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A statistical assessment of genotypic sensitivity of groundnut (*Arachis hypogae* L.) to drought in line source sprinkler experiments

M. Singh,[1] R.C.N. Rao & J.H. Williams[2]
International Crops Research Institute for the Semi Arid Tropics (ICRISAT), Patancheru, A.P. 502 324;
[1] Present address: ICARDA, P.O. Box 5466, Aleppo, Syria; [2] Sahelian Center, ICRISAT, Niamey, Niger

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Summary

Comparison of genotypes in line source based drought screening has a number of statistical problems because of the systematic nature of irrigation treatments. A method of applying the joint regression approach has been developed and applied to evaluate sensitivity of 22 groundnut genotypes grown under 11 patterns of drought which were simulated in the field using a line-source sprinkler technique. The experimental errors in neighbouring environments are assumed correlated to account for the systematic nature of the environments. The estimation of parameters of the model and comparison of genotypes for their sensitivity to drought are presented for the pod yield. Stability in performance across the line-source environment was estimated for 22 genotypes. None of the genotypes tested was insensitive to drought across all patterns. Genotypes with stability and high mean yield could be identified in early and mid-season drought patterns but not in other patterns where genotypic sensitivity was strongly correlated with yield performance.

Introduction

The evaluation of genotypes using regression coefficients or stability indices across a wide range of environments has attracted considerable attention (Finlay & Wilkinson, 1963; Eberhart & Russell, 1966). This approach is based on the regression of individual performance at a site against the mean of all genotypes at that site. A genotype is considered stable if the regression coefficients is close to one, which means that genotypic yield is maintained by and large close to the average response of all genotypes across different environments (Lin et al., 1986), while a regression coefficient close to zero would correspond to a genotype insensitive to changing environments.

At ICRISAT Center, groundnut genotypes tolerant to drought are identified using a line-source sprinkler technique (Hanks et al., 1976). This technique provides a range of environments differing primarily in the amount of water received, resulting in variable drought intensities. Morgan & Carr (1988) have used the distance from line-source as a covariate to explain the effect of drought environments created. This does not consider interdependence of plot errors arising due to the systematic nature of the environments. Further, the wind velocity during the operation of sprinklers may affect distribution of water at a given distance from the sprinkler line source, limiting the role of distance in evaluating crop response in line-source sprinkler experiments. The covariate adjustment

