GENOTYPE BY ENVIRONMENT INTERACTION STUDY OF YIELD FOR GRAIN SORGHUM IN OKLAHOMA

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CHAPTER I

PREFATORY STATEMENT

The macroenvironment in Oklahoma varies from location to location within any one year and also from year to year at any specified location. Practical experience suggests, however, that a certain degree of predictability does exist for the state as a whole while even more predictability exists when only portions of the state are considered.

Sorghum [*Sorghum bicolor* (L.) Moench] constitutes one of the major grain crops produced in Oklahoma. By state law, commercial seed companies must enter their hybrids in state-conducted performance trials prior to marketing those hybrids within the state. Grain sorghum performance trials are currently conducted at 10 locations throughout the major agricultural regions of Oklahoma for that purpose.

Using 1973 through 1978 data from those test locations, the effects were studied that genotype by environment interaction may have on grain yield responses for sorghum. Such an investigation should be of value because previous studies of a similar nature on numerous other crops have supplied evidence in regard to future cultivar evaluations and breeding efforts.

The format of this paper, beginning with Chapter II, reflects the standards set forth in the 1976 edition of the "Handbook and Style Manual for ASA, CSSA, and SSSA Publications" as published by the Crop Science Society of America.

CHAPTER II

GENOTYPE BY ENVIRONMENT INTERACTION STUDY OF YIELD FOR GRAIN SORGHUM IN OKLAHOMA

ABSTRACT

This study was conducted to examine the statistical significance of the mean squares pertinent to a genotype by environment interaction investigation and to compare the relative magnitudes of their corresponding variance components to ascertain what changes might be implemented in future testing and breeding of grain sorghum (_Sorghum bicolor_ (L.) Moench) in Oklahoma. Grain yield data were obtained from representative hybrids belonging to the three maturity types (early, medium, and late) entered in the sorghum performance trials conducted in Oklahoma at three irrigated and seven dryland locations over six years. Analyses of variance combined over all locations were evaluated for each of the independent maturity groups and two-year periods: 1973-1974, 1975-1976, and 1977-1978. Locations were then subgrouped together into relatively homogeneous testing environments based primarily on the significance of the genotype by location interactions for the three maturity types, and the relative sizes of the genotype by location components compared to the genotype components. The genotype by year and genotype by location by year interactions were also considered in deriving future testing and breeding implications for Oklahoma.

Based on the data and methods used, it was determined that two irrigated tests for all maturity types, one at Goodwell and the other at Tipton, should be conducted; that two additional dryland tests for the early-maturing sorghums should be conducted at Boise City and Mangum; and that four dryland tests for the medium- and late-maturing hybrids should be conducted at Boise City, Mangum, Haskell, and Chickasha or Stratford.

Additional index words: Sorghum bicolor (L.) Moench, Performance testing, Maturity-type evaluation, Sorghum breeding.

CHAPTER III

INTRODUCTION

Sorghum (*Sorghum bicolor* (L.) Moench) is one of the major grain crops grown in Oklahoma, and it is produced over a wide range of environmental conditions. Performance trials for sorghum are currently conducted each year in the state at 10 locations, seven dryland and three irrigated, at a considerable expense in time, energy, and research funds (5). See Fig. 1 for the specific locations in use.

Oklahoma's climate is characterized as continental in type. Summers are long and hot, and winters are usually short and cold. Maximum precipitation occurs in the spring and decreases through the summer with May usually being the wettest month. The rainfall distribution in the state decreases sharply from east to west (12). See Fig. 2 for mean annual rainfall patterns for the state.

Comstock and Moll (4) indicated that the effects of genotype and environment are not independent and that the primary concern about genotype by environment (GE) interactions centers around the way in which such interactions reduce the efficiency of genotype evaluation. For that reason, it is important to obtain information on genotype by location, genotype by year, and genotype by location by year interactions for the various traits of a crop. With those estimates, it should be possible to make rational decisions on the allocation and number of locations and years to be used in performance trials (13), whether of strains, cultivars, or hybrids. The purpose of this study was to examine GE interactions for grain sorghum in Oklahoma and to consider their implications on future sorghum testing and breeding within the state.

