Theor Appl Genet (1985) 71:22–25

Evaluation of cultivar-testing locations in sugarcane *

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Received October 30, 1984; Accepted February 9, 1985
Communicated by G. S. Khush

Summary. Selection of test locations, representative of conditions and practices of an area can be a challenging process in a breeding program. Data from two groups of sugarcane (trispecies hybrids of *Saccharum* sp.) cultivar experiments in Florida were analyzed to determine if relative cultivar response at any two of six current locations was sufficiently similar so that at least one location could be replaced by a location with a different environment. The parameter analyzed was metric tons per ha of sugar (THS). To determine similarity between location pairs for all cultivars within each group of cultivars, an unbiased stability-variance parameter ($\hat{\sigma}_i^2$) developed by Shukla was used. After $\hat{\sigma}_i^2$ identified similar location pairs, single degree of freedom interactions were calculated for important cultivars to determine which of the location pairs identified by $\hat{\sigma}_i^2$ contained the two most similar locations. Use of the above procedure can assist in making optimum location assignments in a breeding program.

Key words: Cultivar × environment interactions – Stability-variance parameter – Single degree of freedom interaction – *Saccharum* sp.

Introduction

Selection of test locations for cultivar evaluation can be a challenging process in a sugarcane (*Saccharum* sp.) breeding program. The primary criterion in choosing a location should be that the location is representative of conditions and practices of the area served by the cultivar-testing program. As suggested by Busey (1983), genotypes may respond differently across locations, thus it is important to select locations which represent all major conditions and practices being served by the program. In many cultivar-evaluation programs, economic constraints do not permit such a complete location representation.

Organizations may try to initiate a cultivar-evaluation program by selecting locations with as wide a range as possible of representative environmental conditions, cultural practices, and hence, yield levels. However, after data become available, location assignments should be refined by making overall location yield level a secondary consideration and relative cultivar performance among locations the primary consideration. It may be more valuable for a cultivar-evaluation program to include two locations with similar overall yield levels but with differences in relative yields among cultivars than to include two locations with different overall yield levels but similar relative yields among cultivars. Brown et al. (1983) indicated two ways of improving the efficiency of large-scale breeding programs; viz., 1) to classify nursery environments into homogeneous groups for germplasm exchange, and 2) to make selections based on data from environments that are optimal for selection. They described such an environment as one in which: 1) the trait is expressed, 2) genetic variance is maximized, 3) environmental and genotype × environmental variance is minimized, 4) the growing region of the entries included in the test is accurately represented, 5) the environment is accessible for efficient and inexpensive testing of entries, and 6) conditions 1 through 5 are consistent over years.

The Florida sugarcane industry has recently expanded into areas with environmental conditions different from the current locations used in the cultivar-evaluation program. Thus, to include locations which are representative of a large portion of the areas and practices being served by the program, we felt that a location change may have been needed. We wanted to discover if we could replace at least one of six of our current locations where relative cultivar performance was similar to that of another location.

The purpose of this study was to identify a procedure which could evaluate locations in a breeding

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program relative to each other. A recent study by Kang and Miller (1984) compared three methods of partitioning genotype×environment interactions into stability-variance components assignable to each cultivar in sugarcane. We felt that the unbiased stability-variance parameter ($\hat{\sigma}_i^2$) of Shukla (1972) could be used as a first step to evaluate similarity among locations. Thereafter, single degree of freedom interactions could be used to determine the location pairs identified by $\hat{\sigma}_i^2$ with the most similar information for the tested cultivars.

Materials and methods

Previously published results from two groups of sugarcane cultivar trials conducted in Florida were analyzed in this study (Glaz et al. 1980, 1981, 1982; Rice 1979). The first group of 12 cultivars (CP 74 series) was planted in the fall of 1977 at six locations and harvested as the plant crop from November 1978 to March 1979, and as first- and second-ratoon crops in the two subsequent harvest seasons. The planting and harvesting of the 12 cultivars in the second group (CP 75 series) occurred one year after planting and harvesting of the first group of cultivars. Comparisons for locations from the CP 74 series were only made through the first-ratoon crop, due to missing data in the second-ratoon crop. All cultivars between groups were different except for 'CP 63-588', the reference cultivar used in each group.