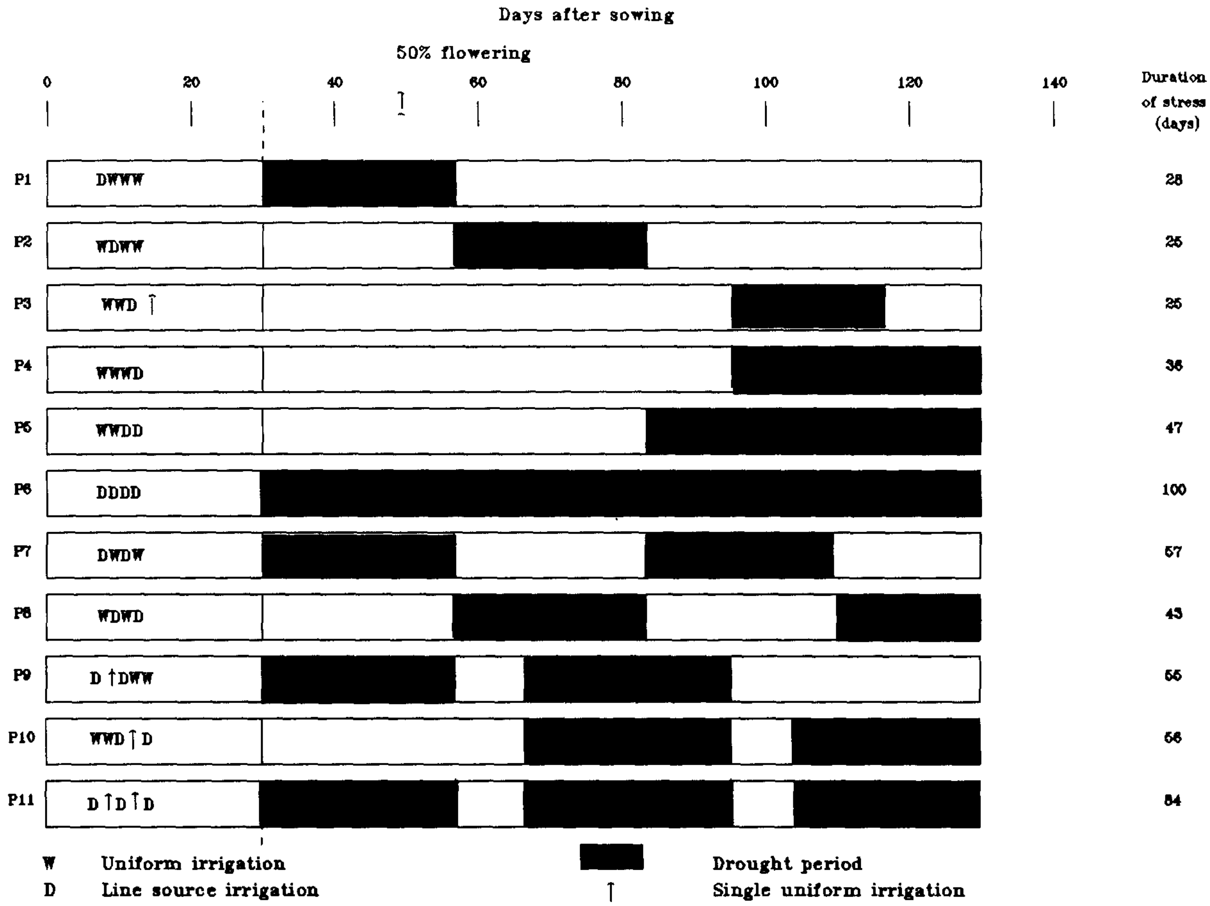

Fig. 1. Timing and duration of single and multiple droughts applied in the experiment.

also suffers from the fact that the position of stress environments are linearly related to distance and this could reduce or eliminate the evaluated effect of the treatment even when there is a true substantial effect.

In the present study the systematic nature of the environments was modelled using a correlated structure for experimental errors. With correlated errors in the model, the regression approach for estimation and comparison of genotypic drought sensitivities was applied on a data set collected from an experiment involving 22 genotypes grown under 11 different patterns of drought using a line-source sprinkler system.

Material and methods

The experimental procedure

The experiment was conducted during the postrainy season (November end to April) 1982–83 at ICRISAT Center in Central India. The detailed methodology and crop management has been described by Nageswara Rao et al. (1989). Briefly, a field experiment was conducted to examine the effect of timing, intensity and duration of drought on genotypic sensitivity to drought. Twenty-two groundnut genotypes were subjected to 12 different patterns of drought, which constituted either a single drought or multiple droughts imposed at different crop growth stages. Within each drought pattern, 8 levels of water deficits (drought intensities) were created using a line-source sprinkler

