GENOTYPE BY ENVIRONMENT INTERACTIONS OF HARVEST INDEX AND OTHER TRAITS IN NINE HARD RED WINTER WHEAT CULTIVARS

By

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TABLE OF CONTENTS

LIST OF TABLES

CHAPTER I

INTRODUCTION

The ability of a crop cultivar to perform well over a series of environments has long been appreciated by both the agronomist and producer. Cultivars will often exhibit a wide range in production response to different environments. Some will perform well only when grown in a specific environment while others respond equally well over a wide range of environments. The most desirable cutlivars of Hard Red Winter Wheat (*Triticum aestivum* L.) grown in the central plains region of North America are those which have high yield potential and exhibit general adaptation. Weather conditions tend to be harsh and variable in this region so a cultivars ability to yield consistently is very important.

Regional performance trials encompassing several states, as well as intrastate trials have been used in the Hard Red Winter Wheat (HRWW) production area since the 1930's in an effort to identify superior genotypes for production recommendations. The evaluation of these trials may be confusing, however, as the ranking by performance of a set of cultivars may change from one location to another. When this happens a genotype by environment (GxE) interaction is said to occur. GxE interactions are of major importance to both the producer and the breeder. Producers want a cultivar with a high yield potential that will yield consistently over years. Cultivars which exhibit large GxE interactions may yield high in a good season but may yield poorly in a bad one. To a breeder, GxE interactions can cause difficulty in demonstrating the superiority of any one advanced breeding line in his performance trials. This can make it difficult to decide which line is best suited for development as a cultivar. The research required to properly characterize performance stability is costly in that it requires testing at several locations usually for more than one year. Because of this, the performance stability of any one line is not determined until late in the breeding program and many times not until after the line has been released as a cultivar.

This study was conducted in an effort to determine the extent of GxE interactions in a select group of HRWW cultivars and to compute stability parameters for each cultivar.

CHAPTER II

LITERATURE REVIEW

Cultivars grown over a wide range of envirovnmental conditions tend to respond differently when these conditions change. These varying responses can actually change the ranking of cultivars over several locations when evaluated in different year combinations. When this happens a genotype by environment interaction is said to occur. Simmonds (20), defines a GxE interaction as the change in ranking by yield that occurs when two or more genotypes are compared in different environments and found to differ in their production response. GxE interactions are important to both the plant breeder and the producer. To a breeder they can cause difficulty in demonstrating the superiority of any one line or cultivar. Producers want cultivars which are stable in performance over years and have a high yield potential, interacting with the environment in a predictable manner.

Comstock and Moll (5), reported that the obvious effect of GxE interactions is to reduce the correlation between genotype and phenotype making valid inferences difficult. They have shown statistically that the effect of large GxE interactions in a plant breeding program can reduce progress from selection. Eberhart and Russell (7), found that GxE interactions cause difficulty in demonstrating the significant superiority of any one cultivar over another.

Miller et al. (14) examined the magnitude of GxE, genotype by year and genotype by year by environment interactions in cotton (<u>Gossypium</u>

hirsutum L.) testing procedures. Campbell and Lafever (4), examined cultivar selection procedures for soft red winter wheat. Both groups of researchers calculated the variance components for all interactions and found GxE interactions to be of considerable importance when determining relative yield.

Because of these problems a number of methods have been proposed to reduce the effects of GxE interactions. One such method is stratification of environments. It has been suggested that the region a breeder is using to develop improved cultivars can be subdivided into divisions of similar environments. These subdivisions are usually made by characterizing areas of similar rainfall, temperature and soil type.

Murray and Verhalen (15) studied the GxE interactions of eleven cotton cultivars grown at three locations for three years in Oklahoma. They obtained a very large and significant GxE interaction for yield and suggested the state should be subdivided (stratification of environments) in some manner for cultivar evaluation and breeding.

Liang et al. (13) studied GxE interactions in wheat (Triticum aestivum L.), barley (Hordeum vulgare L.) and oats (Avena sativa L.). Ten cultivars were evaluated at thirteen locations during 1962-64. They also found that stratification of environments aided in reducing GxE interactions for each subarea.

Although subdividing an area may reduce the GxE interaction effect of that subarea the overall effect of GxE interaction is still present. Stratification would lead to the development of cultivars specifically adapted to that area. These cultivars might not contain the stability characterized by cultivars with general adaptation therefore this method would not be the most desirable one to use if the objective is to develop cultivars with wide adaptation.

Use of genetic mixtures is another method proposed to reduce GxE interactions. Jensen (12) suggested that the use of multiline cultivars of oats (*Avena sativa* L.) as compared to pure lines would have greater stability, broader adaptation to environments and greater disease protection than a pure line cultivar.

Allard and Bradshaw (1) suggested that a heterozygous, heterogeneous plant population offers the best opportunity to produce cultivars which exhibit small GxE interactions. They used the term "individual buffering" when each member of the population is well adapted to a range of environments and "population buffering" if the cultivar consists of a number of genotypes each adapted to a somewhat different range of environments.

Various workers, (e.g., Immer et al. (11), Salmon (19), Horner and Frey (10)), discussed some of the problems in comparing cultivar yields in several locations and for several years. Their reports suggest that the magnitude of cultivar by location and cultivar by year interactions were the basic measures of adaptability. In general, if the magnitude of the interaction is small, then the cultivar is considered stable and widely adapted.

