GENOTYPE BY ENVIRONMENT INTERACTION STUDY OF BERMUDAGRASS FORAGE YIELD IN OKLAHOMA

By

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CHAPTER I

INTRODUCTION

Bermuda, Cynodon dactylon (L.) Pers., is the most widely used warm-season, perennial, introduced grass in the southern U.S.A. It is a sod-forming species used for pasture, turf, and soil stabilization. Bermudagrass is normally cross-pollinated, but as with many perennial grass species, the fertility of individual genotypes is often low and the percentage of total florets setting seed is consequently low (Ahring, Taliaferro, and Morrison, 1974). However, individual plants are easily propagated vegetatively, and practically all commercial cultivars are individual plants (genotypes) that are asexually propagated. The potential value of bermudagrass was recognized over 200 years ago (Burton, 1973). Its widespread use and acceptance as a forage crop began only recently in the 1940's with the release of the 'Coastal' cultivar (Burton, 1943). Later, the release of the 'Midland' cultivar (Harlan, Burton, and Elder, 1954) increased the popularity of bermudagrass as a forage because of its superiority in winterhardiness in comparison to Coastal. Recent emphasis in developing bermudagrass cultivars such as 'Hardie' and 'Tifton 44' (Taliaferro and Richardson, 1980; Burton and Monson, 1978) has been directed toward combining adaptability, and quantity and quality of yield.

A large number of winter hardy cultivars with relatively high forage yielding potential, reasonably good nutritive value, and ability to withstand close grazing have been identified in the grass breeding program in Oklahoma. At the time of release of new cultivars, it is important that accurate information be available on their adaptation characteristics. Frequently, two or more such cultivars will perform differently under a set of environmental conditions. This kind of occurrence is called cultivar by environment interaction.

Characterization of genotype by environment interactions of bermudagrass cultivars in Oklahoma is important because of their use over a wide range of climatic and edaphic conditions. These conditions range from the dry semiarid regions in the western part of the state to the proportionally more humid areas of eastern Oklahoma. Annual precipitation amounts in the state decrease sharply from east to west. Maximum precipitation occurs in the spring and decreases through the summer until fall. May is usually the wettest month. January ranks as Oklahoma's driest month (Oklahoma Water Resources Board, 1980). In addition, at particular locations, temperature and rainfall may vary greatly from year to year. Elucidation of the magnitude of genotype by environment interactions for adaptation and forage yield characteristics of bermudagrass cultivars in Oklahoma would permit more intelligent decisions to be made regarding the amount of resource allocation necessary for a reasonably accurate characterization of long-term yield potential.

This study was conducted for the purpose of determining the occurrence and magnitude of genotype-environment interactions for forage yield of three commercial cultivars and 21 experimental bermudagrass strains in Oklahoma. The primary objective was to ascertain the adaptation and performance of new cultivars and experimental bermudagrass strains relative to adapted commercial cultivars. A secondary objective was to assess the importance of genotype-environment interactions for forage yield in the state; and a third purpose was to compare the relative adequacy of statistical methods in measuring stability of forage yield in bermudagrass genotypes.

CHAPTER II

REVIEW OF LITERATURE

Genotype-Environment Interactions in General

In plant breeding programs, interactions between genotype and environment are important in evaluating potential new cultivars for improved quantity and quality of forage characteristics. Allard and Bradshaw (1964) reviewed the results of several workers with regard to genotype-environment (GE) interactions and discussed their implications in applied plant breeding. The potential number of interactions is very large when many genotypes and environments are considered, i.e., for m genotypes and n environments there are $\frac{(mn)!}{m!n!}$ possible types of interaction. Allard and Bradshaw (1964, as cited in Haldane, 1946) reported the following points: (1) chances of analyzing and explaining even a small proportion of the possible number of interactions are very small; (2) using a small sample of a population of genotypes provides little information on the importance and magnitude of genotype-environment interaction; and (3) it is difficult to identify a genotype adapted to a relatively limited and uniform environment because of the existence of a large number of possible interactions. Accordingly, genotype by location interactions are considered to be in the predictable category of environmental variations while genotype by year and genotype by location by year interactions are unpredictable. The latter group was thought to be more "interesting" to the plant breeder since the effects of these interactions are more difficult to counteract. Performance tests are used to obtain average yield comparisons of cultivars by replicating tests over years and over sites within years. In the analysis of variance for a typical variety trial, Comstock and Moll (1963) suggested that the number of replications, locations, and years must each be a minimum of two in order to obtain unconfounded estimates of the principal interaction components. In a recent review, Hill (1975) discussed the problems related to GE interactions and the methods used to evaluate their magnitude. He gave suggestions on conducting studies on this subject.

Performance comparisons of new experimental cultivars with standard cultivars are based primarily on yield and/or some other important agronomic characters. According to Simmonds (1978), it is not valid to base decisions only on mean yields or percentages in the presence of substantial genotype-environment effects. He stated that a decision could be supplemented by emphasis on regression analysis or a statistical adjustment by filling additive constants to varieties. He listed two potential advantageous effects of transferring emphasis from means to regression: (1) more accurate assessment of the kind of environment a new variety might be adapted to, and (2) to enforce closer attention to site choices. According to Hill (1975) the main advantage of using the linear regression technique is in reducing complex GE interactions to a series of linear responses. He concluded that the linear regression approach facilitates the decision-making process in a particular breeding program.

Genotype-Environment Interactions in Perennial Crops

Although GE interactions have been studied extensively in annual crops and significant advances have been made in understanding and measuring these interactions, only limited applications dealing with perennial forages have been reported (Breese, 1969; Hill and Samuel, 1971; Nguyen, Sleper, and Hunt, 1980; Barker, Hovin, Carlson, Drolsom, Sleper, Ross, and Casler, 1981; Gray, 1982 and Hill and Baylor, 1983).

Barker et al. (1981) reported that there are difficulties in interpreting the type of analyses used in annual crops when they are applied to perennial forage crops because of repeated harvests within a year to determine total seasonal production. They pointed out that perennial forage crops are used in many different environments and they are subjected to a wide array of management systems in which harvesting can occur at any point during yield accumulation and throughout each of several seasons.

In studies showing the existence, nature, and importance of genotype-environmental interactions, Nguyen et al. (1980) evaluated 25 synthetics and two cultivars of tall fescue (*Festica arundinacea* Schreb.) at two locations in Missouri over a three-year period for herbage yield. They found significant differences among entries, and a significant entry by environment (linear) interaction for herbage dry matter yield indicating different environmental responses among the entries tested. Similar results were obtained by Gray (1982) who measured forage yield of 20 clones of orchardgrass (*Dactylis glomerata* L.) for three years at three different locations. He found significant differences among genotypes and among environments for reproductive, vegetative, and total yield. The first order interactions, i.e., genotype by location, genotype by year, and location by year, and the second order interaction, i.e., genotype by location by year were significant for all yield measurements.

Barker et al. (1981) measured GE interactions using forage yield data from 60 reed canarygrass (Phalaris arundinacea L.) clones tested for three years at six locations. They found significant genetic differences for seasonal dry matter yield. Genotype by location, and genotype by location by year interactions were highly significant, while the genotype by year interaction was nonsignificant. Location and genotype by location effects were inconsistent among years. A very large interaction existed between year and location in respect to all sources of variation. Hill and Baylor (1983) evaluated 49 cultivars and experimental lines of alfalfa (Medicago sativa L.) for total season forage yield for three years at two sites under two harvest managements. Significant yield differences were all attributable to entries, all two factor interactions, and to the site by management by entry interaction. They reported, however, that interaction effects due to sites by years by entries, managements by years by entries, and sites by managements by years by entries were not significant.

The relative performance of cultivars over a range of environmental contrasts cannot be estimated by only examining the average yields over all environments or conducting a routine analysis of variance. According to Breese (1969); Tan, Tan, and Walton (1979), and Nguyen et al. (1980), the analysis of variance approach provides information only on the existence and magnitude of GE interactions, but no generalization can be made on the relative performance of individual genotypes over environments.

Regression analysis was first proposed by Yates and Cochran (1938) to compare the yield performance of a set of cereal varieties grown at several centers for several seasons. This form of analysis was expanded by Finlay and Wilkinson (1963) and Eberhart and Russell (1966) to detect and measure the magnitude of GE interactions in barley and maize, respectively. These methods were developed for and used primarily in annual crop species, although they have had limited application to perennial species (Nguyen et al. 1980; Gray, 1982).

The most widely used methods of analysis of stability of cultivars in yield trials have involved linear regression of the genotype mean yield on an environmental index (Eberhart and Russell, 1966; Freeman, 1973). In the Eberhart-Russell model the environmental index is usually the mean of all entries or the mean of a subset of entries in the trials.

Casler and Hovin (1984) stated that stability measures are of two types: (1) the yield response to environmental changes and (2) the stability (consistency) of that response. Nguyen et al. (1980) and Gray (1982) evaluated the stability of forage yield in tall fescue and orchardgrass clones, respectively. They found that the stability parameters, namely the regression coefficient and deviation from regression mean square, were useful statistics in that they allow additional information to be used to compare both species for yield and adaptation. In contrast, Barker et al. (1981) reported that mean yield per se was the most useful statistic for determining genetic yield potential because stability parameters were closely related to each other and, therefore, did not provide consistent information on the clonal performance. The results of Hill and Baylor (1983) supported those of Barker et al. Hill and Baylor pointed out that regression analysis did not provide a simple interpretation of the observed response of cultivars to different environments. Langer, Frey, and Bailey, (1979), Nguyen et al. (1980) and Gray (1982) used two additional stability indices: (1) the coefficient of determination (R^2), and (2) ecovalence (w) defined as an individual cultivar's contribution to the total interaction between cultivars and environments. They found high correlation between these stability indices and the mean square deviation from regression. They concluded that any of these indices (S_d^2, R^2, or w) would be effective to measure the stability of forage yield among genotypes.

In perennial forage crops, the environmental effects associated with individual years and locations are not the only factors contributing to GE interactions. According to Taliaferro, Denman, Morrison, and Holbert, (1973), for a perennial plant, such as alfalfa, stand persistence is an important factor in the evaluation process. Stand persistence is affected by many factors such as winterhardiness, clipping frequencies, drought tolerance, and reaction to insect and disease pests. Therefore, performance tests of perennial species need to be conducted over a series of years.

Hill and Baylor (1983) pointed out that yields of perennial crops are usually measured on the same plots for a number of years and that there are problems associated with stability analyses of data from these perennial crops that are not found in annual crops. They gave as an example the potential for a differential change in yields of strains as the stand ages.

Hill and Baylor (1983) compared the ability of three different statistical analytical methods in characterizing GE interactions. The methods were a routine multi-factor analysis of variance, linear regression of individual entry means on the mean of all entries in each environment as well as linear regression with the ith entry eliminated from the environmental mean, and an orthogonal contrast analysis that partitioned the variation over environments for each entry into sources due to years, sites, managements, and all possible interactions between these factors. They reported that cultivars performed differently as they became older. They found that entries which increased in yield relative to the average of all entries in the trial as the stand aged had moderate or high resistance to diseases. They concluded that the orthogonal contrast analysis was easier to interpret than regression on environmental means for analysis of GE interaction in perennial crops such as alfalfa, especially when a pattern such as the response to age of stand was present and could not be detected by regression analysis.

CHAPTER III

MATERIALS AND METHODS

Three commercial cultivars and 21 experimental strains of bermudagrass were established in tests at five Oklahoma locations (Chickasha, Haskell, Lahoma, Perkins and Tipton) in the spring of 1980. The test at each location was conducted to compare the performance of the experimental strains with that of the commercial cultivars. Data were taken on forage yield of all strains and cultivars at the five locations for three years (1981 through 1983).

Test locations included all major Oklahoma environments except those of the extreme southeastern and northwestern parts of the state (Figure 1). These were chosen to provide differences in soil type, annual precipitation, and temperature representative of major areas within the state where bermudagrass is grown. Chickasha, in the central part of the state, represents a moderate rainfall area and has a Reinach silt loam soil, a coarse silty, mixed, thermic Pachic Haplustoll. Haskell, in the east central part of the state receives a higher average rainfall amount compared to the western regions. It has a Taloka silt loam soil belonging to the fine, mixed, thermic Mollic Albaqualf. Lahoma, in north central Oklahoma, has a rainfall average intermediate to those of Chickasha and Haskell. The test site at Lahoma was on a Grant silt loam soil, a fine-silty, mixed, thermic Udic Agriustoll. Perkins is in the north central part of the state.