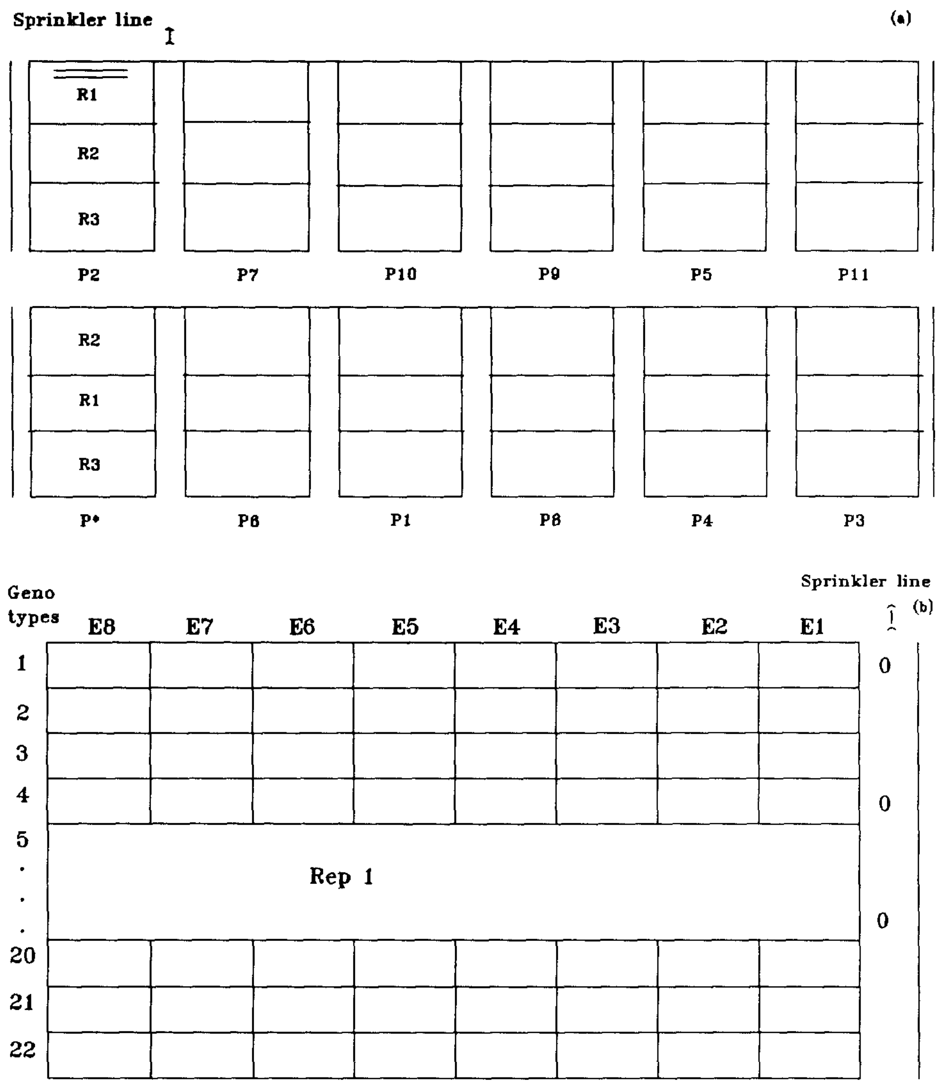

Fig. 2. (a) Field plan of the experiment (P: drought pattern, R: replication) with genotypes sown in paired rows. (b) A closer view of the eight stress environments E1 to E8 in a general replication (unrandomized genotypes). * drought pattern excluded from analysis.

(LS) technique (Hanks et al., 1976). Pod yield data of twenty-two genotypes (given below) in 11 drought patterns (Fig. 1) was used for the present study. Field layout and arrangements of sprinkler irrigation are shown in Fig. 2.

Groundnut genotypes

1. CGC-4063, 2. J11 × Robut 33-1, 3. ICGS-24, 4. ICGS-36, 5. ICGS-11, 6. ICGS-35, 7. ICGS-21, 8. X41-X-1-BX GALDIN-1, 9. MANFREDI × X-14-4-B-19-B, 10. TMV2, 11. Faizpur 1-5-2, 12. J 11, 13. NC Ac 17090, 14. NC Ac 17142, 15. Gangapuri, 16. EC-76446, 17. EC 109271 (55-437), 18. EC-21024, 19. Manfredi-107, 20. Kraporicas Str 16, 21. NC Ac 16129, and 22. JL 24.

A model for yield response

The method described below would be considered for each of the $r = 3$ replicates individually. Here $i = 1, \ldots, v$; $j = 1, \ldots, L$, where $v = 22$ is the number of genotypes and L = 8 is the number of environments considered. Let y_{ij} be the response of i-th genotype in j-th environment created by LS in a replicate. The response y_{ij} can be expressed using the regression model:

$$y_{ij} = \zeta_i + \beta_i \theta_j + \varepsilon_{ij} \tag{1}$$

The parameter ζ_i measures the overall performance of the i-th genotype, β_i measures its sensitivity to the environments and θ_j is the j-th stress environment mean over genotypes adjusted for estimates of other parameters, this mean being expressed as a deviation. The model (1) has been applied widely for examining the stability of varieties or genotypes across environment by Yates & Cochran (1938), Finlay & Wilkinson (1963), Perkins & Jinks (1968), Eberhart & Russell (1966) and Digby (1979), among others. The θ's are unknown and will be estimated from the data, unlike the Eberhart & Russell (1966) method where these were computed from the means of the environments. Under the commonly used genotypes × environment model, the errors ε_{ij} are independent, but we shall use correlated errors to model the systematic nature of the environments. The drought stress is minimum near the LS in environment E_1 and gradually increases to a maximum in environment E_8 (Fig. 2b). Although there are several spatial statistical models to account for systematic trends in fertility (Wilkinson et al., 1983; Besag & Kempton, 1986), we shall use the following simple model on errors from neighbouring plots in the direction of stress:

$$\varepsilon_{ij} = \varrho\, \varepsilon_{ij-1} + \eta_{ij} \tag{2}$$

The quantity ϱ is the first order auto-correlation, η_{ij}'s are assumed independent normally distributed random variables with mean zero and variance σ^2_η. Further,

$$\mathrm{var}(\varepsilon_{ij}) = \sigma^2_\eta/(1\text{-}\varrho^2) = \sigma^2.$$