Stability is the consistancy of a cultivar's performance and is largely dependent on its adaptability to changing environmental conditions. Simmonds (20), pointed out that in developing cultivars that are better adapted to changing conditions, the plant breeder is faced with the choice of either breeding for specific or general adaptation. Cultivars with general adaptation are considered to contain some stability. These cultivars may not be the highest yielding when tested under optimum conditions but yield consistently even when tested in substandard or limiting environments.

Breeding for specific adaptation may be satisfactory only if the area of production of a variety is limited to its specific area of adaptation. This could be the case in horticultural crops where plants are exposed to virtually no environmental stress. Even with crops grown in a labor intensive situation, some general adaptation would be desirable to provide some production stability.

Two approaches have been made in the study of cultivar adaptation. The first approach involves quantifying the environment in specific terms such as amount of water, nutrients, light intensity, etc. Grafius (9), used this component approach in his study of oat (*Avena sativa* L.) and barley (*Hordeum vulgare* L.) cultivar performance in Michigan. Grafius (9) and others who have used similar approaches have found that environments are too complex to adequately assess each environmental component and their interactions.

The second approach to adaptation studies involves measuring the environment without identifying each physical component. Plaisted and Peterson (17), presented a method to predict stability of yield when several cultivars were tested at any number of locations. They examined the arithmetic mean for GxE interaction variance components. The cultivar with the smallest mean value would be the one that contributed the least to the GxE interaction and therefore would be considered the most stable of the cultivars tested.

Baker (3), defined stability of hard red spring wheat as being inversely proportional to the sum of squares for the GxE interaction attributable to that cultivar. Finlay and Wilkinson (8), adopted a statistical approach from Yates and Cochran (26) in their study of the adaptation of barley (Hordeum vulgare L.) cultivars in South Australia. They used linear regression of individual cultivar yields on the mean yield of all cultivars at that environment as a measure of stability. The regression coefficient, b, was used as a quantitative measure of phenotypic stability. Typically, stability is characterized by b=1. In this study the ideal cultivar is one with maximum yield potential and phenotypic stabilty. Unfortunately, in their evaluation of 277 barley cultivars, those with good phenotypic stability had low mean yields.

This statistical approach was explored in more detail by Eberhart and Russell (7) in 1966. They developed a mathematical model that could be used to describe the performance of a cultivar. The model, $Y_{ij} = \mu_i + \beta I_j + \delta_{ij}$, defines stability parameters that may be used to describe the performance of a cultivar over a series of environments. Y_{ij} is the mean yield of the i^{th} cultivar at the j^{th} environment, μ_i is the i^{th} cultivar mean over all environments, β_i is the regression coefficient that measures the response of the i^{th} cultivar to varying environments, δ_{ij} is the deviation from regression of the i^{th} cultivar at the j^{th} environment and I_j is the environmental index. Using this approach they found the deviations from regression to be a very important stability parameter.

Perkins and Jenks (18) also used this model to detect and measure the magnitude of GxE interactions in tobacco (Nicotiana rustica L.). Their analysis revealed that most of the lines evaluated exhibited GxE interactions and for some of the lines the GxE interactions were wholly or partially accounted for by linear regression. They also demonstrated the practical implications of breeding for the simultaneous improvement of sensitivity to the environment and yield. In order to select simultaneously for phenotypic stability and high performance it is essential that the breeding material be assessed at the beginning of the program for relative mean performance and stabilty (18). This assessment must be conducted throughout the breeding program at appropriate stages.

Many researchers have used this method to describe the stability characteristics in crop cultivars. Stroike and Johnson (23) used regression analysis to describe cultivars of winter wheat grown in an international nursery. Nguyen et al. (16) used this method to determine stability parameters for herbage yield of tall fescue synthetics. Tai et al. (24) used this method in the analysis of sugarcane production stability. More recently, Baenziger et al. (2), used the stability model of Eberhart and Russell to evaluate the effect of GxE interactions on the milling and baking qualities of Soft Red Winter Wheat in an effort to determine how many locations should be used to accuratley assess these characteristics. They found that cultivar means for quality characteristics from any one environment were highly correlated with the regional cultivar means. This indicated that for preliminary quality evaluations, data from one environment is sufficient for ranking cultivars by quality characteristics.

Although stability is a desirable characteristic for any crop cultivar it appears to be difficult to incorporate into a breeding program. Simmonds (20) suggested the reason for this is that it is difficult and costly to identify stable lines early in a breeding program. Extensive testing, usually at several locations, is required to identify lines which exhibit stability.

For a wheat cultivar, stability in grain production is as important as yielding ability. This makes the determination of stability a crucial factor in recommending cultivars for production. The utilization of a stability model as Eberhart and Russell (7) have defined will make this decision a little easier.

Harvest index (HI) for wheat, as defined by Donald (6), is the ratio of grain produced to total above ground biomass. It is a measure of the yield efficiency of a genotype and is thought to be a more reliable measure of a cultivar's ability to yield because it is effected less by environmental conditions. However, at the time this paper was written no literature was found on the existance of GxE interactions for harvest index in Hard Red Winter Wheat (Triticum aestivum L.).

Little work has been done on directly attempting to improve harvest index. Singh and Stoskopf (22) reported that relatively little effort has been directed towards selecting on the basis of harvest index in cereal crops. This fact has been substantiated by Sims (21) who evaluated a large group of Australian oat cultivars and found harvest index to have been increased as the indirect result of improvements in grain yield.

