Theor Appl Genet (1991) 81:679–684

THEORETICAL AND APPLIED GENETICS

An integrated approach to oilseed rape cultivar selection using phenotypic stability *

J. E. Brandle [1], and A. L. Brûlé-Babel [2]**

[1] Agriculture Canada Research Station, P.O. Box 186, Delhi, Ontario N4B 2W9, Canada
[2] Plant Science Department, University of Manitoba, Winnipeg R3T 2N2, Canada

Received June 20, 1990; Accepted September 26, 1990
Communicated by A. R. Hallauer

Summary. Various methods of evaluating phenotypic stability have been proposed; however, no single method can adequately describe cultivar performance. The objectives of this study were to integrate a number of methods of evaluating stability and to use this approach for cultivar selection. These objectives were considered in the context of the broad-based oilseed rape cultivar (*Brassica napus* spp. *oleifera*) evaluation system currently used in western Canada. Regression analysis was used to assess cultivar response to environments. Cluster analysis was used to assemble cultivars into groups with similar regression coefficients (b_i) and mean yield. Three parametric stability parameters, years within locations mean square (MS_i Y/L), Shukla's stability variance (σ_i^2), and Francis and Kannenberg's coefficient of variability (CV_i), were compared to determine which method would be most suitable for selection of oilseed rape cultivars from within clustered groups. Yield data from three cultivars and six breeding lines that had been tested for 2 years at 26 locations in the Western Canola Cooperative Test 'A' were used for all calculations. The cluster analysis was successful in identifying commercially acceptable breeding lines. The parameter MS_i Y/L was considered to be more appropriate than either CV_i or σ_i^2, because it measured only the unpredictable portion of the genotype × environment interaction and was independent of the other cultivars in the test. The use of cluster analysis to group entries with similar b_i values and mean yields, followed by selection for stability within groups, was advocated.

Key words: *Brassica napus* L. – Canola – Genotype-environment interaction – Cluster analysis

Introduction

Phenotypic stability parameters can be useful measures of cultivar adaptation. However, some of the different parameters reflect a different aspect of stability and no single method can adequately explain cultivar performance across environments. Lin et al. (1986) have established three major concepts of stability. Cultivars with Type 1 stability have a small among-environment variance. Type 1 stability is related to homeostasis and has been associated with low yield (Becker 1981; Lin et al. 1986). Francis and Kannenberg's (1978) coefficient of variability (CV_i) is a measure of Type 1 stability. If a cultivar's linear response to environment mean yield is parallel to the mean response of all genotypes in the trial, it exhibits Type 2 stability. Type 2 stability is a relative measure and depends on the other cultivars in the test. Shukla's (1972) stability variance parameter (σ_i^2) is a measure of Type 2 stability. Type 3 stability is measured by the residual mean square from the regression of individual cultivar yields on an environmental index (Eberhart and Russell 1966). This stability parameter has been criticized as descriptive in nature rather than predictive (Lin et al. 1986), and will not be considered in this study.

Lin and Binns (1988a) have recently proposed a fourth concept of stability (Type 4). A cultivar is considered to have Type 4 stability if its years-within-locations mean square (MS_i Y/L) is small. This parameter measures cultivar response to unpredictable variation in the environment and is representative of the homeostatic properties of a cultivar. Cultivar response to the pre-

* Contribution No. 846 of the Plant Science Department, University of Manitoba
** To whom correspondence should be addressed

dictable component of the environment is described using regression coefficients (b_i) similar to those proposed by Finlay and Wilkinson (1963), except that in this case they are based on location effects averaged over years. Lin and Thompson (1975) presented a method of clustering cultivars with similar regression coefficients and mean yields. This clustering procedure could be combined with an extension of the analysis proposed by Lin and Binns (1988 a) in order to group cultivars with similar responses to environments. One of the parametric stability parameters could then be employed to select stable cultivars from within clusters.

In western Canada, the final stage of oilseed rape (*Brassica napus* spp. *oleifera*) cultivar evaluation prior to licensing is accomplished within the framework of the Western Canola Cooperative Test 'A.' Breeding lines are submitted from the various breeding programs throughout the country and they are evaluated at a large number of locations. After the 1st year, worthy lines are retained and then evaluated for a 2nd year. Selected 2nd year lines are again tested for a 3rd year and then considered for registration if their performance is in some way superior to established checks. Broadly adapted breeding lines are favored because of the wide range of environments sampled by the testing system. Therefore, an effective means of identifying this type of line is a prerequisite for success.