Experiments were planted at A. Duda and Sons (Duda); Hatton Bros., Inc. (HT), Gulf and Western Food Products Co. at Okeelanta (OK), A. F. Saunders, Inc. (SAU), S. D. Corp. (SD), and Wedgworth Farms, Inc. (WED). All experiments were conducted on Terra Ceia, Pahokee, or Lauderhill muck; all organic soils with the only documented difference being depth of organic soil (Snyder et al. 1978). The field plot design at each location was a randomized complete block with four replications. Each plot consisted of four rows, 9.1 m long with 1.5 m between rows. A 1.5 m alley separated the end of each plot from the beginning of the next plot.

All cane was burned and then harvested by hand cutting. Fifteen full length stalks were taken at random from each plot for milling and crusher juice analysis. Total cane weight was measured from each plot with a tractor-mounted weighing device. Results reported herein are metric tons per ha of sugar (THS). All THS values were theoretical and calculated by using Arceneaux's modification of the Winter-Carp-Geerlig formula (Arceneaux 1935).

For each cultivar series and crop, data from all six locations were combined and analyzed as split plots with locations as whole plots and cultivars as subplots. The unbiased stability-variance parameter was calculated for each location in the plant-cane and ratoon crops according to equation number 11 of Shukla (1972). The only change made was that of interchanging locations and cultivars. The formula was as follows:

$$\hat{\sigma}_i^2 = [1/(s-1)(t-1)(t-2)] \times [t(t-1) \sum_j (Uij - \bar{U}i.)^2 - \sum_i \sum_j (Uij - \bar{U}i.)^2]$$

where $Uij = Yij - \bar{Y}.j$, $\bar{U}i = \Sigma j\, Uij/s$; s = number of cultivars, t = number of locations, Yij is the i^{th} location of the j^{th} cultivar, and Y.j is mean of all locations for the j^{th} cultivar. Significance tests of the individual $\hat{\sigma}_i^2$'s for locations were calculated as described by Shukla (1972) and Kang and Miller (1984). ($F^* = \hat{\sigma}_i^2/\hat{\sigma}_0^2$ where F* will have an approximate F distribution with (s − 1) and st (r − 1) degrees of freedom. $\hat{\sigma}_0^2$ = Error Mean Square (Error b) from the split-plot analysis of variance and r = replications.)

To determine which locations had the most similar $\hat{\sigma}_i^2$, locations were compared two at a time in all possible combinations in each crop for each group of cultivars. The absolute values of the differences in $\hat{\sigma}_i^2$ for each pair were then summed for all crops for both groups of cultivars.

The above method identified three location pairs where the locations within each pair yielded similar enough data for all cultivars combined to warrant further investigation. To determine which of the above three location pairs consisted of the most similar locations and to obtain information for "important cultivars" isolated from the average of all cultivars, single degree of freedom interactions were calculated according to procedures described by Steel and Torrie (1960). ("Important cultivars" were those which were already released commercially or had a good chance of being released.) An example of a single degree of freedom interaction analyzed is: HT vs. OK×'CP 63-588' vs. 'CP 74-2005'. The Error b term from the split-plot was used as the pooled variance in testing significance of all single degree of freedom interactions.

