ON MEASURING DIFFERENTIAL YIELDING ABILITIES OF WHEAT CULTIVARS OVER VARYING ENVIRONMENTS

by

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INTRODUCTION

The ability of one cultivar to produce higher yields than another cultivar is not easy to measure. Many environmental factors are known to effect the cultivar yields, such as temperature, water, soils, insects and disease. Several models have been developed to predict yields for different cultivars of winter wheat. Pederson and Seif (1974a, 1974b) examined yields as a function of sites and years and as a function of the seasons.

Pederson and Seif (1975) also developed a model for estimating the "true" yield of wheat genotypes as a function of sites, years, cultivars and all possible interactions. Freeman (1973) reviewed nearly 100 references on the subject of genotype X environment interaction.

Feyerherm and Paulsen (1984) examined the differential yielding ability (DYA) of pairs of cultivars when planted at the same location in the same year. Check cultivars were established for different classes of wheat and within a location-year cultivars were compared to their respective checks.

In this paper, the DYA of two wheat cultivars is modeled as a function of environmental effects. For purposes of this paper, the Weather Yield Function (WYF) developed by Feyerherm and Paulsen (a measure of the effect of weather on yield), will be used as a direct environmental measure and location and year will be surrogates for environmental variables in general. The purpose will be to examine four methods of estimating the DYA between pairs of cultivars of hard winter wheat.

THIS BOOK CONTAINS NUMEROUS PAGES WITH DIAGRAMS THAT ARE CROOKED COMPARED TO THE REST OF THE INFORMATION ON THE PAGE.

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Attention will be given to models that test possible interactions between cultivars and environmental factors. Interactions, when present, indicate that the difference between cultivar yields varies with changes in environmental conditions. For example, some cultivars may be able to express their yielding ability better than others under favorable environmental conditions.

There is a large body of historical data on yields of winter wheat over many years, across many locations, and with a variety of environmental conditions. This will be used to explore the possible relationships between DYA's and the environment.

MATERIALS AND METHODS

Data Base

The data base that is available is not a statistical sample nor is it the entire population of winter wheat performance trials. It will be analyzed as if it was a random sample from a hypothetical population of winter wheat trials. The large number of observations (1537) will give a general picture of differential yielding abilities and cultivar by environment interaction effects on wheat yields.

Data were available on wheat yields from cultivar performance trials conducted at state experiment stations since the early 1900s. This investigation was restricted to a study of yields of hard red winter wheat (*Triticum aestivum* L.) during the period 1920 to 1980, in Nebraska, Kansas, and Oklahoma. These three states produce the majority of the hard red winter wheat grown in the United States.

Cultivars selected for this study were chosen on the basis of the number of times they participated in performance trials, the number of time they participated in trials with other selected cultivars, and on their popularity with growers. The cultivars selected for study and their release dates were 'Turkey' (1874), 'Triumph' (1940), 'Commanche' (1942), 'Bison' (1956), 'Scout' (1963), and 'Centurk' (1971).

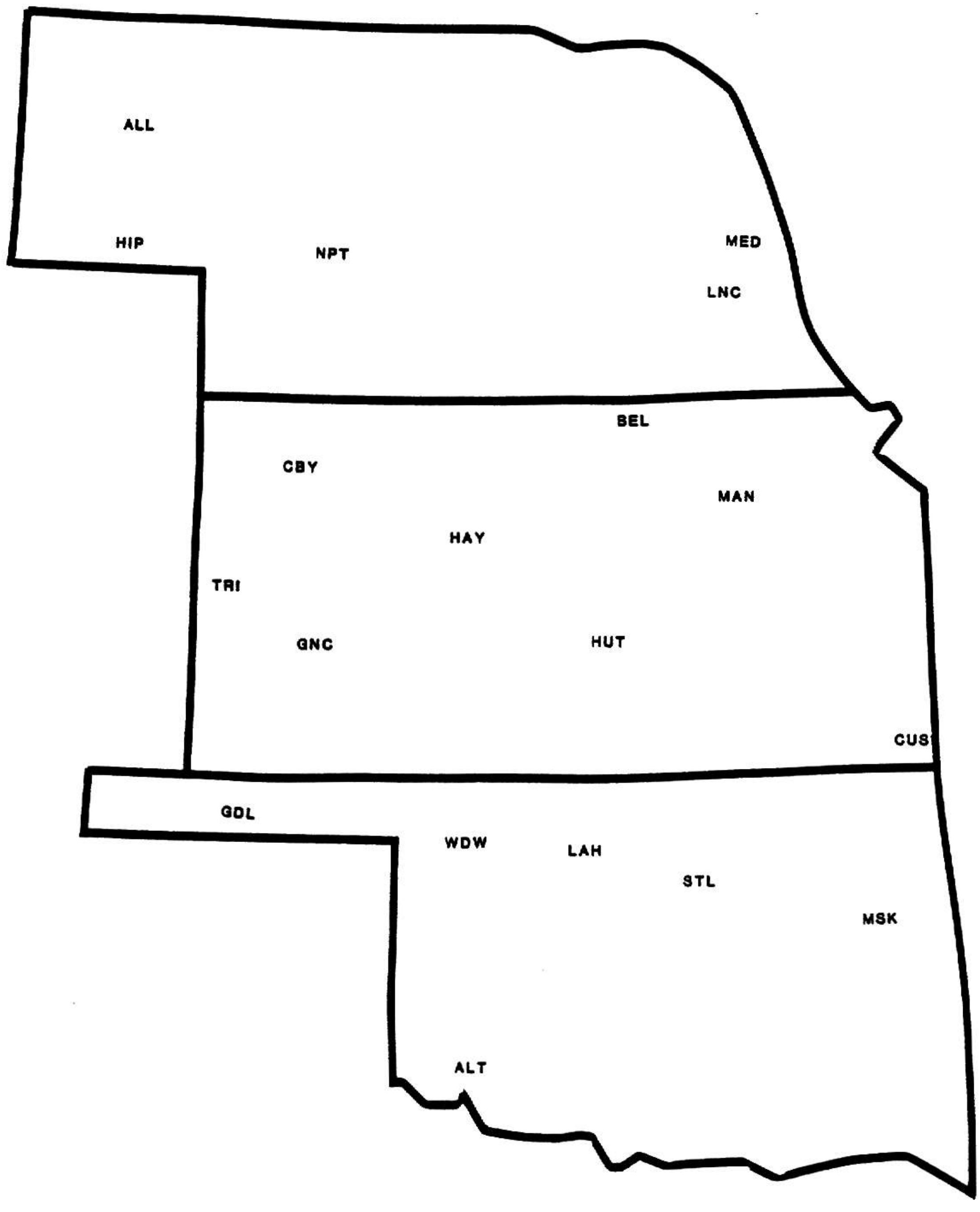
To enlarge sample sizes some substitute cultivars were used when the substitution seemed appropriate. Turkey was not grown at all locations, so the cultivar 'Kharkof' was used as a substitute. It is very similar to Turkey. It came originally from Russia, it was old, introduced in 1900, and hardiness and disease resistance of the two cultivars were similar.

