielding genotypes. Though the genotype main effect was significant for both grain and total yields, grain and total yields of genotypes differed significantly in the irrigated but not in the nonirrigated treatment (except HMP559 which produced relatively more total yield than other genotypes). Genotype × irrigation interaction was significant for grain yield but not for total yield. This significant interaction means that yield of some genotypes is reduced to a greater degree than other genotypes under water stress.

Leaf Diffusion Resistances

Irrigation and genotype main effects for average afternoon LDR_{ad}, LDR_{ab}, and LDR were significant, whereas irrigation × genotype interactions for these stress indices were not significant (Table 3). Differences among majority of genotypes in average afternoon LDR_{ad}, LDR_{ab}, and LDR were not significant in the irrigated treatment (Table 5). However, in the nonirrigated treatment, genotypic differences in average afternoon LDR_{ad} and LDR were significant except average afternoon LDR_{ab}. The two tall cultivars (Serere-3A and HMP559) had greater average afternoon LDR than other cultivars. These results are contrary to the results reported in wheat by Fischer and Sanchez (1979). They found that at low leaf water potentials taller genotypes had higher leaf permeability than dwarf cultivars. Genotypic differences in leaf diffusion resistance were also observed in sorghum by Henzell et al. (1975) in a growth chamber study.

The LDR_{ad} of pearl millet (like sorghum, Teare and Kanemasu, 1972) was higher than LDR_{ab} (Table 5). Differences in LDR_{ad} and LDR_{ab} could be attributed to differences in the stomatal frequency on the leaf surfaces in a crop species (Teare and Kanemasu, 1972) and to the microclimatic influences on the leaves.

Table 6. Average afternoon ψ_L, $\psi_{\pi L}$, $\psi_{\pi S}$, and water use of pearl millet genotypes in irrigated and nonirrigated treatments.

	ψ_L (MPa)		$\psi_{\pi L}$ (MPa)		$\psi_{\pi S}$ (MPa)		Water use (cm)	
Genotype	Irrig.	Nonirrig.	Irrig.	Nonirrig.	Irrig.	Nonirrig.	Irrig.	Nonirrig.
HMP 600	−2.49 ab	−2.91 a	−2.19 abc	−2.39 ab	−1.62 abc	−1.89 bc	61.3 ab	36.0 ab
HMP 1700	−2.37 abc	−2.73 ab	−2.41 a	−2.39 ab	−1.85 a	−2.07 ab	58.6 ab	30.6 ab
Serere-3A	−2.43 abc	−2.87 a	−2.16 abc	−2.35 abc	−1.84 a	−2.01 ab	53.6 ab	27.9 b
HMP 550	−2.37 abc	−2.85 a	−2.00 bc	−2.24 abc	−1.66 abc	−2.14 ab	59.2 ab	34.9 ab
Senegal bulk	−2.26 c	−2.69 ab	−1.99 bc	−2.16 bc	−1.46 bc	−1.92 bc	62.0 ab	43.2 a
HMP 559	−2.32 abc	−2.60 b	−1.89 c	−2.05 c	−1.39 c	−1.60 c	64.3 a	27.8 b
2221 × 7024	−2.27 bc	−2.85 a	−2.22 ab	−2.45 ab	−1.92 a	−2.17 ab	50.1 b	33.2 ab
2221 × 4104	−2.45 abc	−2.91 a	−2.29 ab	−2.39 ab	−1.64 abc	−2.06 ab	58.8 ab	34.6 ab
2094 × 4104	−2.51 a	−2.82 a	−2.28 ab	−2.46 ab	−1.82 a	−1.98 ab	60.4 ab	36.9 ab
2094 × 7024	−2.23 c	−2.88 a	−2.09 abc	−2.52 a	−1.75 ab	−2.30 a	53.7 ab	30.0 ab

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

Table 7. Simple correlations across genotypes among average afternoon LDR_{ad}, LDR_{ab}, LDR, ψ_L, $\psi_{\pi L}$, $\psi_{\pi S}$, and water use in irrigated and nonirrigated treatments (n = 10).