The objectives of this study were to present an integrated approach to oilseed rape cultivar selection that combines cluster analysis with other parametric measures of stability. This objective will be considered in the context of the broad-based oilseed rape cultivar evaluation system currently used in western Canada.

Materials and methods

Mean yields for nine oilseed rape cultivars and breeding lines were obtained from the 1986 and 1987 Reports on Cooperative Canola Test 'A' with permission of the test coordinator, Dr. K. Downey, Agriculture Canada, Saskatoon. The individual trials in the test were conducted within the provinces of Manitoba, Saskatchewan, and Alberta during 1986 and 1987 at 32 and 31 locations, respectively. A randomized complete block design with four replications was used for all trials. Twenty-five locations that had been consistently in both years were chosen for the analysis. The cultivars included in this study were three commercial checks ('Westar,' 'Regent,' 'Tribute') and six breeding lines (CV1, CV2, CV3, CV4, CV5, and CV6). The latter six entries had been entered into the test either in 1985 or 1986 and were selected for further testing in 1987. Westar is the standard commercial cultivar against which all breeding lines in the Western Cooperative Canola Test are measured.

Entry × location means, averaged over years, were regressed on an environmental index, and the resultant b_i values for each entry were considered as a measure of response to environments. The environmental index in this case was the deviation of the location means, averaged over years, from the grand mean. To visually assess general adaptability, the entry mean and the maximum yield from each location, averaged over years, were plotted against location means (Lin and Binns 1988 b).

The MS_i Y/L value was calculated for each cultivar to reflect sensitivity to unpredictable environmental variation (Lin and Binns 1988 a). The analysis of variance, MS_i Y/L values, and regression coefficients were calculated using the General Linear Models Procedure of the Statistical Analysis System (SAS 1985). A fixed effects model was assumed for the analysis of variance. The σ_i^2 (Shukla 1972) and CV_i parameters (Francis and Kannenberg 1978) were calculated for each cultivar using cultivar × environment means, where each year-location combination constituted an individual environment. The relationships between MS_i Y/L, σ_i^2, CV_i, and b_i were measured using Spearman's rank correlation coefficient (Steel and Torrie 1980). Rank correlations were used instead of ordinary correlation coefficients because the stability parameters could not be assumed to be normally distributed.

In order to classify breeding lines as like or unlike commercial checks in term of their mean yields and response to environments, Lin and Thompson's (1975) clustering procedure was used. The first step in the analysis requires calculation of a dissimilarity matrix that represents the variance ratio for heterogeneity of regressions for each pair of entries. An unweighted pair group clustering algorithim is then applied to the matrix, resulting in a dissimilarity index that is simply the variance ratio used for testing heterogeneity of regressions for the group entries. The *F*-test for a common regression line is used as the stopping criterion. When the value of the index exceeds the *F* value for *r* and (*m*-1)(*n*-2) degress of freedom, the clustering process is stopped (where *m* represents the number of entries in the trial, *n* the number of locations, and *r* the number of entries in the group). The method is an extension of Finlay and Wilkinson's (1963) regression approach that groups entries into homogenous subsets, within which all members have a common regression. The actual calculations were performed using software (S116) developed by the Statistical Research Section of Agriculture Canada (Lin 1988). The entry × location means, averaged over years, used to calculate b_i were also used for the cluster analysis.

Results and discussion

The analysis of variance indicated that heterogeneity of regressions was highly significant ($P<0.01$) and accounted for 11% of the genotype × location sums of squares (Table 1). Therefore, there were significant differences among the b_i values of cultivars (Table 2). Coefficients of determination (r^2) for the individual cultivars ranged from 75% to 96%, indicating a good linear fit (Table 2). The cluster analysis resulted in the following five response groups:

Group 1: Tribute
Group 2: CV6
Group 3: CV5
Group 4: Regent, CV3
Group 5: Westar, CV1, CV2, CV4

Relative to the regression of maximum yields ($b_i=1.10$), the Group 1 cultivar Tribute was not responsive to environments (Fig. 1) and had very low mean yield (Table 2). The Group 2 cultivar CV6 was highly responsive to environments but had low mean yield, indicating poor adaptation to low-yielding environments and only average