Not a great deal is known about GE interactions in sorghum. Liang and Walter (8) studied 21 sorghum hybrids at seven locations over two years in Kansas. They found the two-factor interactions for yield were significant, but those interaction components were relatively small compared to the three-factor interaction and genetic variance components. They concluded that grouping locations together into regions of the state reduces the magnitude of the genotype by year and the genotype by location interactions, but did not seem to have a consistent effect on the second-order interaction. Unpredictable climatic patterns in Kansas coupled with local factors such as soil types and management practices were suggested as sources of the three-factor interactions. Roa (14) conducted GE research on sorghum grain and fodder yield, plant height, and days to mid-bloom at 18 locations during the years 1963-1964 in India. He determined that the second-order interaction and the genotype by location interaction were significant for each trait. Relative to the component estimates for genotype, his estimates for genotype by location, genotype by location by year, and error were larger than the genotype by year interaction for yield.

CHAPTER IV

MATERIALS AND METHODS

Data used in this study were collected from 6 years, 1973 through 1978, of hybrid sorghum performance trials conducted at 10 locations in Oklahoma for the three sorghum maturity groups, i.e., early, medium, and late.

The 10 locations were Boise City, Mangum, Lahoma, Perkins, Chickasha, Stratford, and Haskell under dryland conditions and Goodwell, Tipton, and Altus where irrigation was possible. All major environments in Oklahoma where sorghum is grown are represented by at least one of those locations. Boise City and Goodwell in the far western part of the state typify the High Plains or northwestern Panhandle region of Oklahoma. Boise City has a soil complex of Mansker loam, a member of the fine-loamy, carbonitic, thermic Calciorthidic Paleustolls and Dalhart loam, a member of the fine-loamy, mixed, mesic Aridic Haplustalfs. Goodwell has a Richfield clay loam, a member of the fine, montmorillonitic, mesic Aridic Argiustolls. Tipton, Altus, and Mangum, in the southwestern part of the state, are characterized by semi-arid moisture conditions and high summer temperatures. Tipton has a Tipton silt loam, a member of the fine-loamy, mixed, thermic Pachic Argiustolls. Altus has a soil complex of Tillman clay loam, a member of the fine, mixed, thermic Typic Paleustolls, and Hollister clay loam, a member of the fine, mixed, thermic Pachic Paleustolls. Mangum has a Meno sandy loam, a member of the loamy, mixed, thermic Aquic Arenic Hapustalfs. Lahoma, Chickasha, Perkins, Stratford, and Haskell represent the central and eastern portions of the state receiving increasing average rainfall amounts compared to the western regions. Lahoma has a Pond Creek silt loam, a member of the fine-silty, mixed, thermic Pachic Argiustolls. Chickasha has a Reinach silt loam, a member of the coarse-silty, mixed, thermic Pachic Haplustolls. Perkins has a Teller loam, a member of the fine-loamy, mixed, thermic Udic Argiustolls. Stratford has a Vanoss fine sandy loam, a member of the fine-silty, mixed, thermic Udic Argiustolls. Haskell has Taloka silt loam, a member of the fine, mixed, thermic Mollic Albaqualfs.

An effort was made to maximize entries and locations within a data set. Eleven, nine, and five early maturing varieties were entered and evaluated for the two-year increments of 1973-1974, 1975-1976, and 1977-1978, respectively. In addition, three different representative sets of seven medium-maturing hybrids; and three sets of the late-maturing hybrids, numbering: 24, 22, and 32, were studied during the same time periods, respectively. Each year-maturity group-hybrid combination was totally independent of the others.