	LDR_{ad}	LDR_{ab}	LDR	ψ_L	$\psi_{\pi L}$	$\psi_{\pi S}$
	Correlation coefficients† (Irrig. treatment)					
LDR_{ab}	0.56					
LDR	0.79**	0.94**				
ψ_L	0.13	−0.25	−0.17			
$\psi_{\pi L}$	0.47	0.41	0.46	0.47		
$\psi_{\pi S}$	0.34	0.30	0.36	0.16	0.72*	
Water use	0.09	0.31	0.28	−0.29	−0.33	0.79**
	Correlation coefficients† (Nonirrig. treatment)					
LDR_{ab}	0.37					
LDR	0.76*	0.88**				
ψ_L	−0.17	0.47	0.23			
$\psi_{\pi L}$	0.04	0.46	0.34	0.75*		
$\psi_{\pi S}$	−0.07	0.63	0.42	0.65*	0.75*	
Water use	−0.72*	−0.59	−0.78**	−0.03	0.08	0.00

*,** Significant at 0.05 and 0.01 levels of probability, respectively.
† Irrigation × genotype means were based to calculate correlation coefficients and each of these means is based upon three observations.

Leaf Water Potentials

Irrigation main effect for average afternoon ψ_L was not significant, whereas genotype main effect was significant (Table 3). Irrigation × genotype interaction was not significant. Although the genotype main effect for average afternoon ψ_L was significant, the majority of genotypes did not differ in their average afternoon ψ_L in both irrigated and nonirrigated treatments. In the irrigated treatment, Senegal Bulk had the highest ψ_L (less negative) while HMP600 had the lowest (more negative) average afternoon ψ_L. Similarly, hybrids 2221 × 7024 and 2094 × 7024 had higher average afternoon ψ_L than other two hybrids. In the nonirrigated treatment, hybrids did not differ significantly in their average afternoon ψ_L, while HMP600 maintained lowest average afternoon ψ_L as in the irrigated treatment. Average afternoon ψ_L of genotypes did not correlate with average afternoon LDR_{ad}, LDR_{ab}, and LDR in either the irrigated or nonirrigated treatment (Table 7). This indicates that genotypes that have low average afternoon ψ_L may not necessarily have high average afternoon LDR and vice versa.

Leaf and Stem Osmotic Potentials

Irrigation and genotype main effects for $\psi_{\pi L}$ and $\psi_{\pi s}$ were statistically significant (Table 3). Genotype × irrigation interaction was not significant for both $\psi_{\pi L}$ and $\psi_{\pi s}$. Majority of genotypes were not significantly different in average afternoon $\psi_{\pi L}$ and $\psi_{\pi s}$ in both irrigated or nonirrigated treatments. Senegal Bulk and HMP559 had relatively high (less negative) average afternoon $\psi_{\pi L}$ and $\psi_{\pi s}$ (Table 6), compared with other genotypes in both irrigated and nonirrigated treatments. Average afternoon $\psi_{\pi L}$ of genotypes did not correlate with average afternoon LDR_{ad}, LDR_{ab}, or LDR in both the irrigated and nonirrigated treatments (Table 7).

Water Use

Irrigation main effect for water use was significant, but the genotype main effect and irrigation × genotype interaction for water use were not significant (Table 3). Most of the irrigated or nonirrigated genotypes studied were not significantly different in crop-water use (Table 6). In the nonirrigated treatment, Senegal Bulk used the greatest amount of water, whereas Serere-3A and HMP559 were lowest in water use. In the nonirrigated treatment, average afternoon LDR was negatively and significantly correlated (r = −0.78) with water use, indicating that genotypes with greater water use had low average afternoon LDR (Table 8). This correlation of water use and average afternoon LDR was not significant in the irrigated treatment.

Correlation of Crop Yields with Stress Indices

In the irrigated treatment, grain yield was negatively and significantly correlated with average afternoon LDR_{ab} (r = −0.90) and LDR (r = −0.85). Grain yield ratio was significantly correlated with average afternoon LDR_{ab} (r = 0.71) and LDR (r = 0.66). Total yield did not correlate with any stress index based on leaf diffusion resistance measurements. Total yield ratio, however, was positively and significantly correlated with average afternoon LDR_{ab} (r = 0.73) and LDR (r = 0.66).

