EVIDENCE OF CROSS-OVER INTERACTION INVOLVING FOUR SPRING WHEAT CULTIVARS

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Abstract

Cross-over interaction is the most extreme case of genotype-environmental (G x E) interaction. Genotypic rank reversals from one environment to the next may be indicative of yield instability. If not repeatable, cross over interaction is undesirable from both the cultivar recommendation and plant breeding perspectives. The objective of this study was to investigate the erratic yield performance of 'Oslo' and 'Fielder' spring wheat. Oslo, 'HY 320', Fielder and, 'Columbus' were grown in seven environments (four dryland, three irrigated) spanning three years (1986 - 1988). Significant (p=0.05) G x E interaction was detected for all traits measured: grain yield , harvest index, spikelets/spike, kernels/spike, kernel weight and spikes/m^2 . Cross-overs were not statistically significant for kernels/spike and spikes/m^2. Half of the significant cross-overs were caused by the differential reaction of the four cultivars to rust at Outlook in 1986. Yield rank reversals between Oslo and Columbus appeared to be related to spikelets/spike and kernels/spike. Changes in rank between Fielder and HY 320 were associated with harvest index and kernel weight.

Introduction

Extensive yield comparisons (n=214) between the CPS wheat cultivar Oslo and CWRS cultivars such as Neepawa or Katepwa (Graf et al., 1990) suggest a differential genotypic response to environments. Baker (1988a) demonstrated significant genotype-environmental interaction (G x E) for yield comparisons between Fielder and HY 320 spring wheats.

For a given set of genotypes and environments, G x E is the phenomenon whereby genotype differences in agronomic performance, disease reaction and/or end-use quality characteristics are not consistent from one environment to the next. Genotype-environmental interaction falls into two main categories (Baker, 1988b): G x E resulting from a non-parallel response of genotypes to environment with (1) similar genotype ranks from one environment to the next or (2) changing genotypic ranks from one environment to the next. Inconsistent genotype rankings or "cross-overs" are of concern from both a crop production and crop breeding standpoint.

Non-repeatable (between years) cross-over interaction in adaptational crop trials would preclude concrete regional cultivar recommendations. In the same vein, marketers of new cultivars would find it difficult to make accurate claims of

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cultivar performance. Similarly, cross-over interaction reduces the efficiency of crop breeding programs by complicating the identification of superior genotypes.

The objective of this study was to investigate the erratic yield performance of Oslo and Fielder spring wheat.

MATERIALS AND METHODS

Four spring wheat cultivars: Columbus, Oslo, Fielder and HY 320 were used as checks in advanced-generation SWP yield trials. Although similar in maturity, Oslo differs from standard CWRS cultivars in plant height, yield components and photoperiod response. Fielder and HY 320 are both semi-dwarf, photoperiod insensitive, later maturing cultivars with high yield potentials.

Yield trials were grown in seven environments (Table 2). One of the sites (Outlook) was irrigated. The seeding rates were approximately 290, 330 and 440 seeds/m^2 at Watrous, North Battleford and Outlook, respectively. The harvested area was either 4.3 m^2 (Watrous) or 3.8 m^2 (North Battleford and Outlook). Approximately 50 kg/ha of 11-51-0 fertilizer was drilled in with the seed. The Outlook site received an additional 100 kg/ha actual N in the form of anhydrous ammonia and fertigated 28-0-0. The dryland trials were seeded on fallow while the irrigated trials were seeded on potato, canola and lentil stubble in 1986, 1987 and 1988, respectively. Seeding dates ranged from 11 May to 25 May. A randomized complete block design with four replicates was used for all trials.

Yield components and harvest indices were determined from 10 upper-canopy shoots (main stems or primary tillers) harvested at maturity and oven-dried at 80° C for 24 h. Main stems and primary tillers have proven to be good indicators of genotypic differences in yield components and harvest index (Hucl and Baker, 1989).

A combined analysis of variance based on a mixed model (genotypes - fixed, environments-random) was carried out for each of six variables. The Azzalini-Cox test for cross-over interaction as described by Baker (1988a) was used at $p = 0.05$. The pooled error variance was used in calculating the test's critical value.

