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Comparison of unpredictable environmental variation generated by year and by seeding-time factors for measuring type 4 stability

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Summary. Type 4 stability has been proposed to measure a cultivar's homeostatic property to resist unpredictable environmental variation. The requirement for calculating this stability is that the experiment must contain a time factor in addition to the cultivar × location factors. Of the two time factors, year and seeding-time, the latter is less attractive biologically because it represents only a part of the broader context of unpredictable variation represented by years, but it is attractive in terms of shortening the test period. Investigation of historical data from the Eastern Cooperative trials and the Ontario Production trials in Canada indicates that the unpredictable variation generated by seeding-time was about half that generated by year. Although type 4 stability measured by both factors appears to be the same, the stability measured by seeding-time is more prone to variation. The implication is that complete substitution of the year factor by seeding-time is not appropriate, but use of both factors in combination may be sensible.

Key words: Genotype × environmental interaction – Cultivar × location × year experiment – Regional trial

Introduction

Lin and Binns (1988) proposed a method of analyzing cultivar × location × year experiments based on the concept of separation of predictable (e.g. soil) and unpredictable environmental variation (e.g. weather). Since predictable variation can be controlled to a certain extent by selecting cultivars with specific adaptability to regions, but unpredictable variation cannot be controlled (one must rely on the homeostatic property of the cultivar itself), different selection criteria are necessary with respect to each type of environmental variation. For predictable variation, we use Finlay and Wilkinson's (1963) regression analysis to identify the cultivar's optimum range of locations; for unpredictable variation, we use the years-within-location mean square (MS) to assess the cultivar's stability (type 4 stability). In contrast to the three types of conventional stability parameters discussed by Lin et al. (1986), type 4 stability has the advantage of being independent of other cultivars included in the test and being a homeostatic characteristic of the cultivar coping with unpredictable variation. The latter property is particularly important for cultivar selection, a property possessed by neither type 2 nor type 3. Type 1 has this property, but because predictable variation is also included in the assessment, this type of stability often loses its practical value because of its negative correlation with yield.

However, one disadvantage of type 4 is that it requires the experiment to include a time factor in addition to cultivar × location. The reason is that only then can predictable variation such as may arise from the soil factor be separated from unpredictable variation (weather). The ideal time factor is "year", since it is the most natural. However, this factor is expensive and time-consuming. A less effective but still sensible alternative is to use different seeding-times, because they represent differential weather sequences for the same developmental phase of cultivars, thus consituting a degree of unpredictable variation. Although the unpredictable variation generated by a year factor and that by seeding-time may not be of exactly the same nature, there is good reason to believe that the cultivar that is stable under different

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seeding-times (better adjustment of its life cycle to local weather condition) is more likely to withstand better in different years. Direct investigation of this hypothesis is possible if the data of a cultivar × location × year × seeding-time experiment is available. However, such a test requires considerable resources. A less expensive but still useful study can be made based on independent experiments of cultivar × location × year and cultivar × location × seeding-time, provided that these independent tests cover approximately the same region.

The purpose of this paper is to use historical data to compare the magnitude of unpredictable environmental variation generated by year and seeding-time factors. The feasibility of using seeding-time as a combined time factor (with year) for assessing type 4 stability is also discussed.

Data and methods

Eighteen sets of regional trial data for six-row barley and oats, were constructed based on reports of the Plant Research Centre (Ottawa). Sets 1–14 were from the Eastern Cooperative trials of 1980–1988 (covering Ontario, Quebec and Maritimes regions, but only Ontario data were used); each set consisted of three years. Since the data of the same year were used in successive sets, not all the sets are independent. However, since the cultivars and location included in each set are not necessarily the same, they constitute a degree of independent sampling. Sets 15–18 were from the Ontario Production trials (covering Ontario alone) of 1984 and 1985. Each year three seeding-times were used. The starting times at each location are different (ranging from April 13–May 11 in 1984 and from April 17–May 14 in 1985), but the succeeding two seeding-times were always two weeks apart. In these four sets of data, two seeding rates (0.072 and 0.108 m^3/arec) were used. We shall assume cultivar × seeding rates to be a single factor as in Lin and Binns (1988).

In each set, location × time means averaged over all cultivars were analyzed by the one-way ANOVA. As a quantitative measure to assess the value of the two time factors for type 4 stability estimation, we made the assumption that locations are random (although not very realistic), and estimated the intraclass correlation within locations and its confidence limits (Snedecor and Cochran 1980, p 245).

