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Genotype-environment interactions of data for fifteen years from Tennessee small grain variety trials

Charng-wuu Wu

To the Graduate Council:

I am submitting herewith a dissertation written by Charng-wuu Wu entitled "Genotype-environment interactions of data for fifteen years from Tennessee small grain variety trials." I have examined the final electronic copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Plant, Soil and Environmental Sciences.

Vernon H. Reich, Major Professor

We have read this dissertation and recommend its acceptance:

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To the Graduate Council:

I am submitting herewith a dissertation written by Charng-wuu Wu entitled "Genotype-Environment Interactions of Data for Fifteen Years from Tennessee Small Grain Variety Trials." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Plant and Soil Science.

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GENOTYPE-ENVIRONMENT INTERACTIONS OF DATA FOR FIFTEEN YEARS FROM TENNESSEE SMALL GRAIN VARIETY TRIALS

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Charng-wuu Wu

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ABSTRACT

The objectives of this study were to obtain estimates of the relative magnitudes of the various types of genotype X environment interactions on variety evaluation procedures, and to determine the correlations of yield among all locations.

Data from the University of Tennessee Agricultural Experiment Station performance trials from 1963 to 1977 were utilized for this research. Twenty-two varieties of winter wheat at eight locations, 15 varieties of winter barley and 11 varieties of winter oats at six locations were evaluated.

The genotype X environment interactions were all significant, except genotype X year interaction for oats. The magnitudes of their components were relatively small in relation to genotype components, except genotype X year interactions for wheat and barley. These results indicated that there was an important differential response to specific environmental conditions which was not accounted for by locations, but some differential varietal responses might be accounted for by years.

The correlations of variety performances for wheat and barley were significantly correlated among most of the locations. However those for oats were not significantly correlated among most of the locations. These results indicated that the varieties of wheat and barley were more generally adapted, whereas, varieties of oats were more restricted to certain locations.

Yield testing in environments which tended to result in similar rankings of variety performance could be reduced to a smaller number of environments. This could result in substantial savings to a breeding project for the expensive task of yield testing.

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CHAPTER I

INTRODUCTION

Variety tests conducted for the purpose of comparing grain yield of elite experimental lines and newly released varieties with a standard variety are of considerable importance in plant breeding programs. These tests are usually grown over several years and many locations; accordingly, it seems desirable to obtain information on the importance of genotype-environment interactions in varietal tests conducted under such circumstances. These interactions could provide information about the effect of different years and locations on variety performance and have value for assessing the stability of performance of new varieties.

The environmental variation is sometimes very large. The variation at a single location over years can be as great as that between locations in one year. Therefore, breeding of varieties with broad adaptation is a goal of many breeders. However, development of varieties generally results from the selection of favorable plant types grown in a limited set of environments. Evaluation of materials in a wide range of environments is expensive and often impossible due to a limited quantity of seed.

The University of Tennessee Agricultural Experiment Station conducts variety tests of wheat (*Triticum aestevum* L. emthell), barley (*Hordeum vulgare* L.), and oats (*Avena sativa* L.) at several locations across Tennessee each year. The purpose of this testing program is to evaluate the performance of varieties of these crops and to recommend the suitable varieties to farmers or other agencies.

The data from the variety tests of these crops from 1963 to 1977 were utilized in this study. The procedure of least-square analysis of data involving computerized computation of analyses of variance was followed.

The objectives of this study were to:

1. Analyze the magnitude of genotype, genotype X environment, and error variances for yield and certain other characters of wheat, barley, and oats grown in Tennessee.

2. Estimate the correlation of variety performance in all possible location combinations and, utilizing least-squares means, determine which locations would provide the most meaningful information if there was a failure at another location.

CHAPTER II

LITERATURE REVIEW

Research workers, mainly in the United States, have reported estimates of genotype X environment interactions and have drawn some general conclusions about the relative magnitudes of the different variances. Comstock and Moll (5) have shown that the variances which are pertinent to plant breeding problems are those associated with variety X year, variety X location, and variety X year X location interactions.

In studying the variety X location interaction, Horner and Frey (14) obtained estimates for spring oats from nine locations in Iowa for five years. The variety X location component was reduced by 11, 21, 30, and 40 percent, respectively, when the area was subdivided into two, three, four, and five subareas. Liang et al. (18) in Kansas, evaluated ten varieties of winter wheat at 13 locations, four varieties of winter barley at ten locations, and five spring oats varieties at five locations for a three-year period. They reported that the variety X year interactions were small and often nonsignificant, but the second-order interactions of variety X location X year were highly significant. Significant variety X location interactions were obtained for wheat and barley, indicating the state could be divided into subareas. However, they suggested that each subarea should be considered as an independent unit in testing the significance of variety X location interaction because the decrease or increase in the magnitude of variety X location mean squares of subareas does not always provide the true picture of significance when compared to that for the state as a whole. Gandhi et al. (9) conducting trials with wheat in India, reported that the second-order interactions have generally been smaller than either the vareity X year or variety X location interactions, and, also, the vareity X year interacton was smaller than the variety X location interaction. On the basis of the large interaction of variety X location, they suggested that the number of locations must be increased.

Kaltsikes (16) estimated genotype X environment interaction variances from western Canada's cooperative fall rye test grown from 1963 to 1967 and determined that all first-order interactions were significantly greater than zero at the 0.05 level of probability. Testing at 20 locations for three years with four replicates could detect yield differences as small as 10 percent of the mean of the highest yielding cultivar. He concluded that for further reduction of the measurable yield difference, more locations would be necessary. Campbell and Lafever (3) used Uniform Eastern Soft Winter Wheat Nursery data from nine locations and three years as a basis for examining cultivar selection and testing procedures in the Northern Soft Red Winter Wheat Region. They reported that cultivars should be tested more than one year; however, testing more than three years appeared to be of little value, especially as the number of locations was increased.

Sprague and Federer (25) using corn yield trials determined the optimum number of years, locations, and replications for maximizing genotypic gain. Apart from cost considerations, their conclusion was to increase the number of locations at the expense of replications at each location.

