Line-Source vs. Irrigated/Nonirrigated Treatments for Evaluation of Genotype Drought Response

V. Mahalakshmi,* F.R. Bidinger, and G.D.P. Rao

ABSTRACT

The need for efficient and effective screening for drought response of crops is well recognized. The line-source sprinkler technique used in many crop breeding programs to evaluate genotype response to drought stress has the advantage over the traditional irrigated/nonirrigated or uniform plot technique in that it creates a continuous range of moisture deficits which permit the estimation of genotype response. In situations where the response is linear, however, the line source may not provide additional information compared to that available from the uniform plot, if both techniques sample the same range of moisture deficits. Field experiments were conducted over 2 yr to compare both screening techniques for evaluating genotype response of pearl millet [*Pennisetum glaucum* (L.) R. Br.] to water deficit at grain filling. The soil was an Alfisol (Udic Rhodustalf) with approximately 60 mm of plant-available moisture. Mean grain yields for individual positions along the moisture gradient in the line source, and means over genotypes for each replicate in the uniform plot were used as independent variables (environment means) to estimate individual genotype stress response by regression. Predicted genotype grain yield at 250 g m^{-2} mean yield and genotype regression coefficients were compared. There were no differences in the estimated genotype grain yields at 250 g m^{-2} mean grain yield from the two techniques in either year. Slopes differed in only four of the 32 genotypes in 1982 and two of the eight genotypes in 1984. When genotype response to the stress gradient is linear, the simpler uniform plot technique can be used for preliminary genotype evaluation with little loss of information.

IMPROVED DROUGHT TOLERANCE is a major objective in plant breeding programs for rainfed crops in semiarid regions. A common procedure for evaluating drought response of cultivars is to evaluate the relative performance of cultivars in locations where drought stress is likely to occur (Eberhart and Russell, 1966). This procedure is dependent on year-to-year changes in weather and often is extremely time consuming. Recently the line-source sprinkler irrigation technique which delivers a continuously and linearly declining amount of water (Hanks et al., 1976) has been used extensively for screening of crop genotypes (Garrity et al., 1982; Cruz and O'Toole, 1984; O'Neill et al., 1983). This technique has the advantage of creating different irrigation deficit levels in a small area, as there is no need for a buffer area around each treatment since the incremental change in water applied between adjacent treatments is small. Although the soil moisture environments produced by this technique are not randomized, it is possible to construct and compare genotype response functions (Hanks et al., 1980).

The traditional comparison of irrigated/nonirrigated plots (uniform-plot technique) provides data only on the extremes of the range of soil moisture environments created by the line source. Ideally a genotype function fitted to the extremes of the line source, or to the irrigated/nonirrigated uniform plot treatments, may not differ from the function derived from the entire line source data set in situations where genotype response is linear. In situations where the response is nonlinear, the line source does provide the needed additional information. The use of this technique is more complicated than the use of the uniform plot technique, particularly where wind causes uneven water distribution patterns, and irrigations must be done at night. If genotype response to water is linear, as is often reported (Aragon and De Datta, 1982; Garrity et al., 1982; Seetharama et al., 1987; Mahalakshmi et al., 1988) then the simpler uniform plot techniques might serve equally well as the line source, at least for preliminary genotype evaluation. This hypothesis was tested in two comparisons of the uniform plot and line source techniques in which we measured grain yield response of different pearl millet [*Pennisetum glaucum* (L.) R. Br.] genotypes to drought stress during grain filling. Previous evaluations of this crop in this type of stress have indicated a linear response of yield to stress (Mahalakshmi et al., 1988).

MATERIALS AND METHODS

The experiments were conducted in the field during the 1982 and 1984 dry seasons (January–May) at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) (17°30'N and 78°16'E). The soil was an Alfisol with approximately 60 mm of available plant moisture. Since this is a rain-free period, the crop was fully irrigated except during the treatment periods.

The 1982 comparison consisted of two separate but adjacent experiments: the first was a line source irrigation experiment beginning at flowering (described in Mahalakshmi et al., 1988). The second experiment was an irrigated/nonirrigated comparison with two treatments viz., a furrow-irrigated control and a terminal-water-stress treatment imposed by withholding irrigation from flowering to maturity. The design in the latter experiment was a modified split-plot (strip) design.

