GENOTYPE X ENVIRONMENT INTERACTION AMONG SECONDARY VARIETY TRIALS IN THE NORTHERN REGION OF THE SOUTH AFRICAN SUGAR INDUSTRY

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Abstract

The response of sugarcane genotypes to conditions encountered in different environments varies. This may result in a change in the ranking of individuals within a series of genotypes when measured in different environments, giving rise to genotype x environment interaction.

Interaction between genotype and environment impacts on the breeding strategy. If there is no interaction, then the best genotype in one environment will be the best in the other environments, but if there is significant interaction, particular genotypes must be sought for different environments.

The irrigated northern region of the South African sugar industry consists of two main areas; Pongola and Komatipoort/Malelane. A distance of about 400 km separates these areas. The initial stages of the breeding and selection programme (stages 1 through to 4) are conducted on the SASEX research station situated in the Pongola area. Secondary variety trials (stage 5 trials) are established on a minimum of two sites in both areas annually, to assess the performance of new selections.

Environmental sensitivity and genetic correlations, as a measure of genotype x environment interaction, for 28 genotypes tested in replicated secondary variety trials at five sites in the irrigated north are presented. Possible implications for the selection and breeding strategy for the irrigated north are discussed.

Keywords: breeding, genotype x environment interaction, selection, sugarcane, variety

Introduction

The irrigated northern region of the South African sugar industry consists of two main areas; Pongola and Komatipoort/Malelane. These areas are separated by about 400 km. The initial stages of the sugarcane breeding and selection programme (stages 1 through to 4) for this region are conducted on the research station of the South African Sugar Association Experiment Station (SASEX), situated in the Pongola area. During these stages families of bi-parental crosses are evaluated, during which the number of clones are substantially reduced from about 35 000 in stage one to 30 at the end of stage four. This select group of sugarcane clones is then established in stage five trials (secondary variety trials) at a minimum of two sites in both areas annually, to assess the performance of potential new varieties.

At present, for a clone to be released commercially as a variety it has to perform well at several sites. Clones that do well over several crops at one site, but fail at other sites, are not released. Thus the system favors those clones that are adaptable and grow well in a range of environments, and it discriminates against clones that are site specific and will only grow in special environments (Butterfield, 1995).

The change in the relative performance of clones (genotypes) to conditions encountered within different environments (e.g. sites, years, crop cycle, and season) is termed genotype x environment (GxE) interaction. GxE interaction has been identified in sugarcane at both the clonal level (Kang and Miller, 1984) and the family level (Bull, Hogarth and Basford, 1992).

Genotype x environment interaction is an important issue facing plant breeders. If the breeding goal is wide adaptation, the best strategy would be to identify several different environments within the region and place a test location in each to select for adaptability (Gauch & Zobel, 1997). In other words, the use of a single selection site to identify elite clones or families may limit the gains from selection compared to clones or families evaluated over multiple locations.

It should be noted that, as yields increase over time, it becomes increasingly difficult to find stable clones adapted to a range of environments, and that the biggest increase in productivity will be as a result of identifying specific clones for specific sites (Butterfield, 1995). Therefore to optimize growers' yields, despite genotype-environment interactions that cause no one genotype to win everywhere and always, the growing region should be subdivided into relatively homogeneous environments and specialized genotypes bred for each of these environments.

According to Falconer (1989) the concept of genetic correlation can be applied to some of the breeding problems associated with the interaction of genotype and environment. A trait measured in two different environments can be regarded not as one character but as two. By regarding performance in different environments as different characters, genetic correlations between them can be calculated. If the genetic correlation is high, then performance in two environments represents very nearly the same character, determined by nearly the same set of genes. If it is low, then the characters are different, and high performance in both environments requires a different set of genes.

Falconer (1989) also recommended looking at "environmental sensitivity" to help understand responses in different environments. A genotype's environmental sensitivity is the regression of its own values on the environmental values (mean of all genotypes in an environment). A high genetic correlation means that all genotypes react similarly to environmental differences and would have regression lines that are all nearly parallel. A low genetic correlation would mean that the genotypes react differently and have regression lines with different slopes.

Although secondary variety trials have been a part of the breeding and selection programme for many years, the five sites under investigation in this paper are the latest group of sites and collectively have only been in existence since 1997. The aim of this study was to investigate the genotype x environment interaction among these sites, specifically considering the value of these sites for the selection of stable varieties for the region as well as the possible sub-division of the region into breeding areas.