In studying the performance of four varieties of upland cotton in 101 environments across the Cotton Belt of the Southern United States, Abou-El-Fittouh et al. (1) found that for all traits other than yield, a three-factor interaction was the predominant interaction component of variance and, except for seed index and lint percent, the genotype X year component was the least important. They pointed out that the relative importance of the genotype X location component would be expected to increase as the reference base of locations is expanded.

However, other workers have reported different results in their studies. In studying the variety X year interaction, from an analysis of data from long-term variety tests of wheat, Salmom(23) concluded that the variety X year interaction for yield was substantial and that it would be advantageous in many variety testing programs to use relatively few replications and several years. Rasmusson and Lambert (20), utilizing data from eight locations for a four-year period involving six varieties to estimate the variety X environment interactions for yield in barley varietal tests, reported that a highly significant variety X year X location interaction was obtained. The variety X year component was substantially smaller, but was significant at the 5 percent level, whereas the variety X location interaction was not significant. They concluded that there was an important differential response to specific environmental conditions which was not accounted for by either year or location groupings. They suggested that the use of additional years, locations, or replicates was most effective in that order named in reducing the standard error of a theoretical variety mean.

Two populations of F_3-derived lines of barley were studied by Rasmusson and Glass (21) in the F_5, F_6, and F_7 generations. The genotype X location, genotype X year, and genotype X location X year components of variance were smaller in magnitude than the genotypic and error components in both populations for all traits except one. With a few exceptions, the genotype X location X year component of variance was larger than the genotype X location or genotype X year component. The genotype X year component was larger than the genotype X location component in nearly all cases. The data indicated also that replication in their test was unnecessary.

Reitz and Salmon (22), summarized 20 years of improvement of hard red winter wheat in the United States, and concluded that uniform regional nurseries at locations in several states provide useful information in a few years on adaptacion of varieties that would require many years if evaluation were restricted to one or a few locations. Interstation correlations of variety yields in regional nurseries usually were equal to, and only occasionally larger than, interannual correlations at a single station. They suggested that environment, even at a single location, cannot easily be identified with a particular set of environmental factors, and that general adaptation would be important even in a restricted area of production of a variety. However, using the regression technique of Finlay and Wilkinson (8), Walton (30) analyzed the behavior and adaptability of widely grown commercial strains of Canadian hard spring wheat and showed that the advantage derived from rust-resistant varieties has been to increase yields under high productivity conditions. Therefore, he concluded that an attempt to produce varieties of wide adaptation, while worth undertaking, is less likely to succeed than is a breeding program whose objectives are closely related to the local needs of the area in whkch the work is conducted.

Joppa, Lebsock and Bubch (15) reported on the yield stability of selected spring wheat cultivars grown in the Uniform Regional Spring Wheat Nurseries from 1959 to 1968 using the model of Eberhart and Ressell (6). They concluded that the use of the regression analysis on such data could materially absist the plant breeder in making decisions regarding cultivar release. Stroike and Johnson (27) studied the performance stability of 28 cultivars grown in an International Winter Wheat Performance Nursery in 1969 and 1970. The statistical model developed by Eberhart and Russell (6) was utilized for computation of three evaluation parameters. The mean is a measure of average performance of a cultivar over environments. The regression coefficient measures cultivar response to changes in environment. The deviation mean square provides evidence of predictability of cultivar response to environment according to the regression coefficient. The three parameters together provided useful interpretive information on the general adaptation and performance stability of winter wheat cultivars. They concluded that the stability parameters indicated the existence of wide cultivar differences in response to environment as well as in predictability of response.

In summary, it is noted from the reported previous investigations that the estimates of genotype X environment components varied considerably, not only from character to character in the same crop, but also from crop to crop in the same area. Therefore, general inference is difficult to make as to other crops grown in other areas.

CHAPTER III

MATERIALS AND METHODS

I. DATA COLLECTION

The University of Tennessee Agricultural Experiment Station conducts small grain variety tests to study the performances of wheat, barley, and oat varieties and experimental lines at the various experiment stations across the state each year. Data for winter wheat, barley, and oat varieties from these tests for the years 1963 through 1977 were utilized for this study.

These tests were conducted at six stations for barley and oats and at eight stations for wheat. The six stations where barley and oats were tested were the Tobacco Experiment Station (Greeneville), Main Station (Knoxville), Plateau Experiment Station (Crossville), Highland Rim Experiment Station (Springfield), Middle Tennessee Experiment Station (Spring Hill), and West Tennessee Experiment Station (Jackson). In addition to these six stations, a few varieties of wheat were tested also at the University of Tennessee at Martin ana Milan Field Station (Milan) in each of several years. These eight stations are widely scattered in the state, and each represents a different area. They are described in Table 1. A brief summary of monthly average temperatures and precipitation for the 15 growing seasons for each of the testing sites are presented in Tables 2 and 3.

Table 1. Locations of Small Grain Variety Tests in Tennessee, 1963-1977

Station	Latitude	Longitude	Elevation (ft.)
Greeneville	36°06′	82°51′	1320
Knoxville	35°53′	83°57′	830
Crossville	36°01′	85°08′	1810
Springfield	36°28′	86°50′	745
Spring Hill[1]	35°41′	86°58′	-
Jackson	35°37′	88°50′	400
Martin	36°20′	88°52′	340
Milan	35°56′	88°46′	430

[1]The information for elevaton of Spring Hill is not available.

Table 2. Average Monthly Temperature (°F) for the Small Grain Growing Season in Each Location (1963-1977)

Location[1]	Jan.	Feb.	Mar.	Apr.	May	June	Oct.	Nov.	Dec.	Season Average
Greeneville	36.3	38.1	48.4	57.5	64.9	72.1	57.4	47.0	39.5	51.2
Knoxville	37.5	40.0	50.3	59.9	66.6	73.7	59.2	48.8	41.1	53.0
Crossville	31.9	34.0	44.6	55.1	61.7	68.5	54.9	44.8	36.0	47.9
Springfield	33.0	36.1	46.9	57.7	65.4	73.3	57.5	46.8	37.8	50.5
Jackson	36.1	39.4	49.9	60.8	67.9	75.5	60.0	49.4	40.3	53.3
Martin	35.9	39.7	50.4	56.8	68.5	76.1	60.7	49.6	40.2	53.1
Milan	34.6	38.0	48.6	59.5	66.8	74.5	58.3	48.2	39.1	52.0

[1]Data for Spring Hill are not available.