Results and discussion

For all crops and both groups of cultivars, all F values for cultivar×location interaction were significant (Table 1). In addition, most of the $\hat{\sigma}_i^2$'s for separate locations were significant. The only $\hat{\sigma}_i^2$ values which were not significant in the CP74 series were for Duda in plant crop; HT, OK, and SD in first ratoon, and HT and SD in second ratoon. The $\hat{\sigma}_i^2$ values not significant in the CP75 series were for WED, SD, and SAU in plant crop, first ratoon, and second ratoon, respectively. Thus, in general, there was significant differentiation among cultivars at each of the six locations. If there had been at least two locations that did not have significant $\hat{\sigma}_i^2$ values most of the time, then the analysis could have ended at that point, and one of those locations could have been replaced. Both locations would not have been replaced since they would still have been representative of yield levels and practices used by growers in a large portion of the area served by our breeding program.

Since all locations had mostly significant $\hat{\sigma}_i^2$ values, it was necessary to determine which locations had the most similar $\hat{\sigma}_i^2$'s. Table 2 shows all location pair possibilities and the sum of their $\hat{\sigma}_i^2$ differences from all crops for cultivars from the CP74 and CP75 series. The $\hat{\sigma}_i^2$ differences for OK vs. SAU, OK vs. SD, and HT vs. OK were the lowest.

A logical decision at this point would have been to have a new location replace OK because it was one of the locations in all three of the most similar location pairs. However, to carry out this analysis completely, let us assume that it would not be practical to replace OK. Thus, an analysis is needed to differentiate the three

Table 1. Stability-variance parameter ($\hat{\sigma}_i^2$) for THS by location and crop for two series of sugarcane cultivars

Location	Crop		
	Plant	First-ratoon	Second-ratoon
	CP 74 Series		
Duda	2.75	9.14**	10.57**
HT	6.51**	2.67	2.58
OK	7.03**	1.63	–
SAU	11.74**	4.14*	4.94**
SD	4.43**	2.48	2.01
WED	3.27**	15.25**	8.16**
F value for Cultivar × location	3.10**	2.66**	3.63**
Error mean square	1.52	2.26	1.56
	CP 75 Series		
Duda	6.93**	13.78**	7.97**
HT	11.21**	15.94**	9.62**
OK	9.97**	6.09**	4.90*
SAU	9.53**	8.62**	1.64
SD	6.22**	4.62	12.33**
WED	3.25	5.77*	9.40**
F value for Cultivar × location	3.81**	3.37**	2.95**
Error mean square	2.06	2.71	2.59

*, ** Significance at the 0.05 and 0.01 levels, respectively. Stability-variance parameter significance corresponds to values of F which are not shown

Table 2. Sums of absolute values of $\hat{\sigma}_i^2$ differences from all location pairs for the cultivars from the CP 74 series and CP 75 series

Location comparison	Sum of CP 74 series and CP 75 series differences[a] THS
OK vs. SAU	13.45
OK vs. SD	16.10
HT vs. OK	17.37
Duda vs. HT	18.32
Duda vs. WED	19.76
SD vs. WED	20.98
HT vs. SD	21.29
Duda vs. SD	22.57
HT vs. SAU	23.68
Duda vs. OK	25.59
SAU vs. SD	26.97
Duda vs. SAU	28.08
OK vs. WED	28.92
HT vs. WED	34.17
SAU vs. WED	36.47

[a] The differences in plant-crop and first-ratoon crop $\hat{\sigma}_i^2$ values from each location pair for the cultivars in the CP 74 series were summed with the differences in plant-crop, fist-ratoon crop, and second-ratoon crop $\hat{\sigma}_i^2$ values from each location pair for the cultivars in the CP75 series

Table 3. Values of F of important single degree of freedom interactions for THS of cultivar and location comparisons from the CP 74 series of sugarcane cultivars