Lin et al. (1986) have presented a critical assessment of various stability measures. In the present paper, the coefficient β_i is used to indicate sensitivity of a given genotype to a given drought pattern. For instance, β = 0 implies a 'broad adaptation', a biological concept of genotypic stability (Becker, 1981), while β = 1 implies 'specific adaptation', an agronomic concept of genotypic stability (Finlay & Wilkinson, 1963; Perkins & Jinks, 1968). The comparison of two genotypes i and i′ for drought sensitivity can easily be statistically made using the difference $\beta_i - \beta_{i'}$ and its standard error.

Estimation of parameters and test of significance

We apply the generalized least square method to estimate parameters ζ's, β's and θ's obtained by minimising

$$Q = \sum_i (\underline{y}_i - \zeta_i\underline{J} - \beta_i\underline{\theta})' \,\underline{\Omega}^{-1} (\underline{y}_i - \zeta_i\underline{J} - \beta_i\underline{\theta}) + 2\lambda\underline{\theta}'\underline{J} \tag{3}$$

where $\underline{y}_i = (y_{i1}, y_{i2}, \ldots y_{iL})'$; $\underline{\theta} = (\theta_1, \theta_2, \ldots \theta_L)'$, $\underline{J}$ is L-component column vector of unities; and λ is Lagrangian multiplier. The matrix $\underline{\Omega}$ is given by

$$\underline{\Omega} = ((\varrho^{|j-j'|}));\ j, j' = 1, 2, \ldots, L.$$

The dispersion matrix of $\underline{y}_i$ is $\sigma^2\,\underline{\Omega}$. The estimates $\hat{\zeta}_i$ and $\hat{\beta}_i$, obtained by iteration simplify to

$$\begin{bmatrix} \hat{\zeta}_i \\ \hat{\beta}_i \end{bmatrix} = \underline{A}^{-1}\underline{b}_i,\ (i = 1, 2, \ldots, v)$$

and the asymptotic variance-covariance of $(\hat{\zeta}_i, \hat{\beta}_i)$ is $\sigma^2(1-\varrho^2)\underline{A}^{-1}$. The expression for matrix $\underline{A}$, vectors $\underline{b}_i$ and details on the iterative scheme of estimation are available from the authors.

When the number of error degrees of freedom is large, the test for the drought sensitive genotype i can be obtained by computing $Z = \hat{\beta}_i/\mathrm{ese}\,(\hat{\beta}_i)$ or $(\hat{\beta}_i - 1)/\mathrm{ese}(\hat{\beta}_i)$ and comparing Z against the standard normal deviate. The term ese (·) denotes the estimate of standard error. For comparing the sensitivity of two genotypes i and i′ one may use $Z = (\hat{\beta}_i - \hat{\beta}_{i'})/\mathrm{ese}\,(\hat{\beta}_i - \hat{\beta}_{i'}$ as above. The estimates of ζ's and β's were obtained for each replication separately. The means and standard errors of these estimates were estimated from three replications for each genotype within each pattern, which formed the basis of statistical tests.

Results and discussion

Present in Table 1 are the estimates of ϱ and σ from each replication of each drought pattern. The estimates of sensitivities β's and performance ζ's in all drought patterns are not presented for the sake of brevity. However, the genotypic variability for stability and yield performance for only two selected drought patterns, 3 and 10, are given in Fig. 3a and 3b respectively. Genotypic sensitivities (β's) were tested for their statistical significance and the set of patterns in which an individual genotype was found stable or was more sensitive than local checks (TMV 2 or JL 24 at 5% level of significance) are presented in Table 2.