Similarly the cultivar 'Scout 66' which is a selection out of Scout was substituted for Scout at those locations-years where Scout was not tested.

The selected cultivars were tested in performance trials at 19 state experimental stations over the years 1920 to 1980. Figure 1 is a map showing the locations of the 19 stations.

The impact of weather on yields was measured by a weather-yield function (WYF) developed by Feyerherm and Paulsen (1981, 1986). The WYF is a function of weather-related variables measured over different periods in a crop calendar for winter wheat. The ends of the periods were designated by: P = planting, W = begin

Figure 1. Locations of Performance Trials.



winter dormancy, S = spring green-up, J = jointing, F = flag leaf, H = heading, M = milk, D = dough, and R = ripe. For example, the period of time from planting (P) to beginning of winter dormancy (W) was indicated by PW. The length of PW was 60 days, SJ was 40 days, JF and FH are 20 days each, and HM, MD, and DR were each 10 days. The period WS was variable across locations. The calendar dates for P and H, at each location were determined by a planting date and heading date model, respectively.

There were six types of weather-related variables in the weather-yield function. They were:

AE(ab)= sum of daily simulated evapotranspiration amounts over the period (ab) in inches,

XPR(ab)= sum of daily simulated soil moisture amounts which measure daily exceedance of the 10 inch capacity of the VSMB (versatile soil moisture budget) over the period (ab) measured in inches,

XPR5(HR)= the amount of precipitation over the period HR minus five inches if the precipitation exceeded five inches; otherwise the value was zero,

TN(ab)= mean of the daily minimum temperatures over the period (ab) in degrees F,

TX(ab)= mean of the daily maximum temperatures over the period (ab) in degrees F,

CD(ab)= sum of the daily increments in temperature over the period (ab) where a daily increment was zero if a daily TN was above a threshold but equaled the threshold minus the temperature if the daily TN was below the threshold measured in degrees F. The threshold varied linearly from 0 to 30 degrees during the period SF, and from 30 to 32 degrees during FH, and was 32 degrees during HM.

The weather-yield function (WYF) in bushels/acre was:

WYF = 80.8 + WYF(PW) + WYF(WS) + WYF(SJ) + WYF(JH) + WYF(HR), where

$$WYF(PW) = 2.91 * AE(PW)^{1/2} - 0.326 * TX(PW),$$

$$WYF(WS) = -0.89 * PR(WS) - 0.00213 * TX(WS)^2,$$

$$WYF(SJ) = -0.181 * TN(SJ),$$

$$WYF(JH) = 12.36 * AE(JF) - 2.655 * AE(JF)^2 + 1.43 * AE(FH) -0.71 * XPR(JH) -0.362 * TN(JH) -0.649 * (0.5 * CD(JF) + CD(FH)),$$

$$WYF(HR) = 1.02 * AE(HR) - 0.80 * XPR5(HR) - 0.307 * TX(HD) - 0.649 * CD(HM)$$

The WYF was developed by Feyerherm and Paulsen over several years to give estimates of the size of the hard red winter wheat harvest for a year given the weather data. Computed values of WYF were matched with cultivar yield data for each location-year represented in the data set.

Statistical Approach

The interest in this investigation focuses on the differential yielding ability (DYA) between pairs of cultivars. Questions concern whether DYA is constant under different weather conditions, different disease patterns, over different soils, etc.. Accordingly four different statistical models were used to test hypotheses and estimate parameters relative to DYA values.

Model 1: $D_k(i,j) = B_0 + B_1 WYF_k + B_2 N_k + e_k$

where:

Dk(i,j) = difference in yields (in bushels per acre) between cultivars i and j for location-year k, WYFk = the WYF effect for location-year k,

Nk = effect of applied nitrogen in location-year k in poulds per acre,

ek = error term,

and

B_0, B_1, and B_2 are parameters.

Purpose:

Examine the differential yielding ability (DYA) as a function of weather and applied nitrogen. The interactions of weather X cultivar and nitrogen X cultivar are being tested. If the interactions exist, it means that the DYA being measured for cultivars i and j is dependent on the weather and/or the amount of applied nitrogen.

Model 2: $D_k(i,j) = B_0 + B_1 WYF_k + e_k$

where:

Dk(i,j) =difference in yields (in bushels per acre) between cultivars i and j for location-year k,

WYFk = value of WYF for location-year k,

ek = error term,

B_0 = overall mean when $WYF_k = 0$

B1 = the change in DYA for a unit change in WYF.

Purpose:

Determine if differential yielding ability (DYA) is a function of weather. If so, statistically one would say that a cultivar X weather interaction exists when estimating yields. Practically, it means 'that the amount by which the yielding ability of cultivar i exceeds that of cultivar j depends on the level of WYF.

Model 3: $D_{hk}(i,j) = B_0 + L_h + T_k + e_{hk}$

where:

Dhk(i,j) =difference in yield (in bushels per acre) between cultivars i and j for location h and year k,

Lh = effects common to location h,

Tk = effects common to year k,

ehk = error term, and

BO = is an overall mean.

Purpose:

If the L_h are not all zero, it suggests that the DYA for cultivars i and j depends on certain soil characteristics (e.g. type, depth, chemical composition, etc.) and/or climatological differences. Briefly, one says that a cultivar X location interaction exists. If the T_k's are not all zero, it suggests that the DYA for cultivars i and j depends on environmental characteristics (e.g. weather, diseases and other pests, etc.) and a cultivar X year interaction exists. Roughly, location effect is a surrogate for effects related to soils and climate while years are a surrogate for weather, pests, and possibly other factors. However, there is overlap in this representation since diseases may show up as both year-to-year and location effects.

Model 4: $Y_{gk} = A_0 + C_g + A_1 * WYF_k + A_2 * N_k + A_3 * (C_g * WYF)_k + A_4 * (C_g N)_k + e_{gk}$

where:

Ygk =yield of cultivar g in location-year k in bushels per acre,

Cg =effects common to cultivar g,

WYFk =value of WYF for location-year k,

Nk =amount of applied nitrogen in location-year k in bushels per acre,

(Cg*WYF)k= effect of cultivar X weather interaction in location--year k, (CgN)k = effect of cultivar X nitrogen interaction in location--year k, and

A_0, A_1, A_2, A_3, and A_4, are parameters.

Purpose:

Examine yield differences for cultivars when they were not necessarily sampled in the same location-year. Because cultivars i and j will not be restricted to the same location--years, the WYF and applied nitrogen effects will be used as covariates to adjust differences in cultivar means. Interactions between cultivars and WYF and cultivars and nitrogen will also be examined.