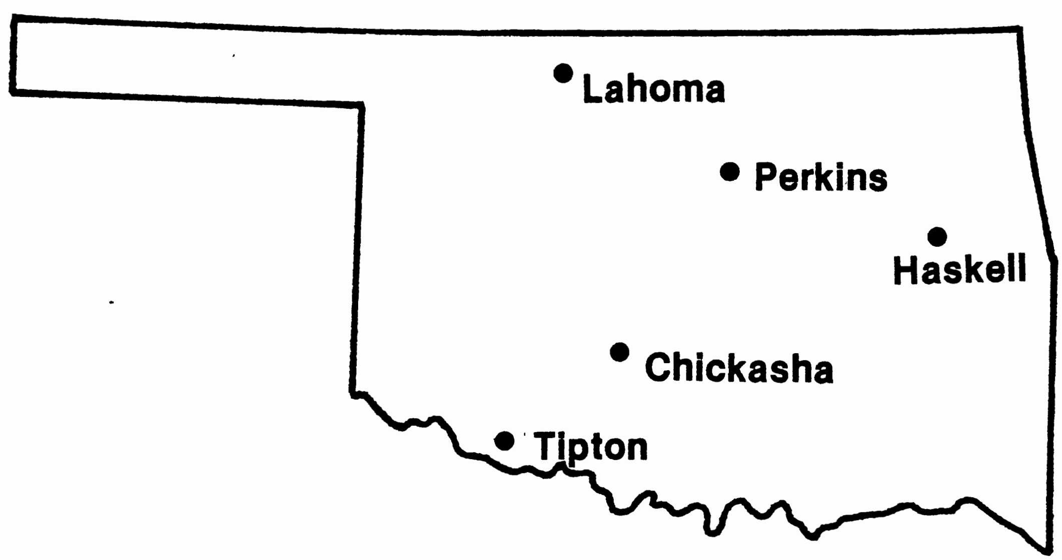

Figure 1. Locations of Bermudagrass Performance Tests in Oklahoma

Average precipitation at Perkins is similar to that of Chickasha and Haskell. It has a Teller loam soil, a fine loamy, mixed, thermic Udic Agriustoll. Tipton is in the southwestern part of the state and is characterized by dry sub-humid moisture conditions with high summer temperatures. It has a Tipton silt loam soil belonging to the fine-loamy, mixed, thermic Pachic Agriustoll.

The commercially available cultivars included in the tests were 'Midland', 'Hardie', and 'Tifton 44', listed as entries 1, 2, and 3, respectively, in Table I. The cultivar Midland was released in 1953 cooperatively by the Oklahoma and Georgia Agricultural Experiment Stations and the USDA-ARS (Hein, 1953). It is widely grown throughout Oklahoma and across the upper south. The cultivar Hardie was released in 1974 by the Oklahoma Agricultural Experiment Station on the basis of increased yield and quality of forage as indicated by small plot performance tests and laboratory measures of quality. Compared with Midland, Hardie bermudagrass makes more early-season growth and establishes faster. It has good winterhardiness and is adapted throughout Oklahoma (Taliaferro and Richardson, 1980). The Tifton 44 cultivar was released in 1978 by the USDA-ARS and the Georgia Agricultural Experiment Station. Relative to 'Coastal' bermudagrass, Tifton 44 is described as being 6.8 percent more digestible, more winter hardy and equal in yield potential (Burton and Monson, 1978).

The experimental strains included in this study were from the Oklahoma State University bermudagrass breeding program. The experimental designations and test entry numbers (4 through 24) are given in Table I.

TABLE I

ENTRY NO., DESIGNATION, AND ORIGIN OF BERMUDAGRASS CULTIVARS AND EXPERIMENTAL STRAINS

Entry No.	Designation	Origin
1	Midland	Coastal x Common from Indiana
2	Hardie	Cynodon accession 9945A x (8153 x 9953)
3	Tifton 44	Coastal x an accession from Berlin
4	74 x 7-1	9217 x SS-16
5	74 x 7-1	9217 x SS-16
6	74 x 8-1	9217 x SS-27
7	74 x 9-1	10743 x Coastal
8	74 x 9-10	Coastal x 10978a
9	74 x 11-2	Colorado x SS-27
10	74 x 12-1	(Gx9945) x IN 35-1
11	74 x 12-5	(Gx9946) x SS-21
12	74 x 12-6	9959 x Coastal
13	74 x 12-12	SS-16 x Colorado
14	74 x 14-1	SS-16 x 9959
15	74 x 17-8	9954 PROX
16	74 x 18-11	Coastal PROX
17	74 x 19-1	Coastal PROX
18	74 x 19-5	Coastal PROX
19	74 x 21-6	IN 34-1 x HN 1-2
20	74 x 21-8	Colorado x IN 35-1
21	LCB 6-35	OP Seedling
22	LCB 7-25	OP Seedling
23	LCB 11-6	OP Seedling
24	LCB 11-13	OP Seedling

These experimental strains were selected on the basis of winter hardiness, disease resistance, yield potential, dry matter digestibility and, to a degree, for sod density. Not all of the experimental strains were superior for all of these traits. Some experimentals were included in the tests because of their high dry matter digestibility even though they did not have good sod density or vise versa. The cultivars and experimental strains were clonally propagated from original single plant material. They were increased vegetatively in the greenhouse at the Oklahoma State University Agronomy Research Station, divided, and transplanted to their experimental sites.

The field plot design of all trials was a randomized complete block with four replications. Plots were established by planting ten plants spaced 0.61m apart in a row. These were allowed to spread laterally to eventually cover an area 22.8 m^2 (i.e. 3 x 7.6 m). Nitrogen was applied in the form of ammonium nitrate (NH_4NO_3) at the rate of 336 kg of actual N/ha/year, split into three equal applications. The first application was applied in mid-April, about the time of active growth initiation. The second application was made after the first harvest, which was usually about June 5. The final application was made soon after the second harvest, about July 15. Atrazine [2-chloro-4-(ethylamino)-6-(isopropylamino)-s-triazine] and simazine [2-chloro-4, 6-bis(ethylamino)-s-triazine] were used as pre-emergence herbicide. Atrazine was applied at the rate of 1.1 to 1.7 kg of active ingredient per ha in the fall at selected locations to control cool season weedy species. Simazine was usually applied to all bermuda grass field tests in early spring at a rate ranging from 1.1 to 1.7 kg of active ingredient per ha for control of warm-season weedy species.

An effort was made to harvest each test four times per year (Table II). The first seasonal harvest at each location was taken approximately the first week of June in 1982 and 1983. However, no data were taken on the first cutting of 1981 at any of the five locations because of non-uniform plot cover. Also, there was insufficient growth on the Lahoma test due to drought in August and September 1983 to permit a scheduled harvest. Forage yield was determined by harvesting a 0.9 x 6 m cutting swath from the center of each plot with a small sickle-bar mower. Green weight was adjusted for moisture by taking a sample of the harvested forage and drying it in a forced air oven at 45^{o}C for a week. Subsequently, these data were used to convert yield to a dry matter basis reported as megagrams of dry matter per ha ($Mg.ha^{-1}=10^{3}kg.ha^{-1}$).

Statistical analyses were conducted on the first seasonal yield, the summation of yields from three succeeding seasonal harvests of regrowth forage, and the total seasonal yield. The methods of analyses included: (1) an analysis of variance according to the split plot in time proposed by Steel and Torrie (1980) with entries, locations, and years as the main effects. All effects in the statistical model were considered to be fixed except replications. Years following transplanting were treated as sub-plots in the split-plot design. Forage-yields were measured from the same plots each year. Approximate F-tests and their significance were calculated using the appropriate mean square error. (2) Joint regression

TABLE II

DATES ESTABLISHED AND HARVEST DATES OF BERMUDAGRASS TESTS INCLUDED IN THE GE INTERACTION STUDY

	Chickasha	Haskell	Lahoma	Perkins	Tipton
Dates established	27 May 1980	13 May 1980	3 June 1980	1 July 1980	5 June 1980
Harvest dates					
1981					
2nd	26 June	13 July	28 July	6 August	8 July
3rd	24 August	25 August	17 September	15 September	17 September
4th	29 October	11 December	24 November	12 November	6 November
1982					
1st	7 June	4 June	14 June	4 June	10 June
2nd	6 July	6 July	15 July	16 July	14 July
3rd	2 September	24 August	18 August	8 September	17 August
4th	22 November	9 November		7 December	16 November
1983					
1st	7 June	1 June	14 June	10 June	7 June
2nd	20 July	8 July	15 July	11 July	18 July
3rd	31 August	22 September		7 September	5 October
4th	1 Deember	17 November	8 December	7 December	7 December

analyses suggested by Perkins and Jinks (1968) were computed on forage dry matter yields from 10 and 15 environments for first seasonal yield and regrowth and total seasonal yields, respectively (each year within a given location is considered as an individual environment). The genotype-environment interaction sum of squares as partitioned into a component due to heterogeneity between the slopes of the regressions and a component due to residual which measured the scatter of points about the regression lines. In this analysis, the two components, heterogeneity of regression and residual were tested against the error terms derived from the combined split-plot analysis. Two stability parameters as proposed by Eberhart and Russell (1966) were computed: the linear regression coefficient (b-value) and the mean square deviation from regression (S_d^2-value). The b-values were determined from the regression of average entry dry matter yields on the average yield of all entries in each environment to measure the linear response to environmental change. The S_d^2-value of a cultivar measures how well the predicted response agrees with the observed response and includes GE interactions and other interactions associated with linear regressions. A t-test employing each cultivar's standard error of regression was used to test each regression coefficient against the hypothesis that it did not differ from unity (Steel and Torrie, 1980). S_d^2 values were tested using the pooled error. Simple correlation coefficients on the ranks were calculated to measure the relationship between cultivar mean ($\overline{X}$), b, and S_d^2 (Snedecor and Cochran, 1980). Ranks were assigned to cultivars in an increasing order, the lowest value was given the Rank of 1. (3) Orthogonal contrast analyses were also made using the procedure described in the General Linear Models (GLM) section of the SAS User's Guide Statistics 1982 edition to detect the performance of genotypes associated with age of stand. The orthogonal contrasts were computed on regrowth forage and total seasonal yield.They corresponded to year-linear Y(L), and year-quadratic Y(Q) effects by locations and Y(L), and Y(Q) effects with entries. Because F-tests indicated the presence of Y(L) x location, Y(Q) x location, Y(L) x entry, and Y(Q) x entry, Y(L) and Y(Q) responses were computed and tested for each entry at each location. The linear effect represents the change in yield of respective entries from 1981 to 1983. It was measured by comparing 1981 yields to 1983 yields. The quadratic effect represents deviation from linearity; it was estimated by comparing the yields in 1982 with the average yields of 1981 and 1983 for respective entries.

CHAPTER IV

RESULTS AND DISCUSSION

Mean Yields and Analyses of Variance

Entry mean yields averaged over the five locations differed significantly ($P<0.05$) in each of the three years and for the combined period of study (Tables III, IV, and V). The mean yields of cultivars and experimental strains at the respective locations, averaged over years, differed significantly ($P<0.05$) (Tables VI, VII, and VIII). Large differences existed among locations for dry matter yield. Yields at Chickasha and Haskell were highest. Yields at Chickasha were about twice those at Perkins.

Significant differences ($P<0.01$) were found among entries for first seasonal, regrowth, and total seasonal dry matter yields (Tables IX and X). The range of average first seasonal yields was from 4.23 to 7.88 Mg/ha with accession 11-2 (entry 9) being the highest yielding entry (Table III). Regrowth yields ranged from 7.12 to 11.40 Mg/ha (Table IV), and total seasonal yields ranged from 11.18 to 16.62 Mg/ha (Table V). The highest yielding cultivar was Hardie (entry 2); two experimental strains 11-2 (entry 9) and 12-6 (entry 12) had the highest total dry matter yields. Location and year effects were highly significant ($P<0.01$) in all yield measurements (Table IX and X). The significance of location and year effects showed that

TABLE III

MEAN DRY MATTER YIELDS OF BERMUDAGRASS ENTRIES AT THE FIRST SEASONAL HARVEST DURING 1982 AND 1983--VALUES ARE AVERAGED OVER FIVE LOCATIONS

	Dry Matter Yield, Megagrams/ha					
Entry No.	1982	Rank	1983	Rank	Avg.	Rank
9	8.87	1	6.89	1	7.88	1
2	8.46	2	5.41	7	6.94	2
18	7.96	4	5.62	3	6.79	3
5	8.12	3	5.29	8	6.70	4
12	7.42	12	5.86	2	6.64	5
20	7.38	13	5.65	4	6.52	6
13	7.13	14	5.56	5	6.34	7
22	7.64	10	5.00	9	6.32	8
3	6.99	16	5.44	6	6.22	9
4	7.51	11	4.84	12	6.18	10
6	7.74	7	4.66	13	6.18	10
14	7.91	5	4.41	16	6.16	12
11	7.74	6	4.42	15	6.08	13
15	7.10	15	5.00	9	6.05	14
1	7.66	9	4.31	18	5.98	15
16	7.67	8	4.08	19	5.88	16
19	6.68	20	4.87	11	5.77	17
23	6.88	17	4.40	17	5.64	18
8	6.72	18	3.89	20	5.30	19
10	5.68	19	4.60	14	5.14	20
7	6.43	23	3.73	21	5.08	21
17	6.53	21	3.42	22	4.98	22
24	6.47	22	3.24	23	4.86	23
21	5.28	24	3.19	24	4.23	24
LSD 0.05	1.95		1.24		1.37	
CV%	19.39		18.81		16.53	

