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A comparative evaluation of two methods of selecting locations used for testing spring wheat cultivars*

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Summary. One of the considerations of regional cultivar evaluation programs is to optimize the number of locations used for testing. Although optimization of numbers of locations using cluster analysis has been previously attempted, no objective comparison of methods has yet been made. A new clustering method that uses the pairwise contribution of locations to the cultivar × location mean square as the distance measure (LB) was compared to another method that employs diallel correlations as the distance measure (CL). Data from six spring wheat (*Triticum aestivum* L. em Thell) cultivars grown at 13 locations for five years were used in the initial cluster analysis. Another set of data, from a separate year, consisting of yields of the original 6 cultivars and a set of 12 independent cultivars was then used to check the validity of the original groupings and to compare the two methods. When the 6 original cultivars were considered, the LB technique was found to be superior to the CL. When the 12 independent cultivars were used, neither method was considered to be superior. Because of the lack of flexibility on the part of the LB method, neither technique could be deemed as fully adequate.

Key words: *Triticum aestivum* – Genotype – Environment interactions – Cluster analysis

Introduction

In practical terms cultivar × environment interactions generally result from the failure of differences between tested cultivars to remain consistent across environments. Cultivars may change in relative ranking from one environment to the next, and in some cases one cultivar may be significantly better adapted to a given environment than another (Baker 1988). In order to have some measure of cultivar × environment interactions and to identify situations in which differential adaptation may be contributing to the interactions, cultivar evaluation trials are normally conducted for multiple years at multiple locations. The amount of testing is usually in accordance with available funds, but it often becomes necessary to reduce testing in order to conserve resources. It is, however, difficult to determine which and how many locations are needed to obtain an adequate sample of regional environments, while at the same time preventing repetition of sites with similar environmental responses. If too few locations are chosen, the cultivars in the trials will not have been tested under the full range of conditions prevalent in the region. If too many locations are used, there is a risk of redundancy and wastage of resources.

Some of the early methods of optimizing the number of locations used for testing did not indicate which of the original locations should be retained in the resulting subset (Rasmusson and Lambert 1961). Decisions concerning optimum location numbers were based on the precision of cultivar means averaged over years and locations. This practice is somewhat misleading, because the use of overall means fails to recognize the presence of cultivar × environment interactions. If the interaction structure of the original experiment is ignored, the resultant subset of locations should be considered as having been selected essentially at random. Depending on the nature of the locations and the magnitude of the cultivar × environment interactions, the use of random or unstructured subsets of locations can be very deceptive. The

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locations chosen could represent multiple replications of a single environmental response type or single replications of multiple environmental response types (Lin and Butler 1988).

Campbell and Lafever (1977) used Guitards' (1960) diallel correlations as a distance measure and grouped locations using cluster analysis. The method was originally proposed as a means of representing locational similarities, but can easily be extended and used as a means of removing locations with similar responses. Lin and Butler (1988) developed a post-mortem approach to evaluate which and how many locations should be used in a cultivar testing program. The method is based on two complementary procedures, the first of which determines the number of locations that are required to generate the interaction structure of the sampled regions. The second is a clustering procedure that groups locations into subsets, within which cultivar × location (C × L) interactions are homogeneous. The number of groups from which individual locations can be chosen is based on the optimum location number determined in the first step. The intended result of the process is the elimination of redundant locations. Lin and Butler (1988) purport that the interaction structure of the original experiment is maintained, which should ensure the ability of the testing program to identify differentially adapted cultivars.

The two methods of grouping locations, both based on cluster analysis, have not previously been compared. Furthermore, it has not been determined if the small subset of broadly adapted check cultivars used in the initial analysis generates a result that is applicable to future years of testing with other previously untested cultivars.

The primary purpose of this study was to compare the utility of the two clustering techniques and to determine if they are sufficiently flexible to allow changes in the trial entries. Data generated from spring wheat (*Triticum aestivum* L. em Thell) cultivars grown at locations used in the 1983–1987 and 1989 Manitoba Crop Variety Trials will provide the basis for comparison.