The estimates of auto-correlation (ϱ) between errors of neighbouring stress environments varied from − 0.58 to 0.24 over replicates and patterns (Table 1). An application of large sample test based on the Neumann ratio (Johnston, 1972), indicated that auto-correlation estimates differed significantly from zero (at 5% level) for some replications of a drought pattern, but not in other replications. For example, each of the three estimates in drought pattern 1 differed significantly from zero while the estimate of auto-correlation in other patterns differed significantly from zero only in replication 1. The changes in the estimates of sensitivity and per-

Table 1. Estimates of correlation and error standard deviation

Pattern	Replications		
	1	2	3
		$\hat{\varrho}$	
1	− 0.26	0.24	− 0.16
2	− 0.33	0.03	− 0.11
3	− 0.48	− 0.16	− 0.03
4	− 0.24	− 0.16	0.05
6	− 0.55	− 0.20	− 0.14
7	− 0.36	− 0.01	0.04
8	− 0.44	− 0.16	− 0.15
9	− 0.47	0.03	0.02
10	− 0.53	− 0.16	− 0.18
11	− 0.58	− 0.08	− 0.01
12	− 0.46	− 0.07	0.04
		$\hat{\sigma}$	
1	36	47	59
2	64	75	74
3	57	53	55
4	51	49	54
6	44	44	44
7	33	41	47
8	44	58	54
9	31	41	39
10	42	47	49
11	41	54	51
12	32	38	50

Table 2. An assessment of stable genotypes $\beta_i = 1$ for drought stress under various patterns and selection of genotypes with more sensitivity than that of controls

Genotypes i	Patterns where		
	$\beta_i = 1$	$B_i > \beta_{10}$ (TMV 2)	$\beta_i > \beta_{22}$ (JL 24)
1	1 to 4, 6 to 10	–	4, 5, 8
2	2, 3, 4, 6, 7, 9, 10	1,5	4, 5, 8, 9
3	1 to 4, 5 to 11	–	3, 4, 5, 9
4	2, 3, 4, 5, 6, 8 to 11	–	4, 6, 9
5	1 to 4, 6 to 10	–	4, 5, 6, 9, 11
6	1 to 4, 5, 6, 7, 9, 10	–	9, 11
7	2, 3, 5, 6, 7, 9, 10	1	8
8	1, 2, 4, 6, 7 to 11	–	3, 4, 5, 8, 9
9	1, 2, 3, 6 to 10	–	5, 8
10	1, 2, 4, 5, 6, 7, 10, 11	–	3, 4, 6, 8, 9
11	2, 3, 4, 10	–	–
12	2, 3, 4, 5 to 11	–	4, 9
13	1, 2, 3, 5 to 10	–	3, 4, 6, 8, 11
14	1 to 4, 5 to 11	–	4, 8, 9
15	1, 2, 7, 9, 10	4, 6	3, 4, 5, 6, 8, 9, 11
16	1 to 4, 5 to 11	–	6
17	1, 2, 3, 6 to 11	–	3, 4, 6, 8, 9
18	1 to 4, 5 to 10	–	7, 8
19	1 to 4, 5 to 11	–	4, 6
20	2, 4, 6 to 11	–	5
21	1 to 4, 5 to 10	11	4, 6, 8, 9, 11
22	1, 2, 3, 7, 10, 11	–	–