TABLE IV

MEAN DRY MATTER YIELDS OF REGROWTH FORAGE OF BERMUDAGRASS ENTRIES DURING 1981, 1982, AND 1983--VALUES ARE AVERAGED OVER FIVE LOCATIONS

Entry No.	Dry Matter Yield, Megagrams/ha. 1981	Rank	1982	Rank	1983	Rank	Avg.	Rank
12	13.79	6	11.52	1	8.88	1	11.40	1
9	14.40	1	11.19	2	8.54	2	11.37	2
18	13.87	5	10.76	3	7.56	8	10.73	3
2	14.35	2	10.11	9	7.50	10	10.65	4
17	13.27	9	10.52	4	8.04	4	10.61	5
15	14.00	4	9.85	14	7.49	11	10.45	6
13	12.99	11	10.25	7	7.83	6	10.35	7
16	14.15	3	9.92	13	6.71	16	10.26	8
19	11.99	19	10.08	10	8.28	3	10.12	9
8	12.20	16	10.34	5	7.56	9	10.03	10
20	12.11	17	10.31	6	7.67	7	10.03	10
7	12.54	14	10.20	8	6.81	15	9.84	12
1	13.12	10	9.43	16	6.90	13	9.82	13
5	12.84	12	9.59	15	6.89	14	9.77	14
3	11.33	23	10.03	12	7.85	5	9.74	15
14	11.92	20	10.04	11	7.25	12	9.73	16
10	13.67	7	8.50	22	6.08	19	9.42	17
6	13.31	8	8.88	19	5.91	21	9.37	18
23	12.74	13	8.55	21	6.63	17	9.30	19
4	12.28	15	9.09	17	6.02	20	9.13	20
22	12.01	18	8.85	20	6.49	18	9.12	21
21	11.53	22	9.02	18	5.69	23	8.74	22
24	11.62	21	7.74	23	5.90	22	8.42	23
11	9.39	24	7.33	24	4.65	24	7.12	24
LSD 0.05	2.81		2.03		1.52		1.88	
CV%	15.94		15.15		15.58		13.85	

TABLE V

MEAN TOTAL SEASONAL DRY MATTER YIELDS OF BERMUDAGRASS ENTRIES DURING 1981, 1982, AND 1983--VALUES ARE AVERAGED OVER FIVE LOCATIONS

Entry No.	Dry Matter Yield, Megagrams/ha.							
	1981	Rank	1982	Rank	1983	Rank	Avg.	Rank
9	14.40	1	20.05	1	15.42	1	16.62	1
12	13.79	6	18.94	2	14.74	2	15.83	2
2	14.35	2	18.57	4	12.91	8	15.28	3
18	13.87	5	18.72	3	13.18	6	15.26	4
13	12.99	11	17.37	9	13.38	3	14.58	5
15	14.00	4	16.99	14	12.49	9	14.48	6
20	12.11	17	17.69	7	13.32	4	14.37	7
5	12.84	12	17.71	6	12.18	10	14.24	8
16	14.15	3	17.59	8	10.79	18	14.18	9
19	11.99	19	16.76	15	13.14	7	13.97	10
17	13.27	9	17.05	11	11.46	13	13.93	11
3	11.33	23	17.03	13	13.29	5	13.88	12
14	11.92	20	17.95	5	11.66	11	13.84	13
1	13.12	10	17.09	10	11.21	15	13.81	14
8	12.20	16	17.05	12	11.44	14	13.56	15
6	13.31	8	16.62	18	10.53	21	13.48	16
22	12.01	18	16.49	19	11.49	12	13.33	17
4	12.28	15	16.67	16	10.86	17	13.25	18
7	12.54	14	16.63	17	10.54	20	13.24	19
23	12.73	13	15.43	20	11.03	16	13.06	20
10	13.67	7	14.18	24	10.69	19	12.85	21
24	11.62	21	14.21	23	9.14	22	11.66	22
21	11.53	22	14.29	22	8.88	24	11.57	23
11	9.39	24	15.07	21	9.06	23	11.18	24
LSD 0.05	2.81		3.34		2.33		2.31	
CV%	15.94		14.24		14.29		12.05	

TABLE VI

MEAN DRY MATTER YIELDS (Mg/ha) OF BERMUDAGRASS ENTRIES AT THE FIRST SEASONAL HARVEST AT EACH OF FIVE LOCATIONS--VALUES ARE AVERAGED OVER THREE YEARS

Entry No.	Chickasha	Rank	Haskell	Rank	Lahoma	Rank	Perkins	Rank	Tipton	Rank
9	8.47	1	7.69	1	8.24	1	6.40	1	8.58	2
18	8.15	2	6.66	9	6.84	4	5.29	8	7.01	8
12	7.73	3	6.14	14	7.11	2	5.91	2	6.31	18
13	7.55	4	6.28	11	5.96	14	5.21	10	6.72	10
2	7.52	5	6.68	8	6.68	6	5.62	4	8.17	3
5	7.50	6	6.96	5	7.03	3	5.05	11	6.98	9
16	6.93	7	6.91	6	5.73	16	3.30	24	6.50	13
8	6.85	8	5.05	22	3.37	24	5.42	7	5.81	21
11	6.85	8	6.04	15	6.83	5	4.24	15	6.43	14
20	6.72	10	7.00	3	6.62	7	5.54	6	6.69	11
22	6.69	11	6.15	13	6.56	9	5.82	3	6.37	16
14	6.53	12	6.79	7	6.59	8	4.90	13	6.00	19
3	6.44	13	7.49	2	5.88	15	5.55	5	5.73	22
19	6.39	14	6.37	10	5.24	19	5.26	9	5.60	23
23	6.38	15	5.44	18	5.97	13	4.02	19	6.40	15
6	6.07	16	5.48	17	6.16	11	4.19	16	8.98	1
1	6.05	17	6.18	12	6.11	12	4.51	14	7.08	7
15	6.01	18	6.87	4	5.35	18	4.05	18	7.97	5
4	5.88	19	5.43	19	6.45	10	5.03	12	8.10	4
24	5.64	20	4.03	24	5.07	20	3.60	22	5.95	20
7	5.26	21	5.42	20	5.53	17	3.50	23	7.70	6
17	4.77	22	4.84	23	5.00	22	3.66	21	6.62	12
10	4.40	23	5.87	16	5.03	21	4.08	17	6.32	17
21	4.22	24	5.14	21	4.10	23	3.78	20	3.92	24
LSD 0.05	1.37		1.37		1.37		1.37		1.37	
CV%	15.35		16.19		16.58		20.88		14.88	

TABLE VII

MEAN DRY MATTER YIELDS (Mg/ha) OF REGROWTH FORAGE OF BERMUDAGRASS ENTRIES AT EACH OF FIVE LOCATIONS--VALUES ARE AVERAGED OVER THREE YEARS

Entry No.	Chickasha	Rank	Haskell	Rank	Lahoma	Rank	Perkins	Rank	Tipton	Rank
13	15.96	1	12.39	15	7.36	6	7.20	12	8.86	8
2	15.92	2	13.14	6	8.07	2	8.13	7	8.01	18
16	15.80	3	13.14	6	6.79	12	6.89	15	8.68	10
12	15.65	4	13.95	3	8.20	1	9.23	2	9.97	2
8	15.53	5	13.14	6	4.83	23	7.60	9	9.06	6
9	15.50	6	14.49	1	7.96	3	9.49	1	9.43	4
18	15.41	7	13.29	5	7.20	8	8.77	4	8.98	7
7	14.96	8	12.77	14	6.40	16	5.94	22	9.18	5
5	14.79	9	12.38	16	7.36	6	6.86	16	7.48	22
17	14.35	10	13.78	4	7.58	4	7.21	11	10.13	1
19	14.26	11	13.06	11	6.33	18	8.72	5	8.19	19
15	14.15	12	14.06	2	6.97	10	7.07	13	9.97	2
1	13.99	13	13.06	11	6.00	20	7.45	10	8.57	12
6	13.78	14	11.51	20	6.62	14	6.70	18	8.23	15
14	13.31	15	13.12	9	5.86	22	8.37	6	8.01	18
23	13.25	16	11.75	19	7.01	9	5.74	23	8.77	9
20	13.09	17	12.22	17	7.53	5	9.08	3	8.21	16
22	12.96	18	11.83	18	6.36	17	6.93	14	7.50	21
3	12.82	19	13.12	9	6.64	13	7.63	8	8.49	13
24	12.79	20	10.37	23	6.61	15	6.15	20	6.18	23
4	12.79	21	11.35	21	6.10	19	6.77	17	8.64	11
10	12.78	22	12.88	13	6.84	11	6.23	19	8.36	14
21	12.62	23	11.03	22	5.97	21	6.10	21	8.00	20
11	11.34	24	9.69	24	4.61	24	4.56	24	5.41	24
LSD 0.05	1.88		1.88		1.88		1.88		1.88	
CV%	9.66		10.82		20.24		18.66		16.13	

TABLE VIII

MEAN TOTAL SEASONAL DRY MATTER YIELDS (Mg/ha) OF BERMUDAGRASS ENTRIES AT EACH OF FIVE LOCATIONS--VALUES ARE AVERAGED OVER THREE YEARS

Entry No.	Chickasha	Rank	Haskell	Rank	Lahoma	Rank	Perkins	Rank	Tipton	Rank
9	21.14	1	19.62	1	13.45	1	13.76	1	15.15	2
13	21.00	2	16.57	15	11.33	7	10.67	11	13.34	9
2	20.94	3	17.59	8	12.52	3	11.88	6	13.46	8
18	20.84	4	17.74	6	11.76	6	12.29	4	13.66	7
12	20.80	5	18.04	4	12.94	2	13.18	2	14.17	5
16	20.42	6	17.74	5	10.61	12	9.10	18	13.01	12
8	20.10	7	16.51	16	7.07	24	11.21	9	12.93	14
5	19.79	8	17.01	11	12.05	4	10.23	13	12.13	18
19	18.52	9	17.34	9	9.82	21	12.22	5	11.93	20
7	18.46	10	16.39	17	10.09	18	8.27	23	12.98	13
15	18.16	11	18.64	2	10.54	14	9.77	15	15.28	1
1	18.03	12	17.17	10	10.07	19	10.46	12	13.30	10
6	17.82	13	15.17	20	10.73	11	9.50	17	14.21	4
14	17.66	14	17.64	7	10.25	16	11.64	7	12.01	19
20	17.57	15	16.89	13	11.94	5	12.78	3	12.67	15
17	17.53	16	17.01	12	10.91	9	9.65	16	14.54	3
23	17.50	17	15.37	19	9.82	21	8.42	22	13.04	11
22	17.42	18	15.93	18	10.74	10	10.81	10	11.75	21
3	17.12	19	18.11	3	10.55	13	11.33	8	12.30	17
4	16.71	20	14.97	21	10.40	15	10.12	14	14.04	6
24	16.55	21	13.06	24	9.98	20	8.55	21	10.15	23
11	15.91	22	13.71	23	9.16	22	7.38	24	9.70	24
10	15.71	23	16.80	14	10.20	17	8.95	19	12.57	16
21	15.44	24	14.46	22	8.70	23	8.62	20	10.61	22
LSD 0.05	2.31		2.31		2.31		2.31		2.31	
CV%	9.05		9.99		15.54		15.92		12.92	

TABLE IX

SPLIT-PLOT ANALYSIS OF VARIANCE FOR THE FIRST SEASONAL YIELDS OF BERMUDAGRASS ENTRIES

Source of Variation	D.f.	M.S.	F
Locations (Loc)	4	107.20	36.83**
Rep/(Loc)	15	2.91	
Entries (E)	23	24.87	13.89**
Loc x E	92	3.95	2.20**
E x Rep/(Loc)	345	1.79	
Years(Y)	1	1,511.96	578.70**
Loc x Y	4	232.58	89.02**
Y x Rep/(Loc)	15	2.61	
E x Y	23	5.16	5.25**
Loc x E x Y	92	1.64	1.67**
Error [E x Y x Rep/(Loc)]	345	0.98	
Corrected Total	959		

**Significant at 0.01 level of probability

TABLE X

SPLIT-PLOT ANALYSES OF VARIANCE FOR REGROWTH AND TOTAL SEASONAL FORAGE YIELDS OF BERMUDAGRASS ENTRIES

Source of Variation	d.f.	Regrowth Yield M.S.	Regrowth Yield F	Total Seasonal Yield M.S.	Total Seasonal Yield F
Locations (Loc)	4	3,141.94	229.06**	3,655.82	161.34**
Rep/(Loc)	15	13.72		22.66	
Entries (E)	23	52.48	13.91**	96.78	13.40**
Loc x E	92	6.66	1.76**	13.37	1.85**
E x Rep/(Loc)	345	3.77		7.22	
Years(Y)	2	3,879.46	676.05**	3,585.24	402.39**
Loc x Y	8	905.11	157.73**	1,335.60	149.90**
Y x Rep/(Loc)	30	5.74		8.91	
E x Y	46	8.10	4.38**	15.73	5.69**
Loc x E x Y	184	3.72	2.01**	5.01	1.81**
Error [E x Y x Rep/(Loc)]	690	1.85		2.77	
Corrected Total	1,439				

**Significant at 0.01 level of probability.

variations in environmental conditions influenced entry responses throughout the tests. The variation can be attributed to the differences in soil moisture conditions, temperature (Tables XXII, XXIII, and XXIV, Appendix B) and soil type during the growing seasons. The first order interactions, i.e., locations x entries, locations x years and entries x years, were highly significant ($P<0.01$) in all cases. Location x year mean squares were consistently larger than all other interaction mean squares. The large location x year mean square indicated that location effects from year to year were inconsistent. Entry x location x year interaction was highly significant ($P<0.01$) in all three analyses. The existance of interactions of entries with locations and years indicates that bermudagrass cultivars and experimental strains exhibit differential responses in the different environments. Consequently, tests in different environments are necessary to obtain reliable estimates of relative yield performance of genotypes for a geographical area like the state of Oklahoma.

