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THE UNIVERSITY OF ALBERTA

GENOTYPE-ENVIRONMENT INTERACTION, STABILITY AND COMBINING ABILITY ANALYSES IN SMOOTH BROMEGRASS

by

WAI-KOON LAU TAN

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH
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FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled Genotype-Environment Interaction, Stability and Combining Ability Analyses in Smooth Bromegrass submitted by Wai-Koon Lau Tan in partial fulfilment of the requirements for the degree of Doctor of Philosophy in Plant Breeding.

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ABSTRACT

Twenty-one progenies of smooth bromegrass (*Bromus inermis* Leyss.) from a 7x7 half diallel cross with their parents were evaluated at four locations in Alberta and in two years for the genetic variation and stability in expression of their yield potentials along with leaf and tiller characteristics.

Years, locations and their interactions were highly significant in the combined analysis of variance, and each of these effects was therefore treated as an individual environment in subsequent analysis. The partition of the genotypic variance into general combining ability (GCA) and specific combining ability (SCA) showed that for all characters except spring, fall and annual yield, GCA was more important than SCA, indicating the importance of additive genetic effect. Although the genotype x environment (GE) interaction were highly significant, variation accounted for by combining ability effects was generally higher than the interaction effects of GCA and SCA with environments.

The joint regression analysis further partitioned the GE interaction into heterogeneity among regressions and its residual. A significant part of the interaction was ascribed to the heterogeneity among regression lines for all characters and therefore was predictable. However, the residual components were significant in most cases. Hence there was also the presence of some unpredictable and unaccountable variation.

Regression coefficient and deviation from regression line for each genotype were the two stability parameters to be considered together with mean performance in the evaluation of each genotype. Five high yielding genotypes, namely 12, 13, 16, 25 and 36, had general adaptability, while genotypes 23 and 26 were specially suited to poor environment.

Combining ability analysis revealed that GCA and SCA were both important in the expression of mean yields (spring, fall and annual). Inheritance of linear regression was controlled predominantly by GCA whereas both GCA and SCA were equally important in the expression of deviation. Genotype 1 was the most desirable parent, as it transmitted to its progeny high yield potential and average linear response. The other good combiner for yield was the genotype 6 but it transmitted below average linear response.

SCA analysis revealed that genotypes 12, 13 and 16 combined both high yield and average stability. Genotype 34 was found superior in favourable environments, but its non-linear fluctuations were rather high.

Phenotypic and genotypic correlation coefficients indicated that all the yield types, including spring, fall, annual yields, and yield per area, were all significantly correlated. Very few morphological characters seemed to associate with yields, among these were tiller density and plant height. Beside these two characters, other characters such as leaf area, leaf, stem and tiller dry weight were also correlated with yield per area but not with other yield types.

Both direct and transformed scales were used throughout this study. Tests of significance among means were generally similar on both scales, but for heterogeneity among regressions, the tests produced different results.

The results indicated that a more complicated approach, such as recurrent selections involving multi-location and multi-year testing, seems necessary in breeding for high yielding bromegrass cultivars in Alberta.

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I. INTRODUCTION

Valid interpretations of mechanisms of inheritance as well as predictions of performance in breeding programs depend mainly on accurate assessments of genotype values. These assessments must be made from data on phenotypes that reflect both nongenetic and genetic influences on plant development (Moll and Stuber, 1974; Comstock and Moll, 1963). Unfortunately the genetic effects are not independent of the nongenetic environmental effects. The phenotypic response to a change in environment is not the same for all genotypes; these are reflected by the difference in the relative rankings of genotypes in different environments. This interplay of genetic and nongenetic effects, i.e. of genotype-environment (GE) interaction, reduces the correlation between genotype and phenotype, which in turn reduces confidence in inferences from experimental data relevant to both plant improvement and inheritance mechanisms.

According to Allard and Bradshaw (1964), environment variation can be classified into two types: predictable and unpredictable. Predictable variation includes all permanent characters of environment, such as climate and soil type, as well as cyclic fluctuations such as day length. Also included in this category are those which can be fixed at will (such as planting date, sowing density, harvest methods, and other agronomic practices). Unpredictable variation includes fluctuations in weather, such as amount and distribution of rainfall and temperatures. Although the distinction between the two categories is not always clear cut, they have distinctly different impacts in breeding programs, both on operational procedures at the selection stages and on testing stages. Therefore, results based on one location and one year have limited practical implication.

The significance of GE interactions to plant breeders depends on their objectives. If cultivars that perform well over a broad spectrum of environments are desired, small GE interactions and well-buffered cultivars are favoured. If cultivars that are adapted to very specific or predictable environments are desired, large interactions may be beneficial, whereas buffering may be of little consequence. There are, however, dangers in an extremely inflexible cultivar because of both the state of influx with regards to management ideals and the mismanagement which can be expected to occur on some occasions under practical farming conditions and the variable climate. Information on performance in a range of environments is of vital importance to the breeder, whether his interest is in the production of a cultivar with a narrow or with a relatively wide spectrum of adaptation. In Alberta, the varying soil climatic patterns from the north to the south, and from the west to the east are so great that perhaps large interactions and cultivars adapted to more specific regions of the province may be more feasible than well-buffered cultivars for the whole province.

The ability of individuals to respond to varying environments by changing phenotypic expression is of special interest in herbage plants, since no other crops are expected to yield under such a diversity of climatic, edaphic and management conditions. This is especially true in perennial grasses, where successive harvests are subject to marked contrasts in the external environment. There are also certain areas in Canada where high protein legumes cannot be grown (Wilson and Winch, 1977). Under such conditions grass will remain the prime component of programs for pasture or stored feed, but adequate amounts of nitrogen must be applied to obtain high yields. Cultivars or genotypes which have a certain amount of stability but will be responsive to favourable environment (e.g. nitrogen) would be favoured. Thus, GE interaction studies are of the utmost practical importance in measuring the genotypic reaction to environmental variations.

Until recently, differential responses of genotypes or varieties to varying environments were determined using the analysis of variance (Comstock and Robinson, 1952). Over the past few years interest in the form of regression analysis first proposed by Yates and Cochran (1938) has been revived by the studies of Finlay and Wilkinson (1963) and the Birmingham School of Genetics (e.g. Bucio Alanis and Hill, 1966; Perkins and Jinks, 1968). The significant feature in the regression analysis is that genetic expression can be simply and predictably related to the environment when the latter is measured by its effect on the character under study.

The present investigation was initiated to examine the magnitude of GE interaction with a 7x7 half diallel cross of smooth bromegrass (*Bromus inermis* Leyss.), which had been studied for a number of aspects, including leaf and tiller characteristics (Tan et al., 1976a, b; Walton, 1976; Murchison, 1977), canopy (Tan et al., 1977), and quality (Tan et al., 1978). More precisely, the objectives are:

1. to evaluate the magnitudes of general combining ability, specific combining ability and their interactions with different environments;
2. to use the regression procedure to analyse and study the GE interaction on the data obtained. The estimates of linear and non-linear parameters provide an account of the dynamic response of bromegrass genotypes to changing environments, and may be used with mean performance to assess the potentialities of various genotypes; and
3. to relate stability parameters with combining ability effects in the selection of bromegrass genotypes which combine high yield with average stability in differing Alberta environments.

II. LITERATURE REVIEW

Early Approaches to the Study of GE Interactions - the Use of Variance Components

The existence of interactions between genotypes and environmental factors has long been recognised. Factorial design was adapted to the analysis of GE interaction, because the total variation ascribable to genotypes and environments was partitioned into three orthogonal comparisons: (1) measuring the differences between genotypes, (2) measuring environmental differences, and (3) assessing their joint effects (Hill, 1975).

Fisher laid the foundations for use of factorial design and analysis of field experiments (Hill, 1975). Among those who developed it further and were responsible for using the analysis of variance to investigate GE interactions are, e.g. Sprague and Federer (1951), Comstock and Robinson (1952), Hanson, Robinson and Comstock (1956) and Comstock and Moll (1963). Unbiased estimates of the genetic and GE components of variance can be readily obtained by equating the expected mean squares with those calculated from the experiment. The precise form taken by the expected values of the mean squares will depend upon the underlying assumptions made in the analysis. Unbiased estimates of the components of variance may be attained through properly designed experiments. Accuracy of these estimates will depend on the size of the experiments.

The Use of Regression Methods

The idea of breaking down an interaction into several parts was missing in the variance component approach. The method of partitioning GE interaction was first devised by Yates and Cochran (1938), but attracted little attention until Finlay and Wilkinson (1963) rediscovered the same method and used it for an analysis of adaptation in a trial with 277 varieties of barley in seven environments. A similar method was also used by Walton in the study of cotton (1957; 1958; and 1961). This method involves computing for each variety the regression of individual yield on the environmental mean, which was measured by the mean yield of all varieties for each site and season. The regression has since emerged as one of the most useful statistical tools for analysing GE interactions.

The approach falls into two parts, a conventional analysis of variance being followed by a joint regression analysis. From the joint regression analysis, the GE interaction sum of squares can be partitioned into two orthogonal items, heterogeneity of regression and deviation from regression. The former measures that portion of the GE interactions which is due to differences between the fitted regression lines, with (t-1) degrees of freedom (d.f.) (t being the number of genotypes); the latter measures the accumulated deviations of the observed values around these fitted lines, with (t-1)(s-2)d.f. (s being the number of environments). Each of these terms can be compared with the experimental error, and the heterogeneity of regression further compared with the deviation in order to see if it accounts for a significantly large part of the observed interaction.

Regression methods were also considered by Rowe and Andrew (1964) and Eberhart and Russell (1966), who added together the sums of squares for environments and GE interactions and repartitioned this into a linear component between environments ~~with~~ 1 d.f., a linear component of the GE interaction with (t-1)d.f., and deviations from regression. The deviations were found separately for each of the t genotypes with (s-2)d.f. each.

The linear regression technique is versatile and can be used to predict the performance either of genotypes in environments other than those sampled experimentally or of segregating generations from the non-segregating generations from which they were derived. The technique has been usefully applied to a number of different crop and plant species since its rediscovery, such as barley (*Hordeum vulgare*

L.) (Finlay and Wilkinson, 1963; Paroda and Hayes, 1971), wheat (*Triticum aestivum* L.) (Kaltsikes and Larter, 1970), maize (*Zea mays* L.) (Eberhart and Russell, 1966; Ottaviano and Sari Gorla, 1972; Dhillon and Singh, 1977), orchard grass (*Dactylis glomerata* L.) (Breese, 1969); perennial ryegrass (*Lolium perenne* L.) (Troughton, 1970; Hill and Samuel, 1971), soybean (*Glycine max* L. Merr.)(Baihaki, Stucker and Lambert, 1976), strawberry (*Fragaria chiloensis*) (Gooding, Jennings and Topham, 1975), peas (*Pisum sativum* L.) (Snoad and Arthur, 1974), *Nicotiana rustica* (Bucio Alanis, 1966; Bucio ALanis and Hill, 1966; Perkins and Jinks, 1968), *Arabidopsis thaliana* (Westerman and Lawrence, 1970), and *Schizophyllum commune* (Fripp and Caten, 1971). In many instances, the linear regression technique adequately describes the behaviour of genotypes over a range of environments.

The linear regression technique has been widely adapted in various designs and experiments in recent years. For example, Breese and Hill (1973), Hill (1973), and Wright (1971, 1977) have adapted the techinque to the analysis of competition experiments based upon the diallel arrangement, that is where the competitors are grown as monocultures in all possible 50:50 mixtures.

Lin, Binns and Thompson (1977) described a model combining the features of Griffing's diallel cross analysis with regression analysis for genotype-environment interactions. They claimed the main advantage for studying GE interactions in a diallel cross experiment is that 'both the combining abilities of genetic effects and their linear function of combining ability components by environment interaction can be studied simultaneously'. Furthermore, the authors (Lin et al., 1977) claimed the model provides not only a direct and easy biological interpretation but also an easy assessment of both heterosis and heterosis by environment interaction.

Limitations of Regression Methods on the Use of Environmental Mean

Although the linear regression approach has been very widely used, it has frequently been the subject of controversy. Freeman and Perkins (1971) have criticized the use of marginal means of the environments as independent variables in the regression analysis, claiming their use violates the fundamental statistical assumptions of regression analysis. If, as Freeman and Perkins (1971) further suggested, it is necessary that points on the abscissa (*x-variate*) should be known precisely and occur at equal intervals over the observed range, such as controlled environment chambers, then the results would inevitably be of more theoretical than practical interest. However, Hardwick and Wood (1972) proposed that if a large number of genotypes are included, and if the environmental range is such that the between-environments mean squares are significantly greater than the error mean square, any bias which results should not prove serious in practice.

In view of the criticism of Freeman and Perkins (1971), different ways of providing an independent assessment of the environment have been suggested:

1. The use of control genotypes or extra replicates of the full genotype set (Fripp and Caten, 1971; Jinks and Connolly, 1973). Fripp and Caten (1971) found that with a large number of genotypes, the results for regression on a control genotype differed little from those for regression on the mean of the test genotypes. Further, Fripp (1972) compared both biological and physical measures of the environment and found that the analyses, again for a large number of genotypes, gave very similar results for all reasonable external measures and the environmental mean.
2. The use of parental genotypes as standards in relation to any generation derived from crosses between them (Bucio Alanis and Hill, 1966; Breese, 1969; Bucio Alanis, Perkins and Jinks, 1969; Jinks and Perkins, 1970; Perkins, 1970). Perkins and Jinks (1973) regressed values for a large number of genotypes on their environmental means and on values derived from other, closely related, sets of

genotypes; they found that all analyses generally gave similar values for significance, but that regressions on means derived from only a few independent genotypes were sometimes so insensitive as to give rise to problems of interpretation.

3. By regressing the performance of the *i*th genotype onto an index composed of the remaining genotypes (Mather and Caligari, 1974). This removes the statistical objection without needing to include extra individuals in the experiment, though estimates so obtained will be distorted, both by error variation and by any departure from linearity on the part of the individual regressions.

Finally, Tai(1971) has employed 'structural relationship analysis' to overcome the limitations of regressing one set of variables on another which is not independent of it. Assuming that the environmental and GE effects are jointly normally distributed, it is possible to derive maximum likelihood estimates of the linear response of the *i*th line to the environmental effects (α_i) and the deviation from the linear response in terms of the magnitude of the error variance(λ_i). These estimates may be compared with their counterparts obtained by regression analysis.

Stability Parameters

Considerable interest exists in the mechanisms by which an individual stabilizes its behaviour in the face of varying environmental influences (Bradshaw, 1965). The definitions of stability are many and varied, even within the confines of GE interactions.

Plaisted and Peterson (1959) based their measures of stability upon the contribution of the *i*th genotype to the GE interaction sum of squares. Finlay and Wilkinson (1963) defined stable genotypes as those with a low regression coefficient ($b_i<1.0$) while genotypes with a high regression value ($b_i>1.0$) are unstable. Stable varieties with high mean yields are regarded as those specifically adapted to low-yielding environments, and unstable varieties with high mean yields are specifically adapted to high-yielding environments. Hanson (1970) devised a composite measure of stability which combines the contribution of the ith genotype to the GE interaction sum of squares with its response to environmental change. Eberhart and Russell (1966) also used b_i as the first measure of stability but went further and regarded the mean square of deviation S_{di}^2 as a second measure. They defined a stable genotype as a line which has $b_i=1.0$ and $S_{di}^2=0$. Perkins and Jinks (1968) obtained similar parameters to that of Eberhart and Russell (1966) and Finlay and Wilkinson (1963) from a biometrical genetic model, but their regression coefficients β_i(i.e. b_i-1) centered around 0.0 rather than 1.0.

Tai (1971) used α_i as one measure of stability and also defined a second measure λ_i. Tai's parameters, α_i and λ_i, have equivalent meaning to the b_i and S_{di}^2, of Eberhart and Russell (1966), respectively, except that Tai's α_i and λ_i center around 0.0 and 1.0, respectively. Tai (1971) defined 'a perfectly stable variety was $(\alpha_i,\lambda_i) = (-1,1)$ and a variety with average stability was $(\alpha_i,\lambda_i) = (0,1)$'.

Scales and Transformations

Most estimates of stability parameters have been made on a direct scale, but square root (Westerman and Lawrence 1970) and logarithmic scales (Finlay and Wilkinson, 1963) have been also used. Jowett (1972) estimated stability parameters for grain sorghum (*Sorghum bicolor* L.) on both direct and logarithmic scales. The ranking of single crosses, three-way crosses, and varieties by regression coefficients differed on the two scales. This supports the observation by Knight (1970), that different conclusions may be drawn from regression coefficients when measured on different scales. Breese and Hill (1973) also found that, not only did a log transformation of data taken from competition experiments fail to remove the interactions which were present, but it also completely altered the interpretation of the results. By contrast, Mather (1971) asserted that no deep-seated biological significance can be attached to the particular scale chosen.

Recent evidence on oats (*Avena sativa* L.) by Eagles, Hinz and Frey (1977) further supports the ~~postulation that~~ regression coefficient parameters differed substantially on the ~~two scales i.e. direct and~~ transformed scales. Therefore, they warned that great care should be taken when comparing regression coefficient parameters estimated on different scales. However, they added that if the GE interaction can be removed by using any of the family of transformations $Y=X^a$ where a ranged from 0 to 1 (or any other monotonic transformation), the interaction will likely be of the type which cannot be exploited by selection.

The Use of Multivariate Techniques to Study GE Interactions

There can be no doubt that the most useful of the GE interaction techniques has been the regression approach. For successful application of the regression method, a very high proportion of the interaction sum of squares should be explained by linear regression. The conditions making for success, i.e. linearity of regression, are very difficult to determine, and one set of characters has frequently been found to give linear regressions, while another set of characters measured on the same set of genotypes has not (Freeman, 1973).

In practice there are often wide deviations from linearity. There are situations where the linear regression technique may over-simplify the true response pattern to an extent which could lead to erroneous conclusions (Witcombe and Whittington, 1971). The results of a number of studies suggest that there is often more than one way in which responses differ, that is, the interaction contains more than one significant principal component. Multivariate methods will therefore likely be alternative ~~techniques to the analyses of GE interactions.~~

Multivariate techniques of anlayses are essentially an extension of the univariate techniques. The purposes of multivariate analysis may be summarized in terms of the analysis of GE interactions as follows (Hill, 1973):

first, to assess the simultaneous effects of a number of environmental factors where these can be measured and ranked in order of importance by determining how much of the observed variation is accounted for by each individual factor, or composite factor derived therefrom;

secondly, to maximize differences between cultivars (or environments) relative to differences within cultivars (or environments).

Multivariate techniques have not been widely used in plant breeding, still less in the analysis of GE interactions. Freeman (1973) listed several multivariate techniques; amongst them principal component analysis, canonical analysis, cluster analysis, and factor analysis, which could be of prospective value in the analysis of GE interactions. Tai (1975) also proposed the method of path coefficient based on postulated causal relationships.

Freeman and Dowker (1973) applied principal component analysis to data recorded from a series of yield trials in carrots after the joint regression analysis had been only partially successful in explaining the observed GE interactions. They concluded the use of principal component analysis supplied no additional information beyond that obtained from the analysis of variance. A similar conculsion was drawn by Perkins (1972) using the same analysis. Shukla (1972; cited by Freeman, 1973) also demonstrated no clear advantage of canonical analysis over regression analysis on environmental variables.

Multivariate techniques will undoubtedly figure prominently in the GE interaction context, particularly where linearity fails. Even so the linear regression technique will continue to play an important part in furthering our understanding of GE interactions because, despite its imperfections, it does have the twin merits, of simplicity and biological relevance (Hill, 1975). There are without doubt biological problems which can be most effectively solved by multivariate techniques. But, as Hill (1975) stated, 'there is the very real danger that biological relevance will be sacrificed for statistical pedantry', against which we must guard.

III. MATERIALS AND METHODS

Selections of Environments and Parents, and Experimental Designs

A seven-parent diallel cross, without reciprocals, of smooth bromegrass (*Bromus inermis* Leyss.) was grown at four locations over three years. The locations were chosen to provide differences in soil type, annual rainfall, and seasonal temperatures representing the cultivated areas within the province of Alberta. The regions and locations were: Northwest - Beaverlodge, Research Station, Canada Department of Agriculture; Central - Edmonton, Parkland farm; Central-east - Kinsella, University Ranch; and South - Lethbridge, Research Station, Canada Department of Agriculture. The soil characteristics, fertility and climatic factors for each site are described in Tables 1, 2, and 3. All locations had been fallowed the year before planting. Approximately 88 and 68 kg/ha of nitrogen, and 55 and 36 kg/ha of phosphorous were applied in September 1975 and 1976, respectively, to all locations.

The details of the origin and selections of the parental clones are described in Table 4 . Seeds of the 21 single crosses were obtained by mutual pollination (Mishra and Drolsom, 1972) without emasculation in the greenhouse during the winter of 1972-73. Hybrid seed and tillers of the parents were planted in the green house in individual peat-pots for a month. The parental propagules and F_1 progenies were then transplanted to each site in 1975 (actual planting dates for each site are given in Table 5) in randomized, complete block design with six replications. Because of the limited number of hybrid seed, each plot consisted of five plants spaced 120 cm between plants within and between plots. The test was bordered by rows of cultivar 'Magna' with the same spacing as that of the plots. Cultivation was limited to between plots, so that plants within plots naturally grew into each other after two years and were considered as a sward in the third year (1977). The trials were not harvested until 1976, the second year of establishment.

Table 1. Description of soil of each of the four locations in which the smooth bromegrass genotypes were grown.

Location	Classification (Order; Great group; and Sub-group)	Type	Topography	Drainage
Beaverlodge	Association of the following: 1. Solodic dark grey chernozem (40%); 2. Solodic grey luvisol (40%); and 3. Dark grey solod (20%).	Silt loam to clay loam	gently sloping (2-5%)	moderately well drained
Kinsella	Orthic black Chernozem	Sandy loam	gently sloping (2-5%)	well drained
Lethbridge*	Orthic dark brown chernozem	Loam	level topography	well drained
Edmonton	Eluviated black chernozem	Silty clay loam	level topography	moderately well drained

* on irrigated site. Irrigated twice during the experimental period:
i. Four weeks after establishment in June 1975,
ii. Two weeks before 1st harvest in June 1977, equivalent to approximately 3 inches of water.

Table 2. Descriptions of initial and final soil fertility levels of the bromegrass plots at four locations and two dates.

Location	Depth of Sample (cm)	Fertility level Nitrogen (N)	Phosphorous (P)	Potassium (K)	Soil Reaction (pH)
I. September 1975 (Initial):		------------ kg/ha	------------	------------	
Beaverlodge	0-15	81	19	543	6.4
	15-30	53	3	400	5.8
Kinsella	0-15	58	34	511	6.1
	15-30	44	8	316	6.5
Lethbridge	0-15	84	39	623	7.9
	15-30	71	8	420	7.7
Edmonton	0-15	85	34	669	5.9
	15-30	94	25	601	6.0
II. September 1977 (Final):					
Beaverlodge	0-15	9	23	474	6.0
	15-30	4	3	477	5.4
Kinsella	0-15	11	43	394	6.1
	15-30	2	8	260	6.5
Lethbridge	0-15	60	48	680	7.9
	15-30	94	11	436	7.8
Edmonton	0-15	9	51	1081	6.1
	15-30	5	37	676	6.3

Table 3. Description of the major climatic factors for the four locations in the year of establishment (1975) and the two following years.

Year	Location	Temperature(°C)			Precipitation			Sunshine (h/day)
		Max	Min	Ave	Rain	Snow	Total	
					mm	cm	mm	
1975	Beaverlodge	6.6	-4.1	1.2	237.4	199.3	436.7	6.1
	Kinsella	6.1	-2.7	1.7	279.6	130.0	409.6	-
	Lethbridge	10.1	-2.2	3.9	361.7	144.2	505.9	5.7
	Edmonton	8.0	-1.8	3.1	319.8	118.0	425.5	5.9
1976	Beaverlodge	8.2	-2.1	3.0	431.0	133.8	564.8	5.7
	Kinsella	8.5	1.4	4.9	328.9	72.1	401.0	-
	Lethbridge	13.4	-0.3	6.5	242.8	81.7	303.7	6.5
	Edmonton	10.6	-0.3	5.2	320.4	107.7	415.7	6.1
1977	Beaverlodge	7.4	-2.7	2.4	459.2	101.8	561.0	5.7
	Kinsella	16.9	-11.3	2.8	315.2	77.4	392.6	-
	Lethbridge	12.2	1.3	6.8	169.6	140.4	290.5	6.4
	Edmonton	9.8	-0.7	4.6	425.0	86.1	505.0	6.4

Table 4. A description of the origin of the parental clones used in the diallel cross.

Parent	Code	Origin
UA5	1	Random selection from 'Magna", an intermediate northern-southern type bromegrass.
UA9	2	Random selection from 'Carlton', a northern-type bromegrass.
UA10	3	Random selection from S7388, a synthetic susceptible to Selenophoma bromigena and Pyrenophora bromi from Saskatoon by Smith and Knowles (Walton, 1974).
UA12	4	Random selection from 'Lincoln', a southern-type bromegrass.
B40	5	Selection by Smith and Knowles (Walton, 1974) showing resistance to Selenophoma bromigena and Pyrenophora bromi. Yielded low in a previous diallel experiment.
B42	6	Selection by Smith and Knowles (Walton, 1974) showing resistance to Selenophoma bromigena and Pyrenophora bromi. Highest yielding resistant strain from a previous diallel experiment where it also gave a good GCA and high yielding progeny when crossed with UA9.
43	7	Collected from an old auction yard on a farm near Sedgewick in 1970. Outyielded 'Carlton' by 19% in 1972 and 17% in 1971.

Table 5. Records of dates of planting and harvesting for the four locations.

Locations	Planting Date	Date of Harvesting			
		1976		1977	
		Spring	Fall	Spring	Fall
Beaverlodge	5 June, 1975	7 July	31 Aug	28 June	23 Aug
Kinsella	2 June, 1975	11 June	27 Aug	10 June	18 Aug
Lethbridge	30 May, 1975	17 June	24 Aug	15 June	25 Aug
Edmonton	13 June, 1975	30 June	23 Aug	20 June	29 Aug

Sampling Techniques

Ten headed tillers, two from each plant, were randomly sampled from each plot in June each year prior to the spring harvests for each location. Number of green leaves per tiller was counted and the leaf blade area per tiller was measured using an automatic leaf area meter (Hayashi Denko, Model AAM-5). The tillers were separated into leaves and stems to obtain per tiller leaf dry weight, stem dry weight, and whole tiller dry weight. Specific leaf weight (SLW) was obtained by dividing leaf dry weight by leaf area.

Both fertile and sterile tillers in an area of 196 cm^2 (i.e. 14cm x 14cm) were taken from each plant for all locations except Beaverlodge, where the area was reduced to 100 cm^2 (10cm x 10cm). The sample was weighed to determine yield per area (g/dm^2), and was counted for the number of tillers. The records were later converted to a per unit area basis. Plant height was recorded for each plant before the spring harvest. Two hay crops were harvested before anthesis for each of the two years, the dates are given in Table 5. Five whole plants from each plot were harvested in 1976, whereas a plot size of 60cm x 450cm was harvested in 1977. Forage yield was expressed as dry weight in grams per plot.