In 1984, the comparison was carried out in a single, replicated experiment. In addition to the three treatments used in 1982, a fully irrigated control treatment by sprinklers was also included to simulate the rows adjacent to the line source receiving maximum irrigation. In 1982 there were two replicates in the line source (on either side of the sprinkler) and four replicates in the uniform plot experiment, spread along a known soil gradient in a noncontinuous pattern. In 1984 the four treatments were arranged in a modified split (strip)-plot design with four replicates (Fig. 1). The sprinkler irrigated control treatment was arranged between the two sprinkler lines of the line source treatment which were 12 m apart (Fig. 1). Genotypes were randomly allocated within all treatments. The line source created nine irrigation deficit environments arranged in strips on either side of the sprinkler line. Each irrigation deficit treatment consisted of two adjacent rows 0.75 m apart. The subplot (genotype) unit in the line source consisted of two adjacent rows of 2-m length

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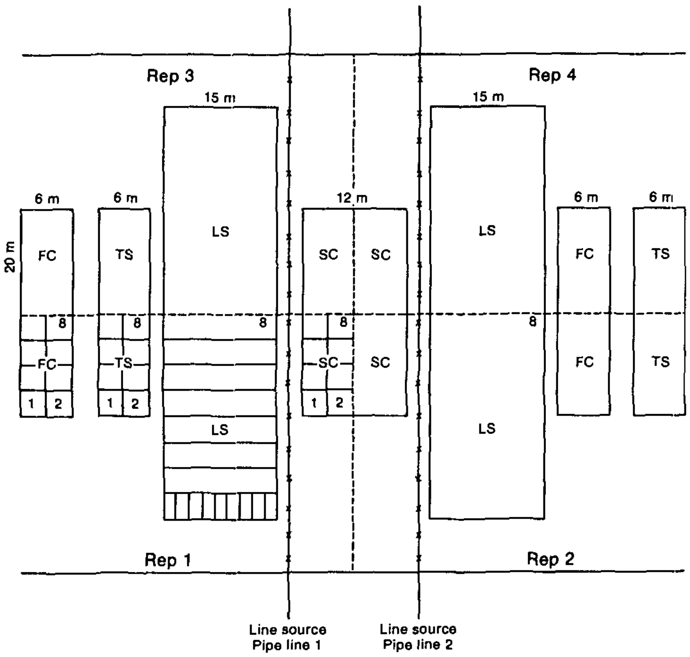

Fig. 1. Experimental layout in 1984 with the line sources (LS) sprinkler irrigated (SC), furrow irrigated control (FC) and terminal stress (TS) with replicates delimited by broken lines.

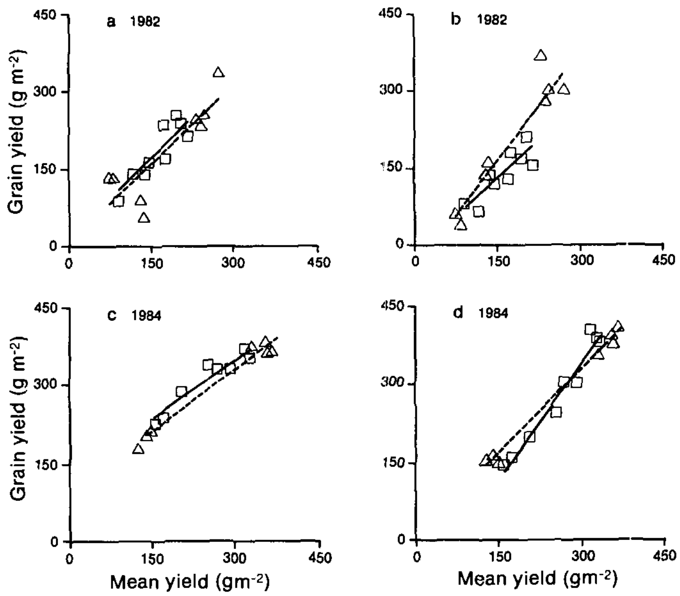

Fig. 2. Comparison of the regression lines of genotype grain yields against mean grain yields at different irrigation deficits from line source (□; ——) and uniform plot (△; - - -). Genotype with similar slopes in 1982 (a) and 1984 (c); and genotypes with differing slopes in 1982 (b) and 1984 (d).

