EFFECT OF INTRAROW PLANT SPACING ON THE EFFECTIVENESS OF FAMILY SELECTION IN SUGARCANE: SELECTION INDICES

Orlando De Sousa-Vieira and Scott B. Milligan

SUMMARY

*Cross prediction trials or progeny tests for family selection are commonly employed at the beginning of each breeding cycle in clonally propagated crops such as sugarcane (*Saccharum *spp. Hybrid). When selecting sugarcane families, the factors affecting variability between and within those families should be considered. This research examined the influence of family and intra-row plant spacing on the efficiency of the index selection procedure as a method of simultaneous improvement of a population for multiple traits at the first selection stage of the Louisiana Sugarcane Variety Development Program (LSVDP). Therefore, the main objective of this study was to develop a selection index for selecting sugarcane families within the LSVDP. Expected genetic advance values for plant weight were greater in the wide-spaced indices than in the narrow-spaced ones. Irrespective of plant spacing, selection indices revealed that an increase in efficiency was observed over direct selection for plant weight when all four plant weight contributing traits were included along with plant weight. The efficiency in selection tended to decrease when indices were based on fewer traits. Nevertheless, a few of the indices that included two traits had relative efficiencies comparable to the best indices and the majority certainly was as effective as direct selection for plant weight.*

EFECTO DE LA DISTANCIA ENTRE PLANTAS EN LA EFICIENCIA EN LA SELECCIÓN DE FAMILIAS DE CAÑA DE AZÚCAR: ÍNDICES DE SELECCIÓN

Orlando De Sousa-Vieira y Scott B. Milligan

RESUMEN

*Las pruebas de progenie son comúnmente utilizadas para la selección de familias en cultivos de reproducción asexual como la caña de azúcar (*Saccharum *spp. Híbrido). En la selección de familias de caña es importante considerar los factores que afectan la variabilidad existente, no solo entre familias, sino también dentro de cada familia. Se examinó la influencia de familias y del espacio entre plántulas de caña de azúcar en la eficiencia del índice de selección como una metodología para mejorar simultáneamente una población por múltiples características. El trabajo se llevó a cabo en la etapa inicial del Programa de Desarrollo de Variedades de Caña de Azúcar de Louisiana, EEUU (LSVDP, por sus siglas en inglés). El objetivo principal fue desarrollar un índice para selección de familias de caña de azúcar dentro del LSVDP. El avance genético esperado para el peso de planta fue mayor en los índices obtenidos usando datos provenientes de familias donde la distancia entre individuos fue mayor. Independientemente de la distancia entre plántulas dentro de la hilera, los índices de selección donde intervinieron los cuatro componentes del carácter peso de planta, incluyendo a éste, resultaron ser más eficientes que la selección directa para ese mismo carácter. La eficiencia en la selección tendió a disminuir en la medida en que los índices contenían menos caracteres. Sin embargo, algunos de los índices que incluían solo dos caracteres mostraron eficiencias comparables a los mejores índices y la mayoría de ellos fueron más efectivos que la selección directa por peso de planta.*

Introduction

Most of the traits of primary importance in sugarcane are quantitative in nature and not highly heritable. Furthermore, when selecting for a primary trait such as cane yield, the selection is being done for several secondary traits that influence the primary trait rather than for the primary trait itself. The genetic and phenotypic associations between those secondary traits are of practical interest since selection for one trait will have a simultaneous effect on the related traits. Understanding that improvement of one trait may cause improvement or deterioration in associated trait(s) serves to highlight the need for simultaneous consideration of all traits that are important in a crop species (Baker, 1986). Because most breeding programs are concerned with simultaneous improvement of several traits, the selection index has become the best alternative, provided that reliable estimates of genetic and phenotypic variances and covariances are available and appropriate eco-

KEYWORDS / Clonal Propagation / Family Selection / Index Selection / Plant Breeding / *Saccharum* spp. /

Received: 10/31/2008. Modified: 11/16/2009. Accepted: 11/17/2009.