In 1962, Van Dobben (25) compared the leading wheat cultivars of Europe since the turn of the century and found a progressive increase in harvest index from 34 to 40%. High yielding semidwarf cultivars had an improved grain to straw ratio over taller cultivars and showed a change in harvest index from 32 to 38% due to utilization of semidwarf cultivars.

It is the purpose of this study to examine the performance and stability of a select group of Hard Red Winter Wheat cultivars in an effort to determine the effect of GxE interactions on grain yield, biological yield, harvest index and plant height.

CHAPTER III

MATERIALS AND METHODS

Nine Hard Red Winter Wheat cultivars (*Triticum aestivum* L.) commonly grown in the Southern Great Plains region were evaluated at five locations in Oklahoma over a two-year period. Locations were chosen to provide an array of environmental conditions, especially rainfall amounts which tends to be the most important wheat production constraint in the state. A soil-type description of these sites along with rainfall data can be found in Table I. Buffalo, in northwest Oklahoma had the highest pH and received the least amount of rainfall between the Fall of 1981 and the Summer of 1983. Custer City is located in western Oklahoma, Lamont in the northcentral part of the state and Guthrie is located in central Oklahoma. Talala, located in the northeast part of the state, received the highest amount of rainfall during the course of this experiment and can be found in northeast Oklahoma. In order to determine how each cultivar responded to different environments, locations and years were considered seperate, thus having ten environments. Yield levels for each environment (location mean) were found to be consistant with previous years test results.

The cultivars, 'Centurk 78', 'Hawk', 'Newton', 'Payne', 'TAM W-101', 'TAM 105', 'Triumph 64', 'Vona' and 'Wings' were chosen to represent those genotypes which are currently being produced in this region. Table II contains agronomic descriptions of each cultivar. Two main criteria for selection of cultivars were maturity and plant height.

Cultivars were grown in a randomized complete block design with four replications. Plots were 3 m X 8 m. From a sample area within the plot, plants were harvested at ground level with a hand sickle and tied into a bundle. The harvested sample area consisted of one 5 m row. The heads of each bundle were covered with a bag to prevent loss of grain and then tagged for identification.

Plant height (cm) and biological yield (kg/ha) were determined before threshing. Grain yield (kg/ha) was determined after threshing and harvest index (HI) was computed from the equation HI = grain yield/biological yield.

The first step in the analysis of these data was to perform a combined analysis of variance using fixed effects in the statistical model. This analysis was conducted to determine the existance and magnitude of GxE interactions for biological yield, grain yield, harvest index and plant height. Standard F-tests were used to determine the presence of significant differences among cultivars. Regression analysis was used to determine stability parameters as defined by Eberhart and Russell (7). In this method the individual cultivar response to changing environments was determined by regression of individual cultivar means within each environment on the mean of all cultivars in that environment (environmental index). The regression coefficient (b value) serves as the first stability parameter. Cultivars with b values greater than one are considered responsive to increasingly favorable conditions but are designated as unstable in performance over environments. Cultivars with b values of one are less responsive but will perform in a more predictable or stable manner. A two sided t-test was used to test b values for each cultivar to see if they differ from unity. The equation for this test is: $t = (b-1)/se(b)$, where b is the regression coefficient and se is the standard error of individual cutivars.

The regression analysis of variance also provides additional information. The methods of Eberhart and Russell permit the GxE interaction mean square to be partitioned into the heterogeneity of regression and into the remainder or residual. If the heterogeneity mean square alone is significant we can to predict, within the limits of the sampling error, all the GxE interactions for each cultivar from the linear regression on environmental values. If the remainder mean square alone is significant there is either no relationship or no simple relationship, between the GxE interaction and the environmental index, thus no prediction can be made. If both the hetergeneity between regression and the remainder mean squares are significant the practical usefulness of prediction will depend on the relative magnitudes of the two mean squares.

If the remainder mean square is significant then there are cultivars present in the test that are unstable or unpredictable in performance. To determine which cultivars contribute to this instability, the second stability parameter is calculated. This consists of the individual cultivar residual mean square being tested over the average error in the regression ANOVA. If significant, the cultivar is considered unstable for this parameter.

Cultivars were examined for both parameters. Those with regression coefficients equal to one and with nonsignificant residual mean squares are classified as stable.

CHAPTER IV

RESULTS AND DISCUSSION

The combined analysis of variance for grain yield (Table III) indicated differences among cultivars. This analysis also indicated that there were no significant differences among cultivars for production of biological yield (Table IV). This means that each cultivar produced an equal amount of biomass with differences in grain yield resulting from the ability of a genotype to partition or direct its energy towards grain production rather than the production of stems and leaves (6). Harvest index is an indicator of this partitioning ability. Differences among cultivars for harvest index and plant height were significant (Tables V and VI).

Means and LSD's for all four characteristics measured are found in Table VII. These means were computed over five locations and two years. Values for grain yield ranged form 3430 kg/ha for Wings to 2720 kg/ha for Newton. According to the combined ANOVA there was no significant difference among cultivars for biological yield. Means for biological yeild ranged from 9444 kg/ha to 8755 kg/ha for Centurk 78 and Triumph 64 respectively. Harvest index values ranged from 0.35 for Wings to 0.30 for Centurk 78. Plant height values ranged form 99 cm for Triumph 64 and Centurk 78 to 86 cm for TAM-W101. Means and LSD values for each location and year are contained in Table VIII for grain yield, Table IX for biological yield, Table X for harvest index and Table XI for plant height.