RESULTS AND DISCUSSION

Table 1 shows a comparison of the six selected cultivars on the basis of maturity, winter hardiness, and resistance to seven diseases and pests. Triumph is the earliest maturing of the cultivars with the least winter hardiness. Turkey is at the other extreme being the last to mature and also the most winter hardy.

Turkey is unique because of its low resistance to all of the major diseases. Bison was thought to have good disease resistance when it was introduced but it developed that Bison had poor resistance to diseases, except for bunt. Bison is therefore the second poorest cultivar selected in terms of disease resistance. The other cultivars all have good or moderate resistance to at least two of the diseases.

Models 1, 2 and 3 tested DYA as a function of environmental factors when both cultivars were at the same location-year. Every combination of the cultivars except Centurk and Commanche was

Table 1. Maturity, Winter-hardiness, and Disease Resistance Scores[+] for Selected Cultivars

	Maturity	Winter Hardiness	Bunt	Loose Smut	Leaf Rust	Stem Rust	Hessian Fly	Wheat Streak Mosiac	Soil-borne Mosiac
Turkey/ Karkof	8	1	7	8	6	8	7	7	7
Triumph	1	7	8	2	8	8	8	4	8
Commanche	5	3	2	6	5	7	7	4	2
Bison	5	3	2	8	9	9	8	7	9
Scout/ Scout 66	3	3	6	3	6	5	7	5	9
Centurk	3	2	7	3	4	2	6	9	4

[+] For Maturity early = 0 and late = 9.
For all others characteristics, good resistance = 0 and poor resistance = 9.

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available in the data base. These two cultivars were not tested together in any of the experiment station performance trials. Most of the cultivar combinations had 80 or more observations. The exceptions were Scout and Commanche (n=27), Centurk and Triumph (n=42), and Centurk and Bison (n=8). The largest number of observations was for the combination Turkey and Commanche (n=223).

The WYF, nitrogen, and yield data were available for 1537 observations. The WYF values ranged from 4 to 43 bushels per acre with larger numbers indicating more favorable weather conditions for winter wheat. The mean was at 29 and the median was at 30 and it had a negatively skewed distribution. Table 2 gives a summary of average yields and number of observations for each cultivar within different ranges of WYF.

In Table 2, one can observe that average yields generally increase with improved weather conditions. The exceptions occur when there are a small number of observations. The table further shows that over a large number of location-years, each of the cultivars tend to have similar weather conditions as measured by the average WYF and the shape of frequency distributions. The range of mean values of WYF's is from 30.2 for Triumph to 31.9 for Centurk. The cultivars Bison and Centurk were not tested under the most severe weather conditions (i.e. WYF less than or equal to 10) and are associated with the highest average WYF.

The average yield across cultivars and locations ranged from 6.8 bushels per acre in 1919 to 51.0 bushels per acre in 1980. Figure 2 is a graph indicating the yields for each year

Table 2 Average Yields by Cultivar and WYF Classes and Average WYF Values per Cultivar.

Range of WYF	Turkey/ Karkof		Triumph		Commanche		Bison		Scout/ Scout 66		Centurk		All Cultivars	
	Mean	n	Mean	n	Mean	n	Mean	n	Mean	n	Mean	n	Mean	n
0 - 10	10.6	2	17.1	2	17.4	1	----	0	13.4	1	----	0	14.4	6
10.1 - 20	14.3	24	19.8	19	18.5	14	24.0	6	24.1	10	38.5	3	19.5	76
20.1 - 25	18.0	41	18.9	26	19.4	24	18.2	12	31.2	15	30.2	5	20.6	123
25.1 - 30	25.9	99	30.8	58	29.3	51	33.3	21	37.1	52	40.2	28	31.0	307
30.1 - 35	30.2	225	32.8	112	33.1	110	34.1	66	41.8	109	46.0	74	34.9	681
35.1 - 40	32.4	99	36.6	48	36.3	36	40.1	34	47.3	58	50.4	35	38.9	298
40.1 - 50	33.4	6	39.8	3	40.7	3	46.1	2	52.3	2	43.8	1	40.2	17
Average Yield for All WYF	28.0	496	30.8	268	30.7	239	33.8	141	40.7	247	45.2	146	33.1	1537
Average WYF per Cultivar	31.2		30.2		30.4		31.8		31.2		31.9		31.0	