The harvesting dates as listed in Table 5 were kept as close to one another as possible. However, some delay due to unfavourable weather was unavoidable.

Statistical Analyses

Transformation

One of the assumptions underlying the analysis of variance is that the experimental factors shall have the same variance. Error mean squares from the variance analyses of experiments with identical treatments, but conducted in different environments, are often heterogeneous (Yates and Cochran, 1938). When experimental means and error variances are correlated, a transformation to stabilize the error variance is recommended before conducting a combined analysis (Bartlett, 1947).

To remove the correlation between the error mean squares and experimental means, a transformation of the form as outlined was made.

$$Y = g(X)$$

where X is the character in the original scale, Y is the character on the transformed scale,

$$g(X) = X^a$$

where a is a constant (Hinz and Eagles, 1976). The method described by Hinz and Eagles (1976) was followed to obtain the value of a. However, in cases where the Hinz and Eagles method was unsuccessful, a logarithmic transformation was used. Table 6 listed the types of transformation applied; data for leaf number and height were homogeneous and were, therefore, not transformed.

Table 6. A list of the type of transformation applied to the characters studied and the correlation coefficients (r) between means and error mean squares of eight environments for each character.

	Type of Transformation		r	
	Root	Logarithm	Before Transformation	After Transformation
<u>Yield</u>				
Spring yield	0.685	--	0.49	0.04
Fall yield	0.5	--	0.89	0.15
Annual yield	0.5	--	0.59	0.10
Yield/area	--	(-1) x $\log_e$	0.92	-0.21
<u>Leaf Characters</u>				
Leaf area	0.445	--	0.97	0.13
Leaf no	--	--	-0.08	--
Leaf dry wt	0.25	--	0.67	-0.17
Specific leaf wt	--	(-1) x $\log_e$	-0.07	0.20
<u>Tiller Characters</u>				
Stem dry wt	0.25	--	0.91	-0.05
Tiller dry wt	0.25	--	0.89	-0.10
Tiller density	0.58	--	0.45	-0.07
Leaf stem ratio	--	(-1) x $\log_e$	-0.19	0.33
Height	--	--	0.14	--

Analysis of Variance and Diallel Analysis

All statistics were analysed using the plot means of the characters. In the combined analysis of variance, all sources including years, locations, and genotypes were assumed fixed, therefore the main effects and interactions were tested against their corresponding error variance.

The source of variation caused by genotypes (including parents and F_1 progenies) in the analysis of variance was further partitioned into general combining ability (GCA) and specific combining abiltiy (SCA). As highly significant differences were obtained for years-locations combination for almost every character (Tables 13,14,15), each year-location combination was considered an environment in subsequent analysis. The genotypes x years and genotypes x locations were pooled to become genotypes x environments, which was partitioned into GCA x environments and SCA x environments effects. The data were analysed using the computer program DIALL (Schaffer and Usanis, 1969).

Griffing's (1956) Model I, Method 2 (parents and one set of F_1s) and Method 4 (one set of F_1s) were used to evaluate GCA and SCA effects for each individual environment.

Phenotypic and genotypic correlation for all possible combinations of the characters measured were calculated according to the method outlined by Johnson, Robinson and Comstock (1955). Correlation coefficients for GCA and SCA were also computed from the variance and covariance components as described by Griffing (1956).

Regression Analysis

Regression technique was used for further analysis of the GE interactions using the methods of Perkins and Jinks (1968), and Freeman and Perkins (1971). Two measures of environment were used. The first measure was the average of all entries in the trial at that environment. Each of the 28 genotypes was regressed upon that environmental mean. The second measure was the average of the seven parental genotypes, the analysis was performed by regressing the mean of each of the 21 F_1 progenies on the environmental mean.

All factors were again assumed fixed. All sources including heterogeneity of regression and its residual were tested against error, except the combined regression was compared against the residual within environments. In the case where both heterogeneity of regression and residual were significant, the regression term was tested against its own residual.

Stability parameters

Stability parameters were calculated following Eberhart and Russell (1966). Stability parameter estimates such as mean, regression coefficient, and stability variance for each genotype across environments, were computed to compare relative stability of the genotypes for all yield types, leaf area, tiller dry weight, tiller density and height. The stability variance was a slight modification from Eberhart and Russell's mean square of deviation from regression (S_{di}^2). Stability variance was measured by the ratio of the deviation mean square (Dev. MS) to the pooled error mean square (MSE/r), whereas S_{di}^2 was the difference between the Dev. MS and MSE/r. A stable genotype is therefore defined as a genotype which has an above average mean performance, a coefficient of regression of 1.0 and stability variance of 1.0.

IV. RESULTS AND DISCUSSION

SECTION I

Environmental Means

Genotypic means for each environment and for all environments are shown in Appendix Tables 1 to 13 for all thirteen characters. Means and coefficients of variation (CV) for all genotypes at each of the four locations and two years are presented in Tables 7, 8 and 9. There are large differences between locations and between years for yield, leaf and stem characters. In general, Edmonton and Lethbridge were recognized as higher yielding environments than either Beaverlodge or Kinsella based on the average annual yield of the two years (Table 7). Beaverlodge is characterized by its shorter and cooler summer, and Kinsella is situated in a drier part of the province. The field plot at Lethbridge, though situated in the semi-arid southern part of the province, was located on irrigated land. The constant seepage of water from the irrigation ditch and the infrequent irrigation at the driest part of the season (e.g. June 1977), together with its long hot summer, made Lethbridge one of the highest yielding areas.

In 1976 the highest mean spring and fall yields were obtained at Lethbridge and Edmonton where yields were approximately twice that harvested at Beaverlodge. In 1977, the best yield was obtained at Edmonton where yield was more than two fold that of Kinsella. In 1976 the fall yields were generally higher than the spring yield at all locations except Lethbridge. A reverse pattern was displayed for 1977 due mainly to the nitrogen being depleted by the vigorous spring growth. The soil analysis conducted in the fall (Table 2) confirmed that nitrogen levels were low. The low fall yield of 1977

Table 7. Means and coefficients of variation (CV) for yield characters of smooth bromegrass, measured at four locations and for two years.

Character	Beaverlodge		Kinsella		Lethbridge		Edmonton	
	Mean	CV	Mean	CV	Mean	CV	Mean	CV
		%		%		%		%
1976								
Spring yield (g/plot)	1139.2	31.8	1229.4	19.8	2702.2	17.8	1892.5	18.2
Fall yield (g/plot)	1526.5	23.4	2221.6	15.4	2474.1	14.6	2152.0	17.2
Annual yield (g/plot)	2665.7	25.7	3451.1	15.8	5176.3	15.1	4044.5	15.5
Yield/area (g/dm^2)	68.5	8.3	25.2	13.4	44.2	7.4	43.1	7.4
1977								
Spring yield (g/plot)	2296.3	15.3	1766.8	12.4	2517.1	12.5	3272.5	11.2
Fall yield (g/plot)	1028.3	26.9	414.7	28.7	1176.9	17.9	1464.9	21.3
Annual yield (g/plot)	3324.6	15.2	2181.5	12.4	3694.0	12.4	4737.4	11.4
Yield/area (g/dm^2)	36.9	8.0	16.8	8.9	21.4	8.6	21.4	6.2

Table 8. Means and coefficients of variation (CV) for leaf characters of smooth bromegrass measured at four locations and for two years.

Character	Beaverlodge		Kinsella		Lethbridge		Edmonton	
	Mean	CV	Mean	CV	Mean	CV	Mean	CV
		%		%		%		%
1976								
Leaf area (cm^2/tiller)	96.9	14.2	102.3	13.5	109.5	13.0	92.9	13.2
Leaf no (no/tiller)	4.9	9.6	4.9	6.8	4.9	7.2	4.8	8.0
Leaf dry wt (g/tiller)	0.66	14.6	0.57	15.7	0.50	14.1	0.58	16.6
Specific leaf wt (x 10^{-2}; g/cm^2)	0.68	6.1	0.55	8.0	0.46	8.2	0.62	8.3
1977								
Leaf area (cm^2/tiller)	96.5	14.2	55.6	17.3	57.7	18.0	99.7	14.0
Leaf no (no/tiller)	4.2	9.7	4.1	9.6	4.1	9.7	4.5	8.5
Leaf dry wt (g/tiller)	0.57	14.1	0.31	19.3	0.30	18.6	0.47	18.3
Specific leaf wt ([illegible] 10^{-2}; g/cm^2)	0.59	9.3	0.54	7.2	0.52	8.6	0.47	8.0

Table 9. Means and coefficients of variation (CV) for tiller characters of smooth bromegrass measured at four locations and for two years.

Character	Beaverlodge		Kinsella		Lethbridge		Edmonton	
	Mean	CV	Mean	CV	Mean	CV	Mean	CV
		%		%		%		%
1976								
Stem dry wt (g/tiller)	3.72	12.9	1.73	15.2	2.08	15.6	2.53	15.6
Tiller dry wt (g/tiller)	4.38	12.7	2.30	14.4	2.58	14.8	3.11	15.4
Tiller density (no/dm^2)	30.2	8.0	19.2	9.3	28.2	7.6	25.7	6.8
Leaf stem ratio	0.18	9.0	0.33	11.5	0.24	9.3	0.23	9.9
Height (cm)	109.6	7.6	91.5	7.1	105.2	5.7	116.9	5.5
1977								
Stem dry wt (g/tiller)	2.78	13.2	1.38	16.1	1.63	18.6	2.03	19.5
Tiller dry wt (g/tiller)	3.36	12.3	1.68	15.9	1.93	18.2	2.50	18.6
Tiller density (no/dm^2)	19.2	11.4	19.6	12.3	21.7	9.9	16.0	8.9
Leaf stem ratio	0.21	13.9	0.22	13.5	0.19	12.8	0.24	13.2
Height (cm)	127.7	4.4	91.3	4.9	97.6	5.7	125.4	4.6

reflected that one fall fertilizer application per year was inadequate for fully grown bromegrass cut more than once in a season. Split fertilizer applications would be recommended.

The CVs for spring, fall and annual yield at Beaverlodge were consistently higher than the CV's of other locations in 1976 (Table 7) indicating that the measurements were subject to greater variation than at other locations. This may be due in part to the great soil heterogeneity within that area (Table 1). The variation became less obvious in the 1977 data.

Yields per unit area were similar at Lethbridge and Edmonton, while Beaverlodge had the highest and Kinsella the lowest in 1976. The same pattern holds for 1977, but the values were smaller. The plants grown at Beaverlodge had heavier leaves and stems (Table 8), and more and heavier tillers (Table 9) than at all other locations in both years. A reverse situation was obtained for Kinsella except that the tiller density in 1977 was high. All or some of these factors may have contributed to the yield per unit area. The interrelationships among yield types and between yield and its morphological components will be dealt with in greater detail later. Leaf number and SLW were considered relatively stable. The leaf area per tiller was similar for both years at both Beaverlodge and Edmonton, but for Lethbridge and Kinsella, the leaf area in 1977 was only half that of 1976. Plants at Beaverlodge and Edmonton were consistently taller in both years, and were approximately 30% taller than those of Kinsella and Lethbridge in 1977.

Transformation

Large differences between the error mean squares are shown for most of the characters measured in each environment (Tables 10, 11 and 12). The relationships between the means and error mean squares are presented in Table 6. Also presented in Table 6 are the correlation coefficients between the means and error mean squares computed from the transformed data, showing that these two statistics now are independent. Furthermore, the transformation reduced the heterogeneity of error mean squares considerably for most of the characters (Tables 10, 11 and 12). For yield per unit area, the difference between the largest error mean square and the smallest was much greater on the direct scale than on the transformed scale (Table 10). For example, the largest error mean square for yield per area on the direct scale was 32.67 for year 1976 at Beaverlodge, which was 18 times greater than the smallest error mean square, 1.78 for 1977 in Edmonton. However, on the transformed scale, the largest error mean square (0.1996) was only 5 times larger than the smallest mean square (0.04). For SLW, the largest error mean square was 82 times the smallest on the direct scale, but 2.5 times the smallest on the transformed scale; and for leaf stem ratio, the largest error mean square was 28 times the smallest on the direct scale, but 5 times the smallest on the transformed scale. This explained why transformation was applied to SLW and leaf stem ratio even though there were no apparent correlations between their means and error mean squares (Table 6). In fact, the correlation coefficients between the means and error mean squares for the two characters were increased after transformation. However, the smaller increments were compensated for by the reduction in the heterogeneity of error mean squares. Neither leaf number nor height were transformed since they showed either no or only a small correlation between the mean and error mean squares (Table 6). Also, their error variances were sufficiently homogeneous (Tables 11 and 12).

Analyses of variance were conducted on all characters measured on both direct and transformed scales. Tests of significance from computations using data on the direct scale were only approximations because of the known association between evironmental means and error variances on this scale. However, this is the scale commonly used to measure adaptation parameters in agronomic research, and analyses using it might be helpful for interpretation purposes.

Table 10. Error mean squares from analysis of variance for individual environments for yield characters measured on both direct and transformed scales.

	Yield/area	Spring yield	Fall yield	Annual yield
DIRECT				
1976				
Beaverlodge	32.67	131382	127930	470925
Kinsella	11.49	59581	117954	300233
Lethbridge	10.75	233282	130575	612329
Edmonton	10.26	119410	137213	392427
1977				
Beaverlodge	8.84	123399	76481	256138
Kinsella	2.25	48485	14209	73321
Lethbridge	3.40	100116	44657	210728
Edmonton	1.78	135126	97608	295587
TRANSFORMED				
1976				
Beaverlodge	0.0724	682	22.4	43.9
Kinsella	0.1996	321	14.1	23.1
Lethbridge	0.0601	791	14.8	33.1
Edmonton	0.0653	503	15.6	25.2
1977				
Beaverlodge	0.0653	459	26.1	20.5
Kinsella	0.0863	210	8.5	8.4
Lethbridge	0.0748	362	10.3	15.8
Edmonton	0.0400	393	18.2	16.1

Table 11. Error mean squares from analysis of variance for individual environments for leaf characters measured on both direct and transformed scales.

	Leaf area	Leaf no	Leaf dry wt	Specific leaf wt
DIRECT				
1976				
Beaverlodge	189.1	0.222	0.093	0.0017
Kinsella	192.8	0.111	0.080	0.0019
Lethbridge	202.8	0.127	0.051	0.0014
Edmonton	152.4	0.151	0.093	0.0026
1977				
Beaverlodge	188.3	0.167	0.066	0.0030
Kinsella	93.0	0.154	0.034	0.0015
Lethbridge	107.9	0.159	0.072	0.1153
Edmonton	196.1	0.144	0.077	0.0014
TRANSFORMED				
1976				
Beaverlodge	0.228	--	0.111	0.372
Kinsella	0.234	--	0.125	0.701
Lethbridge	0.227	--	0.088	0.594
Edmonton	0.200	--	0.122	0.679
1977				
Beaverlodge	0.229	--	0.090	0.924
Kinsella	0.204	--	0.112	0.501
Lethbridge	0.247	--	0.123	0.763
Edmonton	0.247	--	0.147	0.635

Table 12. Error mean squares from analysis of variance for individual environments for tiller characters measured on both direct and transformed scales.

	Stem dry wt	Tiller dry wt	Tiller density	Leaf stem ratio	Height
DIRECT					
1976					
Beaverlodge	0.231	0.314	5.864	0.025	69.66
Kinsella	0.069	0.110	3.238	0.144	42.05
Lethbridge	0.106	0.147	4.685	0.053	35.84
Edmonton	0.156	0.229	3.051	0.052	41.31
1977					
Beaverlodge	0.135	0.173	4.848	0.084	32.29
Kinsella	0.049	0.072	5.873	0.094	20.14
Lethbridge	0.092	0.125	4.634	0.713	31.57
Edmonton	0.157	0.216	2.073	0.100	34.10
TRANSFORMED					
1976					
Beaverlodge	0.222	0.234	0.111	0.082	--
Kinsella	0.204	0.218	0.090	0.123	--
Lethbridge	0.226	0.228	0.093	0.087	--
Edmonton	0.217	0.233	0.067	0.097	--
1977					
Beaverlodge	0.209	0.199	0.132	0.185	--
Kinsella	0.180	0.191	0.157	0.173	--
Lethbridge	0.282	0.290	0.110	0.392	--
Edmonton	0.310	0.319	0.067	0.171	--

Combined Analysis of Variance and Diallel Analysis

The combined analyses of variance for yield, leaf and stem characters are shown in Tables 13, 14 and 15, respectively, All the main effects were highly significant when tested by their corresponding errors. In general, the analyses show that for both scales the genotypes interacted significantly with years and with locations which must include climatic, edaphic and management factors. The second order interactions, genotype x location x year, were significant for most characters, with the exception of stem dry weight, tiller density and leaf stem ratio on the direct scale, and leaf area and leaf stem ratio on the transformed scale. For stem dry weight and tiller dry weight, the non-significant location by year interaction on the transformed scale indicated that the locations ranked similarly from one year to another. No general pattern was obtained for other characters. Both scales agreed well except in a few instances which were mainly the higher order interactions, where the two scales were either in disagreement or were significant at different levels of probability.

As the analyses showed that locations, years and their interactions were highly significant, the data from the four locations, two years, and their interactions were therefore treated as eight different environments in subsequent analyses. Model I, method 2, of the analysis of Griffing (1956) was used to partition the variation among genotypes into that due to general combining ability (GCA) and specific combining ability (SCA). The interaction between genotype and environment was further divided into GCA by environment and SCA by environment interactions for all characters (Tables 16, 17 and 18).

All GCA and SCA mean squares and their interactions with environments were highly significant for all characters on both scales. The two scales closely agreed for all cases. Variation accounted for by combini[illegible]bility effects, in general, was appreciably higher than the interaction effects of GCA and SCA with the environments. Mean

Table 13. Mean squares for the yield characters measured on direct and transformed scales for the seven parents and 21 progenies tested in four locations and two years.

Source of Variation	d.f.	Direct Scale				Transformed Scale			
		Yield/ area	Spring yield	Fall yield	Annual yield	Yield/ area	Spring yield	Fall yield	Annual yield
Locations (L)	3	58388†	1121100†	302980†	2563700†	44.82†	436350†	6533†	18249†
Years (Y)	1	150050†	1753200†	3863800†	411690*	122.92†	726530†	71210†	2540*
L x Y	3	7722†	414180†	299080†	1185300†	1.73†	150800†	6858†	8429†
Error 'a'	40	58	17476	20679	62523	0.04	7206	425	472
Genotypes (G)	27	1402†	16417†	11193†	48794†	1.20†	6809†	218†	377†
G x L	81	203†	3776†	2442†	10634†	0.09†	1492†	42†	78†
G x Y	27	296†	4269†	6212†	17394†	0.05†	1576†	106†	109†
G x L x Y	81	81†	2919†	1560†	6639†	0.03†	1013†	23**	40†
Error 'b'	1080	10	1188	933	3264	0.01	465	16	23

*, **, † Significant at the 0.05, 0.01 and 0.001 probability levels, respectively.

Table 14. Mean squares for the leaf characters measured on direct and transformed scales for the seven parents and 21 progenies tested in four locations and two years.

Source of Variation	d.f.	Direct Scale				Transformed Scale		
		Leaf area	Leaf no.	Leaf dry wt	Specific leaf wt	Leaf area	Leaf dry wt	Specific leaf wt
Locations (L)	3	27248†	1.744*	3.130†	1.237†	46.33†	0.603†	3.921†
Years (Y)	1	177670†	145.890†	9.057†	0.682†	275.68†	1.877†	1.839†
L x Y	3	78169†	3.842†	0.594†	0.662†	119.16†	0.179†	2.268†
Error 'a'	40	1442	0.550	0.026	0.018	1.97	0.004	0.055
Genotypes (G)	27	15539†	5.302†	0.816†	0.107†	21.25†	0.142†	0.340†
G x L	81	480†	0.492†	0.030†	0.006†	0.57†	0.003†	0.020†
G x Y	27	627†	0.277**	0.031†	0.003*	0.52†	0.002**	0.011**
G x L x Y	81	209†	0.216*	0.011†	0.003**	0.21ns	0.001*	0.009**
Error 'b'	1080	165	0.154	0.006	0.001	0.22	0.001	0.006

ns not significant.

*, **, † significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

Table 15. Mean squares for the tiller characters measured on direct and transformed scales for the seven parents and 21 progenies tested in four locations and two years.

Source of Variation	d.f.	Direct Scale					Transformed Scale			
		Stem dry wt	Tiller dry wt	Tiller density	Leaf stem ratio	Height	Stem dry wt	Tiller dry wt	Tiller density	Leaf stem ratio
Location (L)	3	185.30†	233.49†	2574.9†	.4276†	67877†	3.1628†	2.9874†	60.40†	7.288†
Years (Y)	1	105.14†	175.92†	15007.0†	.2903†	7424**	1.9264†	2.5268†	354.01†	4.452†
L x Y	3	5.64†	3.42**	2182.7†	.3139†	10310†	0.0153ns	0.0096ns	53.39†	5.255†
Error 'a'	40	0.47	0.62	14.3	.0050	619	0.0077	0.0078	0.34	0.079
Genotypes (G)	27	16.48†	24.38†	840.9†	.0156†	3022†	0.2984†	0.3263†	20.38†	0.295†
G x L	81	0.80†	1.08†	49.0†	.0029†	170†	0.0062†	0.0063†	1.14†	0.040†
G x Y	27	0.31†	0.50†	73.9†	.0025*	64*	0.0038*	0.0040*	1.32†	0.030**
G x L x Y	81	0.21ns	0.28†	19.1ns	.0016ns	65†	0.0031*	0.0032*	0.40†	0.016ns
Error 'b'	1080	0.12	0.17	4.2	.0015	38	0.0023	0.0023	0.10	0.016

ns not significant.

*, **, † significant at the 0.05, 0.01 and 0.001 probability levels, respectively.

Table 16. Combining ability analysis for the yield characters measured on direct and transformed scales for the seven parents and 21 progenies tested in eight environments.

	d.f.	Yield/area	Spring yield	Fall yield	Annual yield
DIRECT					
GCA	6	5208.31 †	2703444 †	1786186 †	8084411 †
SCA	21	315.27 †	1338329 †	928825 †	3963690 †
GCA x E	42	411.00 †	870746 †	601385 †	2463160 †
SCA x E	147	94.10 †	198637 †	162855 †	567532 †
Error	1080	10.186	118850	93332	326470
GCA:SCA		16.5	2.2	1.9	2.0
TRANSFORMED					
GCA	6	4.5208†	11754 †	420.93†	668.25†
SCA	21	0.2607†	5394 †	160.98†	294.65†
GCA x E	42	0.1002†	3182 †	100.30†	157.06†
SCA x E	147	0.0556†	761 †	27.34†	40.60†
Error	1080	0.0083	465	16.31	23.32
GCA:SCA		17.3	2.2	2.6	2.2

† Significant at the 0.001 probability level.

Table 17. Combining ability analysis for the leaf characters measured on direct and transformed scales for the seven parents and 21 progenies tested in eight environments.

Source	d.f.	Leaf area	Leaf no	Leaf dry wt	Specific leaf wt
DIRECT					
GCA	6	61701 †	18.126†	3.3553†	0.4429†
SCA	21	2349 †	1.638†	0.0908†	0.0113†
GCA x E	42	876 †	0.587†	0.0613†	0.0098†
SCA x E	147	245 †	0.273†	0.0111†	0.0031†
Error	1080	165	0.154	0.0065	0.0019
GCA:SCA		26.2	11.0	36.9	38.9
TRANSFORMED					
GCA	6	83.892†	--	0.5815†	1.398 †
SCA	21	3.355†	--	0.0175†	0.038 †
GCA x E	42	0.765†	--	0.0046†	0.031 †
SCA x E	147	0.309†	--	0.0015†	0.009 †
Error	1080	0.227	--	0.0011	0.006
GCA:SCA		24.9	--	33.2	36.0

† Significant at the 0.001 probability level.

Table 18. Combining ability analysis for the tiller characters measured on direct and transformed scales for the seven parents and 21 progenies tested in eight environments.

Source	d.f.	Stem dry wt	Tiller dry wt	Tiller density	Leaf stem ratio	Height
DIRECT						
GCA	6	65.783 †	98.050 †	3196.6 †	0.04869†	10478†
SCA	21	2.398 †	3.342 †	167.9 †	0.00620†	892†
GCA x E	42	1.428 †	1.934 †	94.6 †	0.00422†	278†
SCA x E	147	0.210 †	0.294 †	24.1 †	0.00179†	61†
Error	1080	0.124	0.173	4.2	0.00158	38
GCA:SCA		27.4	29.3	19.0	7.8	11.7
TRANSFORMED						
GCA	6	1.1780†	1.2990†	78.00†	0.9739 †	--
SCA	21	0.0471†	0.0484†	3.91†	0.1019 †	--
GCA x E	42	0.0092†	0.0095†	1.86†	0.0516 †	--
SCA x E	147	0.0032†	0.0032†	0.56†	0.0223 †	--
Error	1080	0.0023	0.0024	0.10	0.0164	--
GCA:SCA		24.9	26.7	19.8	9.5	--

† Significant at the 0.001 probability level.

squares of SCA were highly significant for all the characters. However, the ratio of GCA to SCA showed that the genetic variability for each character was associated with GCA rather than SCA, indicating the importance of additive genetic effect. Exceptions to this were spring, fall and annual yield, where both GCA and SCA were equally important since the ratios were approximately 2. The GCA to SCA ratios for the other traits, on the other hand, ranged from 7.8 for leaf stem ratio to 38.9 for SLW, both on the direct scale. These results agreed well with those reported previously (Tan et al., 1976b, 1977), where results were based on one year and one location only.

In contrast to the three types of yield, the GCA to SCA ratio was high for yield per unit area. This may imply that more rapid response would be expected through selection on yield per unit area than selection on yield per plot.

The GCA effects of the parents and the SCA effects of the progenies will be considered in detail in conjunction with stability parameters in Section II.

Correlation

Phenotypic and genotypic correlation coefficients among yield types and between yield and other morphological characters are presented in Tables 19 and 20, respectively. These correlation coefficients estimated the joint responses among characters in this population. Phenotypic correlations showed that the yield types were all significantly associated. As expected, large positive genotypic correlation coefficients were obtained among all yield types.

On breaking down the genotypic correlations between characters into additive(GCA) and non-additive (SCA) genetic correlation, the additive genetic correlation will include all the additive covariance and interactions involving them, and that of non-additive genetic correlation will include dominance and all epistatic covariances. The magnitudes of both additive and non-additive genetic correlations among yield types were similar to or exceed the phenotypic and genotypic correlations

Table 19. Correlation coefficients of phenotypic (r_P), genotypic (r_G), general combining ability (r_{GCA}), and specific combining ability (r_{SCA}) among yield characters in smooth bromegrass.§

Character		Fall Yield	Annual Yield	Yield/area
Spring yield	r_P	0.78†	0.95†	0.48**
	r_G	0.80	0.96	0.54
	r_{GCA}	1.09	1.00	0.62
	r_{SCA}	0.78	0.96	0.72
Fall yield	r_P		0.93†	0.67†
	r_G		0.93	0.73
	r_{GCA}		1.02	1.60
	r_{SCA}		0.93	0.76
Annual yield	r_P			0.58†
	r_G			0.66
	r_{GCA}			0.92
	r_{SCA}			0.79

§ Statistical test is provided for r_P only.