Plots consisted of one row for each location, except for the irrigated locations where two row plots were used. Plot lengths were 13.7 m at all locations, except for 7.6 m at Boise City and 8.5 m at Goodwell. Tipton and Altus had 1.0 m between plots and 0.3 m between rows within plots. Plants were thinned to 15.2 cm apart at Mangum, Chickasha, and Boise City; 7.6 cm at irrigated locations, and 10.2 cm for the remainder of the locations. Yield data were obtained by hand harvesting representative lengths within each plot. Heads were threshed with a 250 V Vogel small grains thresher. Grain weight per plot was converted into kg per hectare. All plots were fertilized in accordance with recommendation based on soil tests and anticipated yield potentials. Nitrogen application was based on expected moisture availability at each location. All experiments were sprayed irregularly as required over the six years for greenbugs except for the Goodwell test, which received treatment annually with ethyl parathion.

Sorghum hybrids were entered in a split-plot randomized complete block experimental design with three replications. Randomization was such that hybrids were grown within their respective maturity groups, i.e., main plots. Subplots (hybrid entries) were randomized within main plots. A conventional analysis of variance was used for each of the two-year time periods, maximizing numbers of locations in each analysis (consistent with a balanced design). Each of the maturity groups were analyzed separately. Bartlett's (1) test for homogeneity of variance indicated that the individual time-period analyses could not be pooled. The model and methods outlined by Comstock and Moll (4) were used to analyze the data. Interpretation as discussed by Comstock and Moll (4), Miller et al. (9), and Miller et al. (10) were followed as guidelines in the interpretation of these results. Cochran's (3) methods for deciding upon appropriate F-tests and degrees of freedom were also employed.

CHAPTER V

RESULTS AND DISCUSSION

Estimates of variance components pertinent to a GE study and their corresponding mean square significance levels for the early-, medium-, and late-maturity groups are given in Tables 1, 2, and 3, respectively.

Early-Maturing Hybrids

In Table 1, the three analyses over all locations show the genotype by year (GY) interaction for early maturing hybrids not significant at even the 0.10 level of probability or higher. The response of early hybrids to years is thus similar from one year to the next.

The genotype by location (GL) interaction component over all locations was significant ($P<0.10$ or 0.05) for the two-year periods, 1973-1974 and 1977-1978, but not for 1975-1976. Where significant, the GL component was very large relative to the genotypic (G) component. (Negative variances are theoretically impossible; but where such estimates are actually obtained, it is usually assumed that the estimates are either zero or a relatively small positive number and that sampling variation was responsible for the negative estimate (11). In this experiment, such estimates were assumed to be zero.) A significant GL interaction suggests that some of the location effects evoke some predictable differential responses among the hybrids. In other words, certain hybrids ranked fairly consistently relative to one another during the test periods from location to location. If a GL component is relatively large in magnitude, it may indicate that a large portion of the differential genotypic responses for that trait could be accounted for by relatively consistent differences in the sorghum-growing locations. In a sense, the relative size of GE components indicates in a practical manner the relative importance of a corresponding source of variation. The corresponding mean square significance tends to suggest statistical importance (9), i.e., whether or not that component can be demonstrated to be present. By grouping locations, a reduction in the magnitude of the GL interaction would be expected. In addition, it should also become statistically nonsignificant as the testing environment tends to become more homogeneous (6, 10).

The genotype by year by location (GYL) interaction over all locations was relatively large compared to the G component and significant for two of the three periods. A large and significant three-factor interaction suggested that the hybrids exhibited unpredictable differential responses when grown in different environments (8, 9, 10), and that testing in multiple environments is necessary. Based on the significance levels and relative sizes of the GY and GL components, in determining those multiple environments which should be used more emphasis should be placed on location than on years. The grouping of locations together into subgroups did not appear to have a consistent effect on the significance level or magnitude of the second-order interaction.

