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Cooperators at the nursery sites in 1969, 1970.

Country	Station	Cooperator(s)	Year(s) 1969	1970
Afghanistan	Kabul	M. Ayub; E. V. Staker	*	*
Afghanistan	Mazar-i-Sharif	M. Ayub; E. V. Staker; C. K. Magee		*
Algeria	El-Harrach	T. Nezzal	*	*
Argentina	Bordenave	S. G. Garbini; E. F. Godoy	*	*
Argentina	Pergamino	J. Rath; E. F. Godoy	*	*
Austria	Vienna	R. Hron; H. Fössleitner		*
Brazil	Rocha Farm	A. M. Schlehuber; M. Rocha		*
Bulgaria	Tolbukin	B. Simeonov; G. Petrov		*
Chile	Temuco	J. Acevedo	*	*
England	Cambridge	F. G. H. Lupton		*
Finland	Jokioinen	R. Manner		*
France	Versailles	C. Goujan	*	*
Germany	Monsheim	A. Lein		*
Germany	Weihenstephan	G. Fischbeck		*
Hungary	Martonvasar	S. Rajki		*
India	Shalimar, Kashmir	S. P. Kohli; H. S. Mannd; D. Singh		*
India	Simla	S. P. Kohli		*
Iran	Karaj	H. C. Thorpe; M. A. Yahabian	*	*
Iran	Kermanshah	H. C. Thorpe	*	
Iran	Mashad	H. C. Thorpe; A. Bahador		*
Iraq	Sulaimaniya	C. L. Pan; A. I. Alaka; I. A. Al-Salihi	*	*
Italy	Milano	M. C. Scalfati	*	*
Italy	Rieti	G. Zittelli; U. Cillis	*	*
Japan	Sapporo	T. Kumagai; H. Araki	*	*
Netherlands	Wageningen	A. C. Zeven; J. Sneep; H. Masselink	*	*
Romania	Fundulea	T. E. Muresan; N. Eustatin; Gh Ittu	*	*
South Korea	Suwon	H. Choi; D. Ree	*	*
Sweden	Svalof	G. Olsson	*	*
Switzerland	Zurich	G. Popow; F. Weilenmann		*
Turkey	Ankara	A. Demirlicakmak; H. P. H. Johnson	*	*
Turkey	Eskisehir	R. Gerek; H. Kutluk; H. P. H. Johnson	*	*
USA	Davis, CA	J. A. Ruppert; C. O. Qualset	*	*
USA	Ft. Collins, CO	J. R. Welsh		*
USA	Lincoln, NE	V. A. Johnson; J. W. Schmidt	*	*
USA	Ithaca, NY	N. Jensen		*
USA	Raleigh, NC	C. F. Murphy	*	*
USA	Stillwater, OK	E. L. Smith; L. H. Edwards	*	*
USA	Pullman, WA	R. E. Allan		*
Yugoslavia	Novi Sad	S. Borojević	*	*
Yugoslavia	Zagreb	J. Potocanac; P. Javoc		*

Winter Wheat Cultivar Performance In an International Array of Environments

J. E. Stroike, V. A. Johnson[1]

INTRODUCTION

Genotype-environment interactions are of major importance to plant breeders. They provide information about the effect of different environments on cultivar performance and have value for assessment of performance stability of new cultivars.

There is seldom, if ever, complete duplication of an environment. The variation of environment at a single location over years can be as great as that between locations in one year. Breeding of cultivars, then, with broad adaptation is a goal of many wheat breeders as a means of achieving maximum performance stability of cultivars over years even within a restricted area of production.

Development of cultivars and hybrids in most breeding programs 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 seldom is possible.

The International Winter Wheat Performance Nursery (IWWPN) organized in 1968 by the Nebraska Agricultural Experiment Station in cooperation with the Agricultural Research Service, U.S. Department of Agriculture, under a contract with the Agency for International Development, U.S. Department of State, has presented a unique opportunity to measure the performance and stability of 28 winter wheat cultivars over an international array of environments. Computations of three parameters for yield, selected agronomic traits, and grain protein and lysine were made from nursery data recorded in 1969 and 1970. The procedure of Eberhart and Russell (10) involving computation of an environmental index was followed.

Objectives of the study were to:

1. Measure the performance characteristics of 28 representative winter wheat cultivars from wheat producing countries throughout the world.

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2. Determine the applicability of the parameters for description of traits other than yield.

3. Assess the usefulness of the parameters for identification of superior cultivars for use in breeding programs.

LITERATURE REVIEW

The literature contains many reports of plant adaptation and genotype x environment relationships. Most cultivated crops have been investigated to define the most appropriate plant breeding scheme for evaluation of genotypes according to their response to environments.

Genotype x environment interactions and their implications for applied plant breeding were discussed in detail by Allard and Bradshaw (2) and Comstock and Moll (8). Frankel (13) pointed out that the plant breeder is faced with the choice of breeding either for closely defined ecological conditions or for more extensive conditions that require genotypes of general or broad adaptability.

Estimates of genotype x environment interactions have been reported by many researchers. Comstock and Moll (8) 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. Baker (4) reported differences between estimates of the ratio of genotype x location interaction relative to experimental error from Western Canada and from other areas reported in the literature in an attempt to find possible application of such estimates from one area to another. The wider environmental variability of Western Canada and differences in experimental techniques were postulated to be the cause of the observed differences in variance estimates.

Studies on cotton reported by Miller et al. (26) indicated that genotype x environment interactions are important for lint yield, but less important for yield components and fiber traits. Abou-El-Fittouh, Rawlings and Miller (1) studied the performance of four varieties of Upland cotton in 101 environments across the Cotton Belt of the Southern United States. They found that for all traits other than yield, a three-factor interaction was the predominant interaction component of variance and, excepting seed index and lint percent, the genotype x year component was the least important. They pointed out that relative importance of the genotype x location component would be expected to increase as the reference base of locations is expanded.

Estimates of genotype x environment interaction variances were obtained from a western Canada Cooperative fall rye test grown from 1963 to 1967 by Kaltsikes (19). He determined that all first-order interactions and second-order interactions were significantly greater than zero at the 0.05 level of probability. Testing in 20 locations for three years with four replicates could detect yield differences as small as 10% of the mean of the highest yielding cultivar. He concluded that for further reduction of the measurable yield difference, more locations would be necessary.

Anand (3) analyzed data from trials involving 12 varieties of wheat at four sites grown for three years in India. Variety x site x year and variety x site interactions were significant, indicating that the performance of varieties varied with the environment.

Dracea and Saulescu (9) analyzed yield variability of five winter wheat varieties over a six-year period in Romania. They found that the best measure of stability was obtained by determining the total yield variance of each variety and calculating the yield regression against the average yield of the experiment.

Smocek (29) calculated yield ecovalence from data obtained in three years of field trials with eighteen varieties of winter wheat in Czechoslovakia. The order of the ecovalence of varieties from a one-year experiment did not conform satisfactorily with the results from two or three years. Significant agreement was found, however, between the ecovalences from two and three years. Smocek concluded that overall adaptability of the varieties was influenced mainly by genotype x year interaction.

Bieri (6) determined, from analysis of yield trials conducted in Switzerland during 1957 to 1966, that genetic variance tended to be low but the error component was high with interactions between genotype and environments in different cereal species. Interactions between genotype and environment were most significant, with site being important in spring wheat and barley, and year in winter wheat. Both year and site produced medium genotype x environment interactions in oats.

The literature contains numerous other reports (7, 24, 25, 27) of genotype x environment studies.

Phenotype stability was defined by Lewis (21) as the ability of an individual to produce a certain narrow range of phenotypes in different environments. Genotype x environment interactions have been studied extensively but varietal stability was not measured in most trials. Plaisted and Peterson (15) presented a method to estimate the variance component of variety x location interactions for potato varieties tested at a number of locations in one year. A combined analysis of variance over all locations was computed for pairs of varieties and an estimate of the variety x location variance was obtained for each pair. An arithmetic mean of these estimates was calculated for each variety. The variety with the smallest value would be the one that exhibited the smallest variety x location interaction and was considered to be the most "stable" variety.

Yates and Cochran (34) proposed that the regression of yield on the environmental index, as measured by the mean yield of all cultivars in a particular environment, would provide a parameter for characterization of the stability of hybrids. Finlay and Wilkinson (12) utilized this technique to compare the performance of a set of cultivars grown at many sites for several seasons. A linear regression of each cultivar mean yield on the mean yield of all cultivars for each site in each season was computed. The mean yield of all cultivars at each site and for each season provided a numerical grading of environment over sites and seasons. In the computations of means and regressions, the basic yields were measured by Finlay and Wilkinson on a logarithmic scale to achieve a high degree of regression linearity of individual yields on site means.

Regression coefficients and cultivar mean yields over environments were used to classify cultivars specifically adapted to high or low yielding environments and for general adaptability. The regression coefficient also provided a measure of phenotypic stability. Average phenotypic stability was indicated by a regression coefficient of unity ($\beta_i = 1.0$). A cultivar with $\beta_i < 1.0$ had above average stability, $\beta_i > 1.0$ had below average stability, and $\beta_i = 0.0$ represented absolute phenotypic stability, i.e., a constant grain yield in all environments. The ideal cultivar was described by Finlay and Wilkinson as possessing genetic potential in the highest yielding environment and maximum phenotypic stability.

Finlay (11) followed this procedure in measuring the adaptation of hybrid barley populations grown in South Australia. He was able to demonstrate yield superiority of hybrid populations over homogeneous varieties grown in an array of environments. He noted that much of the increased phenotypic stability of the F_2 can be attributed to heterosis in genotypes specifically adapted to low yielding environments in which the heterotic effects would be maximal.

Johnson, Shafer and Schmidt (16) used a similar procedure to analyze the general adaptation of hard red winter wheat for the Great Plains of the United States. Their computations revealed substantial progress in variety improvement for the Central and Southern Plains. In new varieties, high yield potential was combined with improved stability of performance.

In 1966, Eberhart and Russell (10) proposed the use of two stability parameters to describe the performance of a variety over an array of environments. They proposed that the regression of each cultivar on an environmental index and a function of the squared deviations from this regression would provide useful estimates of cultivar stability parameters. These parameters are defined with the following model:

$$Y_{ij} = \mu_i + \beta_i I_j + \delta_{ij},$$

where Y_{ij} is the cultivar mean of the ith cultivar at the jth environment, μ_i is the mean of the ith cultivar over all environments, β_i is the regression coefficient that measures the response of the ith cultivar to varying environments, δ_{ij} is the deviation from regression of the ith cultivar at the jth environment, and I_j is the environmental index obtained as the mean of all cultivars at the jth environment minus the grand mean.

The environmental index proposed by Eberhart and Russell is primarily a coded deviation of each environment from the grand mean over all environments. This forces the regression of the mean of cultivars on the environmental index to have unit slope ($\beta_i = 1.0$). They suggested that a "stable cultivar" of maize was one with above average performance in all environments. Hence, they defined a stable cultivar as one with a high mean yield, a unit regression coefficient, and deviation from regression as small as possible ($S_d^2 = 0$). They have since concluded that the actual deviation mean square is more useful than S_d^2 as a measure of cultivar predictability (personal communication with Dr. S. A. Eberhart).

The basic difference between these models is the use of an environmental index instead of actual mean yields, and the application of an additional parameter, namely the deviation mean square value, in the Eberhart-Russell model. They suggested that the deviation mean square may be the more important parameter for evaluating maize in the United States.

Tai (33) used a method similar to that of Eberhart and Russell to compute stability parameters that estimated the genotypic potential of a potato cultivar for stable performance over environments. He concluded from the wide variation in relatively unpredictable deviations from linear response observed in all traits that the deviation mean square was much more important than the relatively predictable regression coefficient of the linear response.

Baker (5) proposed from a study of genotype x environment interactions for yield of wheat grown in Western Canada, that stability of a variety is inversely proportional to the sum of squares for genotype x environment interaction attributable to that variety. A low covariance of genotype x environment effects with environmental effects would be an indication of varietal stability.

Joppa, Lebsock and Busch (18) 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 Russell. They concluded that the use of the regression analysis on such data could materially assist the plant breeder in making decisions regarding cultivar release. The Eberhart-Russell model also was used by Reich and Atkins (28) to evaluate the yield stability of populations of Grain Sorghum in different environments. The populations consisted of 8 parental lines, 16 F_1 hybrids, 16 two-component blends of parental lines, and 16 two-component hybrid blends of grain sorghum (*Sorghum bicolor* L. Moench). Parameters for grain yield indicated that hybrid blends were the most productive and stable populations, although none were distinctly superior for all parameters.

MATERIALS AND METHODS

Materials

The International Winter Wheat Performance Nursery was established to study the performance of winter wheat cultivars and experimental lines in the various winter wheat environments of the world. It was designed to identify superior winter wheat genotypes for use in breeding wheats with improved nutritional quality, and to be a source of new genetic material in wheat improvement programs of nursery cooperators. Data from the first and second IWWPNs grown in 1969 and 1970 respectively were utilized for this study.

The first nursery was grown at 23 sites in 16 countries. The second nursery was grown at 38 sites in 24 countries. These testing sites are described in Table 1.

Cultivars and experimental lines of winter wheat were nominated for nursery testing by cooperators. Seed of each candidate cultivar provided initially by cooperators was increased under U.S. quarantine at Yuma, Arizona, before inclusion in the nursery. Pedigrees of the 30 cultivars included in the first and second nurseries appear in Table 2.

Methods

The International Nursery was comprised of 30 cultivars grown in a randomized complete block design with four replications. The seeding rate in 1969 was 80 kg/ha at all sites. Each plot consisted of six rows with the four center rows harvested for yield. Row length was 2.5 meters. Spacing between rows was 30 centimeters. In 1970, nursery seed was provided to cooperators in the approximate quantity requested by them. Row length and distance between rows were adjusted at each site to achieve a seeding rate consistent with local practice.

In 1969, data were reported and seed samples for protein analyses were received from all nursery sites except Versailles, France; El-Harrach, Algeria; and Lincoln, Nebraska. Severe lodging at Versailles rendered the nursery useless for yield purposes. Data were not reported from El-Harrach. Loss of stands from low temperatures and heavy ice cover during the winter resulted in abandonment of the nursery at Lincoln.

Data were reported from all nursery sites except Versailles, France; Pullman, Washington; and Simla, India in 1970. The nursery was

Table 1. International Winter Wheat Performance Nursery sites in 1969 and 1970.