Results and discussion

Intraclass correlation coefficients (ϱ) and the 90% confidence limits are shown in Table 1. Because the numbers of degrees of freedom associated with each ANOVA are small (less than ten for location and less than 20 for time within location) the intervals are quite large (about 70%), which makes comparison of ϱ-values difficult. However, among the 14 sets with the year factor, 11 intervals contain zero, while among the four sets of seeding-time only one does. This suggests that intraclass correlation of year is mostly negligible, while that of seeding-

Table 1. Intraclass correlation (ϱ) and 90% confidence intervals

Set	Crop	Year	C × L × T	ϱ[a] (%)	Confidence limits: Lower	Upper
Time factor: year						
1	Barley	1980–1982	6 × 8 × 3	29.4	−5.4	69.6
2	Barley	1981–1983	3 × 8 × 3	27.7	−6.8	68.4
3	Barley	1982–1984	7 × 6 × 3	24.3	−7.9	63.5
4	Barley	1983–1985	5 × 8 × 3	−5.8	−29.5	39.2
5	Barley	1984–1986	5 × 8 × 3	−3.7	−28.5	41.2
6	Barley	1985–1987	4 × 9 × 3	18.5	−12.4	59.0
7	Barley	1986–1988	2 × 7 × 3	−6.1	−31.1	42.8
8	Oats	1980–1982	4 × 6 × 3	31.9	−8.1	77.4
9	Oats	1981–1983	8 × 8 × 3	3.3	−24.3	48.6
10	Oats	1982–1984	10 × 7 × 3	−1.7	−28.6	47.0
11	Oats	1983–1985	12 × 5 × 3	58.3	14.1	90.9
12	Oats	1984–1986	3 × 10 × 3	43.2	10.9	74.2
13	Oats	1985–1987	3 × 8 × 3	27.7	−7.0	68.3
14	Oats	1986–1988	4 × 8 × 3	44.6	10.3	79.3
			(Average)	20.9		
Time factor: seeding-time						
15	Barley	1984	22 × 7 × 3	73.7	43.3	92.3
16	Barley	1985	18 × 5 × 3	33.8	−10.0	82.4
17	Oats	1984	12 × 7 × 3	68.0	34.7	90.4
18	Oats	1985	16 × 5 × 3	57.7	13.4	90.7
			(Average)	58.3		

[a] Based on the location × time mean averaged over all cultivars

Table 2. Intraclass correlations of years within locations for each cultivar in Eastern Canada (%) for set 3 and set 10

Cultivar	Ontario	Quebec and Maritimes	Overall
Set 3: Barley (1982–1984)			
	(6)[a]	(9)	(15)
BRUC	10.5	42.2	30.7
CONQ	26.1	43.5	41.6
LAUR	14.7	43.2	42.7
LEGE	26.3	48.3	40.6
BOWE	24.3	47.1	45.9
CG17	22.5	38.9	31.9
OB-3	28.4	50.1	43.1
Cult. mean	24.3	47.1	41.5
Set 10: Oats (1982–1984)			
	(7)	(4)	(11)
ELGI	−16.1	5.0	−8.5
LAMA	9.3	−20.7	−2.4
OXFO	−14.7	−16.7	−15.1
SHAW	10.5	−19.4	−0.2
TERR	27.8	11.2	20.8
O447	−11.1	3.9	−2.2
O501	5.1	−0.1	2.6
OGLE	−4.7	30.4	14.6
QRO8	−2.5	−22.4	−10.0
Q186	12.6	−23.5	−0.5
Cult. mean	−1.7	−8.5	−4.6

[a] Numbers of location at each region

Table 3. ANOVA for set 19 (barley) and set 20 (oats)

Source	Set 19 (16 × 5 × 3 × 2)		Set 20 (12 × 5 × 3 × 2)		Expected MS
	df	MS	*df*	MS	
Location (L)	4	1,959,272	4	5,138,784	$\sigma_S^2+3\sigma_Y^2+6\sigma_L^2$
Time (T)/L	25	(499,629)	25	(1,155,415)	
Year (Y)/L	5	624,029	5	2,299,338	$\sigma_S^2+3\sigma_Y^2$
Seed-time/Y/L	20	468,579	20	869,434	σ_S^2
$\hat{\sigma}_S^2$		222,541		473,241	
$\hat{\sigma}_Y^2$		51,817		476,635	
$\hat{\sigma}_S^2$		468,529		869,434	
$\hat{\varrho}_Y^a$		30.0		26.0	
$\hat{\varrho}_S$		36.9		52.0	