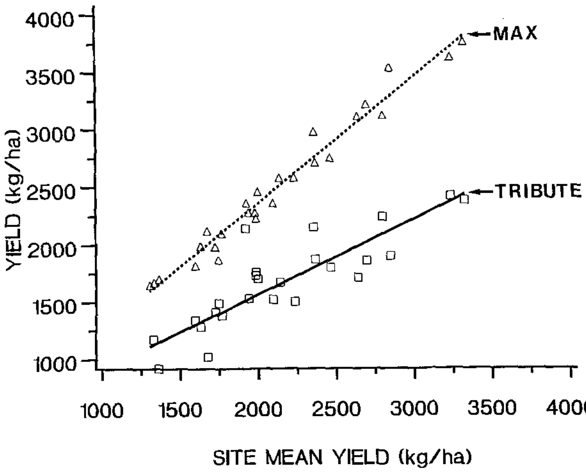

Fig. 1. Comparison of the response to environments of Tribute with the maximum response (MAX)

Table 1. Combined analysis of variance for yield of nine oilseed rape cultivars and breeding lines grown at 26 locations for 2 years

Source	*df*	Mean squares (kg ha^{-1})^2 × 10^{-4}
Location (L)	25	552.316
Year (Y)	1	1119.725
Y × L	25	342.764
Entry (C)	8	314.071
C × L	200	7.791
heterogeneity of *b*	8	20.481 **
residuals	192	7.262
C × Y	8	77.380
C × Y × L	200	6.668