Country	Station	Latitude				Longitude				Elevation (m)
Afghanistan	Kabul	34°	33′		N	69°	11′		E	1803
Afghanistan	Mazar-i-Sharif**	36°	42′		N	67°	13′		E	378
Algeria	El-Harrach	36°	0′		N	7°	0′		E	700
Argentina	Bordenave	37°	50′	55″	S	63°	1′	20″	W	212
Argentina	Pergamino	33°	52′	58″	S	60°	35′	15″	W	68
Austria	Vienna**	48°	12′		N	16°	45′		E	147
Brazil	Rocha Farm**	31°		40″	S	53°		45″	W	200
Bulgaria	Tolbukin**	43°	40′		N	28°	10′		E	236
Chile	Temuco	38°	40′		S	72°	25′		W	332
England	Cambridge**	52°	30′		N	00°	15′		E	15
Finland	Jokioinen**	60°	49′		N	23°	29′		E	92
France	Versailles	48°	53′		N	2°	40′		E	30
Germany	Monsheim**	49°	35′		N	8°	20′		E	166
Germany	Weihenstephan**	48°	24′		N	11°	44′		E	467
Hungary	Martonvasar**	47°	21′		N	18°	49′		E	150
India	Shalimar, Kashmir**	35°	0′		N	75°	0′		E	1600
India	Simla**	32°	0′		N	77°	0′		E	1890
Iran	Karaj	35°	47′		N	50°	0′		E	1300
Iran	Kermanshah*	34°	19′		N	47°	5′		E	1410
Iran	Mashad**	36°	16′		N	59°	38′		E	985
Iraq	Sulaimaniya	36°	0′		N	46°	0′		E	700
Italy	Milano	45°	13′		N	9°	25′		E	73
Italy	Rieti	42°	24′		N	12°	52′		E	402
Japan	Sapporo	43°	3′		N	141°	20′		E	60
Netherlands	Wageningen	51°	58′	2″	N	5°	38′	30″	E	7
Romania	Fundulea	44°	30′		N	24°	10′		E	66
South Korea	Suwon	37°	16′		N	126°	59′		E	37
Sweden	Svalof	55°	35′		N	13°	6′		E	50
Switzerland	Zurich**	47°	29′		N	8°	32′		E	445
Turkey	Ankara	39°	57′		N	32°	53′		E	850
Turkey	Eskisehir	36°	45′		N	30°	95′		E	789
USA	Davis, CA	38°	32′		N	121°	45′		W	15
USA	Ft. Collins, CO**	40°		30″	N	150°	0′		W	1525
USA	Lincoln, NE	41°	10′		N	96°	25′		W	360
USA	Ithaca, NY**	42°	0′		N	76°	0′		W	365
USA	Raleigh, NC	35°	42′		N	80°	37′		W	251
USA	Stillwater, OK	36°	6′		N	97°	4′		W	270
USA	Pullman, WA**	46°	42′		N	117°	8′		W	775
Yugoslavia	Novi Sad	45°	5′		N	19°	8′		E	84
Yugoslavia	Zagreb**	45°	49′		N	15°	59′		E	122

* 1st IWWPN only.
** 2nd IWWPN only.

not seeded at Versailles. Nurseries at Pullman and Simla were destroyed by hail and drought, respectively.

Seed samples were received from all sites reporting data in 1970 except Sulaimaniya, Iraq; Zagreb, Yugoslavia; and Shalimar, Kashmir, India. Protein and lysine analyses were made on these samples in the University of Nebraska Wheat Quality Laboratory. Samples from Tolbulkin, Bulgaria were not analyzed due to excessive seed treatment which interfered with the lysine procedure utilized. The seed samples

Name	C.I., P.I. or Sel. No.	Country of origin	Pedigree
Arthur	14425	Indiana, USA	Purdue 5752-A1-1P-2
Atlas 66	12561	N. Carolina, USA	Frondoso/2/Redhart/3/Noll 28
Bankuti 1201	232943	Hungary	Bankuti 5/Marquis
Benhur	14054	Indiana, USA	Complex cross involving Knox 62, Hope, Hussar and Kenya Farmer
Bezostaia	15158	USSR	Lutescens 17/Skorospelka 2
Blueboy	14031	N. Carolina, USA	Brevor/Norin 10/Anderson/Coker 55-9
Cappelle Desprez	262223	France	Vilmorin 27/Hybride du Jocquois
Felix	295992	The Netherlands	Tassilo/Carsten/2/Carsten/Marquillo
Fertodi 293	268072	Hungary	Kawvale/Bankuti
Gage	13532	Nebraska, USA	Ponca/3/Mediterranean/Hope/2/Pawnee
Gaines	13448	Washington, USA	Norin 10/Brevor, Sel. 14/Brevor/Oro/Turkey/Florence/Oro/Fortyfold/Federation
Heine VII	209794	W. Germany	Hybrid with short Straw/Svalofs Kronen
High Protein Sel	Purd 4930A6-28-2-1	Indiana, USA	Complex cross involving Frondoso
High Protein Sel	NB67730	Nebraska, USA	Atlas 66/Comanche
Inia 66[1]	14195	Mexico	Lerma Rojo 64/Sonora 64
Lancer	13547	Nebraska, USA	Turkey/Cheyenne/2/Hope/2*Cheyenne
Lerma Rojo 64[1]	13929	Mexico	Lerma Rojo/4/Lerma 52/3/Norin 10/Brevor/2/Yaqui 50
Odin	264272	Sweden	Gluten/Ergo I
Parker	13285	Kansas, USA	Quivira/3/Kanred/Hard Federation/2/Prelude/Kanred/4/Kawvale/Marquillo/2/Kawvale/Tenmarq
Riley 67	14110	Indiana, USA	Riley *5/3/Knox Type 7/Transfer/2/Purdue 50
San Pastore	213835	Italy	Villa Glori/Balilla
Scout 66	13996	Nebraska, USA	Sel. from Nebred/2/Hope/Turkey/3/Cheyenne/Ponca
Shawnee	14157	Kansas, USA	Sel. from Mediterranean/Hope/2/Pawnee/3/Oro/Illinois *1/2/Comanche
Stadler	13704	Missouri, USA	Thorne/Clarkan
Sturdy	13684	Texas, USA	Sinvalocho/Wichita/2/Hope/Cheyenne/3/2*Wichita/4/Sen Seun
Timwin	13787	Wisconsin, USA	Knox/3/(Brevor/Norin, Sel. 10/2/H483a-3-5)F_1
Triumph 64	13679	Oklahoma, USA	Danne Bdl. Blackhull/3/Kanred/Blackhull/2/Florence/4/Kanred/Blackhull/2/Triumph
Winalta	13670	Canada	Minter/Wichita
Yorkstar	14026	New York, USA	Genesee *3/3/Yorkwin/2/Norin 10/Brevor
Yung Kwang	———	South Korea	—————————

[1] Spring wheat

from El-Harrach had received severe insect damage and were not analyzed.

Adjustment of lysine to a common 13.5% protein level was proposed by Johnson et al. (17) based upon a regression analysis of 4,100 varieties of common wheat from the World Collection. Similar adjustment of lysine values was made in this study.

Nursery cooperators provided cultivar performance information as follows:

Yield of grain: weight of clean grain from each plot reported as quintals per hectare.

Test weight: weight of clean grain in kilograms per hectoliter.

Flowering date: date of anther extrusion from approximately 1/3 of the spikes in a plot reported as number of days from Jan. 1.

Ripening date: date of physiological plant maturity reported as number of days from Jan. 1.

Plant height: average height of plants in centimeters, excluding awns.

Lodging: percent of plot with lodged straw at maturity.

Shattering: percent of grain lost from spikes in the standing border rows of plots two weeks after harvest of the yield rows.

Winter survival: percent of live plants in the center rows of each plot in the spring.

Frost damage: percent of flower sterility in plots resulting from late spring frosts.

Diseases: severity in percent; response according to the modified Cobb scale for stripe rust *(Puccinia striiformis)* West., stem rust *(Puccinia graminis tritici),* Eriks. & Henn., leaf rust *(Puccinia recondita)* Rob. ex Desm., and other diseases present in sufficient intensity to permit classification of cultivar reaction.

Disease and frost damage were not summarized in this study.

Cultivar means and an appropriate analysis of variance were computed for each agronomic variable at each location. Data from all nursery sites were then combined within years and over years for computation of means and analyses of variance. Analyses of data from individual sites and combined sites were presented initially in reports by Stroike, et al. (31,32). They provide the basic data utilized in this study.

Stability parameters computed according to the Eberhart and Russell model were utilized to describe the performance of cultivars over environments. In the analyses, the cultivar x location interaction is partitioned into a cultivar x location (linear) interaction and a pooled deviation mean square. The cultivar x location (linear) interaction mean square provided a test of genetic differences among cultivars for their regression upon the environmental indexes.

An environmental index was computed for each location by subtracting the grand mean of cultivars over all locations from the location mean. The mean of a cultivar at each location was then regressed upon the environmental index. The regression coefficient and the deviations from regression were the parameters utilized to evaluate stability of performance over locations.

Tests for significance of differences among cultivar means, regression coefficients and deviations from regression were made in accordance with the methods outlined by Eberhart and Russell. Duncan's Multiple Range Test was computed for cultivar means according to the method outlined by Steele and Torrie (30).

Cultivar x location (linear) interaction sum of squares was obtained from the summation of the sum of squares for the deviation due to regression over all cultivars multiplied by the number of replications, minus the location (linear) sum of squares. Pooled deviations were obtained from the summation of the sum of squares for deviations from regression over all cultivars multiplied by the number of replications. Multiplication by replications was necessary to place the analysis on an equal sampling basis, since the linear regression analysis was performed on the mean of four replications, and the factorial analysis of variance was computed over four replications.

A factorial analysis of variance of cultivar data over locations and years was computed. An approximate F-test was made to measure differences between cultivars. Location means in 1969 and 1970 did not have the same rank. Orthogonal polynomial coefficients were then required for linear regression analysis of location means from data combined for 1969 and 1970; otherwise the treatment of data over years was similar to that for data within years.

Reasonable biological interpretation of the computed pooled deviations x years was not possible because of the different ranking of location means from 1969 to 1970. Consequently, the orthogonal polynomial coefficients used to fit the data averaged over years were not applicable to the location means on an individual year basis in that portion of the analysis of variance table involving year x location interactions.

EXPERIMENTAL RESULTS

Twenty-eight winter wheat cultivars listed in Table 2 were compared in the study. Means of agronomic, grain quality and disease data from each nursery site and summaries according to each data field were reported by Stroike, et al. (31,32). General information concerning each nursery site and description of climatic conditions during the test also were reported.

Yield

Stability parameters for yield are presented in Table 3 for 28 winter wheat cultivars grown in the first and second IWWPN's. Cultivar mean yields ranged from 26.7 to 45.1 q/ha in 1969. In 1970 the range in mean yields was approximately the same as in 1969 but averaged 5 q/ha lower. The agreement in cultivar yield rankings in the 1st and 2nd nurseries was fair. Only five cultivars had the same rank but several cultivars were similar in rank in 1969 and 1970. Two-year mean yields ranged from 24.3 q/ha for Odin to 43.7 q/ha for Bezostaia. Timwin, Arthur and Sturdy produced relatively high mean yields which were not significantly different statistically from that of Bezostaia over the two years. Blueboy was the second highest yielding cultivar in the 1969 nursery but was less productive in 1970 because of poor seed germination.

Regression coefficients for cultivar mean yields on environmental indexes in 1969 ranged from 1.21 for Bezostaia to only 0.64 for Triumph 64. In 1970 the regression coefficient of Bezostaia dropped to 1.03. Arthur had the highest coefficient of 1.25. The 0.75 coefficient for Winalta was the lowest in the nursery. Triumph 64 was third lowest with 0.81. Bezostaia, Timwin, Yung Kwang and Heine VII were consistently above unity ($\beta_i = 1.0$) in each year and over two years. Regression coefficients for Triumph 64, Purdue 4930A6-28-2-1 and Winalta were below unity in each year and over years. Bezostaia with the highest 2-year mean yield and Odin with the lowest 2-year mean yield produced the highest 2-year regression coefficients.

Arthur, Scout 66 and Fertodi 293 had much larger regression coefficients when grown at 31 sites in 1970 than when grown at 16 sites in 1969. Regression coefficients for some cultivars were much smaller in 1970 than in 1969. An example is Stadler which decreased from 1.17 to 0.91.

Deviation mean square values of yield differed greatly among cultivars grown in these nurseries. In 1969 they ranged from 153.2 for Odin to a low of only 11.6 for Riley 67. In 1970 the range was from 136.8 for Odin to 13.3 for Winalta. Odin's deviation from regression was notably large in each year. Deviation mean squares for Winalta and Gage were consistently low in each year and over two years.

Three cultivars with widely different 2-year yield stability parameters are compared in Figure 1. Bezostaia with a high mean yield and high regression coefficient is compared with Odin and Triumph 64. The low regression coefficient of Triumph 64 contrasts with the higher values for Bezostaia and Odin. Further contrast was the large deviation mean square for Odin compared to relatively low values for Bezostaia and Triumph 64.

Regression of yields for Scout 66 and Riley 67 on the environ-

Table 3. Stability parameters for yield of 28 winter wheat cultivars grown in the International Winter Wheat Performance Nursery in 1969 and 1970.

