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THE STRATEGY FOR REGIONAL SELECTION FOR THE DEVELOPMENT OF ENERGY SUGARCANE CULTIVARS PROFILES

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Sugarcane is one of the main crops cultivated in Brazil, and grows well in latitudes between 31° and 5° of the south hemisphere. This tropical climate range usually shows shorter and colder days, and such weather conditions may be increased close to the Tropic of Capricorn which is the most traditional region of sugarcane cultivation in Brazil's Center-South. These tropical areas are mainly characterized by a rainy summer followed by a dry winter season. Surrounding areas of lower latitude are usually characterized by long periods of an extensive drought season, showing concentrated rain distributions during the crop cycle, and also by higher maximum temperatures, which may result in a higher evapotranspiration rate, affecting the accumulation of sugarcane biomass. The major climate components that control sugarcane growth, yield and quality are temperature, light and available water (CAMARGO, 2005).

In Brazil, sugarcane is cultivated in a variety of different soils, such as Latosols, Argisols, Nitosols, Cambisols, Neosols, Vertisols, Plinthosols etc. Within each one of these classes there is also a great variability in the chemical potentiality, which is responsible for conferring specific characteristics for each type, enabling their classification on eutrophic, mesotrophjfic, distrophic, acric, mesoalic and alic soils in this universe (PRADO, 2008).

Brazilian sugarcane expansion areas comprise mainly "cerrado" (savannah) areas, including west and northwest area of São Paulo state; south of Minas Gerais state, eastern Mato Grosso do Sul state, Goiás, Tocantins, and Maranhão states and west of Bahia state. Although these areas are located in different latitudes, they have some particularities when compared to traditionally occupied regions by this crop. For instance, these areas have a greater water deficit along the year and also remarkable differences regarding vegetative growth, flowering, sucrose accumulation and resistance against pests and diseases. For this reason, sugarcane genetic breeding programs have adopted specific strategies for the development of varieties locally adapted to these new environments, re-orientating the hybridization and selection processes, as well as establishing regional experimental stations for selection (LANDELL, 2008).

The hybridization process (crossing) is the main procedure used up to now to generate genetic variability on sugarcane in order to perform the selection of superior individuals. A population of sugarcane seedlings that has this condition will be much higher and bigger is the variability of the parents involved in the hybridization process. A careful characterization of the productive environment where the seedlings are introduced allows breeders to isolate important environment factors, facilitating the selection of regional-adapted genotypes Thus, the environment mapping of representative sugarcane cultivation regions is an essential procedure to be considered in hybridization (choice of the parents) and selection phases.

Deviations on relative behavior of genotypes due to differences of the environment are known as the genotype x environment interaction (*G* *x E*). Knowing such interaction is important for breeders to define their initial objectives, i.e., if the aim is the development of varieties for a broad range of environments or for a specific environment (BORÉM, 1998). ROBERTSON (1959) defined two types of *G x E* interaction: simple and complex. Simple interaction does not show greater difficulties for breeders, considering that a superior genotype in a specific environment will also probably be it in other environments. Nevertheless, the complex interaction is the most prominent one, where an inversion of behaviors is observed, reflected by the impair genotypes responses to environmental variations.

Adaptability and stability of the variety are other aspects that must be taken into account. Adaptability refers to the ability of a variety to take advantage of environmental variations in a positive way. Stability refers to the ability of a variety to show a predictable behavior due to environmental changes. There are two main types of stability: static and dynamic. Static stability occurs when a variety has a constant behavior, independently of changes in the environment, and does not show deviations related to its behavior. It is also known as biological stability and it is more closely related to traits that are less influenced by environment (qualitative traits), as well as the sucrose accumulation curve (maturation) and coloring of stalks, for example. On the other hand, dynamic stability, also designated as agronomic stability, is more associated with quantitative traits. It is characterized when a determined genotype responds to an environmental variation in a predictable way. This stability, if well estimated, consists on an important tool for varietal management. Therefore, a promising variety must show a high yield and stability in different environmental conditions (LANDELL, 2008). Thus, for a good classification of a cultivar regarding its agronomic potential, it is necessary to associate the know-how on the productive environment with the individual performance. Thus a cultivar may be classified as: a) stable, when it has a reasonable response to most favorable growing conditions but also shows an average response in non-favorable conditions; b) responsive, which shows great responses in favorable growing conditions, but does not adapt to more restrictive environments; and c) rustics or low maintenance cultivar, which, contrary to the responsive cultivar, is the most adaptable to restrictive environments, but does not have good performance in favorable cultivation conditions.