Three of the 10 locations were irrigated. It seemed logical to separate those locations from the dryland locations for initial groupings because of the profound effect of moisture availability on crop yield. Yield data for the irrigated and dryland locations were reanalyzed separately; and those results are presented in the third and fourth columns, respectively, of Table 1. The GY and GL interactions were not significant at the 0.05 probability level in any case for either grouping. The GL interaction component was significant at the 0.10 level in one data set, i.e., dryland in 1973-1974; and it was only about 50% as large as the G component. Apparently, testing early-maturing hybrids more than one year is not necessary; and because the GL interactions were not significant or large in nearly all cases, evidence exists that the irrigated and dryland groups of locations each represent a nearly homogeneous environment (8, 9, 10). If an environment is homogeneous, a minimum of only one test is necessary to obtain reliable estimates for the relative yield performance of a crop. The three-factor interactions were highly significant ($P<0.01$) for both irrigated and dryland locations, except for 1977-1978 under dryland. This points out that hybrids were exhibiting unpredictable differential responses in the different environments and that tests in different environments are necessary to obtain reliable estimates of relative yield performance for early-maturing sorghums. The GYL interaction does not, however, give any clue as to how the testing for early maturing hybrids should be distributed to sample those environments. Considering the relative significance levels and magnitudes of the GY and GL components and that occasionally experiments are unsuccessful for one reason or another, probably two irrigated and two dryland locations per year are required.

Medium-Maturing Hybrids

In Table 2 are provided the results from analyses involving the medium-maturing hybrids. Over all locations, the GY interaction was significant for 1975-1976 only. The GL interaction was significant ($P < 0.10$) in two of three cases. The GYL interaction was significant ($P < 0.10$) in two of three cases. The GYL interaction was significant ($P < 0.05$) for 1973-1974 and 1975-1976 and highly significant ($P < 0.01$) for 1977-1978. On the basis of the two GL interactions being significant, it was decided that sufficient risk was involved to necessitate grouping locations into irrigated vs. dryland. Results from the reanalysis of those groups were similar to those given in Table 1 for the early-maturing hybrids.

The GY interaction for the irrigated locations were significant ($P < 0.05$) and has a relatively large component compared to G. The GL and GYL interactions were also significant ($P < 0.10$) and had large components. Because two of the three analyses for the irrigated group were not significant for the GL interaction and a significant ($P < 0.05$) GY interaction also occurred in only one of three instances, it is apparent that irrigated tests for medium-maturing hybrids need only be done in one location and one year. However, because of the large and significant GYL interactions, testing in multiple environments are again necessary. Because it is possible to obtain the same amount of information more quickly by testing over locations than by testing over years, probably two locations are required to adequately test medium-maturing hybrids under irrigation.

In the dryland data column the GL interaction was significant and large in two of the three years, i.e., ($P < 0.05$) for 1975-1976 and

($P < 0.10$) for 1977-1978. Therefore, it was deemed necessary to subdivide the dryland group in some manner by omitting one or more locations from the analysis. Boise City seemed a logical location to omit because it receives on the average considerably less annual precipitation than the other locations (Fig. 2). Because the Boise City location was not used in the 1975-1976 analysis, data columns three and four reflect the same statistics for this time period. Inspection of the data in column four reflects evidence that subdivision is still necessary because two of the three GL interaction components were still large and significant relative to G. Boise City and Mangum (the next driest dryland location) were both then omitted. The data from the ensuing analyses are given in the last column of that table. The GL interactions after that last subdivision were not significant in any of the three analyses. For two of the three cases, the GYL interaction was not significant either. This points to the need for a minimum of one test location to adequately sample varietal responses in this group of locations. To test medium-maturing hybrids on dryland, the Boise City and Mangum locations are probably needed in western Oklahoma plus two of the other five locations currently in use.

In Table 4 under the medium-maturity column heading are variance components and their corresponding mean square significance levels from analyses of Boise City and Mangum together for the years, 1973-1974 and 1977-1978. Because the GL interaction is significant ($P < 0.05$) and its component so large relative to G in 1977-1978, it would imply that Boise City and Mangum should be treated as representing different environments. Even so, this may not be a true indication because during 1973-1974 no differences were evidenced. The nonsignificant GY interaction for both analyses seems to indicate that minimal attention in these tests need be given to years.

Late-Maturing Hybrids

In Table 3 are the pertinent variance components and their corresponding mean square significance levels for grain yield in late-maturing sorghum hybrids. The mean square significance levels appear to be somewhat similar to those pointed out for the medium-maturing hybrids. Following a similar type reasoning process as before, all locations were subgrouped into irrigated vs. dryland. The irrigated locations required no further subdivisions whereas the dryland locations did. Two of the three GL cases omitting Boise City in column four were significant at the 0.10 probability level. Because of the unpredictable nature of the Oklahoma climate, this was judged to present sufficient risk to justify subdividing the dryland group of locations as was done for the medium-maturing hybrids, i.e., Boise City and Mangum vs. the others.