Orlando De Sousa-Vieira. Ph.D. Louisiana State University, USA. Researcher, Instituto Nacional de Investigaciones Agrícolas (INIA). Address: INIA, Apartado 25, San Felipe, Estado Yaracuy 3201, Venezuela. e-mail: odesousa@inia.gob.ve

Scott B. Milligan. Ph.D. Louisiana State University, USA. Former Professor, Louisiana State University. Former Researcher at United States Sugar Corp. and USDA. e-mail: scottmilligan@earthlink.net

EFEITO DO ESPAÇAMENTO ENTRE TOUCEIRAS NA EFICIÊNCIA NA SELEÇÃO DE FAMILIAS DE CANA-DE-AÇÚCAR: ÍNDICES DE SELEÇÃO

Orlando De Sousa-Vieira e Scott B. Milligan

RESUMO

*Ensaios de predição de cruzamentos o testes de progênie são comumente utilizados no início de cada ciclo de melhoramento genético das culturas de reprodução vegetativa como a cana-de-açúcar (*Saccharum *spp. Híbrido). Na seleção de famílias de cana-de-açúcar é importante considerar os fatores que afetam a variabilidade, não só entre as famílias, mais também dentro de cada família. Analisou-se a influência das famílias e do espaçamento entre plantas na eficiência do índice de seleção como uma metodologia para melhorar simultaneamente mais de uma característica em uma população. O trabalho foi feito na fase inicial do Programa de Desenvolvimento de Variedades de Cana-de-Açúcar de Louisiana, EEUU (LSVDP, por sua sigla em Inglês). Portanto, o principal objetivo foi desenvolver um índice para a seleção de famílias de cana-de-açúcar dentro do LSVDP. O ganho genético esperado para o peso da touceira foi maior nos índices obtidos a partir de dados de famílias onde a distancia entre indivíduos foi maior. Os resultados indicaram que, quando os quatro caracteres que contribuem para o peso da touceira foram incluídos, independentemente do espaçamento entre touceiras, os índices de seleção apresentaram aumento na eficiência na seleção, em comparação com a seleção direta para o peso da touceira. Á medida que os índices de seleção foram baseados em menos caracteres, a eficiência na seleção tendeu a diminuir. No entanto, alguns dos índices que incluía dois caracteres tiveran eficiências comparáveis a os melhores índices e certamente a maioria deles foram tão eficazes como a seleção direta para peso da touceira.*

nomic weights of each trait can be determined (Hallauer and Miranda, 1981; Milligan *et al*., 2003).

Since the early nineties the Louisiana Sugarcane Variety Development Program (LSVDP) has been using progeny appraisal data to identify sugarcane families with most potential to produce superior individuals. The LSVDP uses an initial 50% family selection and subsequent 20% individual selection within those families.

De Sousa-Vieira and Milligan (1999) examined intra-row plant spacing as a source of variation affecting the efficacy of progeny testing and family selection at the first selection stage of the LSVDP. They showed that intra-row plant spacing affects the variance and reliability of a trait. The work reported in this paper aimed to examine the interrelationships of cane yield components and the effect of intra-row plant spacing on the estimation of a selection index for selecting sugarcane families within the LSVDP.

Materials and Methods

The population and experimental methodology used herein have been described by De Sousa-Vieira and Milligan (1999, 2005), and was planned to simulate the initial family selection stage in a sugarcane breeding program. In brief, 25 bi-parental families were randomly selected. The progeny of those families were then transplanted to the field at two locations: the United States Department of Agriculture (USDA) Ardoyne Farm near Chacahoula, and the St. Gabriel Research Station, both in Louisiana State, USA. Individual plants from each cross were planted in a randomized complete block design using two blocks with a split plot treatment arrangement where the main plots were intra-row plant spacings of 41cm (standard at LSVDP) and 82cm on rows 1.8m apart. Subplots were families. Each subplot consisted of two rows with up to 16 seedlings in each row. Planting and data collection were done during two consecutive years at the same locations. Data were collected in first ratoon cane.