So, a new cultivar should be characterized according to its performance in different production environments. An estimative of how a genotype behaves under environmental changes may be determined by quantifying the *genotype x environment* interaction. Under the genetic context, it is possible to quantify this interaction through the instability of the genotypic expression of homozygous and heterozygous alleles (CRUZ, 2003). Several authors have studied this interaction, and developed concepts and indexes of stability, describing methods to estimate phenotypic stability in plants.

Among all methods suggested to evaluate the genotypic performance, one of the most traditional is analyses of groups of experiments. This method considers that a genotype which shows less variance will be the most stable. However, it is very common that low-variance genotypes also show low yield.

Methods based on regression have been widely accepted and used, because with them it is possible to describe the individual responses of different genotypes in a group of environments. These methods estimate an index to each environment studied from the average performance of genotypes. However, to obtain a straight line in regression, theoretically, production and the environmental index must have normal distributions. Some methods will be better described as following:

a) FINLAY and WILKINSOM method (1963): it proposes a calculation of the response for each cultivar regarding the environmental index, which will be obtained by the average of genotypes in a given environment. The regression coefficient (b) will be the estimative of a genotype stability, knowing: b = 1 represents the average stability (agronomic stability), b = 0 represents a cultivar completely stable (biological stability). Best cultivars will be those which is possible to associate higher yield with $\underline{b} = 1$.

b) EBERHART and RUSSEL method (1966): provides information about the relative performance of each genotype in relation to the environmental average, as well as in relation to its linear response. For these authors, the ideal cultivar will be those which show superior average yield, wide or general adaptability ($\underline{b} = 1$) and high predictability or stability ($\sigma^2 = 0$). Main contribution of this method was to enable an estimative environmental index through the difference of average yield in each environment regarding total average yield, which makes possible the stratification of the studied environments.

c) TAI method (1971): it is based in a methodology that estimates the adaptability (linear response of a given genotype, $\underline{b}_i$, under environmental effects) and the stability (linear response in terms of the magnitude of the error variance in relation to the error associated to GA_{ij} interaction). A perfectly stable genotype would show $\underline{b}_i = -1$ e $\lambda_i = 1$. This corresponds to the biologic stability, i.e., a theoretical stability that is unlike to be found in traits of agronomic interest linked to yield.

VERMA *et al*. method (1978): it is a modification of former methods, dividing the evaluation environments in two subgroups, which would represent either favorable or unfavorable environments, according to the deviation related to the general location average. Thus, this method consists of an evaluation of a genotype response through linear regressions into two environmental groups: unfavorable (negative environmental index, $\underline{b}_1$) and favorable (positive environmental index, $\underline{b}_2$). But it is necessary to have a large number of environments, in order to each subgroup has a minimum number of locations that allow valid statistical comparisons. According to VERMA *et al*. (1978), there are three types of genotypes:

- Ideal genotype: high yield capacity, low response to unfavorable environments ($\underline{b}_1 < 1$) and responsive to favorable environments ($\underline{b}_2 > 1$).
- Genotypes indicated to favorable environments: responsive to favorable environments ($\underline{b}_2 > 1$), but sensitive to adverse conditions of the environments ($\underline{b}_1 > 1$).
- Genotypes indicated to unfavorable environments: not responsive to favorable environments ($\underline{b}_2 < 1$), but not so sensitive to adverse conditions of the environments ($\underline{b}_1 < 1$).

Lately, AMMI (*Additive Main Effects and Multiplicative Interaction Analysis*) method has been used by many researchers in plant breeding. It is a matrix method that builds new variables (AMMI0, AMMI1, AMMI2,..., or AMMIF) which are independent to each other and capture *G x E* interactions. Usually, first two AMMIs are enough to capture most part of *G x E* variance and allow the interpretation through Biplots. This analysis combines, in just one model, additive components for main effects (genotypes and environments) and multiplicative components for *G x E* interaction. Therefore, it is very useful to identify genotypes of high yield and largely adapted, as well as to define the so-called agronomic zoning (DUARTE, 1999).

Figure 1 shows an example of the application of this method in sugarcane. Genotypes and locations closer to the IPCA1 axis in AMMI1, and close to the intersection of IPCA1 or IPCA2 axis in AMMI2 are considered the most stable. The most productive genotype, IACSP94-4004, is located in a distant region of IPCA1 axis, indicating an adaptation to more specific conditions, while cultivar IACSP93-3046, also very productive, has shown high stability, positioning itself closer to IPCA1 axis.