The experimental strains 11-2, 12-6 and 19-5 (entries 9, 12, and 18, respectively) and the cultivar Hardie (entry 2) were consistently among the highest yielders in all environments. Experimental strain 7-7 (entry 5) ranked four for the first seasonal yield and then ranked 14 and eight on regrowth, and total seasonal yield, respectively. In all three cases, the experimental strains 8-1, 12-1, 18-11 (entries, 6, 10, and 16, respectively) were high yielders during the first year but yield decreased as the plot stand aged (Tables III, VI, and V). However, low yielders during the first year, Tifton 44 (entry 3) and 21-8 (entry 20), increased in the succeeding years.

Regression Analyses

The joint-regression analyses of the kind proposed by Perkins and Jinks (1968) are presented in Table XI for first seasonal yield, and in Table XII for regrowth and total seasonal yields.

F-value differences from joint regression analysis between entries, between environments, and the genotype x environment interactions were highly significant ($P<0.01$) for all forage yield measurements. Significant ($P<0.01$) heterogeneities between regression mean squares and remainder mean squares indicated that the relationship was not strictly linear. The linear portion accounted for only 19 and 10 percent of the GE interaction sum of squares for first seasonal and regrowth yield and for total seasonal yield, respectively. Therefore, regression analyses did not provide good estimates of individual entry performance across environments.

In the stability analyses, the regression of entry mean yield on the environmental index resulted in regression coefficients (b-values) ranging from 0.67 to 1.38 for first seasonal yield, 0.77 to 1.20 for regrowth yield, and 0.81 to 1.20 for total seasonal yield (Table XIII). These ranges are comparable to those reported in other studies where variation among regressions was significant. Nguyen et al. (1980) reported that large variation in b-values indicate large differences in genotype responses to specific environments. For first seasonal yields, four entries had b-values significantly ($P<0.05$) different from 1.0. Three b-values were significant ($P<0.05$) for regrowth yields, and only two were significant ($P<0.05$) for total yields.

TABLE XI

JOINT REGRESSION ANALYSIS OF VARIANCE OF FIRST SEASONAL YIELDS OF BERMUDAGRASS ENTRIES EVALUATED AT FIVE LOCATIONS AND FOR THREE YEARS

Source of Variation	d.f.	M.S.	F
Entries (E)	23	24.87	25.30**
Environments (ENV)	9	319.01	324.52**
E x ENV:	207	3.06	3.11**
Het.bet.reg's	23	5.25	5.34**
Remainder	184	2.78	2.83**
Error	345	0.98	

** Indicates significance at the 0.01 level of probability.

TABLE XII

JOINT REGRESSION ANALYSES OF REGROWTH AND TOTAL SEASONAL DRY MATTER YIELDS OF BERMUDAGRASS ENTRIES EVALUATED AT FIVE LOCATIONS FOR THREE YEARS

Source of Variation	d.f.	Regrowth Yield		Total Seasonal Yield	
		M.S.	F	M.S.	F
Entries (E)	23	52.48	28.40**	96.78	34.98**
Environments (ENV)	14	1,969.11	1,065.54**	2,319.90	838.42**
E x ENV	322	5.19	2.81**	8.93	3.23**
Het.bet.reg's	23	14.01	7.58**	13.04	4.71**
Remainder	299	4.51	2.44**	8.61	3.11**
Error	690	1.85		2.77	

**Indicates significance at the 0.01 level of probability.

TABLE XIII

STABILITY PARAMETER ESTIMATES FOR FORAGE YIELDS OF BERMUDAGRASS ENTRIES BASED ON 15 ENVIRONMENTS

Entries	First Seasonal Yield		Regrowth Yield		Total Seasonal Yield	
	$b \pm s_b$	S^2_d	$b \pm s_b$	S^2_d	$b \pm s_b$	S^2_d
1	1.17 ± 0.09	0.023	1.04 ± 0.06	0.000†	1.01 ± 0.06	0.000†
2	1.23* ± 0.10	0.000†	1.13 ± 0.07	0.000†	1.11* ± 0.04	0.000†
3	0.74 ± 0.19	0.753**	0.79 ± 0.07	0.370	0.91 ± 0.12	2.591**
4	1.18 ± 0.21	0.613	0.98 ± 0.07	0.028	0.99 ± 0.13	0.956
5	1.11 ± 0.10	0.000†	1.06 ± 0.07	0.030	1.08 ± 0.08	0.000†
6	1.38 ± 0.23	0.666	1.08 ± 0.07	0.933**	1.03 ± 0.12	1.081
7	1.07 ± 0.07	0.000†	1.17 ± 0.01	0.256	1.19 ± 0.08	0.058
8	1.00 ± 0.25	1.582**	1.11* ± 0.09	2.652**	1.20 ± 0.12	2.606**
9	0.94 ± 0.08	0.000†	1.01 ± 0.01	0.000†	1.00 ± 0.07	0.313
10	0.78 ± 0.21	0.772*	1.13 ± 0.11	1.177**	0.95 ± 0.14	4.167**
11	1.23 ± 0.11	0.022	0.88 ± 0.09	0.000†	0.99 ± 0.10	0.691
12	0.71 ± 0.15	0.481**	0.92 ± 0.06	0.005	0.91 ± 0.07	0.766*
13	0.78 ± 0.15	0.357*	0.97 ± 0.15	0.293	0.97 ± 0.14	1.410*
14	1.12 ± 0.16	0.213	0.96 ± 0.10	0.000†	1.05 ± 0.10	0.000†
15	1.05 ± 0.18	0.592*	1.07 ± 0.09	0.178	1.04 ± 0.12	1.111
16	1.29 ± 0.19	0.870**	1.20 ± 0.08	0.448*	1.16 ± 0.11	2.176**
17	1.11 ± 0.15	0.413*	0.99 ± 0.09	0.101	0.99 ± 0.11	0.772
18	0.94 ± 0.12	0.192	1.06* ± 0.05	0.000†	1.05 ± 0.05	0.000†
19	0.69* ± 0.11	0.368	0.90 ± 0.10	0.821**	0.93 ± 0.11	1.500**
20	0.72* ± 0.10	0.002	0.77 ± 0.08	0.296	0.81* ± 0.07	1.148**
21	0.67* ± 0.12	0.260*	0.96 ± 0.12	0.942**	0.92 ± 0.06	0.714*
22	0.93 ± 0.10	0.000†	0.90 ± 0.05	0.000†	0.90 ± 0.06	0.000†
23	0.99 ± 0.08	0.000†	1.00 ± 0.09	0.881**	0.92 ± 0.08	0.801*
24	1.18 ± 0.12	0.308**	0.94* ± 0.05	0.830*	0.89 ± 0.07	1.439**

*,**Significantly different from 1.0 for the regression coefficients and from 0.0 for the deviation mean squares at 0.05 and 0.01 levels of probability, respectively.

†Negative estimate for which the most reasonable value is zero.

The deviation from regression mean square is the second stability parameter which Langer et al. (1979) considered a true measure of production stability. Mean square deviations from regression were significant for 41 percent, 33 percent and 46 percent of the entries for first seasonal, regrowth, and total seasonal yields, respectively. Of the six highest yielding entries, Hardie (entry 2) and 7-7 (entry 5) had b values near 1.0 and low standard deviations from regression for first seasonal yield. Similar results were observed for 11-2 (entry 9), 17-8 (entry 15), 19-5 (entry 18) and Hardie for regrowth yield. For total seasonal yield only 11-2 and 19-5 had b-values near 1.0 and low standard deviations from regression. These stability parameter characteristics (b-value $\geq$ 1.0 and S_d^2 value = 0.0) indicate responsiveness to favorable environments and stability of performance. In contrast, 12-12 (entry 13) and 17-8 (entry 15) with a mean yield ranking of five and six, respectively had b-values near 1.0 and high standard deviations from regression. According to Breese (1969), genotypes with regression coefficients greater than one would be relatively better adapted to more favorable conditions, whereas, genotypes with coefficients less than one would be relatively better adapted to less favorable growing conditions. Joppa, Lebsock, and Bush (1971) added however that these specific conditions are ignored if decisions regarding recommendations are based on mean yield in all environments. Gray (1982) pointed out that the most stable cultivars of perennial forage crops which normally decline in yield over years, should have high yield, b values less than one, and low deviations from regression. However, stability analyses of bermudagrass data in this study showed that these genotypes are desirable only under good growing conditions.

Rank-correlation coefficients between mean yields and stability parameters are presented in Table XIV. Low and negative first seasonal yield rank-correlation coefficients were found between mean yields and the two stability parameters as well as between b and S_d^2 values, but these were not statistically significant. The mean regrowth and total seasonal yields were positively related to the regression coefficients and somewhat negatively related to the deviations from regression mean squares, while b-values were positively related with S_d^2 in regrowth yield, and negatively related with S_d^2 values for total seasonal yield. In all these cases, mean yields were not significantly correlated to any stability parameter. Significant correlations were not observed between linear regression coefficients and deviation from regression mean squares. Most of these statistic correlations seemed to follow the patterns suggested by Eberhart and Russell (1966). Thus, a positive relationship exists between the $\overline{X}$ and b values. Similar results were reported by other investigators (Nguyen et al. 1980; Gray, 1982). In this study the non-significant rank-correlation coefficients showed that little relationship exists between the yielding ability of genotypes and their capacity to respond to environmental variation.

The relationship between first seasonal and regrowth yields is presented in Table XV. The rank-coefficients of correlation (r=0.44 and r=0.43) indicated significant ($P<0.05$) positive correlation between mean yield of the first seasonal harvest ($\overline{X}_1$) and mean yield of the regrowth forage ($\overline{X}_2$) and between b_1 and b_2, the linear responses of first seasonal and regrowth yield, respectively. It was also shown that residuals ($S_{d_1}^2$) for first seasonal yield were

TABLE XIV

RANK-CORRELATION COEFFICIENTS BETWEEN MEAN FORAGE YIELDS AND STABILITY PARAMETERS FOR FORAGE YIELD IN BERMUDAGRASS BASED ON 15 ENVIRONMENTS

Statistics Correlated†		Forage Yield		
Statistic 1	Statistic 2	First Seasonal Yield	Regrowth Yield	Total Seasonal Yield
		------------Megagram/ha------------		
$\overline{X}$	b	-0.03	0.29	0.22
$\overline{X}$	S_d^2	-0.33	-0.27	-0.16
b	S_d^2	-0.01	0.16	-0.28

† None of the correlations are significant.

TABLE XV

RANK-CORRELATION COEFFICIENTS BETWEEN MEAN FORAGE YIELDS AND BETWEEN YIELD STABILITY PARAMETERS FROM FIRST SEASONAL HARVEST AND REGROWTH FORAGE DATA

Statistics Correlated		
Statistic 1	Statistic 2	Dry Matter Yield
		---Megagram/ha---
$\bar{X}_1$	$\bar{X}_2$	0.44*
b_1	b_2	0.43*
S^2_{d1}	S^2_{d2}	0.54**

*,** Rank-correlation coefficients are significantly different from zero at 0.05 and 0.01 levels of probability, respectively.

significantly ($P < 0.01$) correlated with residuals ($S_{d^2}^2$) of regrowth. However, neither the results from the first seasonal harvest alone or results from the regrowth forage yields alone seem to be adequate for evaluating the adaptation and performance of bermudagrass forage yield in the state.