Millable stalk number per plant, stalk length, and mid-stalk diameter were recorded. Stalk length was measured from the stalk base to the first visible dewlap (leaf collar) of two random stalks for each plant. The same two stalks were measured for mid-stalk internode diameter using a caliper. Stalk weight was estimated (Miller and James, 1974; Gravois *et al*., 1991; Chang and Milligan, 1992) as the volume of the stalk assuming a perfect cylinder with specific gravity of one:

$$\text{Stalk weight} = d\pi r^2 L$$

where d: density ($1.0 gm\cdot cm^{-3}$), r: stalk radius (cm), and L: stalk length (cm). Plant weight was estimated as stalk weight times stalk number per plant.

Selection indices

To construct an optimum selection index, one needs the genotypic and phenotypic variances and covariances, and the relative economic values or weights of all traits (Kang, 1994). Symbolically, a selection index (I) takes the form

$$I = b_1X_1 + b_2X_2 + \ldots + b_nX_n$$

where X_i: observed phenotypic value of the i^{th} trait, and b: weight assigned to that trait in the selection index.

Selection indices were estimated as

$$\mathbf{b} = \mathbf{P}^{-1}\,\mathbf{G}\,\mathbf{a}$$

where **b**: vector of index coefficients, $\mathbf{P}^{-1}$: inverse of the phenotypic variance-covariance matrix, **G**: genotypic variance-covariance matrix, and **a**: vector of relative economic values or weights (Smith, 1936; Brim *et al*., 1959; Baker, 1986; Kang, 1994).

Using family mean data, covariance components between all possible pairs of traits were estimated. Mean product expectations are analogous to the mean squares expectations for the analysis of variance. Thus, estimates of phenotypic and genetic covariance components were derived in the same fashion as for variance components by using product moment method.

Genetic and phenotypic correlations on a family mean basis, between the traits, were computed as

$$r_{ij} = \sigma_{ij} / \sigma_i \sigma_j$$

where σ_{ij}: genetic or phenotypic covariance between traits i and j, σ_i: genetic or phenotypic standard deviation for trait i, and σ_j: genetic or phenotypic standard deviation for trait j.

Twenty-six indices were constructed for each intra-row plant spacing using different trait combinations. Selection indices were constructed according to Smith (1936), as illustrated by Brim *et al*. (1959). Plant weight was taken as the final product; therefore, a relative economic weight of one was assigned to plant weight and zero to all other traits.

Expected genetic advance (EGA) from selection was estimated (Brim *et al*., 1959; Miller *et al*., 1978; Kang, 1994) as

$$\text{EGA} = 0.795\left(\sum_{x=1}^{n} b_i \; G_i\right)^{1/2}$$

where 0.795: value corresponding to a selection intensity (k) of 50% assuming 200 families (standard procedure), b_i: phenotypic weights and G_i: genotypic variance-covariance. An index of relative efficiency (IRE) was estimated based on the assumption that the efficiency of EGA, when selection is based on plant weight alone, is 100. The index of relative efficiency only compares the predicted gain of an index to selection for plant weight alone within the same plant spacing.

Results and Discussion

Twenty-six different indices were constructed for each of the two intra-row spacings, and the estimated index relative efficiency (IRE) for each individual index was calculated (Table I). In each case, it was assumed that the top 50% of 200 sugarcane families would be selected, as is currently practiced in the LSVDP.

Expected genetic advance for plant weight was 0.502kg/plant for narrow spaced plants and 1.138kg/plant for wide spaced plants when selection was based on plant weight alone. This value is used as a basis for comparison of the relative efficiency of the indices (IRE). The IRE compared only within row spacing.

Expected genetic advance values for plant weight were greater in the wide-spaced indices than in the narrow-spaced ones. Ranking of the indices did not appear to be greatly affected by spacing; the best indices in wide-spaced plants were also the best indices in narrow-spaced plants. Even though spacing may not affect indices ranks, it might affect both family performance and individual selection effectiveness within a family.