Table 3. Average Monthly Precipitation (in.) for the Small Grain Growing Season in Each Location (1963-1977)

Location[1]	Jan.	Feb.	Mar.	Apr.	May	June	Oct.	Nov.	Dec.	Season Total
Greeneville	3.22	2.96	4.70	3.75	4.05	3.64	2.99	2.86	3.07	31.24
Knoxville	4.80	3.91	6.28	4.49	4.62	4.65	3.24	4.02	5.04	42.05
Crossville	5.02	4.48	7.36	5.41	5.70	4.60	3.47	4.42	5.71	46.17
Springfield	3.89	3.52	5.94	4.31	4.65	4.01	2.62	4.16	4.50	37.60
Jackson	3.68	3.99	5.31	5.50	5.59	3.64	3.05	4.20	4.71	39.67
Martin	3.97	3.57	6.05	5.30	4.62	4.75	2.94	4.13	4.32	39.65
Milan	3.94	4.08	5.70	5.40	5.36	4.33	3.04	4.39	4.79	41.03

[1]Data for Spring Hill are not available.

Varieties and experimental lines of winter wheat, barley, and oats which had been tested for three or more years at two or more locations were selected for this study. There were 22 varieites of winter wheat, 15 varieties of winter barley, and 11 varieties of winter oats. The varieties and experimental lines used in this study and brief descriptions of them appear in Tables 4, 5, and 6.

All experiments were conducted as randomized, complete block designs with four replicates. There were five or six rows in each plot. Each plot was at least 40 feet long. All rows were harvested. Seeds were planted by a grain drill or plot grain drill, and harvested by combine. Performance was based on yield in bushels per acre, and test weight in pounds per bushel.

II. STATISTICAL ANALYSES

The statistical analyses of data were computed by the IBM 360 computer at the University of Tennessee Computer Center. In these analyses, the mean yields of 22 wheat varieties, 15 barley varieties, and 11 oat varieties were evaluated at each location during 15 years by the Statistical Analysis System (SAS) (2), using the principle of least squares analysis developed by W. R. Harvey (12). Each crop was evaluated separately. The mathematical model for this analysis was:

$$Y_{ij} = U + S_i + V_j + R$$

where

Y_{ij} = mean yield of i^{th} year and j^{th} variety,

U = overall mean,

Table 4. Brief Descriptions of Winter Wheat Varieties

Variety	Appearance and Characteristics	Disease and Insect Resistance
Abe	Similar in apperance to Arthur. Abe may be distinguished from Arthur and Arthur 71 by its blue-green foliage from young plants to the boot stage and by its longer awnlets.	Resistant to Hessian fly and leaf rust, stem rust, powdery mildew, loose smut, and soil-borne mosaic.
Arthur	A very early winter-hardy, soft red winter variety with good straw strength. It has good test weight.	Resistant to certain races of powdery mildew, and moderately resistant to leaf rust and loose smut. Resistant to some races of Hessian fly. It is sensitive to acid soil.
Arthur 71	Similar in apperance to Arthur.	Resistant to leaf rust and all known races of Hessian fly.
Benhur	It occasionally has blackening of heads and stems which is a characteristic derived from a parent which conributed stem rust resistance.	Resistant to some races of Hessian fly. Resistant to stem rust and moderately resistant to leaf rust.
Blueboy	A semidwarf wheat with good yielding ability, low test weight and excellent standing ability. It is variable in plant height and has a blue color before ripening.	Not resistant to most races of Hessian fly. Moderately resistant to leaf rust and powdery mildew.
Coker 68-15[1]		

Table 4 (continued)

Variety	Appearance and Characteristics	Disease and Insect Resistance
Coker 68-19[1]		
Knox	A very early winter-hardy variety with short straw. Due to its tendency to stool during warm spells in the early spring, it may be injured by late spring freezes. Should be grazed to delay maturity.	Resistant to many races of leaf rust.
Knox 62	Similar to Knox.	Resistant to some races of Hessian fly.
McNair 1587	A medium height, midseason, soft red winter wheat with blue green erect foliage. It has large, plump-seeded light brown awnletted spikes.	Moderately resistant to leaf rust and powdery mildew. Resistant to some races of Hessian fly and is susceptible to stem rust.
McNair 1813[1]		
McNair 2203[1]		
McNair 4823	A short, stiff-strawed variety with good winter-hardiness.	Resistant to leaf rust and most races of Hessian fly. Susceptible to powdery mildew.
Monon	A very early winter-hardy variety with moderate stiff straw.	Resistant to some races of Hessian fly and highly resistant to leaf rust in the mature plant stage.

Table 4 (continued)

Variety	Appearance and Characteristics	Disease and Insect Resistance
Oasis	Similar to Arthur 71 in agronomic characteristics.	Resistant to rusts, powdery mildew, Hessian fly, and leaf blotch.
Redcoat	A medium-short, midseason soft red winter wheat. It has excellent straw strength, good test weight, excellent yielding ability and good winter survival.	Resistant to stem rust and Hessian fly.
Reed	A late-maturing variety with good straw strength.	Resistant to some races of Hessian fly, leaf rust, and soil-borne mosaic. Moderately susceptible to stem rust, powdery mildew, and loose smut.
Riley	Similar to Monon.	Resistant to loose smut.
Seneca	A red-chaffed variety of medium height and fair standing ability.	Susceptible to leaf rust.
Stoddard	It is medium-tall with beardless heads. It has good winter-hardiness.	Moderately resistant to soil-borne mosaic. Susceptible to powdery mildew, stem rust and Hessian fly.
Tenn. 60-25[1]		

Table 4 (continued)

Variety	Appearance and Characteristics	Disease and Insect Resistance
Triumph	A hard red winter wheat, early maturity, short stiff straw, good test weight, yield well in area of adaptation.	Resistant to loose smut and tolerant to wheat streak mosaic. Susceptible to leaf rust, stem rust, soil-borne mosaic, bunt, and Hessian fly.