**, † significant at the 0.01, and 0.001 probability levels, respectively, where n=28.

Table 20. Correlation coefficients of phenotypic (r_P), genotypic (r_G), general combining ability (r_{GCA}), and specific combining ability (r_{SCA}) among yield and leaf, tiller characters in smooth bromegrass.§

Character		Leaf character				Tiller character				
		Leaf area	Leaf no	Leaf dry wt	Specific leaf wt	Stem dry wt	Tiller dry wt	Tiller density	Leaf stem ratio	Height
Spring yield	r_P	.12	.09	-.06	-0.45*	0.05	.03	0.51**	-0.42*	.38*
	r_G	.25	.24	.06	-0.37	0.18	.16	0.54	-0.46	.49
	r_{GCA}	-.33	-.70	-.76	-1.48	-0.58	-.61	0.93	-0.73	.02
	r_{SCA}	.66	.55	.52	-0.14	0.62	.61	-0.12	-0.51	.75
Fall yield	r_P	.28	-.02	.10	-0.31	0.24	.22	0.28	-0.48**	.58†
	r_G	.34	.05	.18	-0.22	0.33	.30	0.17	-0.52	.70
	r_{GCA}	.39	-.75	-.11	0.14	-1.32	.09	1.48	-1.09	.76
	r_{SCA}	.53	.27	.47	0.62	0.09	.61	-0.16	-0.48	.88
Annual yield	r_P	.21	.04	.01	-0.41*	0.15	.12	0.36*	-0.48**	.51**
	r_G	.31	.16	.12	-0.32	0.26	.24	0.49	-0.52	.62
	r_{GCA}	-.01	-.71	-.47	-0.26	-1.38	-.30	0.96	-0.87	.33
	r_{SCA}	.64	.45	.53	0.66	-0.04	.64	-0.15	-0.52	.86
Yield/area	r_P	.57†	.23	.37*	-0.18	0.43*	.42*	0.40*	-0.14	.69†
	r_G	.56	.27	.38	-0.19	0.44	.43	0.40	-0.22	.70
	r_{GCA}	.60	.19	.40	-0.14	0.43	.43	0.61	-0.02	.70
	r_{SCA}	.48	.37	.35	-0.33	0.47	.46	0.48	-0.48	.71

§ statistical test is provided for r_P only.

*, **, † significant at the 0.05, 0.01, and 0.001 probability levels, respectively, where n=28.

(Table 19). The additive genetic correlations were considerably greater than the non-additive genetic correlations in most cases, except between spring yield and yield per unit area.

Very few of the morphological characters measured were associated with yield (Table 20). Height was positively while leaf stem ratio was negatively correlated with spring, fall and annual yield. Tiller density was significantly correlated phenotypically with all yield types except fall yield. Significant, negative correlation coefficients were noted for SLW and spring and annual yield. More morphological characters showed significant phenotypic correlations with yield per area than with other yield types. These morphological characters included leaf area, leaf, stem and tiller dry weight, tiller density and height. Genotypic correlation coefficients were of similar or slightly higher magnitudes than the phenotypic correlation coefficients. Further partition of the genotypic response showed that the close genotypic associations between the height and the spring and annual yields were due mainly to the non-additive genetic effects and little, if any, to the additive genetic effects. The close associations between tiller density and the types of yield were mainly due to additive genetic variance, while the association due to non-additive genetic variation were negative, small and negligible. The large additive genetic correlation coefficients indicated that in this population selection towards high yield would be in conjunction with increased tiller density. For high yield per area selection through large leaf area, greater number of tiller and per tiller dry weight should also be effective.

The number of tillers per unit ground area (or tiller density, in no/dm^2) and tiller dry weight are considered as the two major components of forage yield. The relative importance of these two components in their contribution to forage yield have been reported previously by various workers. In the present study and the previous reports (Tan et al., 1977a, b) tiller density showed a highly positive correlation with forage yield, but the association between tiller dry weight and forage yield was not significant. The results are in close agreement with those in *Lolium* species (Lazenby and Rogers, 1962; Thomson et al., 1973), and suggest that tiller density is of greater importance in determining yield than tiller dry weight. Conversely, different results on the associations between tiller density, tiller size and yield have been reported in a number of forage species, including orchardgrass (Knight, 1970), perennial ryegrass (Troughton, 1965), and bromegrass (Walton, 1976).

SECTION II

Joint Regression Analysis

Tables 21, 22 and 23 show the further partition of the GE interactions using the joint regression analysis on both scales. In this analysis regressions of genotype means from environments (i.e. locations and years) were compared with environmental means derived from the whole population. Such analyses made possible the determination for each character how much of the GE interaction could be accounted for by the heterogeneity of the regressions, that is by the differences between slopes of the regression lines, and how much was residual and therefore unpredictable. The two components were tested against the error terms derived from analysis of variance. Regardless of which character was being examined a significant part of the GE interaction could always be demonstrated as being due to the differences between the slopes of the regression lines. In all instances the unpredictable residual deviations were also significant on both scales.

When both the mean square of heterogeneity of regression and the mean square of residual were significant when tested against the error term, the validity of any predictions would depend on the relative magnitudes of the two mean squares (Perkins and Jinks, 1968). If the mean square of heterogeneity of regression was

Table 21. Mean squares from the joint regression analyses for the yield characters measured on direct and transformed scales for 28 genotypes tested in eight environments, with environmental means derived from all genotypes.

Source of Variation	d.f.	Direct Scale				Transformed Scale			
		Yield/ area	Spring yield	Fall yield	Annual yield	Yield/ area	Spring yield	Fall yield	Annual yield
Genotypes (G)	27	1402†	16417†	11193†	48794†	1.207†	6810†	218†	377†
Environments (E)	7	49768†	908410†	809990†	1665500†	37.517†	355430†	15912†	11797†
Interaction (G x E)	(189)								
Heterogeneity of reg.	27	756† §	4134†	5192† §	8954†	0.095† §	1586†	93† §	56†
Residual	162	66†	3370†	2171†	10043†	0.061†	1251†	35†	68†
Replicates/environment	40	58†	17476†	20679†	62523†	0.049†	7206†	425†	472†
Error	1080	10	1188	933	3264	0.008	465	16	23

† significant at the 0.001 probability level, when compared with error.

§ significant at the 0.001 probability level for the heterogeneity of regression when compared with residual.

Table 22. Mean squares from the joint regression analyses for the leaf characters measured on direct and transformed scales for 28 genotypes tested in eight environments, with environmental means derived from all genotypes.

Source of Variation	d.f.	Direct Scale				Transformed Scale		
		Leaf area	Leaf no	Leaf dry wt	Specific leaf wt	Leaf area	Leaf dry wt	Specific leaf wt
Genotypes (G)	27	15539†	5.302†	0.816†	0.107†	21.25†	0.1428†	0.341†
Environment (E)	7	70560†	23.235†	2.890†	0.912†	110.31†	0.6040†	2.915†
Interaction (G x E)	(189)							
Heterogeneity of reg.	27	920† §	0.293**	0.073† §	0.003*	0.55†	0.0029†	0.009*
Residual	162	296†	0.352†	0.013†	0.005†	0.38†	0.0022†	0.015†
Replicates/environment	40	1442†	0.551†	0.026†	0.019†	1.97†	0.0048†	0.056†
Error	1080	165	0.155	0.006	0.002	0.22	0.0011	0.006

*, **, † significant at the 0.05, 0.01, and 0.001 probability levels, respectively, when compared with error.

§ significant at the 0.05 probability level for the heterogeneity of regression when compared with residual.

Table 23. Mean squares from the joint regression analyses for the tiller characters measured on direct and transformed scales for 28 genotypes tested in eight environments, with environmental means derived from all genotypes.

Source of Variation	d.f.	Direct Scale					Transformed Scale			
		Stem dry wt	Tiller dry wt	Tiller density	Leaf stem ratio	Height	Stem dry wt	Tiller dry wt	Tiller density	Leaf stem ratio
Genotypes (G)	27	16.484†	24.389†	841.0†	0.0167†	3022†	0.2984†	0.3264†	20.38†	0.3114†
Environments (E)	7	96.852†	126.666†	4182.8†	0.3718†	34570†	1.6374†	1.6454†	99.34†	6.1372†
Interaction (G x E)	(189)									
Heterogeneity of regression	27	2.076† §	2.749† §	97.0† §	0.0024† §	78**	0.0066† §	0.0063†	1.45† §	0.0207*
Residual	162	0.215†	0.311†	30.2†	0.0013†	115†	0.0042†	0.0044†	0.75†	0.0269†
Replicates/ environment	40	0.474†	0.627†	14.3†	0.0050†	619†	0.0077†	0.0078†	0.34†	0.0798†
Error	1080	0.125	0.173	4.3	0.0007	38	0.0023	0.0024	0.10	0.0135

*, **, † significant at the 0.05, 0.01, and 0.001 probability levels, respectively, when compared with error.

§ significant at the 0.05 probability level for the heterogeneity of regression when compared with residual.

significant when compared with that of residual, the prediction of GE interactions based on the linear regression would still have considerable practical value. Both yield per area and fall yield showed significant regression when compared with the residual on both scales (Table 21). Variations due to heterogeneity among regressions for leaf area and leaf dry weight were both significant on the direct scale but not on the transformed scale (Table 22). Mean squares for heterogeneity of regressions were significant for stem dry weight, tiller dry weight, tiller density and leaf stem ratio on the direct scale, but only stem dry weight and tiller density were significant on the transformed scale.

Thus, the linear model would retain considerable predictive value for the genotypes concerned for some of the characters such as tiller density, stem dry weight, yield per area and fall yield as most of the interactions were accounted for by the heterogeneity of regressions. According to Perkins and Jinks (1968), even if the mean squares due to heterogeneity among regressions was not significant when tested against residual mean square; this did not rule out the possibility that the regressions of each genotype mean on to the environmental mean for some of the genotypes taken individually may be highly significant when tested against their residual mean squares. Therefore, for those particular genotypes reliable predictions can still be made.

Attention to the problems that can arise from assessing an environment by the mean of the genotypes grown in it has been drawn by Freeman and Perkins (1971). Their main criticism of the technique was that the genotype means contribute to, and hence, were not statistically independent of, the environmental means on which they were regressed. Yates and Cochran (1938) originally justified this procedure on the ground that, because the joint regression sum of squares equalled the environmental sum of squares, the GE interaction sum of squares could then be partitioned orthogonally into two items, one measuring differences between the slopes of the fitted lines, the other measuring the residual deviations about these lines. Freeman (1973) agreed that this procedure was perfectly valid provided inferences were drawn only about the sample of genotypes and environments used in the experiment, that is the model was fixed.

Assuming a fixed model, the joint regression analysis presented in Tables 21, 22 and 23 are considered statistically valid. The present trial includes seven parents and 21 progenies in all environments, which coincides with one of the experimental designs outlined by Freeman and Perkins (1971), who approached these problems by providing independent estimates of the environment by the mean of the parental genotypes. In this study the method of Freeman and Perkins(1971) was followed and the results of the analysis are presented in Tables 24, 25 and 26 for yield, leaf, and tiller characters, respectively, on both scales.

Most of the terms in Table 24 are significant at the 0.1 per cent level when compared with the error. The mean squares for heterogeneity of regressions were significantly greater than their residuals for yield per area, spring yield and fall yield on the direct scale, but were significant only for spring and fall yield on the transformed scale. For each character, the combined regression slope was not significantly different from unity, but the residual about this regression was not negligible. Mean squares for heterogeneity among regressions were significantly greater than the error for all leaf characters except SLW on both scales (Table 25). When compared with their residuals, mean squares of the heterogeneity of regression were significant for leaf area and leaf dry weight on the direct scale, but not on the transformed scale.

In Table 26, height was the only character which did not show significant linear response on the direct scale when regressions were compared with either error or residual terms. The mean squares of heterogeneity among regressions for tiller density remained significant while leaf stem ratio was not significant after the scale had been transformed.

The effect of transformation has become obvious in the joint regression

Table 24. Mean squares from the joint regression analyses for the yield characters measured on direct and transformed scales for 21 genotypes tested in eight environments, with environmental means derived from the parental genotypes.

Source of Variation	d.f.	Direct Scale Yield/ area	 Spring yield	 Fall yield	 Annual yield	Transformed Scale Yield/ area	 Spring yield	 Fall yield	 Annual yield
Genotypes (G)	20	1198†	11732†	11185†	40145†	0.983†	4645†	220†	298†
Environments (E)	(7)								
Combined reg.	1	277834†	4375780†	4132470†	7890490†	204.866†	1697860†	80231†	54495†
Residual	6	1947†	36786†	25771†	111335†	1.027†	14190†	602†	922†
Interaction (G x E)	(140)								
Heterogeneity of regression	20	544† §	4132† §	3784† §	7132**	0.048†	1596† §	65† §	51†
Residual	120	61†	2298†	1545†	6999†	0.049†	810†	23†	42†
Replicates/ environment	40	46†	13292†	15833†	48584†	0.039†	5296†	317†	351†
Error	800	10	1171	914	3183	0.008	453	15	22

*, **, † significant at the 0.05, 0.01 and 0.001 probability levels, respectively, when compared with error.

§ significant at the 0.05 probability level for the heterogeneity of regression when compared with residual.

Table 25. Mean squares from the joint regression analyses for the leaf characters measured on the direct and transformed scales for 21 genotypes tested in eight environments, with environmental means derived from the parental genotypes.

Source of Variation	d.f.	Direct Scale Leaf area	Direct Scale Leaf no	Direct Scale Leaf dry wt	Direct Scale Specific leaf wt	Transformed Scale Leaf area	Transformed Scale Leaf dry wt	Transformed Scale Specific leaf wt
Genotypes (G)	20	12727†	4.69†	0.709†	0.0937†	17.172†	0.2788†	0.3146†
Environments (E)	(7)							
Combined reg.	1	376194†	111.96†	15.161†	4.4080†	578.916†	8.5900†	14.285 †
Residual	6	784†	1.53†	0.028†	0.0087†	1.624†	0.0081†	0.0296†
Interaction (G x E)	(140)							
Heterogeneity of reg.	20	686† §	0.25*	0.054† §	0.0025ns	0.434**	0.0046†	0.0085ns
Residual	120	249†	0.27†	0.010†	0.0028†	0.298**	0.0030†	0.0097†
Replicates/environment	40	1110†	0.41†	0.021†	0.0140†	1.482†	0.0038†	0.0414†
Error	800	165	0.15	0.006	0.0016	0.221	0.0011	0.0055

ns not significant.

*, **, † significant at the 0.05, 0.01 and 0.001 probability levels, respectively.

§ significant at the 0.05 probability level for the heterogeneity of regression when compared with residual.

Table 26. Mean squares from the joint regression analyses for the tiller characters measured on direct and transformed scales for 21 genotypes tested in eight environments, with environmental means derived from the parental genotypes.

Source of Variation	d.f.	Direct Scale					Transformed Scale			
		Stem dry wt	Tiller dry wt	Tiller density	Leaf stem ratio	Height	Stem dry wt	Tiller dry wt	Tiller density	Leaf stem ratio
Genotypes (G)	20	14.971†	22.021†	848.7†	0.0108†	2429†	0.2788†	0.3021†	20.42†	0.195†
Environments (E)	(7)									
Combined reg.	1	511.157†	668.760†	19866.1†	1.9310†	173103†	8.590 †	8.624 †	467.19†	31.692†
Residual	6	0.348**	0.545**	446.1†	0.0040†	1529†	0.0081**	0.0091†	10.75†	0.085†
Interaction (G x E)	(140)									
Heterogeneity of regression	20	1.258† §	1.719† §	70.2† §	0.0022† §	34ns	0.0046**	0.0046**	0.99† §	0.017ns
Residual	120	0.149ns	0.219*	22.5†	0.0010**	91†	0.0030**	0.0031**	0.51†	0.021†
Replicates/ environment	40	0.381†	0.511†	12.6†	0.0033†	434†	0.0066†	0.0067†	0.29†	0.061†
Error	800	0.123	0.169	4.2	0.0007	40	0.0022	0.0022	0.10	0.013

ns not significant.

*, **, † significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

§ significant at the 0.05 probability level for the heterogeneity of regression when compared with residual.

analysis. Test of significance among means discussed in Section I were similar on both scales. For heterogeneity among regressions, the tests produced different results. This suggested that tests of significance on the direct scale were accurate among means, but were not accurate among regressions. Cases where drastic changes of variance ratios when different scales are used were not unusual. Transformation may be used to reduce both interaction effects and heterogeneity of variances (Bartlett, 1947). However, if the GE interaction could be removed by using any of the transformation encountered in this study (or any other monotonic transformation), the interaction will likely be of the kind that cannot be exploited by selection (Eagles et al., 1977).

The use of different measures of environment also created some differences in the significance of the linear responses. For example, most of the interaction for spring yield was accounted for by heterogeneity of regressions on both scales when the environmental means were measured by the mean of the parental genotypes, but was not significant on either scale when the overall mean of the 28 genotypes was taken into the measure of environment. These conflicting results from the present study cautions the choice of measure of environment. It would affect the interpretation of results from regression analysis. The differences which arose from the two measures of environments would likely be the result of the use of too few parental genotypes as a measure of environment, as postulated by Perkins and Jinks (1973).

Stability Parameters

Stability parameter estimates for each genotype across environments were computed to compare relative stability of the genotypes. A stable genotype was defined as a genotype which had a regression coefficient of 1.0 and stability variance around 1.0. Of all traits, yield characters such as spring, fall and annual yields are of major agronomic interest and are the most important criteria on which stability of field crops is being considered. Yield per area and other morphological characters, such as leaf area, tiller weight and density, and height, were also included, to show that stability of genotypes may vary with traits, that is, the genotypes which were rated as stable for one character may be unstable for other characters.

The primary stability parameter for plant cultivars according to Finlay and Wilkinson (1963), is the regression coefficient of the means of a cultivar upon the environmental indexes. This statistic measures whether a given cultivar produces relatively better or worse than all cultivars in the environments with low- and high-productivity potentials. Herein, $b=1.0$ will be designated as average stability (see Finlay and Wilkinson, 1963), values above unity will be classed as less stable than average (below average stability) and values below, as more stable than average (above average stability). Since the heterogeneity among regressions was not a very large proportion of the GE interaction for most characters, the partition of the pooled deviation into stability variances for every genotype appeared very important. It is therefore necessary to consider the two stability parameters together with mean performances of each genotype, mainly following Eberhart and Russell's (1966) definition of stability, *viz.*, $b_i=1.0$ and $S_{di}^2=0$.

The stability parameters of each genotype, including parents and progenies, for spring, fall and annual yields are given in Tables 27, 28 and 29 on both scales. Graphic summaries are also given in Figures 1, 2 and 3 for spring, fall and annual yields, respectively, on direct scale only since those of the transformed scale closely followed similar patterns. The graphs show the relationships between yield (spring, fall and annual) and linear response of genotypes, and are considered useful in selecting stable genotypes. The vertical line is the grand mean, whereas the horizontal line is the average slope ($b=1.0$). All stability variances significantly greater than the error variance ($P<0.05$) are shown by symbol '✱'. For clarity, a code number instead of pedigree, as given in Table 4, is marked for each genotype.

The spring yield varied from 1655 to 2335 grams per plot. The regression

Table 27. Means, regression coefficients, and stability variances for spring yield measured on both direct and transformed scales on 28 bromegrass genotypes.

Genotypes	Direct Scale			Transformed Scale	
	Mean	Regression coefficient	Stability variance	Regression coefficient	Stability variance
	(g)				
Parents					
1	2198	1.19‡	1.30	1.18	1.18
2	2107	0.82	5.02†	0.81	4.54†
3	1970	0.98	2.77*	1.02	2.97**
4	1655	0.95	6.91†	1.03	8.06†
5	1726	1.09	3.77†	1.15	3.50**
6	2316	1.18	3.71**	1.13	2.99**
7	2071	1.21	10.99†	1.19	11.20†
Progenies					
12	2317	0.83	2.00	0.80	1.80
13	2269	0.92	1.07	0.92	1.07
14	1984	1.15	0.95	1.17‡	0.89
15	1969	1.03	4.62†	1.03	4.52†
16	2288	1.07	1.81	1.05	1.69
17	2205	0.88	1.96	0.88	1.66
23	1882	0.72‡	1.78	0.75‡	1.78
24	2102	0.94	0.70	0.95	0.66
25	2141	1.01	1.02	1.00	1.02
26	2269	0.86	0.63	0.84‡	0.54
27	2246	0.91	1.79	0.87	1.68
34	2335	1.12	2.08	1.10	1.68
35	1948	0.94	0.69	0.94	0.78
36	2119	0.97	0.65	0.95	0.68
37	2135	0.77	4.60†	0.77	3.90†
45	2199	1.25	2.68*	1.25	2.39*
46	1864	1.01	1.07	1.06	1.06
47	1982	1.01	3.19**	1.05	2.87**
56	1954	1.07	5.20†	1.06	4.38†
57	2268	1.05	0.56	1.03	0.58
67	2326	1.06	2.90**	1.02	2.32*
Grand mean	2102.1				
LSD (.05)	237				

‡ denotes regression coefficients that were higher or lower than 1.0 at the 0.05 probability level.

*, **, † denote deviations from regression greater than the pooled error in analysis of variance at the 0.05, 0.01, and 0.001 probability levels, respectively.

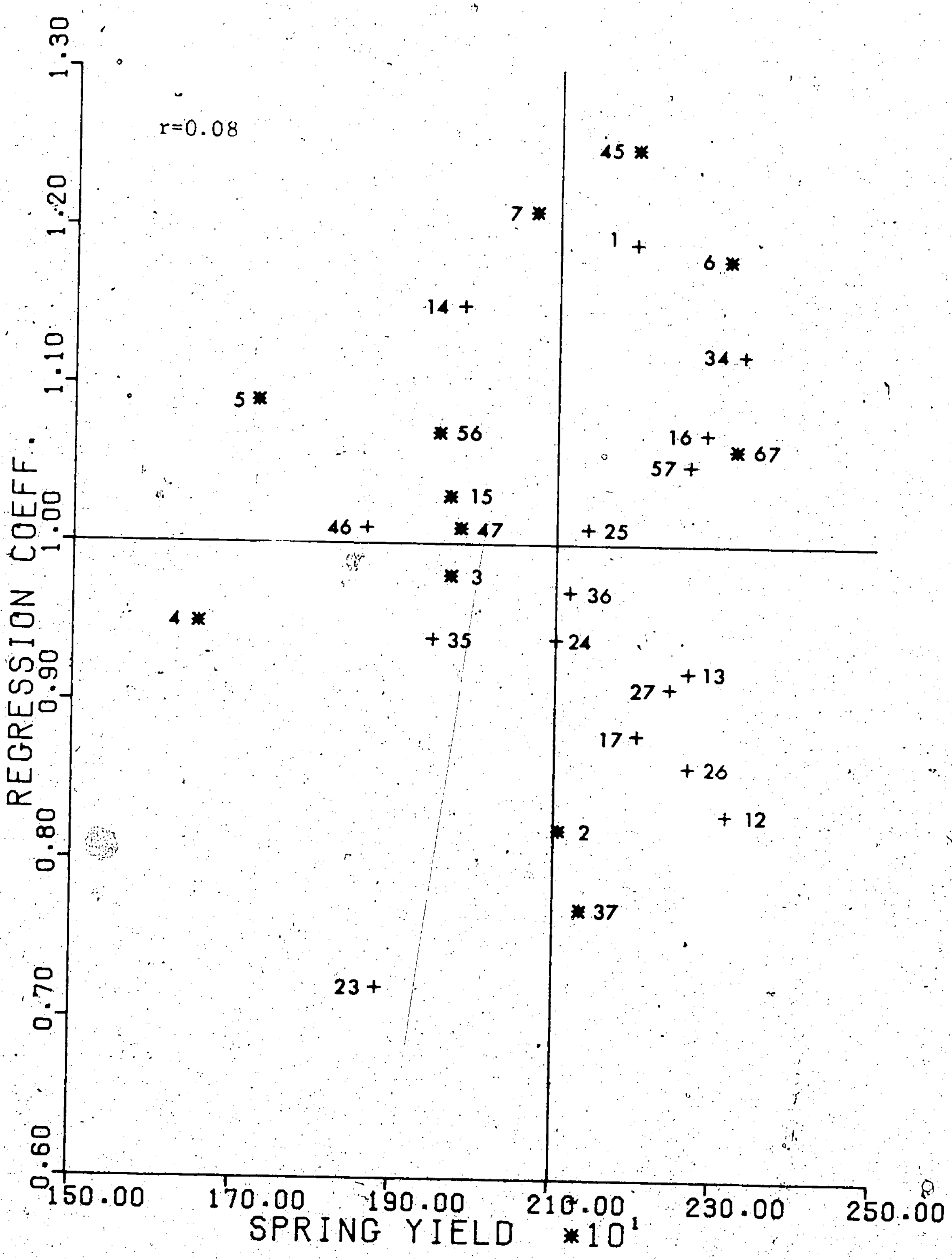

Fig. 1. The relationship between spring yield (g/plot) and stability of 28 bromegrass genotypes.
✱ Stability variance significant ($P < 0.05$);
\+ Stability variance not significant.

Table 28. Means, regression coefficients, and stability variances for fall yield measured on both direct and transformed scales on 28 bromegrass genotypes.

	Direct Scale			Transformed Scale	
Genotypes	Mean	Regression, coefficient	Stability variance	Regression coefficient	Stability variance
	(g)				
Parents					
1	1546	1.06	2.04	1.08	3.56**
2	1643	1.11	3.86†	1.09	2.39*
3	1468	0.76	3.04**	0.78	2.98**
4	1336	1.13	5.73†	1.13	6.28†
5	1386	0.62	8.05†	0.64	8.12†
6	1803	1.10	1.07	1.02	0.89
7	1475	1.18	5.65†	1.25	3.92†
Progenies					
12	1752	0.99	1.58	0.92	1.47
13	1718	0.99	0.58	0.92	0.40
14	1431	0.98	1.32	1.03	1.08
15	1605	0.78	5.51†	0.77	4.60†
16	1691	0.96	0.81	0.94	0.88
17	1614	1.32‡	1.52	1.27‡	1.42
23	1381	0.75‡	0.73	0.79‡	0.58
24	1581	1.04	0.31	1.02	0.35
25	1655	0.90	1.65	0.91	1.28
26	1666	0.98	1.14	0.97	0.79
27	1576	1.19	1.71	1.17	1.47
34	1727	1.17	2.87**	1.13	2.17*
35	1594	0.91	0.47	0.88‡	0.32
36	1648	0.96	1.56	0.95	1.39
37	1656	1.10	2.04	1.03	2.09
45	1440	0.98	0.33	1.04	0.64
46	1159	0.87‡	0.61	1.03	1.26
47	1289	1.07	1.50	1.15	1.70
56	1484	0.82	2.17*	0.82	2.09
57	1663	1.14	2.35*	1.11	1.96
67	1610	1.16	2.60*	1.15	2.08
Grand mean	1557.5				
LSD (.05)	205				

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‡ denotes regression coefficients that were higher or lower than 1.0 at the 0.05 probability level.