Cultivar comparison	Location comparison		
	HT vs. OK	OK vs. SAU	OK vs. SD
Plant crop	Value of F		
'CP 63-588' vs. all other cultivars	1.57	3.39	0.79
'CP 74-1188' vs. all other cultivars	1.69	2.99	0.02
'CP 74-2005' vs. all other cultivars	3.43	3.66	1.96
'CP 63-588' vs. 'CP 74-1188'	1.42	0.01	0.48
'CP 63-588' vs. 'CP 74-2005'	0.11	0.00	0.12
'CP 74-1188' vs. 'CP 74-2005'	2.54	0.01	1.08
First-ratoon crop			
'CP 63-588' vs. all other cultivars	0.50	0.00	0.00
'CP 74-1188' vs. all other cultivars	2.83	0.97	0.05
'CP 74-2005' vs. all other cultivars	2.17	2.04	4.01*
'CP 63-588' vs. 'CP 74-1188'	0.43	0.51	0.03
'CP 63-588' vs. CP 74-2005'	0.27	0.85	1.96
'CP 74-1188' vs. 'CP 74-2005'	0.27	2.67	1.45

* Significance at the 0.05 level

similar location pairs. Single degree of freedom interactions were used for this purpose. Even if only one location pair had been identified by $\hat{\sigma}_i^2$, single degree of freedom interaction analysis would still have been advisable to verify that the similarity indicated by $\hat{\sigma}_i^2$ was true on a cultivar by cultivar basis and not just a coincidental similarity of averages of all cultivars.

Results of the single degree of freedom interactions for the CP74 and CP75 series are shown in Tables 3 and 4, respectively. There were very few significant interactions and many values of F were approximately zero. Thus, the important individual cultivars analyzed for each location pair reacted similarly to the average of all the cultivars analyzed with $\hat{\sigma}_i^2$. There were no decisive differences among the three location pairs. HT vs. OK, OK vs. SAU, and OK vs. SD had 6, 4, and 2 significant interactions with cultivar comparisons, respectively. These data show that a location from any pair or even from two of the pairs could be replaced without appreciable loss of data.

Before initiating this study, we felt reasonably certain, based on our perceptions of environment, farming practices, and yield levels, that the choice for a replaceable location would come from DUDA, HT, SD or WED. This emphasizes the point made earlier that although when beginning a breeding program, location choices must usually be made by using yield level as a major criterion, after a program is in place, location choices should be refined according to cultivar × location analyses.

Table 4. Values of F of important single degree of freedom interactions for THS of cultivar and location comparisons from the CP 75 series of sugarcane cultivars

Cultivars comparison	Location comparison		
	HT vs. OK	OK vs. SAU	OK vs. SD
Plant crop	Value of F		
'CP 63-588' vs. all other cultivars	0.46	1.74	0.09
'CP 63-588' vs. 'CP 75-1082'	3.08	0.65	0.05
'CP 63-588' vs. 'CP 75-1091'	0.16	1.57	0.00
'CP 63-588' vs. 'CP 75-1553'	0.30	7.12**	0.09
'CP 63-588' vs. 'CP 75-1632'	2.06	0.95	0.39
'CP 75-1082' vs. 'CP 75-1091'	1.83	0.20	0.07
'CP 75-1082' vs. 'CP 75-1553'	5.32*	3.46	0.26
'CP 75-1082' vs. 'CP 75-1632'	0.10	0.45	0.71
'CP 75-1091' vs. 'CP 75-1553'	0.91	2.00	0.07
'CP 75-1091' vs. 'CP 75-1632'	1.06	0.08	0.34
'CP 75-1553' vs. 'CP 75-1632'	3.94	2.87	0.11
First-ratoon crop			
'CP 63-588' vs. all other cultivars	2.70	2.29	0.28
'CP 63-588' vs. 'CP 75-1082'	0.15	0.36	0.38
'CP 63-588' vs. 'CP 75-1091'	0.65	0.20	0.02
'CP 63-588' vs. 'CP 75-1553'	2.02	5.70*	0.19
'CP 63-588' vs. 'CP 75-1632'	0.94	0.04	0.91
'CP 75-1082' vs. 'CP 75-1091'	0.18	1.10	0.23
'CP 75-1082' vs. 'CP 75-1553'	3.25	8.22**	1.10
'CP 75-1082' vs. 'CP 75-1632'	0.35	0.65	0.11
'CP 75-1091' vs. 'CP 75-1553'	4.97*	3.30	0.33
'CP 75-1091' vs. 'CP 75-1632'	0.03	0.06	0.66
'CP 75-1553' vs. 'CP 75-1632'	5.73*	4.24*	1.92
Second-ratoon crop			
'CP 63-588' vs. all other cultivars	2.83	0.01	1.46
'CP 63-588' vs. 'CP 75-1082'	11.26**	0.03	0.27
'CP 63-588' vs. 'CP 75-1091'	2.71	0.05	0.21
'CP 63-588' vs. 'CP 75-1553'	2.90	0.18	1.54
'CP 63-588' vs. 'CP 75-1632'	5.57*	0.69	0.68
'CP 75-1082' vs. 'CP 75-1091'	2.92	0.16	0.95
'CP 75-1082' vs. 'CP 75-1553'	2.73	0.36	3.11
'CP 75-1082' vs. 'CP 75-1632'	0.93	1.03	0.09
'CP 75-1091' vs. 'CP 75-1553'	0.00	0.04	0.62
'CP 75-1091' vs. 'CP 75-1632'	0.51	0.37	1.64
'CP 75-1553' vs. 'CP 75-1632'	0.43	0.17	4.28*