[1]Descriptions are not available.

Table 5. Brief Descriptions of Winter Barley Varieties

Variety	Appearance and Characteristics	Disease and Insect Resistance
Barsoy	An early-maturing, rough-awned, six-rowed variety with straw strength. It should be suited for double cropping.	
Colonial 2	A six-rowed winter barley that is awnletted, has a short, stiff straw.	Resistant to certain races of mildew and tolerant to moderate infections of leaf rust.
Dayton	A winter-hardy, semirough-awned, early variety with good standing ability, medium tall.	Susceptible to mildew and scald.
Harrison	A medium-late, medium-tall rough-awned variety with good standing ability.	Good resistance to powdery mildew, leaf rust, and scald. Some resistance to net blotch. Nonacid tolerant and performs best at pH of 6 or above. It has performed very poorly at pH of 5 or below.
Hudson	A winter-hardy, rough-awned variety with fair standing ability.	Good resistance to mildew and scald.
Jefferson	This variety is an awnless counter-part of Harrison. It does not stand or yield as well as Harrison. Medium-late maturity.	
Kenbar	A winter-hardy variety of medium height.	Good resistance to mildew and fair resistant to scald. Tolerant to low pH soil.

Table 5 (continued)

Variety	Appearance and Characteristics	Disease and Insect Resistance
Keowee	This variety was selected from a cross of Davie X Hudson. It has a prostrate seedling type of growth. It is six-rowed and has medium length awns similar to Wade in appearance. It is medium-late in maturity.	
Knob[1]		
McNair 601[1]		
Rogers	A six-rowed, rough-awned variety with winter habit. It is medium in height and maturity and has good strength of straw. It tillers heavily, and many of the heads are nodding. The short, plump, smooth kernels thresh rather free of awns and gives a high test weight. It is classed as a feed barley and is medium in winter-hardiness.	Resistant to mildew and to some races of loose smut.
Tenn. 59-15[1]		
Tenn. 61-119[1]		
Volbar	A winter-hardy, six-rowed, tall, rough-awned variety with medium late maturity.	Lodging resistance. Slightly tolerant to barley yellow dwarf virus disease. Very resistant to spot blotch and net blotch.

Table 5 (continued)

Variety	Appearance and Characteristics	Disease and Insect Resistance
Wade	A winter-hardy, six-rowed, short-awned variety with medium height and medium-late maturity. The spike is parallel and dense, and seeds may be characterized by the lack of lemma teeth, semiwrinkled, and a short-haired rachilla.	Susceptible to powdery mildew. Tolerant to low pH soils.

[1]Descriptions are not available.

Table 6. Brief Descriptions of Winter Oats Varieties

Variety	Appearance and Characteristics	Disease and Insect Resistance
Blount	A short-strawed oat slightly less winter-hardy than Forkedeer, with high yield.	Due to its lodging resistance, it is suited to relatively high levels of fertility.
Coker 66-22	This variety has yielded well in the tests and is a few days earlier than Blount. It has weak straw. There has been little or no winter killing.	Lodges more than Blount.
Coker 70-16	This variety is similar to Coker 66-22 in maturity and test weight. It has better standing ability and yielded more grain than Coker 66-22.	
Compact	A short, stiff strawed winter variety with high yield potential and high test weight combined with good winter survival, excellent standing ability and thresh-ability, but tends to shatter if harvest is delayed.	Susceptible to crown and stem rust, but some resistance to smut.
Cumberland	A short, stiff-strawed variety of medium-late maturity. Slightly more winter-hardy and production than Blount.	Has good lodging resistance.
Forkedeer	A very winter-hardy variety with yellow grain. Medium tall.	Has a tendency to lodge under conditions of high fertility. Susceptible to crown rust.

Table 6 (continued)

Variety	Appearance and Characteristics	Disease and Insect Resistance
Ora	Short, stiff strawed, large kernals, and medium maturity.	High lodging resistance. Resistant to crown rust and Helminthosporium blight.
Tenn. 59-19[1]		
Tenn. 61-25[1]		
Tenn. 61-225[1]		
Yancey[1]		

[1]Descriptions are not available.

S_i = effect of i^{th} year (i = 1 to 15),

V_j = effect of j^{th} variety (j = 1 to 22 for wheat; 1 to 15 for barley; 1 to 11 for oats),

R = residual term, containing error and first-order interaction.

The relative performances of these varieties of different crops between locations were measured by coefficients of correlation calculated from the least squares means. The differences among these correlation coefficients were compared, using tests to determine if correlation coefficients were homogeneous (24).

Data for heading date and test weight were compared by the same procedures.

Since large storage requirements were not available for the SAS procedure of least-squares analysis from this IBM computer, the "Absorption" computational technique was used to estimate the variances of main effects and first-order interactions. However, it was not possible to obtain the second-order interaction directly, and it was considered to be the residual. The mathematical model for absorption of the variable variety, for example, was:

$$Y_{ik} = U + S_i + L_k + (S*L)_{ik} + R$$

where

Y_{ik} = mean yield of i^{th} year and k^{th} location,

U = overall mean,

S_i = effect of i^{th} year,

L_k = effect of k^{th} location,

$(S*L)_{ik}$ = interaction of i^{th} year and k^{th} location, and

R = residual term.

Similarly, the variables year and location were absorbed in turn in order to obtain the estimates of variety and interaction effects.

In examining the relative magnitudes of the different sources of variation concerned, the error variance was assumed to be small because it could not be estimated, since individual plot observations were not available and the mean of all replications in each test was used in all computations. Therefore, these estimations were biased; however, the bias should be small because of the number of observations involved.

The generalized form of the analyses of variance and the expectation of mean squares are shown in Table 7. Varieties, years, and locations are considered representative samples of their respective populations and as random variables in the analysis. Because of the missing data, the degrees of freedom and the sum of squares were obtained by adjustment using least-squares analybis. Tests of significance were by the appropriate "F" tests.