*, **, † denote deviations from regression greater than the pooled error in analysis of variance at the 0.05, 0.01, and 0.001 probability levels, respectively.

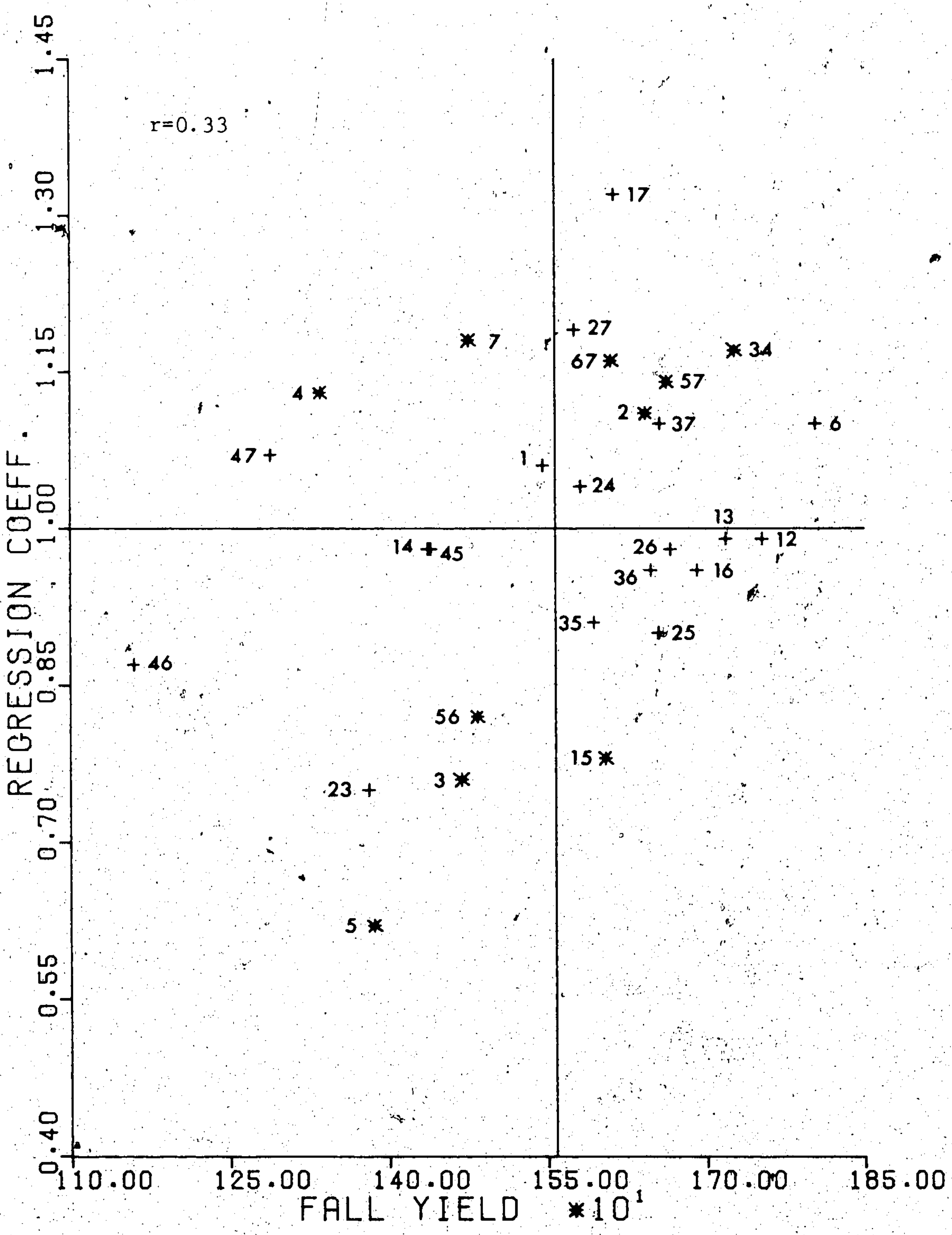

Fig. 2. The relationship between fall yield (g/plot) and stability of 28 bromegrass genotypes.
✱ Stability variance significant ($P < 0.05$);
+ Stability variance not significant.

Table 29. Means, regression coefficients, and stability variances for annual yield measured on both direct and transformed scales on 28 bromegrass genotypes.

Genotypes	Direct Scale			Transformed Scale	
	Mean	Regression coefficient	Stability variance	Regression coefficient	Stability variance
Parents	(g)				
1	3744	1.16	2.09	1.15	2.25*
2	3750	0.84	4.44†	0.85	3.87†
3	3439	0.82	3.93†	0.90	4.51†
4	2992	1.14	6.75†	1.21	9.36†
5	3112	0.92	8.99†	0.96	8.37†
6	4119	1.12	2.73*	1.07	2.09
7	3547	1.27	9.56†	1.25	8.82†
Progenies					
12	4070	0.81	1.92	0.77	2.04
13	3988	0.93	0.78	0.88	0.72
14	3415	1.12	1.01	1.16	0.99
15	3574	0.81	6.54†	0.82	5.74†
16	3980	1.01	1.71	0.99	1.55
17	3819	1.09	3.73**	1.06	2.97**
23	3263	0.70‡	1.40	0.76‡	1.35
24	3684	0.99	0.68	0.99	0.60
25	3796	0.93	1.59	0.92	1.49
26	3936	0.85‡	0.36	0.82	0.40
27	3822	1.02	2.54*	0.99	2.61*
34	4063	1.26	2.19*	1.18	1.68
35	3542	0.88	0.63	0.90	0.62
36	3767	1.07	0.64	1.05	0.59
37	3791	0.90	4.87†	0.88	4.20†
45	3639	1.15	1.93	1.16	1.91
46	3023	0.94	0.55	1.01	0.74
47	3271	1.12	2.40*	1.18	1.94
56	3438	0.92	4.53†	0.96	3.45**
57	3932	1.04	1.33	1.02	1.26
67	3937	1.16	3.13**	1.09	2.51**
Grand mean	3659.5				
LSD (.05)	400				

‡ denotes regression coefficients that were higher or lower than 1.0 at the 0.05 probability level.

*, **, † denote deviations from regression greater than the pooled error in analysis of variance at the 0.05, 0.01, and 0.001 probability levels, respectively.

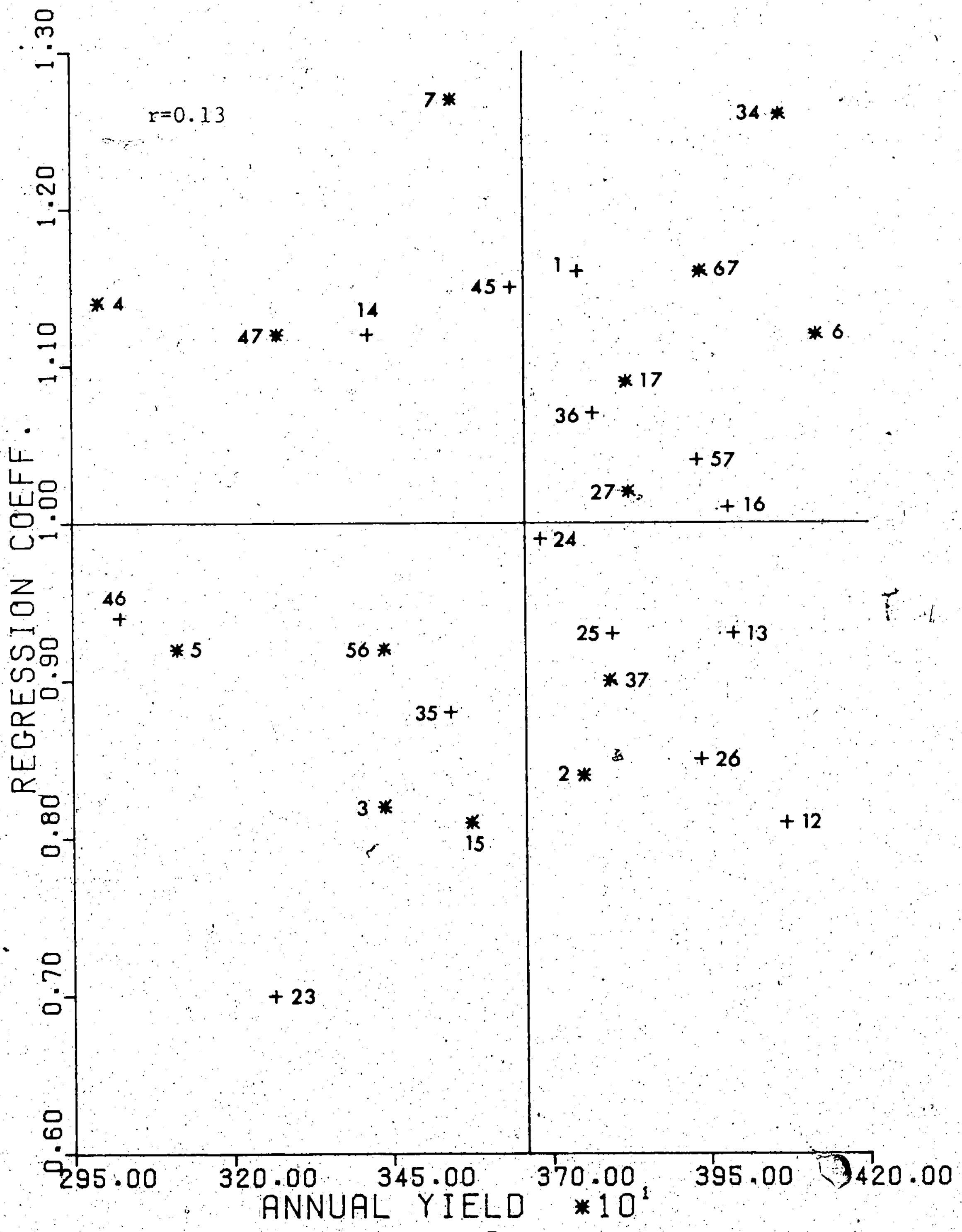

Fig. 3. The relationship between annual yield (g/plot) and stability of 28 bromegrass genotypes.
✱ Stability variance significant (P < 0.05);
\+ Stability variance not significant.

coefficients ranged from 0.72 to 1.25 (Table 27 and Fig.1). Four genotypes, namely 1, 14, 23 and 26 had regression coefficients significantly different from unity on one scale or both (Table 27). Six out of the seven parental genotypes and six progeny genotypes had significant deviation mean squares. Joint consideration of parameters indicated that genotypes 1, 12, 13, 16, 17, 24, 25, 27, 34, 36, 37, 45, 57, 6 and 67 combined high yield and average linear response. Genotypes 37, 45, 6 and 67, however, recorded significant deviations. Genotype 26 had high yield and above average linear response($b<1.0$) (Table 27) and genotype 1, on the other hand, had below average linear response ($b>1.0$).

Fall yield varied from 1159 (genotype 46) to 1803 (genotype 6) grams per plot and the regression coefficient ranged from 0.65 (genotype 5) to 1.32 (genotype 17) (Tables 28 and Fig. 2). Seventeen genotypes recorded higher yield than the mean of all genotypes. These genotypes were: 6, 12, 34, 13, 16, 57, 37, 26, 25, 2, 36, 17, 67, 15, 35, 24 and 27. All these genotypes except 17 and 35 had average linear response ($b=1$). Deviation mean squares were significant for five genotypes, namely 34, 57, 2, 67 and 15. This suggested general adaptability of most of the high yielding genotypes for fall yield.

The annual yield varied from 2992 (genotype 4) to 4119 (genotype 6) grams per plot, and the regression coefficients ranged from 0.7 (genotype 23) to 1.27 (genotype 7) (Table 29 and Fig. 3). Sixteen genotypes had higher yield than the mean of all genotypes. Among these genotypes only one (i.e. 26) had regression coefficient which was significantly smaller than unity, and seven, namely 6, 34, 67, 17, 27, 37 and 2, had significant deviation mean squares.

Joint consideration of the three yield types (spring, fall and annual) and the stability parameters indicated that five genotypes had consistently combined high yields, average linear responses and non-significant deviations. These genotypes were; 12, 13, 16, 25, and 36. Genotype 23, on the other hand, had shown maximum stability combined with low yields. Genotype 26 had combined high yield and above average response for spring and annual yield, and average linear response for fall yield. This genotype may be preferred to genotype 23 where a highly stable genotype is desired.

Correlation coefficients between regression coefficients and mean yields of each genotype was 0.08 for spring yield. Positive but non-significant correlations were obtained between regression coefficients and mean fall yields (r=0.33) and between regression coeficients and annual yields (r=0.13). Therefore, it seems possible to select genotypes which have above average stability and high yields, such as genotype 26. Thess results are in contrast to those reported by Eberhart and Russell (1966) in maize, and by Fatunla and Frey (1976) and Eagles et al. (1977) in oats, where they obtained significant correlations between mean yields and regressions.

Tables 30 to 34 are presented to show that a phenotype which is classified as stable for one character may be unstable for other characters. For yield per area (Table 30) none of the genotypes which had high yield per area were close to average stability. Table 31 shows that among those genotypes (1, 16, 25, 35, 36, 57, and 67) which had large leaf areas and were rated as having average stability, three genotypes (16, 25 and 36) also had average stability in yields (spring, fall and annual). For tiller dry weight (Table 32), genotypes 1, 12, 13, 14, 34, 35, and 36 had average stability, but among them only genotypes 13, 35 and 36 combined higher tiller weight than their overall mean. Genotype 37 with average stability for fall yield was the only genotype which had average stability for high tiller density (Table 33). Genotypes 13, 15, 16, 34, 35, 36, 56 and 67 combined both average stability and above average plant height (Table 34).

The data indicate that it is rather difficult to select a genotype which had average stability for yields and will also be of average stability for other morphological characters, such as high tiller density, heavy tiller weight, large leaf area, and plant height. Genotype 36 probably combined average stability and high means for the most characters, which included yields (spring, fall and annual), leaf area, tiller dry weight

Table 30. Means, regression coefficients, and stability variances for yield per area measured on both direct and transformed scales on 28 bromegrass genotypes.

Genotypes	Direct Scale			Transformed Scale	
	Mean	Regression coefficient	Stability variance	Regression coefficient	Stability variance
Parents	(g/dm^2)				
1	37.7	0.99	2.79*	0.97	5.06†
2	39.4	1.23‡	6.28†	1.08	5.06†
3	33.1	0.69‡	17.41†	0.83	10.12†
4	23.4	0.52‡	6.65†	0.76	16.63†
5	35.1	0.82‡	6.74†	0.80	8.67†
6	40.4	1.09	2.75*	0.95	2.16*
7	25.1	0.53‡	14.59†	0.88	23.86†
Progenies					
12	43.3	1.48‡	12.22†	1.13	6.50†
13	41.7	1.19‡	6.73†	1.00	13.73†
14	34.7	1.07	1.06	1.10‡	1.44
15	37.0	1.04	2.06	0.97	2.16*
16	41.5	1.33‡	7.50†	1.07	3.61**
17	30.5	0.89‡	0.40	1.02	0.72
23	37.8	1.11	5.07†	0.97	5.78†
24	35.5	1.07	2.90**	1.11	5.78†
25	36.8	1.19‡	6.02†	1.07	4.33†
26	40.0	1.23	11.03†	1.08	5.06†
27	32.0	1.02	9.67†	1.07	9.39†
34	34.8	1.02	5.04†	1.12	9.39†
35	36.3	1.15‡	1.54	1.08	1.44
36	38.9	1.35‡	9.08†	1.13	4.33†
37	30.6	0.84‡	2.72*	0.99	6.50†
45	33.6	0.97	3.12**	1.02	4.33†
46	25.8	0.71‡	5.18†	1.01	10.84†
47	23.7	0.58‡	2.07	0.89	7.23†
56	37.5	1.11	6.60†	1.00	5.78†
57	31.0	0.79‡	7.25†	0.95	6.50†
67	33.9	0.94	10.53†	0.94	9.39†
Grand mean	34.7				
LSD (.05)	5.1				

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‡ denotes regression coefficients that were higher or lower than 1.0 at the 0.05 probability level.

*, **, † denote deviations from regression greater than the pooled error in analysis of variance at the 0.05, 0.01, and 0.001 probability levels, respectively.

Table 31. Means, regression coefficients, and stability variances for leaf area measured on both direct and transformed scales on 28 bromegrass genotypes.

Genotypes	Direct Scale			Transformed Scale	
	Mean	Regression coefficient	Stability variance	Regression coefficient	Stability variance
Parents	(cm^2)				
1	89.9	0.91	2.06	0.92	2.03
2	76.8	0.84	1.29	0.91	1.42
3	69.4	0.75	6.80†	0.84	8.17†
4	70.6	0.79‡	0.44	0.91	0.50
5	114.4	1.13	3.75†	0.99	2.69*
6	118.7	1.58‡	1.89	1.39‡	1.37
7	57.2	0.71	2.40*	0.90	3.43**
Progenies					
12	86.1	0.88	1.28	0.90	1.31
13	94.9	0.81‡	0.47	0.76‡	0.47
14	73.4	0.80‡	0.52	0.89	0.58
15	118.2	1.32	4.43†	1.16	3.03**
16	107.4	1.20	1.77	1.08	1.45
17	74.3	0.93	0.25	1.04	0.18
23	74.6	0.68‡	0.58	0.74‡	0.71
24	69.1	0.83	1.30	0.93	1.31
25	99.9	1.15	1.07	1.10	1.05
26	107.0	1.22‡	0.85	1.10	0.71
27	69.7	0.80	0.82	0.91	0.89
34	83.8	0.90	1.53	0.96	1.95
35	101.7	1.08	1.53	1.01	1.26
36	100.2	1.16	1.99	1.11	1.63
37	67.5	0.87	0.39	1.02	0.34
45	112.2	1.42‡	1.18	1.27‡	0.84
46	87.7	0.94	2.58*	0.96	2.08
47	69.3	0.88	1.[illegible]2	1.02	2.11*
56	111.3	1.29	2.38*	1.17	1.89
57	92.7	1.07	1.96	1.03	1.55
67	90.0	1.06	0.8[illegible]	1.05	0.73
Grand mean	88.9				
LSD (.05)	7.9				

‡ denotes regression coefficients that were higher or lower than 1.0 at the 0.05 probability level.

*, **, † denote deviations from regression greater than the pooled error in analysis of variance at the 0.05, 0.01, and 0.001 probability levels, respectively.

Table 32. Means, regression coefficients, and stability variances for tiller dry weight measured on both direct and transformed scales on 8 bromegrass genotypes.

	Direct Scale			Transformed Scale	
Genotypes	Mean (g)	Regression coefficient	Stability variance	Regression coefficient	Stability variance
Parents					
1	06	0.91	1.45	0.88	2.00
2	2.12	0.89	2.04	1.11	3.45**
	2.15	0.55‡	5.70†	0.73	5.50†
4	2.09	0.78‡	0.52	0.98	0.95
5	4.05	1.64	6.95†	1.20	4.27†
6	3.69	1.60‡	3.46**	1.22	1.77
7	1.87	0.53‡	2.83**	0.83	4.70†
Progenies					
12	2.45	1.03	0.89	1.07	1.17
13	2.70	0.99	1.07	0.96	1.31
14	2.12	0.95	0.69	1.18	1.00
15	4.13	1.51‡	1.69	1.11	1.00
16	3.28	1.26‡	2.00	1.04	1.40
17	2.23	0.82‡	0.79	0.96	1.07
23	1.99	0.77‡	1.45	0.93	3.12**
24	2.00	0.64‡	0.27	0.83‡	0.50
25	3.35	1.14‡	0.34	0.96	0.32
26	3.00	1.22‡	0.48	1.11	0.54
27	1.97	0.85‡	0.38	1.06	0.50
34	2.42	0.93	1.00	1.05	1.15
35	3.53	1.17	1.59	0.96	1.32
36	3.02	1.18	1.34	1.07	1.12
37	1.94	0.80‡	0.20	1.05	0.37
45	3.80	1.21‡	1.17	0.96	0.70
46	2.43	0.66‡	2.76*	0.80	2.90**
47	2.00	0.74‡	1.90	0.98	2.87**
56	3.58	1.32‡	0.44	1.07	0.37
57	3.14	0.88	2.28*	0.81	1.87
67	2.84	1.06	2.62*	1.05	2.40*
Grand mean	2.73				
LSD (.05)	0.32				

‡ denotes regression coefficients that were higher or lower than 1.0 at the 0.05 probability level.

*, **, † denote deviations from regression greater than the pooled error in analysis of variance at the 0.05, 0.01, and 0.001 probability levels, respectively.

Table 33. Means, regression coefficients, and stability variances for tiller density measured on both direct and transformed scales on 28 bromegrass genotypes.

Genotypes	Direct Scale			Transformed Scale	
	Mean (no/dm^2)	Regression coefficient	Stability variance	Regression coefficient	Stability variance
Parents					
1	28.1	1.46‡	8.08	1.43‡	7.97†
2	28.3	1.51	11.38†	1.42	10.69†
3	27.1	1.11	7.65†	1.07	6.99†
4	17.8	0.44‡	11.74†	0.51	14.21†
5	16.1	0.56	23.46†	0.68	30.40†
6	21.9	0.85	12.74†	0.88	11.38†
7	21.7	0.87	9.02†	0.89	9.71†
Progenies					
12	28.1	1.77‡	5.25†	1.60‡	3.58**
13	25.2	1.20	4.99†	1.15	5.08†
14	25.2	1.15	5.49†	1.12	5.31†
15	16.2	0.71‡	2.40*	0.84	3.12**
16	23.2	0.93	4.11†	0.91	3.69**
17	21.6	1.06	2.30*	1.07	2.71*
23	31.9	1.45	10.98†	1.29	7.97†
24	26.2	1.20	14.47†	1.15	14.04†
25	19.1	0.79‡	1.40	0.86	1.73
26	25.2	1.09	2.56*	1.05	2.19*
27	25.1	1.11	12.63†	1.03	10.57†
34	22.6	1.07	3.14**	1.09	3.35**
35	18.0	0.81	4.93†	0.91	5.66†
36	25.4	1.20	7.13†	1.15	6.82†
37	25.8	0.96	1.90	0.90	1.67
45	16.3	0.83	2.63*	0.95	3.69**
46	18.6	0.92	2.49*	0.99	2.60*
47	19.4	0.75	11.34†	0.79	12.48†
56	19.3	0.80	3.12**	0.87	4.04†
57	17.6	0.69‡	1.50	0.77‡	2.08
67	23.2	0.67‡	1.84	0.68‡	1.79
Grand mean	22.5				
LSD (.05)	2.5				

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‡ denotes regression coefficients that were higher or lower than 1.0 at the 0.05 probability level.

*, **, † denote deviations from regression greater than the pooled error in analysis of variance at the 0.05, 0.01, and 0.001 probability levels, respectively.

Table 34. Means, regression coefficients, and stability variances for height of 28 bromegrass genotypes.

Genotypes	Direct Scale Mean	 Regression coefficient	 Stability variance
	(cm)		
Parents			
1	111	0.97	2.42*
2	101	1.25	2.86**
3	105	1.04	8.79†
4	97	0.76	4.33†
5	114	0.92	4.18†
6	127	0.99	4.08†
7	97	1.06	5.44†
Progenies			
12	107	0.97	2.56*
13	113	0.94	1.48
14	101	1.04	2.59*
15	116	1.09	1.04
16	118	1.00	1.88
17	105	1.00	3.09**
23	99	0.96	2.43*
24	101	0.90	0.50
25	113	1.18‡	0.70
26	113	1.07	3.72**
27	100	1.10	2.24*
34	108	0.92	0.99
35	114	1.01	1.33
36	114	1.04	1.81
37	102	1.01	6.57†
45	113	0.98	2.50*
46	96	0.88	5.48†
47	95	0.88	2.73*
56	114	0.95	1.10
57	107	1.01	2.45*
67	113	1.04	1.65
Grand mean	108.1		
LSD (.05)	4		

‡ denotes regression coefficients that were higher or lower than 1.0 at the 0.05 probability level.

*, **, † denote deviations from regression greater than the pooled error in analysis of variance at the 0.05, 0.01, and 0.001 probability levels, respectively.

and plant height. It seems therefore reasonable to conclude that different genotypes could be classified as stable for different sets of characters even though all the characters were measured from the same set of genotypes.

There were also differences between the two scales used in the tests of significance for both regression coefficients and stability variances. In no cases will a genotype be considered stable unless the parameters of both scales agree to certain extent.

Relationships Between Stability Parameters and Combining Abilities for Yields

The diallel design of the present experiment permits the partition of regression coefficients and deviation mean squares into GCA and SCA. Therefore, the combining ability of a genotype for both parameters and yield can be jointly examined. Combining ability analyses for the means, linear regression and deviation mean squares for the yield types are given in Table 35. Only the three yield types, namely spring, fall and annual yields, are presented in the joint consideration between combining ability of mean yield and combining ability for the stability parameters, i.e. regression coefficient and deviation mean square, with respect to practical selection in breeding.

Variation in the expression of mean yield due to GCA, SCA and their interactions with environments was significant when compared with the pooled error (Table 35). The relative magnitudes of GCA to SCA indicated both GCA and SCA were equally important for mean yields. For regression coefficient, the variation due to GCA was significantly greater than that of SCA. This applied to all three yield types. The GCA variance of deviation mean square was, on the other hand, not significantly greater than that of SCA. Hence, the differences in linear response of genotypes to environments were primarily due to GCA, while both GCA and SCA were equally important in the expression of deviations. Data on both scales, direct and transformed (*viz.*, power and logarithm), closely agreed for the levels of significance. Furthermore,

Table 35. Mean squares for combining ability of stability parameters: means ($\bar{X}$), regression coefficients (b) and deviation mean squares.

Source	d.f.	Spring yield $\bar{X}$	Spring yield b	Spring yield Deviation MS	Fall yield $\bar{X}$	Fall yield b	Fall yield Deviation MS	Annual yield $\bar{X}$	Annual yield b	Annual yield Deviation MS
Direct Scale										
GCA	6	27034†	0.409§	2414	17861†	0.709§	3500	80844†	0.124§	2388
SCA	21	13383†	0.116	2036	9288†	0.125	3091	39637†	0.032	1666
GCA x E	42	8707†			6013†			24631†		
SCA x E	147	1986†			1628†			5675†		
Error	1080	1188			933			3264		
Transformed Scale										
GCA	6	1175†	0.469§	388	421†	0.799§	29	668†	0.597§	101
SCA	21	539†	0.098	332	161†	0.069	23	294†	0.077	93
GCA x E	42	318†			100†			157†		
SCA x E	147	76†			27†			40†		
Error	1080	46			16			23		

† significant at the 0.001 probability level when sources were tested by error.

§ significant at the 0.05 probability level when GCA was tested by SCA.

the direct scale was the scale commonly used to measure adaptation parameters in agronomic research. Therefore, only the direct scale will be presented in subsequent discussion.