Cultivar	Mean (q/ha)			Regression coefficient			Deviation mean square		
	1969	1970	1969–1970	1969	1970	1969–1970	1969	1970	1969–1970
No. of sites	16	31	15	16	31	15	16	31	15
Bezostaia	45.1	39.5	43.7	1.21	1.03	1.21	37.5	57.6	33.7
Timwin	39.9	35.4	39.2	1.05	1.15	1.16	24.0	67.9	14.1
Arthur	38.0	33.7	38.6	0.83	1.25	0.96	58.2	64.8	43.3
Sturdy	40.5	32.2	38.5	1.04	1.01	0.92	19.6	46.2	17.3
Parker	39.7	32.7	38.3	0.99	1.11	0.98	15.4	51.8	14.0
Scout 66	38.3	34.5	38.1	0.82	1.23	1.00	49.8	25.4	12.2
Fertodi 293	39.2	32.4	37.1	0.98	1.17	1.04	16.1	32.7	10.6
Blueboy[1]	43.5	29.0	37.0	1.19	0.99	1.14	53.9	85.8	27.3
Yung Kwang	38.0	29.9	36.9	1.11	1.03	1.01	24.1	88.8	33.7
Stadler	36.8	31.5	36.0	1.17	0.91	1.18	29.9	95.3	28.4
San Pastore	41.0	26.7	35.9	0.98	0.99	0.75	28.3	123.8	39.2
Gage	37.0	32.0	35.8	0.94	1.11	0.97	14.1	21.4	10.0
Shawnee	36.4	30.5	35.6	0.99	1.12	1.06	19.2	48.8	17.0
Benhur	38.5	29.7	35.5	0.98	0.78	0.79	19.5	105.3	47.6
Riley 67	36.3	31.5	35.3	0.97	0.97	0.99	11.6	30.7	18.2
Lancer	36.5	32.4	35.1	0.94	1.01	0.95	25.7	37.5	18.5
Yorkstar	35.7	30.8	34.9	0.99	1.08	1.14	73.7	50.1	54.8
Triumph 64	35.5	29.8	34.6	0.64	0.81	0.67	44.6	51.9	25.7
Heine VII	36.6	30.7	34.2	1.19	1.01	1.14	45.0	110.4	59.8
NB67730	34.8	28.1	33.3	0.92	1.02	0.90	22.7	27.7	18.6
Bankuti 1201	35.6	28.4	33.2	0.95	1.11	1.01	31.0	16.9	19.9
Atlas 66	33.4	28.8	32.2	0.89	1.01	0.98	40.4	53.2	27.0
Purdue 28-2-1[2]	32.9	27.0	31.8	0.79	0.88	0.86	49.4	34.6	38.2
Winalta	32.1	28.1	30.7	0.91	0.75	0.80	17.5	13.3	9.1
Gaines	30.6	26.9	30.0	1.01	0.88	0.97	43.4	71.9	40.3
Cappelle Desprez	32.5	25.8	29.1	1.18	0.88	1.05	48.9	67.6	39.2
Felix	29.5	23.5	26.7	1.16	0.84	1.16	96.5	121.1	88.6
Odin	26.7	21.5	24.3	1.18	0.84	1.23	153.2	136.8	122.7

[1] Poor seed germination in 1970.
[2] Purdue 4930A6-28-2-1

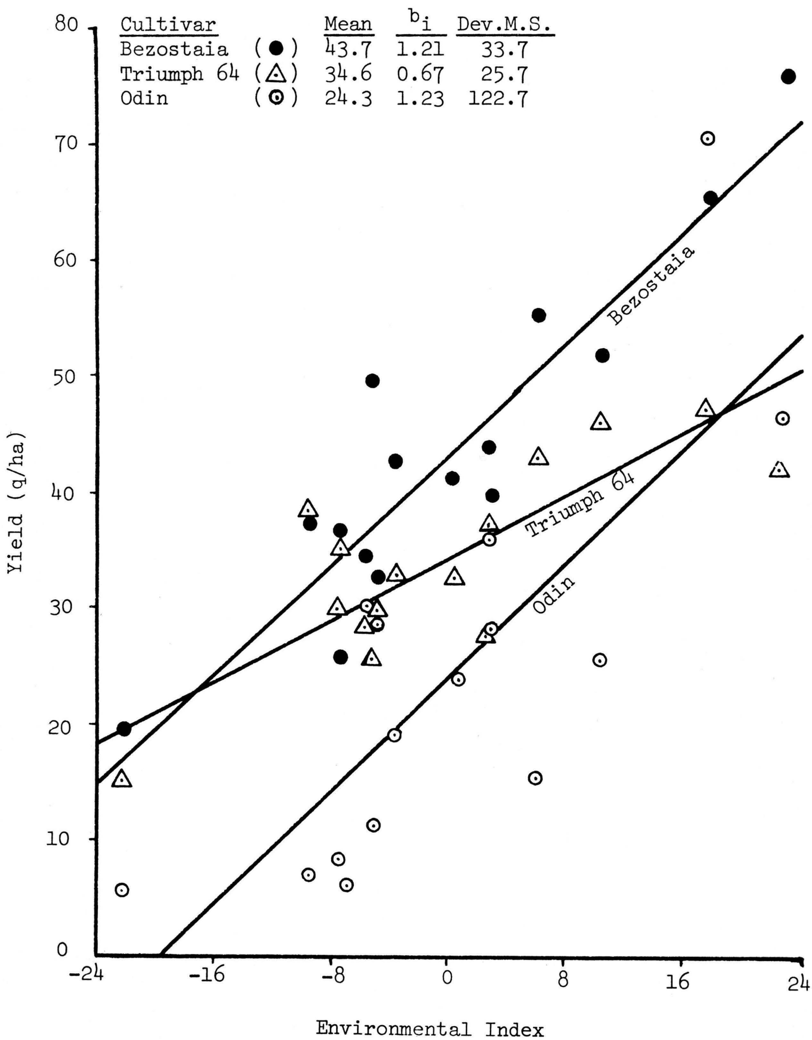

Figure 1. Regression of 2-year mean yields of three cultivars on environmental indexes of the International Winter Wheat Performance Nursery grown in 1969 and 1970.

mental indexes of the second IWWPN are shown in Figure 2. The mean yields of these cultivars were about equal as were their deviation mean square values. They differed sharply in the magnitude of regression coefficients. The larger regression coefficient of Scout 66 indicates that its potential yield is higher than that of Riley 67 in the more favorable environments.

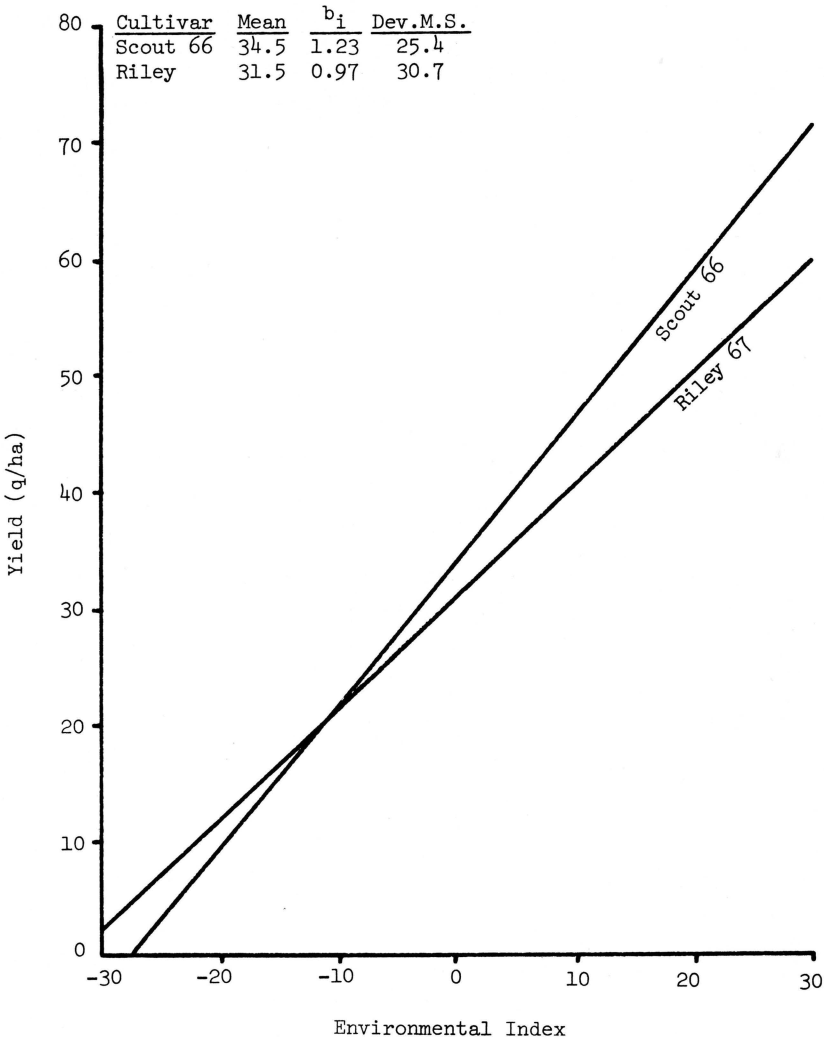

Figure 2. Regression of yield of Scout 66 and Riley 67 on environmental indexes of the International Winter Wheat Performance Nursery grown in 1970.

Regression of yields for Scout 66 and Stadler on the environmental indexes of the second IWWPN is shown in Figure 3. Their mean yields were similar but they possessed widely different regression coefficients and deviation mean square values.

Yields of Yorkstar and Riley 67 regressed on the environmental indexes of the second IWWPN are compared in Figure 4. The two

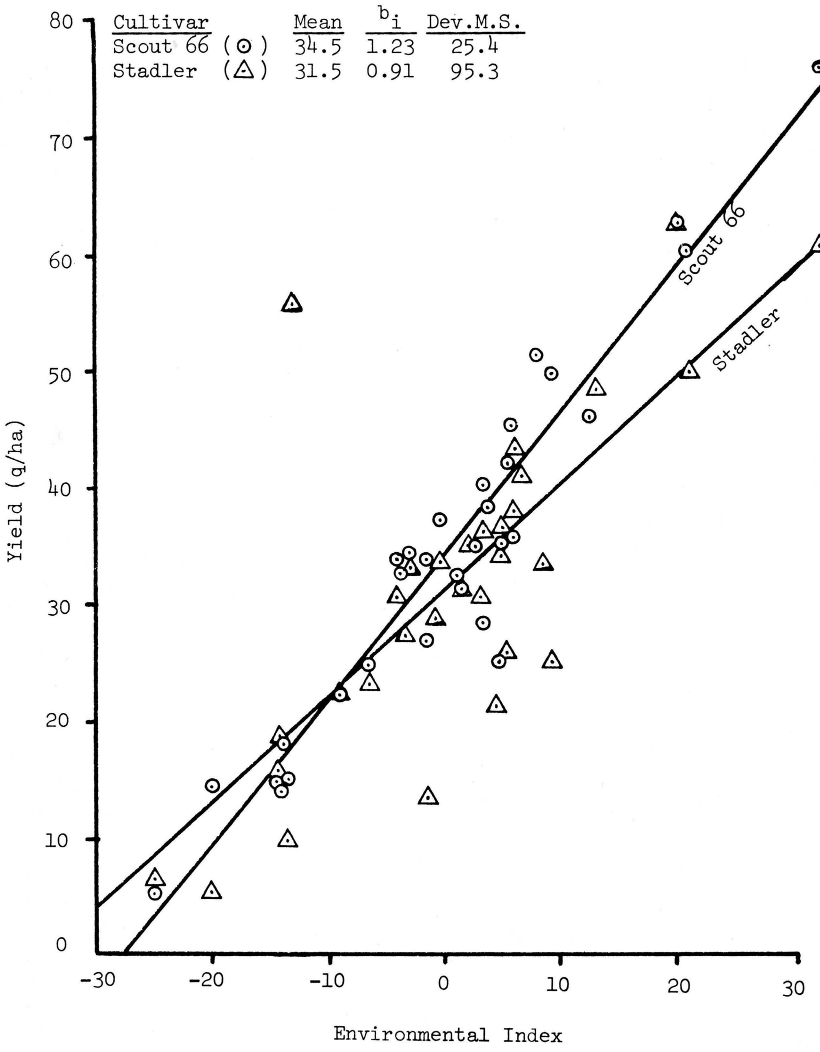

Figure 3. Regression of yield of Scout 66 and Stadler on environmental indexes of the International Winter Wheat Performance Nursery grown in 1970.

cultivars had similar mean yields and regression coefficients. The deviation mean square for Yorkstar was large and that of Riley 67 was small.

Bezostaia produced a high mean yield of 45.1 q/ha and a high regression coefficient of 1.21 in the first IWWPN (Table 3). Atlas 66 produced a low mean yield of 33.4 q/ha and a low regression coefficient

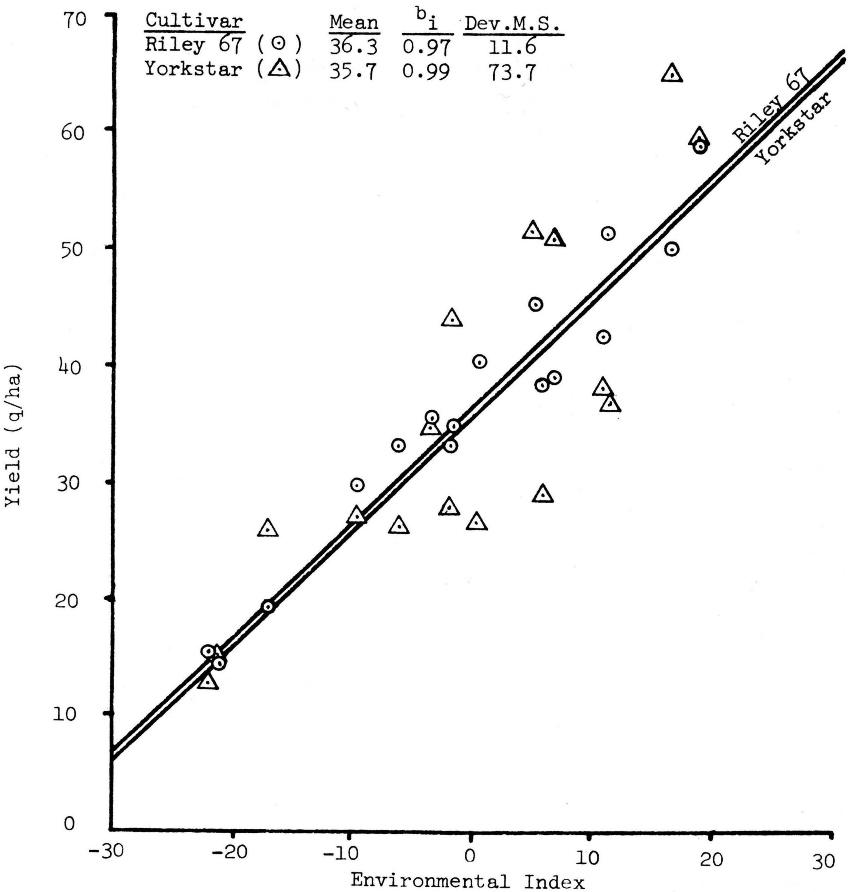

Figure 4. Regression of yield of Yorkstar and Riley 67 on environmental indexes of the International Winter Wheat Performance Nursery grown in 1969.

of 0.89 in the first IWWPN. The deviation mean square values for Bezostaia and Atlas 66 were similar. The yield regressions of these two cultivars on the environmental indexes of the first IWWPN are contrasted in Figure 5.

Figure 6 graphically illustrates the differences between cultivars Cappelle Desprez and Arthur for their regressions of yield on environmental indexes of the second IWWPN. Arthur with the larger mean yield but low regression coefficient sharply contrasts with the smaller mean yield and high regression coefficient of Cappelle Desprez. Deviation mean square values are similar for the two cultivars. The larger mean yield of Arthur over all environments clearly is associated with its higher yield than Cappelle Desprez in the poorer environments.