The highest gain in expected genetic advance, both in narrow (121.91%), and wide (106.15%) intra-row plant spacings, was obtained when selection was based on Index 1, which incorporated information of all five traits. Indices 4 and 6 had the same expected genetic advance as Index 1 did for widely spaced families and was comparable to Index 1 for narrow spaced families. Index 4 did not include stalk diameter, and Index 6 did not include plant weight. The relatively high expected genetic advance for these two indices was probably due to the presence of intermediate variables that contain some information about the traits that were excluded. In Index 4, stalk weight was an intermediate variable which contained information about stalk diameter, and in Index 6 the information about plant weight is contained in the genotypic covariances of plant weight and all the other traits.

TABLE I
EXPECTED GENETIC ADVANCE (EGA) IN PLANT WEIGHT FROM THE USE OF VARIOUS SELECTION INDICES AND THEIR RELATIVE EFFICIENCY (IRE) IN SUGARCANE FAMILY SELECTION AT TWO INTRA-ROW PLANT SPACINGS

		Index coefficients						
Index	Spacing	Stalk number	Stalk length	Stalk diameter	Stalk weight	Plant weight	EGA (kg)	IRE* (%)
	Narrow					1.000	0.502	100.00
	Wide					1.000	1.138	100.00
1	Narrow	-0.089	0.028	-0.068	2.153	0.202	0.612	121.91
	Wide	0.190	0.033	0.059	8.246	-0.084	1.208	106.15
2	Narrow		0.023	-0.129	4.456	0.069	0.611	121.71
	Wide		0.050	0.204	1.585	0.187	1.202	105.62
3	Narrow	-0.009		-0.464	10.674	0.116	0.606	120.72
	Wide	0.260		-0.360	17.329	-0.150	1.120	105.80
4	Narrow	-0.099	0.032		0.780	0.215	0.611	121.71
	Wide	0.195	0.029		9.417	-0.091	1.208	106.15
5	Narrow	-0.115	0.034	0.027		0.241	0.611	121.71
	Wide	0.116	0.058	0.409		0.038	1.205	105.89
6	Narrow	0.026	0.024	-0.135	5.069		0.610	121.51
	Wide	0.148	0.036	0.091	6.539		1.208	106.15
7	Narrow			-0.463	10.773	0.102	0.606	120.72
	Wide			-0.474	13.904	0.248	1.192	104.75
8	Narrow		0.031		2.123	0.064	0.610	121.51
	Wide		0.038		5.258	0.187	1.202	105.62
9	Narrow		0.037	0.104		0.067	0.608	121.12
	Wide		0.055	0.286		0.192	1.202	105.62
10	Narrow		0.027	-0.103	4.344		0.609	121.31
	Wide		0.060	0.204	3.382		1.196	105.10
11	Narrow	0.063			5.037	0.135	0.555	110.56
	Wide	0.340			12.763	-0.145	1.192	104.75
12	Narrow	-0.341		-0.161		0.857	0.541	107.77
	Wide	0.012		0.110		0.646	1.142	100.35
13	Narrow	0.053		-0.465	11.620		0.606	120.72
	Wide	0.189		-0.359	15.381		1.203	105.71
14	Narrow	-0.138	0.034			0.282	0.611	121.71
	Wide	-0.117	0.044			0.475	1.185	104.13
15	Narrow	0.020	0.032		2.567		0.609	121.31
	Wide	0.150	0.030		8.195		1.207	106.06
16	Narrow	0.012	0.040	0.126			0.607	120.92
	Wide	0.133	0.059	0.434			1.205	105.89
17	Narrow				4.248	0.238	0.554	110.36
	Wide				5.684	0.436	1.168	102.64
18	Narrow			0.059		0.428	0.505	100.60
	Wide			0.098		0.660	1.142	100.35
19	Narrow			-0.517	12.400		0.602	119.92
	Wide			-0.666	19.941		1.179	103.60
20	Narrow		0.036			0.123	0.601	119.72
	Wide		0.040			0.416	1.177	103.43
21	Narrow		0.033		2.456		0.608	121.12
	Wide		0.048		7.060		1.194	104.92
22	Narrow	-0.210				0.660	0.531	105.78
	Wide	-0.055				0.741	1.140	100.18
23	Narrow	0.136			6.119		0.554	110.36
	Wide	0.272			10.896		1.191	104.66
24	Narrow	0.221		0.272			0.408	81.27
	Wide	0.467		0.660			1.078	94.73
25	Narrow	-0.011	0.044				0.594	118.33
	Wide	0.005	0.081				1.117	98.15
26	Narrow		0.041	0.123			0.607	120.92
	Wide		0.072	0.385			1.195	105.01