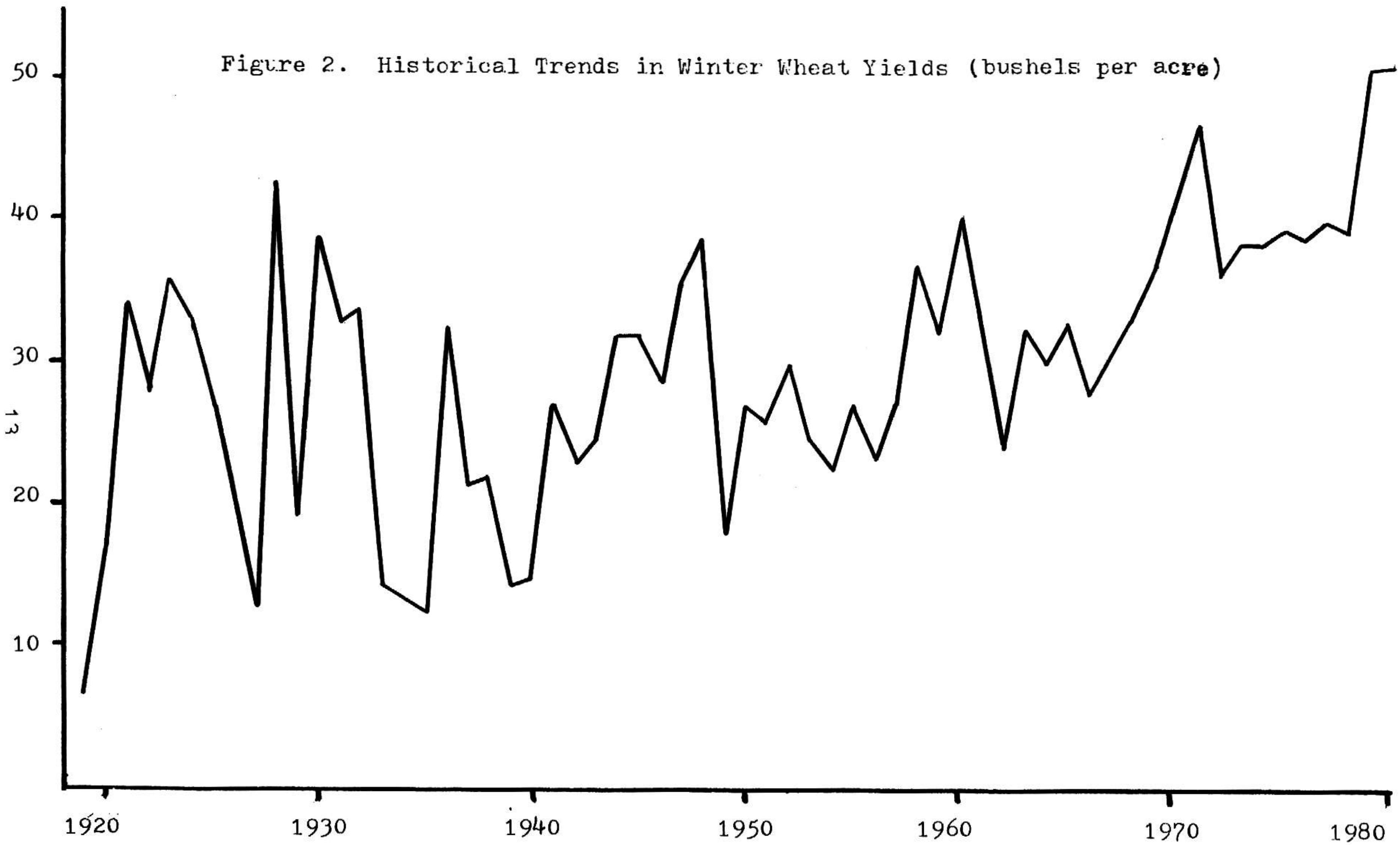


Figure 2. Historical Trends in Winter Wheat Yields (bushels per acre)

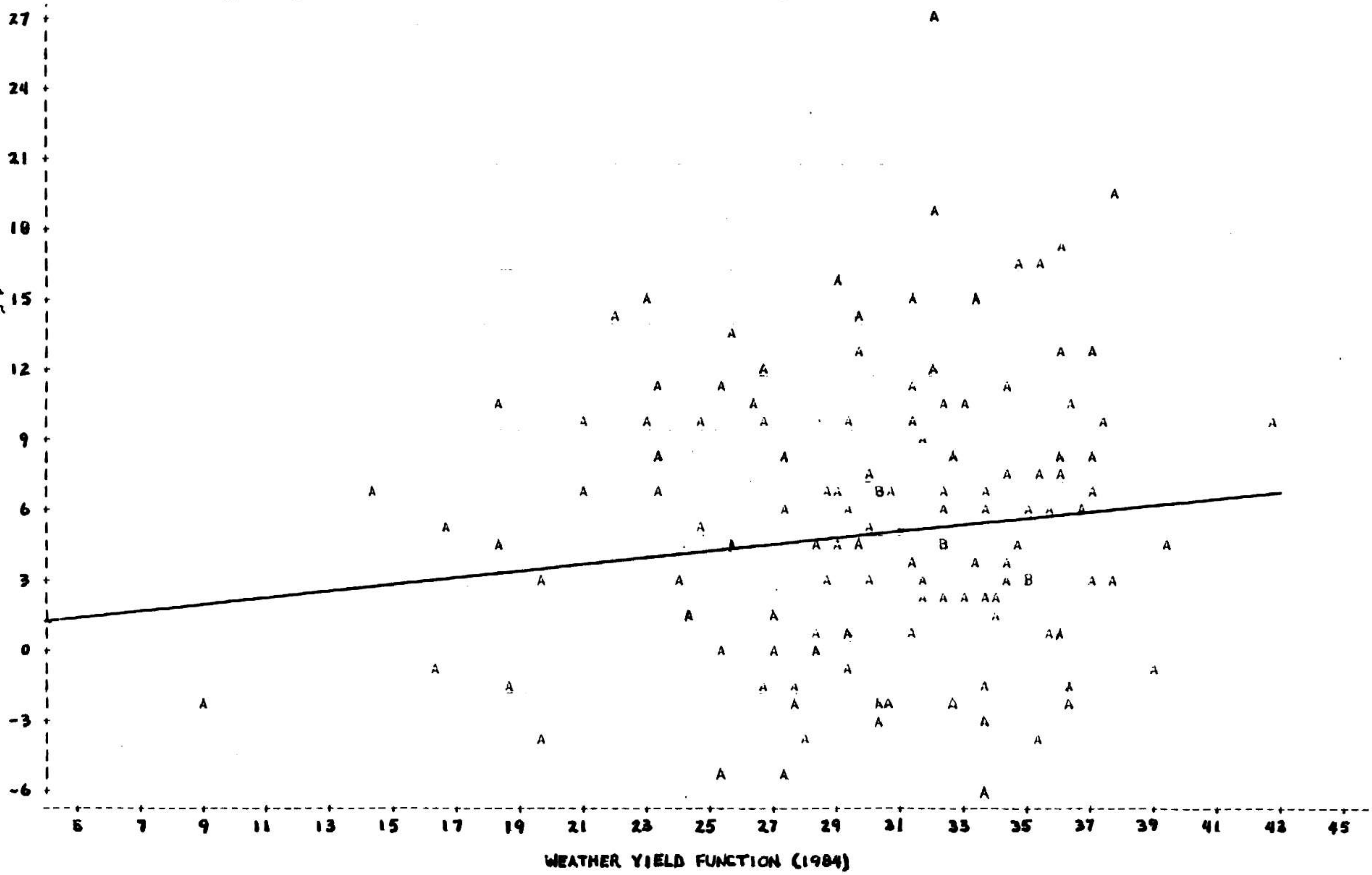
and their upward trend. Year-to-year yield changes were due to changing weather, changes in diseases and pests, changes in the mix of locations and cultivars. Prior to 1940, Turkey was the only cultivar among the six in this study being tested. All other cultivars were introduced after 1940. They have better disease resistance and higher overall average yields which contributed to the growth trend of yields.

Preliminary plots of cultivar differences against WYF were made before beginning analysis of the models. Figure 3 is a plot of yield differences (Scout - Triumph) against WYF. The difference between the two yields appears to be a random set of points within a circle. The actual regression line has been drawn in to show that the slope is nearly zero and the DYA for these cultivars probably is not a function of WYF.