Some authors recognize the ideal genotype as the one with high yield capacity and responsive to favorable environments, besides being little affected to unfavorable conditions. However, there are cultivars that despite having an average behavior under unfavorable environmental conditions, they are salient in the best environments, being

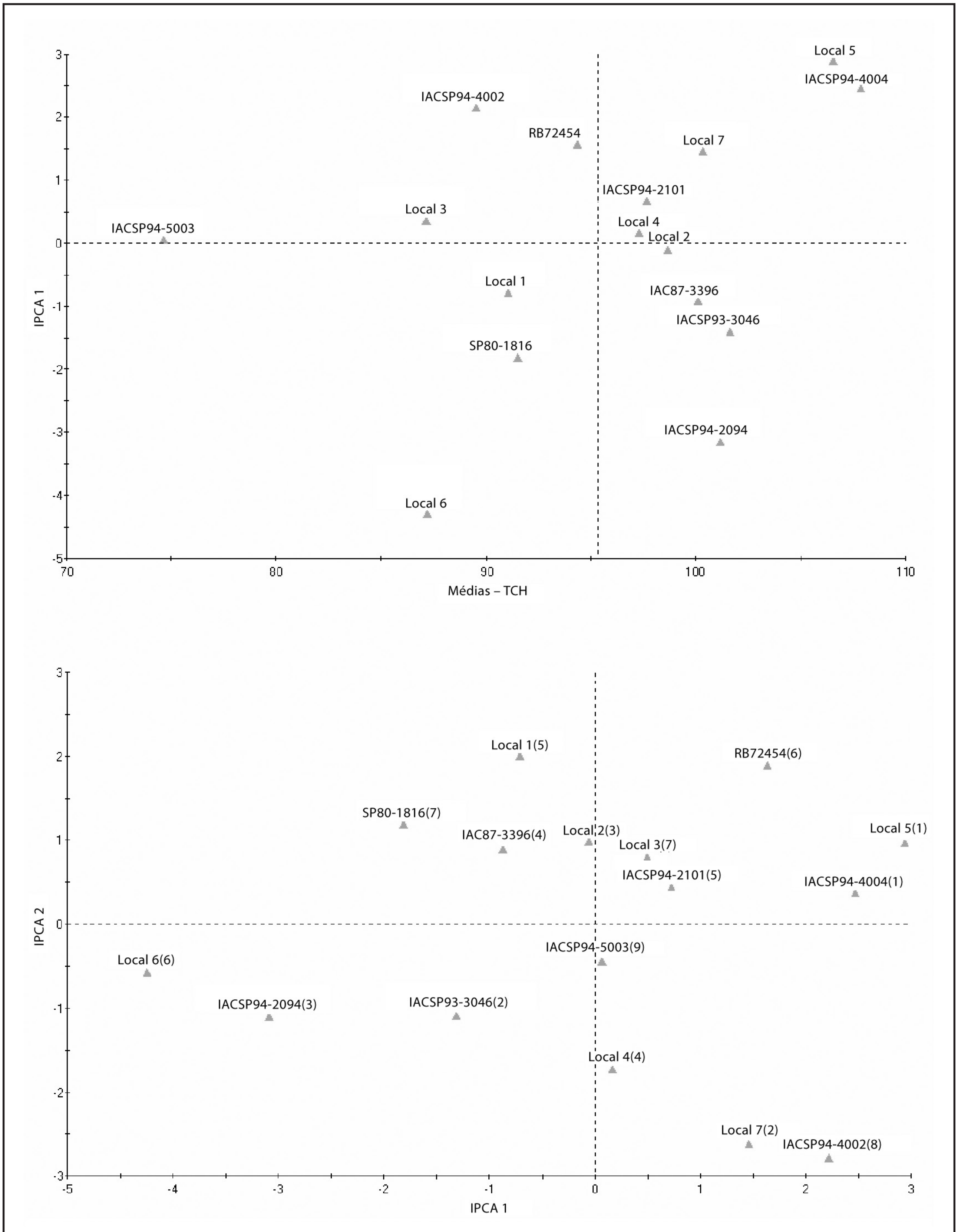

FIGURE 1 Biplot of AMMI analyses and average TCH (1st biplot); AMMI1 and AMMI2 analyses (2nd biplot), for IAC network essays (ESTADUAL 2002), with nine genotypes in seven environments (average TCH for four cuts performed in the middle of harvesting time).

characterized as responsive or demanding. Others are distinguished only in unfavorable environments and are denominated rustics or not demanding. Frequently, cultivars that fit this last group have lower yield potential.