RESULTS AND DISCUSSION

Variance due to G x E (Table 1) was highly significant ($p = 0.01$) for all variables except spikes/m^2 ($p = 0.05$). For grain yield, kernel weight and spikes/m^2 variation due to G x E was greater than that attributable to genotypes.

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Averaged over environments (Table 2) the semi-dwarf genotypes (Oslo, HY 320, Fielder) had higher harvest indices, more spikelets/spike and more kernels/spike than Columbus (standard-height). The environments sampled provided a wide range of yields and yield components. With one exception (Watrous, 1987) the irrigated sites out-yielded the dryland sites.

Changes in genotype rank from one environment to the next were detected on an arithmetic basis (Table 3) for nearly all traits measured when Oslo was compared to either Columbus (d1 = difference 1) or HY 320 (d2) and Fielder was compared to HY 320 (d3). Rank changes (i.e. cross-overs) are indicated by changes in sign (- versus +). Based on the Azzalini-Cox test, cross-overs for kernels/spike and spikes/m^2 were not statistically significant ($p = 0.05$). Significant ($p = 0.05$) cross-overs were detected for comparisons between Oslo and Columbus (yield, spikelets/spike, kernel weight). Cross-overs between Fielder and HY 320 were significant in only one case (grain yield). The frequency of significant cross-overs tended to be low (8.3 or 16.7%) with the exception of spikelets/spike (41.7% for d1 (Table 3)).

All the significant cross-over interactions involved a heavily rusted (leaf and stem) site (Outlook, 1986). Stem rust infection was reported at a very early date (June 11) in the Outlook region in 1986 (McFadden, 1988). A combination of disease avoidance (early maturity) and good rust resistance provided Oslo with a distinct yield advantage over HY 320 at Outlook in 1986 (Table 3). Similarly, early maturity and superior stem rust resistance resulted in Oslo out-yielding Columbus under heavy disease pressure. As a result of leaf rust susceptibility, Fielder yielded distinctly less than HY 320 at Outlook in 1986. Differential genotypic responses to a combination of leaf rust (*Puccinia recondita*) and stem rust (*P. graminis* f. sp. *tritici*) have been shown to have a large influence on G x E in Western Canada (Baker, 1971).

Oslo yielded significantly less than Columbus (d1) and HY 320 (d2) under dryland conditions (Watrous, 1987) resulting in significant cross-over interactions (Table 3). The reason for this cross-over is not clear. The Watrous site in 1987 was the highest yielding dryland site. Below average rainfall (Table 4) prior to heading, however, probably affected Oslo to a greater extent than Columbus and HY 320 as indicated by lower spikelet and kernel numbers (Table 3).

The early maturity of Oslo would limit yield compensation as a result of later-season precipitation (Table 4). Above average precipitation in July resulted in regrowth at Watrous in 1987 and to a lesser extent in 1986. Under post-anthesis drought conditions in North Dakota, Oslo has been classified as stress tolerant (Bruckner and Frohberg, 1987a). Oslo appears to escape later-season stress by flowering earlier and completing its life cycle faster than other genotypes (Bruckner and Frohberg, 1987b). Oslo may perform well under conditions where post-anthesis stress (high temperatures and evapotranspiration rates) prevails, however, this does not appear to be the case where pre-anthesis stress occurs.

Fielder out-yielded HY 320 significantly in the lowest - yielding dryland environment (Watrous, 1986) and under irrigation in the absence of disease pressure (Outlook, 1987). Fielder and HY 320 are similar in morphology and phenology (Baker, 1988a) yet are subject to cross-over interaction. Fielder has a documented vernalization requirement (Jedel et al., 1986) while HY 320 has not been classified to date. It is possible that differing vernalization requirements are, in part, responsible for the cross-over interactions between Fielder and HY 320 in the absence of disease pressure.

Correlations between grain yield and yield-related traits (Table 5), based on paired genotype differences (Table 4), suggest different mechanisms may be at play in causing the observed G x E effects. In the case of Oslo - Columbus comparisons (d1) spikelet and kernel production responded differently to environmental conditions. For d2 (Oslo - HY 320), differential tillering, kernel filling and harvest index responses appeared to be more important. Harvest index and to a lesser extent kernel filling appear to have been related to yield G x E when contrasting Fielder and HY 320.