Table 7. Form of Variance Analysis and Mean Square Expectations

Source		Mean square expectation[1]
Year (Y)		$\sigma_e^2 + r\,\sigma_{vy\ell}^2 + rv\,\sigma_{y\ell}^2 + r\ell\,\sigma_{vy}^2 + rv\ell\,\sigma_y^2$
Location (L)		$\sigma_e^2 + r\,\sigma_{vyl}^2 + rv\,\sigma_{yl}^2 + ry\,\sigma_{vl}^2 + rvy\,\sigma_\ell^2$
Location X Year		$\sigma_e^2 + r\,\sigma_{vyl}^2 + rv\,\sigma_{yl}^2$
Variety (V)		$\sigma_e^2 + r\,\sigma_{vyl}^2 + rl\,\sigma_{vy}^2 + ry\,\sigma_{vl}^2 + ryl\,\sigma_v^2$
Variety X Year		$\sigma_e^2 + r\,\sigma_{vy\ell}^2 + rl\,\sigma_{vy}^2$
Variety X Location		$\sigma_e^2 + r\,\sigma_{vy\ell}^2 + ry\,\sigma_{v\ell}^2$
Residual	V*Y*L	$\sigma_e^2 + r\,\sigma_{vy\ell}^2$
	Error	σ_e^2

[1] y, 1, v, and r are number of years, locations, varieties, and replicates, respectively; σ_e^2 = error variance; σ_{vl}^2 = variance due to interaction of varieties and locations; etc.

CHAPTER IV

RESULTS

I. ANALYSES OF VARIANCE

The analyses of variance for yield of wheat, barley, and oats are presented in Tables 8, 9, and 10, respectively. Components of variance estimates from the analysis also are shown in these tables. The relative magnitudes of these components indicate the relative importance of the corresponding sources of variation in this study.

Considering wheat, it is noted that variety, variety X location, and variety X year mean squares were all significant at the 1 percent level of probability. The significant variety X location interaction indicates that some varieties tended to rank differently in yield at certain locations than they did at other locations. The fact that this source of variation was relatively small in magnitude, however, indicates that a rather large portion of the differential varietal responses could not be accounted for by consistent differences in the wheat-growing environments of the different locations. The significant variety X year interaction indicates that the varieties ranked differently in yield performance in three or more of the 15 years of testing. However, the variance component of variety X year interaction was larger than that of variety X location interaction, further indicating that varietal reaction among years was less conbistent than among locations. The significant variety variance component indicates that varieties differed in their expressed genetic potential for yield.

Table 8. Analysis of Variance for Yield of 22 Winter Wheat Varieties Tested at 8 Locations from 1963 through 1977

Source of Variation	Degree of Freedom	Mean Square	F	Variance Component
Years	14	3214.88	4.60**	3.52
Locations	7	1897.85	2.71*	0.89
Year X Location	82	699.51	22.70**	7.60
Varieties	21	393.81	4.30**	0.63
Variety X Year	81	71.49	2.32**	1.27
Variety X Location	134	51.02	1.66**	0.34
Residual	429	30.82		7.71

*Significant at the 5 percent level of probability.

**Significant at the 1 percent level of probability.

Table 9. Analysis of Variance for Yield of 15 Winter Barley Varieties Tested at 6 Locations from 1963 through 1977

Source of Variation	Degree of Freedom	Mean Square	F	Variance Component
Years	14	6231.81	8.25**	14.94
Locations	5	2953.50	3.91**	2.40
Year X Location	66	755.27	6.75**	10.72
Varieties	14	1575.93	6.30**	3.68
Variety X Year	57	209.68	1.87**	4.07
Variety X Location	70	152.55	1.36*	0.68
Residual	260	111.95		27.99

*Significant at the 5 percent level of probability.

**Significant at the 1 percent level of probability.

Table 10. Analysis of Variance for Yield of 11 Winter Oats Varieties Tested at 6 Locations from 1963 through 1977

Source of Variation	Degree of Freedom	Mean Square	F	Variance Component
Years	14	7826.20	4.14**	22.31
Locations	5	14698.72	7.77**	19.11
Year X Location	57	1892.39	15.70**	40.27
Varieties	10	1677.15	4.69**	3.67
Variety X Year	44	164.20	1.36	1.82
Variety X Location	50	313.75	2.60**	3.22
Residual	170	120.53		30.13

**Significant at the 1 percent level of probability.

It is likewise noted that variety, and variety X year mean squares were both highly significant for barley; whereas the variety X location interaction was only significant at the 5 percent level of probability. The variance component of variety X year interaction was much larger than that of variety X location interaction, which indicates that the reaction of barley varieties among years was much less consistent than among locations. Also, the significant variety variance component was large. It was much larger than that of wheat, implying that barley varieties were much more different in genetic expression of yield than the wheat varieties used in this study.

For oats, however, the variety X year inceraction mean square was not significant, but the variety and variety X location components were highly significant as in wheat and barley. The nonsignificant variety X year interaction indicates that the varieties ranked essentially the same during each of the 15 years of testing when averaged over locations. Unlike wheat and barley, the variance component of variety X location interaction was larger than that of variety X year interaction, indicating that varietal reaction of oats among locations was less consistent than among years.

II. CORRELATION COEFFICIENTS

Coefficients of correlation of least-squares mean yield among locations are presented in Tables 11, 12, and 13 for wheat, barley, and oats, respectively.