The average GCA effects for spring yield ranged from -115 to 71 (Fig. 4). Four parents, 1, 2, 6 and 7, had GCA effects greater than zero; parent 6 being the best combiner for spring yield. The estimates of GCA for the regression coefficient varied from -0.121 to 0.059 (Fig. 4). Parent 5 had the highest GCA effects for regression coefficient of spring yield, while parent 7 had near zero GCA effect. The lowest GCA effect was obtained for parent 2, followed by parent 3. Figure 4 shows the association between GCA effects of mean yield and GCA effects of regression coefficient. Parents 6 and 1, the best general combiners for mean spring yield performance, had positive GCA effects for regression coefficient. Parent 7 seems promising since it had moderately high GCA for spring yield and near zero GCA, for regression. Thus, according to the average GCA effect presented in Figure 4, parent 7 would transmit to its progeny high spring yield and average stability. Parent 2 transmitted above average stability to its progeny and had positive GCA estimates for spring yield.

Figure 5 examines the association of GCA effects between spring yield and regression with respect to individual environments. The figure shows apparent GCA x environment interactions by the different ranking of the environments within each genotype. It revealed that the environmental mean of a genotype as shown in Figure 4 was not as informative as that shown by individual environments when genotype x environment interaction was prevalent. For example, parent 7 was among the highest combiners for spring yield when average GCA for all environments was considered (Fig. 4), but when individual environments were examined (Fig. 5), it had positive GCA effects only at four of the eight environments. Parent 2 transmitted to its progeny high spring yield of above average stability in five of the eight environments. Parent 1 had positive GCA effects for spring yield at the highest number of environments - all

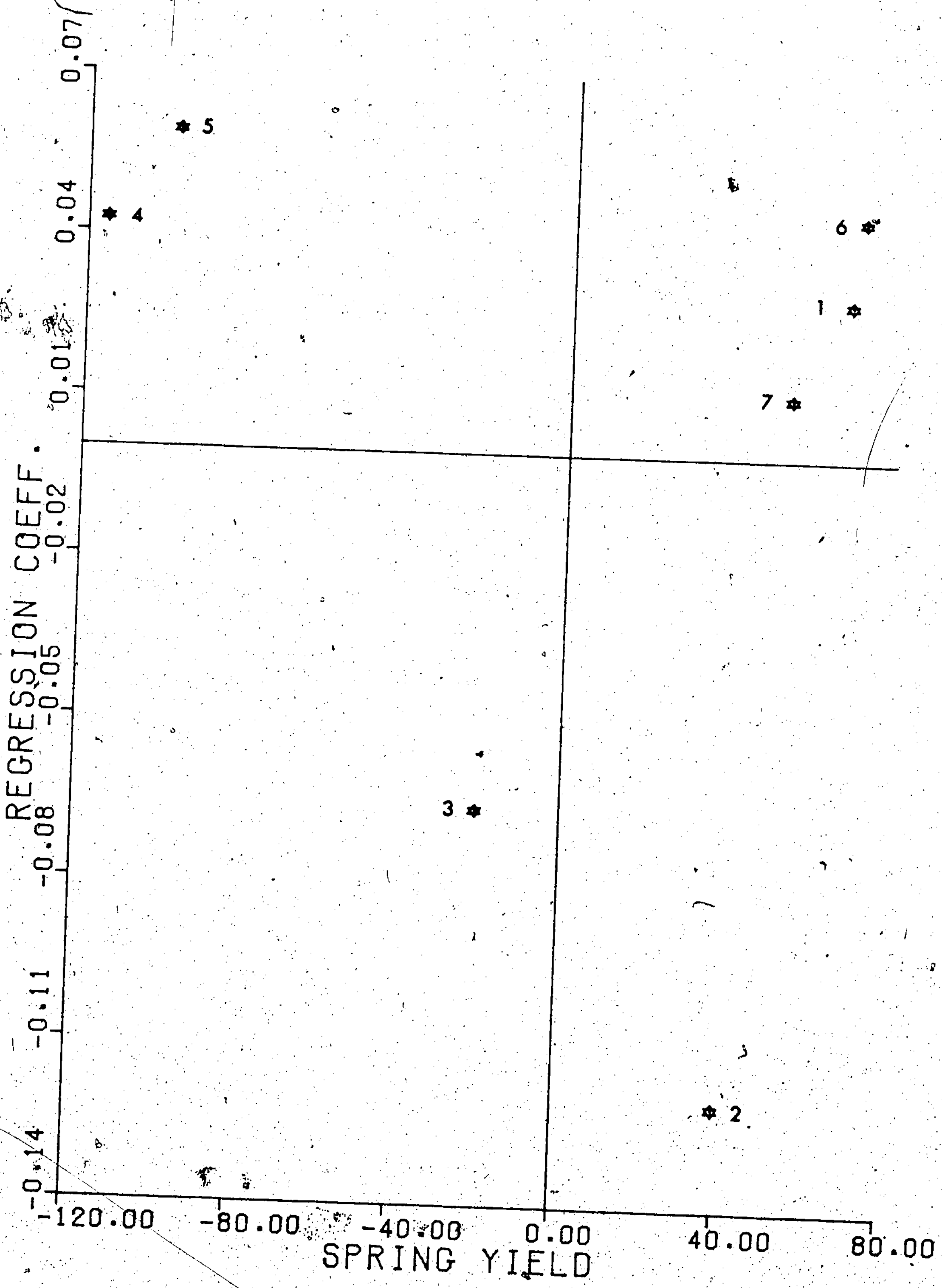

Fig. 4. The relationship between mean GCA effects for spring yield and regression coefficient for all environments.

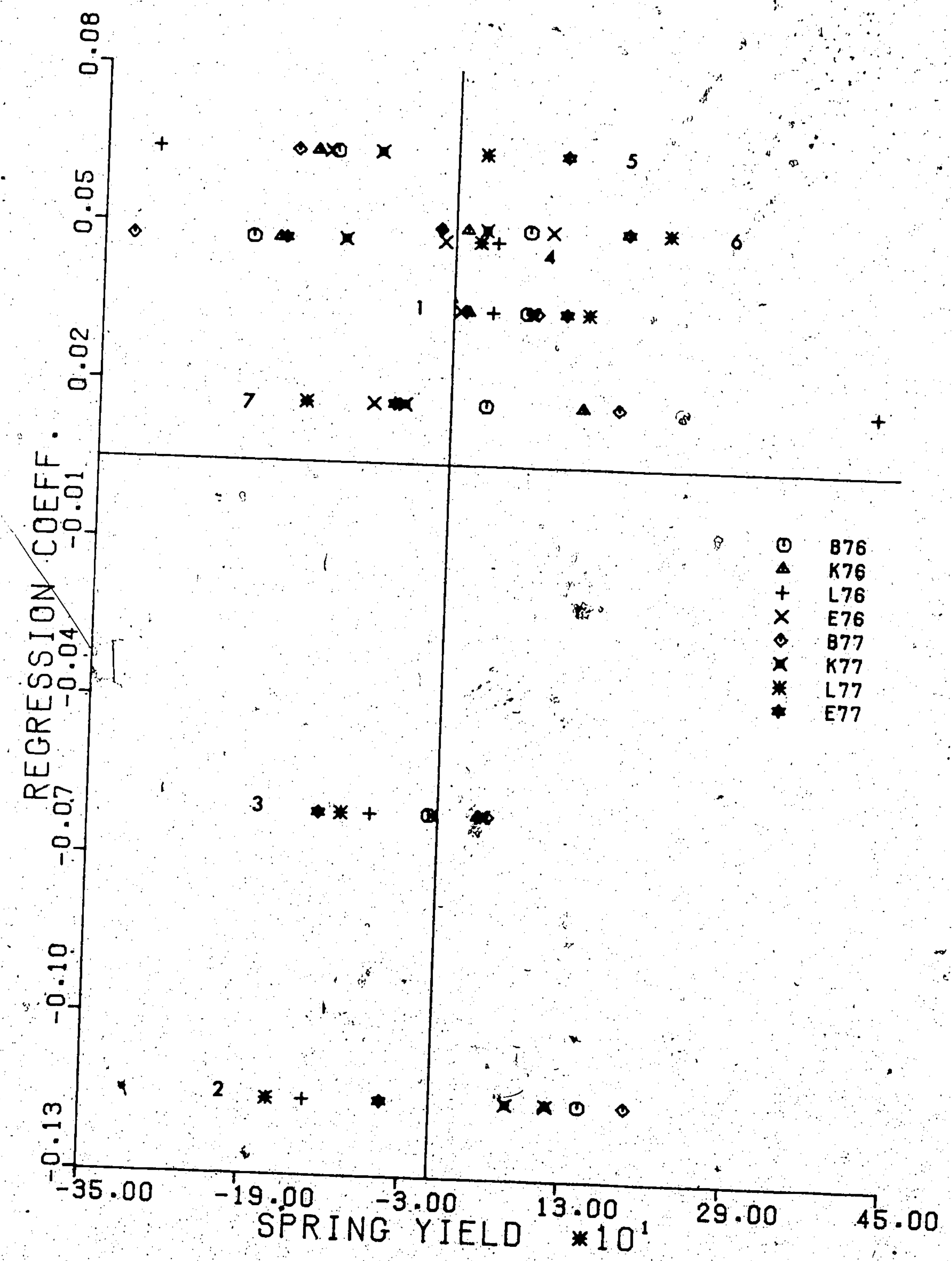

Fig. 5. The relationship between GCA effects for spring yield and regression coefficient for eight individual environments. (B:Beaverlodge; K:Kinsella; L:Lethbridge; E:Edmonton)

eight, and a near average stability. It was followed by parent 6, which had positive GCA effects for six environments, and positive GCA effects for regression coefficients.

With the exception of parent 1 which combined the highest spring yield and average stability, no generalization can be made for the rest of the parents. It appears rather difficult to obtain a parent which combined well at all environments.

For fall yield, parents 1, 2 and 6 transmitted average stability to their progenies and had the highest GCA effects for mean fall yield (Fig. 6). Parents 5 and 7 had, respectively, the lowest and the highest GCA for regression coefficients. Figure 7 provides information on the GCA effects of fall yield and regression coefficient for each environment. Parent 1 and 6 combined equally well for fall yield and average stability at all environments. For parent 2, there was a greater variation among environments than for the aforementioned parents. With the exception of one environment, i.e. Lethbridge 1976, parent 2 transmitted above average fall yield and average stability to its progeny.

Considering annual hay production (Fig. 8), parents 1 and 6 again had higher GCA effects than the rest of the parents; the former had near average stability while the latter had rather high GCA effect for regression. Both parents showed high consistencies over all environments (Fig. 9). Parent 2 transmitted above average stability as well as high annual yield to its progeny at five of the eight environments studied.

Joint consideration of the GCA effects of the three yield characters indicated that parent 1, a random selection from 'Magna' which is one of the leading cultivars in Western Canada, seems to have the highest potential among the seven clones. As shown in Figures 1, 2 and 3, the parent 1 itself was neither the best yielder nor stable. Yet as indicated by the GCA effects, progenies of this clone will likely have high yield and average stability, and will show consistent performance over environments. The next good yield combiner, parent 6 had positive GCA effects for linear response. This

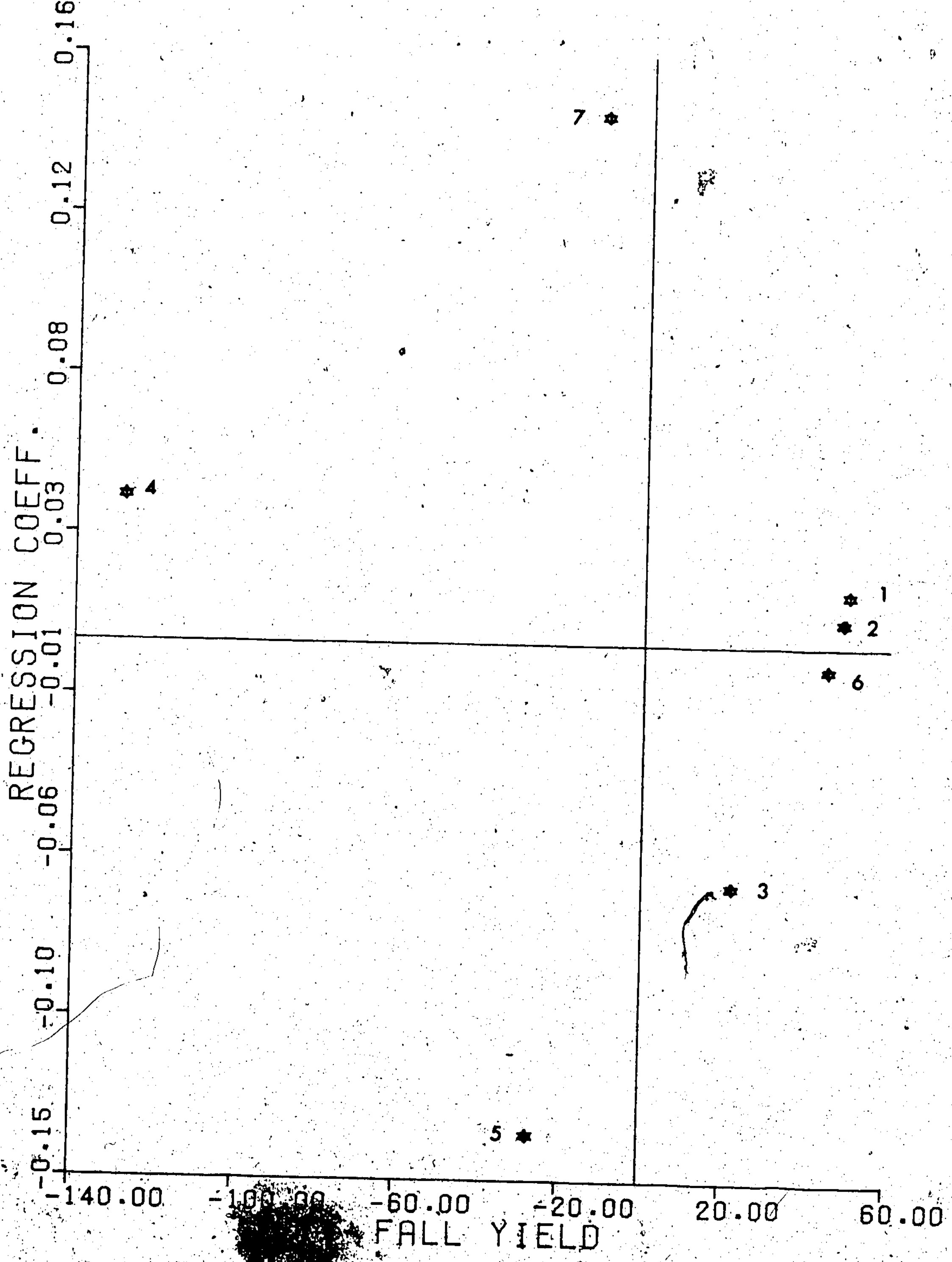

Fig. 6. The relationship between mean GCA effects for fall yield and regression coefficient for all environments.

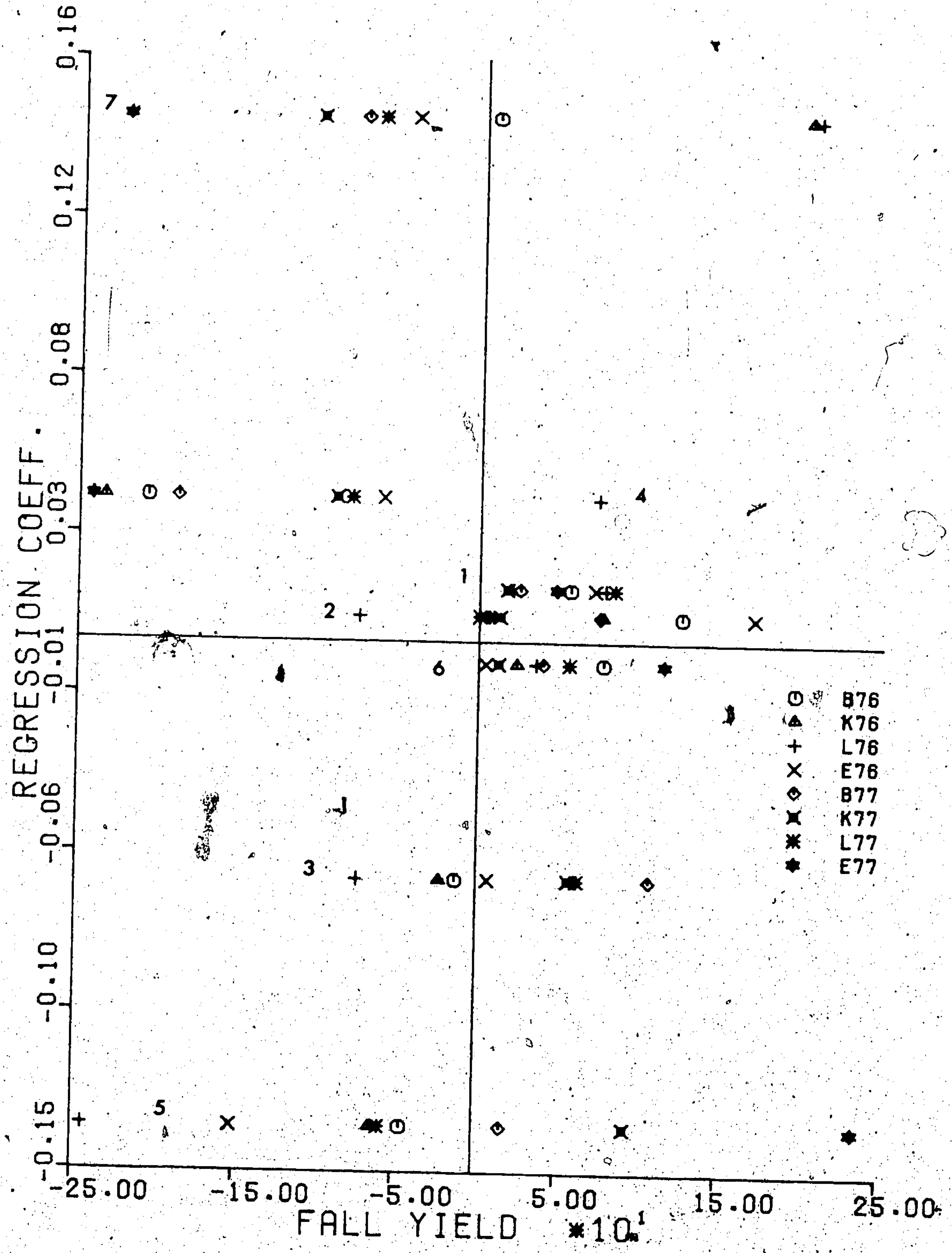

Fig. 7. The relationship between GCA effects for fall yield and regression coefficient for eight individual environments. (B:Beaverlodge; K:Kinsella; L:Lethbridge; E:Edmonton)

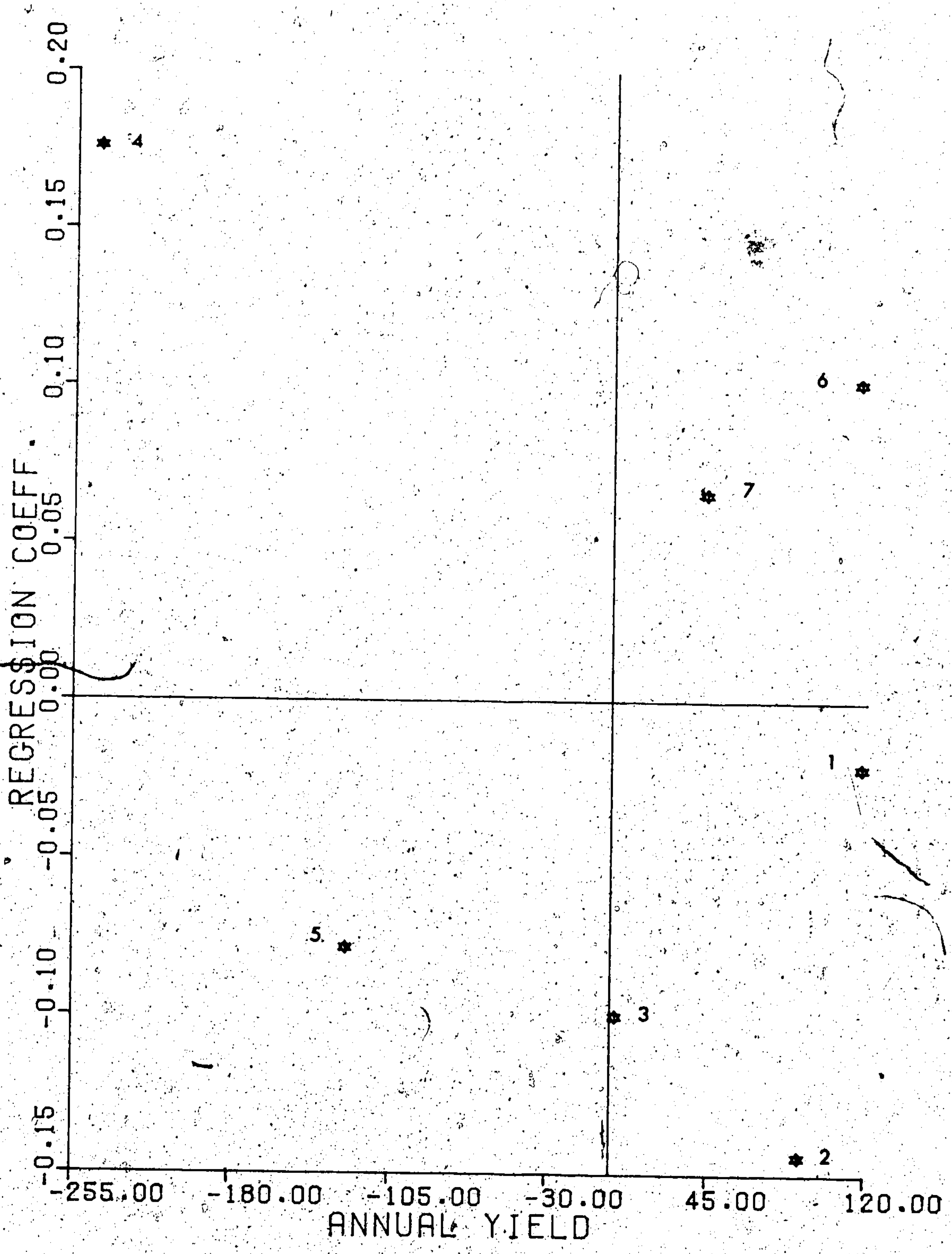

Fig. 8. The relationship between mean GCA effects for annual yield and regression coefficient for all environments.

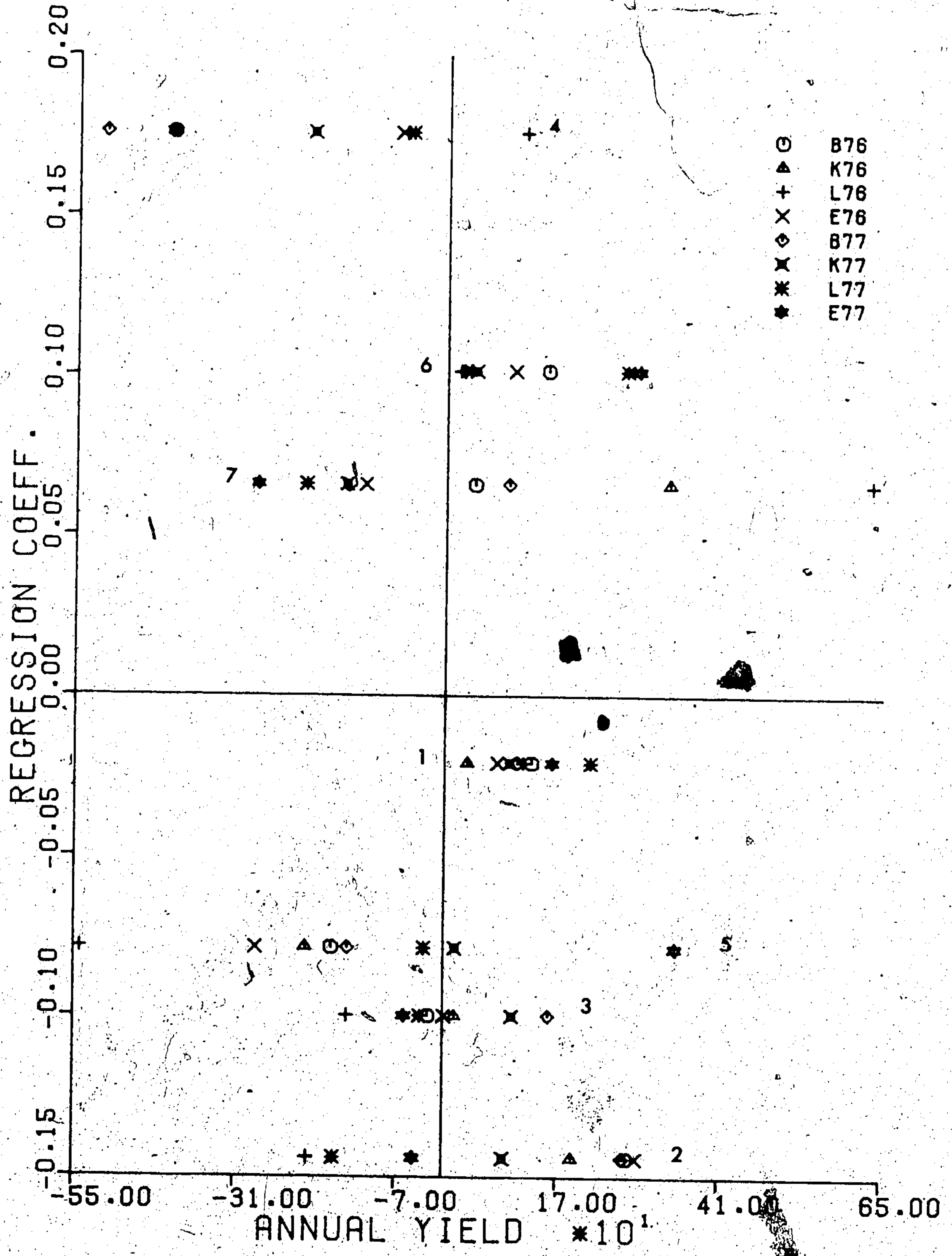

Fig. 9. The relationship between GCA effects for annual yield and regression coefficient for eight individual environments. (B:Beaverlodge; K:Kinsella; L:Lethbridge; E:Edmonton)

parent may have some potential value in areas which are fertile and properly managed. Parent 2 demonstrated the highest GCA effects for stability of all parents; however, it did not combine equally high yield in such favourable environments, as Edmonton in 1977, Lethbridge in both 1976 and 1977, as in other less favourable environments (Figure 9). Parent 3 transmitted above average stability but rather low yield to its progenies in many of the environments tested.