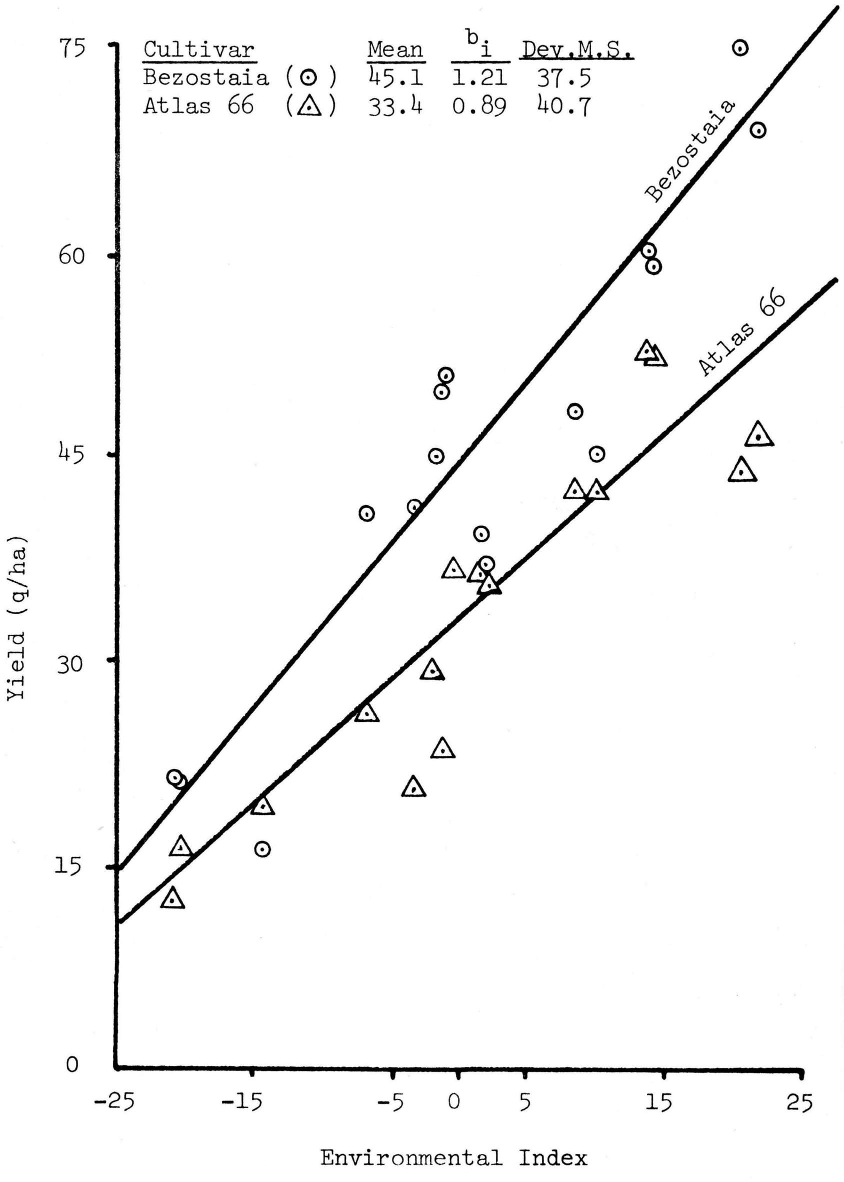

Figure 5. Regression of yield of Bezostaia and Atlas 66 on environmental indexes of the International Winter Wheat Performance Nursery ***grown in 1969.***

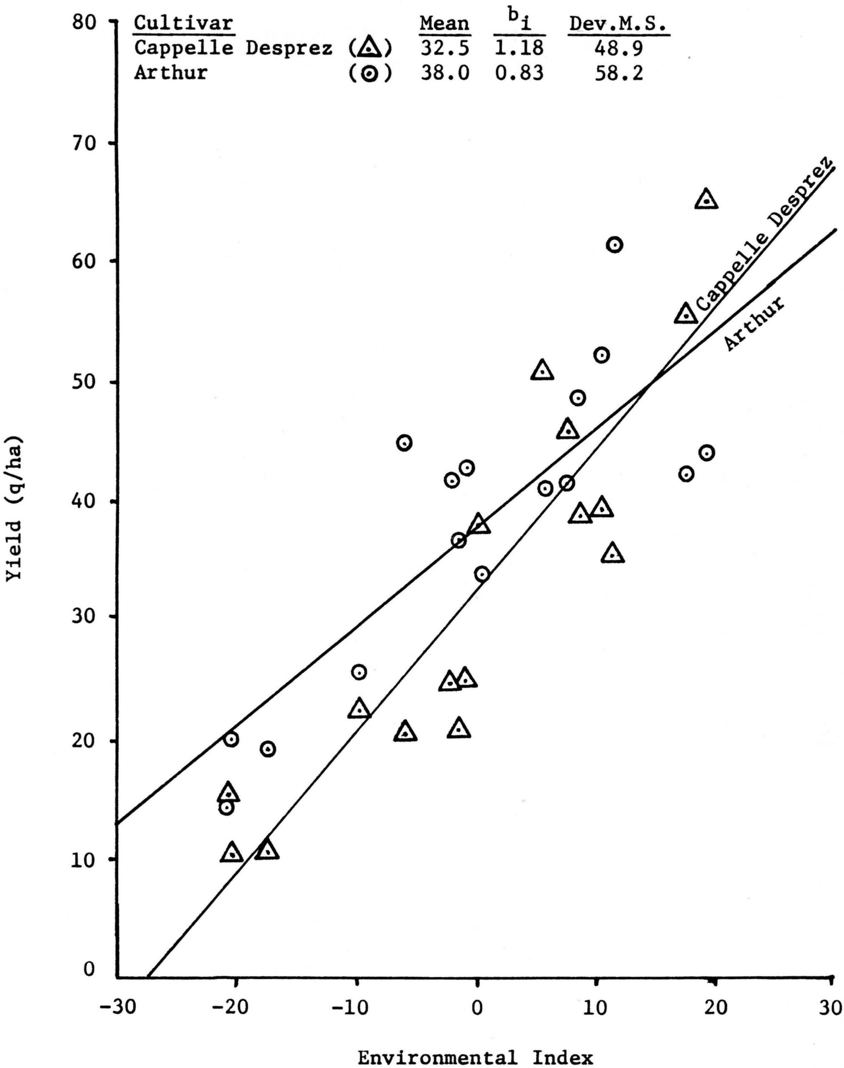

Figure 6. Regression of yield of Cappelle Desprez and Arthur on environmental indexes of the International Winter Wheat Performance Nursery grown in 1970.

Test Weight

Stability parameters for test weight are presented in Table 4 for 28 winter wheat cultivars grown in the first and second IWWPNs. Test weight means varied widely, ranging from 70.0 kg/hl for Odin to

Table 4. Stability parameters for test weight of 28 winter wheat cultivars grown in the International Winter Wheat Performance Nursery in 1969 and 1970.

Cultivar	Mean (kg/hl)			Regression coefficient			Deviation mean square		
	1969	1970	1969–1970	1969	1970	1969–1970	1969	1970	1969–1970
No. of sites	10	12	8	10	12	8	10	12	8
Parker	82.4	80.3	81.2	0.54	0.70	0.64	1.1	8.2	1.5
Bezostaia	81.3	79.9	80.6	0.74	0.84	0.78	1.4	17.3	1.7
Triumph 64	80.9	80.2	80.2	0.73	0.76	0.74	2.2	6.9	2.2
Shawnee	80.8	79.2	80.2	0.61	1.05	0.92	2.2	53.8	3.1
Lancer	80.8	79.0	79.6	0.80	1.08	1.00	2.8	9.2	3.0
Winalta	80.2	79.0	79.5	0.72	0.99	0.92	6.0	8.8	3.0
Benhur	80.3	78.9	79.5	0.88	0.82	0.84	1.8	13.9	3.1
Purdue 28-2-1[1]	80.3	78.9	79.5	0.64	0.69	0.68	1.7	14.8	3.5
Scout 66	80.7	79.0	79.5	0.80	0.82	0.81	2.6	13.9	3.9
Gage	80.2	78.2	78.9	0.64	0.81	0.75	2.0	8.8	2.1
Arthur	80.3	77.9	78.8	0.48	0.88	0.70	0.8	24.4	3.5
Sturdy	79.9	77.4	78.7	0.94	1.02	1.02	1.6	17.3	2.3
Bankuti 1201	79.9	78.4	78.6	0.73	1.08	0.98	3.4	28.6	4.8
NB67730	80.1	77.9	78.5	0.79	0.74	0.75	3.5	8.7	3.4
Stadler	79.4	77.5	78.3	0.76	1.20	1.10	6.9	61.1	13.7
Fertodi 293	78.7	76.9	77.6	0.86	1.01	1.01	4.1	7.1	1.3
Riley 67	79.1	76.7	77.3	0.96	1.09	1.03	1.2	36.6	5.3
San Pastore	78.4	76.6	77.2	0.87	0.83	0.81	0.8	11.0	0.9
Atlas 66	78.1	76.5	76.9	0.99	1.15	1.13	5.5	29.4	5.8
Timwin	77.6	75.8	76.6	0.55	1.02	0.88	5.5	11.6	3.1
Yung Kwang	77.3	75.6	76.5	0.76	0.88	0.85	1.9	18.1	2.0
Blueboy	75.5	71.5	73.7	0.86	0.94	0.87	3.8	35.0	4.3
Yorkstar	72.5	71.0	71.7	1.25	1.27	1.28	9.8	18.6	6.4
Heine VII	73.9	71.7	71.6	1.51	1.40	1.35	19.3	32.5	10.8
Gaines	72.3	69.7	70.4	1.58	1.41	1.41	11.2	84.5	7.1
Cappelle Desprez	71.1	70.6	70.1	1.99	1.21	1.48	12.8	19.2	10.2
Odin	70.0	70.8	69.4	2.49	1.00	1.54	24.0	98.5	27.4
Felix	70.3	70.4	68.2	2.54	1.30	1.72	22.1	66.9	27.4

[1] Purdue 4930A6-28-2-1

82.4 kg/hl for Parker in 1969, and from 69.7 kg/hl for Gaines to 80.3 kg/hl for Parker in 1970. Two-year means over eight sites ranged from 68.2 kg/hl for Felix to 81.2 kg/hl for Parker. There were large cultivar differences in regression coefficients which ranged from 2.54 to 0.48 for Felix and Arthur, respectively in 1969 and from 1.41 to 0.69 for Gaines and Purdue 4930A6-28-2-1, respectively in 1970.

Deviation mean squares for test weight were relatively small in 1969, ranging from 0.8 for Arthur and San Pastore to 24.0 for Odin. In 1970 the deviation mean squares were much larger, ranging from 6.9 for Triumph 64 to 98.5 for Odin. Parker and Bezostaia produced high mean test weights with small regression coefficients and deviation mean squares over two years. Felix and Odin produced lower test weights with large regression coefficients and deviation mean squares. These striking differences are graphically shown in Figure 7.

Maturity

Stability parameters for flowering dates of 28 winter wheat cultivars grown in the first and second IWWPNs appear in Table 5.

There were 18 days difference in 1969 and 17 days difference in 1970 between the earliest and latest flowering cultivars. Odin, Felix and Cappelle Desprez were consistently the latest to flower. San Pastore, Triumph 64 and Benhur were consistently the earliest cultivars to flower. Regression coefficients ranged from 0.80 for Odin to 1.16 for San Pastore in 1969 and from 0.83 for Odin to 1.13 for Atlas 66 in 1970. Deviation mean squares ranged from 1.7 for Purdue 4930A6-28-2-1 to 22.7 for Gage in the first nursery. In the second nursery deviation mean squares ranged from 1.7 to 59.4 for Riley 67 and Odin, respectively.

Most cultivars were highly consistent for all flowering stability parameters in 1969 and 1970. Ten cultivars flowered on the average in exactly the same number of days from Jan. 1 in each year. Twelve cultivars differed by only one day and no cultivar differed by more than three days for mean flowering in the two years. Several cultivars, notably Yung Kwang, Benhur, Parker, Purdue 4930A6-28-2-1, Fertodi 293, Yorkstar and Felix, exhibited highly consistent regression coefficients and deviation mean squares for flowering date in the two years.

Stability parameters for ripening dates are presented in Table 6. They show the same cultivar consistency over years as was shown in flowering dates. The range in ripening dates among cultivars was 13 days in 1969 and 14 days in 1970. Regression coefficients for ripening in 1970 ranged from 0.85 to 1.15 for Timwin and Blueboy, respectively. Blueboy produced consistently the highest regression coefficients in 1969 and 1970. Deviation mean squares for ripening in 1969 ranged from only 1.6 for Parker to 52.0 for Timwin and from 1.9 for Shawnee

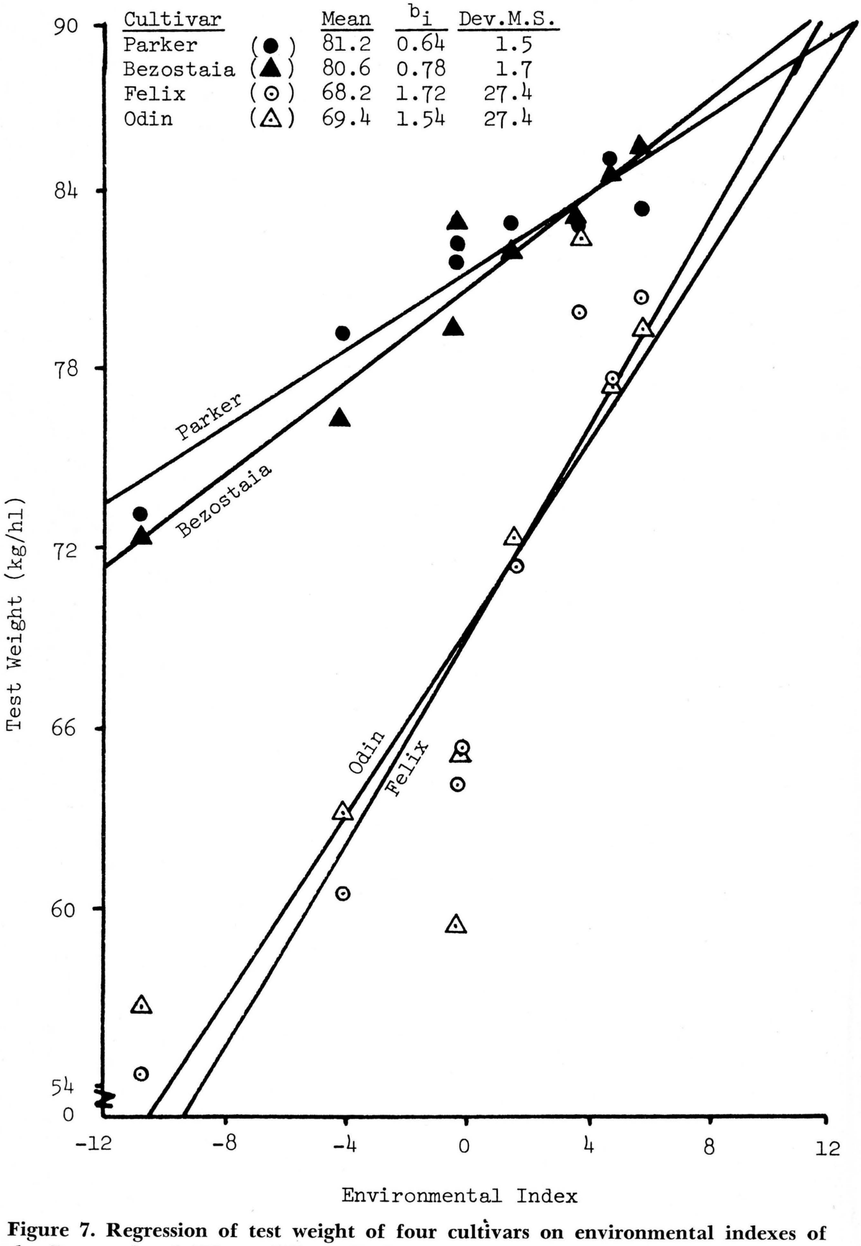

Figure 7. Regression of test weight of four cultivars on environmental indexes of the International Winter Wheat Performance Nursery grown in 1969 and 1970.