In the nonirrigated treatment, average afternoon LDR_{ab} was significantly correlated with total yield (r = 0.79) and grain yield (r = −0.72). Average afternoon LDR did not correlate with crop yields and yield ratios.

Correlation of yields with LDR suggested that genotypes with the highest transpiration rates had the highest grain yield. Consequently, selection for higher grain yields should be based on LDR measurements, however LDR_{ab} is more dependable than LDR in both the irrigated and nonirrigated conditions. In the nonstressed environment (irrigated), the stable yields of genotypes would be characterized by low conductance,

Table 8. Simple correlations across genotypes of average afternoon, LDR_{ad}, LDR_{ab}, LDR, ψ_L, $\psi_{\pi L}$, $\psi_{\pi S}$, and water use with yields and yield ratios in irrigated and nonirrigated treatments (n = 10).

	LDR_{ad}	LDR_{ab}	LDR	ψ_L	$\psi_{\pi L}$	$\psi_{\pi S}$	Water use
			Correlation coefficients† (Irrig. treatment)				
Total yield	0.11	−0.19	−0.14	0.49	0.28	0.16	−0.02
Total yield ratio	0.33	0.73*	0.66*	−0.55	0.17	0.44	0.61
Grain yield	−0.48	−0.90**	−0.85**	0.23	−0.53	−0.64*	−0.58
Grain yield ratio	0.34	0.71*	0.66*	−0.31	0.32	0.62	0.63
			Correlation coefficients† (Nonirrig. treatment)				
Total yield	0.00	0.79**	0.54	0.53	0.53	0.75*	−0.33
Total yield ratio	0.15	0.54	0.48	0.20	0.44	0.71*	−0.34
Grain yield	−0.26	−0.72*	−0.59	−0.45	−0.29	−0.31	0.25
Grain yield ratio	0.19	0.51	0.48	0.34	0.64*	0.78**	−0.25

*,** Significant at 0.05 and 0.01 levels of probability, respectively.
† Irrigation × genotype means were used to calculate correlation coefficients and each of these means is based upon three observations.

a hypothesis supported by the positive and significant correlation of grain yield ratio with average afternoon LDR_{ab} and LDR in the irrigated treatment (Table 8). Similar correlations of LDR or leaf permeability with yield have been reported in sorghum by Blum (1974a) and in wheat by Shimshi and Ephrat (1975).

Average afternoon ψ_L did not significantly correlate with total yield, grain yield, total yield ratio, or grain yield ratio in either irrigated or nonirrigated treatment. These results are consistent with those obtained by earlier workers in other crops (Kaul, 1969; Kaul and Crowle, 1971 and 1974). Similarly, $\psi_{\pi L}$ did not correlate with any yield or yield ratio in either treatment except that grain yield ratio was positively and significantly correlated (r = 0.64) with average afternoon $\psi_{\pi L}$ in the nonirrigated treatment.

In the nonirrigated treatment, average afternoon $\psi_{\pi s}$ was significantly correlated with total yield (r = 0.75), total yield ratio (r = 0.71), and grain yield ratio (r = 0.78); but did not correlate with grain yield (r = −0.31). This suggests that genotypes that maintained high (less negative) average afternoon $\psi_{\pi L}$ and $\psi_{\pi s}$ under water stress had high yield stability, but may not be high in grain yield. In the irrigated treatment, correlations of yields and yield ratios with average afternoon $\psi_{\pi s}$ were not significant except that grain yield was negatively and significantly correlated with average afternoon $\psi_{\pi s}$ (r = −0.64).

From this study it is concluded that leaf conductance rather than plant water status (leaf water potential) is positively correlated with grain yield in both stressed and nonstressed environments. Genotypes that have low conductance in nonstressed environment or that have high leaf and stem osmotic potential in stressed environment have greater grain yield stability.

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