Combined ANOVA's (Table III through Table VI) indicate that differences among locations were highly significant for all four characters measured. Year effects were significant for all traits except biological yield. Both year x cultivar and location x cultivar interactions were highly significant for all four traits measured. These statistics indicate that there were fluctuations in environmental conditions throughout the experiment. Change in environmental conditions is a part of cultivar x environment (GxE) interaction. This GxE interaction, which is significant for each characteristic measured causes difficulty in ranking a group of cultivars tested over a series of locations.

A regression analysis was conducted in an effort to determine stability of each cultivar. This analysis, which was modeled after the methods of Eberhart and Russell (7), consists of regressing each cultivar mean on an environmental index. This index is simply the mean of all cultivars at that particular location. This type of regression analysis allows for the cultivar x environment interaction to be seperated into two component parts, the heterogeneity of regression and the residual. If the heterogeneity mean square is significant, when tested over the error term, and not the residual then we can predict within the limits of the sampling error, all the GxE interactions for each cultivar from its linear regression on environmental index. If the remainder mean square is significant, there are cultivars present in the test whose performance is unpredictable. In other words, their GxE interaction cannot be accounted for with the regression analysis and their performance results in unstable production patterns.

Regression analyses of variance for grain yield, biological yield, harvest index, and plant height are shown in Table XII through Table XV respectively. In this analysis, environments were location and year combinations. The residual component of the cultivar x environment interaction mean square is significant for all four traits measured. This indicates the presence of cultivars in the test whose performance cannot be predicted due to their production instability.

Two stability parameters were utilized in this analysis in an effort to determine production stability for each cultivar. These parameters are the regression coefficient or b value and the residual mean square. The regression coefficient is an indicator of a cultivar's response to different environments. Cultivars with b values greater than one are very responsive to specific conditions and do well when grown in highly productive environments but are poor producers when grown under limiting conditions. This specific adaptation causes significant GxE interactions which are unpredictable.

The residual mean square can be used as a measure of a cultivar's consistency in performance over varying environments. The significance of a cultivar's residual mean square, when tested over the average error, is the second stability parameter. If this parameter is statistically significant then the performance of a cultivar is considered unpredictable. The ideal cultivar then is one with a high mean yield, a regression coefficient (b value) equal to one and a nonsignificant residual mean square. The residual mean squares and regression coefficients for grain yield, biological yield, harvest index and plant height can be found in tables XVI through XIX respectively.

The regression coefficient for grain yield found in Table XVI indicates the cultivar Wings to be the most responsive of all cultivars examined with a regression coefficient of 1.79. Centurk 78 had the smallest response of all cultivars with a regression coefficient of 0.62. Regression coefficients for biological yield are found in Table XVII. These values ranged from 1.17 for Hawk to 0.82 for Triumph 64. Values for harvest index ranged from a low of 0.64 for Payne to 1.25 for Wings (Table VIII). Table XIX presents the regression coefficients for plant height with values ranging from 0.85 for Vona to 1.26 for Centurk 78.

The regression coefficients were tested using a two sided t-test to see if they were significantly different from one (Table XX). The regression coefficient for grain yield of TAM W-101 was found to be significantly different from one while coefficients for Centurk 78 and TAM W-101 were different from one for plant height (cm).

Residual mean squares and F values, generated by dividing the residual mean square over the error term, provide information concerning the second stability parameter. Three of nine cultivars examined were found to have nonsignificant residual mean squares for grain yield. They are Hawk, TAM W-101, and TAM 105. This information can be found in Table XVI. Residual mean squares for biological yield (Table XVII) indicate that Hawk, TAM W-101, TAM 105, Triumph 64 and Vona are all stable in production of biomass. Residual mean squares and F values for harvest index (Table XVIII) showed that five cultivars were stable in performance as their residual mean square is not significant. These cultivars are Centurk 78, Hawk, Newton, TAM W-101 and TAM 105. Residual mean squares for plant height (Table XIX) show these same five cultivars to be stable also for plant height. This indicates a close relationship between plant height and harvest index.

Hawk and TAM 105 were the only cultivars which displayed production stability for all four characteristics measured. These two cultivars also exhibited production stability for grain yield. Because grain yield is the most important factor that determines a wheat cultivar's worth or value, it is evident that stability for grain yield is of primary importance. Cultivars which exhibit stability in production may not necessarily be the highest yielding when grown in optimum conditions or seasons but will be the most consistant when produced in environments with fluctuating conditions. Because environmental conditions in the Hard Red Winter Wheat production area tend to be harsh and variable, stability of production is considered to be a very desirable characteristic. Cultivars which lack this stability of production will most likely be replaced by those that are stable in production.

CHAPTER V

SUMMARY AND CONCLUSIONS

Nine Hard Red Winter Wheat cultivars were evaluated at five locations for two years in order to determine stability of performance and to detect GxE interactions of grain yield, biological yield, harvest index and plant height. The combined analysis of variance indicated significant differences among cultivars for grain yield, harvest index and plant height but not for biological yield. Grain yield means ranged from 3430 kg/ha for Wings to 2720 kg/ha for Newton. Harvest index means ranged from 0.35 for Wings to 0.30 kg/ha for Newton. Plant height means ranged from 99 cm for Triumph 64 and Centurk 78 to 86 cm for Tam W-101. Location effects were significant for all four traits measured. Year effects were significant for all traits except biological yield. Both year x cultivar and location x cultivar interactions were significant for all traits measured. This indicates the occurence of fluctuations in environmental conditions which is a major cause of GxE interactions. The occurence of GxE interactions can cause difficulty in ranking cultivars in several locations.