Materials and methods

Yield data from 12 wheat cultivars were obtained from the Manitoba Crop Variety Trials conducted under the Canada-Manitoba AgriFood Agreement by the University of Manitoba. Results from the years 1983–1987 were used to establish clusters of locations, and other data from 1989 was used in the comparative evaluation. The wheat cultivars used in the analysis of the 1983–1987 data were: 'HY320', 'Glenlea', 'Neepawa', 'Columbus', 'Benito' and 'Katepwa'. The entries are planted on the majority of spring wheat acreage in Manitoba and represent a range of response types. 'HY320' is a high yielding semidwarf wheat from the Canada Prairie Spring class, and 'Glenlea' is a high yielding cultivar from the Utility Wheat class. The latter four entries are representative of cultivars from the Hard Red Spring class. For the 1989 data, two sets of cultivars were used. The first set contained the same cultivars as those from the 1983–1987 data (hereafter known as "checks"), and the second group contained 12 breeding line (hereafter known as "independent") and cultivars that had recently been entered into the trials. The independent entries were: 'Kenyon', 'Laura', 'Oslo', 'Roblin', 'BW114', 'BW120', 'BW122', 'BW125', 'BW606', 'BW618', 'HY355', and 'HY368'.

Table 1. Summary of locations used for testing wheat cultivars in the Manitoba Crop Variety Trials

Location	Agroclimatic Zone	Abbreviation
Waskada	1	Was
Mariapolis	2A	Mar
Shoal Lake	2	Sho
Brandon	2	Bra
Portage	3A	Por
Bagot	3A	Bag
Glenlea	3	Gle
Dauphin	3	Dau
Beausejour	4	Bea
Teulon	4	Teu
Vita	4	Vit
Roblin	5	Rob
Swan River	5	Swa

The 13 locations used in the analysis and their agroclimatic zones are summarized in Table 1. Zonation was based on the number of growing degree days (5 °C base), average frost-free days and relative water deficit. A randomized complete block design, with four replications, was used at each location. Plots consisted of four rows, 5 m long with 30 cm between rows. The seeding rate was approximately 60 kg ha^{-1} at each location. Seeding was completed during the first 2 weeks of May in each year. Fertilizer was applied according to soil test recommendations, and weeds were controlled by hand. The center two rows of each plot were harvested by hand, bagged, dried and then threshed to determine seed yield of each plot.

Both analyses proposed by Lin and Butler (1988) were conducted using C × L means averaged over years, as recommended for situations in which the cultivar × year × location interaction in the analysis of variance was found to be significant. The first procedure involved calculation of the largest possible cultivar × environment interaction for each number (i.e., from 2 to 13) of locations in the data set. Once these mean squares had been calculated, the particular locations that produced that largest mean square were found by inspection of the calculations. This largest value was calculated backward, starting with 13 locations and working back stepwise to 2 locations. The maximum C × L mean square for each number of locations was expressed as a percentage of the maximum C × L mean square for 2 locations, then plotted against the corresponding number of locations from 2 to 13. The optimum number of locations is then determined by inspection of the resultant curve (see Fig. 1). The point at which the rate of decrease in the C × L mean square appears to have stabilized near a minimum is used as the putative optimum.

The second step in the Lin and Butler (1988) procedure groups the locations using Sokal and Michener's (1958) unweighted pair group method and a clustering algorithm that has been described by Lin (1982). More flexibility in location selection is allowed in this second step than the first. The dissimilarity matrix resulting from the calculation of the size of the contribution of each pair of locations to the overall C × L mean square

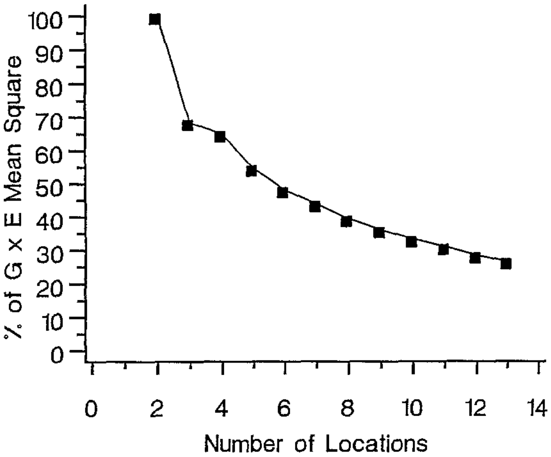

Fig. 1. The largest C × L mean square for each number of locations expressed as a percentage of the largest mean square for two locations