(1982) or 4-m length (1984). In the uniform plot, the subplot units consisted of four rows of 4-m length in both years.

Thirty two advanced breeding materials of pearl millet consisting of hybrids and composites in 1982 and eight hybrids in 1984 were machine-planted in rows on ridges 0.75 m apart and irrigated. In 1982 and 1984 the crop emerged on 25 Jan. Rows were oversown and thinned to 0.10 m between plants when the crop was 10 d old. Nitrogen and P (P_2O_5), each at the rate of 40 kg ha^{-1}, were banded into the ridges before planting. Additional N at the rate of 40 kg ha^{-1} was side dressed at 15 d after emergence (DAE).

The crop was furrow-irrigated at weekly intervals from sowing to 45 DAE by flooding the furrows between ridges. In both years irrigation deficit treatments by the line source were imposed from 51 DAE until maturity, and irrigation in the terminal stress treatment was withheld from 51 DAE until maturity. The amount of irrigation applied to the rows nearest to line source, and to the fully irrigated control treatment by sprinklers, was calculated to replace approximately two-thirds of the cumulative class A pan-evaporation for the preceding week. The irrigated control treatment in the uniform plot was furrow irrigated at weekly intervals during grain filling; water applied was not measured, but was sufficient to avoid visible symptoms of stress for the weekly irrigation interval. At maturity, panicles were harvested from the two center rows of 3-m length (4.5 m^2) in all plots, except the line source treatment in 1982 where 1.5-m length (2.25 m^2) was harvested. Harvested samples were dried at 60 °C and grain yield determined from the entire sample.

Data were analyzed to compare genotype response to water deficit as determined from the line source and uniform plot techniques. In the line source, mean grain yields (over replications and genotypes) were used to represent the various irrigation deficit environments. Individual genotype response was determined by regressing individual genotype mean yield in each irrigation deficit environment against the mean yields for the irrigation deficit environments (Eberhart and Russell, 1966). In the uniform plot, the individual replicate (four) means (over all genotypes) were used as environmental means for each treatment. Individual genotype response was then determined by regressing individual genotype plot yields on their respective replicate mean yields for the furrow-irrigated control and terminal stress (FC-TS) or the sprinkler irrigated control and terminal stress (SC-TS) treatment pairs. This method provided eight data points for the uniform plot technique compared to nine for the line source genotype regressions (Fig. 2).

Genotypes with a lower regression coefficient (low b values) were considered as less drought susceptible. Grain yielding ability per se was evaluated from the estimated yield at an environmental yield of 250 g m^{-2}. The preferred genotypes would thus combine a high yielding ability with a low b value.

The two screening techniques were evaluated by the response surfaces, the regression coefficients and yield potential of the genotype in the two techniques. Yield potential of genotypes in the two techniques was determined through the estimated grain yields of individual genotypes at an environmental yield level of 250 g m^{-2} (the approximate mean nonstressed yield under the experimental conditions). Estimated genotype yields at an environmental yield of 250 g m^{-2} were compared by a two-tailed t-test in 1982 (separate experiments) and an F test in 1984 (single experiment). Comparison of regression coefficients (b) from the regressions of individual genotype yields on the environmental mean yields from the two techniques were used to determine the differences in genotype responses. Regression coefficients were evaluated according to Snedecor and Cochran (1967).

RESULTS AND DISCUSSION

Estimated grain yields at mean grain yield of 250 g m^{-2} of the 32 genotypes ranged from 183 g m^{-2} to 393 g m^{-2} in the line source and 212 g m^{-2} to 308 g m^{-2} in the uniform plot (Table 1). Despite the wide range in genotype grain yield potential there was no difference in the estimated values of yield of a genotype at mean 250 g m^{-2} between the two techniques (t = 0.013). The regression coefficients in the line source ranged from 0.35 to 1.51 and in the uniform plot from

Table 1. Comparison of the predicted yields (Y) at mean grain yield of 250 g m^{-2}, the regression coefficient (b) of genotype yield vs. drought environmental mean yield, and the coefficient of determination (r^2) in 1982.