Table 5. Stability parameters for date of flowering of 28 winter wheat cultivars grown in the International Winter Wheat Performance Nursery in 1969 and 1970.

Cultivar	Mean (days from Jan. 1)			Regression coefficient			Deviation mean square		
	1969	1970	1969–1970	1969	1970	1969–1970	1969	1970	1969–1970
No. of sites	12	24	11	12	24	11	12	24	11
San Pastore	138	138	138	1.16	1.04	1.10	4.6	11.1	5.4
Triumph 64	139	137	138	1.06	1.05	1.07	11.7	9.8	3.2
Benhur	138	137	138	1.06	1.04	1.07	5.1	9.4	1.3
Sturdy	140	139	140	1.06	0.99	1.01	7.5	11.2	5.8
Arthur	141	139	140	1.14	1.04	1.08	2.4	6.3	2.8
Parker	141	140	141	1.07	1.03	1.05	3.8	4.4	2.3
Scout 66	142	141	141	1.00	0.98	1.02	6.6	18.2	4.7
NB67730	143	141	141	0.95	0.98	1.00	15.7	3.6	1.6
Yung Kwang	141	141	141	0.91	0.93	0.92	2.2	3.3	1.4
Purdue 28-2-1[1]	142	141	142	1.02	0.98	1.01	1.7	2.5	0.9
Stadler	141	141	142	1.12	1.06	1.08	6.2	5.4	2.1
Bezostaia	142	141	142	1.13	1.06	1.11	5.8	4.5	3.4
Riley 67	142	141	142	1.14	1.08	1.10	3.3	1.7	0.9
Gage	145	143	143	1.01	1.01	1.04	22.7	3.2	3.8
Shawnee	143	144	144	1.05	1.00	1.02	6.4	3.9	0.7
Atlas 66	146	143	144	1.08	1.13	1.13	15.6	4.8	3.9
Bankuti 1201	144	144	144	0.96	1.04	1.03	2.3	8.8	3.8
Timwin	144	145	144	1.07	0.94	1.00	2.7	14.7	1.5
Fertodi 293	144	144	144	1.00	1.02	1.02	1.9	3.1	2.2
Lancer	146	146	145	0.94	0.95	0.97	21.8	12.5	2.3
Blueboy	145	145	146	1.07	1.11	1.04	3.9	14.5	3.8
Yorkstar	148	147	147	0.95	0.94	0.96	10.7	8.3	2.2
Winalta	147	147	147	0.88	0.99	0.92	8.9	9.3	2.7
Gaines	150	149	148	0.85	0.92	0.90	10.9	6.8	3.1
Heine VII	151	149	149	0.90	1.03	0.96	9.5	49.1	17.7
Cappelle Desprez	153	152	154	0.79	1.00	0.83	13.7	37.7	12.9
Felix	155	155	155	0.83	0.85	0.96	21.4	20.3	11.4
Odin	156	156	156	0.80	0.83	0.76	13.7	59.4	27.7

[1] Purdue 4930A6-28-2-1

Table 6. Stability parameters for date of ripening of 28 winter wheat cultivars grown in the International Winter Wheat Performance Nursery in 1969 and 1970.

Cultivar	Mean (days from Jan. 1)			Regression coefficient			Deviation mean square		
	1969	1970	1969–1970	1969	1970	1969–1970	1969	1970	1969–1970
No. of sites	11	18	9	11	18	9	11	18	9
San Pastore	179	182	183	1.01	0.98	1.00	8.3	9.0	8.6
Triumph 64	178	183	183	1.04	0.99	1.02	18.8	5.3	1.6
Benhur	179	184	184	1.08	1.02	1.06	12.5	6.4	7.2
Riley 67	179	185	184	0.91	1.04	1.02	34.7	2.4	11.5
Stadler	180	185	184	0.89	1.01	0.98	35.8	5.1	12.9
Arthur	181	184	185	1.07	1.03	1.09	3.0	6.4	2.5
Scout 66	182	185	185	0.92	0.99	0.98	4.7	6.6	4.1
Purdue 28-2-1[1]	181	185	185	1.00	0.99	1.02	2.4	2.5	1.7
Sturdy	182	184	186	0.98	0.95	0.99	2.7	5.2	0.8
NB67730	181	185	186	0.94	0.95	0.96	1.7	6.0	1.8
Yung Kwang	182	184	186	0.90	0.91	0.91	5.3	15.2	3.2
Parker	183	185	186	1.02	1.02	1.03	1.6	3.5	0.4
Timwin	181	187	186	0.85	1.01	0.94	52.0	3.5	21.7
Gage	183	186	187	0.99	1.02	1.03	2.7	8.5	4.0
Fertodi 293	183	187	187	0.97	1.06	1.00	5.7	12.1	3.3
Lancer	182	188	187	0.95	0.97	0.97	32.1	4.0	8.6
Shawnee	183	187	188	1.01	1.03	1.02	8.1	1.9	0.6
Bezostaia	185	187	188	1.12	1.05	1.08	4.4	3.0	0.9
Bankuti 1201	184	188	188	0.95	1.02	0.99	4.7	6.7	3.3
Winalta	184	189	189	0.97	1.02	0.98	3.3	4.6	1.1
Yorkstar	185	189	189	1.00	1.02	1.02	8.5	4.2	2.8
Atlas 66	185	188	189	1.12	1.10	1.12	7.0	7.7	7.4
Gaines	187	189	190	1.00	0.99	1.00	8.5	5.7	8.1
Blueboy	187	191	192	1.15	1.14	1.14	4.8	7.8	5.9
Heine VII	191	192	194	1.07	0.97	0.98	21.6	11.1	5.9
Felix	192	193	195	1.03	0.95	0.92	22.6	25.0	18.1
Cappelle Desprez	192	193	196	0.99	0.94	0.88	21.4	17.3	7.4
Odin	193	195	197	1.07	0.89	0.89	13.3	29.9	10.6

[1] Purdue 4930A6-28-2-1

to 29.9 for Odin in 1970. Parker exhibited the lowest 2-year deviation mean square value of 0.4 and Timwin had the highest value of 21.7. Odin and Benhur with contrasting means for ripening but similar regression coefficients and deviation mean squares are compared in Figure 8.

Plant Height

Stability parameters for plant height are summarized in Table 7. Cultivars were widely different. Gaines was the shortest and Sturdy the second shortest cultivars each year. Bankuti 1201 and NB67730 were the tallest growing with an average height 66% greater than Gaines and Sturdy. Regression coefficients ranged from 0.64 for Gaines to 1.28 for Atlas 66 in 1969 and from 0.62 for Gaines to 1.31 for Bankuti 1201 in 1970. The shortest cultivars as a group had substantially lower regression coefficients for plant height than the taller

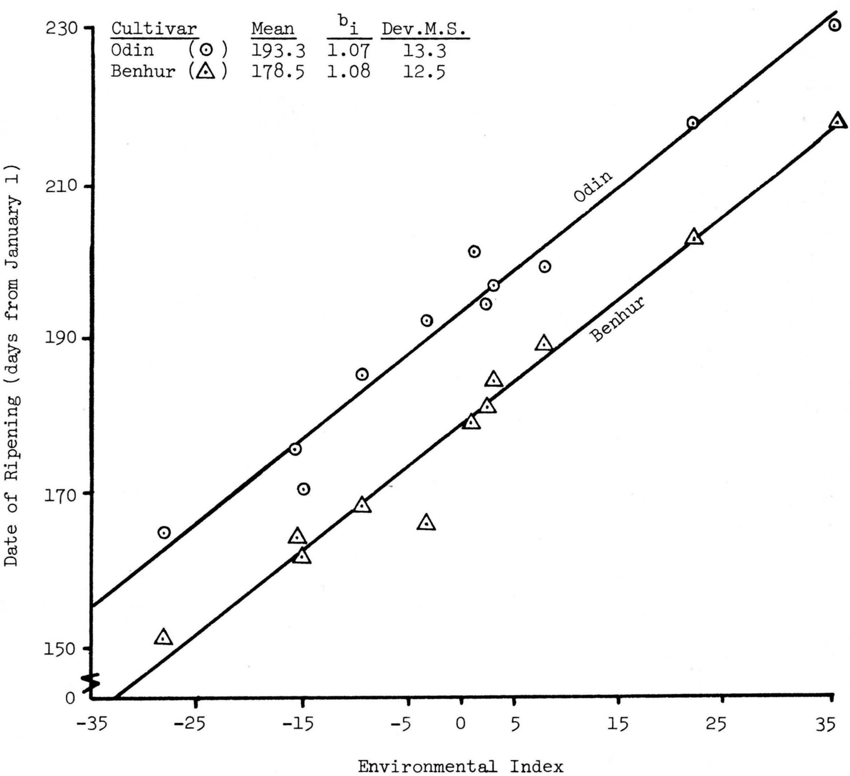

Figure 8. Regression of date of ripening of Odin and Benhur on environmental indexes of the International Winter Wheat Performance Nursery grown in 1969.

Table 7. **Stability parameters for plant height of 28 winter wheat cultivars grown in the International Winter Wheat Performance Nursery in 1969 and 1970.**

Cultivar	Mean (cm)			Regression coefficient			Deviation mean square		
	1969	1970	1969–1970	1969	1970	1969–1970	1969	1970	1969–1970
No. of sites	12	24	11	12	24	11	12	24	11
Gaines	74	74	74	0.64	0.62	0.60	20.7	25.7	15.6
Sturdy	81	78	80	0.82	0.69	0.77	43.5	82.3	24.1
Timwin	88	81	85	0.68	0.79	0.74	15.3	24.0	15.8
Cappelle Desprez	94	87	91	0.96	0.75	0.57	17.4	46.5	18.8
San Pastore	95	86	91	0.98	0.95	1.07	18.0	58.6	20.5
Felix	94	85	92	0.99	0.79	0.64	54.8	78.5	19.3
Blueboy	97	88	94	0.62	0.98	0.83	15.6	47.4	20.4
Bezostaia	96	91	95	0.90	0.87	0.92	25.8	36.0	26.2
Parker	100	95	97	1.01	0.99	0.99	19.9	28.5	2.0
Arthur	100	93	98	1.12	1.05	1.05	11.6	24.7	9.1
Heine VII	99	93	98	1.04	0.95	0.86	25.5	23.3	5.0
Benhur	102	95	99	0.97	1.14	1.10	27.3	35.4	29.0
Yorkstar	101	96	101	0.69	0.83	0.82	50.5	19.1	15.5
Yung Kwang	103	95	101	1.03	0.93	1.13	20.8	32.2	16.2
Triumph 64	107	97	101	1.10	1.06	1.25	30.6	38.5	6.6
Riley 67	107	98	104	1.00	1.05	1.10	10.3	18.0	8.3
Gage	108	99	104	1.20	1.12	1.24	28.5	15.2	11.2
Scout 66	111	98	106	1.01	1.18	1.11	29.2	33.9	13.5
Shawnee	111	103	108	1.08	1.05	1.00	14.7	46.4	20.0
Lancer	111	102	108	1.12	1.09	1.10	20.0	26.4	19.0
Stadler	109	104	109	0.98	1.12	1.13	24.1	11.5	11.0
Odin	111	102	110	1.15	1.06	0.91	173.9	192.5	88.8
Winalta	113	107	111	0.98	1.05	1.13	33.9	28.4	13.9
Purdue 28-2-1[1]	116	104	111	1.15	1.18	1.16	13.7	38.1	21.9
Fertodi 293	118	106	114	1.06	1.16	1.14	64.7	14.3	30.0
Atlas 66	118	105	115	1.28	1.17	1.24	33.1	98.9	59.7
NB67730	119	108	116	1.22	1.08	1.14	30.0	17.9	14.7
Bankuti 1201	124	110	118	1.23	1.31	1.27	38.4	30.5	16.6

[1] Purdue 4930A6-28-2-1

cultivars. Deviation mean squares for plant height were of similar magnitude for all cultivars except Odin which exhibited large deviations from regression in each year.

Lodging

Stability parameters for lodging are summarized in Table 8. Wide differences among cultivars were measured. In 1969 they ranged from only 3 percent for Felix to 49 percent for NB67730. In 1970 Gaines lodged the least and Scout 66 the most severely on the average. As would be anticipated, the shortest cultivars as a group lodged less than the tall-growing cultivars. The Nebraska cultivars NB67730, Scout 66 and Lancer, all of which were tall-growing, were highly susceptible to lodging as were Bankuti 1201 and Winalta.

Regression coefficients for lodging followed the same trend as mean lodging. Short-statured cultivars responded less to changes in environment than inherently taller-growing cultivars. This is shown by their lower regression coefficients. Lodging deviation mean squares tended to be much lower in 1969 than in 1970. However, in both years they were large in relation to the means for lodging.

Regressions of lodging of Bankuti 1201 and Cappelle Desprez on environmental indexes in 1969 are shown in Figure 9. Regression coefficients of the two cultivars were similar but their deviation mean squares differed widely.

Winter Survival

Differential winter killing was reported from only 10 sites in 1969 and 13 sites in 1970. Only five sites reported killing in both years.

Stability parameters for winter survival are shown in Table 9. Cultivar means for winter survival at sites reporting differential survival were relatively high in 1969, ranging from 87.7 percent to 92.9 percent for Heine VII and Scout 66, respectively. In 1970 the means were somewhat lower, ranging from 59.2 percent for Blueboy to 84.5 percent for Bezostaia. Two-year means ranged from 79.5 percent for Atlas 66 to 92.7 percent for Bezostaia. Regression coefficients for winter survival showed little similarity for cultivars from 1969 to 1970 and have questionable usefulness for predictive purposes. Deviation mean squares also varied greatly among cultivars and between years.