– under none of the drought patterns

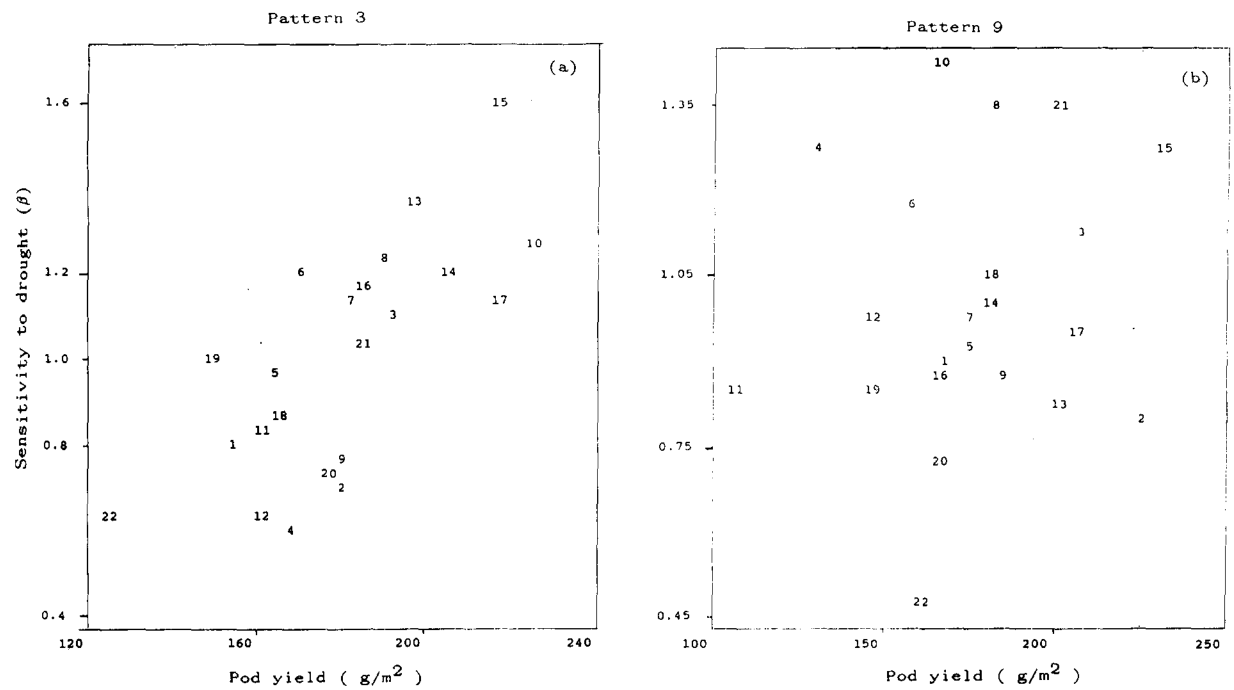

Fig. 3. Relationship between sensitivity to drought (β) and pod yield performance (ς) of groundnut genotypes. Genotypes are identified by serial numbers in the experimental procedure.

formance of genotypes due to accountability of auto-correlation ϱ varied with the magnitude of the estimates of ϱ (not presented in the paper). The estimates of σ^2 (error variability) were lower when the model was fitted with ϱ.

Once β and ζ had been estimated, they were plotted against each other for each pattern to allow selection of genotypes with above average values for both attributes. In those drought patterns involving end-of-season drought, there was a strong correlation between β and ζ (Fig. 3a) suggesting that stability across drought environments required a sacrifice of genotypic yield potential in non-limiting environments. However, in patterns involving mid-season drought, the association between β and ζ was poor (Fig. 3b, for example, correlation $r = -0.16$, -0.29 and 0.15 for patterns 2, 8 and 10 respectively), suggesting that drought tolerance can be combined with high yield potential for these patterns.

The test of significance for deviation of β's, from zero indicated that no genotype was insensitive to drought. The second column in Table 2 indicates the nature of genotypes based on the concept of specific adaptation ($\beta_i = 1$). Using this approach, genotype Faizpur 1-5-2 (no. 11) was found to be stable in four patterns but low yielding. Gangapuri (genotype no. 15) was stable and high yielding in five patterns, i.e. patterns 1, 2, 7, 9 and 10, in which drought occurred during the end-of-season. This suggests possible benefits associated with escape mechanisms under end-of-season drought conditions. Genotypes ICGS 24, NC Ac 17142 and EC 76446 were stable in all eleven patterns and their yields were above average. The performance of other genotypes was intermediate.

There were only three genotypes showing significantly higher sensitivity (lower β values) than that of TMV 2 (Table 2), one of the local checks. The presence of genotype X pattern interaction on sensitivity was evident since genotype ICGV 86744 had higher β values than that of TMV 2 in patterns 1 and 5, while Gangapuri had higher β values in patterns 4 and 6 and NC Ac 16129 in pattern 11. Genotype JL 24 had highly variable yield across the drought environments.

The present paper visualizes a situation where the environments were treated as correlated since the LS generated a systematic gradient of water deficit within a given drought pattern. The joint regression approach, when modified to account for the systematic nature of environments, suits the experimental situation well and allows statistical comparison of drought sensitivity of a genotype within a drought pattern as well as genotype × drought pattern interaction effects.

With patterns where genotypic performance was strongly associated with genotypic sensitivity β, selection of genotypes could be done based on their yield performance. Usually such strong associations were found when drought occurred during the seed filling phase.

One aspect of the approach which requires further research is the selection of genotypes for patterns of drought in which ζ and β are strongly correlated. However, it is unlikely that the water deficit environment created using the LS occurs with the same frequency in natural conditions. There is a need to evaluate possibilities of weighting the ϱ from the line-source experiments with the natural occurrences of drought patterns in the environments.

In those patterns where ζ and β are not associated, it might be possible to screen and select genotypes with low β without sacrificing yield potential. This analysis showed that there was little or no association between ζ and β in those drought patterns where recovery from drought is involved. This indicates a possibility of selecting and combining genotypes with high ζ and low β through breeding to combine low sensitivity with high yield potential.

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