Considering wheat, correlations of yields at Greeneville and Knoxville with all other locations, except Milan and Jackson with

Table 11. Correlation Coefficients and Coefficients of Determination (in Parentheses) for Yield of 22 Winter Wheat Varieties among 8 Locations, Utilizing Least-Squares Means

	Knoxville	Crossville	Springfield	Spring Hill	Jackson	Martin	Milan
Greeneville	0.75**	0.67**	0.58**	0.80**	0.46*	0.73**	0.26
	(0.56)	(0.45)	(0.34)	(0.64)	(0.21)	(0.53)	(0.07)
Knoxville		0.72**	0.64**	0.72**	0.54**	0.71**	0.37
		(0.52)	(0.41)	(0.52)	(0.29)	(0.50)	(0.14)
Crossville			0.53*	0.84**	0.33	0.72**	0.37
			(0.28)	(0.71)	(0.11)	(0.52)	(0.14)
Springfield				0.65**	0.31	0.67**	0.33
				(0.42)	(0.10)	(0.45)	(0.11)
Spring Hill					0.29	0.82**	0.27
					(0.08)	(0.67)	(0.07)
Jackson						0.24	0.41
						(0.06)	(0.17)
Martin							0.28
							(0.08)

*Significantly different from zero at the 5 percent level of probability.

**Significantly different from zero at the 1 percent level of probability.

Table 12. Correlation Coefficients and Coefficients of Determination (in Parentheses) for Yield of 15 Winter Barley Varieties among 6 Locations, Utilizing Least-Squares Means

	Knoxville	Crossville	Springfield	Spring Hill	Jackson
Greeneville	0.59* (0.35)	0.72** (0.52)	0.63* (0.40)	0.84** (0.71)	0.63* (0.40)
Knoxville		0.37 (0.14)	0.33 (0.11)	0.70** (0.49)	0.32 (0.10)
Crossville			0.64* (0.41)	0.54* (0.29)	0.60* (0.36)
Springfield				0.63* (0.40)	0.82** (0.67)
Spring Hill					0.60* (0.36)

**Significantly different from zero at the 1 percent level of probability.

*Significantly different from zero at the 5 percent level of probability.

Table 13. Correlation Coefficients and Coefficients of Determination (in Parentheses) for Yield of 11 Winter Oats Varieties among 6 Locations, Utilizing Least-Squares Means

	Knoxville	Crossville	Springfield	Spring Hill	Jackson
Greeneville	-0.39 (0.15)	0.54 (0.29)	0.04 (0.00)	0.54 (0.29)	0.20 (0.04)
Knoxville		0.33 (0.11)	0.43 (0.18)	-0.03 (0.00)	0.30 (0.09)
Crossville			0.48 (0.23)	0.50 (0.25)	0.56 (0.31)
Springfield				0.81** (0.66)	0.96** (0.92)
Spring Hill					0.87** (0.76)

**Significantly different from zero at the 1 percent level of probability.

Greeneville, and Milan with Knoxville, were significant at the 1 percent level. Greeneville with Jackson was correlated at the 5 percent level. The high correlations between either Greeneville or Knoxville and most of the other locations would imply that these are the desirable sites for selecting wheat varieties with general adaptation to all areas of state, except Jackson and Milan, whereas, varieties selected at Milan and Jackson would not necessarily be expected to perform well throughout the state.

Testing by Fisher's method of transformation (24), these locations were sorted into two groups, Jackson and Milan, which were low in correlation with most of the other locations, were included in one group; and the rest of the locations were the other group. Fisher's test showed that the sample correlations of the group of six locations, Greeneville, Knoxville, Crossville, Springfield, Spring Hill, and Martin, were drawn from a common population, indicating that the performances of wheat varieties were similar among these locations. It is suggested that these loations could provide meaningful information for each other whenever the variety test at one or some of them failed.

In regard to barley, correlation of yields at Greeneville and Spring Hill with all other locations were significant at the 5 percent level of probability. Knoxville, however, was not significantly correlated with the other loations, except Greeneville and Spring Hill. Also Crossville, Springfield, and Jackson were significantly correlated at the 5 percent level with all other locations, except Knoxville.

Fisher's method of transformation (24) results indicate that the sample correlations of all locations where barley was grown were drawn from a common population, which implies that barley varieties performed similarly at all locacions. It is, therefore, suggested that the data of all locations might be used to predict the variety performance of barley at any other location. Nevertheless, the coefficients of determination (r^2) were generally low among these locations, suggesting that none of these locations would be the best site for selecting barley varieties with general adaptation.

For oats, only Springfield, Spring Hill, and Jackson were highly correlated with each other; whereas, the remainder of the locations were not significantly correlated. Consequently, for oats, there does not appear to be any locacion that is a desirable site for selecting varieties with general adaptation.

Fisher's method of transformation (24) indicates that the sample correlations of Springfield, Spring Hill, and Jackson were drawn from a common population; whereas, Greeneville, Knoxville, and Crossville were not. Furthermore, Springfield, Spring Hill, and Jackson were relatively high in their coefficients of determination. These results indicate that only these three locations might provide meaningful information on oats variety yield potential.

Coefficients of correlation of variety heading date and test weight of wheat, barley, and oats among locations are presented in Tables 14 through 19.

Considering heading date, all locations were significantly correlated with each other, except Knoxville and Milan for wheat, Greeneville and Jackson for barley, and Jackson with all locations for

Table 14. Correlation Coefficients and Coefficients of Determination (in Parentheses) for Heading Date of 22 Winter Wheat Varieties among 8 Locations, Utilizing Least-Squares Means

	Knoxville	Crossville	Springfield	Spring Hill	Jackson	Martin	Milan
Greeneville	0.38	0.86**	0.90**	0.86**	0.79**	0.83**	0.06
	(0.14)	(0.74)	(0.81)	(0.74)	(0.62)	(0.69)	(0.00)
Knoxville		0.46*	0.28	0.29	0.57**	0.10	0.34
		(0.21)	(0.08)	(0.08)	(0.32)	(0.01)	(0.12)
Crossville			0.81**	0.82**	0.70**	0.75**	0.20
			(0.66)	(0.67)	(0.49)	(0.56)	(0.04)
Springfield				0.96**	0.87**	0.92**	0.06
				(0.92)	(0.76)	(0.85)	(0.00)
Spring Hill					0.83**	0.87**	0.06
					(0.69)	(0.76)	(0.00)
Jackson						0.76**	0.13
						(0.58)	(0.02)
Martin							0.03
							(0.00)

*Significantly different from zero at the 5 percent level of probability.