Shattering

Stability parameters for shattering of 28 winter wheat cultivars grown in the first and second IWWPNs are presented in Table 10. They are based on only four reporting sites in 1969 and 10 in 1970. Cultivar means for shattering are small, ranging from only 1.3 percent

Table 8. Stability parameters for lodging of 28 winter wheat cultivars grown in the International Winter Wheat Performance Nursery in 1969 and 1970.

Cultivar	Mean (%)			Regression coefficient			Deviation mean square		
	1969	1970	1969–1970	1969	1970	1969–1970	1969	1970	1969–1970
No. of sites	11	22	8	11	22	8	11	22	8
Felix	3	13	1	0.18	0.73	0.08	50.2	434.9	0.8
Sturdy	5	11	2	0.27	0.85	0.14	97.3	443.5	4.0
Gaines	5	10	3	0.43	0.68	0.24	21.7	278.2	7.6
Odin	4	14	6	0.25	0.75	0.15	31.1	229.1	39.1
Blueboy	11	11	8	0.96	0.62	0.56	68.0	241.4	55.7
Heine VII	11	17	9	0.83	0.87	0.55	96.4	366.7	67.1
Cappelle Desprez	10	11	9	0.98	0.63	0.69	66.5	204.7	20.5
San Pastore	10	19	12	1.05	0.76	0.82	91.0	186.4	69.7
Bezostaia	14	19	13	1.08	0.95	0.79	119.3	202.2	65.5
Benhur	13	21	16	1.09	0.88	0.78	85.6	249.1	49.0
Parker	13	20	17	1.14	1.02	0.91	92.1	184.6	45.7
Purdue 28-2-1[1]	22	22	23	1.14	1.10	1.03	114.0	90.6	67.3
Arthur	19	24	24	1.29	1.04	1.06	81.0	196.4	87.8
Yorkstar	17	25	27	1.32	1.17	1.41	171.6	124.9	84.1
Shawnee	22	25	27	0.93	1.16	1.24	157.0	234.5	156.6
Timwin	18	24	29	1.25	1.06	1.09	150.2	251.7	83.3
Yung Kwang	25	33	32	1.24	1.30	1.23	147.6	225.9	46.0
Stadler	24	30	33	1.32	1.18	1.20	144.3	128.8	133.8
Gage	29	28	35	1.21	1.25	1.56	220.1	176.0	23.4
Riley 67	24	34	37	1.36	1.30	1.50	39.5	193.9	31.4
Fertodi 293	27	33	37	1.16	1.27	1.55	69.2	418.6	71.0
Atlas 66	33	38	37	1.10	1.15	1.35	456.4	372.2	138.5
Triumph 64	38	38	42	1.08	0.89	1.31	429.9	687.9	92.3
Winalta	36	38	44	1.18	1.03	1.39	337.1	660.7	37.8
Lancer	40	39	46	1.17	1.13	1.42	189.4	465.9	29.8
Scout 66	45	46	51	1.07	0.98	1.24	231.5	502.9	155.5
Bankuti 1201	45	42	51	1.02	1.10	1.41	283.7	719.3	107.2
NB67730	49	42	51	0.90	1.13	1.29	274.5	362.1	139.9

[1] Purdue 4930A6-28-2-1

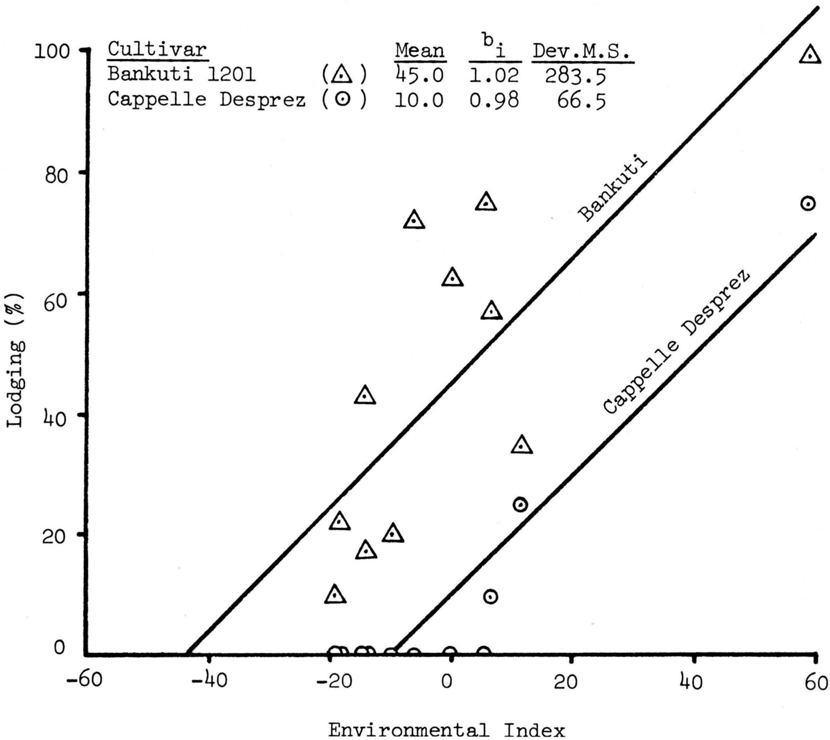

Figure 9. Regression of plant lodging of Bankuti 1201 and Cappelle Desprez on environmental indexes of the International Winter Wheat Performance Nursery grown in 1969.

for Sturdy and Winalta to 10.6 percent for San Pastore in 1969, and from 2.2 percent for Scout 66 to 21.4 percent for San Pastore in 1970. Two-year means from only three sites ranged from 2.2 percent to 14.2 percent for Sturdy and Purdue 4930A6-28-2-1, respectively.

Regression coefficients for shattering ranged from only 0.30 for Sturdy and Winalta to 1.57 for Scout 66 in 1969. Sturdy had a low coefficient. Deviation mean squares were widely different between years. They ranged from 0.0 to 2.91 in 1969 and from 2.4 to 341.5 in 1970. Sturdy had a low mean for shattering in each year, with very low regression coefficients and deviation mean squares.

Grain Quality

Stability parameters for grain protein appear in Table 11. Large differences in cultivar means occurred in both years. The range in mean protein content among cultivars was the same in each year (5.2 percentage points). There was good agreement in cultivar rankings

Table 9. Stability parameters for winter survival of 28 winter wheat cultivars grown in the International Winter Wheat Performance Nursery in 1969 and 1970.

Cultivar	Mean (%)			Regression coefficient			Deviation mean square		
	1969	1970	1969–1970	1969	1970	1969–1970	1969	1970	1969–1970
No. of sites	10	13	5	10	13	5	10	13	5
Bezostaia	89.1	84.5	92.7	1.06	0.73	0.58	27.8	57.3	4.6
Scout 66	92.9	76.6	92.1	0.80	1.09	0.86	1.9	14.1	9.5
NB67730	92.7	74.0	92.0	0.74	1.29	0.93	3.2	14.8	10.0
Purdue 28-2-1[1]	89.5	79.5	91.6	1.18	0.97	0.67	13.4	55.1	4.9
Yung Kwang	91.6	72.5	91.2	0.79	1.21	0.68	2.2	70.1	6.4
Fertodi 293	91.0	72.8	91.1	1.12	1.19	1.14	9.4	47.9	11.5
Parker	90.2	76.9	91.1	1.01	1.12	0.52	7.7	45.7	2.6
Benhur	91.0	81.6	91.1	1.02	0.60	0.87	12.4	112.7	12.9
Triumph 64	91.4	79.5	90.9	0.99	0.90	1.19	6.1	31.2	7.2
Gaines	92.2	76.0	90.8	0.75	1.14	1.01	2.9	22.2	1.1
Winalta	92.5	76.0	90.6	0.89	1.02	0.57	4.6	55.8	24.3
Gage	92.4	75.4	90.5	0.75	1.09	0.84	2.2	62.5	0.6
Arthur	89.4	81.4	90.4	1.18	0.72	0.79	13.0	48.7	8.7
Yorkstar	90.0	77.4	90.3	1.28	0.84	0.76	19.5	31.1	10.5
Sturdy	89.9	75.2	90.3	1.19	1.10	0.69	13.9	19.6	1.3
Stadler	90.7	82.7	90.2	0.72	0.63	0.88	17.7	119.4	5.8
Riley 67	90.1	79.9	90.1	1.15	0.78	0.83	14.1	39.1	11.7
Lancer	91.8	73.9	90.0	0.85	1.09	0.90	2.7	15.9	10.7
Bankuti 1201	93.4	69.0	89.7	0.75	1.24	1.31	4.7	41.5	7.9
Timwin	90.5	77.2	88.9	0.77	0.76	1.22	20.5	115.3	18.0
Heine VII	87.7	70.4	88.5	1.22	1.15	1.10	55.6	68.2	27.8
Odin	91.3	74.9	87.3	1.20	0.82	1.18	19.8	88.9	58.5
Shawnee	89.3	72.1	87.1	0.92	1.25	1.14	20.7	28.2	23.4
Felix	90.9	72.4	85.1	1.24	0.90	1.47	17.2	57.5	16.4
Cappelle Desprez	89.2	64.5	82.9	1.20	1.15	1.30	59.4	227.8	179.0
Blueboy[2]	91.6	59.2	82.2	0.75	1.00	1.32	15.1	364.0	34.6
San Pastore	89.1	63.3	80.9	0.84	1.12	1.34	55.1	169.9	134.2
Atlas 66	83.4	64.8	79.5	1.65	1.11	1.91	181.2	264.8	273.4

[1] Purdue 4930A6-28-2-1

[2] Poor seed germination in 1970.

Table 10. Stability parameters for shattering of 28 winter wheat cultivars grown in the International Winter Wheat Performance Nursery in 1969 and 1970.

Cultivar	Mean (%)			Regression coefficient			Deviation mean square		
	1969	1970	1969–1970	1969	1970	1969–1970	1969	1970	1969–1970
No. of sites	4	10	3	4	10	3	4	10	3
Sturdy	1.3	3.0	2.2	0.30	0.42	0.35	0.00	9.03	0.12
Heine VII	1.9	4.8	2.9	0.45	0.73	0.51	0.00	31.16	0.01
Benhur	4.2	7.2	3.0	0.96	1.14	0.46	0.11	70.69	0.32
Bezostaia	1.9	6.1	3.1	0.45	1.06	0.50	0.00	53.35	0.08
Odin	4.7	3.2	3.2	1.03	0.56	0.49	0.21	22.18	0.01
Fertodi 293	4.8	4.4	3.2	1.12	0.59	0.55	0.02	20.10	0.03
Stadler	5.3	7.1	3.7	1.18	0.79	0.55	0.14	52.33	0.10
NB67730	3.5	4.7	4.1	0.82	0.66	0.69	0.03	5.00	0.06
Gage	6.1	9.2	4.1	1.22	1.10	0.58	2.24	211.50	1.30
Scout 66	6.6	2.2	4.5	1.57	0.43	0.77	0.01	20.98	0.03
Felix	2.8	5.5	4.7	0.57	0.74	0.80	0.47	6.49	0.02
Yung Kwang	4.4	8.2	4.7	1.05	0.75	0.80	0.00	162.42	0.10
Bankuti 1201	6.0	5.8	4.9	1.42	0.67	0.84	0.00	18.35	0.02
Gaines	5.1	3.1	5.1	1.20	0.49	0.88	0.02	13.98	0.03
Lancer	5.6	4.4	5.4	1.25	0.60	0.90	0.23	2.42	0.00
Parker	4.6	8.9	5.4	1.03	1.16	0.91	0.15	103.52	0.13
Cappelle Desprez	4.8	6.1	5.5	1.12	0.87	0.95	0.01	10.40	0.03
Triumph 64	4.5	8.8	5.8	1.04	1.13	0.98	0.02	91.26	0.15
Shawnee	4.8	5.0	6.1	1.12	0.74	1.06	0.01	17.79	0.05
Atlas 66	5.2	7.0	6.7	1.08	1.07	1.06	1.38	55.38	0.18
Riley 67	6.0	12.7	8.5	1.12	1.42	1.24	1.73	55.22	0.22
Winalta	1.3	7.9	8.8	0.30	0.88	1.54	0.00	156.10	0.02
Timwin	4.4	7.4	8.9	0.85	0.93	1.31	0.58	63.20	0.28
Blueboy	3.0	9.0	10.3	0.56	1.23	1.63	0.68	156.59	0.89
Arthur	7.9	18.3	11.6	1.47	2.17	1.74	0.96	50.77	0.68
San Pastore	10.6	21.4	11.9	1.46	2.06	1.60	0.47	341.54	0.05
Yorkstar	5.4	13.2	13.8	1.07	1.45	2.15	0.94	141.37	2.00
Purdue 28-2-1[1]	8.9	20.5	14.2	1.19	2.15	2.16	2.91	99.47	1.23

[1] Purdue 4930A6-28-2-1

Table 11. Stability parameters for grain protein content of 28 winter wheat cultivars grown in the International Winter Wheat Performance Nursery in 1969 and 1970.

Cultivar	Mean (%)			Regression coefficient			Deviation mean square		
	1969	1970	1969–1970	1969	1970	1969–1970	1969	1970	1969–1970
No. of sites	11	23	10	11	23	10	11	23	10
Atlas 66	17.0	18.3	17.7	1.12	0.90	0.61	0.57	1.15	0.78
Purdue 28-2-1[1]	16.3	18.4	17.3	1.07	1.22	1.21	0.70	2.90	1.19
NB67730	16.1	17.3	16.6	1.20	1.11	0.98	1.18	1.08	0.67
Cappelle Desprez	15.2	15.9	15.9	1.02	1.01	0.87	2.21	2.07	1.87
Triumph 64	14.8	15.7	15.5	0.61	0.82	0.65	1.34	1.14	0.62
Bankuti 1201	14.9	15.8	15.4	0.89	0.90	0.89	0.43	0.58	0.37
Odin	14.4	15.6	15.1	1.18	1.04	0.85	1.25	3.82	1.70
Fertodi 293	14.5	15.3	15.0	0.84	1.31	0.90	0.36	0.51	0.49
Benhur	14.2	15.7	14.9	1.01	0.94	1.14	0.60	0.90	0.37
Sturdy	14.1	15.2	14.8	1.18	0.73	0.51	0.58	0.70	0.44
Gage	14.1	15.2	14.7	1.04	1.08	1.09	0.79	0.64	0.47
Felix	14.0	15.3	14.7	1.23	0.96	0.89	2.02	3.75	2.32
Scout 66	14.1	14.9	14.7	0.93	0.94	1.08	0.91	1.62	0.90
Arthur	14.0	15.2	14.6	0.96	1.08	1.21	0.84	0.70	0.32
Heine VII	14.3	14.5	14.6	1.29	1.06	1.06	2.21	1.89	1.99
Parker	14.1	15.1	14.6	1.04	1.00	0.95	0.17	0.90	0.39
Yung Kwang	13.6	15.4	14.4	1.19	0.98	0.92	1.67	0.98	1.07
Riley 67	13.9	14.9	14.3	1.44	1.21	1.56	0.41	0.77	0.46
Timwin	13.9	15.2	14.3	1.02	0.95	0.92	0.12	0.50	0.16
Lancer	13.7	14.4	14.2	0.68	0.92	0.95	0.49	0.51	0.58
Winalta	13.4	14.4	14.1	0.92	0.82	0.94	0.52	0.55	0.42
San Pastore	13.1	14.5	13.9	0.70	1.21	0.85	1.64	1.20	1.15
Blueboy	13.2	14.6	13.9	1.29	0.93	1.09	0.93	0.53	0.45
Shawnee	13.4	14.5	13.9	0.87	1.05	1.06	0.37	0.68	0.36
Bezostaia	13.2	14.2	13.8	0.55	0.88	0.77	0.32	0.45	0.22
Stadler	12.7	14.3	13.3	1.04	0.92	1.20	0.31	0.86	0.23
Gaines	12.3	13.7	13.2	1.05	1.08	1.38	0.43	1.80	0.68
Yorkstar	11.8	13.1	12.6	1.17	0.98	1.47	0.88	1.48	0.80

[1] Purdue 4930A6-28-2-1

for protein between the two years. Atlas 66, Purdue 4930A6-28-2-1 and NB67730, all known to possess genes for high protein content, had the highest mean protein content. Yorkstar and Gaines were consistently the lowest in protein. Four cultivars with high and low grain protein content are contrasted in Figure 10. Cappelle Desprez ranked fourth each year.