Orthogonal Contrasts

Orthogonal contrasts were analyzed on regrowth and total seasonal yields to detect entry response to age of stand. An attempt to identify patterns was made by relating trends to visual rating on plant winterhardiness, sod density, and height at the start of the growing season. Significant variations ($P < 0.01$) were observed for Y(L) x locations and Y(Q) x locations for both regrowth and total seasonal yield data for each entry (Table XVI). Y(L) x entry and Y(Q) x entry were significant ($P < 0.05$ or $P < 0.01$) at all locations with the exceptin of Y(L) x entry at Tipton for regrowth and total seasonal yields and Y(Q) x entry for regrowth at Chickasha (Table XVII). Consequently, linear and quadratic trends differed in direction and magnitude across locations and entries and it would be hazardous to interpret Y(L) and Y(Q) effects for each entry averaged over locations. The linear trend for regrowth yield was downward in the 24 entries at the Chickasha, Haskell, and Tipton locations and for 22 of the entries at Lahoma and Perkins (Table XVIII). Quadratic effects were negative for each of the 24 entries at the Chickasha and Lahoma locations and for 14 entries at Perkins. Positive quadratic effects were found for all entries at Tipton and for all but one entry at

TABLE XVI

F-TESTS OF Y(L)xLoc AND Y(Q)xLoc FOR REGROWTH AND TOTAL SEASONAL YIELDS OF BERMUDAGRASS ENTRIES

Entry No.	Regrowth Yield		Total Seasonal Yield	
	Y(L)xLoc	Y(Q)xLoc	Y(L)xLoc	Y(Q)xLoc
1	15.26**	21.22**	11.95**	24.33**
2	20.74**	31.54**	14.90**	43.74**
3	4.56**	23.99**	4.56**	31.21**
4	16.52**	28.80**	16.42**	45.81**
5	21.08**	24.09**	15.25**	28.88**
6	28.43**	24.99**	24.44**	34.97**
7	32.58**	42.15**	24.97**	41.08**
8	24.90**	38.26**	16.59**	33.84**
9	24.80**	18.48**	18.05**	25.14**
10	33.87**	30.68**	20.02**	44.07**
11	11.58**	17.56**	9.31**	21.95**
12	12.50**	22.32**	9.67**	19.40**
13	13.81**	13.98**	8.73**	20.29**
14	16.05**	34.41**	11.17**	34.11**
15	14.81**	30.71**	9.37**	41.49**
16	25.74**	22.45**	13.65**	24.50**
17	19.59**	26.32**	14.79**	31.02**
18	17.56**	30.04**	9.13**	28.91**
19	14.59**	26.69**	11.40**	23.28**
20	9.70**	19.52**	8.32**	19.31**
21	14.35**	34.16**	9.14**	29.97**
22	6.96**	20.63**	8.07**	23.51**
23	16.92**	30.03**	11.25**	27.69**
24	19.66**	22.65**	13.74**	26.24**

**Significant at 0.01 level of probability.

TABLE XVII

F-TESTS OF Y(L)xEntry AND Y(Q)xEntry FOR REGROWTH AND TOTAL SEASONAL YIELDS AT THE TEST LOCATIONS

Location	Regrowth Yield		Total Seasonal Yield	
	Y(L)xEntry	Y(Q)xEntry	Y(L)xEntry	Y(Q)xEntry
Chickasha	3.96**	1.10	4.97**	1.61*
Haskell	4.66**	2.40**	6.01**	4.11**
Lahoma	3.99**	1.92**	2.86**	3.57**
Perkins	2.52**	2.31**	3.29**	2.12**
Tipton	1.54	2.00**	0.59	1.66*

*,** Significant at 0.05 and 0.01 levels of probability, respectively.

TABLE XVIII

ORTHOGONAL CONTRAST EFFECTS FOR EACH ENTRY AT EACH LOCATION ON REGROWTH YIELDS

	Entry Number											
	1	2	3	4	5	6	7	8	9	10	11	12
	Megagrams/ha											
Chickasha												
Y(L)	-5.79**	-6.76**	-2.55**	-5.03**	-5.71**	-7.73**	-6.56**	-4.72**	-6.38**	-7.15**	-4.32**	-4.68**
Y(Q)	-1.61	-1.88	-1.29	-1.66	-1.74	-2.23	-2.15	-2.07	-1.39	-2.09	-1.21	-1.50
Haskell												
Y(L)	-3.93**	-3.82**	-2.50**	-4.28**	-4.07**	-3.51**	-4.54**	-3.17**	-3.07**	-5.86**	-3.58**	-3.02**
Y(Q)	0.35	0.97	1.13	0.69	0.76	0.53	0.80	0.60	1.10	0.56	1.20	0.86
Lahoma												
Y(L)	-1.91*	-1.88*	-0.95	-1.55	-1.41	-1.50	-0.43	1.25	-1.47	-1.35	-1.60	-1.93*
Y(Q)	-1.17	-1.68	-1.20	-1.25	-1.19	-1.04	-0.92	-0.51	-1.01	-1.99	-0.75	-1.09
Perkins												
Y(L)	-0.93	-1.09	-0.34	-0.56	-0.14	-1.50	-0.10	-1.11	-0.05	-0.67	-0.18	-0.01
Y(Q)	-0.15	-0.37	0.37	0.11	0.16	0.28	0.54	0.10	-0.38	-0.14	-0.13	0.44
Tipton												
Y(L)	-2.98**	-3.59**	-2.38*	-4.25**	-3.55**	-4.26**	-2.71**	-3.85**	-3.70**	-3.94**	-2.18*	-2.64**
Y(Q)	1.61	1.61	1.72	2.01	1.55	1.26	2.60	2.64	1.21	1.36	1.41	1.59

TABLE XVIII (Continued)

	Entry Number											
	13	14	15	16	17	18	19	20	21	22	23	24
	Megagrams/ha											
Chickasha												
Y(L)	-4.75**	-4.58**	-5.30**	-7.49**	-5.41**	-6.21*	-4.12**	-3.55**	-4.82**	-4.08**	-5.37**	-5.93**
Y(Q)	-0.50	-1.43	-1.85	-1.90	-1.65	-1.47	-1.87	-1.11	-1.29	-1.65	-1.81	-1.55
Haskell												
Y(L)	-3.17**	-3.52**	-3.94**	-3.65**	-2.74**	-3.16**	-2.62**	-3.24**	-4.67**	-3.54**	-4.18**	-3.29**
Y(Q)	0.54	0.98	0.67	0.70	0.50	1.00	1.02	1.08	0.69	0.71	-0.13	0.31
Lahoma												
Y(L)	-1.11	-1.39	-1.36	-2.76**	-1.27	-2.09**	0.40	-0.88	-2.47*	-1.59	-2.39*	-2.90**
Y(Q)	-1.53	-0.96	-1.96	-1.02	-1.04	-1.39	-1.11	-0.94	-1.04	-1.04	-1.70	-1.66
Perkins												
Y(L)	-0.41	0.39	-1.24	-0.78	0.08	-0.78	-0.38	-0.33	-0.51	-1.23	-0.13	-0.02
Y(Q)	0.01	-0.40	0.16	-0.01	-0.06	-0.12	0.34	-0.02	-0.37	-0.15	-0.20	-0.30
Tipton												
Y(L)	-3.48**	-2.57**	-4.42**	-3.92**	-3.73**	-3.53**	-2.57**	-3.11**	-2.13*	-3.38**	-3.21**	-2.15*
Y(Q)	1.20	2.57	1.48	1.39	2.02	2.04	1.53	1.69	2.69	1.46	1.94	1.49

*,** Indicate contrast effects significantly different from zero at the 0.05 and 0.01 levels of probability, respectively.

Haskell. Neither positive nor negative quadratic effects were significant. A significant ($P < 0.05$ or $P < 0.01$) negative linear trend was found for each of the 24 entries at Chickasha, Haskell, Tipton and for eight entries at Lahoma. However, none of the negative linear trends was significant for any entry at Perkins. These data on regrowth indicated that yield decreased from year 1981 to year 1983 at all locations. This decrease could be related to differences in environmental conditions, i.e., soil type, moisture patterns, etc. The non-significant linear effect at Perkins could be explained in part by more favorable soil moisture conditions during 1983. Regrowth yield trends over years from selected entries at each location are presented in Figure 2.

At Chickasha (Table XIX), a decreasing linear effect was observed for total seasonal yield for all entries but Tifton 44 (entry 3). Sixty-two percent of the entries had significant negative linear trends ($P < 0.05$ or $P < 0.01$). The significant yield decrease of low yielding entries such as entries 21, 23, and 24 confirm the visual rating of these entries on winterhardiness, sod density, and plant height at the start of the 1981, 1983, and 1984 growing seasons (Tables XXV, XXVI, and XXVII, Appendix C). However the high yielding entries 9 and 18 have significant ($P < 0.05$) negative linear response at this location. At Haskell and Tipton, there were decreasing trends in total seasonal yields over years for all entries. These trends or responses, were not significant for any entry at Tipton, however, at Haskell negative trends were significant ($P < 0.05$ or $P < 0.01$) for 25 percent of the entries. Positive change in yield was observed at

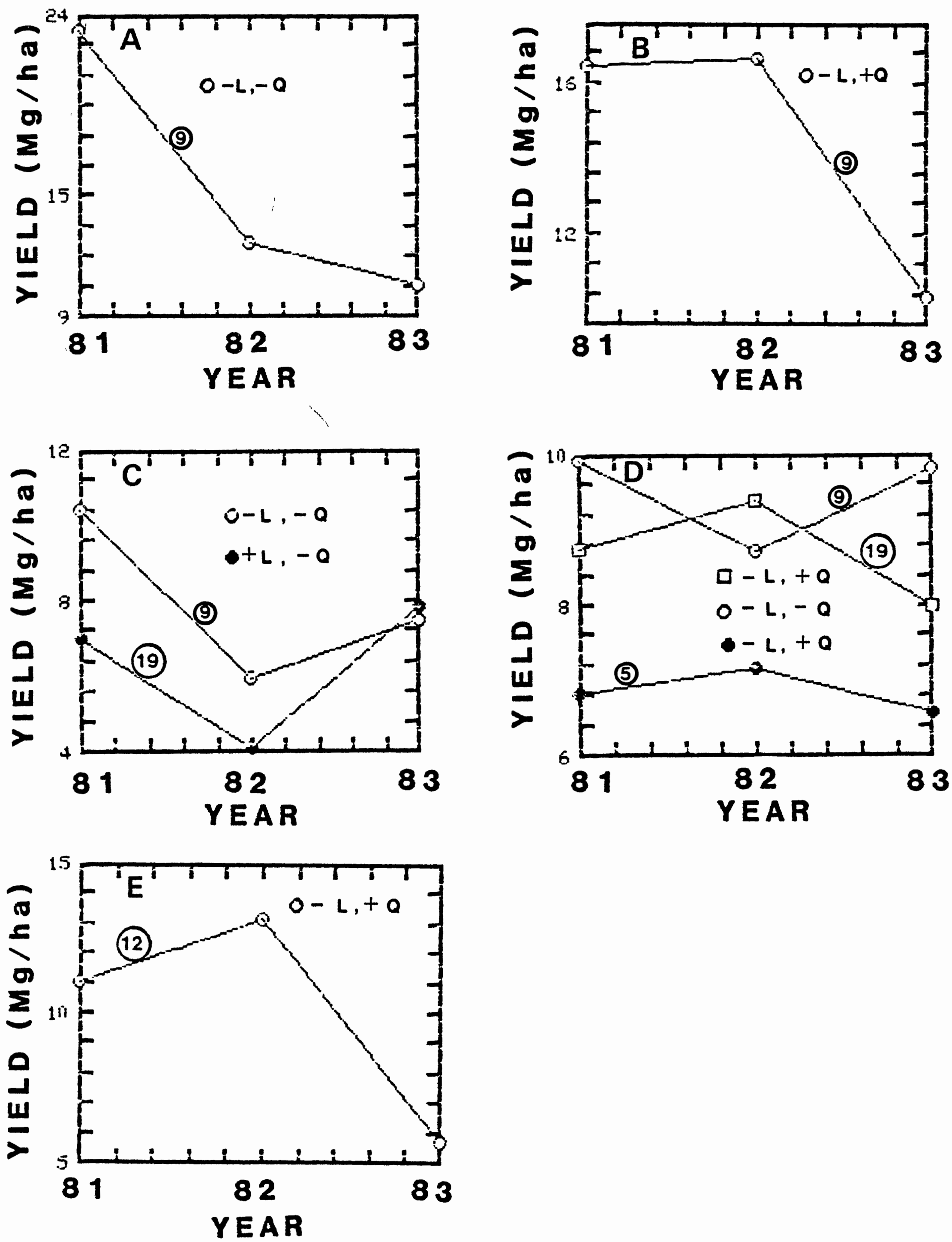

Figure 2. Regrowth Yield Trends Over Years for Selected Entries at Chickasha (A), Haskell (B), Lahoma (C), Perkins (D), and Tipton (E). Circled numbers represent entries.