Material and Methods

Twenty-eight advanced genotypes, selected from an original population of approximately 50 000, were established in secondary variety trials at five locations in 1997. Two commercial varieties, NCo376 and N14, were included as standards in all the trials. Three of the trials were sited in the Pongola area and one each near Komatipoort and Malalane in the more northerly part of the region. Trials were not established during the same season, certain trials being established in autumn (March) and others in spring (September/October). In terms of the milling season, trials established/harvested in autumn (March) are early season and those established in spring (September/October) are late season. Table 1 depicts the season of planting, together with the site codes of the five trials.

Each trial consisted of three replications in a randomized complete block design, with a plot size of six rows, eight meters long. Data were collected from two crops, namely plant cane and first ratoon, during 1998 and 1999 respectively. Traits assessed were mass of cane (tcane)(t/ha), estimated recoverable crystal percent cane (erc%) and mass estimated recoverable crystal (terc)(t/ha).

The interaction of genotypes with environments was estimated from an analysis of variance, while the amount attributable to differences of sensitivity was obtained from the heterogeneity of regression slopes. Components of variance/covariance were estimated using the residual maximum likelihood (REML) method of the Genstat package (Genstat, 1993).

Genetic correlations were computed in each case by dividing the mean covariance component estimate for the two traits by the geometric mean of the two mean variance component estimates (Falconer, 1989).

Table 1. List of secondary variety trials established in the northern irrigated area of the South African sugar industry during 1997.

Area	Site	Season planted	Code
Pongola	Research station	Autumn (early)	FV
Pongola	Research station	Spring (late)	FV2
Pongola	Froneman farm	Spring (late)	NP
Komatipoort/ Malelane	Mhlati	Spring (late)	NT
Komatipoort/ Malelane	Komatidraai	Autumn (early)	NK

Results and discussion

Analyses of variance for tcane, erc% and terc on all data combined are presented in Table 2. The site x clone interaction was highly significant for all three traits assessed. Site effects are confounded with season effects in this study. Season, however, was accepted as an integral part of the site effect and was ignored. Highly significant site x clone interaction was also calculated, except for tcane in the first ratoon, from analysis of variance (not shown) over sites, done separately for plant cane and the first ratoon.

Sugarcane (Saccharum sp. hybrid) is a vegetatively propagated crop that is usually harvested for a number of crops before it is replanted. "Crop" refers to plant cane crop or ratoon crop, a ratoon crop being that developing from a harvested field. The crop x clone interaction component for erc% was non-significant and that of tcane and terc significant on the five and one percent level, respectively (Table 2). Unless trials are replicated over several years, crop effects are confounded with year effects. Milligan et al. (1990) in a study, in which crop and year effects were studied independently, concluded that the potential gain strongly suggested selection across locations instead of across years. Mirzawan et al. (1994) also emphasized the need to concentrate more on testing across locations than on ratooning ability within a location.

Genetic correlations for tcane, erc% and terc among the different sites are presented in Table 3a, 3b and 3c, respectively. Correlations were estimated separately for plant cane and the first ratoon. The range of correlations was from medium (0.45) to high (0.88). In general, genetic correlations among sites were higher within the first ratoon crop compared with the plant crop. There was a higher frequency of medium correlations between early-late season sites than between early–early or late-late season sites. The genetic correlations did not high-

Table 2. Analyses of variance (mean squares) for tons cane per hectare (tcane), estimated recoverable crystal percent (erc%) and tons estimated recoverable crystal per hectare (terc) for plant and first ratoon crops combined.

Source	df	tcane	erc%	terc
Site	4	80723.5**	121.5**	897.5**
Crop	1	10736.5**	19.7**	395.1**
Site x Crop	4	29308.0**	49.3**	442.8**
Clone	27	1719.5**	14.8**	28.9**
Site x Clone	104	304.2**	2.6**	8.6**
Crop x Clone	27	283.3*	1.7	7.9**
Residual	704	175.1	1.2	4.0

*,** significant at the 5 and 1 % level of probability, respectively

light any two sites being very similar from a genetic perspective, especially when plant and ratoon correlations were combined or when correlations across all three traits were considered simultaneously. Thus, concerning the selection of stable varieties across environments within this region, the five sites are probably all warranted.

Table 4 shows the percentage "environmental sensitive" clones; i.e. the percentage of clones with regression coefficients above 1.2 and below 0.8. A regression coefficient of 1.0 represents a stable genotype.