*The index relative efficiency (IRE) compares the predicted gain of an index to selection for plant weight alone within the same plant spacing.

The range of index relative efficiency for the twenty-six indices was between 81.32 and 121.76% for narrow intra-row plant spacing and between 94.75 and 106.15% for wide intra-row plant spacing. As a general rule, expected genetic advance increased over selection for plant weight alone, when selection indices were used. Just two indices for wide planted and one index for narrow planted families had a lower expected genetic advance than selecting for plant weight alone. Expected genetic advance for several selection indices was comparable to that of plant weight alone. Indices that included number of stalks per plant, stalk diameter, and/or stalk length resulted in the highest expected genetic advance.

Irrespective of plant spacing, Indices 21 and 26 gave the highest expected gain from selection when just two traits were included in an index. The use of any of these indices would probably select for taller, larger diameter, and heavier stalks, which is good, but it may not take into consideration the number of stalks per plant. In the same fashion, Index 15 was comparable with Index 1 without the inclusion of stalk diameter and plant weight. This index will probably give favorable results since it took into account, directly or indirectly all five traits.

The results suggest that a combination of traits, such as the ones indicated in this study will lead to a higher efficiency in family selection, which is definitely superior to selection for plant weight alone. The right combination would be the one from which sugarcane breeders at LSVDP could get the maximum expected gain from selection with minimum cost, resources and efforts. The study also suggests that selection using indices obtained from wide-spaced sugarcane families would be more effective than selection using indices obtained from narrow-spaced families where competition between a plant and surrounding plants might influence a plant character.

REFERENCES

Baker RJ (1986) *Selection Indices in Plant Breeding*. CRC Press. Boca Raton, FL, USA. 218 pp.

Brim CA, Johnson HW, Cockerham CC (1959) Multiple selection criteria in soybeans. *Agron. J. 51*: 42-46.

Chang YS, Milligan SB (1992) Estimating the potential of sugarcane families to produce elite genotypes using univariate cross prediction methods. *Theor. Appl. Genet. 84*: 662-671.

De Sousa-Vieira O, Milligan SB (1999) Intra-row plant spacing and family x environment interaction effects on sugarcane family evaluation. *Crop Sci. 39*:358-364.

De Sousa-Vieira O, Milligan SB (2005) Interrelationships of cane yield components and their utility in sugarcane family selection: path coefficient analysis. *Interciencia 30*: 93-96.

Gravois KA, Milligan SB, Martin FA (1991) Indirect selection for increased sucrose yield in early sugarcane testing stages. *Field Crops Res. 26*: 67-73.

Hallauer AR, Miranda JB (1981) Quantitative Genetics in Maize Breeding. 1st ed. The Iowa State University Press. Ames, IO, USA. 468 pp.

Kang MS (1994) Applied Quantitative Genetics. Louisiana State University, Baton Rouge, LA, USA. 157 pp.

Miller JD, James NI (1974) The influence of stalk density on cane yield. *Proc. Int. Soc. Sugar Cane Technol. 15*: 177-184.

Miller JD, James NI, Lyrene PM (1978) Selection indices in sugarcane. *Crop Sci. 18*: 369-372.

Milligan SB, Balzarini M, White WH (2003) Broad-Sense heritabilities, genetic correlations, and selection indices for sugarcane borer resistance and their relation to yield loss. *Crop Sci. 43*: 1729-1735.

Smith HF (1936) A discriminant function for plant selection. *Ann. Eugenics 7*: 240-250.