	Line source			Uniform plot			
Genotype	Y (g m^{-2})	b	r^2 (%)	Y (g m^{-2})	b	r^2 (%)	Difference in b value
MBH 110	202	0.35	22	308	0.95	80	*
ICH 226	187	0.53	34	270	1.02	87	*
BJ 104	232	0.56	37	247	0.65	80	
SSC P 80	183	0.63	52	232	0.84	79	
ICMS 8017	185	0.70	74	203	0.81	69	
NEC P3 80	260	0.72	47	213	0.47	53	
PSB 8	189	0.76	68	206	0.81	79	
MC P1 80	250	0.77	47	240	0.86	86	
ICMS 7918	235	0.81	74	265	1.20	96	*
ICMS 7914	235	0.83	54	221	0.87	87	
BK 560	293	0.90	57	267	0.99	65	
ICMS 7703	243	0.93	81	295	1.19	85	
ICMS 8010	223	0.96	73	298	1.39	96	*
IVS P2 80	204	0.96	76	237	1.01	95	
ICMS 7844	239	0.98	69	214	0.86	77	
WC P3 80	230	0.99	79	223	0.87	88	
ICH 220	272	1.04	77	262	1.03	73	
WC P4 80	258	1.06	76	245	0.94	70	
ICMS 8025	210	1.07	86	212	0.83	80	
ICMS 7916	292	1.13	54	242	0.94	87	
ICH 118	230	1.14	79	240	1.13	77	
MC P2 80	306	1.15	73	239	0.77	96	
ICMS 7903	246	1.16	83	215	0.85	75	
MBH 131	335	1.20	75	277	1.00	67	
ICMS 7909	267	1.22	78	265	1.31	81	
MC A 80	308	1.25	82	249	1.02	88	
ICH 435	261	1.27	83	272	0.90	61	
ICH 426	276	1.28	61	267	1.37	84	
ICMS 7806	268	1.34	69	249	1.11	82	
ICH 433	309	1.39	76	295	1.43	83	
ICH 438	393	1.40	69	280	1.21	84	
ICH 425	232	1.51	89	260	1.40	84	

Regression coefficients determined by both techniques were statistically different as indicated by an *($P < 0.05$).

0.47 to 1.45. Because in the uniform plot, the regression line had only two clusters of data points (at the extremes of the yield range) compared to the line source with a more even distribution of points (Fig. 2a), coefficients of determination (r^2) are expected to be higher in uniform plot than in the line source, which was the case in 23 of the 32 cases.

Individual genotypes differed in response to water deficit (regression coefficient). However, genotype response as determined by the two techniques differed in only 4 of 32 cases (Table 1). In two of the four cases where slopes differed between the two techniques (genotypes MBH 110 and ICH 226), both slope and coefficient of determination were low in the line source, indicating a poor fit of the data to a linear model. The genotypes could be grouped into three groups based on the comparison between the two techniques. The first group ($n = 28$) had similar slopes and high coefficients of determination (r^2) in both the techniques (e.g., ICH 118, Fig. 2a). The second group ($n = 2$) differed in slope with high coefficients of determination (e.g., ICMS 8010, Fig. 2b). The last group ($n = 2$) differed in slope with low coefficients of determination (MBH 110, ICH226). Nonlinear response curves were fitted to the line source data for these two genotypes, but there was no improvement over the linear fits, due to a large degree of scatter in the data.

In 1982, plot size, numbers of replications, and mode of irrigation in the irrigated (control) treatment were different between the two techniques, and the treatments were arranged in two separate experiments. The comparison was repeated in 1984 as a single experiment, without these differences. However, only eight genotypes could be accommodated in the same land area in the line source. The eight genotypes chosen were single cross hybrids and only four hybrids

Table 2. Comparison of the predicted yields (Y) at mean grain yield of 250 g m^{-2}, and the regression coefficient (b) of yield vs. environmental mean yield, and coefficient of determination (r^2) in 1984.