Tons erc per hectare (terc) was the most stable trait of the three traits assessed when considering the combined plant and first ratoon data. Only 7.7% and 11.5% of genotypes had regression coefficients less than 0.8 or greater than 1.2, respectively. Figure 1 depicts a stable genotype (regression coefficient = 1.0) together with genotypes with regression coefficients above 1.2 (genotype performing relatively better on good sites) and below 0.8 (genotype performing relatively better on poor sites).

The results do not highlight that the more northerly area of Komatipoort/Malelane should be considered a separate environment to Pongola as far as breeding specific varieties is concerned. An environment as defined by Gauch and Zobel (1997) is a portion of a crop production area with a fairly homogenous environment that causes similar genotypes to perform best. Sub-division of an area into different homogeneous environments for the purpose of breeding varieties for each environment should only be considered after defining the environments and then comparing gains and costs. Most plant breeders feel that they should exploit rather than ignore the potential for yield increases that resides in genotype-environment interaction. Subdivision of a crop production area into different environments implies more work for plant breeders, but subdivision also implies faster progress for plant breeders and higher yields for growers (Gauch & Zobel, 1997). Further studies regarding the quantification of GxE components (e.g. genotype x season, genotype x year and genotype x site) together with defining the environments within the region are needed before the subdivision of the region into breeding areas can be considered further.

Conclusion

The current limited understanding of the specific environmental challenges causing differential clonal performance restricts further rationalization of the present breeding program. Research directed at gaining an understanding of the nature and causes of genotype x environment interaction is warranted. Such knowledge would lead to more effective and efficient breeding/selection strategies being implemented.

Table 3. Genetic correlation among sites for plant (above diagonal) and first ratoon (below diagonal) crops for a) tons cane per hectare (tcane), b) estimated recoverable crystal percent cane (erc%) and c) tons estimated recoverable crystal per hectare (terc).

a)

	NT	NK	NP	FV	FV2
NT	***	0.68	0.68	0.70	0.71
NK	0.71	***	0.57	0.74	0.71
NP	0.78	0.80	***	0.59	0.67
FV	0.79	0.88	0.73	***	0.79
FV2	0.64	0.80	0.78	0.72	***

b)

	NT	NK	NP	FV	FV2
NT	***	0.64	0.79	0.59	0.82
NK	0.75	***	0.74	0.76	0.77
NP	0.69	0.59	***	0.83	0.75
FV	0.87	0.82	0.88	***	0.82
FV2	0.71	0.57	0.71	0.79	***

c)

	NT	NK	NP	FV	FV2
NT	***	0.50	0.66	0.51	0.65
NK	0.79	***	0.45	0.70	0.67
NP	0.67	0.66	***	0.50	0.62
FV	0.83	0.80	0.71	***	0.76
FV2	0.67	0.73	0.75	0.72	***

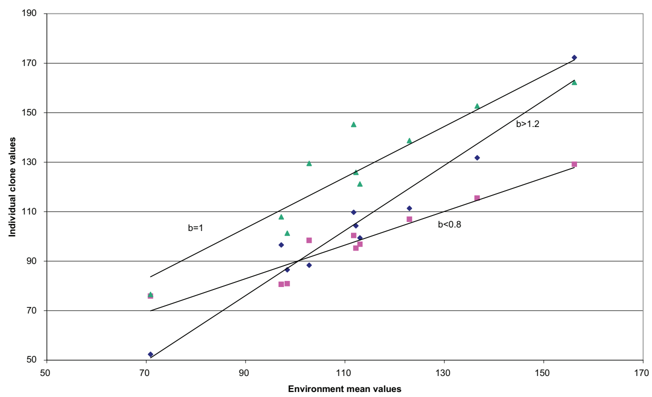

Figure 1. Regression of three genotypes' individual values for tons cane per hectare on the environmental (site) mean value as an example of environmental sensitivity of different genotypes.

Table 4. Percentage of regression coefficients greater than 1.2 and less than 0.8 for tcane, erc% and terc for 28 genotypes included in secondary variety trials established in 1997.

		b<1	b>1	b<0.8	b>1.2
tcane	Plant	53.8	46.2	11.5	15.4
	1st Ratoon	46.2	53.8	30.8	11.5
	Combined	46.4	53.6	17.9	28.6
erc%	Plant	46.2	53.8	38.5	26.9
	1st Ratoon	53.8	46.2	30.8	26.9
	Combined	57.7	42.3	30.8	30.8
terc	Plant	57.7	42.3	23.1	15.4
	1st Ratoon	38.5	61.5	34.6	19.2
	Combined	46.2	53.8	7.7	11.5

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