In Table 4 under the column heading for late-maturing hybrids, are variance components and their corresponding mean square significance levels for the years, 1973-1974 and 1977-1978, for the combined analyses of Boise City and Mangum. Once again, one of the GL interactions was significant but not the other. Such evidence was judged to be sufficient to treat Mangum and Boise City as being separate environments for variety testing. The GY components for late-maturing hybrids appeared to be consistently more important on dryland than under irrigation and more important for late-maturing types than for early- or medium-maturing ones. The GYL interactions were significant in almost every case for the late-maturing hybrids.

Testing and Breeding Implications

A number of items need to be considered with respect to the above statistical results and their implications on future testing and breeding procedures for the state of Oklahoma. Moisture availability appears to continue to be the dominant environmental factor with which crops (specifically sorghum in this case) must contend. Subgroupings of irrigated locations usually did not exhibit significant GL components, whereas, dryland locations usually did, especially for the medium- and late-maturing hybrids. The necessity of sound methods for predicting crop performance are needed under the environmental conditions which exist in the state.

Bilbro (2) stated that increases in dryland acreages are expected in the future as a result of irrigation water depletion. The need for having more than one dryland or irrigated test for the state as a whole would be an absolute necessity due to the everpresent possibility of crop failure at any specific location. For the early- and medium-maturity groups of sorghum hybrids, the GY interaction was generally not significant. The hybrid responses for a location were generally similar from one year to the next. The GYL interaction was significant for all maturity groups in most analyses suggesting that multiple environments within an area must be sampled for accurate estimation of hybrid differences. Because the presence of these interactions does not indicate how experiments should be distributed over locations and years and because GL is generally more important than GY for sorghum in

Oklahoma, more emphasis should be given to locations than years in deciding which test environments to use.

Despite the evidence implied from nonsignificant GL interaction components that only one location would be sufficient to predict yield performance for the irrigated locations, the necessity of two tests would seem to be in order. If only one test is planted and that test is lost due to hail (or some other environmental hazard), a complete test year would be lost. Having two irrigated experiments would make the complete loss of a test year much more unlikely. The three Oklahoma counties in the Panhandle have consistently ranked either 1, 2, 3, or 4 in grain sorghum production in the state and counties in the Southwest have ranked anywhere from fourth to tenth. Having one irrigated test for each maturity type of sorghum in the Panhandle at Goodwell and one in the Southwest part of the state should be adequate for those two major production areas. At present, two irrigated tests are conducted in the Southwest. Because the Altus location receives only supplemental irrigation water, it seems reasonable to omit it as a test location and retain the test at Tipton. Thus, the irrigated tests should be reduced from three to two. Though GY components were generally not significant, GYL components almost always were. Therefore, these tests should probably be conducted in two years to be more confident that the multiple environments required by significant GYL components are fulfilled. Three or more years are probably not necessary.

For the early-maturing hybrids, the statistical evidence seems to point out that all dryland tests presently being conducted could be adequately replaced by just one test to characterize hybrid responses for the state as a whole. However, the possibility of crop failure would demand that two tests be conducted. One test should probably be located at Boise City since it would give greatly needed input to dryland sorghum performance in the Panhandle counties where sorghum is a major crop. A second test could be located at any of the other remaining dryland sites, of which Mangum would probably be the most practical because of its location in the midst of the major southwestern sorghum-producing counties. These tests, in accordance with the nonsignificant GY interactions, but significant GYL interactions, need only be conducted over a two-year period.