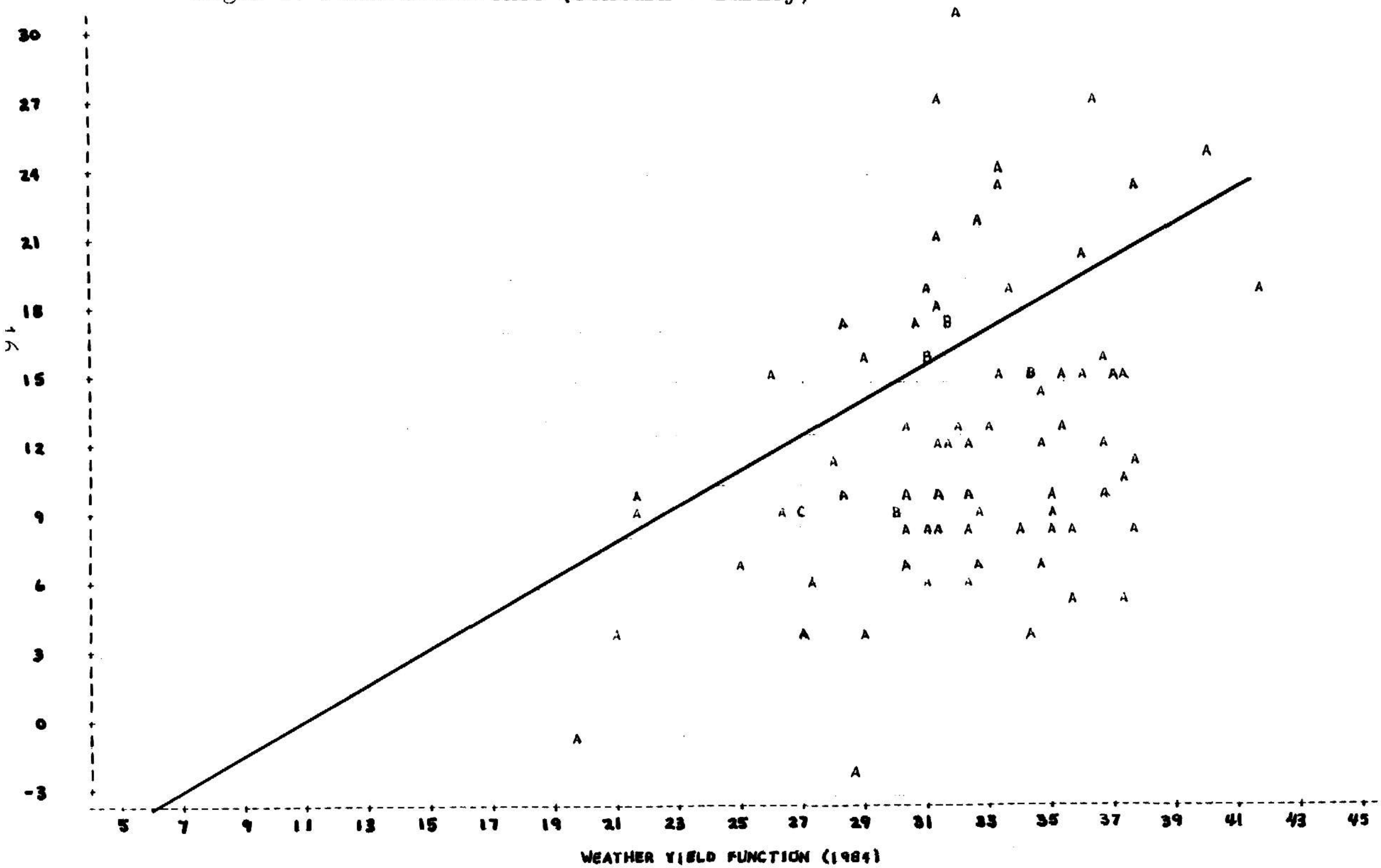
Figure 4 is a plot of yield differences (Centurk - Turkey) against WYF. The pattern of points appears to have a linear upward trend. This implies that perhaps there is a cultivar X WYF interaction for these two cultivars. The regression line has been drawn in to show that the slope is probably not zero.

These two plots therefore are an indication that further investigation into the cultivar X WYF interaction is needed. Tests using models 1 and 2 will determine whether the regression line in Figure 4 is estimating a slope that is statistically different from zero.

Figure 3. Yield Difference (Scout - Triumph)



Figue 4. Yield Difference (Centurk - Turkey)



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Analysis of Model 1 --

$$D_k(i,j) = B_0 + B_1 WYF_k + B_2 N_k + e_k.$$

When DYA was tested as a function of weather and applied nitrogen, the estimate of B_2 (b_2) was significantly different from zero at alpha = .05 for only one pair, Turkey and Centurk. Table 3 is a summary of the values of b_1, b_2 and n for each pair of cultivars. The cultivars are listed down the left-hand side and across the top. The first number in each group of numbers is the estimate of the slope of the regression line in the WYF direction (b_1). The second number in each group is the estimate of the slope of the regression line in the Nitrogen direction (b_2). The third number is the number of observations used to calculate the regression line.

B_2 was significantly different from zero (b_2 = .08 and standard error of b_2 = .03) for only the Centurk-Turkey pair which suggests an interaction between cultivars and applied nitrogen for this pair. At a rate of 40 pounds of nitrogen per acre, the DYA between Centurk and Turkey is estimated to be 3.2 bushels per acre greater than when no nitrogen is applied.

Since applied nitrogen was significant in the model only once, it was dropped out and model 2 was considered.

Analysis of Model 2 --

$$D_k(i,j) = B_0 + B_1 WYF_k + e_k.$$

Cultivar yield differences were tested as a function of the WYF using regression analysis. If a regression line through

Table 3. Regression Coefficients for WYF and Applied Nitrogen (N) in Model 1 for Different Pairs of Cultivars

		Turkey/ Karkof	Triumph	Commanche	Bison	Scout/ Scout66	Centurk
Turkey/ Karkof		-----					
Trimuph	b1	.26 *	-----				
	b2	.02					
	n	182					
Commanche	b1	.24 *	.08	-----			
	b2	.02	.03				
	n	221	156				
Bison	b1	.14	.29 *	-.10	-----		
	b2	.03	-.01	-.01			
	n	139	102	92			
Scout/ Scout 66	b1	.31 *	.02	.02	.02	-----	
	b2	.04	.03	-.00	.01		
	n	157	116	28	71		
Centurk	b1	.48 *	-.07	NT	.26	.01	-----
	b2	.08 *	.04		.05	.03	
	n	82	36		7	138	

* - significantly different from zero at alpha = .05
NT - not tested

the points has a slope of zero there is no cultivar X WYF interaction.

The regression analysis confirms the observations made by inspecting the plots. Some slopes are zero and others are not. Table 4 summarizes this regression analysis. The cultivars are listed down the left-hand side and across the top. Cell numbers are statistics on the cultivar combinations represented by that row and column. The first statistic is the estimate of the slope (b_1) of the regression line; the second is an estimate of the standard error of the estimate, and the third is the sample size.

A number of the slopes test out to be significantly different from zero so cultivar X WYF interaction effects appear to exist for certain pairs of cultivars.

It is interesting to note that for all pairs of cultivars that included Turkey, the estimated slope of the yield difference was different from zero and that the slope was positive. This implies that the difference in yield between Turkey and all the other tested cultivars is greater in good weather than it is in poor weather.