**Significantly different from zero at the 1 percent level of probability.

Table 15. Correlation Coefficients and Coefficients of Determination (in Parentheses) for Heading Date of 15 Winter Barley Varieties among 6 Locations, Utilizing Least-Squares Means

	Knoxville	Crossville	Springfield	Spring Hill	Jackson
Greeneville	0.50 (0.25)	0.63* (0.40)	0.42 (0.18)	0.54* (0.29)	0.29 (0.08)
Knoxville		0.63* (0.40)	0.70** (0.49)	0.63* (0.40)	0.67** (0.45)
Crossville			0.68** (0.46)	0.82** (0.67)	0.38 (0.14)
Springfield				0.64* (0.41)	0.69** (0.48)
Spring Hill					0.42 (0.18)

*Significantly different from zero at the 5 percent level of probability.

**Significantly different from zero at the 1 percent level of probability.

Table 16. Correlation Coefficients and Coefficients of Determination (in Parentheses) for Heading Date of 11 Winter Oats Varieties among 6 Locations, Utilizing Least-Squares Means

	Knoxville	Crossville	Springfield	Spring Hill	Jackson
Greeneville	0.79** (0.62)	0.91** (0.83)	0.80** (0.64)	0.88** (0.77)	0.40 (0.16)
Knoxville		0.75** (0.56)	0.82** (0.67)	0.88** (0.77)	0.42 (0.18)
Crossville			0.64* (0.41)	0.85** (0.72)	0.41 (0.17)
Springfield				0.89** (0.79)	0.16 (0.03)
Spring Hill					0.16 (0.03)

*Significantly different from zero at the 5 percent level of probability.

**Significantly different from zero at the 1 percent level of probability.

Table 17. Correlation Coefficients and Coefficients of Determination (in Parentheses) for Test Weight of 22 Winter Wheat Varieties among 8 Locations, Utilizing Least-Squares Means

	Knoxville	Crossville	Springfield	Spring Hill	Jackson	Martin	Milan
Greeneville	0.89**	0.73**	0.19	0.89**	0.74**	0.78**	0.02
	(0.79)	(0.53)	(0.04)	(0.79)	(0.55)	(0.61)	(0.00)
Knoxville		0.78**	0.23	0.87**	0.72**	0.67**	-0.01
		(0.61)	(0.05)	(0.76)	(0.52)	(0.45)	(0.00)
Crossville			0.55**	0.76**	0.74**	0.68**	-0.02
			(0.30)	(0.58)	(0.55)	(0.46)	(0.00)
Springfield				0.21	0.19	0.23	0.45*
				(0.04)	(0.04)	(0.05)	(0.20)
Spring Hill					0.80**	0.74**	-0.10
					(0.64)	(0.55)	(0.01)
Jackson						0.75**	-0.17
						(0.56)	(0.03)
Martin							-0.06
							(0.00)

*Significantly different from zero at the 5 percent level of probability.

**Significantly different from zero at the 1 percent level of probability.

Table 18. Correlation Coefficients and Coefficients of Determination (in Parentheses) for Test Weight of 15 Winter Barley Varieties among 6 Locations, Utilizing Least-Squares Means

	Knoxville	Crossville	Springfield	Spring Hill	Jackson
Greeneville	0.94** (0.88)	0.87** (0.76)	0.87** (0.76)	0.95** (0.90)	0.89** (0.79)
Knoxville		0.87** (0.76)	0.91** (0.83)	0.98** (0.96)	0.91** (0.83)
Crossville			0.74** (0.55)	0.87** (0.76)	0.88** (0.77)
Springfield				0.95** (0.90)	0.93** (0.86)
Spring Hill					0.96** (0.92)

**Significantly different from zero at the 1 percent level of probability.

Table 19. Correlation Coefficients and Coefficients of Determination (in Parentheses) for Test Weight of 11 Winter Oats Varieties among 6 Locations, Utilizing Least-Squares Means

	Knoxville	Crossville	Springfield	Spring Hill	Jackson
Greeneville	0.95** (0.90)	0.69* (0.48)	0.25 (0.06)	0.75** (0.56)	0.37 (0.14)
Knoxville		0.55 (0.30)	0.18 (0.03)	0.69* (0.48)	0.19 (0.04)
Crossville			0.57 (0.32)	0.66* (0.44)	0.75** (0.56)
Springfield				0.77** (0.59)	0.59 (0.35)
Spring Hill					0.42 (0.18)

*Significantly different from zero at the 5 percent level of probability.

**Significantly different from zero at the 1 percent level of probability.

oats. This indicates that heading date of small grains was quite similar for most of the regions in the state, and this character would not need to be recorded at all locations.

In regard to test weight, all locations were highly significantly correlated for barley; and except for Springfield and Milan, all locations also were highly significantly correlated for wheat. For oats, however, there was no location significantly correlated with all other locations. These results are similar to those obtained for yield.

The results from heading date and test weight could be misleading if not carefully interpreted because these variables were not recorded for each location each year.

CHAPTER V

DISCUSSION

Variety tests serve two objectives: (1) to identify superior varieties for recommendation to farmers and (2) to develop principles upon which adaptation depends. For the latter, a knowledge of differential response and its relation to varietal characteristics are of fundamental importance.

The existence of genotype X location interactions and their effects on progress from selection are widely recognized. Genotype X year interactions are always important in developing improved varieties. Genotype X location interactions are of relatively little importance in selecting material for local adaptation, but often assume a dominant role in selecting for wide adaptation. Good estimates of genotype X year and genotype X location interactions are necessary in evaluating the efficiency of testing programs and determining the optimum allocation of years and locations.

In the study reported herein, locations were considered as random samples of all sites in Tennessee. Furthermore, the years in which the tests were carried out were considered to be random samples of all years.

In all cases, except variety X year interaction for oats, the variety X year and variety X location interactions were significantly greater than zero at the 1 percent or 5 percent levels of probability.

The significance of these F tests, however, is probably less important than the magnitudes of the interaction variance components relative to the magnitude of the variety variance component, if selection among varieties is to be effective. Because no test was made of the homogeneity of the error mean squares for yield from the individual experiments, possibly variation was different for individual experiments. Very often there may be a great amount of variability among them, and this, according to Cochran and Cox (4), leads to too many significant results for a given tabular F value.