Figures 10, 11 and 12 show the association between GCA effects of mean yields (spring, fall and annual) and the GCA effects for mean squares of deviations from regression. These figures again confirm that parents 1 and 6 combined high yield and small deviation mean squares with high consistency over the range of environments. Parents 2 and 3 were the next best in their abilities to transmit small deviation from regression to their progenies, but were inconsistent in yielding performances in varying environments. Parents 5 and 7 had the highest mean squares of deviation, hence were highly unstable for transmission of yielding performances to their progenies.

The GCA effects for mean yields and the GCA effects for linear response were not significantly correlated in any of the yield types (r=-0.26 for spring; r=-0.11 for fall; and r=-0.35 for annual yield). These suggest a lack of association between these attributes and the possibility of breeding cultivars which combined high yield performance and stability.

Since both GCA and SCA were equally important in determining yields, the associations between SCA effects of mean yield and SCA effects of regression coefficients were examined in details in Figures 13 to 18 inclusive, for the three yield types on environmental means (Figs. 13, 15 and 17) and on individual environments (Figs. 14, 16 and 18).

Figure 13 shows that genotype 34 combined the highest mean SCA effect of spring yield and regression coefficient, and was followed by 45, 67, 16 and 13.

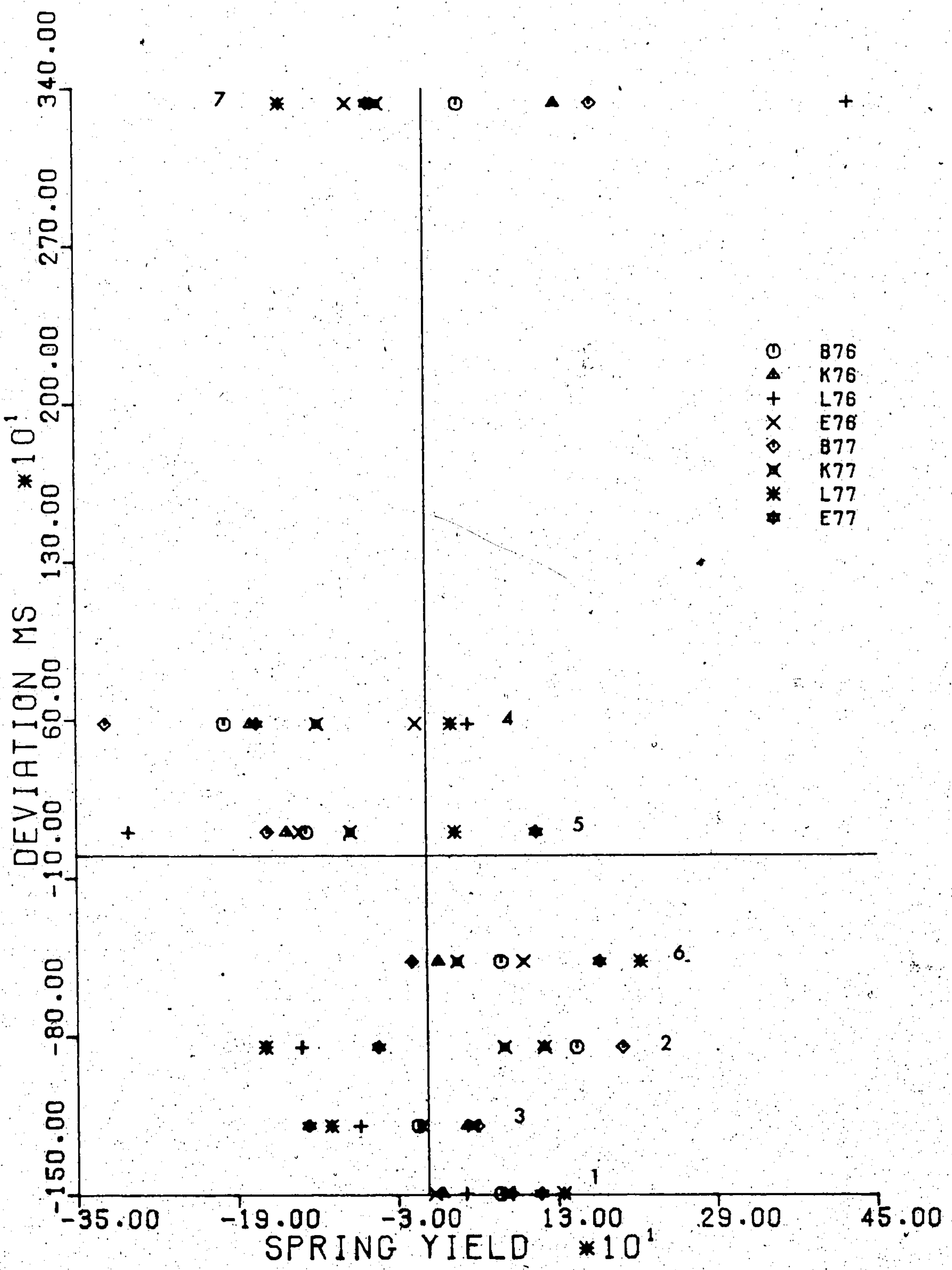

Fig. 10. The relationship between GCA effects for spring yield and deviation mean square for eight individual environments. (B:Beaverlodge; K:Kinsella; L:Lethbridge; E:Edmonton)

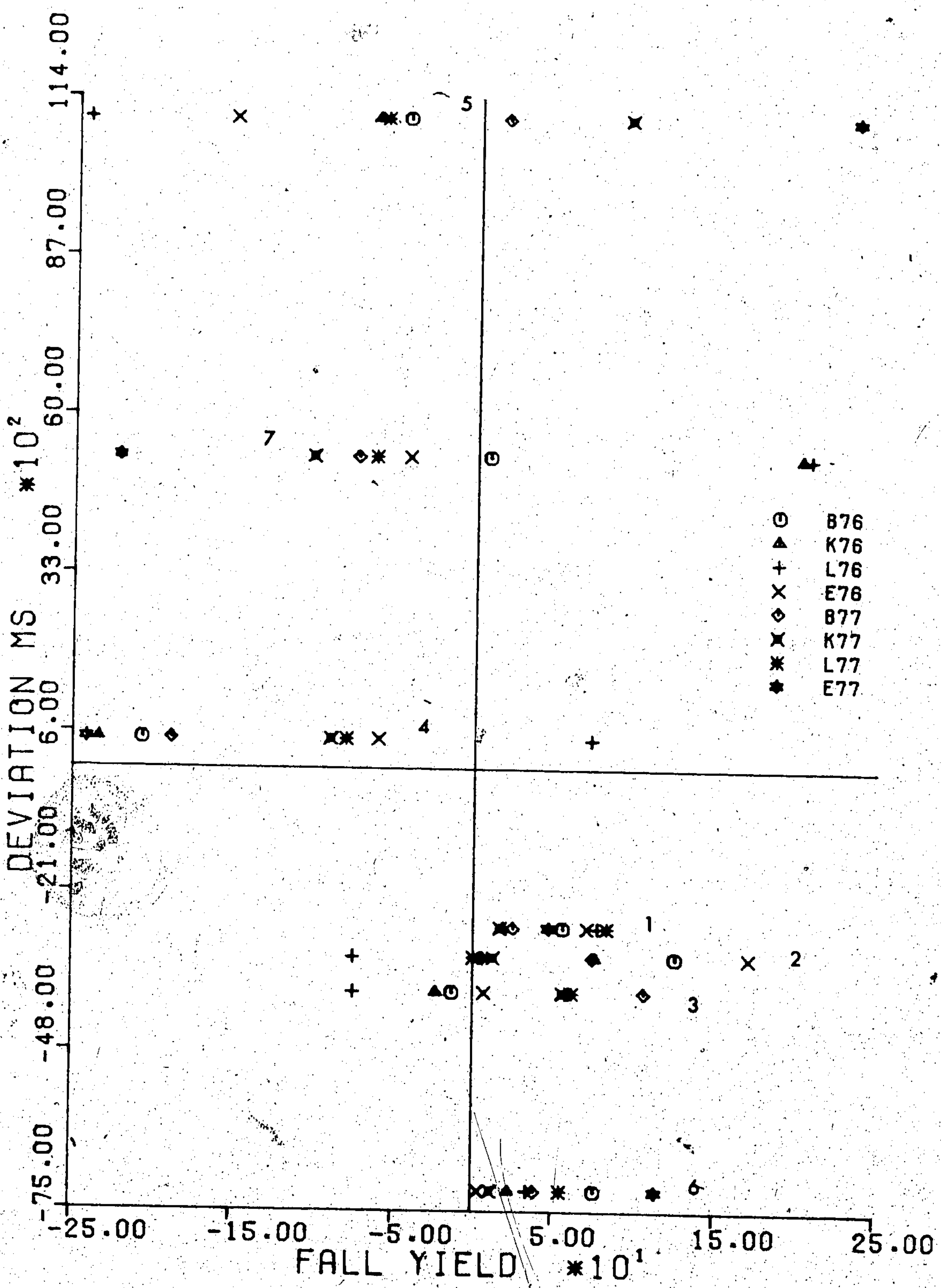

Fig. 11. The relationship between GCA effects for fall yield and deviation mean square for eight individual environments. (B:Beaverlodge; L:Lethbridge; K:Kinsella; E:Edmonton)

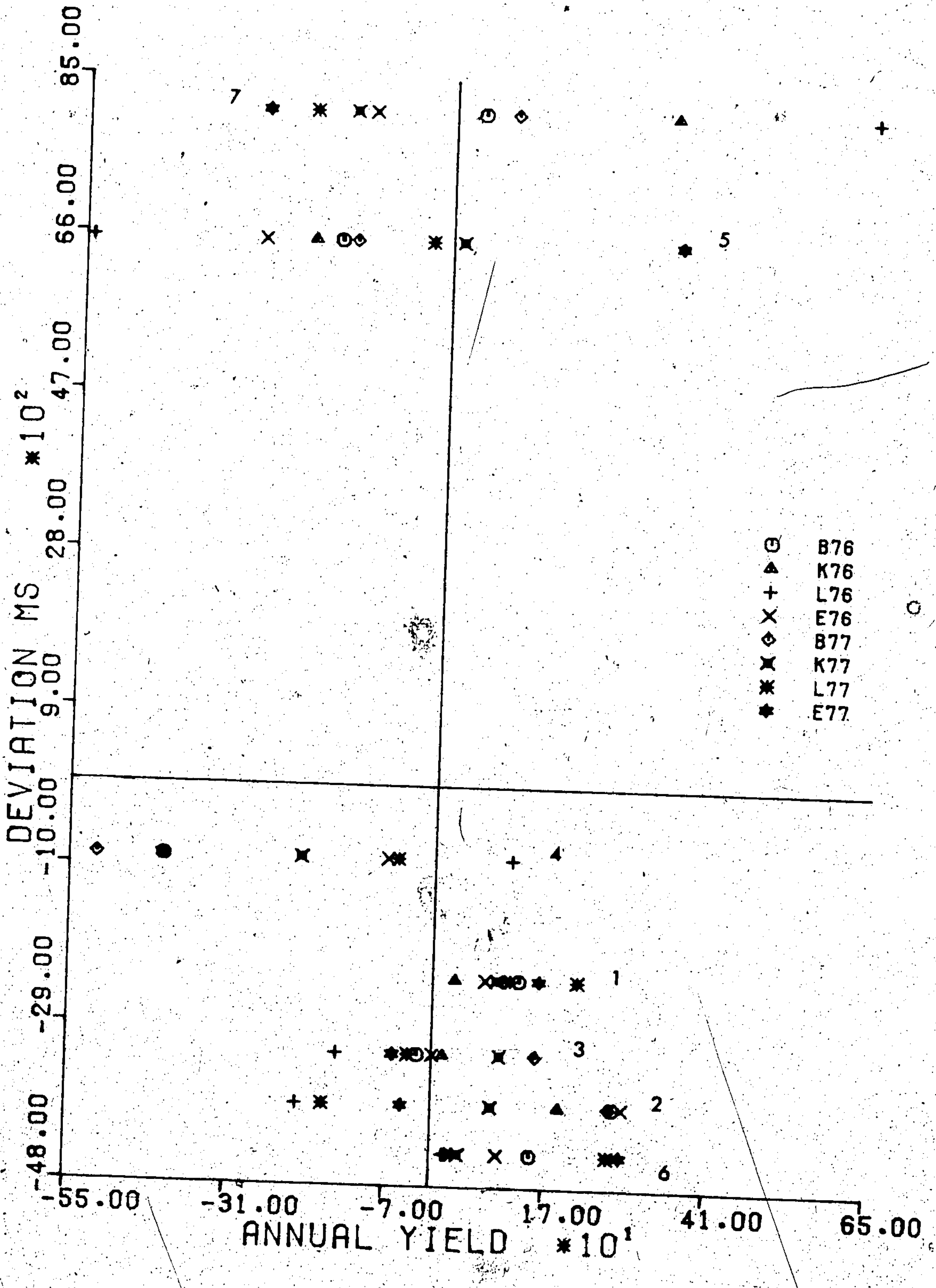

Fig. 12. The relationship between GCA effects for annual yield and deviation mean square for eight individual environments. (B:Beaverlodge; K:Kinsella; L:Lethbridge; E:Edmonton)

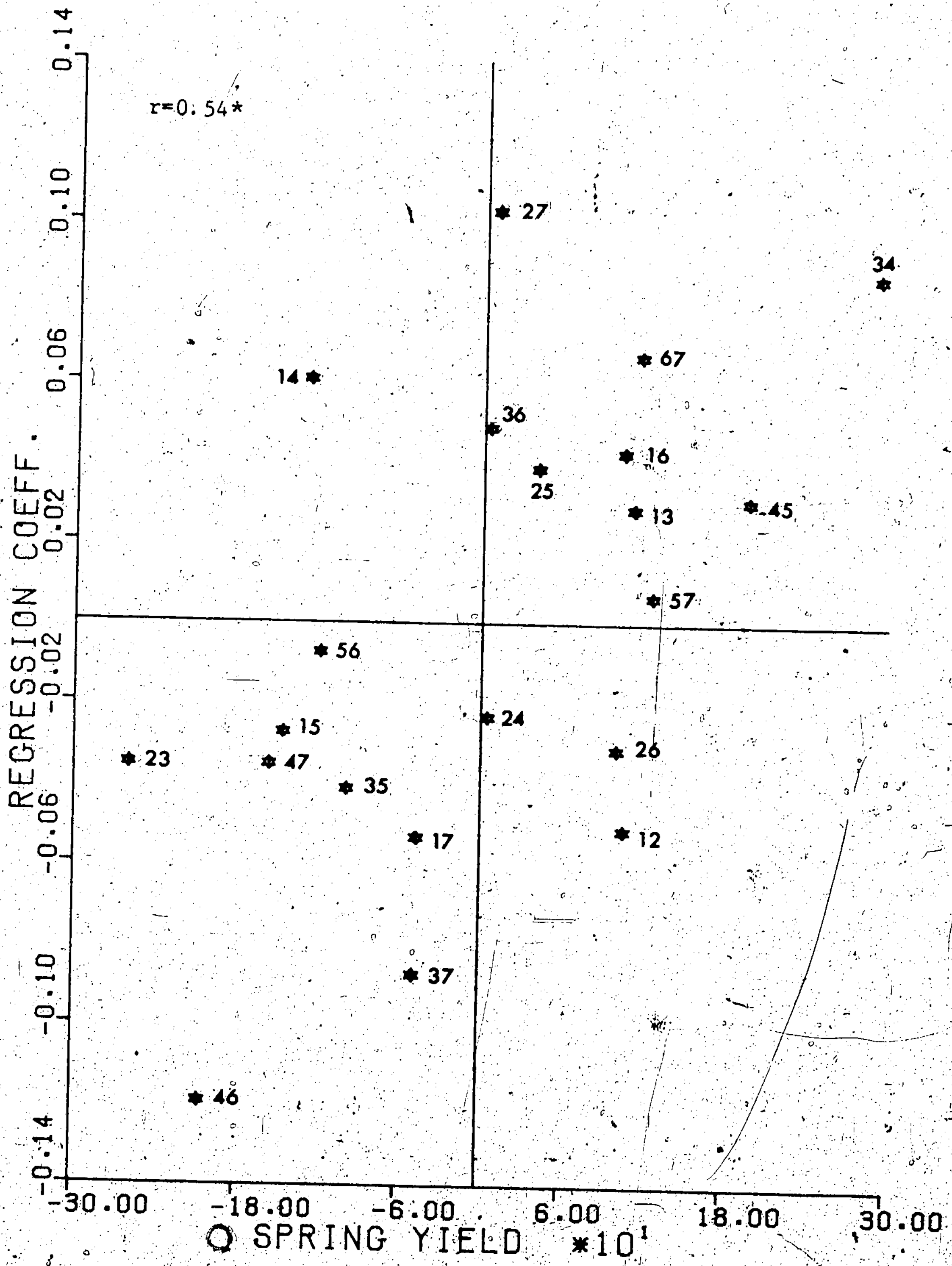

Fig. 13. The relationship between mean SCA effects for spring yield and regression coefficient for all environments.
* $P < 0.05$.

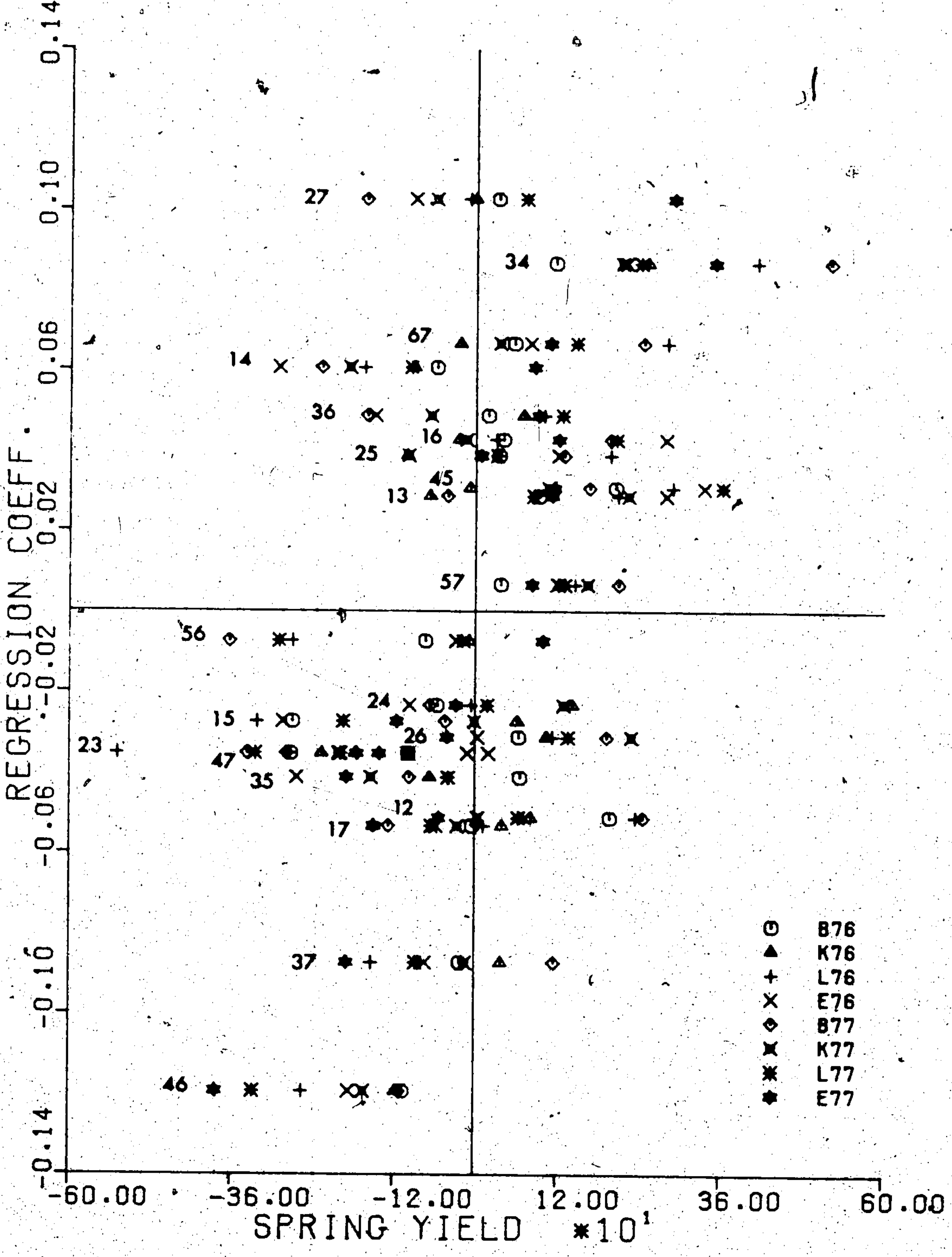

Fig. 14. The relationship between SCA effects for spring yield and regression coefficient for eight individual environments. (B:Beaverlodge; K:Kinsella; L:Lethbridge; E:Edmonton)

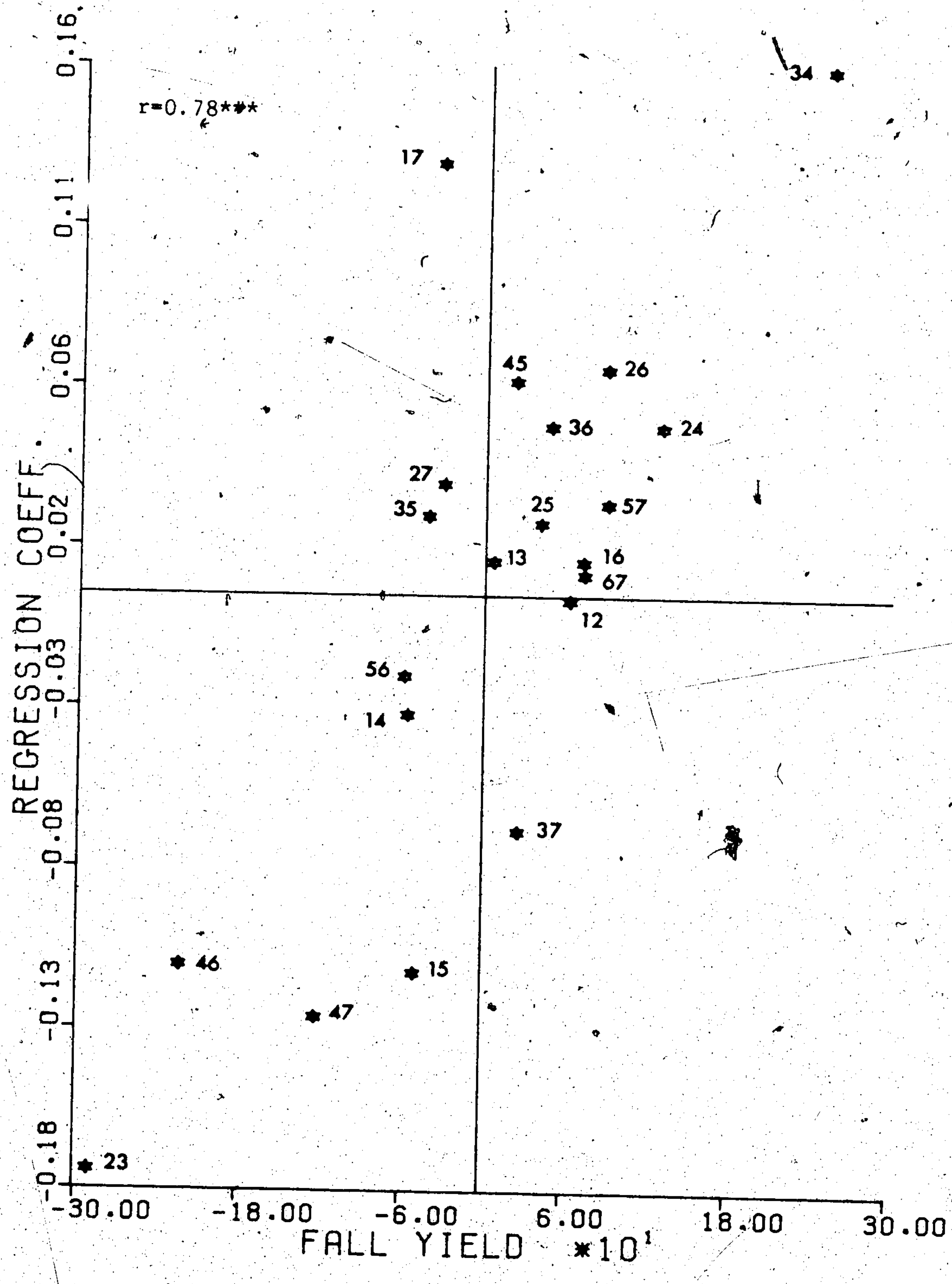

Fig. 15. The relationship between mean SCA effects for fall yield and regression coefficient for all environments. *** $P < 0.001$.