The statistical evidence given earlier and the possible implications it may have for the dryland tests make it appear that for the medium- and late-maturing hybrids, there exists essentially two regions in the state in which dryland tests should be conducted. Those regions are the western region which comprises two locations, Mangum and Boise City, and the eastern region which consists of the remaining locations. Of those remaining locations, counties in northeastern Oklahoma will many times rank in the top 10 in grain sorghum production per acre. Therefore, to encourage production in that part of the state, one location for medium- and late-maturing sorghum hybrid testing should probably be located at Haskell. A second location for the medium- and late-maturing hybrids should probably be conducted at either Chickasha or Stratford.

The same subdivisions required to adequately test sorghum hybrids would be required for use in the sorghum breeding program to maximize progress per unit of time.

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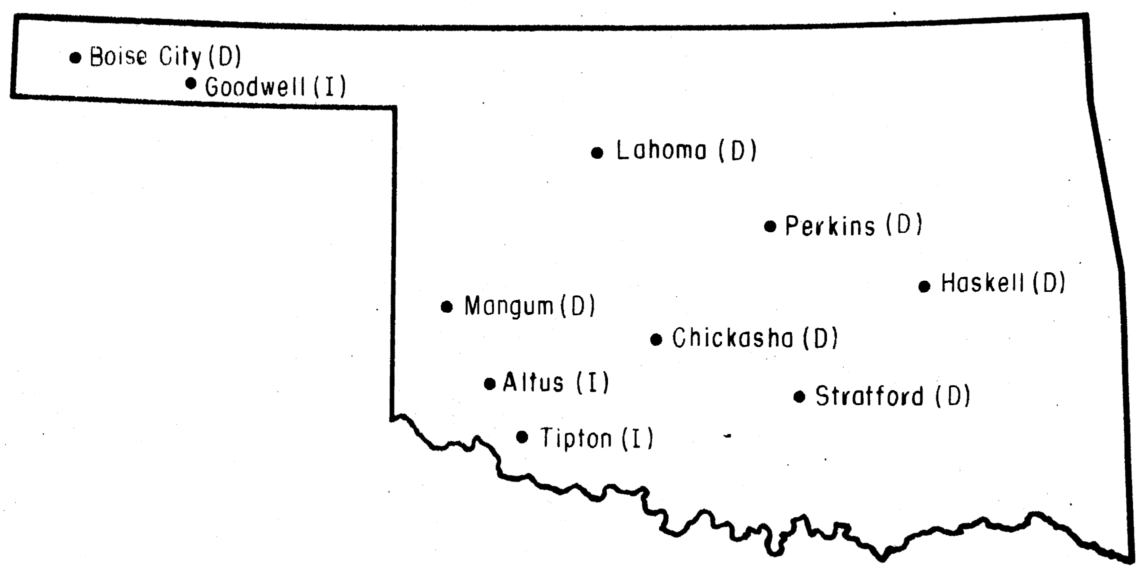

Fig. 1. Locations of current sorghum performance trials in Oklahoma (I = irrigated and D = dryland locations).