Variety X location interaction variance components were statistically significant but small relative to variety variance components for wheat, barley, and oats, indicating that plant breeding in Tennessee could produce small grain varieties which perform well on a more general environmental range, and that there would be little if any advantage to be gained from attempting to test at additional locations either for the variety trials or the breeding programs.

Variety tests usually are not conducted on the same land or area each year. It is well known that different fields and sections of the same field are not equally uniform with regard to soil type and other soil factors. Many factors such as soil moisture, soil fertility, rainfall pattern, light (quality, quantity, and distribution), temperature, humidity, air movement, presence or absence of other organisms (animals, pathogens, weeds, etc.), and many other factors make up an environment. It seems probable that each environment is more or less unique.

Environmental fluctuations during the growth period may not be consistent over years or follow any pattern in any geographical area.

Observation of environmental conditions suggested that distribution of rainfall, changes in temperature, and disease infection were the important factors determining relative performance of small grain varieties in Tennessee. Moisture stress at some locations during a critical period of growth, such as tillering, may have a profound effect upon yield. Varieties differing in date of maturity may be favored by corresponding optimum seasonal conditions. Differences in soil type in the area sampled appear to have little effect per se on the relative performance of the varieties.

Components of variance due to variety X year interaction were significant and relatively larger than components of variance due to differences in varieties of wheat and barley; in oats, however, the variety X year interaction component was nonsignificant and small relative to the variety component. These results indicate that wheat and barley varieties did not perform the same way relative to each other in each of the 15 years of testing; whereas, the relative rankings of oat varieties performed consistently from year to year. This, however, may be due to the restricted germ plasm available for winter hardiness in winter oats.

The different performances of varieties of wheat, barley, and oats and the variety X year interactions, seem likely to be the result of variation in hardiness and resistance to barley yellow dwarf virus disease. After studying the information from the individual performance trials from 1963 through 1977, it was noted that there was winter killing or disease infections of most oat varieties in almost every year at most of the testing locations. For wheat and barley, however, the winter killing and disease infection occurs only during a few years at a few locations for specific varieties. It is suggested that winter-hardy, barley yellow dwarf virus disease resistant oat varieties should receive more attention than breeding for the same characteristics in barley or wheat.

The variety variance components of wheat, barley, and oats were all highly significant at the 1 percent level of probability. However, the components for barley and oats which were of about the same magnitude, were relatively greater than the variety component in wheat. This indicates that the differences in genetic potential for yields were relatively large among the varieties of barley and oats compared to the genetic potential of wheat varieties.

Location mean squares for wheat, barley, and oats were all significant at the 5 percent or 1 percent level of probability, but the magnitudes of their variance components were quite different. Such comparisons need to be made on a like basis of yield such as pounds per acre. When these transformations were made, oats was the greatest, being about four times greater than that for barley and more than six times greater than that for wheat. These results imply that there were some environmental fluctuations among the locations, and these fluctuations were expressed more extremely by oats than by wheat or barley. These fluctuations were shown by the mean yield of all varieties on each location for all years in which they were grown.

Tables 11, 12, and 13 (see pages 29 and 30) show that yields among the locations where wheat and barley were grown were much more strongly correlated than those where oats were grown. These results show also that the fluctuations of mean yields among locations was much larger in oats than in wheat and barley, indicating that wheat varieties and barley varieties performed more similarly among the locations than did oat varieties. It indicates also that wheat and barley varieties were more generally adapted over all the state, whereas, oat varieties were generally more restricted to certain locations. Therefore, it is suggested that breeding for more generally adapted oat varieties is of more importance. However, this might be accomplished by improving winter hardiness and barley yellow dwarf virus resistance with the breeding program.

CHAPTER VI

SUMMARY AND CONCLUSIONS

Sixteen varieties of barley and eleven varieties of oats were evaluated at six locations, and, in addition, twenty-two varieties of wheat were evaluated at eight locations in Tennessee for a 15-year period. Analyses of these data provide information on the nature and magnitude of variety X environment interactions.

The variety X environment first-order interactions were all significant, except for variety X year interaction in oats. The magnitudes of the components of interaction variance were relatively small in relation to the variety variance components, except in the case of variety X year interactions in wheat and barley. The relatively large and significant variety X year interaction components in wheat and barley indicates that the varieties responded quite differently in each of the 15 years of testing, which means that varieties need to be tested several years before recommendation are made. The nonsignificant variety X year interaction component in oats indicates that the varieties generally performed in the same way in each of the 15 years of testing, therefore recommendation could be made using fewer years of data for oats than for barley and wheat. The significant but relatively small variety X location interaction components indicates that the varieties tended to rank more consistently for yield at some locations than did at other locations, but a rather large portion of the differential varietal responses could not be accounted for by consistent differences in the environments of the different locations.

Information from the individual tests suggests that the pattern of rainfall, cold temperatures and disease infections were the important factors determining differential varietal response.

The lack of sizeable variety X location interactions in the state as a whole, indicates that small grain varieties generally perform well on a more general environmental range and that they do not need to be tested at additiona locations for breeding or testing purposes.

Correlations of variety performances among locations for wheat, barley, and oats were quite different. Barley varieties did not perform significantly different among the locations. Wheat varieties also performed quite similarly in all locations, except Jackson and Milan. However, the yield fluctuations of oat varieties were relatively large among locations. These results indicate that the varieties of wheat and barley were more generally adapted throughout the state; while varieties of oats were more restricted to certain locations, perhaps due to winter injury.

The locations among which variety performances were generally correlated could be used to predict meaningful information for each other, if a test failure should occur at one of these locations. All locations for barley; all locations, except Jackson and Milan, for wheat; and Springfield, Spring Hill, and Jackson for oats could be utilized in this manner.

Greeneville and Knoxville appeared to be the better sites for selection of widely adapted wheat varieties. However, there was no one most desirable site for barley and oats to be selected for wide adaptation.

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