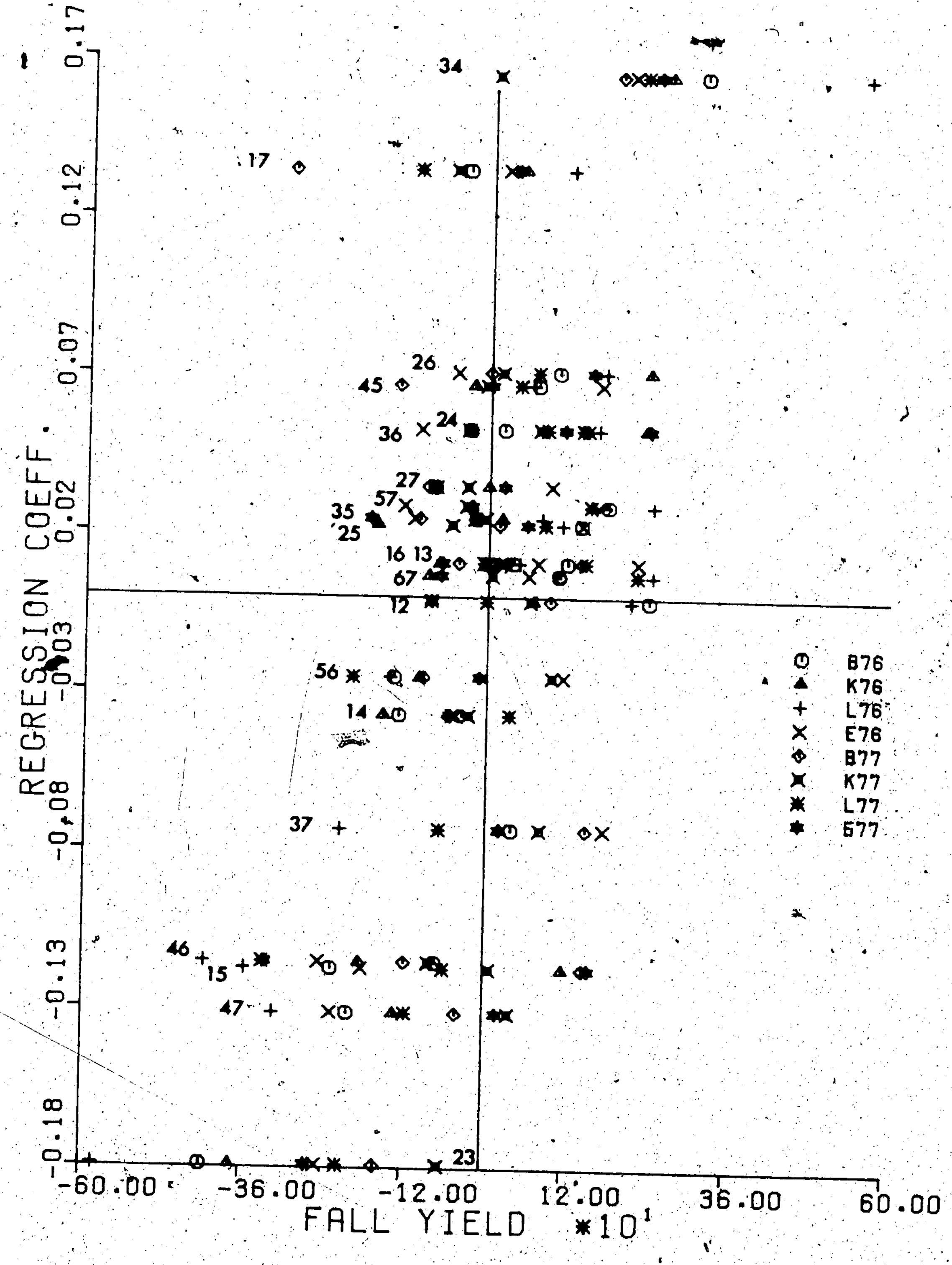

Fig. 16. The relationship between SCA effects for fall yield and regression coefficient for eight individual environments. (B:Beaverlodge; K:Kinsella; L:Lethbridge; E:Edmonton)

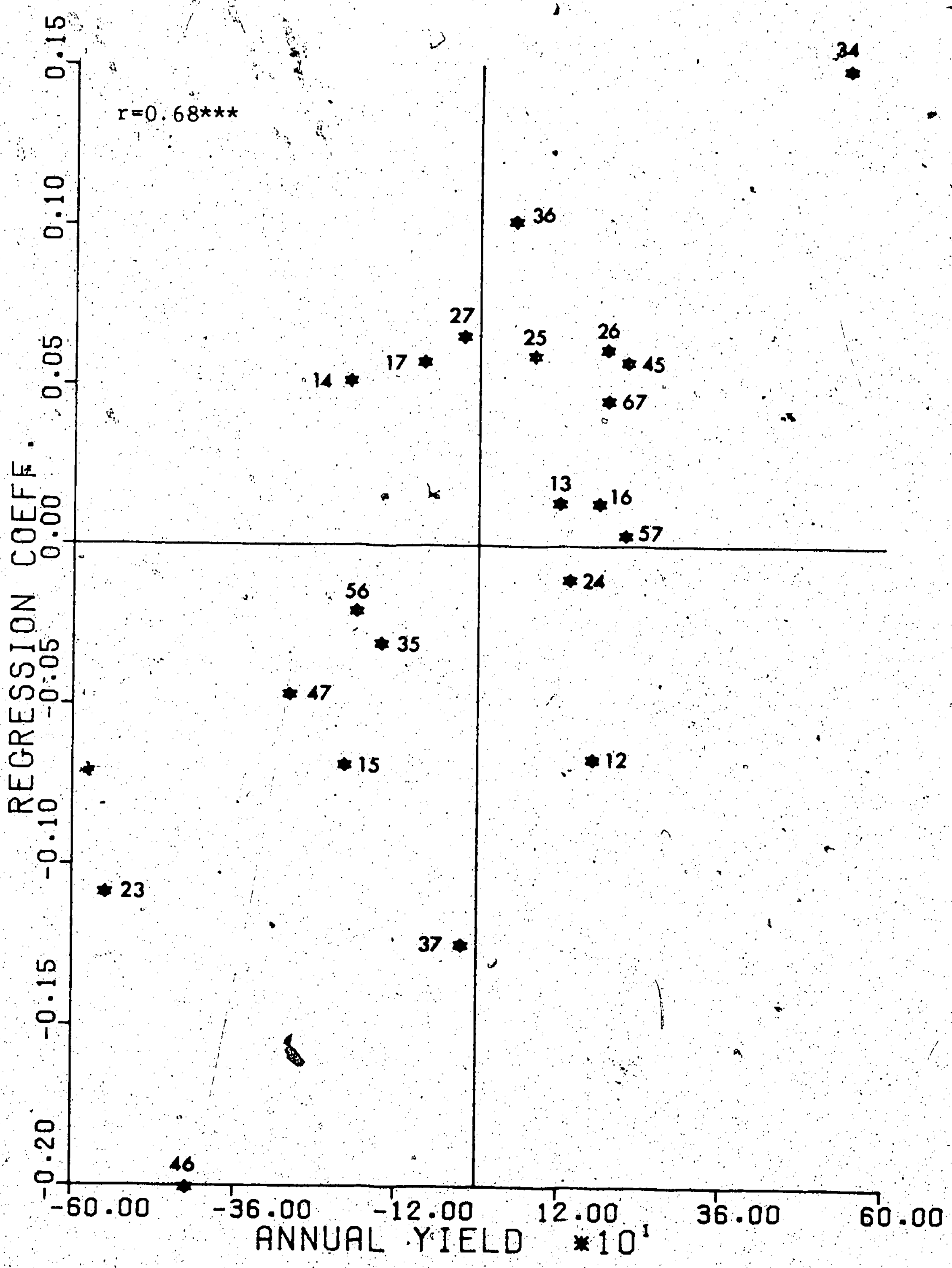

Fig. 17. The relationship between SCA effects for annual yield and regression coefficient for all environments.
*** $P < 0.001$.

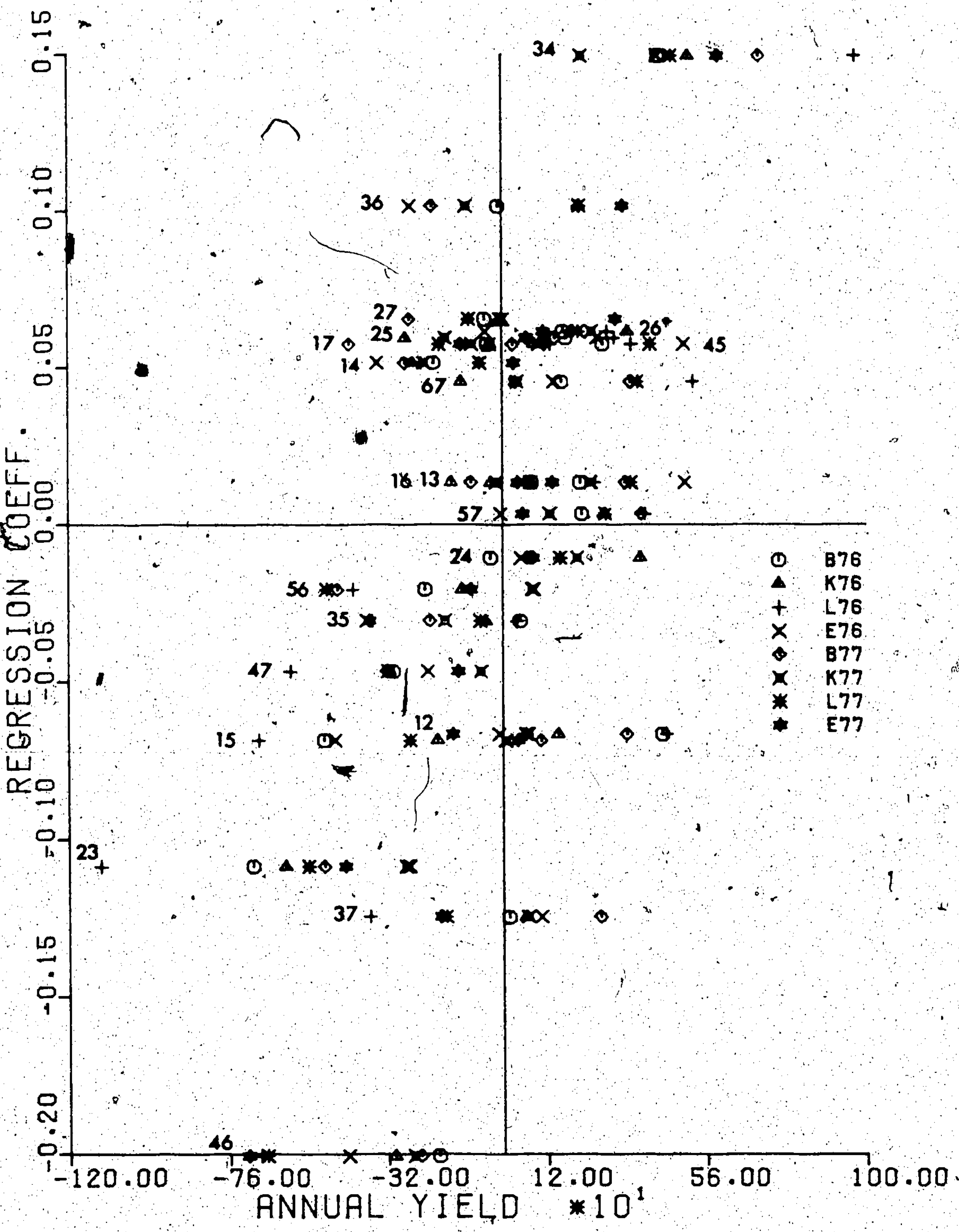

Fig. 18. The relationship between SCA effects for annual yield and regression coefficient for eight individual environments. (B:Beaverlodge; K:Kinsella; L:Lethbridge; E:Edmonton)

Genotypes 12 and 26, on the other hand, had low mean SCA estimates for regression and above average SCA for spring yield. Genotype 57 combined high yield and average stability. Figure 14 shows that all of these genotypes showed certain consistencies over environments. Genotype 34 again showed the highest mean SCA effect for both fall yield and regression (Fig. 15) and had the highest consistency in all eight environments (Fig. 16). Genotypes 16, 67 and 12 had above average SCA for fall yield and average stability. None of the genotypes combined consistently high fall yield and above average stability. Genotype 34 again had remarkably high mean SCA estimates for both annual yield and regression (Fig. 17) and displayed the highest consistency in all environments (Fig. 18). Genotypes 57, 16, 24 and 13 had higher than average SCA for annual yield and near zero mean SCA for regression. Genotype 12 combined high yield and above average stability in most of the environments (Fig. 18). Genotypes 23, 46 and 47 had combined above average stability and consistently low yield. There were highly significant correlation coefficients between mean SCA effects of regression and spring (r=0.54, 0.05 level), fall (r=0.78, 0.001 level), and annual (r=0.68, 0.001 level) yields. Therefore, genotypes which had high SCA estimates for yield tended to be relatively unstable, and those which had low SCA for yields tended to be stable.

The results obtained from the association of SCA effects between yields and regression were in general agreement with those obtained from the graphs showing the relationship between mean yields and regression (Figs. 1, 2 and 3), although the latter pairs showed no significant correlations. Genotypes 12, 13, 16 and 24, which were identified earlier as potentially good genotypes were again found to have desirable potential by combining ability analysis. Genotypes 25 and 36 appeared more desirable in the mean-regression association than in the combining ability analysis. Genotype 34 had its potential in favourable environments; unfortunately, because its stability variances were significant for both fall and annual yields, certain limits would be imposed on the use of this otherwise superior genotype. Genotype 23 was, at the other extreme, stable but had a yield performance which was far too low to be useful in practical breeding.

V. GENERAL DISCUSSION

In the combined analysis of variance, the main effects of years, locations and genotypes were highly significant for yield, leaf and tiller characters in smooth bromegrass. The analysis also showed that the genotypes interacted significantly with locations and years. Since genotypes and environmental interactions were highly significant, no immediate generalization could be made on the relative performance of these genotypes over even a restricted range of environments. Since the analysis of variance gave no further useful explanation of the GE interaction, the data were futher analysed by the joint regression methods as proposed by Perkins and Jinks (1968).

The joint regression analysis by ascribed a significant part of the GE interaction to the heterogeneity of the regression lines in every character. The regression technique turned complex GE interactions into a series of linear and thus predictable responses. However, the residual component was also significant in most instances, so there was a certain amount of unpredictable and unaccountable variation.

The model, proposed by Finlay and Wilkinson (1963) and further elaborated by Eberhart and Russell (1966), provided a method of screening individual genotypes. They suggested that regression coefficients and deviation mean squares be considered with mean performance as criteria for stability. However, it is difficult to decide the relative weight to be attached to these three parameters while selecting materials in a practical breeding program. Some workers (Eberhart and Russell, 1966, 1969; Busch, Hammond and Frohberg, 1976) have suggested that the deviation mean square is a more important stability parameter than linear regression.

In the present investigation, both the heterogeneity among regressions and the residuals were highly significant for most of the characters. The relative magnitudes of mean squares suggested that in most cases where regressions were not significantly greater than their residuals, both linear regression and deviation mean square should be considered for each genotype.

Results from the two methods of assessment of environments, namely, by the means of all genotypes and of parental genotypes, led some different conclusions for some of the characters measured in the present studies. Fripp and Caten (1971) found little differences between the use of a control genotype and the use of the mean of a large number of the test genotypes to estimate environments. Perkins and Jinks (1973) also obtained similar values of significance between environmental means measured by a large number of genotypes and those derived from other closely related sets of genotypes. Regressions on mean derived from only a few independent genotypes might be the cause of the problems of interpretation (Perkins and Jinks, 1973).

Diallel analysis indicated that both GCA and SCA were involved and of equal importance in the inheritance of yields, including spring, fall and annual yields. Interactions (GCA x E and SCA x E) also accounted for significant variation, thereby indicating the importance of multi-environmental testing. For regression estimates, mean squares due to GCA were about 3.5 (spring and annual yields) to 5.6 (fall yield) times as great as those due to SCA; while mean squares due to GCA and SCA for deviations did not differ significantly. A predominance of additive effects in the inheritance of linear responses was recorded by Eberhart and Russell (1966, 1969) and Patanothai and Atkins (1974). Both additive and non-additive effects were involved in inheritance of deviations from regression (Eberhart and Russell, 1969; Dhillon and Singh, 1977). Busch et al. (1976), however, indicated that deviation from regression was simply inherited and could be predicted from the parents. In contrast, Patanothai and Atkins (1974) concluded that the inheritance of deviations from regression was complex.

The presence of a substantial proportion of variability due to the additive genetic component in the inheritance of linear response suggests that it should be possible to exploit this fraction of variability in developing high yielding stable cultivars. However, the differences among the genotypes for mean yield were ascribable to both additive and non-additive genetic variance. Therefore, a more complicated approach, such as recurrent selections involving multi-location and multi-year testing, seems necessary.

None of the parents had general adaptability and high mean performance for all three yield types. Parent 1, however, had high and consistent mean GCA effects for mean yields, near zero GCA effects for linear response and low GCA effects for deviations from regression, thus transmitting both high yields and average stability. It may be the most suited parent for hybridization program. However, since SCA was equally as important as GCA in determining yield, not all the progenies of parent 1 were equally high in yield. This seemed obvious because only half of the crosses (genotypes 12, 13 and 16) involving parent 1 as one of their parents had above average yield as well as average stability. One other good combiner, parent 6, had positive GCA effects for linear response which suggested that its progeny can do well in fertile and well-managed environments, but not as well in unfavourable environments.

The results presented here illustrated that regression analyses are powerful tools in the analysis of GE interactions. In cases where deviation mean squares were as important as the heterogeneity among regressions, further partition of the pooled deviation into individual genotypes proved useful in discriminating genotypes for stability parameters. The technique has been used to analyse yield in a number of other experiments involving different gr[illegible]pulation and species from the smooth bromegrass reported here. In a[illegible] stability of characters other than yield was also evaluated, which is rarely done in other crops except peas (Snoad and Arthur, 1974). When yield is considered alone, two successive harvests and the total annual yield were included. Only those genotypes which showed some degree of consistency for all three yield types were selected. The use of diallel cross design in the present experiment permits the joint investigation of combining ability and the stability parameters.

With the diverse climatic conditions in Alberta, the data showed that to obtain genotypes which will be consistently high in yield and highly stable for the whole province would be difficult. One of the alternatives would be to sub-divide the whole province into zones. Under such division, more genotypes are expected to show specific adaptation as well as high mean performance. Because of the few locations used in this study, no immediate suggestion could be made for the possible zoning for the province.

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APPENDICES

Appendix Table 1. Mean spring yield (g/plot) of smooth bromegrass grown at eight environments in Alberta.

Genotype	Beaverlodge		Kinsella		Lethbridge		Edmonton		Genotypic Mean
	1976	1977	1976	1977	1976	1977	1976	1977	
1	1134	2146	1147	1903	2880	2887	1828	3662	2198
2	1246	2492	1395	2008	2225	1977	2100	3417	2107
3	808	2233	1272	1891	2171	2437	1670	3283	1970
4	624	1082	797	1658	2372	2133	1772	2808	1655
5	738	1623	738	1569	1958	2369	1524	3295	1726
6	1185	2200	1364	2082	2651	3122	2009	3917	2316
7	942	2399	1407	1648	3459	2264	1040	3416	2071
12	1610	2899	1485	1928	2821	2574	2047	3179	2317
13	1396	2454	1245	2139	2920	2527	2203	3273	2269
14	971	2059	1023	1539	2664	2688	1582	3346	1984
15	860	2317	1264	1821	2062	2500	1478	3451	1969
16	1344	2589	1199	1795	2645	2932	2252	3553	2288
17	1325	2513	1464	1819	3098	2362	1989	3070	2205
23	1121	2220	1169	1666	2147	1945	2001	2791	1882
24	1065	2282	1341	1811	2787	2631	1866	3037	2102
25	1256	2553	1185	1676	2546	2557	1974	3383	2141
26	1459	2647	1415	1992	2692	2692	2066	3196	2269
27	1453	2540	1506	1740	3040	2328	2045	3317	2246
34	1128	2714	1360	1885	3334	2787	2132	3345	2335
35	1178	2169	1129	1612	2434	2418	1537	3111	1948
36	1303	2135	1290	1689	2805	2615	1861	3258	2119
37	1288	2662	1458	1776	3023	2100	2012	2764	2135
45	1043	2226	989	1687	2883	3163	2088	3516	2199
46	904	1978	904	1403	2567	2503	1776	2882	1864
47	938	2059	1043	1504	3019	2330	2057	2911	1982
56	1037	1800	1099	1646	2107	2451	1822	3672	1954
57	1176	2621	1431	1863	2995	2572	2046	3445	2268
67	1367	2687	1307	1722	3361	2619	2215	3335	2326
$\bar{X}$	1139.2	2296.3	1229.4	1766.8	2702.2	2517.1	1892.5	3272.5	2102.1
L.S.D. (.05)	414.0	401.2	278.8	251.5	551.6	361.4	394.7	419.8	237.5

Appendix Table 2. Mean fall yield (g/plot) of smooth bromegrass grown at eight environments in Alberta.

Genotype	Beaverlodge		Kinsella		Lethbridge		Edmonton		Genotypic Mean
	1976	1977	1976	1977	1976	1977	1976	1977	
1	1459	723	2067	358	2590	1408	2248	1517	1546
2	1565	1117	2406	369	2317	1145	2775	1451	1643
3	1143	1077	2087	527	1896	1264	2143	1613	1468
4	972	514	1794	365	2700	1003	2242	1102	1336
5	1191	780	1779	686	1854	1003	1690	2108	1386
6	1709	1071	2535	518	2818	1506	2354	1920	1803
7	1286	859	2615	187	2767	1147	1617	1329	1475
12	2016	1317	2432	581	2686	1262	2215	1513	1752
13	1811	1252	2239	549	2684	1318	2333	1562	1718
14	1281	953	1895	305	2525	1210	2045	1237	1431
15	1389	1404	2480	543	1996	1155	1972	1905	1605
16	1666	1319	2212	453	2501	1366	2393	1622	1691
17	1637	762	2553	326	2919	1039	2402	1274	1614
23	1355	1069	1905	455	1893	1070	1983	1322	1381
24	1515	1067	2253	396	2581	1271	2215	1357	1581
25	1837	1203	2164	466	2298	1256	2264	1757	1655
26	1814	1110	2425	461	2477	1247	2088	1712	1666
27	1674	898	2471	338	2552	1024	2443	1211	1576
34	1729	1187	2231	342	3147	1422	2235	1525	1727
35	1597	1156	2297	531	2436	1211	1969	1556	1594
36	1599	1153	2276	426	2584	1325	1993	1831	1648
37	1714	1215	2445	468	2585	1099	2485	1242	1656
45	1409	817	1990	332	2365	1127	2088	1395	1440
46	1277	760	1686	178	1997	757	1690	927	1159
47	1192	717	2026	227	2433	900	1919	903	1289
56	1414	1047	2082	560	2041	927	2106	1695	1484
57	1778	1195	2627	353	2761	1208	2075	1310	1663
67	1717	1053	2237	316	2876	1284	2278	1125	1610
$\bar{X}$	1526.5	1028.3	2221.6	414.7	2474.1	1176.9	2152.0	1464.9	1557.5
L.S.D. (.05)	408.5	315.8	392.3	136.1	412.7	241.3	423.1	356.8	205.4

Appendix Table 3. Mean annual yield (g/plot) of smooth bromegrass grown at eight environments in Alberta.

Genotype	Beaverlodge		Kinsella		Lethbridge		Edmonton		Genotypic Mean
	1976	1977	1976	1977	1976	1977	1976	1977	
1	2593	2868	3214	2261	5470	4295	4076	5179	3744
2	2811	3608	3800	2377	4542	3122	4875	4868	3750
3	1951	3310	3359	2418	4066	3701	3813	4895	3439
4	1596	1597	2591	2023	5071	3136	4014	3910	2992
5	1929	2403	2517	2255	3811	3372	3213	5402	3112
6	2893	3271	3899	2600	5468	4628	4363	5837	4119
7	2228	3258	4022	1835	6225	3411	2657	4745	3547
12	3626	4216	3916	2508	5507	3835	4262	4692	4070
13	3207	3706	3484	2688	5604	3845	4535	4835	3988
14	2252	3011	2918	1845	5189	3897	3627	4583	3415
15	2249	3722	3744	2364	4058	3655	3450	5357	3574
16	3010	3909	3411	2248	5145	4298	4645	5175	3980
17	2962	3275	4017	2145	6017	3401	4391	4344	3819
23	2476	3289	3074	2121	4040	3015	3984	4112	3263
24	2580	3349	3594	2207	5369	3902	4081	4394	3684
25	3094	3755	3348	2142	4843	3813	4238	5139	3796
26	3272	3756	3840	2454	5169	3939	4154	4908	3936
27	3127	3437	3977	2078	5591	3353	4488	4527	3822
34	2857	3901	3592	2227	6482	4209	4367	4871	4063
35	2776	3325	3426	2143	4870	3629	3506	4667	3542
36	2902	3287	3565	2114	5388	3940	3854	5089	3767
37	3001	3876	3903	2244	5609	3199	4497	4006	3791
45	2452	3043	2979	2019	5248	4290	4176	4910	3639
46	2181	2738	2591	1581	4564	3260	3466	3809	3023
47	2130	2776	3069	1730	5452	3229	3975	3814	3271
56	2451	2847	3181	2205	4149	3378	3928	5368	3438
57	2954	3817	4058	2216	5756	3780	4121	4755	3932
67	3084	3740	3544	2038	6237	3904	4494	4460	3937
$\bar{X}$	2665.7	3324.6	3451.1	2181.5	5176.3	3694.0	4044.5	4737.4	3659.5
L.S.D. (.05)	783.8	578.0	625.8	309.3	893.8	524.3	715.5	621.0	400.4

Appendix Table 4. Mean yield per area (g/dm^2) of smooth bromegrass grown at eight environments in Alberta.

Genotype	Beaverlodge		Kinsella		Lethbridge		Edmonton		Genotypic Mean
	1976	1977	1976	1977	1976	1977	1976	1977	
1	72.2	39.1	31.7	19.6	49.1	22.0	46.8	21.4	37.7
2	81.1	39.6	28.3	19.4	47.5	22.6	55.9	21.1	39.4
3	49.4	35.5	28.4	17.5	47.5	21.1	44.8	20.8	33.1
4	40.6	18.4	21.0	14.0	28.9	14.0	32.2	17.7	23.4
5	60.8	33.3	23.5	22.4	48.0	23.5	44.5	25.1	35.1
6	75.4	40.7	31.4	21.4	52.8	23.9	52.8	25.4	40.4
7	37.2	26.7	16.7	10.7	33.5	18.5	37.6	20.0	25.1
12	98.9	46.0	33.8	19.3	50.8	23.6	51.1	23.1	43.3
13	80.9	43.4	34.8	23.3	55.3	20.7	52.4	23.3	41.7
14	70.2	37.7	22.3	15.0	46.2	22.1	43.4	20.8	34.7
15	72.6	41.8	26.3	19.8	48.0	23.5	42.9	21.8	37.0
16	90.5	46.0	28.1	19.5	51.3	26.9	46.8	23.4	41.5
17	61.1	33.5	21.7	13.9	38.1	18.9	37.6	19.8	30.5
23	78.1	40.6	28.4	21.2	47.8	22.4	41.7	22.3	37.8
24	70.6	40.4	23.0	14.0	46.1	24.5	44.8	20.6	35.5
25	81.0	38.8	27.1	17.1	42.7	20.0	44.6	23.1	36.8
26	80.8	40.5	26.2	18.1	47.0	24.3	59.4	23.9	40.0
27	70.0	39.0	21.3	14.1	36.0	18.2	36.2	21.6	32.0
34	66.8	40.5	23.1	12.9	45.6	24.6	45.0	20.1	34.8
35	76.8	39.0	24.2	17.1	45.8	22.8	44.1	20.6	36.3
36	89.0	37.9	26.0	18.0	45.3	21.5	51.0	23.0	38.9
37	58.7	36.3	22.8	15.5	38.2	16.3	36.7	20.8	30.6
45	65.4	35.5	20.3	16.5	46.2	22.3	42.1	21.0	33.6
46	47.8	23.9	17.8	10.6	36.9	18.6	33.9	17.3	25.8
47	42.9	24.5	16.7	11.2	31.4	18.9	27.9	16.5	23.7
56	78.1	35.2	32.3	17.7	46.8	23.5	44.8	22.3	37.5
57	54.9	39.2	23.3	15.0	41.7	18.4	35.2	20.6	31.0
67	68.2	39.9	25.8	16.2	43.1	22.7	32.9	22.6	33.9
$\bar{X}$	68.5	36.9	25.2	16.8	44.2	21.4	43.1	21.4	34.7
L.S.D. (.05)	6.5	3.4	3.8	1.7	3.7	2.1	3.6	1.5	5.1

Appendix Table 5. Mean leaf area (cm^2/tiller) of smooth bromegrass grown at eight environments in Alberta.