** Significant at $P = 0.01$

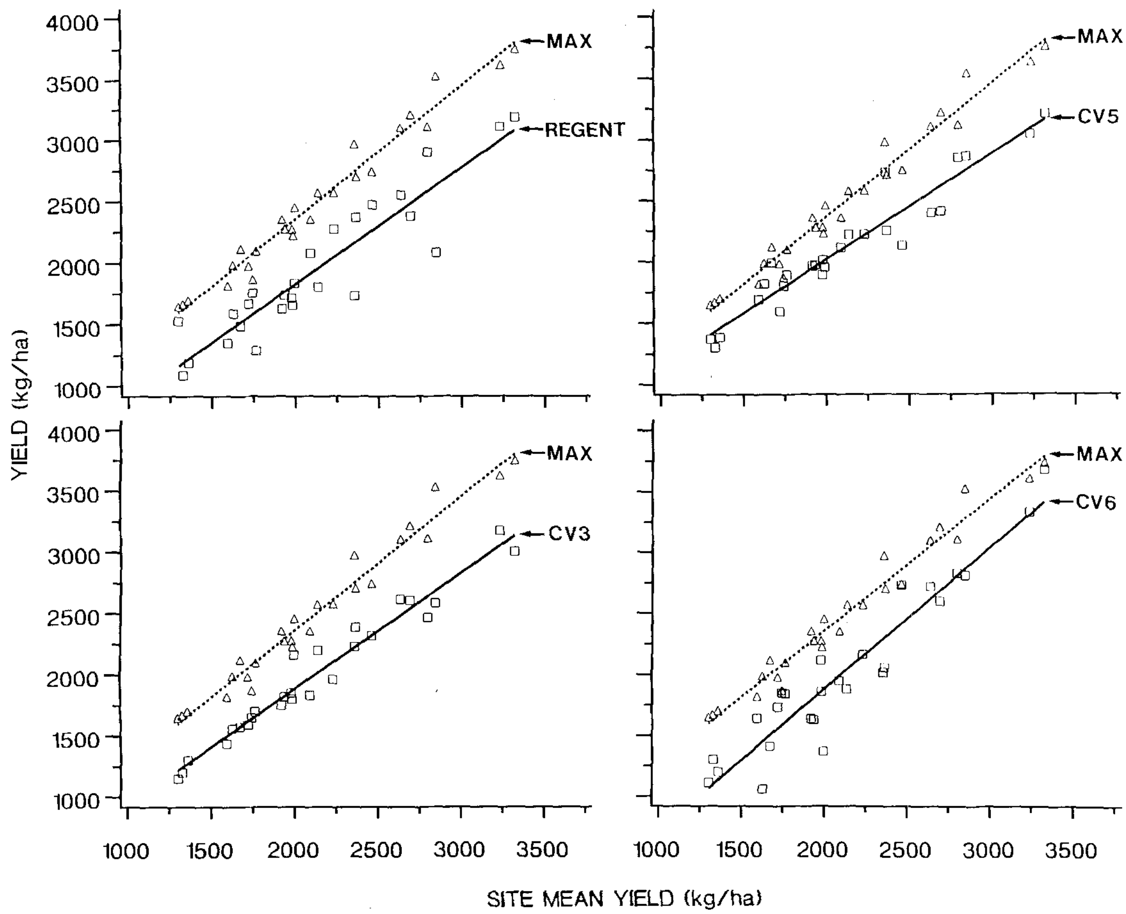

Fig. 2. Comparison of the response to environments of Regent, CV3, CV5, and CV6 with the maximum response (MAX)

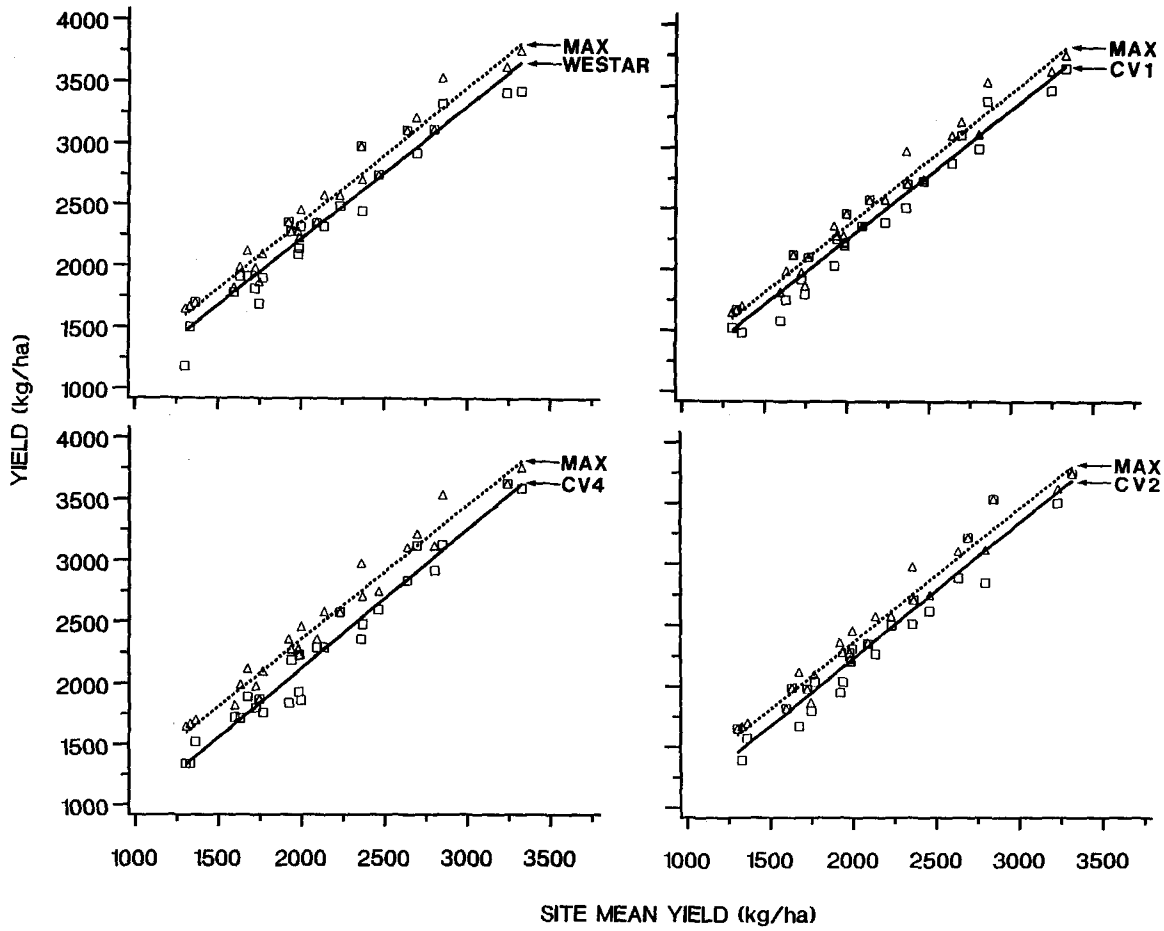

Fig. 3. Comparison of the response to environments of Westar CV1, CV2, and CV4 with the maximum response (MAX)

performance in good environments (Fig. 2). CV5 ranked near the middle in terms of mean yield, but had a low b_i value (Table 2), indicating average performance in the low-yielding environments and poor performance in the high-yielding environments (Fig. 2). The cultivars in Group 4 had quite low mean yields (Table 2) and showed poor response to environments (Fig. 2). No cultivar was found to be substantially better than Westar in terms of both mean yield and response to environments.