TABLE XIX

ORTHOGONAL CONTRAST EFFECTS FOR EACH ENTRY AT EACH LOCATION ON TOTAL SEASONAL YIELDS

	Entry Number											
	1	2	3	4	5	6	7	8	9	10	11	12
	Megagrams/ha											
Chickasha												
Y(L)	-3.79**	-3.81**	0.21	-2.80*	-2.68*	-5.82**	-4.69**	-2.21	-2.78*	-5.19**	-1.87	-1.62
Y(Q)	0.42	0.19	0.24	0.03	0.23	-0.09	-0.52	-0.01	0.67	-1.12	0.91	0.59
Haskell												
Y(L)	-2.15	-1.67	0.08	-2.54*	-1.82	-1.80	-2.96*	-2.10	-0.34	-4.09**	-2.06	-0.74
Y(Q)	2.68	3.28	3.55	2.57	3.15	2.47	2.83	2.89	3.49	2.71	3.71	2.68
Lahoma												
Y(L)	1.04	1.75	2.64*	2.24	2.18	2.03	2.60*	3.12**	3.03**	2.04	1.83	2.18
Y(Q)	-0.05	-0.86	-0.87	-0.74	-0.10	-0.46	-0.26	-0.13	-0.02	-2.03	0.37	-0.46
Perkins												
Y(L)	0.77	1.26	2.02	1.48	2.09	0.13	1.03	1.13	3.01*	1.20	1.38	2.56*
Y(Q)	1.16	1.03	1.72	1.42	1.30	1.45	1.74	1.47	0.83	0.71	1.13	1.81
Tipton												
Y(L)	-0.65	-1.12	-0.06	-1.93	-1.42	-1.49	-1.00	-1.84	-0.37	-1.42	-0.10	-0.02
Y(Q)	4.00*	4.60*	3.22	5.10*	4.08*	4.47*	4.68*	4.50*	3.60	3.06	3.62	3.17

TABLE XIX (Continued)

	Entry Number											
	13	14	15	16	17	18	19	20	21	22	23	24
	Megagrams/ha											
Chickasha												
Y(L)	-1.42	-2.14	-2.86*	-5.12**	-4.09**	-2.85*	-1.69	-0.98	-3.28**	-1.43	-3.03**	-4.28**
Y(Q)	1.21	0.48	-0.28	0.36	0.22	0.61	-0.03	0.81	-0.01	0.17	0.11	0.56
Haskell												
Y(L)	-1.22	-1.72	-1.53	-1.25	-1.14	-0.75	-0.22	-0.67	-2.98*	-1.76	-2.59*	-2.51*
Y(Q)	2.78	3.70	2.84	2.91	2.13	3.04	2.86	3.17	2.43	3.03	1.90	2.22
Lahoma												
Y(L)	2.34*	1.64	1.80	-0.20	1.26	1.61	3.30**	2.81*	-0.38	1.85	0.72	0.33
Y(Q)	-1.00	0.40	-1.55	0.24	-0.24	-0.52	-0.52	-0.21	-0.41	-0.10	-0.82	-0.85
Perkins												
Y(L)	1.75	2.22	0.24	0.41	1.27	1.12	1.86	2.00	0.91	1.23	1.45	1.33
Y(Q)	1.32	1.04	1.38	1.00	1.19	1.51	1.59	1.34	0.74	1.26	0.89	0.75
Tipton												
Y(L)	-0.47	-0.65	-1.42	-2.23	-1.83	-0.84	-0.39	-0.13	-0.89	-1.21	-0.83	-0.40
Y(Q)	2.68	4.65*	3.79	4.03*	4.52*	4.02*	3.08	3.17	4.06*	3.53	3.83	3.71

*,** Indicate contrast effects significantly different from zero at the 0.05 and 0.01 levels of probability, respectively.

Lahoma and Perkins with 29 percent and eight percent significant ($P < 0.05$ or $P < 0.01$), respectively.

Quadratic effects were positive at Tipton, Perkins, and Haskell. They were negative for seven entries at Chickasha and 22 entries at Lahoma. Quadratic effects were not significnat for any entry at the Chickasha, Haskell, Lahoma, and Perkins locations and significant for 50 percent of the entries at Tipton. The lack of significant quadratic effects for all entries for total seasonal yield at four locations indicates that deviation from linear trend was negligible. Therefore, quadrtic effects at these locations were not useful in predicting the trend from one year to another. The significant linear and quadratic responses might be explained by factors other than winterhardiness such as stress factors as well as drought, fertility, or others not yet identified which influence the genetic yield potential of cultivars or experimental strains as the plant aged. Yield trend over years for total seasonal yield of selected entries at each location are represented in Figure 3.

Relationship Between The Three Statistical Methods

None of these analyses alone would be able to predict the genotype performance for forage yield in bermudagrass cultivars and experimental strains. They complement each other. Analyses of variance are able to show the existence and magnitude of GE interactions. Stability parameters and mean yields are used to describe the cultivar performance over a series of environments. However, the regression analyses do not appear to provide a good

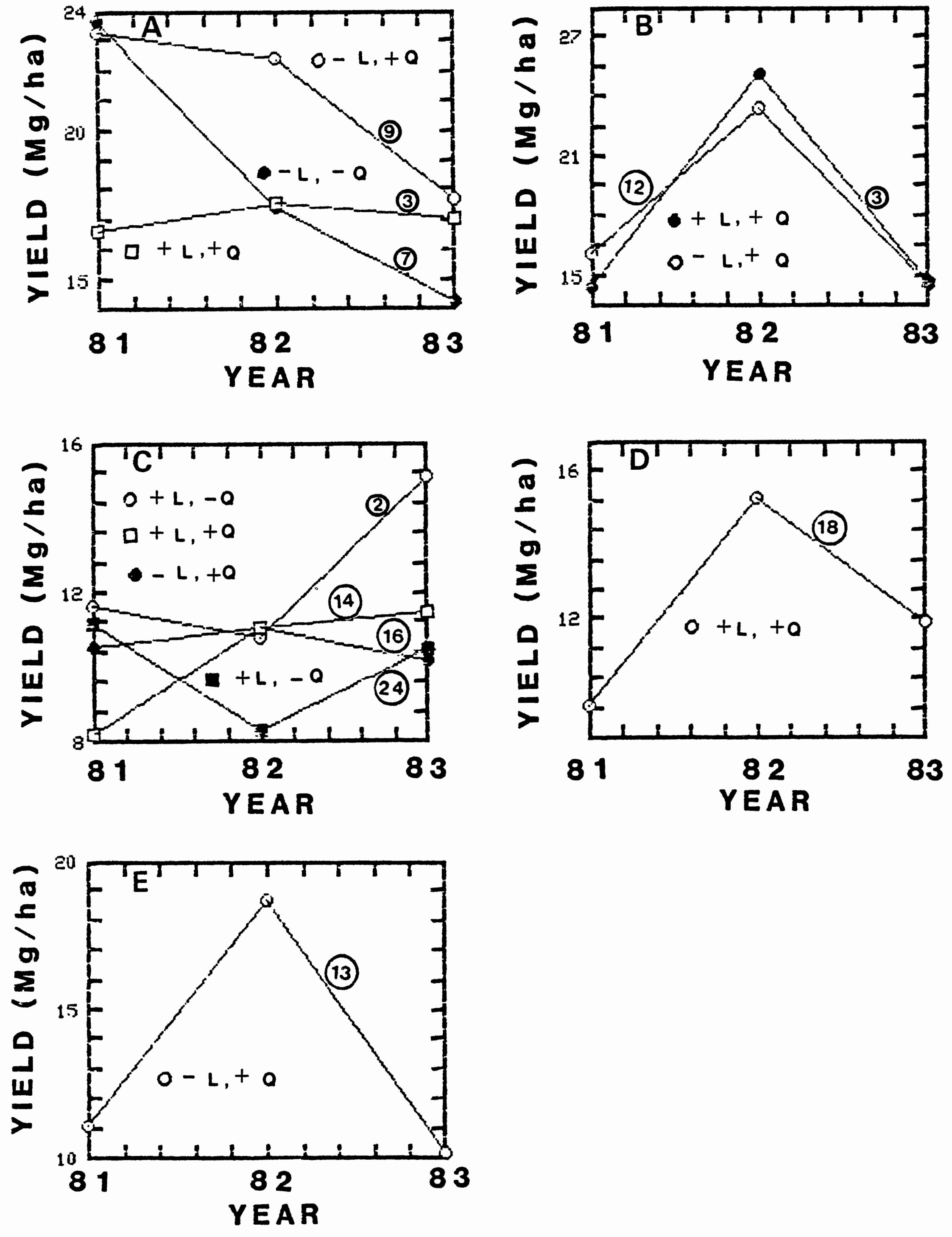

Figure 3. Total Seasonal Yield Trends Over Years for Selected Entries at Chickasha (A), Haskell (B), Lahoma (C), Perkins (D), and Tipton (E). Circled numbers represent entries.

estimate of entry performance across environments. Specific instances of instability were shown using this procedure. Entry performance associated with age of stand was determined using the orthogonal contrast analyses.

CHAPTER V

SUMMARY AND CONCLUSIONS

Standard analyses of variance, regression, and orthogonal contrasts were used in evaluating genotype x environment interactions and in characterizing the performance of entries.

Entries, locations, years, all first order interactions, and the entry x location x year interaction were significant. Significant differences indicate that genotypes respond differently from one environment to another making it difficult to identify superior plants. Bermudagrass cultivars and experimental strains must be tested at several locations representing as many of the major climatic and edaphic regions as possible in a state like Oklahoma.

Heterogeneity between regressions M.S. and remainder M.S. obtained by partitioning GE interaction sum of squares were highly significant for all cases. Because of the significance of the remainder M.S., regression analyses did not provide good estimates of individual entry performance across environments. In the stability analyses, the regression coefficients ranged from 0.67 to 1.38, 0.77 to 1.20 and 0.81 to 1.20 for first seasonal, regrowth, and total seasonal yields, respectively. The deviations from regression mean squares were not homogeneous and were significantly different from zero for 47, 33, and 46 percent of the entries in the respective cases.

Neither mean yield nor stability parameters alone are sufficient to select high yielding and stable genotypes due to the nonsignificant rank-correlation coefficients between mean yield and stability parameters.

On the basis of mean yield, regression coefficients, and mean square deviations from regression, genotypes 11-2 (entry 9), 19-5 (entry 18) and Hardie (entry 2) were the most stable under good growing conditions. Their performance was consistent over locations and years.

The orthogonal contrast partition of the interaction sum of squares indicated that entries differed in their response to years and locations. Interactions between years-linear x locations and years-quadratic x locations as well as years-linear x entries and years-quadratic x entries were significant for all entries indicating that linear and quadratic effects differed across entries and locations. The analysis of each entry in each location shows that some entries increased while others decreased in yield relative to the mean of all entries as the plant ages. In bermudagrass, and other perennial crops, persistence of stand is of major importance. Thus, allocation of resources for evaluation should probably stress using fewer number of locations, but, testing over a longer period of time.

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APPENDIX A

MEAN REGROWTH AND TOTAL SEASONAL DRY MATTER YIELDS OF BERMUDAGRASS ENTRIES AT EACH OF THE FIVE LOCATIONS AND IN EACH YEAR

TABLE XX

MEAN YIELDS OF REGROWTH FORAGE OF BERMUDAGRASS ENTRIES AT EACH OF THE FIVE LOCATIONS AND IN EACH YEAR

Entry No.	Chickasha 1981	Chickasha 1982	Chickasha 1983	Haskell 1981	Haskell 1982	Haskell 1983	Lahoma 1981	Lahoma 1982	Lahoma 1983	Perkins 1981	Perkins 1982	Perkins 1983	Tipton 1981	Tipton 1982	Tipton 1983
	---Megagrams/ha---														
13	21.21	14.97	11.71	15.02	13.47	8.68	10.00	4.30	7.78	7.59	7.21	6.78	11.13	11.27	4.18
2	24.57	12.15	11.04	15.98	15.08	8.34	11.63	4.70	7.88	9.60	7.38	7.42	9.98	11.24	2.81
16	25.18	12.00	10.21	16.09	14.53	8.79	10.57	4.74	5.05	7.69	6.87	6.12	11.21	11.45	3.38
12	21.83	12.66	12.47	16.10	15.67	10.07	11.22	6.02	7.35	8.81	10.12	8.78	11.02	13.15	5.74
8	22.32	11.39	12.87	15.72	14.33	9.37	4.09	3.81	6.58	8.61	7.80	6.38	10.27	14.35	2.57
9	23.26	12.72	10.51	16.46	16.68	10.33	10.43	5.95	7.49	9.92	8.73	9.82	11.92	11.84	4.52
18	23.08	12.48	10.67	15.45	15.30	9.13	10.19	2.86	7.48	9.67	8.52	8.11	10.47	13.06	3.41
7	23.67	10.67	10.54	16.51	14.37	7.44	7.75	4.56	6.89	5.50	7.01	5.30	9.29	14.38	3.87
5	22.24	11.30	10.83	15.69	13.90	7.55	9.96	4.98	7.14	6.84	7.17	6.57	9.47	10.58	2.38
17	21.40	11.06	10.59	16.02	14.78	10.54	9.89	5.51	7.34	7.19	7.09	7.34	11.84	14.17	4.37
19	20.24	10.52	12.01	14.70	15.14	9.45	7.03	4.11	7.84	8.76	9.39	8.00	9.23	11.26	4.08
15	21.29	10.46	10.69	17.34	15.40	9.45	10.29	3.05	7.57	8.15	7.39	5.68	12.91	12.93	4.07
1	21.40	10.77	9.82	16.64	13.76	8.77	9.08	3.65	5.27	8.53	7.15	6.68	9.94	11.80	3.98
6	23.73	9.32	8.28	14.50	12.56	7.47	9.16	4.53	6.17	7.92	7.27	4.92	11.23	10.74	2.71
14	19.32	10.46	10.15	15.66	15.08	8.61	8.21	3.93	5.43	8.39	7.57	9.16	8.01	13.15	2.86
23	20.42	9.63	9.69	16.06	11.49	7.69	11.09	3.62	6.32	6.07	5.33	5.81	10.04	12.65	3.62
20	17.75	10.87	10.65	14.39	14.39	7.91	9.34	5.65	7.58	9.44	9.04	8.78	9.63	11.58	3.41
22	18.69	9.67	10.53	14.66	13.24	7.58	8.99	4.28	5.82	8.31	6.63	5.84	9.43	10.41	2.67
3	16.67	10.24	11.56	14.48	15.38	9.49	8.79	4.23	6.89	7.59	8.38	6.91	9.14	11.92	4.39
24	20.27	9.68	8.41	13.36	10.99	6.78	11.16	3.29	5.36	6.48	5.56	6.43	6.84	9.16	2.54
4	19.48	9.47	9.43	14.94	12.73	6.38	8.90	3.60	5.81	7.22	6.99	6.10	10.88	12.67	2.38
10	22.02	8.61	7.72	18.18	14.01	6.45	10.19	2.86	7.48	7.04	5.95	5.70	10.94	11.08	3.06
21	18.73	10.03	9.09	15.01	12.41	5.68	9.48	3.88	4.54	6.98	5.36	5.95	7.44	13.38	3.17
11	16.87	8.93	8.22	12.07	12.07	4.91	6.96	3.12	3.76	4.87	4.29	4.51	6.18	8.23	1.82
LDS .05	2.81	2.03	1.52	2.81	2.03	1.52	2.81	2.03	1.52	2.81	2.03	1.52	2.81	2.03	1.52
CV%	9.63	13.52	10.64	13.12	10.44	13.39	21.65	34.21	16.92	26.01	20.19	16.17	20.42	12.28	32.14