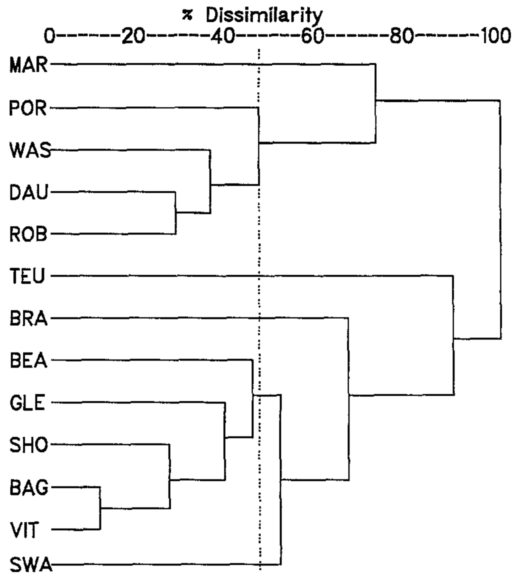

Fig. 2. The dendrogram from the Lin and Butler (1988) cluster analysis

was used to provide the measures of distance for the clustering procedure. Dissimilar locations were defined as those for which responses over cultivars were non-parallel. The clustering portion of the analysis was performed using a computer program (S116) developed by the Statistical Research Section of Agriculture Canada (Lin 1988). The demarcation line in the dendrogram used to create the groups of locations (as in Fig. 2 and 3) was defined by the optimum location number found in step one. One location was then chosen at random from each cluster and used to form the subset used for the comparison.

In order to group locations in a manner similar to that proposed by Campbell and Lafever (1977), correlation coefficients (r) were first calculated between all possible pairs of locations using C × L means averaged over years. Cluster analysis was then performed with the Cluster procedure of the Statistical Analysis System using the average linkage method and 1-r as the distance measure (SAS 1985). Since no stopping criterion was given by Campbell and Lafever (1977), and to facilitate an objective comparison, the number of groups from within which locations were to be selected was the same as that determined in the Lin and Butler (1988) analysis. Locations were again chosen at random from within each cluster and used to form the subset used in the comparison.

The comparison of methods was undertaken using data from the 1989 trial and two distinct sets of entries. The first set of entries contained the original 6 check cultivars and the second 12 independent cultivars. Cultivar × location mean squares were calculated for the check, and independant entries using the locations that were chosen with each of the two clustering procedures. These C × L mean squares were then compared to the mean square for the locations giving the maximum C × L interaction. If the cluster and maximum C × L mean squares were similar, then the clustering procedure was judged to be an effective means of creating a subset of locations with heterogeneous response types. The clustering method with the largest C × L mean square, relative to the maximum for that number of locations, would be considered the most effective. The validity of this evaluation rests on the fact that the particular locations giving the maximum C × L mean square represent the most heterogeneous set of response types for a given number of locations. This heterogeneity is the reason for multilocation testing and must be adequately sampled. Therefore, it assumed that any procedure designed to create groups, within which response types are homogeneous and among which they are heterogeneous, must yield a subset of locations with a C × L mean square similar to that of the maximum, if it is to be judged as effective. The comparison is based on a single year, therefore it may be affected by bias in the C × L mean square resulting from the presence of C × Y × L interactions.

Results and discussion

The analysis of variance of the 1983–1987 wheat data indicated that the cultivar × location, cultivar × year, and cultivar × location × year interactions were all highly significant. Inspection of the curve generated by the first stage of the Lin and Butler (1988) grouping procedure (Fig. 1) did not clearly indicate an optimum number of locations. Given the general objective of substantially reducing the number of locations and the results of the first stage of the grouping procedure, it was decided arbitrarily to use 7 locations as an approximate optimum. Therefore, seven groups were also used as the demarcation point on the dendrogram (Figs. 2 and 3). The absence of an objective means of choosing this optimum number is a weakness associated with this and Campbell and Lafever's (1977) method of reducing numbers of locations.