Regression analysis was conducted in an effort to determine production stability for each cultivar. This analysis consists of regressing individual cultivar means on an environmental index. The regression analysis of variance allows division of the GxE interaction into the heterogeniety of regression and the residual. If all cultivars of regression and the residual. If all cultivars in the test are exhibiting stability in production then the heterogeniety will be significant and not the residual. This was not the case as there were several cultivars present whose performance should be considered unstable. The residual component of the cultivar x environment interaction was significant for all four traits indicating the presence of cultivars in the test that exhibited instability in production.

Two parameters were used to determine the stability of each cultivar. These parameters were the regression coefficient and the residual mean square. The regression coefficient is an indication of a cultivars response to different environments. Cultivars with regression coefficients that differ from one are considered to be unstable in production. The residual mean square is a measure of consistancy in performance of a cultivar over varying environments. Cultivars with a significant residual mean square are unstable and their performance tends to be unpredictable. The ideal cultivar is one with a high mean yield, a regression coefficient equal to one, and a nonsignificant residual mean square. Regression coefficients were examined for each cultivar and trait. Cultivar regression coefficients for biological yield (kg/ha) and harvest index could not be shown to differ from one. Regression coefficients for grain yield (kg/ha) of TAM W-101 was found to differ from one while coefficients for plant height (cm) of Centurk 78 and TAM W-101 differed from one. The residual mean squares were tested over the average error in a standard F-test. Three cultivars were found to have nonsignificant residual mean squares for grain yield. They are Hawk, Tam W-101 and Tam 105. Hawk, Tam W-101, Tam 105, Triumph 64 and Vona were all stable in production of biomass. Five cultivars proved stable for harvest index. They are Centurk 78, Hawk, Newton, Tam W-101 and Tam 105. The same five cultivars were stable for plant height.

Hawk and Tam 105 were the only cultivars which displayed stability according to both parameters for all four traits measured with Hawk having the highest mean grain yield of 2966 kg/ha.

The results of this stability analysis were similar to that done previously by Stroike and Johnson (23) in their effort to describe cultivars of Winter Wheat grown in an international nursery. Older cultivars typically tend to show instability in production while the trend in cultivars today is towards broader adaptation and greater stability.

The use of harvest index as a selection criterion seems to be well founded as it showed stability in all nine cultivars examined. Also, the GxE interaction of harvest index was accounted for in the regression analysis which allows one to predict cultivar harvest index in the environments used in this study.

Stability for grain yield is of primary importance to wheat producers. In the future, cultivars which lack production stability will most likely be replaced by those that are stable performers.

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APPENDIX

TABLE I

ENVIRONMENTAL CHARACTERISTICS FOR
EXPERIMENT LOCATION SITES

Location	pH	Soil Type	Annual Rainfall (cm) 1982	1983	$\overline{X}$[1]	Soil Classification
Buffalo	7.8	St. Paul Silt Loam	63.5	81.3	72.4	Fine-Silty, Mixed, Thermic Pachic Argiustolls
Custer City	6.8	St. Paul Silt Loam	86.9	76.0	81.3	Fine-Silty, Mixed, Thermic Cumulic Argiustolls
Lamont	5.4	Pond Creek Silt Loam	76.2	101.6	89.9	Fine, Silty, Mixed, Thermic Pachic Argiustolls
Guthrie	5.5	Port Silt Loam	99.8	81.8	90.9	Fine-Silty, Mixed, Thermic Cumulic Haplustolls
Talala	6.6	Summit Silty Clay Loam	93.7	109.2	101.6	Fine, Montmorillonitic, Thermic Vertic Argiudolls

[1]Means determined from 1982-83 rainfall data.

TABLE II

RELATIVE MATURITY AND HEIGHT CLASSIFICATION FOR NINE HARD RED WINTER WHEAT CULTIVARS

Cultivar	Maturity	Height Class
Triumph 64	Early	Tall
Centurk 78	Medium	"
Newton	Medium-Late	Intermediate
Payne	Medium	"
TAM 105	Medium-Late	"
Hawk	Medium	"
Wings	Medium-Early	Short
Vona	Early	"
TAM W-101	Medium	"

TABLE III

COMBINED ANALYSIS OF VARIANCE OVER TWO YEARS, FIVE LOCATIONS AND NINE CULTIVARS FOR GRAIN YIELD (KG/HA)

Source	df	MS	F	
YR	1	1,909,408.15	39.45	**
LOC	4	1,463,684.06	30.24	**
YR X LOC	4	1,634,407.93	33.77	**
REP (YR X LOC)	30	2,311,882.78	4.79	**
CUL	8	496,712.76	10.26	**
YR X CUL	8	579,265.54	11.97	**
LOC X CUL	32	172,208.23	3.56	**
YR X LOC X CUL	32	142,454.05	2.94	**
ERROR	240	48,395.82		

* denotes significance at $\alpha = .05$
** denotes significance at $\alpha = .05$ and $\alpha = .01$
NS denotes no significance at $\alpha = .05$ and $\alpha = .01$