TABLE XXI

MEAN TOTAL SEASONAL DRY MATTER YIELDS OF BERMUDAGRASS ENTRIES AT EACH OF THE FIVE LOCATIONS AND IN EACH YEAR

Entry No.	Chickasha 1981	Chickasha 1982	Chickasha 1983	Haskell 1981	Haskell 1982	Haskell 1983	Lahoma 1981	Lahoma 1982	Lahoma 1983	Perkins 1981	Perkins 1982	Perkins 1983	Tipton 1981	Tipton 1982	Tipton 1983
	--------	--------	--------	--------	--------	--------	--------	Megagrams/ha	--------	--------	--------	--------	--------	--------	--------
9	23.26	22.46	17.69	16.46	26.60	15.79	10.43	13.42	16.50	9.92	15.42	15.95	11.92	22.34	11.18
13	21.21	23.41	18.38	15.02	22.13	12.57	10.00	9.32	14.67	7.59	13.31	11.10	11.13	18.70	10.19
2	24.57	21.31	16.94	15.98	24.15	12.64	11.63	10.81	15.13	9.60	13.94	12.11	9.98	22.65	7.74
18	23.08	22.06	17.38	15.45	23.81	13.95	10.67	10.72	13.89	9.67	15.31	11.90	10.47	21.71	8.79
12	21.83	21.99	18.59	16.10	23.41	14.61	11.22	12.01	15.58	8.81	16.80	13.93	11.02	20.51	10.98
16	25.18	21.13	14.94	16.09	23.56	13.59	10.57	11.08	10.17	7.69	11.10	8.51	11.21	21.06	6.76
8	22.32	20.08	17.90	15.72	22.29	11.52	4.09	6.81	10.32	8.61	14.14	10.88	10.27	21.94	6.59
5	22.24	20.25	16.88	15.69	23.31	12.05	9.96	11.86	14.33	6.84	12.82	11.02	9.47	20.30	6.63
19	20.24	18.45	16.87	14.70	23.07	14.26	7.03	8.79	13.64	8.76	15.41	12.49	9.23	18.09	8.46
7	23.67	17.43	14.29	16.51	22.05	10.60	7.75	9.57	12.95	5.50	11.74	7.57	9.29	22.35	7.30
15	21.29	17.60	15.58	17.34	24.31	14.28	10.29	7.44	13.89	8.15	12.54	8.64	12.91	22.86	10.08
1	21.40	18.87	13.81	16.64	22.53	12.34	9.08	9.97	11.17	8.53	12.78	10.07	9.94	21.29	8.65
6	23.73	17.64	12.09	14.50	20.10	10.90	9.16	9.81	13.22	7.92	12.40	8.17	11.23	23.16	8.25
14	19.32	18.62	15.05	15.66	25.05	12.22	8.21	11.04	11.50	8.39	13.72	12.82	8.01	21.32	6.70
20	17.75	19.19	15.78	14.29	23.24	13.05	9.34	11.52	14.96	9.44	15.46	13.44	9.63	19.01	9.36
17	21.40	17.96	13.22	16.02	21.26	13.74	9.89	10.43	12.42	7.19	12.03	9.72	11.84	23.59	8.19
23	20.42	17.72	14.35	16.06	19.18	10.88	11.09	9.35	12.54	6.07	10.21	8.98	10.04	20.69	8.38
22	18.69	17.75	15.82	14.66	21.98	11.14	8.99	10.53	12.68	8.31	13.33	10.77	9.43	18.82	7.01
3	16.67	17.60	17.08	14.48	25.21	14.64	8.79	8.81	14.07	7.59	14.76	11.63	9.14	18.74	9.03
4	19.48	16.78	13.88	14.94	20.12	9.86	8.90	8.92	13.39	7.22	12.97	10.18	10.88	24.24	7.01
24	20.27	17.66	11.71	13.36	17.49	8.33	11.16	8.29	10.50	6.48	10.04	9.14	6.84	17.56	6.04
11	16.87	17.72	13.13	12.07	21.14	7.95	6.96	9.91	10.62	4.87	9.65	7.63	6.18	16.94	5.97
10	22.02	13.48	11.64	18.18	22.21	10.00	10.19	6.14	14.26	7.04	10.37	9.44	10.94	18.69	8.09
21	18.73	15.42	12.17	15.01	19.33	9.05	9.48	7.89	8.73	6.98	10.09	8.79	7.44	18.73	5.66
LSD .05	2.81	3.34	2.33	2.81	3.34	2.33	2.81	3.34	2.33	2.81	3.34	2.33	2.81	3.34	2.33
CV %	9.62	12.77	11.06	13.12	10.75	13.93	21.65	24.66	12.98	26.01	18.63	15.86	20.42	11.67	20.93

APPENDIX B

CLIMATOLOGICAL DATA

TABLE XXII

CLIMATOLOGICAL DATA AT THE FIVE TEST LOCATIONS FOR 1981

LOCATION		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
CHICKASHA	MIN TEMP (C)	-3.3	-0.6	5.0	12.8	13.9	20.0	23.4	19.5	16.7	11.1	3.9	-0.6
	MAX TEMP (C)	11.1	14.5	17.8	26.7	25.0	31.1	36.1	31.7	30.6	20.6	17.2	10.6
	PRECIPITATION (MM)	1	40	79	62	109	154	79	98	35	193	82	2
HASKELL	MIN TEMP (C)	-3.9	1.7	6.1	13.9	13.9	21.1	23.9	20.6	17.8	12.2	6.7	0.6
	MAX TEMP (C)	7.8	24.5	18.4	25.0	23.9	31.1	34.5	31.1	28.9	20.6	15.6	8.9
	PRECIPITATION (MM)	22	37	59	67	169	57	101	101	43	222	57	10
LAHOMA	MIN TEMP (C)	-3.9	-2.8	2.8	10.6	11.7	19.5	22.2	19.5	16.1	11.1	5.0	-1.1
	MAX TEMP (C)	10.0	12.2	15.6	24.5	25.0	33.4	33.9	32.8	30.0	20.0	15.6	8.3
	PRECIPITATION (MM)	5	11	59	32	122	170	64	36	100	107	66	5
PERKINS	MIN TEMP (C)	-5.1	-1.3	3.6	11.5	12.8	20.6	21.1	18.9	15.0	8.3	2.2	-3.9
	MAX TEMP (C)	11.2	13.2	16.7	25.8	25.0	32.2	32.8	30.0	28.4	19.5	13.9	6.7
	PRECIPITATION (MM)	1	26	42	27	176	115	124	129	49	99	103	5
TIPTON	MIN TEMP (C)	-2.8	-2.2	3.9	11.1	13.9	15.0	18.9	20.0	15.6	7.8	3.9	-1.7
	MAX TEMP (C)	15.0	17.2	20.0	27.2	30.0	29.5	37.3	33.9	32.8	23.9	20.0	13.9
	PRECIPITATION (MM)	3	19	47	51	180	202	23	29	36	68	27	7

SOURCE: CLIMATOLOGICAL DATA, OKLAHOMA, NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION, VOL. 90(81).

TABLE XXIII

CLIMATOLOGICAL DATA AT THE FIVE TEST LOCATIONS FOR 1982

LOCATION		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
		MONTH											
CHICKASHA	MIN TEMP (C)	-5.0	-2.2	4.5	11.7	17.2	20.0	24.5	24.4	18.4	11.1	6.7	1.7
	MAX TEMP (C)	8.9	8.9	17.8	22.8	26.1	27.2	32.8	33.9	28.9	23.3	13.3	8.9
	PRECIPITATION (MM)	70	20	33	30	291	101	41	29	61	16	68	45
HASKELL	MIN TEMP (C)	-3.3	0.0	7.2	7.8	15.6	18.4	22.2	22.2	17.2	9.5	5.6	2.8
	MAX TEMP (C)	6.7	8.3	17.2	18.9	24.5	25.6	30.6	33.4	27.2	22.2	13.9	10.6
	PRECIPITATION (MM)	101	25	32	45	225	156	83	61	60	31	140	92
LAHOMA	MIN TEMP (C)	-7.2	-6.7	1.1	4.5	12.8	16.1	20.6	20.0	14.5	6.7	0.0	-2.2
	MAX TEMP (C)	7.2	4.5	15.6	20.0	24.5	27.8	34.5	36.7	31.7	23.9	15.0	9.5
	PRECIPITATION (MM)	18	48	58	66	235	80	83	2.0	18	45	39	38
PERKINS	MIN TEMP (C)	-8.9	-5.6	2.2	5.0	12.2	14.5	20.6	21.7	15.6	7.2	3.3	0.0
	MAX TEMP (C)	5.0	6.1	15.6	19.5	23.4	26.1	32.3	35.0	30.6	24.5	15.0	11.7
	PRECIPITATION (MM)	62	44	35	60	371	134	94	8	22	23	77	93
TIPTON	MIN TEMP (C)	-5.6	-2.2	4.5	8.9	8.9	18.4	21.7	21.7	17.8	10.0	4.5	0.0
	MAX TEMP (C)	11.7	12.8	20.6	22.2	25.6	29.5	35.6	37.3	31.7	27.2	17.8	12.2
	PRECIPITATION (MM)	40	19	54	30	224	137	85	24	62	4	61	54

SOURCE: CLIMATOLOGICAL DATA, OKLAHOMA, NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION, VOL. 91(82).

TABLE XXIV

CLIMATOLOGICAL DATA AT THE FIVE TEST LOCATIONS FOR 1983

LOCATION		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
		MONTH											
	MIN TEMP (C)	0.0	2.2	3.9	6.7	13.9	19.5	21.1	21.7	15.0	11.1	5.6	-7.8
CHICKASHA	MAX TEMP (C)	6.7	8.9	15.0	18.9	23.9	28.4	35.0	36.7	32.8	25.0	17.8	3.9
	PRECIPITATION (MM)	54	97	55	44	126	128	0	58	18	337	14	16
	MIN TEMP (C)	0.6	2.8	5.6	7.8	13.9	18.4	22.2	22.8	16.7	11.1	6.1	-6.7
HASKELL	MAX TEMP (C)	8.3	9.5	12.8	16.1	22.2	26.7	31.7	33.9	28.9	20.0	13.9	-0.6
	PRECIPITATION (MM)	75	40	92	67	165	66	0	21	52	205	87	9
	MIN TEMP (C)	-3.9	-1.7	1.7	3.9	9.5	15.0	19.5	21.7	15.6	10.0	3.3	-10.6
LAHOMA	MAX TEMP (C)	7.2	8.3	12.2	16.1	23.9	29.5	36.1	37.8	30.6	21.7	16.1	1.1
	PRECIPITATION (MM)	21	42	87	85	109	145	0	36	95	121	42	5
	MIN TEMP (C)	-2.8	0.6	3.3	5.6	11.7	16.7	20.6	21.7	15.6	10.6	3.9	-10.0
PERKINS	MAX TEMP (C)	7.8	9.5	12.8	17.8	24.5	28.9	35.6	37.3	30.6	22.8	16.1	0.6
	PRECIPITATION (MM)	18	99	86	54	155	138	1	24	49	270	45	7
	MIN TEMP (C)	-1.7	1.1	3.9	6.7	12.2	16.7	20.0	22.8	18.4	12.8	5.6	-6.7
TIPTON	MAX TEMP (C)	9.5	12.2	17.8	20.0	27.2	30.6	36.7	37.3	35.0	24.5	17.2	3.3
	PRECIPITATION (MM)	87	12	79	37	79	91	8	0	11	284	39	7

SOURCE: CLIMATOLOGICAL DATA, OKLAHOMA, NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION, VOL. 92(83).