[a] See the text

Table 4. Type 4 stability ranking based on three categories of measurement

Cultivar	Type 4 stability measured by: S/L of 1984		S/L of 1985		Y/L × S[a]	
	R1[b]	R2	R1	R2	R1	R2
(Column no.)	(1)	(2)	(3)	(4)	(5)	(6)
Barley						
B-1	8	6	3	4	7	4
B-3	1	1	5	1	3	1
B-4	5	5	2	6	1	3
B-5	2	2	7	8	6	8
B-7	7	8	1	3	2	2
B-9	3	3	4	5	4	5
B-10	4	7	6	2	5	6
B-11	6	4	8	7	8	7
Oats						
O-1	3	2	2	2	1	1
O-2	5	6	5	4	4	4
O-3	2	3	1	3	3	3
O-4	1	1	3	1	2	2
O-5	4	4	4	5	5	5
O-6	6	5	6	6	6	6

[a] Yield MS within locations and seeding time
[b] R_1, R_2 represent seeding rates 1 and 2 respectively

time is not. On average, a mean ϱ-value for the former group is 21% while that for the latter group is 58%. Since the higher the intraclass correlation, the smaller the unpredictable variation, it appears that the unpredictable variation generated by the year factor is about twice as much ([1−0.21]/[1−0.58] = 1.9) as that by seeding-time.

In view of the variability among the first 14 sets, we used sets 3 and 10 to investigate the extent of variation caused by individual cultivars and by different sets of locations (sub-regions). The results (Table 2) show that the ϱ-values are fairly stable with respect to cultivars, but vary considerably among different sub-regions. The first property is encouraging in the sense that it justifies our use of cultivar means for assessing intraclass correlation, but the second property gives us some concern. Because different locations are involved in each set, this may distort the true differences of ϱ-values between groups. To investigate this point, two combined sets of data were constructed: (i) set 19 (barley), 16 × 5 × 2 × 3 (cultivar × location × year × seeding-time) based on sets 15 and 16; and (ii) set 20 (oats), 12 × 5 × 2 × 3 based on sets 17 and 18. These two sets of data were analyzed by a two-stage nested design and two intraclass correlations, one for year (ϱ_Y) and the other for seeding-time (ϱ_S) were calculated as follows:

$$\varrho_Y=\hat{\sigma}_L^2/(\hat{\sigma}_L^2+\hat{\sigma}_Y^2+\hat{\sigma}_S^2)$$

and

$$\varrho_S=(\hat{\sigma}_L^2+\hat{\sigma}_Y^2)/(\hat{\sigma}_L^2+\hat{\sigma}_Y^2+\hat{\sigma}_S^2).$$

The results (Table 3) show that the ratio between ϱ_Y and ϱ_S (Table 3) is about 1:1 for set 19, and is 1:2 for set 20, indicating that one set of the data agrees with the general conclusion but the other does not.

A critical question at this point is whether the unpredictable variation generated by both factors gives the same stability measurements. To check this point, type 4 stability (MS of times/location) of sets 19 and 20 was calculated for three categories: (i) 1984 seeding-time, (ii) 1985 seeding-time, and (iii) years within location × seeding-time. Cultivars (same coded names were used as in Lin and Binns [1988]) in each category were then ranked for each seeding rate separately. This gives six criteria of ranking (coded as 1–6 in Table 4). Spearman's rank correlations were calculated for 9 pairs of the 6 criteria (Table 5). These show that the rank correlations

Table 5. Spearman rank correlations based on data in Table 4

	Barley (Set 19)	Oats (Set 20)
Between two seeding rates		
(1)* and (2)	0.79[b]	0.89[b]
(3) and (4)	0.33	0.71
(5) and (6)	0.71[b]	1.00[b]
Between two years for Seeding-time		
(1) and (3)	−0.43	0.83[b]
(2) and (4)	−0.24	0.83[b]
Between Seeding-time and year		
(1) and (5)	0.19	0.77[a]
(2) and (6)	−0.12	0.77[a]
(3) and (5)	0.71[b]	0.77[a]
(4) and (6)	0.69[a]	0.94[b]

[a] Significant at the 10% level
[b] Significant at the 5% level
* Column numbers of Table 4

between the two stability assessments are fairly similar for set 20, but less so for set 19 since its ranking order varies considerably between the two years.

The general conclusion that can be drawn from the above is that the unpredictable variation generated by seeding-time is smaller than that by year factor. Although the type 4 stabilities measured by both factors are similar, the stability measured by seeding-time is more prone to variation. Therefore, complete substitution of year factor by seeding-time is not appropriate, but a combined use of both factors for measuring type 4 stability may be sensible if shortening the test period is desired.

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