Regression coefficients for protein varied from 0.55 for Bezostaia to 1.44 for Riley 67 in 1969. Bezostaia again had a relatively low coefficient in 1970, although not as low as Sturdy, Atlas 66 and Triumph 64. These same three cultivars also produced the lowest 2-year coefficients for protein content. Purdue 4930A6-28-2-1 exhibited a much larger 2-year mean protein response to environment than did either Atlas 66 or NB67730. Its deviation mean square was low in 1969 but high in 1970. Deviation mean squares for protein content were small for most cultivars, ranging from only 0.12 for Timwin to

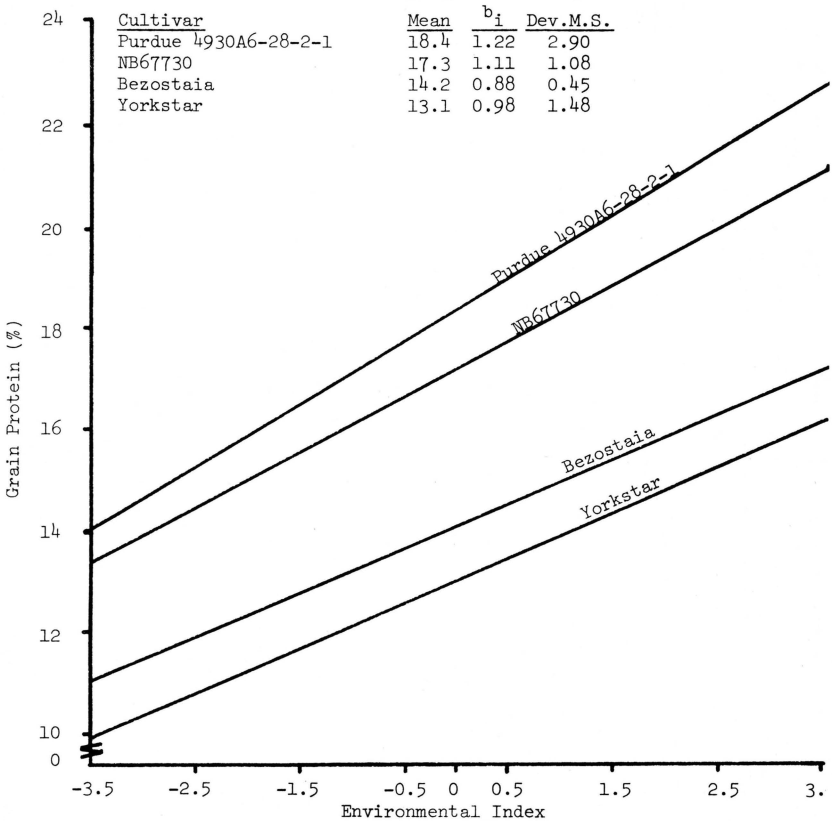

Figure 10. Regression of grain protein content of four cultivars on environmental indexes of the International Winter Wheat Performance Nursery grown in 1970.

Table 12. Comparison of grain protein of 12 cultivars with comparable yield levels grown in the International Winter Wheat Performance Nursery in 1969 and 1970.

Cultivar	Grain yield (q/ha)	Grain protein (%)
No. of sites	15	10
High yield group		
Bezostaia	43.7	13.8
Timwin	39.2	14.3
Arthur	38.6	14.6
Sturdy	38.5	14.8
Parker	38.3	14.6
Scout 66	38.1	14.7
Low yield group		
Heine VII	34.2	14.6
NB67730	33.3	16.6
Bankuti 1201	33.2	15.4
Atlas 66	32.2	17.7
Purdue 4930A6-28-2-1	31.8	17.3
Cappelle Desprez	29.1	15.9

2.21 for Cappelle Desprez and Heine VII in 1969. Bezostaia and Odin had the smallest and largest mean squares, respectively, in 1970. Timwin had the second smallest deviation mean square in 1970. On a 2-year basis, Timwin, Bezostaia and Stadler produced protein values that deviated the least from the regression line.

Protein contents of cultivars with similar grain yields are compared in Table 12. In the high yielding group there were no differences in protein content except Bezostaia which ranged from 0.5 to 1.0 percentage point lower than the other cultivars. Its grain yield was 4.5 to 5.6 q/ha higher than the other cultivars in the group. In the lower yielding group the high protein cultivars, Atlas 66, Purdue 4930A6-28-2-1 and NB67730 ranged from 0.7 to 3.1 percentage points higher in protein content than other cultivars in the group.

Stability parameters for lysine percentage of grain protein appear in Table 13. Cultivar mean differences in lysine were small in each year. They ranged from 2.70 to 3.90 percent in 1969 and from 2.67 to 3.06 percent in 1970. Atlas 66 produced the lowest percent of lysine and Yorkstar the highest in each year. The strongest lysine response to changes in environment was shown by Yorkstar and Gaines, both with 2-year regression coefficients larger than 2.0. Cappelle Desprez and Triumph 64 were the least responsive to changes in the environment. Deviation mean squares were small and varied but little from one year to the next.

A strong negative relationship between grain protein and lysine content is indicated by comparison of mean values shown in Tables 11 and 13. These traits are compared for six cultivars in Table 14.

Table 13. Stability parameters for lysine expressed as percent of grain protein of 28 winter wheat cultivars grown in the International Winter Wheat Performance Nursery in 1969 and 1970.

Cultivar	Mean (%)			Regression coefficient			Deviation mean square		
	1969	1970	1969–1970	1969	1970	1969–1970	1969	1970	1969–1970
No. of sites	11	23	10	11	23	10	11	23	10
Yorkstar	3.19	3.06	3.12	1.37	1.25	2.08	0.008	0.028	0.016
Gaines	3.14	2.99	3.07	1.28	1.35	2.07	0.013	0.012	0.004
Stadler	3.10	2.91	3.02	1.27	1.14	1.97	0.010	0.012	0.008
Timwin	3.02	2.86	2.95	1.19	0.98	0.86	0.005	0.004	0.001
Riley 67	3.00	2.89	2.94	1.16	1.32	1.80	0.017	0.008	0.002
Odin	3.00	2.90	2.93	1.02	0.62	0.68	0.004	0.009	0.003
Blueboy	3.00	2.86	2.93	1.71	1.02	1.56	0.011	0.006	0.003
San Pastore	2.98	2.89	2.92	0.54	1.23	0.11	0.013	0.010	0.007
Felix	2.96	2.87	2.90	0.83	0.40	0.34	0.007	0.010	0.008
Arthur	2.92	2.85	2.88	1.11	1.18	1.47	0.006	0.006	0.003
Bezostaia	2.91	2.87	2.87	0.85	1.00	0.83	0.009	0.004	0.005
Yung Kwang	2.93	2.79	2.87	1.24	0.96	0.88	0.007	0.006	0.002
Winalta	2.93	2.82	2.87	0.80	0.85	0.93	0.005	0.003	0.001
Lancer	2.91	2.85	2.86	0.93	0.96	1.04	0.003	0.007	0.003
Gage	2.91	2.82	2.86	1.04	1.20	1.17	0.013	0.004	0.005
Shawnee	2.90	2.85	2.86	1.24	1.17	1.28	0.003	0.008	0.002
Parker	2.91	2.83	2.85	0.86	1.07	0.84	0.006	0.007	0.005
Heine VII	2.89	2.83	2.84	1.02	1.11	0.73	0.011	0.010	0.006
Scout 66	2.87	2.82	2.83	0.79	1.12	1.18	0.007	0.008	0.004
Fertodi 293	2.87	2.80	2.82	0.74	1.33	0.73	0.003	0.005	0.002
Bankuti 1201	2.85	2.76	2.80	0.81	0.85	0.84	0.006	0.002	0.002
Benhur	2.86	2.75	2.80	1.30	0.98	1.46	0.006	0.008	0.005
Sturdy	2.85	2.76	2.79	0.68	0.82	0.26	0.008	0.006	0.002
Cappelle Desprez	2.82	2.76	2.78	0.32	0.68	0.05	0.005	0.007	0.002
Triumph 64	2.81	2.77	2.77	0.74	1.00	0.23	0.004	0.004	0.001
NB67730	2.79	2.71	2.75	1.23	0.84	1.02	0.004	0.009	0.002
Purdue 28-2-1[1]	2.80	2.69	2.73	1.00	0.98	1.18	0.003	0.002	0.004
Atlas 66	2.70	2.67	2.69	0.92	0.57	0.39	0.003	0.007	0.006

[1] Purdue 4930A6-28-2-1

Table 14. Comparison of grain protein with lysine content in six cultivars grown in the International Winter Wheat Performance Nursery in 1969 and 1970.

Cultivar	Protein (%)	Lysine (% of protein)
Yorkstar	12.6	3.12
Gaines	13.2	3.07
San Pastore	13.9	2.92
Bezostaia	13.8	2.87
Cappelle Desprez	15.9	2.78
Atlas 66	17.7	2.69

Yorkstar with the lowest protein content was highest in lysine. Conversely, Atlas 66 with the highest protein content was lowest in lysine.

Stability parameters for lysine adjusted to a common grain protein level are presented in Table 15. The adjustment for protein failed to remove all differences in lysine among cultivars although none is believed to be inherently different for the trait. Some shifting in rank of cultivar means resulted from the adjustment. Cultivars with high protein content, such as Purdue 4930A6-28-2-1, Atlas 66 and NB67730, had much higher lysine means after the adjustment to a common protein level of 13.5 percent was made.

DISCUSSION

The International Winter Wheat Performance Nursery provided an opportunity to study agronomic performance of cultivars grown over an international array of environments. Rapid identification of superior genotypes for use in breeding programs was provided by the nursery. To sample such a wide array of environments at a local site would be virtually impossible. Major wheat producing areas of the world, except Australia, Canada, China, and the U.S.S.R., were represented in the 1969 and 1970 nurseries. A nursery site was established in the U.S.S.R. in 1972.

Stability Parameters

Regression coefficient and deviation mean square parameters derived from the Eberhart-Russell model are useful for cultivar evaluation because they provide additional predictive measurements. The regression coefficient or the slope of the line predicts the sensitivity of a cultivar to changing environments. The deviation mean square, which is measured from predicted values according to the regression analysis, provides evidence of the consistency or repeatability of performance. If observed means deviate widely from predicted means based on regression analysis, the cultivar would have low predictive performance because of variation unexplained by regression.

Table 15. Stability parameters for adjusted lysine[1] content of 28 winter wheat cultivars grown in the International Winter Wheat Performance Nursery in 1969 and 1970.

Cultivar	Mean (%)			Regression coefficient			Deviation mean square		
	1969	1970	1969–1970	1969	1970	1969–1970	1969	1970	1969–1970
No. of sites	11	23	10	11	23	10	11	23	10
Yorkstar	3.10	3.04	3.07	1.09	0.76	–0.06	0.004	0.014	0.006
Gaines	3.08	3.00	3.05	0.61	1.23	0.31	0.007	0.006	0.003
Odin	3.05	3.01	3.02	1.03	1.11	1.66	0.005	0.007	0.003
Stadler	3.05	2.95	3.01	0.84	0.70	–0.36	0.006	0.006	0.005
Timwin	3.04	2.95	3.00	1.39	0.82	1.12	0.004	0.002	0.000
Riley 67	3.02	2.96	2.99	0.50	1.12	–0.33	0.007	0.003	0.003
Felix	2.99	2.97	2.97	0.95	1.08	1.21	0.005	0.005	0.002
Blueboy	2.98	2.92	2.95	1.35	1.17	0.88	0.007	0.002	0.001
San Pastore	2.97	2.94	2.94	0.67	1.28	0.53	0.004	0.005	0.003
Arthur	2.95	2.94	2.94	1.12	1.16	0.95	0.004	0.003	0.002
Purdue 28-2-1[2]	2.96	2.96	2.93	0.93	1.27	1.35	0.001	0.005	0.001
Gage	2.94	2.90	2.93	0.97	1.17	1.20	0.007	0.002	0.003
Atlas 66	2.89	2.93	2.92	1.12	0.71	1.71	0.003	0.005	0.002
NB67730	2.93	2.92	2.92	1.30	0.78	1.47	0.001	0.007	0.001
Yung Kwang	2.94	2.89	2.92	1.10	0.83	0.98	0.004	0.002	0.001
Parker	2.94	2.92	2.91	0.59	1.17	0.88	0.003	0.003	0.003
Bankuti 1201	2.93	2.89	2.91	1.22	0.61	1.27	0.005	0.002	0.003
Cappelle Desprez	2.92	2.90	2.91	0.91	0.85	1.71	0.011	0.006	0.004
Heine VII	2.93	2.88	2.90	0.93	1.17	0.99	0.011	0.003	0.002
Lancer	2.93	2.90	2.90	1.07	1.03	1.30	0.002	0.004	0.001
Fertodi 293	2.92	2.89	2.90	1.00	0.95	1.09	0.004	0.003	0.001
Winalta	2.93	2.87	2.90	0.91	0.88	1.02	0.003	0.002	0.001
Scout 66	2.91	2.89	2.90	0.60	0.89	0.75	0.005	0.003	0.001
Bezostaia	2.90	2.90	2.89	1.33	1.37	1.99	0.004	0.002	0.002
Triumph 64	2.89	2.89	2.88	1.17	1.06	1.31	0.002	0.003	0.001
Benhur	2.90	2.87	2.88	1.33	1.30	1.81	0.002	0.003	0.002
Shawnee	2.89	2.90	2.88	1.25	0.95	0.89	0.002	0.005	0.001
Sturdy	2.87	2.85	2.85	0.80	0.60	0.27	0.007	0.003	0.003

[1] Adjusted to 13.5% protein
[2] Purdue 4930A6-28-2-1

The mean performance of a cultivar over many environments is indicative of the average performance level that cultivar can be expected to maintain if grown again in a similar range of environments. This average level of performance is important for interpretation of the other two parameters in cultivar evaluation.