*, ** Significance at the 0.05 and 0.01 levels, respectively

As the acreage of a crop expands to areas with different growing conditions, a breeding program serving that crop must be able to make appropriate changes in order to continue selecting successful cultivars. For breeding programs with fixed resources, it is often not feasible to simply add new locations as commercial acreage increases. Under these circumstances, when it is felt that a new test location is necessary, a current test location must be replaced. If data show that cultivars are being sufficiently differentiated at all locations, then it becomes necessary to determine if the differentiation is similar at at least two locations. As a last step, it may be necessary to determine at which location pairs is the cultivar differentiation almost similar. To assist in making the above decisions, the combined use of $\hat{\sigma}_i^2$ and single degree of freedom comparisons is useful.

References

Arceneaux G (1935) A simplified method of making theoretical sugar yield calculations. In accordance with the Winter-Carp-Geerligs formula. Int Sugar J 37:264–265

Brown KD, Sorrells ME, Coffman WR (1983) A method for classification and evaluation of testing environments. Crop Sci 23:889–893

Busey P (1983) Management of crop breeding. In: Wood DR (ed) Crop breeding. Am Soc Agron, Madison Wis

Glaz B, Dean JL, Kang MS, Miller JD, Sosa O Jr, Tai PYP (1981) Sugarcane variety tests in Florida, 1980/81 harvest season. USDA-ARS, New Orleans, 18 pp

Glaz B, Dean JL, Kang MS, Miller JD, Tai PYP, Sosa O Jr (1982) Sugarcane variety tests in Florida, 1981/82 harvest season. USDA-ARS, New Orleans, 21 pp

Glaz B, Dean JL, Miller JD, Tai PYP (1980) Sugarcane variety tests in Florida, 1979/80 harvest season. USDA-ARS, New Orleans, 17 pp

Kang MS, Miller JD (1984) Genotype × environment interactions for cane and sugar yield and their implications in sugarcane breeding. Crop Sci 24:435–440

Rice ER (1979) Sugarcane variety tests in Florida, 1978/79 harvest season. US Sci Educ Admin, New Orleans, 16 pp

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

Snyder GH, Burdine HW, Crockett JR, Gascho GJ, Harrison DS, Kidder G, Mishoe JW, Myhre DL, Pate FM, Shih SF (1978) Water table management for organic soil conservation and crop production in the Florida Everglades. Univ Fl Inst Food Agric Sci Tech Bull 801, 22 pp

Steel RGD, Torrie JH (1960) Principles and procedures of statistics. McGraw-Hill, New York