TABLE IV

COMBINED ANALYSIS OF VARIANCE OVER TWO YEARS, FIVE LOCATIONS AND NINE CULTIVARS FOR BIOLOGICAL YIELD (KG/HA)

Source	df	MS	F	
YR	1	1,079,430.22	3.07	NS
LOC	4	27,327,804.18	77.84	**
YR X LOC	4	23,872,942.18	68.00	**
REP (YR X LOC)	30	1,744,862.34	4.97	**
CUL	8	643,709.77	1.83	NS
YR X CUL	8	1,132,933.33	3.23	**
LOC X CUL	32	770,905.65	2.20	**
YR X LOC X CUL	32	523,004.90	1.49	*
ERROR	240	351,074.92		

* denotes significance at $\alpha = .05$
** denotes significance at $\alpha = .05$ and $\alpha = .01$
NS denotes no significance at $\alpha = .05$ and $\alpha = .01$

TABLE V

COMBINED ANALYSIS OF VARIANCE OVER TWO YEARS, FIVE LOCATIONS AND NINE CULTIVARS FOR HARVEST INDEX

Source	df	MS	F	
YR	1	.0087	37.93	**
LOC	4	.0066	29.11	**
YR X LOC	4	.0057	24.98	**
REP (YR X LOC)	30	.0012	5.09	**
CUL	8	.0025	11.01	**
YR X CUL	8	.0015	6.78	**
LOC X CUL	32	.0006	2.64	**
YR X LOC X CUL	32	.0005	1.98	**
ERROR	240	.0002		

* denotes significance at α = .05
** denotes significance at α = .05 and α = .01
NS denotes no significance at α = .05 and α = .01

TABLE VI

COMBINED ANALYSIS OF VARIANCE OVER TWO YEARS, FIVE LOCATIONS AND NINE CULTIVARS FOR PLANT HEIGHT (CM)

Source	df	MS	F	
YR	1	1549.90	67.41	**
LOC	4	3735.73	162.47	**
YR X LOC	4	3261.03	141.82	**
REP (YR X LOC)	30	168.89	7.35	**
CUL	8	929.27	40.41	**
YR X CUL	8	102.08	4.44	**
LOC X CUL	32	63.79	2.77	**
YR X LOC X CUL	32	39.22	1.71	**
ERROR	240	22.99		

* denotes significance at $\alpha = .05$
** denotes significance at $\alpha = .05$ and $\alpha = .01$
NS denotes no significance at $\alpha = .05$ and $\alpha = .01$

TABLE VII

MEANS FOR GRAIN YIELD (KG/HA), BIOLOGICAL YIELD (KG/HA), HARVEST INDEX AND PLANT HEIGHT (CM), CALCULATED OVER TWO YEARS AND FIVE LOCATIONS FOR NINE HARD RED WINTER WHEAT CULTIVARS

Cultivar	Grain Yield (kg/ha)	Biological Yield (kg/ha)	Harvest Index	Plant Height (cm)
Wings	3430 a*	9376 a	0.35 a	88 de
Vona	3073 b	8970 abc	0.34 a	87 e
Payne	3030 bc	9296 ab	0.32 b	91 bc
Hawk	2966 bcd	9342 ab	0.32 b	89 cd
Centurk 78	2838 cde	9444 a	0.30 c	99 a
TAM 105	2836 de	9004 abc	0.32 b	91 b
TAM W-101	2817 de	8852 bc	0.32 b	86 e
Triumph 64	2725 e	8755 c	0.31 b	99 a
Newton	2720 e	8964 abc	0.31 b	93 b
LSD $\alpha = .05$	522	194	.01	2.1

*Means with the same letter are not significantly different Duncans Multiple Range Test ($\alpha = .05$)

TABLE VIII

MEANS FOR GRAIN YIELD (KG/HA) FOR NINE HARD RED WINTER WHEAT CULTIVARS GROWN AT FIVE LOCATIONS FOR TWO YEARS

	Guthrie		Lamont		Talala		Buffalo		Custer City	
Cultivar	1982	1983	1982	1983	1982	1983	1982	1983	1982	1983
Payne	2397	4333	2311	3621	2595	2905	3536	3127	3163	2309
Wings	3572	4067	3626	3178	5379	2639	3420	2123	3967	2328
Vona	3694	3794	4102	3099	3254	2426	2775	2050	3094	2444
Triumph 64	2536	3566	2331	2587	2993	2378	3056	2521	3300	1991
Tam 105	3241	3343	3361	3355	3440	2141	2887	1789	2775	2025
Centurk 78	2851	3304	2922	3321	2507	3040	3425	2303	2315	2392
Newton	2571	3169	2571	3279	3130	3071	2687	2127	2256	2335
Tam W-101	2997	3044	3339	3320	2779	2421	2600	2586	2878	2203
Hawk	2944	3011	3309	3627	3620	2459	3513	2316	2711	2153
Loc mean	2952	3459	3035	3265	3216	2610	3048	2327	2866	2242
LSD (.05)	704	360	594	626	824	471	769	560	514	578
Combined Loc mean Over 2 yrs	3209		3150		2913		2688		2554	