Three of the five comparisons with Bison had slopes significantly different from zero at the 0.05 significance level. A review of Table 1 shows that the cultivars Turkey and Bison have in common, low resistance to disease and pest. It is possible that disease resistance has made these two cultivars different than the others. The presence of diseases may be correlated with WYF. Weather conditions that are ideal for winter wheat will

Table 4. Regression Coefficients for WYF in Model 2 for Pairs of Cultivars

		Turkey/ Karkof	Triumph	Commanche	Bison	Scout/ Scout66	Centurk
Turkey/ Karkof		-----					
Triumph	b	.27 *	-----				
	s.e.(b)	.09					
	n+	186					
Commanche	b	.25 *	.07				
	s.e.(b)	.06	.07				
	n	223	163				
Bison	b	.16 *	.28 *	-.10	-----		
	s.e.(b)	.07	.09	.07			
	n	141	104	94			
Scout/ Scout 66	b	.36 *	.11	.01	.23 *	-----	
	s.e.(b)	.11	.09	.11	.11		
	n	158	127	28	72		
Centurk	b	.56 *	.05	NT	.30	.11	-----
	s.e.(b)	.16	.30		.15	.10	
	n	83	42		8	144	

* - significantly different than zero at alpha = .05
NT - not tested
\+ - sample size

have high values of WYF and may additionally be ideal growing conditions for dieases. Likewise, weather conditions that are the least favorable for winter wheat will have a low WYF and may also be unfavorable conditions for the growth of diseases.

The cultivar Scout was used as a check for measuring differential yielding ability (DYA) by Feyerherm, et. al. (1984). Slopes of regression lines for Scout are only significantly different from zero for Turkey and Bison. This implies that for the other cultivars, Scout was a good check cultivar when calculating DYA values since the difference between Scout and the other cultivars is relatively uniform over a wide range of weather conditions.

Analysis of Model 3 --

$$D_{hk}(i,j) = B_0 + L_h + T_k + e_{hk}.$$

The yield differential between pairs of cultivars was tested as a function of location and year using the General Linear Models (GLM) procedure in SAS (1982). The objective was to determine if locations and years had a significant effect on DYA values.

Table 5 shows a summary of the General Linear Models analysis of differences for pairs of cultivars. The cultivars are listed across the top of the table and again down the left-hand side. The cell numbers represent probabilities of having larger F values if the respective location and year effects are zero.

It can be observed from the table that years are significant for more pairs of cultivars than locations. Year effects were associated with significance levels greater than 0.15 for

Table 5. Significance Probabilities for Location and Year Effects by Pairs of Cultivars Using Model 3.

	Turkey/ Karkof	Triumph	Commanche	Bison	Scout Scout 66	Centurk
Turkey/ Karkof						
Location	-----					
Year	-----					
Triumph						
Location	.78	-----				
Year	.00	-----				
Commanche						
Location	.85	.69	-----			
Year	.00	.09	-----			
Bison						
Location	.10	.00	.99	-----		
Year	.01	.00	.15	-----		
Scout/ Scout 66						
Location	.00	.02	.33	.27	-----	
Year	.00	.00	.46 <1	.21	-----	
Centurk						
Location	.00	.03	NT	.93	.00	-----
Year	.03	.07	NT	.53 <2	.02	-----

<1 - Represents 5 years
<2 - Represents 4 years and 8 observations
NT - Not tested together

only three entries in the table. In two of the cases less than six years of data were available for the test. It is clear that to estimate the average difference in yielding ability between two cultivars, enough years need to be used to "average out" the year effect and reduce bias towards a set of weather conditions. It is not unusual for 3 to 5 consecutive years to have similar weather patterns and fail to express the full range potential weather.

Most pairs of cultivars were tested together at 7 or more locations. The effect of location was not as pronounced as that of year and several attempts were made to eliminate outlier observations to examine their effect on significance levels. Removal of outliers did not change any significant/non-significant decisions at the alpha = .05 level. This implied that this analysis was not very sensitive to outliers when a large number of observations was used. A large sample size compensated for strange or unusual data.

It is possible that the location effect is being confounded with the WYF effect. Knowing something about the location also says something about the general weather conditions. Table 6 gives the mean and standard error of the coefficient of WYF for each of the 19 locations. On the average and across years, the locations are not being subjected to similar weather patterns. Therefore location and WYF are probably not independent.

There does seem to be some interaction between cultivars and locations but based on table 3 it is not easy to

Table 6. Average WYF, Estimated Slope of WYF, and Standard Error of the Estimate for Each Location.

Location	Average WYF	Estimated Slope of WYF	Standard Error of the Estimate
ALL	31.17	2.12	.43
ALT	29.58	-.39	.63
BEL	33.62	1.57	.32
CBY	30.50	0.85	.19
CUS	31.18	1.12	.27
GDL	22.83	0.76	.24
GNC	27.57	0.63	.16
HAY	31.03	0.99	.15
HIP	31.65	0.42	.47
HUT	33.46	1.09	.22
LAH	31.95	0.71	.55
LNC	34.46	1.11	.40
MAN	33.36	0.75	.26
MED	35.76	0.64	.49
MSK	30.20	2.76	.91
NPT	32.78	1.57	.31
SLT	31.53	1.55	.51
TRI	25.49	1.56	.20
WDW	26.68	0.52	.20

detect. Other variables such as weather, disease, and pestilence may be clouding the issue.

Analysis of Model 4 --

$$Y_{gk} = A_0 + C_g + A_1{*}WYF_k + A_2{*}N_k + A_3{*}(C_g{*}WYF)_k + A_4{*}(C_gN)_k + e_{gk}.$$

Yield data were analyzed as a function of cultivar effects using the WYF and applied nitrogen as covariates. The data were analyzed using Analysis of Variance and Covariance procedures. The latter permitted a test for homogeneity-of-slopes and provided estimates of least squares means for the cultivars.

Analysis of Variance procedures with yield = f(cultivar) showed that cultivars had a significant effect in predicting yields as expected. The Duncan's Mean separation technique was performed with the Analysis of Variance and showed that cultivars Triumph and Commanche did not have significantly different yields but that all other cultivars were significantly different from any other cultivar tested.

Homogeneity-of-slope tests were made to determine whether cultivar by WYF and cultivar by applied nitrogen interactions needed to be in the model. The tests showed that neither interaction term was significant. This is somewhat in disagreement with the observations made using Model 2 which showed cultivar by WYF interaction for certain pairs of cultivars. The homogeneity-of--slope model is not as sensitive a test and failed to detect the interactions because the effect over all cultivars averages out the effect of interactions for particular pairs. Even when the model was tested on each individual location, there were no significant interactions.

Analysis of Covariance procedures were used to examine WYF and applied nitrogen as possible covariates to explain variation in yields when testing for significance among cultivars. Tests were made at each location and then for all locations combined. Table 7 summarizes the results when applied nitrogen is not in the model.