				Uniform plot							
	Line source (LS)			Sprinkler (SC)			Furrow (FC)			Difference in b value	
Genotype	Y (g m^{-2})	b	r^2 (%)	Y (g m^{-2})	b	r^2 (%)	Y (g m^{-2})	b	r^2 (%)	LS vs. SC	LS vs. FC
MBH110	310	0.75	91	287	0.79	98	298	0.88	98		
BJ 104	212	0.77	91	226	0.80	95	222	0.76	92		
BK 560	250	0.84	95	231	0.85	99	244	0.97	97		
ICH 440	248	1.01	96	255	1.12	98	251	1.08	98		
BD 763	259	1.02	97	240	0.89	99	257	1.03	99	*	
ICH 118	210	1.02	97	231	1.29	99	203	1.07	96		
ICH 415	250	1.15	99	259	1.21	98	261	1.22	99		
EICH 8215	262	1.45	96	271	1.05	98	264	0.99	98	*	*

Regression coefficients determined by both techniques were statistically different as indicated by an *($P < 0.05$).

from 1982 were chosen based on the availability of seed.

The predicted grain yields at a mean yield of 250 g m^{-2} of the genotypes from the three treatments (line source, FC-TS, and SC-TS) were not significantly different ($F = 0.02$, $P > 0.98$) (Table 2). The slopes (b) from these three comparisons were not significantly different in six of the eight genotypes (e.g., MBH 110, Fig. 2c). In one of the two remaining genotypes (BD 673), the line source slope differed only from that determined from the SC-TS pair, and in the other (EICH 8215, (Fig. 2d) the line source slope differed from both the uniform plot slopes. As regression fits were good in all genotypes (Table 2), these two cases represent real differences between the two techniques of evaluating genotype response.

Bresler et al. (1982), concluded that the nonrandom nature of the irrigation deficit treatments in the line source was not a major limitation for comparing the genotype grain yield at similar irrigation levels, but that soil variability had a large effect on yields. The improvement in the regression fits (r^2) in both uniform plot and line source data in 1984 clearly supports this. Despite the lower r^2 in 1982, the four genotype responses (regression coefficients) were similar to that of 1984.

The increase in plot size (2.25–4.0-m rows) and number of replicates (two–four) in the line source between 1982 and 1984 resulted in reduced scatter in the data (compare Fig. 2a and c) and improved coefficients of determination (Table 2). Similarly the grouping of the replicates in the uniform plot technique, rather than arranging them down the soil depth gradient, improved the fits of the genotype regressions (compare Fig. 2a and c). The data also indicate that the frequency and/or amount of irrigation given by line source in 1982 was not sufficient for maximum yield, as the furrow-irrigated-control treatment of the uniform plot outyielded the maximum water application treatment of the line source (Fig. 2a, b). The modified design in 1984 avoided this problem (Fig. 2c, d); although there was no evidence that it was responsible for the differences between regressions coefficients in the two techniques in 1982 (e.g., Fig. 2b). However, the area occupied by a genotype in the uniform plot technique was 96 m^2 compared to 240 m^2 for the line source in 1984. The cost in land and data collection to increase plot size and numbers in the line source technique is high.

The high degree of correspondence of the results of genotype evaluation by both the techniques (even in 1982 when coefficients of determination were lower than 1984 because of field design) suggests that initial screening under conditions in which the genotype response to the line source is expected to be linear can be done by the simpler irrigated/nonirrigated empirical technique, without significant loss of information. Genotypes with a superior yield in the absence of stress and/or a low regression coefficient as determined in the uniform plot technique could then be re-evaluated by the line source technique if information on the entire stress response surface was desired. In situations where the response is nonlinear (e.g., Rao et al., 1988) or in studies involving combined effects of water and fertility (Aragon and De Datta, 1982; Beverly et al., 1986) or water and other factors (Seetharama et al., 1987), the line source technique provides the required additional information to fit response surfaces.

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