TABLE IX

MEANS FOR BIOLOGICAL YIELD (KG/HA) FOR NINE HARD RED WINTER WHEAT CULTIVARS GROWN AT FIVE LOCATIONS FOR TWO YEARS

	Lamont		Guthrie		Talala		Buffalo		Custer City	
Cultivar	1982	1983	1982	1983	1982	1983	1982	1983	1982	1983
Payne	8629	12878	7273	11541	8948	8922	10408	8609	9409	6340
Hawk	11331	12371	10620	8835	9631	8187	10025	7156	9336	5924
Tam 105	10838	12124	8894	11331	9267	8238	8680	5988	8787	5888
Centurk 78	11367	11975	8714	11367	7790	10354	9841	7656	8595	6776
Newton	9986	11848	8016	10362	9595	10504	7818	6719	8230	6558
Tam W-101	10172	11236	8181	10585	8218	8868	7888	7462	9259	6655
Vona	11295	10489	8613	10834	9469	8738	8700	6521	8533	6509
Wings	8870	10446	8728	11836	11989	8507	9856	6364	10519	6627
Triumph 64	9158	10036	8179	10840	8467	8394	9449	7252	9790	5976
Loc mean	10498	11491	8328	11035	9073	9047	9058	7081	9036	6361
LSD (.05)	1840	2081	1567	795	1934	1508	1703	1394	1261	1429
Combined Loc mean Over 2 yrs	10965		9682		9060		8069		7699	

TABLE X

MEANS FOR HARVEST INDEX FOR NINE HARD RED WINTER WHEAT CULTIVARS GROWN AT FIVE LOCATIONS FOR TWO YEARS

Cultivar	Guthrie 1982	Guthrie 1983	Custer City 1982	Custer City 1983	Buffalo 1982	Buffalo 1983	Talala 1982	Talala 1983	Lamont 1982	Lamont 1983
Vona	0.44	0.35	0.37	0.37	0.32	0.32	0.35	0.27	0.36	0.29
Wings	0.42	0.34	0.37	0.34	0.35	0.33	0.43	0.31	0.32	0.31
Tam W-101	0.37	0.29	0.31	0.33	0.33	0.35	0.34	0.28	0.33	0.30
Tam 105	0.37	0.30	0.32	0.35	0.33	0.30	0.37	0.26	0.32	0.28
Hawk	0.36	0.28	0.29	0.36	0.35	0.33	0.37	0.29	0.30	0.29
Payne	0.33	0.33	0.34	0.36	0.34	0.37	0.31	0.33	0.27	0.28
Centurk 78	0.33	0.29	0.27	0.36	0.35	0.30	0.32	0.29	0.26	0.28
Newton	0.32	0.31	0.27	0.36	0.34	0.32	0.33	0.29	0.26	0.28
Triumph 64	0.31	0.33	0.34	0.33	0.33	0.34	0.35	0.28	0.25	0.26
Loc mean	0.36	0.31	0.32	0.35	0.34	0.33	0.35	0.29	0.29	0.29
LSD (.05)	0.05	0.02	0.04	0.03	0.04	0.05	0.09	0.02	0.06	0.02
Combined Loc mean Over 2 yrs	0.34		0.34		0.34		0.32		0.29	

TABLE XI

MEANS FOR PLANT HEIGHT (CM) FOR NINE HARD RED WINTER WHEAT CULTIVARS GROWN AT FIVE LOCATIONS FOR TWO YEARS

Cultivar	Lamont 1982	Lamont 1983	Guthrie 1982	Guthrie 1983	Custer City 1982	Custer City 1983	Talala 1982	Talala 1983	Buffalo 1982	Buffalo 1983
Centurk 78	118	110	84	107	104	86	87	106	86	100
Triumph 64	113	109	90	107	114	86	93	99	88	95
Wings	109	91	87	97	86	75	76	92	81	85
Hawk	108	99	81	99	90	75	78	91	78	91
Newton	108	105	85	103	96	88	82	98	76	89
Tam 105	107	100	82	103	92	80	81	94	81	87
Payne	104	100	82	83	89	97	80	105	82	80
Vona	101	92	79	89	95	77	82	96	75	82
Tam W-101	94	92	79	97	87	80	75	90	77	91
Loc mean	108	100	86	100	96	81	83	95	81	91
LSD (.05)	9	6	13	4	5	8	6	5	8	7
Combined Loc mean Over 2 yrs	104		93		89		89		86	

TABLE XII

REGRESSION ANALYSIS OF VARIANCE FOR
GRAIN YIELD (KG/HA)

Source	df	MS	F	
ENV	9	1,589,086.400	32.84	**
CUL	8	496,712.759	10.26	**
ENV X CUL	72	204,212.736	4.22	**
HETEROGENEITY	(8)	260,027.483	5.37	**
RESIDUAL	(64)	197,235.893	4.38	**
ERROR	240	48,395.817		

* = Significant at .05 level
** = Significant at both .05 and .01 levels
NS = Nonsignificant at both .05 and .01 levels

TABLE XIII

REGRESSION ANALYSIS OF VARIANCE FOR BIOLOGICAL YIELD (KG/HA)

Source	df	MS	F	
ENV	9	22,876,471.395	65.14	**
CUL	8	643,709.772	1.83	NS
ENV X CUL	72	700,952.834	2.00	**
HETEROGENEITY	(8)	434,334.757	1.24	NS
RESIDUAL	(64)	734,280.094	2.09	**
ERROR	240	351,074.916		

* = Significant at .05 level
** = Significant at both .05 and .01 levels
NS = Nonsignificant at both .05 and .01 levels