Table 7. Yield as a Function of Cultivar and WYF. Significance Probabilities, Slope of WYF and Standard Error of the Slope

		Prob. of Larger F			
	N	Cultivar Effect	WYF Effect	WYF Slope	Standard Error
ALL	52	.01	.00	2.12	.43
ALT	29	.61	.54	-.39	.63
BEL	124	.00	.00	1.57	.32
CBY	130	.00	.00	0.85	.19
CUS	116	.00	.00	1.12	.27
GDL	31	.29	.00	.76	.24
GNC	132	.03	.00	.63	.16
HAY	174	.00	.00	.99	.15
HIP	24	.14	.38	.42	.47
HUT	129	.00	.00	1.09	.22
LAH	27	.37	.21	.71	.55
LNC	56	.09	.01	1.11	.40
MAN	148	.00	.01	.75	.26
MED	24	.00	.21	.64	.49
MSK	27	.70	.01	2.76	.91
NPT	78	.00	.00	1.57	.31
STL	71	.01	.00	1.55	.51
TRI	95	.24	.00	1.56	.20
WDW	70	.00	.01	.52	.20
All location	1537	.00	.00	1.03	.07

The first column is a list of the locations and the second column is the number of observations for each location. The third and fourth columns are the probability of a greater F value for the cultivar and WYF effects respectively. Column 4 is the estimated slope of the regression line in the WYF direction. Column 5 is the standard error of the estimate of the slope. The bottom row is a summary over all 19 of the locations.

Over all locations there is a significant cultivar and WYF effect but they are not always significant for individual locations. Replication of performance trials over different locations helps to estimate yield differences among cultivars more precisely.

It is interesting to note that the slope of the WYF term is close to 1.0 with a small standard error of 0.07. This says that for estimating purposes, a unit increase in WYF results in 1 bushel per acre increase in yield. When studying the effects of factors other than weather on winter wheat yields, one can initially adjust for weather variation by considering (Yield - WYF).

The mean and standard error of the yield for each cultivar was taken from the Analysis of Variance output and compared to the Least Square Mean and standard error after WYF was added as a covariate. The average value of WYF for a cultivar was used to make the adjustments to the mean and standard error. Table 8 is a comparison of the effect WYF had as a covariate.

Table 8. Cultivar Means and Their Standard Error Before and After Adjusting for WYF.

	Raw Mean Before	Standard Error Before	L.S. Mean After	Standard Error After
	----------- bushels per acre -------------			
Turkey/ Karkof	28.0	.57	28.0	.51
Triumph	30.8	.77	31.6	.70
Commanche	30.7	.81	31.2	.74
Bison	33.7	1.07	33.0	.97
Scout/ Scout 66	40.7	.80	40.4	.73
Centurk	45.7	1.05	44.8	.96

Results indicate that use of WYF results in smaller standard errors of cultivar means. Adjustments to cultivar means for different levels of mean WYF's were all less than 1 bushel per acre.

By considering both applied nitrogen and WYF in model 4, some of the means are adjusted quite dramatically. Table 9 shows the effect on the average yield by adding WYF and applied nitrogen as covariates. Across the top are the cultivars. Down the first column are location codes and names. For each pairing of location and cultivar there are four numbers 1) the raw mean before any adjustment, 2) the L.S. Means after adjusting for WYF, 3) the L.S. Means after adjusting for both WYF and applied nitrogen and 4) the number of observations. Largest adjustments to means

Table 9. Average Yields for Cultivars by Location Based on Three Different Models.+
Number of Years are given in parentheses.

Location		Turkey/ Karkof	Triumph	Commanche		Scout/ Bison	Scout 66	Centurk	Average	Number of Obs.
		- - - - - - - - - - - -	- Cultivars-	- - - - - - - - - - - -						
		-------------------------	b/a	-------------------------						
ALL	Alliance, NE	30.5	21.0	30.5	38.3	43.1	51.2	35.8	52	
		31.3	.	32.7	.	41.7	48.4			
		31.4	25.7	32.8	33.8	41.8	48.5			
		(22)	(2)	(8)	(3)	(10)	(7)			
ALT	Altus, OK		----	29.2	----	----	32.4	35.4	31.9	29
		----	29.2	----	----	32.4	35.4			
		----	29.2	----	----	32.4	35.7			
		0	(11)	0	0	(11)	(7)			
BEL	Bellville, KS	28.5	30.6	28.8	38.0	44.9	50.1	33.9	124	
		28.8	30.6	29.2	36.6	44.7	51.1			
		28.8	31.2	30.5	36.7	42.9	49.1			
		(35)	(24)	(23)	(17)	(17)	(8)			
CBY	Colby, KS		31.2	27.0	33.2	31.6	42.6	49.2	33.8	130
		31.1	28.6	33.7	31.8	42.7	47.5			
		31.2	28.6	33.9	31.9	41.6	46.8			
		(56)	(14)	(22)	(13)	(15)	(10)			
CUS	Columbus, KS	32.0	37.7	37.3	40.1	48.7	55.0	38.9	116	
		32.3	38.0	38.2	40.7	47.6	52.8			
		32.3	38.0	38.2	40.7	47.6	52.7			
		(39)	(21)	(18)	(13)	(16)	(9)			
GDL	Goodwell, OK	----	14.7	9.8	----	17.2	----	14.8	31	
		----	14.7	9.3	----	17.4	----			
		----	15.2	10.0	----	17.8	----			
		0	(13)	(5)	0	(8)	0			
GNC	Garden City, KS	22.8	23.6	26.0	29.0	32.4	38.2	26.6	132	
		23.1	24.2	26.6	28.7	31.7	36.0			
		23.1	24.2	26.6	28.7	31.7	36.0			
		(45)	(21)	(23)	(18)	(16)	(9)			
HAY	Hays, KS	23.4	29.3	27.6	29.2	38.7	43.7	27.9	174	
		23.6	29.2	27.8	28.5	39.0	42.1			
		23.4	30.1	28.7	29.4	38.2	39.3			
		(85)	(17)	(25)	(19)	(18)	(10)			
HIP	Sidney, NE	35.1	----	----	----	41.6	46.2	40.3	24	
		34.9	----	----	----	41.3	46.9			
		34.9	----	----	----	41.3	46.9			
		(9)	0	0	0	(9)	(6)			
HUT	Hutchinson, KS	28.7	32.3	29.6	36.3	40.8	46.6	33.5	129	
		28.8	32.5	30.2	35.9	40.5	45.6			
		28.6	32.7	30.6	36.1	40.2	45.0			
		(38)	(23)	(25)	(15)	(18)	(10)			
LAH	Lahoma, OK	----	35.7	----	----	42.7	39.1	38.8	27	
		----	35.7	----	----	41.7	39.1			
		----	35.4	----	----	41.8	39.2			
		0	(9)	0	0	(9)	(9)			
LNC	Lincoln, NE	29.2	29.1	35.9	32.4	41.2	----	32.4	56	
		30.1	27.4	36.6	31.4	39.5	----			
		32.3	25.6	35.1	29.7	37.7	----			
		(25)	(7)	(11)	(6)	(7)	0			