The Group 5 breeding lines were of greatest interest because they were included with Westar, which is broadly adapted and is the standard against which all breeding lines are compared when considered for licensing. Of further interest is the fact that the breeding lines in Group 5 were all recently licensed as commercial cultivars, indicating that the cluster analysis was successful in identifying commercially viable breeding lines. The cultivars in this group had high mean yields and high b_i values, which indicates that they will respond well to productive environments. Plotting the mean yields of each of the Group 5 cultivars and the maximum cultivar yield at each site against site mean yield (Fig. 3) shows that Westar, CV1, CV2, and CV4 responded in a manner parallel to that of the maximum. The breeding lines and Westar were well adapted to the complete range of productivity levels, giving superior yields in low- as well as high-yielding environments.

The MS_i Y/L values for individual cultivars showed that Tribute was the most stable and CV5 the least stable in terms of their ability to buffer unpredictable variation (Table 2). The CV_i values (Table 2) also reflect homeostasis or buffering ability but, in contrast with the MS_i Y/L values, indicate that CV1 had the most consistent and CV6 the least consistent yields. CV_i is the variance of a cultivar across environments, weighted by the cultivar mean. Differences in this variance between cultivars are a linear function of b_i (Becker 1981). Therefore, CV_i is not independent of b_i and genotypic responses to predictable and unpredictable environmental variation are confounded. Given the fact that the predictable portion of the variation has been excluded from the MS_i Y/L parameter it is probably a more meaningful measure of homeostatis than CV_i. If MS_i Y/L is considered as a unique measure of homeostasis, then CV2 is better buffered than the other cultivars in Group 5. It will be essential to compare the long-term field performance of

Table 2. Yield, regression coefficients, coefficients of determination, and estimates of stability parameters, for nine oilseed rape cultivars and breeding lines grown at 26 locations for 2 years

Cultivar	Yield kg ha^{-1}	b_i[a]	r^2 %	MS_i Y/L $\times 10^{-4}$	σ_i^2 $\times 10^{-4}$	CV_i %
Westar	2353	1.08	93.6	57.58	6.68	34.8
Regent	1943	0.95	85.5	40.33	10.34	37.2
Tribute	1642	0.65	75.2	35.83	16.06	36.2
CV1	2377	1.07	95.6	53.24	2.80	33.5
CV2	2361	1.11	94.7	45.85	4.48	33.6
CV3	1996	0.95	95.9	37.84	4.26	34.6
CV4	2261	1.13	96.5	59.12	4.96	37.8
CV5	2115	0.87	91.6	66.34	13.05	36.2
CV6	2021	1.17	90.1	51.62	14.83	42.0

[a] $b_i = 1.10$ for maximum set of yields

Table 3. Rank correlation coefficients among the various stability parameters and yield of nine oilseed rape cultivars and breeding lines grown at 26 locations for 2 years

	b_i	MS_i Y/L	σ_i^2	CV_i
Yield	0.51	0.60	−0.65	−0.54
b_i		0.34	−0.23	0.24
MS_i Y/L			−0.10	0.13
σ_i^2				0.70*

* Significant at $P = 0.05$, $df = 7$

CV2 to the other Group 5 members in order to further assess the agronomic value of Type 4 stability.

CV_i and MS_i Y/L were not significantly correlated (Table 3); therefore, despite their conceptual association as measures of homeostasis, there was no quantitative relationship. Neither of the correlations between σ_i^2 or b_i and MS_i Y/L were significant, nor was the relationship between MS_i Y/L and yield significant. Therefore, MS_i Y/L is a unique measure of stability, independent of b_i and unrelated to the conventional parameters currently used.