TABLE XIV

REGRESSION ANALYSIS OF VARIANCE
FOR HARVEST INDEX

Source	df	MS	F	
ENV	9	0.0064473	28.26	**
CUL	8	0.0025128	11.01	**
ENV X CUL	72	0.0006401	2.81	**
HETEROGENEITY	(8)	0.0002697	1.18	NS
RESIDUAL	(64)	0.0006864	3.01	**
ERROR	240	0.000228173		

* = Significant at .05 level
** = Significant at both .05 and .01 levels
NS = Nonsignificant at both .05 and .01 levels

TABLE XV

REGRESSION ANALYSIS OF VARIANCE
FOR PLANT HEIGHT (CM)

Source	df	MS	F	
ENV	9	820.470	142.74	**
CUL	8	232.317	40.42	**
ENV X CUL	72	14.282	2.49	**
HETEROGENEITY	(8)	18.977	3.30	**
RESIDUAL	(64)	13.695	2.38	**
ERROR	240	5.748		

 * = Significant at .05 level
** = Significant at both .05 and .01 levels
NS = Nonsignificant at both .05 and .01 levels

TABLE XVI

REGRESSION ANALYSIS OF INDIVIDUAL CULTIVAR MEANS ON ENVIRONMENTAL INDEX FOR GRAIN YIELD (KG/HA)

Cultivar	b	Res. M.S.	F 8/240 df	
Centurk 78	0.62	137,399.00	2.84	**
Hawk	1.10	95,218.80	1.97	NS
Newton	0.67	105,942.00	2.19	*
Payne	0.76	380,921.00	7.87	**
Tam W-101	0.65	71,860.36	1.49	NS
Tam 105	1.39	58,637.02	1.21	NS
Triumph 64	0.79	139,150.00	2.88	**
Vona	1.19	207,916.00	4.30	**
Wings	1.79	380,844.00	7.87	**

Error = 48,395.81

* = Significant at .05 level
** = Significant at both .05 and .01 levels
NS = Nonsignificant at both .05 and .01 levels

TABLE XVII

REGRESSION ANALYSIS OF INDIVIDUAL CULTIVAR MEANS ON ENVIRONMENTAL INDEX FOR BIOLOGICAL YIELD (KG/HA)

Cultivar	b	Res. M.S.	F 8/240 df	
Centurk 78	1.00	744,920	2.12	*
Hawk	1.16	277,490	0.79	NS
Newton	0.98	705,230	2.01	*
Payne	1.02	1,165,679	3.32	**
Tam W-101	0.86	276,672	0.79	NS
Tam 105	1.25	264,304	0.75	NS
Triumph 64	0.81	361,250	1.03	NS
Vona	0.95	402,497	1.15	NS
Wings	0.94	1,676,190	4.78	**
Error = 351,074.91				

* = Significant at .05 level
** = Significant at both .05 and .01 levels
NS = Nonsignificant at both .05 and .01 levels

TABLE XVIII

REGRESSION ANALYSIS OF INDIVIDUAL CULTIVAR MEANS ON ENVIRONMENTAL INDEX FOR HARVEST INDEX

Cultivar	b	Res. M.S.	F 8/240 df	
Centurk 78	0.91	0.000453	1.99	NS
Hawk	1.13	0.000290	1.27	NS
Newton	0.89	0.000447	1.96	NS
Payne	0.63	0.000792	3.47	**
Tam W-101	0.80	0.000381	1.67	NS
Tam 105	1.18	0.000356	1.56	NS
Triumph 64	0.99	0.000677	2.97	**
Vona	1.16	0.001358	5.95	**
Wings	1.25	0.000736	3.23	**
Error = 0.00022				

* = Significant at the .05 level
** = Significant at both .05 and .01 levels
NS = Nonsignificant at both .05 and .01 levels

TABLE XIX

REGRESSION ANALYSIS OF INDIVIDUAL CULTIVAR MEANS ON ENVIRONMENTAL INDEX FOR PLANT HEIGHT (CM)

Cultivar	b	Res. M.S.	F 8/240 df	
Centurk 78	1.25	5.2384	0.91	NS
Hawk	1.13	4.1119	0.71	NS
Newton	1.07	9.9559	1.73	NS
Payne	0.93	16.0587	2.79	**
Tam W-101	0.75	10.2070	1.78	NS
Tam 105	1.04	3.3713	0.59	NS
Triumph 64	1.01	22.6659	3.94	**
Vona	0.84	16.2466	2.83	**
Wings	0.94	21.7020	3.78	**
Error = 5.748				

* = Significant at .05 level
** = Significant at both .05 and .01 levels
NS = Nonsignificant at both .05 and .01 levels

TABLE XX

VALUES FOR TWO SIDED *t* TEST ON REGRESSION COEFFICIENTS

Cultivar	df	Grain Yield (kg/ha)	Biological Yield (kg/ha)	Harvest Index	Plant Ht. (cm)
Centurk 78	8	2.11	0.05	0.32	2.50*
Hawk	8	0.37	1.31	0.54	1.63
Newton	8	1.94	0.11	0.43	0.67
Payne	8	0.70	0.14	1.81	0.54
TAM W-101	8	2.50*	1.40	1.73	3.12*
TAM 105	8	1.50	1.85	0.66	0.67
Triumph	8	0.91	1.63	0.03	0.06
Vona	8	0.85	0.42	0.31	1.25
Wings	8	0.89	0.24	0.54	0.33

*Significantly differs from one ($\alpha = .05$)
**Significantly differs from one ($\alpha = .01$)

VITA 2

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Candidate for the Degree of

Master of Science

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