MAN	Manhattan, KS	30.6	32.2	31.7	32.4	40.2	48.8	33.5	148
		30.7	31.9	31.8	31.9	40.6	49.7		
		30.4	32.4	32.2	32.4	40.4	48.6		
		(55)	(25)	(25)	(17)	(17)	(9)		
MED	Mead, NE	33.1	----	----	----	51.5	53.9	46.2	24
		33.1	----	----	----	51.5	53.9		
		33.1	----	----	----	51.5	53.9		
		(8)	0	0	0	(8)	(8)		
MSK	Muskokee, OK	----	34.0	----	----	38.3	39.4	37.0	27
		----	34.7	----	----	39.0	37.5		
		----	34.6	----	----	39.0	37.6		
		0	(10)	0	0	(10)	(7)		
NPT	North Plate, NE	35.8	33.8	39.2	44.6	44.8	48.0	40.8	78
		36.3	32.7	38.8	42.5	45.1	48.8		
		36.3	32.6	38.6	42.3	45.2	49.1		
		(27)	(4)	(10)	(9)	(18)	(10)		
STL	Stillwater, OK	19.2	36.1	32.0	----	44.1	44.3	36.4	71
		21.7	36.1	34.0	----	42.5	42.3		
		20.7	36.0	33.0	----	43.2	43.6		
		(7)	(27)	(13)	0	(15)	(9)		
TRI	Tribune, KS	23.5	25.0	30.7	28.2	31.1	33.1	27.2	95
		23.0	27.6	30.5	27.1	30.4	33.8		
		23.0	27.6	30.5	27.1	30.4	33.8		
		(35)	(13)	(17)	(11)	(11)	(8)		
WDW	Woodward, OK	20.0	34.8	30.1	----	47.7	54.4	36.7	70
		20.9	34.7	30.6	----	47.2	53.4		
		23.8	35.0	33.5	----	44.6	48.7		
		(8)	(27)	(14)	0	(14)	(7)		
Average		28.0	30.8	30.7	33.8	40.1	45.2	33.1	---
Over		28.0	31.6	31.2	33.0	40.4	44.8		
Locations			28.1	31.5	32.1	33.6	39.6	43.0	
		496	268	239	141	247	146	----	1537

+ Simple means, least-square means after adjusting for WYF, least-squares means after adjusting for WYF and applied nitrogen.

are usually associated with a small number of observations. Note that not all cultivar and location combinations were tested.

Final Summary

Table 10 brings together the major findings for models 1 through 4 relative to measuring yield differences among cultivars. Across the top and down the left-hand side are the 6 selected cultivars. For each combination of cultivars there are three estimates of the difference in means for cultivar yields. First is the mean of the difference. The difference is measured when the two cultivars were tested at the same location-year. The difference is then averaged over all location-years available. This is considered to be the best estimate of the true difference because both members of a pair of cultivars were subjected to roughly the same environmental conditions.

The second estimate of the difference is the difference of the L.S. Means when adjusted for both WYF and applied nitrogen. Differences of the L.S. Means in Table 9 were used to get these estimates of the differences. This second estimate is usable when the first estimate in not available or has a small number of observations.

The third estimate is the difference between the raw means over all locations and years taken from Table 9. In nearly all cases the difference of the raw means is an overestimate of the difference. The reasons for this overestimate are not clear. It is probably related to the difference in time frames. Turkey

Table 10. Comparison of Estimates for the Mean Difference Between Cultivars Using Three Different Models.[+]

		Turkey/ Karkof	Triumph	Commanche	Bison	Scout/ Scout66	Centurk
Turkey/ Karkof		-----					
Triumph	Mean of the Difference	2.32	-----				
	Difference of the LS Means	3.34					
	Difference of the Means	2.80					
Commanche	Mean of the Difference	3.71	-.26				
	Difference of the LS Means	3.96	-.62				
	Difference of the Means	2.68	.11				
Bison	Mean of the Difference	4.68	-2.11	-.93	-----		
	Difference of the LS Means	5.41	-2.07	1.45			
	Difference of the Means	5.87	-3.07	3.19			
Scout/ Scout 66	Mean of the Difference	8.77	6.11	5.25	3.72	-----	
	Difference of the LS Means	11.51	8.17	7.55	6.10		
	Difference of the Means	12.75	9.96	10.07	6.89		
Centurk	Mean of the Difference	12.61	7.52	NT	4.91	3.00	-----
	Difference of the LS Means	14.91	11.57	10.95	9.50	3.40	
	Difference of the Means	17.25	14.46	14.57	11.38	4.50	

NT - not tested

+ Simple mean of differences, Difference of the LS Means Using WYF and Nitrogen as covariates, and Difference of simple means. Simple difference of means not balanced for location and year effects.

was observed over a 60 year period but Centurk was only observed for 9 years.

CONCLUSIONS

The most pronounced cultivar by weather interaction was detected when the cultivars Triumph, Commanche, Scout and Centurk were in turn paired with Turkey. Yield differences between Turkey and the other cultivars increased with improved weather conditions for yield. The cultivar by weather interaction was only confirmed when the difference between two cultivars was being tested for the same location-years. Other tests failed to find this interaction when yields had to be compared among locations and/or among years. A cultivar by nitrogen interaction on yield was detected for the Centurk-Turkey pair only.

The interaction between cultivars and weather may be related to the disease resistance of the cultivars being tested. This is an area for further investigation.

The models tested implied that large numbers of observations are important to the analysis. Furthermore, it is more important to do testing over years than testing over locations if there is a choice between the two. Ten or more years of data is recommended.

The weather indicator WYF and applied nitrogen can be used as covariates with the variable cultivar to make yield estimates that adjust, in part, for location and year effects. However, a better approach is to measure cultivar differences when both cultivars are tested for the same location-years and average the differences.

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ON MEASURING DIFFERENTIAL YIELDING ABILITIES OF WHEAT CULTIVARS OVER VARYING ENVIRONMENTS

by

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AN ABSTRACT OF A MASTER'S REPORT

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A large body of historical data on yields of winter wheat over many years, across many locations, and with a mixture of environmental conditions is used to explore the relationship between cultivar yield and environment. It is often difficult to estimate the "true" difference in yield between pairs of cultivars from previous research because of small sample sizes and varying environmental conditions. This paper explores a means of detecting interactions between the environment and the differential yielding ability (DYA) of a pair of cultivars.

Interactions between DYA and some environmental factors were found for pairs of cultivars when one was the cultivar 'Turkey'. The same interaction was not always detected when both cultivars forming a pair were developed after 1940. The large data base implied that testing over years is more important in yield determination than testing over locations and that a minimum of ten years of testing is recommended to estimate the mean of the difference in yield between pairs of cultivars.

Environmental effects were measured by a weather-yield function (WYF), quantity of applied nitrogen, and surrogates location and yeara weather yield function (WYF). The WYF is a measure of the weather effect on cultivar yield and is a function of various moisture and temperature variables during the planting season for winter wheat.

The DYA is best estimated when pairs of cultivars are tested in the same location-years. If this is not possible then covariates such as applied nitrogen and a measure of weather effects can be used to improve the estimate of DYA for pairs of cultivars. If covariates are not used the estimates of DYA have greater variance and genetic effects are likely to be confounded with non-genetic ones.