SUMMARY

Statistically significant (P = 0.05) cross-over interaction was detected in four out of six traits examined. Approximately half of these cross-over cases were caused by differential cultivar responses to a very severe rust infestation at one site in 1986. Under rust-free conditions an inter-play between cultivar phenology and growing season precipitation patterns appeared to be related to G x E.

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REFERENCES

Baker, R.J. 1971. Effects of stem rust and leaf rust of wheat on genotype-environment interaction for yield. Can. J. Plant Sci. 51: 457-461.

Baker, R.J. 1988a. Tests for cross-over genotype - environmental interactions. Can. J. Plant Sci. 68: 405-410.

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Baker, R.J. 1988b. Analysis of genotype - environmental interactions in crops. ISI Atlas of Science: Animal and Plant Sci. 1: 1-4.

Bruckner, P.L. and Frohberg, R.C. 1987a. Stress tolerance and adaptation in spring what. Crop Sci. 27: 31-36.

Bruckner, P.L. and Frohberg, R.C. 1987b. Rate and duration of grain fill in spring wheat. Crop Sci. 27: 451-455.

Graf, R.J., Hucl, P., Smith, J. and Song, L.S.P. 1990. Oslo red spring wheat, Can. J. Plant Sci. 70 (1): in press.

Hucl, P. and Baker, R.J. 1989. Tiller phenology and yield of spring wheat grown in a semiarid environment. Crop Sci. 29: 631-635.

Jedel, P.E., Evans, L.E. and Scarth, R. 1986. Vernalization responses of a selected group of spring wheat (Triticum aestivum L.) cultivars. Can. J. Plant Sci. 66: 1-9.

McFadden, W. 1988. Saskatchewan winter wheat survey. Proc. Soils and Crops Workshop. Vol 2: 48-66.

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TABLE 1. SUMMARY OF MEAN SQUARES FROM THE ANALYSIS OF VARIANCE FOR GRAIN YIELD AND YIELD COMPONENTS OF FOUR SPRING WHEAT CULTIVARS GROWN IN SEVEN ENVIRONMENTS

Source	df	Grain Yield	Harvest Index	Spikelets/ Spike	Kernels/ Spike	Kernel Weight	Spikes/+ m^2
Environment (E)	6	30972442**	225.0**	43.14**	442.3**	510.7**	499868**
Reps in E	21	452017**	5.5*	0.55*	12.9	8.0**	5440
Genotypes (G)	3	483984	135.6**	30.05**	515.6**	93.2	33189
G x E	18	1068407**	18.0**	13.09**	65.2**	49.4**	13558*
Error	63	112922	3.0	0.29	10.2	4.4	6759

*, ** = Significant at the P < 0.05 and P < 0.01 levels of probability, respectively.
+ df = 3, 5, 15, 18 and 54.

TABLE 2. GENOTYPE AND ENVIRONMENT MEANS FOR GRAIN YIELD AND YIELD COMPONENTS

Genotype	Grain Yield (kg/ha)	Harvest Index (%)	Spikelets/ Spike (no.)	Kernels/ Spike (no.)	Kernel Weight (mg)	Spikes/ m^2 (no.)
Columbus	4219	43.7	13.4	27.9	36.6	561
HY 320	4429	48.6	15.3	38.2	36.6	514
Oslo	4233	48.0	14.6	32.3	35.6	535
Fielder	4474	46.4	15.8	34.5	32.7	600
SE	NS	0.8	0.3	1.5	NS	NS
Environment						
86 NB	3158	46.3	16.9	39.2	36.2	380
86 OTL	4104	42.7	16.8	38.8	27.6	636
86 WTR	3111	53.3	14.9	29.7	39.3	638
87 NB	3593	47.8	13.3	27.7	38.6	377
87 OTL	7149	44.0	14.4	35.6	30.5	-
87 WTR	4763	43.4	12.6	26.4	31.8	823
88 OTL	4492	49.1	14.1	35.1	43.6	461
SE	168	0.6	0.2	0.9	0.7	18