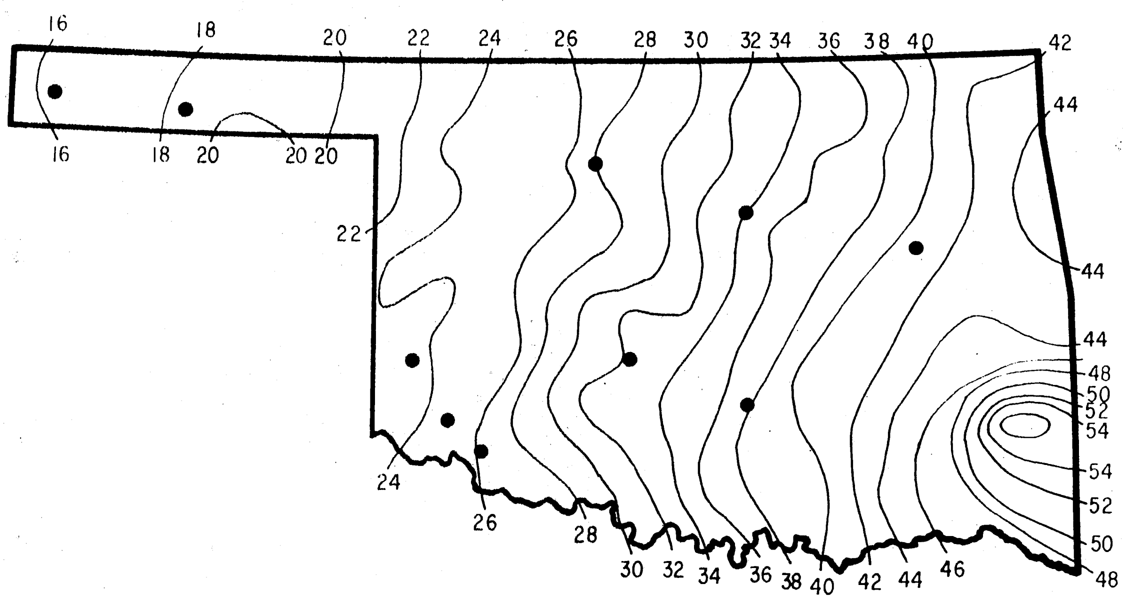

Fig. 2. Long-time mean annual precipitation (in inches) in Oklahoma (one inch = 2.54 cm).

Table 1. Estimates of variance components and their corresponding mean square significance levels for grain yield in early-maturing sorghum hybrids.

Components and years	Locations		
	All	Irrigated	Dryland
1973-1974			
$\hat{\sigma}^2_G$	12,902 *	659,598 **	84,573
$\hat{\sigma}^2_{GY}$	2,291	000 ‡	425
$\hat{\sigma}^2_{GL}$	43,371 †	000	45,497 †
$\hat{\sigma}^2_{GYL}$	190,209 **	523,634 **	98,458 **
$\hat{\sigma}^2_E$	249,584	283,065	235,235
1975-1976 §			
$\hat{\sigma}^2_G$	336,517 **	499,956 **	292,442 **
$\hat{\sigma}^2_{GY}$	000	000	000
$\hat{\sigma}^2_{GL}$	32,045	109,688	000
$\hat{\sigma}^2_{GYL}$	204,170 **	347,786 **	178,736 **
$\hat{\sigma}^2_E$	346,440	495,201	272,061
1977-1978 ¶			
$\hat{\sigma}^2_G$	000	68,607	8,243
$\hat{\sigma}^2_{GY}$	000	000	000
$\hat{\sigma}^2_{GL}$	91,934 *	182,353	000
$\hat{\sigma}^2_{GYL}$	33,123	000	95,472 **
$\hat{\sigma}^2_E$	444,425	866,684	191,071

†, *, ** Significant at the 0.10, 0.05, and 0.01 levels of probability, respectively. ‡ Negative estimates for which the most reasonable values are zero. § Boise City not included. ¶ Chickasha and Lahoma not included.

Table 2. Estimates of variance components and their corresponding mean square significance levels for grain yield in medium-maturing sorghum hybrids.

Components and years	Locations				
	All	Irrigated	Dryland	Dryland §	Dryland ¶
1973-1974					
$\hat{\sigma}^2_G$	416	000	000	000	000
$\hat{\sigma}^2_{GY}$	000 ‡	25,416	12,506	26,802 *	24,134 †
$\hat{\sigma}^2_{GL}$	000	000	6,416	14,804	25,079
$\hat{\sigma}^2_{GYL}$	60,185 *	123,697 *	9,317	000	4,082
$\hat{\sigma}^2_E$	316,882	335,083	309,081	347,858	299,424
1975-1976 #					
$\hat{\sigma}^2_G$	22,268	103,427	5,612	5,612	14,659
$\hat{\sigma}^2_{GY}$	23,096 *	6,053	22,222 *	22,222 *	17,941 †
$\hat{\sigma}^2_{GL}$	31,640 †	000	39,217 *	39,217 *	9,753
$\hat{\sigma}^2_{GYL}$	46,192 *	159,352 *	000	000	6,212
$\hat{\sigma}^2_E$	275,202	401,334	212,136	212,136	198,293
1977-1978 ††					
$\hat{\sigma}^2_G$	14,149	2,989	000	000	000
$\hat{\sigma}^2_{GY}$	14,572	137,418 *	8,271	13,378	35,041
$\hat{\sigma}^2_{GL}$	51,051 †	120,765 †	32,733 †	42,559 †	8,949
$\hat{\sigma}^2_{GYL}$	101,231 **	73,545 †	50,434 **	57,128 **	65,532 *
$\hat{\sigma}^2_E$	193,871	306,296	126,415	148,805	150,739