APPENDIX C

NOTES ON WINTER HARDINESS, SOD DENSITY, AND PLANT HEIGHT OF BERMUDAGRASS ENTIRES AT EACH OF THE FIVE LOCATIONS FOR SPRING 1981, 1983, AND 1984

TABLE XXV

NOTES ON WINTER HARDINESS (W.H.) AND PLANT HEIGHT (Ht.) OF BERMUDAGRASS ENTRIES AT EACH OF THE FIVE LOCATIONS (SPRING 81)ϕ

Entry No.	Chickasha		Haskell		Lahoma		Perkins		Tipton	
	W.H.	Ht.	W.H.	Ht.	W.H.	Ht.	W.H.	Ht.	W.H.	Ht.
1	8.0	10.3	8.5	12.5	8.3	7.8	6.5	7.0	8.3	11.3
2	8.0	9.8	9.0	18.0	8.0	9.0	8.5	9.3	8.3	9.8
3	-	-	8.5	15.0	-	-	6.8	7.5	7.3	7.3
4	7.3	11.5	8.5	14.8	8.5	7.8	8.8	7.5	8.3	10.8
5	7.5	10.3	8.5	14.5	7.5	8.0	6.3	8.0	8.3	8.8
6	8.0	10.3	8.5	13.5	9.0	9.5	8.8	10.0	9.0	11.5
7	7.3	9.5	8.0	10.5	-	-	6.3	6.5	6.8	6.0
8	7.3	10.5	8.8	15.3	-	-	7.8	10.5	7.8	10.0
9	7.8	13.5	8.8	16.0	6.5	7.5	8.0	10.0	7.8	8.5
10	8.5	11.0	9.0	14.0	6.5	6.5	7.5	7.5	8.5	9.5
11	7.5	9.3	7.5	12.0	6.8	6.0	6.3	6.0	7.8	7.8
12	8.0	13.3	8.8	15.3	8.3	9.0	8.3	10.0	8.5	12.0
13	7.0	11.8	8.3	14.5	6.0	7.3	8.3	11.5	7.5	9.5
14	7.5	11.5	8.3	14.5	-	-	7.5	8.3	6.5	7.8
15	8.0	10.5	8.8	17.3	8.0	7.3	8.3	7.5	9.0	12.0
16	8.3	11.5	9.0	16.0	8.3	7.5	7.8	8.0	8.3	10.5
17	7.8	9.0	8.3	10.0	6.3	6.5	7.5	6.0	7.8	7.0
18	8.0	12.8	8.0	15.5	7.8	8.3	8.3	9.8	8.3	11.8
19	7.3	12.8	8.0	15.0	-	-	7.5	9.3	7.5	8.5
20	7.3	11.3	8.0	13.8	6.0	6.8	7.5	8.3	7.5	8.8
21	7.5	10.0	8.5	11.0	5.5	5.0	7.8	6.0	5.3	5.8
22	7.5	11.0	8.5	13.8	7.5	9.0	8.0	9.5	7.8	10.3
23	8.0	10.8	8.5	17.0	7.8	8.0	7.0	6.8	7.8	9.5
24	8.0	10.0	8.5	11.5	7.8	7.3	8.0	7.0	7.3	8.3

ϕRatings of winter hardiness were based on a scale of 0-9, with 9 indicating best winter recovery. Foliage height was measured in inches. All values are averages of four replications.

TABLE XXVI

NOTES ON WINTER HARDINESS (W.H.), SOD DENSITY (S.D.), AND PLANT HEIGHT (Ht.) OF BERMUDAGRASS ENTRIES AT EACH OF THE FIVE LOCATIONS (SPRING 83)ϕ

Entry	Chickasha			Haskell			Lahoma			Perkins			Tipton		
No.	W.H.	S.D.	Ht.	W.H.	S.D.	Ht.	W.H.	S.D.	Ht.	W.H.	S.D.	Ht.	W.H.	S.D.	Ht.
1	8.3	7.8	8.0	9.0	8.8	6.3	8.5	8.5	5.5	8.8	8.3	4.5	9.0	7.8	9.0
2	9.0	8.5	16.5	9.0	6.8	8.8	9.0	8.0	7.5	9.0	7.8	6.5	9.0	7.3	11.0
3	8.5	7.0	12.5	8.5	8.3	6.3	7.5	6.5	5.0	9.0	8.8	4.3	8.5	6.8	10.0
4	8.5	7.5	11.5	8.0	7.8	5.0	8.5	7.3	6.5	9.0	8.0	3.8	9.0	7.3	8.8
5	9.0	8.3	11.5	8.8	8.3	8.0	9.0	8.3	7.3	9.0	8.0	6.3	8.8	7.5	8.8
6	8.0	7.0	8.8	7.8	6.3	7.0	9.0	8.3	6.8	8.0	6.8	5.3	9.0	7.8	12.5
7	8.0	6.7	9.0	9.0	8.0	5.5	7.8	6.5	6.3	8.8	8.0	3.8	9.0	7.3	8.5
8	8.8	8.3	11.8	6.3	5.3	5.8	6.8	6.3	4.3	8.0	7.0	5.0	8.8	7.0	9.5
9	9.0	7.5	16.8	9.0	7.8	9.0	9.0	7.8	8.3	9.0	7.3	7.8	9.0	7.5	11.3
10	8.8	8.0	10.5	8.5	7.3	5.5	9.0	8.0	6.8	9.0	7.8	4.0	9.0	7.0	11.7
11	9.0	8.5	10.5	7.8	7.3	6.5	9.0	9.0	6.0	9.0	9.0	5.0	9.0	8.0	9.8
12	9.0	7.5	14.5	9.0	7.8	7.3	9.0	7.8	6.8	8.8	7.8	6.0	9.0	7.8	11.3
13	9.0	9.0	15.5	7.8	6.5	8.0	6.8	6.5	7.0	8.5	7.3	4.5	9.0	7.0	13.5
14	8.8	8.8	9.0	8.5	8.0	5.5	8.5	7.5	4.8	8.8	7.5	4.3	8.0	6.0	8.5
15	8.5	7.5	13.8	9.0	8.5	6.8	7.5	6.3	6.3	8.8	7.5	4.3	8.8	6.5	12.0
16	8.5	7.3	10.0	9.0	9.0	6.5	7.5	7.0	5.3	8.3	7.5	4.0	8.5	7.3	8.8
17	7.3	7.0	6.7	8.8	8.5	5.3	7.5	7.5	4.5	8.8	8.3	2.5	8.5	7.0	9.0
18	8.8	7.8	15.3	9.0	7.8	6.8	8.5	6.8	6.8	8.8	7.0	4.5	9.0	7.3	10.5
19	8.8	8.3	10.5	9.0	8.5	6.8	6.8	6.5	6.0	8.8	8.3	3.8	9.0	6.8	10.5
20	8.8	7.8	12.3	9.0	9.0	7.0	8.8	8.3	5.8	9.0	9.0	4.0	9.0	7.8	10.5
21	8.3	7.5	9.0	9.0	8.0	5.5	6.8	6.3	5.0	8.8	8.0	4.0	8.0	6.8	8.8
22	9.0	8.5	11.5	7.3	6.5	7.8	7.5	6.8	7.3	8.5	6.8	6.0	9.0	7.0	10.3
23	8.3	7.8	9.5	6.8	6.0	5.3	8.0	7.3	4.5	8.3	7.0	3.3	8.8	6.8	9.0
24	7.8	7.5	8.3	7.0	6.5	4.5	8.8	8.3	5.0	8.5	7.8	3.3	7.8	7.0	8.0

ϕRatings of winter hardiness were based on a scale of 0-9, with 9 indicating best winter recovery.
Ratings of sod density were based on a scale of 0-9, with 9 being most dense.
Foliage height was measured in inches. All values are averages of four replications.

TABLE XXVII

NOTES ON WINTER HARDINESS (W.H.), SOD DENSITY (S.D.), AND PLANT HEIGHT (Ht.) OF BERMUDAGRASS ENTRIES AT EACH OF THE FIVE LOCATIONS (SPRING 84)ϕ

Entry	Chickasha			Haskell			Lahoma			Perkins			Tipton		
No.	W.H.	S.D.	Ht.	W.H.	S.D.	Ht.	W.H.	S.D.	Ht.	W.H.	S.D.	Ht.	W.H.	S.D.	Ht.
1	1.8	6.3	1.0	8.0	8.8	4.3	7.3	7.8	3.0	8.5	7.5	3.3	6.0	5.3	2.8
2	2.8	5.3	1.3	7.0	5.3	4.8	9.0	7.3	5.5	9.0	7.0	5.3	5.5	5.3	3.5
3	1.3	6.5	0.8	3.8	8.8	2.5	4.0	6.5	2.3	7.8	7.5	3.0	6.0	5.3	2.5
4	2.5	5.5	1.5	4.3	7.5	3.3	6.8	7.0	3.3	6.8	6.0	3.5	3.0	2.8	2.0
5	5.5	6.5	3.3	8.8	7.0	4.8	9.0	7.5	4.8	9.0	7.8	6.0	8.8	7.3	4.8
6	2.8	5.5	1.8	4.0	6.8	2.8	5.8	6.5	3.0	6.0	5.5	2.8	5.8	4.8	2.8
7	2.8	6.3	1.5	4.3	8.8	2.5	7.3	7.0	3.5	7.8	7.3	3.0	5.0	4.5	2.0
8	2.8	5.8	1.5	5.3	6.3	2.8	4.0	6.8	2.8	7.0	6.8	3.8	4.8	3.8	2.3
9	4.5	5.8	3.8	9.0	6.8	5.8	9.0	7.5	5.3	8.8	7.3	5.5	6.0	8.0	5.3
10	0.5	7.3	0.8	1.0	8.8	0.8	2.3	8.3	1.8	4.3	5.0	2.5	2.3	1.8	1.5
11	6.8	7.0	4.0	7.5	7.3	4.3	9.0	8.3	4.3	7.8	7.0	4.3	6.8	6.0	3.3
12	3.3	6.0	1.8	7.5	7.8	3.8	9.0	7.3	3.8	9.0	7.5	3.3	8.8	7.8	5.3
13	1.5	5.3	1.0	7.3	6.3	4.3	6.8	6.3	3.8	8.0	7.0	4.0	7.0	5.8	6.8
14	5.5	6.8	2.8	7.8	8.3	3.8	8.0	7.3	3.5	7.5	7.0	3.0	8.5	7.5	4.8
15	2.0	6.0	1.0	2.8	7.0	2.8	5.3	5.8	3.5	7.8	7.3	2.8	3.8	3.0	1.8
16	3.8	5.8	2.3	2.5	7.0	2.5	6.3	7.3	2.8	7.8	7.0	2.8	7.8	6.8	3.8
17	2.5	7.0	1.3	7.8	9.0	3.5	7.0	6.8	3.0	8.3	7.0	3.0	6.3	5.3	2.5
18	2.8	5.8	1.5	4.8	6.5	3.3	8.0	6.8	3.8	9.0	7.8	4.0	7.0	6.0	4.0
19	3.0	6.0	1.5	4.0	7.0	2.5	6.3	6.3	3.0	8.5	7.3	3.5	6.5	6.0	4.0
20	4.3	6.0	2.5	9.0	8.5	4.3	9.0	7.8	3.5	9.0	8.5	3.0	9.0	8.0	4.3
21	2.5	6.3	2.0	5.8	7.5	3.5	3.5	7.5	2.0	7.0	6.5	4.5	5.5	4.8	3.0
22	3.3	5.8	1.8	6.5	6.8	3.5	8.0	6.5	4.0	8.0	6.8	4.5	5.8	5.3	3.8
23	2.3	6.3	1.0	6.5	6.8	3.0	7.8	7.0	3.5	6.5	6.5	2.8	5.0	4.3	2.3
24	3.3	6.5	1.8	8.0	7.3	4.0	7.8	7.3	3.3	7.3	6.8	3.5	5.0	4.5	2.3

ϕRatings of winter hardiness were based on a scale of 0-9, with 9 indicating best winter recovery.
Ratings of sod density were based on a scale of 0-9, with 9 being most dense.
Foliage height was measured in inches. All values are averages of four replications.

VITA

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Master of Science

Thesis: GENOTYPE BY ENVIRONMENT INTERACTION STUDY OF BERMUDAGRASS FORAGE YIELD IN OKLAHOMA

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