NB = North Battleford
OTL = Outlook
WTR = Watrous

TABLE 3. DIFFERENCES IN GRAIN YIELD AND RELATED TRAITS FOR FOUR SPRING WHEAT GENOTYPES GROWN IN SEVEN ENVIRONMENTS

	Grain Yield (kg/ha)			Harvest Index (%)			Spikelets/Spike (No.)		
Environment	d1+	d2	d3	d1	d2	d3	d1	d2	d3
86 NB	+309	-232	-271	+7.2	-1.4	-5.6	+1.9	-1.6	0
86 OTL	+555	+1063	-828	+6.2	+3.1	-7.1	+1.5	-2.4	-0.3
86 WTR	-326	-188	+564	+3.9	-0.2	-0.6	+1.2	-0.2	+0.4
87 NB	-244	-260	+364	+5.6	-0.8	-0.8	-0.8	+0.1	+0.1
87 OTL	+303	-218	+1133	+2.0	-3.7	+0.3	+1.7	-0.1	+0.2
87 WTR	-832	-1303	-480	+2.4	-0.6	+1.5	-0.9	-0.6	+0.5
88 OTL	+336	-233	-156	+3.3	-0.4	-2.0	+2.8	+0.1	+2.4
Critical Value[a]		520				2.7		0.8	
X - Overs (%)[b]	8.3	8.3	16.7	0	8.3	0	41.7	0	0

TABLE 3 (Continued). DIFFERENCES IN GRAIN YIELD AND RELATED TRAITS FOR FOUR SPRING WHEAT GENOTYPES GROWN IN SEVEN ENVIRONMENTS

	Kernels/Spike (No.)			Kernel Weight (mg)			Spikes/m^2 (No.)		
Environment	d1	d2	d3	d1	d2	d3	d1	d2	d3
86 NB	+7.4	-8.6	-10.9	-0.7	+1.6	-3.8	-50	+ 27	+109
86 OTL	+10.3	-10.1	-8.7	-4.6	+4.8	-1.7	-56	+144	+140
86 WTR	-0.5	+2.0	+3.0	+2.7	-1.9	-5.0	-56	- 97	+ 66
87 NB	+4.2	0	+0.3	+4.0	-5.4	-6.6	-48	+ 21	+123
87 OTL	+10.1	-9.3	-9.7	+5.9	-1.7	+2.3	-	-	-
87 WTR	-2.9	-5.0	+0.9	+1.0	-1.0	-6.6	+59	- 79	- 74
88 OTL	+0.6	-10.7	-1.1	0	-5.9	-8.4	- 2	+114	+161
Critical Value[a]		4.9			3.3			123	
X - Overs (%)[b]	0	0	0	16.7	16.7	0	0	0	0

+ d1 = Oslo - Columbus, d2 = Oslo - HY 320, d3 = Fielder - HY 320.
[a] Azzalini - Cox test (p = 0.05).
[b] % of possible cross-overs which were significant at p = 0.05.

TABLE 4. GROWING SEASON PRECIPITATION DATA AT TWO SITES IN 1986 AND 1987

1986	April (mm)	May (mm)	June (mm)	July (mm)	August (mm)
Watrous	7.7(28)+	58.1(134)	38.2(49)	123.3(218)	12.9(29)
North Battleford	12.4(49)	48.3(137)	67.1(111)	142.6(219)	8 (18)
1987					
Watrous	10.9(40)	32.9(76)	54.2(69)	130.5(231)	55.7(127)
North Battleford	13.7(65)	42.4(120)	40.2(67)	108.9(167)	107.3(235)

+ (% of 30 year average)

TABLE 5. RELATIONSHIPS BETWEEN GENOTYPE DIFFERENCES FOR GRAIN YIELD AND FIVE YIELD RELATED TRAITS

	Correlation Co-efficients (r)[a]		
Grain Yield Versus:	d1[b]	d2	d3
Harvest Index	0.39	0.64	0.58
Spikelets/Spike	0.86*	-0.65	0.02
Kernels/Spike	0.79*	-0.32	0.08
Kernel Weight	-0.37	0.57	0.39
Spikes/m^2	0.36	0.71+	0.08

[a] based on n = 7 except spikes/m^2 (n = 6).
[b] d1 = Oslo - Columbus, d2 = Oslo - HY 320, d3 = Fielder - HY 320.
+, * Significant at p = 0.10 and p = 0.05, respectively.