Many different combinations of the stability parameters are possible and each requires somewhat different interpretation. A cultivar may exhibit high mean performance and a high regression coefficient with a low deviation mean square. Such a cultivar could be described as productive, strongly responsive to changes in environment, and with highly predictable performance in specified environments. The cultivar could further be described as particularly well-suited to favorable environments since its performance in such environments would be good relative to other cultivars. As environment becomes poorer, the superiority of the cultivar relative to other cultivars would decrease until in the poor environment it would probably be little different from other cultivars. Bezostaia and Triumph 64 as shown in Figure 1 are examples of this.

A cultivar with high average performance and a high regression coefficient, but with a high deviation mean square, would differ from the cultivar described above primarily in the degree of predictability of its performance in specified environments. It would exhibit random performance variations unassociated with either of the other two parameters. Such a cultivar could not be grown with the same confidence as the first one and thus would be less desirable for the producer. Yorkstar and Riley 67 grown in 1970 are an example of this relationship (Figure 4).

A cultivar with low average performance, high regression coefficient, and low deviation mean square could be described as a nonproductive cultivar with strong and predictable sensitivity to environmental changes. It would be expected to be more productive in favorable environments and less productive in unfavorable environments than a cultivar with similar average performance but low regression coefficient. The cultivars compared in Figure 3 show this relationship. The cultivar might be equally as productive in the poorer environment as a cultivar with higher average performance and higher regression coefficient.

The cultivar with high mean performance but low regression coefficient and deviation mean square presents an interesting contrast to a similarly productive cultivar with high regression coefficient and low deviation mean square. Both are productive cultivars. Both respond to changes in environment in a predictable way, but the first cultivar responds weakly while the second cultivar responds strongly to environmental changes. Consequently, the latter would represent much the better cultivar in the poor range of environments while the first would be favored in the better environments. This relationship is shown for mean yields of Scout 66 and Riley 67 in 1970 (Figure 2).

The cultivars evaluated in the IWWPN in 1969 and 1970 exhibited wide ranges for each of the stability parameters. Many exhibited highly unpredictable performance characteristics. Others were strongly predictable. Some cultivars, notably Bezostaia, were highly productive on the average. Others were nonproductive. There were also wide differences among cultivars in their degree of response to changes in environments. Some exhibited regression coefficients of comparable magnitude in each of the two years; others produced highly dissimilar coefficients. Reasons for this are obscure although the larger number of nursery sites in 1970 may have contributed. An increase in number of sites presumably would provide a better sample of environments. If so, the 1970 parameters may be more reliable than those obtained in 1969.

The stability parameters computed in this study aid in describing a cultivar. They do not necessarily permit their classification into such categories as good, average or poor because these, to have meaning, must relate to specified environments and producer requirements. The parameters do permit cultivar comparisons for average performance, degree of response to changing environments as measured by the Eberhart-Russell model, and predictability of response to specified environments. Such comparisons would be useful for judgments on the part of the breeder concerning cultivar release and recommendations for suitable production situations and areas for the cultivar.

Certain criteria must be recognized for useful application of the stability parameter technique. The reliability of the parameters is proportional to the number of environments sampled. The number and distribution of test sites over as wide a range of environments as possible are essential. It was assumed in this study that the nursery sites were random samples of all environments and that the years in which the nursery was grown were random samples of all years. More extensive testing would be needed to determine the validity of these assumptions. Widely different parameter values in 1969 and 1970 for some cultivars could be interpreted as evidence of inadequate sampling of total environment in one or both years.

Application of the Eberhart-Russell model to quantitative traits probably is valid. By definition, such traits exhibit continuous variation due to gene number and/or effect of environment. Traits strongly affected by environment would seemingly be most usefully described by the stability parameter technique. Qualitative traits, such as chaff color, which exhibit discontinuous variation are not amenable to description by this technique. These considerations entered into the selection of agronomic and grain quality traits selected for measurement in this study.

The application of the Eberhart-Russell model to yield component data by Reich and Atkins (28) is the only such case reported in the literature. Finlay and Wilkinson (1963) made measurements of plant (physiological and morphological) characters to compare to the low or high yielding environments. However, they did not report regression coefficients of these data.

General Versus Specific Adaptation

A cultivar with general adaptation has the ability to perform well relative to other cultivars over a wide range of environments. It may not be the most outstanding cultivar in any one environment. A cultivar with specific adaptation would be expected to perform well in a restricted range of environments. Because its good performance is restricted to a few environments, such a cultivar would not be expected to have a high mean performance in an international nursery. However, low mean performance would not necessarily indicate specific adaptation. It could indicate inferior performance in general. A high regression coefficient would not always indicate specific adaptation. Stability parameters computed in this study reveal more about general adaptability of the cultivars tested than their specific adaptability. Since this model involves the computation of data from many widely different environments, cultivars with general adaptability are most readily identified.

Regionalization of data according to major features of environments would allow for better identification of cultivars with specific adaptation. Wheat-producing areas of the world exhibit widely different production environments. Environments in the continental climate of the United States Great Plains are highly variable for winter wheat production. Major environmental differences occur at one site over years and between sites within a year. A cultivar with general or broad adaptation is needed. The Scout cultivar exhibits such general adaptation in the hard red winter wheat region of the United States (16). The mean yield of Scout 66 was among the highest in the IWWPN each year but was not as high as Bezostaia. Its regression coefficient was low in 1969 but very high in 1970 when there were more nursery sites. The deviation mean square of Scout 66 was low in 1970. The tall, weak straw of Scout 66 may have affected its yield performance in the better environments.

The wet, cool climate of Western Europe contrasts strongly with the climate of the United States Great Plains. It is not as variable in some major features of its environment such as temperature, precipitation and wind velocity. Cultivars with strong, short straw and large spikes characterize the wheats of western Europe. Cappelle Desprez, Heine VII and Felix are such cultivars. All produced relatively low mean yields in the IWWPN. Each may possess high specificity for the Western European climate.

Data Analysis and Interpretation

Performance data were analyzed within years and over years. The latter analyses permitted the inclusion only of those sites from which there were two years of data for a trait. First-order and second-order interactions for each trait were computed.

Second-order interactions were highly significant for all traits. The cultivar x location interaction was highly significant for many traits whereas the cultivar x year interaction was nonsignificant for most traits. For purposes of computation of the stability parameters, it might have been appropriate to ignore years and treat each nursery in each year as a different environment. In so doing the number of environments for use in computing the parameters would have been increased significantly. The nature and objective of a study would dictate the most appropriate procedure. If it were important to separate genetic from environmental effects, analysis over years would be essential.

Stability parameters for most traits in this study indicated wide cultivar differences. Wide ranges in cultivar means for yield, test weight, plant height, lodging and grain protein content were detected. Regression coefficients and deviation mean square values for these traits also differentiated cultivar performance potential. The relative maturity of most cultivars was highly stable. Grain test weight also exhibited high stability. In contrast, grain yield and grain shattering produced highly variable parameters.

Cultivar mean yields in 1970 were generally lower than in 1969. The larger number of nursery sites in 1970 may have contributed. Regression coefficients were similar over years for many cultivars, while others were markedly dissimilar. Bezostaia, the highest yielding cultivar in each year, produced a much smaller coefficient in 1970 than in 1969. Arthur and Scout 66 coefficients were much higher in 1970 than in 1969. These were opposite cultivar reactions to the same array of environments. Parker exemplifies a stable cultivar for yield according to the Eberhart-Russell definition. Its regression coefficient was consistently near unity in each year. Its deviations from regression were relatively low and its mean yield was relatively high compared to most other cultivars tested.

Stability parameters for plant height indicate wide differences among cultivars which were consistent over years for short-statured cultivars like Gaines, Sturdy and Timwin. These cultivars had regression coefficients well below unity each year. The magnitude of the coefficient appeared to be highly correlated with plant height of cultivars. Tall cultivars generally had regression coefficients larger than short cultivars. Deviation mean squares were not highly different among cultivars except for Odin and Felix, which had large deviations. A close positive relationship between cultivar plant height and lodging was evident.

Only four sites in 1969 and 10 sites in 1970 reported differential grain shattering of cultivars. Stability parameters for shattering based on such a small number of environments would have limited reliability—particularly in 1969 when data were reported from so few sites. Average shattering values were small in both years, suggesting that the effect on grain yield was minimal. Regression coefficients were of similar magnitude in each year but deviation mean squares were much larger in 1970 than in 1969. This large variation, which was not associated with cultivar response to changing environment, provides strong evidence that shattering of most cultivars in this study was not a predictable trait.

Mean winter survival of cultivars was high in both years. Differential survival was recorded at only 10 sites in 1969 and 13 sites in 1970. The lowest mean survival of 59.2 percent was recorded for Blueboy in 1970. Poor emergence due to low seed germination may have contributed. Atlas 66 provides a useful indicator of winter severity at nursery sites.

In Nebraska Atlas 66 seldom survives the winter with more than traces of stand. It cannot be grown with assurance of survival anywhere in the United States except in the southeastern part where winters are mild. One must conclude that most of the international sites at which the nursery was grown in 1969 and 1970 had mild winter climates by Nebraska standards.

Stability parameters for winter-hardiness from these sites would have limited, if any, predictive value for Nebraska. On the other hand, they could provide meaningful information for breeders in other parts of the world since the nursery sites presumably were representative of many of the world's major winter wheat production areas.

Atlas 66, Purdue 4930A6-28-2-1 and NB67730 are known to possess genes for high grain protein content. Phenotypic expression of the protein genes has been high in restricted testing in the United States. The stability parameters computed in this study provide additional useful information on the high protein trait. The mean protein contents of these three cultivars in the IWWPN were the highest in the nursery. The protein content of Atlas 66 was less affected than the other two cultivars by changes in environment as measured by regression coefficients. The predictability of protein content in the three cultivars according to deviation mean square values was generally higher in 1969 than in 1970.

Cappelle Desprez is not known to possess genes for high protein. Its mean protein content in the IWWPN indicates that it may have such genes. Its protein content was considerably higher than all other cultivars in the nursery except those known to possess high protein genes. High deviation mean square value for protein in Cappelle Desprez indicate a large amount of protein variation unexplained by the regression analysis.

The protein content of wheat is known to be influenced by grain yield. High yielding cultivars frequently produce grain with less protein than lower yielding cultivars grown in the same environment. Protein comparisons among cultivars without reference to their relative grain yields may not be entirely valid. In the comparisons made in Table 12 the influence of differential yield on protein content was minimized by restricting comparisons to groups of cultivars with comparable yields. The known high protein cultivars produced grain with higher protein content than comparably yielding cultivars.

McNeal et al. (23) have suggested that the protein content of wheat may be influenced by plant height. They contend that development of a high protein semi-dwarf variety may not be possible because of the influence of the size of the vegetative reservoir on grain protein level. Gaines was the shortest cultivar in this study. Its protein content and yield were among the lowest in the study. Cappelle Desprez also was short-statured and low-yielding but produced grain with high protein content. Another short-statured cultivar, Sturdy, was high yielding and intermediate in protein content.

An inverse relationship between protein and the lysine content expressed as percent of protein was first reported by McElroy (22). Johnson et al. (17) also reported such a relationship from analyses of 7,000 wheats in the World Collection. Protein and lysine data from analyses of the IWWPN in this study also show the existence of a pronounced inverse relationship between protein and lysine. Yorkstar, Gaines and Stadler, with the lowest grain protein, were highest in lysine (Tables 11 and 13). Conversely, the high protein cultivars, Atlas 66, Purdue 4930A6-28-2-1 and NB67730, produced protein with the lowest lysine content.

The regression of lysine on protein among wheats in the World Collection has been utilized to adjust lysine values to a common protein level (17). This removes the effect of protein level on lysine and permits lysine comparisons among cultivars that differ widely in protein content. Adjustment of lysine for cultivars in the 1969 and 1970 IWWPNs did not entirely eliminate mean lysine differences among the cultivars, none of which is known to be inherently different in lysine potential (Table 15).

SUMMARY

The performance stability of 28 cultivars grown in an International Winter Wheat Performance Nursery in 1969 and 1970 was studied. The nursery was grown at 20 sites in 14 countries in 1969 and at 35 sites in 23 countries in 1970. Agronomic and quality traits that were analyzed included yield, test weight, maturity, plant height, lodging, winter survival, grain shattering, protein content and lysine content.

A statistical model developed by Eberhart and Russell (1966) was utilized for computation of three evaluation parameters. Cultivar mean performance, regression coefficient and regression deviation mean square were computed for each trait studied. 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 parameters were found to be useful for describing and predicting cultivar performance. None of the parameters alone adequately described cultivar performance. Together, the three parameters provided useful interpretive information on the general adaptation and performance stability of winter wheat cultivars. Application of the parameters in this study was restricted to quantitative traits.

The stability parameters indicated the existence of wide cultivar differences in response to environment as well as in predictability of response. The mean grain yield of a Russian cultivar, Bezostaia, was consistently the highest among the 28 cultivars studied. Bezostaia also responded strongly and predictably in yield to changes in environment. Moderately short, lodging-resistant straw of Bezostaia contributed to its superior performance.

Plant height and lodging were closely associated. Short cultivars lodged less than tall cultivars on the average and responded less strongly to changes in environment. Grain shattering was not a predictable trait among the cultivars in this study. Cultivars exhibited highly consistent mean differences in maturity and in maturity responses to changes in environment. Large differences in cultivar stability for test weight were recorded.

Three cultivars known to possess genes for high grain protein content were included in the study. Phenotypic expression of the high protein trait over international environments was excellent. Atlas 66 exhibited better stability of protein response to changes in environment than the other two high protein cultivars. Among cultivars not known to possess genes for high protein, grain yield and protein content tended to be inversely related.

The range in the lysine content of protein was small among the cultivars studied. None of the cultivars is known to be inherently different for lysine. Lysine expressed as percent of protein was negatively correlated with protein. Adjustment of lysine values to a common protein level by means of a regression of lysine on protein did not entirely remove lysine differences among cultivars.

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