Genotype	Beaverlodge		Kinsella		Lethbridge		Edmonton		Genotypic Mean
	1976	1977	1976	1977	1976	1977	1976	1977	
1	104.5	87.6	93.7	54.4	109.8	66.9	94.5	108.4	89.9
2	76.2	90.0	81.3	51.0	93.4	47.9	81.5	93.4	76.8
3	51.5	63.3	81.0	43.6	93.7	48.9	89.0	84.6	69.4
4	77.7	74.5	87.4	43.9	81.8	45.9	72.7	80.9	70.6
5	125.4	135.7	141.9	79.6	123.1	72.7	116.5	120.8	114.4
6	143.4	135.7	141.0	64.2	149.4	70.5	120.8	125.2	118.7
7	48.6	59.9	65.6	31.5	81.8	41.1	58.2	71.3	57.2
12	104.1	97.7	96.4	58.2	100.7	56.0	84.5	91.3	86.1
13	103.4	99.0	110.9	71.3	108.2	65.8	99.5	101.4	94.9
14	73.9	81.1	80.7	44.8	92.2	50.8	81.2	83.0	73.4
15	135.3	129.9	130.6	74.9	127.1	70.0	129.9	147.9	118.2
16	130.6	116.4	122.1	70.0	133.2	68.5	103.9	115.2	107.4
17	76.4	82.5	87.2	44.7	96.7	44.7	78.6	84.1	74.3
23	76.3	81.2	78.4	54.5	92.3	51.7	75.7	87.2	74.6
24	69.3	70.4	85.1	42.3	94.9	46.9	66.5	78.0	69.1
25	118.3	106.8	119.1	65.8	119.7	58.9	101.1	109.9	99.9
26	125.4	113.1	123.5	68.1	131.6	66.7	114.1	113.7	107.0
27	74.7	83.4	76.2	44.3	90.8	44.5	67.2	76.6	69.7
34	87.3	90.0	95.3	46.1	104.3	62.8	97.0	87.9	83.8
35	113.8	103.5	127.8	67.0	118.2	65.7	108.6	109.0	101.7
36	118.4	117.0	108.4	61.0	114.5	61.0	103.5	118.3	100.2
37	76.7	72.2	75.2	39.9	88.8	40.4	66.9	80.3	67.5
45	129.0	118.8	128.0	63.0	146.7	70.6	123.0	119.1	112.2
46	81.4	98.8	94.6	55.0	117.8	63.2	87.7	103.7	87.7
47	72.6	68.1	84.8	40.0	89.1	41.6	85.5	73.2	69.3
56	125.1	134.4	132.6	69.4	124.3	66.7	112.3	126.1	111.3
57	91.7	100.4	111.1	55.6	126.3	64.8	94.6	97.6	92.7
67	102.0	91.8	104.3	54.1	115.6	59.7	87.4	105.2	90.0
$\bar{X}$	96.9	96.5	102.3	55.6	109.5	57.7	92.9	99.7	88.9
L.S.D. (.05)	15.7	15.6	15.8	11.0	16.2	11.8	14.1	16.0	7.9

Appendix Table 6. Mean leaf number (no/tiller) of smooth bromegrass grown at eight environments in Alberta.

Genotype	Beaverlodge		Kinsella		Lethbridge		Edmonton		Genotypic Mean
	1976	1977	1976	1977	1976	1977	1976	1977	
1	5.3	3.8	4.6	3.5	5.0	4.3	5.6	5.1	4.7
2	4.2	4.0	4.2	3.7	4.9	3.7	4.6	4.4	4.2
3	3.9	3.8	4.3	3.3	4.2	3.5	4.9	4.1	4.0
4	5.2	4.0	5.3	4.3	5.2	4.6	4.6	4.6	4.7
5	4.7	4.1	4.6	4.3	4.1	3.7	4.5	4.5	4.3
6	5.3	4.6	5.2	4.4	5.4	4.1	5.0	4.6	4.8
7	4.2	3.5	4.4	3.2	4.0	3.6	4.1	3.8	3.9
12	5.1	4.4	4.8	4.2	4.8	4.1	4.7	4.4	4.6
13	4.9	4.4	5.2	4.8	5.2	4.4	5.1	4.6	4.8
14	4.7	4.2	5.1	4.4	5.1	4.5	4.8	4.7	4.7
15	5.4	4.4	5.0	4.2	4.9	4.1	5.1	5.1	4.8
16	5.3	4.6	5.2	4.4	5.1	4.1	5.1	4.6	4.8
17	4.5	4.2	4.5	3.6	4.8	3.9	4.3	4.3	4.3
23	4.1	3.8	4.5	3.9	4.5	3.5	4.6	3.9	4.1
24	4.9	4.1	5.0	4.1	5.3	4.5	4.7	4.4	4.6
25	5.0	4.0	4.9	4.0	4.7	3.6	4.5	4.2	4.4
26	5.5	4.5	5.3	4.5	5.5	4.2	4.7	4.4	4.8
27	4.1	4.2	4.5	3.7	4.3	3.5	4.1	3.7	4.0
34	5.1	4.3	5.0	4.2	5.1	4.6	5.1	4.5	4.7
35	4.9	4.0	4.9	4.4	4.6	3.9	4.6	4.3	4.5
36	5.4	4.5	4.9	4.5	5.2	4.1	5.1	4.8	4.8
37	4.6	3.6	4.3	3.4	4.4	3.7	4.2	4.0	4.0
45	5.7	4.7	5.3	4.3	5.6	4.6	5.4	4.9	5.1
46	5.1	4.3	5.3	4.4	5.8	5.1	5.4	5.1	5.1
47	5.0	3.9	5.1	4.1	6.1	4.4	5.1	4.2	4.6
56	4.8	4.4	4.9	4.4	4.5	3.8	4.4	4.4	4.5
57	4.5	4.0	4.5	3.4	4.4	3.8	4.4	4.0	4.1
67	5.0	3.8	4.9	4.0	4.7	4.1	5.1	4.7	.5
$\bar{X}$	4.9	4.2	4.9	4.1	4.9	4.1	4.8	4.5	4.5
L.S.D. (.05)	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.24

Appendix Table 7. Mean leaf dry weight (g/tiller) of smooth bromegrass grown at eight environments in Alberta.

Genotype	Beaverlodge		Kinsella		Lethbridge		Edmonton		Genotypic Mean
	1976	1977	1976	1977	1976	1977	1976	1977	
1	0.67	0.53	0.53	0.31	0.46	0.34	0.59	0.50	0.49
2	0.50	0.47	0.36	0.24	0.40	0.23	0.47	0.42	0.39
3	0.32	0.35	0.39	0.24	0.37	0.20	0.57	0.38	0.36
4	0.65	0.56	0.55	0.24	0.48	0.26	0.44	0.38	0.45
5	0.97	0.98	1.01	0.46	0.62	0.45	0.87	0.65	0.76
6	0.97	0.76	0.71	0.34	0.66	0.39	0.71	0.56	0.64
7	0.29	0.30	0.35	0.15	0.36	0.18	0.38	0.31	0.29
12	0.65	0.55	0.49	0.28	0.40	0.26	0.51	0.42	0.45
13	0.68	0.52	0.55	0.35	0.45	0.32	0.58	0.46	0.49
14	0.50	0.48	0.43	0.23	0.40	0.24	0.53	0.40	0.40
15	1.01	0.88	0.76	0.46	0.70	0.42	0.91	0.79	0.74
16	0.87	0.66	0.69	0.39	0.58	0.37	0.61	0.55	0.59
17	0.50	0.44	0.49	0.24	0.41	0.22	0.51	0.40	0.41
23	0.46	0.44	0.36	0.27	0.36	0.21	0.40	0.37	0.36
24	0.47	0.40	0.45	0.22	0.40	0.24	0.39	0.35	0.37
25	0.80	0.64	0.70	0.39	0.59	0.33	0.65	0.55	0.59
26	0.78	0.63	0.63	0.34	0.56	0.33	0.65	0.52	0.56
27	0.44	0.40	0.36	0.21	0.36	0.20	0.36	0.32	0.33
34	0.60	0.55	0.51	0.24	0.46	0.30	0.60	0.41	0.46
35	0.78	0.66	0.78	0.40	0.55	0.37	0.73	0.58	0.61
36	0.79	0.59	0.53	0.31	0.52	0.31	0.61	0.56	0.53
37	0.45	0.34	0.35	0.18	0.34	0.16	0.37	0.36	0.33
45	0.98	0.79	0.84	0.40	0.77	0.41	0.83	0.64	0.71
46	0.55	0.60	0.55	0.31	0.57	0.33	0.52	0.50	0.50
47	0.50	0.40	0.48	0.21	0.43	0.20	0.53	0.33	0.39
56	0.91	0.85	0.73	0.40	0.64	0.40	0.71	0.65	0.67
57	0.64	0.63	0.68	0.33	0.65	0.35	0.58	0.45	0.54
67	0.65	0.52	0.55	0.27	0.53	0.29	0.50	0.47	0.48
$\bar{X}$	0.66	0.57	0.57	0.31	0.50	0.30	0.58	0.47	0.496
L.S.D. (.05)	0.11	0.09	0.10	0.06	0.08	0.06	0.11	0.10	0.06

Appendix Table 8. Mean specific leaf weight (x 10^{-2}; g/cm^2) of smooth bromegrass grown at eight environments in Alberta.

Genotype	Beaverlodge		Kinsella		Lethbridge		Edmonton		Genotypic Mean
	1976	1977	1976	1977	1976	1977	1976	1977	
1	0.655	0.614	0.569	0.574	0.421	0.520	0.622	0.468	0.555
2	0.665	0.533	0.458	0.482	0.437	0.488	0.580	0.458	0.512
3	0.644	0.563	0.477	0.549	0.405	0.426	0.619	0.453	0.517
4	0.848	0.763	0.623	0.569	0.600	0.574	0.620	0.474	0.634
5	0.785	0.730	0.711	0.586	0.516	0.630	0.755	0.539	0.656
6	0.690	0.565	0.512	0.532	0.445	0.553	0.591	0.453	0.542
7	0.617	0.516	0.533	0.499	0.444	0.460	0.656	0.437	0.520
12	0.623	0.569	0.517	0.483	0.407	0.479	0.608	0.467	0.519
13	0.666	0.532	0.500	0.503	0.418	0.489	0.581	0.459	0.518
14	0.692	0.598	0.537	0.513	0.438	0.473	0.664	0.489	0.550
15	0.753	0.682	0.588	0.613	0.565	0.603	0.703	0.540	0.631
16	0.666	0.576	0.561	0.567	0.439	0.547	0.592	0.484	0.554
17	0.661	0.538	0.565	0.553	0.431	0.501	0.657	0.489	0.549
23	0.607	0.549	0.462	0.506	0.397	0.416	0.531	0.429	0.487
24	0.687	0.574	0.536	0.540	0.432	0.518	0.598	0.457	0.542
25	0.685	0.608	0.591	0.597	0.495	0.581	0.652	0.502	0.589
26	0.626	0.566	0.510	0.509	0.430	0.502	0.576	0.464	0.523
27	0.599	0.491	0.478	0.474	0.401	0.471	0.548	0.420	0.485
34	0.691	0.613	0.541	0.534	0.440	0.495	0.623	0.470	0.551
35	0.695	0.643	0.614	0.598	0.464	0.568	0.678	0.540	0.660
36	0.672	0.518	0.499	0.512	0.456	0.521	0.591	0.480	0.531
37	0.595	0.485	0.469	0.470	0.393	0.412	0.563	0.435	0.478
45	0.773	0.669	0.659	0.643	0.528	0.586	0.677	0.540	0.634
46	0.682	0.620	0.588	0.570	0.486	0.527	0.594	0.492	0.570
47	0.707	0.595	0.575	0.539	0.487	0.505	0.625	0.467	0.562
56	0.739	0.637	0.557	0.582	0.518	0.606	0.640	0.522	0.600
57	0.700	0.641	0.618	0.606	0.514	0.541	0.629	0.471	0.590
67	0.637	0.567	0.531	0.507	0.469	0.507	0.573	0.449	0.530
$\bar{X}$	0.681	0.591	0.549	0.543	0.460	0.518	0.619	0.476	0.555
L.S.D. (.05)	0.047	0.063	0.050	0.045	0.043	0.051	0.06	0.044	0.027

Appendix Table 9. Mean stem dry weight (g/tiller) of smooth bromegrass grown at eight environments in Alberta.

Genotype	Beaverlodge		Kinsella		Lethbridge		Edmonton		Genotypic Mean
	1976	1977	1976	1977	1976	1977	1976	1977	
1	3.60	2.71	1.50	1.61	1.72	1.73	2.43	1.98	2.17
2	3.04	2.06	1.10	0.93	1.42	1.11	2.15	1.95	1.73
3	2.36	2.06	1.40	1.29	1.56	1.15	2.58	1.87	1.79
4	2.69	2.07	1.38	0.96	1.61	1.11	1.82	1.41	1.64
5	5.77	4.71	2.70	1.85	2.83	2.58	3.37	2.46	3.29
6	5.75	3.57	2.44	1.73	2.79	2.34	3.27	2.46	3.05
7	2.13	1.91	1.32	0.80	1.78	1.12	2.04	1.49	1.58
12	3.65	2.44	1.55	1.20	1.61	1.41	2.22	1.90	2.00
13	3.81	2.63	1.83	1.46	1.80	1.55	2.46	2.06	2.20
14	3.07	2.18	1.10	0.85	1.62	1.16	2.21	1.48	1.71
15	5.51	4.36	2.34	2.14	3.07	2.49	3.85	3.29	3.39
16	4.80	3.27	2.16	1.77	2.33	1.95	2.77	2.41	2.69
17	3.08	2.09	1.57	1.10	1.71	1.21	2.20	1.58	1.82
23	2.84	2.23	1.14	1.20	1.40	0.99	1.65	1.51	1.62
24	2.53	2.03	1.30	0.96	1.63	1.27	1.78	1.51	1.63
25	4.53	3.37	2.08	1.92	2.57	2.06	3.01	2.50	2.76
26	4.33	3.04	1.70	1.45	2.10	1.81	2.82	2.24	2.44
27	3.03	2.04	1.19	0.89	1.58	1.15	1.74	1.41	1.63
34	3.19	2.64	1.55	1.11	1.78	1.43	2.38	1.57	1.96
35	4.61	3.68	2.47	1.96	2.40	2.09	3.41	2.74	2.92
36	4.34	2.95	1.76	1.54	2.16	1.86	2.79	2.46	2.49
37	2.80	2.05	1.27	0.88	1.58	1.03	1.79	1.47	1.61
45	4.82	3.63	2.47	2.12	3.19	2.33	3.47	2.65	3.09
46	2.72	2.49	1.43	1.12	2.18	1.58	1.97	1.92	1.93
47	2.57	1.90	1.33	0.83	1.59	1.13	2.18	1.35	1.61
56	4.86	3.55	2.20	1.69	2.68	2.27	3.23	2.75	2.91
57	3.83	3.29	2.26	1.87	2.70	1.90	2.77	2.12	2.60
67	3.94	3.04	1.82	1.29	2.66	1.69	2.34	2.11	2.36
$\bar{X}$	3.72	2.78	1.73	1.38	2.08	1.63	2.53	2.03	2.236
L.S.D. (.05)	0.55	0.42	0.30	0.25	0.37	0.34	0.45	0.45	0.28

Appendix Table 10. Mean tiller dry weight (g/tiller) of smooth bromegrass grown at eight environments in Alberta.

Genotype	Beaverlodge		Kinsella		Lethbridge		Edmonton		Genotypic Mean
	1976	1977	1976	1977	1976	1977	1976	1977	
1	4.28	3.25	2.04	1.92	2.18	2.08	3.02	2.49	2.66
2	3.55	2.53	1.47	1.18	1.83	1.35	2.62	2.37	2.12
3	2.69	2.42	1.79	1.53	1.94	1.36	3.16	2.26	2.15
4	3.35	2.64	1.93	1.20	2.10	1.37	2.27	1.79	2.09
5	6.75	5.69	3.71	2.32	3.45	3.04	4.25	3.12	4.05
6	6.72	4.34	3.16	2.07	3.46	2.73	3.98	3.02	3.69
7	2.43	2.22	1.67	0.96	2.14	1.31	2.42	1.80	1.87
12	4.30	3.00	2.05	1.48	2.01	1.67	2.73	2.33	2.45
13	4.49	3.16	2.38	1.82	2.25	1.87	3.04	2.52	2.70
14	3.58	2.66	1.53	1.08	2.02	1.40	2.74	1.88	2.12
15	6.52	5.25	3.10	2.60	3.77	2.91	4.77	4.08	4.13
16	5.67	3.94	2.85	2.17	2.92	2.33	3.38	2.97	3.28
17	3.59	2.53	2.06	1.35	2.12	1.43	2.72	1.98	2.23
23	3.30	2.67	1.50	1.48	1.76	1.21	2.05	1.89	1.99
24	3.01	2.43	1.76	1.19	2.04	1.51	2.18	1.86	2.00
25	5.34	4.02	2.79	2.31	3.16	2.40	3.67	3.05	3.35
26	5.11	3.68	2.33	1.80	2.67	2.15	3.48	2.76	3.00
27	3.48	2.44	1.55	1.10	1.94	1.36	2.11	1.73	1.97
34	3.80	3.19	2.07	1.36	2.24	1.74	2.99	1.98	2.42
35	5.39	4.34	3.25	2.36	2.95	2.46	4.14	3.33	3.53
36	5.13	3.55	2.30	1.85	2.68	2.17	3.40	3.02	3.02
37	3.25	2.40	1.62	1.07	1.93	1.19	2.17	1.84	1.94
45	5.81	4.42	3.31	2.53	3.96	2.74	4.30	3.30	3.80
46	3.28	3.10	1.99	1.43	2.76	1.91	2.49	2.43	2.43
47	3.08	2.30	1.82	1.04	2.02	1.34	2.72	1.68	2.00
56	5.78	4.41	2.93	2.10	3.32	2.67	3.94	3.41	3.58
57	4.48	3.92	2.94	2.21	3.35	2.25	3.35	2.58	3.14
67	4.59	3.56	2.37	1.56	3.19	1.99	2.84	2.58	2.84
$\bar{X}$	4.38	3.36	2.30	1.68	2.58	1.93	3.11	2.50	2.73
L.S.D. (.05)	0.64	0.47	0.38	0.31	0.44	0.40	0.55	0.53	0.32

Appendix Table 11. Mean tiller density (no/dm^2) of smooth bromegrass grown at eight environments in Alberta.

Genotype	Beaverlodge 1976	Beaverlodge 1977	Kinsella 1976	Kinsella 1977	Lethbridge 1976	Lethbridge 1977	Edmonton 1976	Edmonton 1977	Genotypic Mean
1	33.4	17.0	19.9	19.9	34.5	17.8	27.7	15.1	28.1
2	38.2	23.1	26.1	25.1	39.7	29.8	29.8	15.2	28.3
3	33.8	23.1	26.8	23.8	35.8	27.7	28.8	17.3	27.1
4	20.1	12.7	15.5	16.7	18.9	17.3	24.5	17.2	17.8
5	14.5	9.8	12.8	16.3	22.1	18.4	22.9	12.3	16.1
6	24.9	18.1	18.6	20.6	27.5	19.1	30.5	16.2	21.9
7	29.0	18.0	16.2	16.9	24.9	25.1	25.5	18.1	21.7
12	45.1	22.5	23.8	22.5	36.0	25.8	32.3	17.4	28.1
13	34.5	22.4	22.6	22.7	31.4	20.7	31.1	16.8	25.2
14	35.9	24.2	20.5	22.3	31.0	25.3	26.0	16.5	25.2
15	20.5	12.8	14.1	15.9	22.1	15.9	17.5	10.9	16.2
16	32.9	19.9	21.3	21.3	26.8	23.2	23.8	16.7	23.2
17	31.1	17.4	17.3	17.3	26.8	21.8	24.6	16.5	21.6
23	40.0	26.0	29.3	29.9	44.2	31.6	34.6	19.9	31.9
24	36.2	28.4	21.5	18.3	31.9	24.9	30.8	17.8	26.2
25	25.9	16.3	18.1	16.7	23.4	16.8	21.6	14.1	19.1
26	32.1	20.7	23.5	21.2	32.3	24.1	30.3	17.9	25.2
27	38.2	24.2	20.9	21.2	30.1	22.2	24.6	19.5	25.1
34	30.9	20.1	18.1	17.4	26.8	23.2	27.1	15.3	22.6
35	21.8	15.9	13.0	16.3	25.2	18.9	20.9	12.6	18.0
36	35.4	21.8	23.1	23.8	30.2	21.0	31.9	16.6	25.4
37	34.2	23.2	21.6	24.2	31.9	24.5	27.0	20.2	25.8
45	22.3	14.3	11.3	13.6	22.6	15.5	18.4	12.5	16.3
46	27.5	15.5	15.2	14.6	22.2	18.9	21.3	13.8	18.6
47	28.9	19.2	13.8	16.9	20.3	20.9	20.1	15.5	19.4
56	26.2	14.3	18.9	17.0	24.3	18.6	20.6	14.8	19.3
57	23.2	16.7	13.9	15.0	22.2	16.6	19.2	14.1	17.6
67	29.1	20.1	20.9	23.1	25.5	23.3	25.9	18.2	23.2
$\bar{X}$	30.2	19.2	19.2	19.6	28.2	21.7	25.7	16.0	22.5
L.S.D. (.05).	2.7	2.5	2.0	2.7	2.4	2.4	2.0	1.6	2.5

Appendix Table 12. Mean leaf stem ratio of smooth bromegrass grown at eight environments in Alberta.

Genotype	Beaverlodge 1976	Beaverlodge 1977	Kinsella 1976	Kinsella 1977	Lethbridge 1976	Lethbridge 1977	Edmonton 1976	Edmonton 1977	Genotypic Mean
1	0.187	0.197	0.356	0.191	0.269	0.200	0.241	0.256	0.237
2	0.164	0.233	0.339	0.262	0.292	0.217	0.221	0.221	0.243
3	0.141	0.177	0.277	0.186	0.244	0.189	0.216	0.207	0.204
4	0.243	0.275	0.396	0.255	0.302	0.234	0.247	0.268	0.277
5	0.170	0.209	0.373	0.254	0.223	0.176	0.261	0.265	0.241
6	0.169	0.214	0.301	0.197	0.238	0.166	0.218	0.230	0.216
7	0.141	0.161	0.264	0.196	0.202	0.165	0.187	0.212	0.191
12	0.178	0.229	0.320	0.243	0.254	0.189	0.231	0.227	0.234
13	0.180	0.201	0.309	0.244	0.250	0.211	0.236	0.227	0.232
14	0.165	0.224	0.395	0.272	0.250	0.205	0.247	0.273	0.253
15	0.184	0.202	0.329	0.216	0.230	0.169	0.240	0.241	0.226
16	0.181	0.205	0.321	0.223	0.250	0.192	0.221	0.237	0.229
17	0.163	0.211	0.312	0.222	0.242	0.184	0.232	0.260	0.228
23	0.163	0.200	0.319	0.230	0.263	0.217	0.245	0.246	0.235
24	0.188	0.202	0.349	0.239	0.253	0.190	0.222	0.234	0.234
25	0.179	0.193	0.342	0.206	0.231	0.164	0.220	0.221	0.219
26	0.181	0.211	0.372	0.240	0.268	0.184	0.236	0.245	0.242
27	0.147	0.203	0.307	0.239	0.233	0.185	0.212	0.229	0.219
34	0.190	0.210	0.325	0.225	0.259	0.217	0.254	0.265	0.243
35	0.170	0.181	0.320	0.205	0.229	0.179	0.215	0.217	0.214
36	0.182	0.204	0.305	0.203	0.242	0.168	0.220	0.232	0.219
37	0.162	0.174	0.275	0.210	0.219	0.160	0.211	0.233	0.228
45	0.205	0.220	0.343	0.191	0.243	0.178	0.239	0.245	0.233
46	0.206	0.246	0.388	0.278	0.271	0.208	0.266	0.267	0.266
47	0.200	0.213	0.366	0.259	0.273	0.183	0.245	0.250	0.248
56	0.191	0.241	0.336	0.235	0.239	0.177	0.222	0.239	0.235
57	0.167	0.202	0.305	0.180	0.240	0.184	0.212	0.216	0.213
67	0.166	0.171	0.306	0.217	0.207	0.177	0.214	0.223	0.210
$\bar{X}$	0.177	0.207	0.330	0.226	0.247	0.188	0.229	0.239	0.231
L.S.D. (.05)	0.018	0.033	0.043	0.035	0.026	0.028	0.026	0.036	0.015

Appendix Table 13. Mean plant height (cm) of smooth bromegrass grown at eight environments in Alberta.

Genotype	Beaverlodge		Kinsella		Lethbridge		Edmonton		Genotypic Mean
	1976	1977	1976	1977	1976	1977	1976	1977	
1	110.1	125.2	92.3	95.0	106.8	106.0	123.5	131.7	111
2	100.5	120.8	80.6	83.0	94.5	89.5	117.7	128.8	101
3	91.8	126.8	91.5	94.2	100.0	93.0	118.5	129.3	105
4	95.3	104.8	80.3	87.8	92.9	92.0	106.7	117.8	97
5	116.5	128.0	92.3	98.0	115.1	111.5	128.6	129.3	114
6	131.8	144.2	109.5	102.2	129.5	122.0	137.9	140.8	127
7	91.5	123.6	86.0	81.8	99.3	80.8	102.3	118.5	97
12	112.0	129.8	95.6	91.5	99.2	92.2	113.7	125.7	107
13	114.9	136.3	100.2	99.7	108.1	100.0	120.5	127.3	113
14	102.9	119.7	78.7	81.2	101.9	97.2	109.8	118.8	101
15	119.9	141.8	98.1	98.5	114.0	105.2	123.0	132.2	116
16	126.2	136.7	99.3	98.8	116.5	111.2	127.5	133.5	118
17	105.1	130.2	94.8	91.3	100.1	88.8	114.9	121.2	105
23	101.0	122.8	85.8	87.8	91.7	86.7	104.2	117.3	99
24	100.0	118.5	84.9	87.7	97.6	93.5	108.5	118.8	101
25	119.0	136.0	92.9	94.2	107.3	99.7	122.5	133.0	113
26	123.0	138.3	95.5	92.5	107.2	105.3	120.5	126.5	113
27	103.3	122.5	87.1	82.8	95.4	83.5	106.3	123.0	100
34	112.1	128.0	92.4	90.7	109.1	100.0	113.7	122.5	108
35	121.2	136.0	98.9	97.7	111.1	100.8	122.7	129.0	114
36	122.9	134.2	97.4	95.8	109.1	102.3	125.3	129.3	114
37	103.5	129.3	93.4	88.2	95.4	82.0	107.7	117.0	102
45	113.5	129.0	90.5	96.5	113.6	108.2	123.7	130.5	113
46	97.9	108.7	76.0	76.5	100.7	95.5	107.4	111.0	96
47	91.1	107.5	79.1	80.8	96.1	87.3	104.3	116.3	95
56	117.2	128.8	98.4	96.8	113.1	105.3	126.9	132.3	114
57	106.1	133.3	94.6	92.8	106.3	93.3	112.7	124.5	107
67	117.7	134.3	96.7	92.2	114.3	101.8	124.3	126.7	113
$\bar{X}$	109.6	127.7	91.5	91.3	105.2	97.6	116.9	125.4	108.1
L.S.D. (.05)	9.5	6.5	7.4	5.1	6.8	6.4	7.3	6.6	4.2