The σ_i^2 value for Tribute indicated that its yield performance was not parallel to the other cultivars under test and was therefore considered to be unstable (Table 2). A very low σ_i^2 value indicated that the yield performance of CV1 was parallel to the means of the other cultivars under test and that CV1 was stable according to the Type 2 definition of stability. Becker (1981) defined cultivars with low ecovalence values (Wricke 1964) as agronomically desirable. Since ecovalence and σ_i^2 values are equivalent (Lin et al. 1986) for the purpose of ranking, Becker's (1981) arguments may apply to σ_i^2 values as well. However, Lin et al. (1986) criticized σ_i^2 because cultivars are only stable relative to the particular sample of cultivars used in the test. If all the cultivars used in the test are not representative of those grown in the region, then the relative nature of σ_i^2 as a stability parameter can be misleading. This problem with σ_i^2 is evident with the cultivar Westar, which was found to be highly unstable in earlier work by Brandle and McVetty (1988), but was stable in this study. Therefore, caution must be exercised if σ_i^2 is to be used as a measure of stability in the Westar Canola Cooperative Test and probably regional performance trials in general, because most of the entries in the test are in the early stages of development and cannot be considered to be representative of the cultivars available in the region. MS_i Y/L is independent of the other cultivars in the test and is, therefore, a superior measure of stability relative to σ_i^2. The fact that at least 2 years of testing are required before MS_i Y/L can be measured is a significant limitation. However, promising breeding lines are usually tested for more than a single year before entering the national testing system, so the time factor requirement will be satsified as a matter of course.

MS_i Y/L has a broad inferential base, but does not illustrate the response pattern of a cultivar across environments. Using MS_i Y/L in conjunction with b_i, as was suggested by Lin and Binns (1988a), circumvents this problem and should allow selection of cultivars that are both responsive and homeostatic. Becker (1981) and Lin et al. (1986) have argued that well-buffered cultivars, as defined by Type 1 stability, are generally low yielding. The correlation between yield and MS_i Y/L did indicate a similar trend (Table 3). Furthermore, the lowest yielding cultivar in this data set also had the lowest MS_i Y/L value. The association was not, however, complete. Therefore, the existence of responsive, high-yielding cultivars with good Type 4 stability is possible. CV2 may be an example of such a cultivar.

The results of this investigation indicate that cluster analysis used in conjunction with regression analysis and stability parameters may be a suitable means of selecting cultivars that are stable, high yielding, and responsive. Type 4 stability is the most intuitively appealing of the three parameters used in this investigation; however, further studies involving MS_i Y/L will be required to assess both the repeatability and agronomic value of this measure of homeostasis.

References

Becker HC (1981) Correlations among some statistical measures of phenotypic stability. Euphytica 30:835–840
Brandle JE, McVetty PBE (1988) Genotype × environment interaction and stability analysis of seed yield of oilseed rape grown in Manitoba. Can J Plant Sci 68:381–388
Eberhart SA, Russell WA (1966) Stability parameters for comparing varieties. Crop Sci 6:36–40
Finlay KW, Wilkinson GN (1963) The analysis of adaptation in a plant breeding program. Aust J Agric Res 14:742–754

Francis TR, Kannenberg LW (1978) Yield stability studies in short season maize. 1. A descriptive method of grouping genotypes. Can J Plant Sci 58: 1029–1034

Lin CS (1988) Current status of statistical development at SRS for analyzing plant breeders' data. SRS Newsl 33: 7–12

Lin CS, Binns MR (1988a) A method of analyzing cultivar × location × year experiments: a new stability parameter. Theor Appl Genet 76: 425–430

Lin CS, Binns MR (1988b) A superiority measure of cultivar performance for cultivar × location data. Can J Plant Sci 68: 193–198

Lin CS, Thompson B (1975) An empirical method of grouping genotypes based on a linear function of the genotype-environment interaction. Heredity 34: 255–263

Lin CS, Binns MR, Lefkovitch LP (1986) Stability analysis: where do we stand? Crop Sci 26: 894–900

SAS Institute (1985) SAS user's guide: statistics, 5 edn. SAS Institute, Cary/NC

Shukla GK (1972) Some statistical aspects of partitioning genotype-environmental components of variability. Heredity 29: 237–245

Steel RGD, Torrie JH (1980) Principles and procedures of statistics: a biometrical approach, 2nd edn. McGraw-Hill, New York

Wricke G (1964) The calculation of ecovalence in summer wheat and oat. Z Pflanzenzuecht 52: 127–138 (in Germany)