The following 7 locations were derived from the selection of 1 location from each cluster resulting from the Lin and Butler (1988) analysis of the 1983–1987 data: Bea, Bra, Dau, Mar, Por, Swa and Teu (Fig. 2). Campbell and Lafever's (1977) method identified these 7 locations using the same data set: Bag, Bea, Dau, Gle, Mar, Vit, Was (Fig. 3). Neither of the two cluster analyses grouped the locations in a manner that appeared to be related to their agroclimatic zonation or geographic location. Therefore,

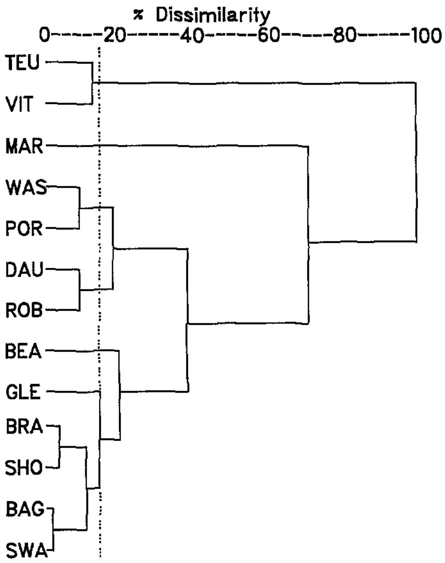

Fig. 3. The dendrogram from the Campbell and Lafever (1977) cluster analysis

both distance measures result in clusters that are probably related more to micro- rather than macro-environmental differences amongst locations. Analysis of variance of the Lin and Butler (1988) and Campbell and Lafever (1977) groups showed that for the first method 72%, and for the second 48% of the C × L interaction sums of squares were accounted for by the cultivar × group interaction. This result suggests that the Lin and Butler (1988) clustering procedure more effectively grouped locations in such a way that the largest portion of the C × L interaction occurred among rather than within groups.

The 7 locations from the 1989 data that gave the maximum C × L mean square for the 6 check cultivars and the independant set of 12 cultivars were as follows: Bra, Dau, Gle, Mar, Por, Teu, Vit. For the set of check cultivars, the C × L mean squares found using Lin and Butler (1988) grouping procedure compared well to the maximum C × L mean squares (Table 2). The ratio between the group and maximum C × L mean squares was 14.1% smaller for Campbell and Lafever's (1977) method than for Lin and Butlers' (1988) method. This result shows that Lin and Butlers' (1988) method of clustering is a superior means of selecting locations because the grouping better reflected heterogeneity of response among locations. When the same analysis was applied to the set of 12 independant cultivars the difference between the two methods was only 5.8%. In this latter case neither of the methods could be judged as substantially better than the other. If contributions to the C × L interaction are an intrinsic component of a given location, as is assumed by Lin and Butlers' (1988) analysis, then changes in the cultivars under test should not influence the efficacy of the grouping procedure. The problem is

Table 2. Cultivar × location (C × L) mean squares from 1989 data obtained using the two clustering procedures (C × L cluster) and the maximum possible C × L mean square for seven locations (C × L max)

Source	L and B[b]		C and L[d]	
	Check	Independent	Check	Independent
	Mean square[c]			
C × L cluster	224,407	269,287	184,994	248,757
C × L max	277,751	353,916	277,751	353,916
Ratio[a]	80.7	76.1	66.6	70.3

[a] (C × L cluster/C × L max) × 100
[b] Cluster C × L mean square based on Lin and Butler (1988) cluster analysis
[c] Check $df = 30$; independant $df = 66$
[d] Cluster C × L mean square based on Campbell and Lafever (1977) cluster analysis

that cultivar testing programs are dynamic, and changes in the entries are a normal part of the testing process. Therefore, any method of grouping locations must be sufficiently flexible to allow changes in the trial entries. Given this observation, either method would work equally well for reducing numbers of locations used for testing spring wheat cultivars in Manitoba. The ratio between the group C × L mean square and the maximum was low for both methods when the independant set of cultivars was used, but may still be better than could be expected using a completely random selection of locations.

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