†, *, ** Significant at the 0.10, 0.05, and 0.01 levels of probability, respectively. ‡ Negative estimates for which the most reasonable values are zero. § Boise City not included. ¶ Boise City and Mangum not included. # Boise City not included. †† Chickasha and Lahoma not included.

Table 3. Estimates of variance components and their corresponding mean square significance levels for grain yield in late-maturing sorghum hybrids.

Components and years	Locations				
	All	Irrigated	Dryland	Dryland §	Dryland ¶
1973-1974					
$\hat{\sigma}^2_G$	46,617 **	149,906 **	18,016	26,056 †	9,982
$\hat{\sigma}^2_{GY}$	7,959	000 ‡	22,255 **	35,554 **	41,491 **
$\hat{\sigma}^2_{GL}$	18,568	000	24,138 †	20,613 †	19,449
$\hat{\sigma}^2_{GYL}$	102,207 **	233,612 **	52,314 **	46,081 **	62,727 **
$\hat{\sigma}^2_E$	344,880	419,103	313,070	351,574	269,261
1975-1976 #					
$\hat{\sigma}^2_G$	29,992 *	65,411 †	000	000	12,975
$\hat{\sigma}^2_{GY}$	23,674 *	12,567	35,031 *	35,031 *	21,765 †
$\hat{\sigma}^2_{GL}$	36,792 †	64,966	36,842 †	36,842 †	11,352
$\hat{\sigma}^2_{GYL}$	115,309 **	157,929 **	88,195 **	88,195 **	38,003 †
$\hat{\sigma}^2_E$	447,635	535,762	403,572	403,572	427,937
1977-1978 ††					
$\hat{\sigma}^2_G$	1,884	8,236	000	1,897	000
$\hat{\sigma}^2_{GY}$	16,948 *	63,994 *	12,433 †	12,532	20,493 †
$\hat{\sigma}^2_{GL}$	16,266 †	30,249	6,296	6,230	18,548
$\hat{\sigma}^2_{GYL}$	52,335 **	12,525	52,508 **	62,631 **	51,261 **
$\hat{\sigma}^2_E$	390,182	690,298	210,112	237,867	205,790

†, *, ** Significant at the 0.10, 0.05, and 0.01 levels of probability, respectively. ‡ Negative estimates for which the most reasonable values are zero. § Boise City not included. ¶ Boise City and Mangum not included. # Boise City not included. †† Chickasha and Lahoma not included.

Table 4. Estimates of variance components and their corresponding mean square significance levels for grain yield in medium- and late-maturing sorghum hybrids for the Boise City and Mangum locations.

Components and years	Maturity groups	
	Medium	Late
1973-1974		
$\hat{\sigma}^2_G$	16,614	14,800
$\hat{\sigma}^2_{GY}$	000 ‡	000
$\hat{\sigma}^2_{GL}$	000	59,163 †
$\hat{\sigma}^2_{GYL}$	70,918	31,746
$\hat{\sigma}^2_E$	333,224	460,803
1977-1978		
$\hat{\sigma}^2_G$	000	000
$\hat{\sigma}^2_{GY}$	000	7,210
$\hat{\sigma}^2_{GL}$	106,821 *	3,934
$\hat{\sigma}^2_{GYL}$	17,325	47,512 *
$\hat{\sigma}^2_E$	214,076	275,250

†, *, ** Significant at the 0.10, 0.05, and 0.01 levels of probability, respectively. ‡ Negative estimates for which the most reasonable values are zero.

VITA 2

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Candidate for the Degree of

Masters of Science

Thesis: GENOTYPE BY ENVIRONMENT INTERACTION STUDY OF YIELD FOR GRAIN SORGHUM IN OKLAHOMA

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