Regional selection has the advantage to allow for a better characterization of a new cultivar, regarding its performance on several yield environments. Studies on phenotypic stability enable one to summarize the huge amount of information obtained from an experimental network, characterizing the yield potential, adaptation to environmental conditions and stability of new cultivars (RAIZER, 1999). Therefore, new sugarcane cultivars have been recommended specifically for different production environments, in association to their specific agricultural management and harvesting period. So, this strategy allows the breeder to take maximum advantage to explore the genetic potential of new cultivars. Nevertheless, considering that Brazilian sugarcane expansion cultivation areas show specific environmental conditions, the possibility of obtaining cultivars more adapted to these new environments drastically decreases when the initial phases of sugarcane breeding are conduced in environments which are very different from commercial planting.

Regional selection minimizes environmental diversity and its interactions with the introduced population. This strategy does not avoid the selection of wide-adapted genotypes based on the average of several places; yet, choosing a specific selection for each place should provide superior gains as described by BRESSIANI (2001).

In addition to the environmental adaptation for yield traits, another aspect of great importance in regional selection concerning the relative importance of traits related to yield. For instance, the ability of a genotype to keep a good tillering ability becomes more important in "cerrado" areas, which is also an indication of tolerance to drought. Other major features for adapting to these particular conditions are: ratooning ability, maintenance of density during the cycle of the crop and the absence of flowering. Such characteristics play an important and strategic role in the selection process.

Qualifying sugarcane production environments is an essential tool for regional selection. Sometimes, although the breeders' task of selecting superior individuals is somehow impaired, particularly when working with different environments of production (soil, climate, biotic factors), and phytotechnic management (MONTALVÁN, 1999) regardless of characterizing, it in relation to its edapho-climatic potential. The qualification of the production environment provides with the necessary support for the perception of a superior genotype, and propitiates the adoption of suitable management strategies. Such strategies must gather more heterogeneous environments, from the stratification of equivalent sub-regions, in which the interaction $G \, x \, E$ is less significant. The stratification or ecologic zoning is a useful procedure, yet having its efficacy restricted due to the occurrence of uncontrollable environmental factors such as rains and variable thermal amplitude.

Hitherto, several breeding programs have adopted regional selection strategies. In the early 90's the *Instituto Agronômico de Campinas – IAC* (Campinas Agronomy Institute) established seven different regions for selection in São Paulo State, based on edapho-climatic parameters. In such regions, IAC has introduced populations of seedlings which have been continually evaluated for many years. After they are considered regional pre-cultivars, they are multiplied and distributed for an experimental network comprising ten states from the Brazil's Center-South region, in order to have their phenotypic stability evaluated. Recently, *Centro de Tecnologia Canavieira* – CTC and Canavialis sugarcane breeding programs have also decided to adopt this strategy. Similar procedures have been widely used throughout the world, by sugarcane breeding programs from Australia (COX *et al.*, 2000), South Africa (SASA, 2004) and Caribbean Islands (KENNEDY, 2000).

Thus, in theory at least, by the end of the regional selection process, a new variety should be obtained in a shorter period of time, around 6 or 7 years. Furthermore, observations built up during successive years on distinct cycles of plants (cane and ratoon cane), together with the

TABLE 1 Singular features aimed on the selection process in each of the regions of IAC Sugarcane Program.

Region	Major features	Phytosanitary problems
01 Piracicaba	Increase on agricultural yield potential and tolerance to aluminum in sub-surface.	Brown rust
02 Ribeirão Preto	Higher shooting ability during drought periods.	Mosaic leaf virus, leaf scald
03 Jaú	Higher resistance to leaf diseases, and higher yield performance in low fertility soils.	Brown, smut leaf scald
04 Mococa	Higher maturation potential under low water deficit conditions.	Brown rust
05 Pindorama	Higher shooting capacity during drought periods.	Leaf scald, nematodes
06 Assis	Higher maturation potential under low water deficit conditions.	Mosaic leaf virus, brown rust red stripe leaf
07 Adamantina	Ability to accumulate increased levels of biomass during vegetative growing period.	Smut
08 Goianésia	Ability to tolerate long periods of drought and absence of flowering.	Smut

interaction of subsequent agricultural years, is now used as the major selection criteria by breeders (LANDELL, 2004).

Table 1 shows the principal traits in each of the selection regions from IAC Sugarcane breeding Program. Actually, one could take advantage of the edapho-climatic regional context where genotypes are inserted, inferring the selection opportunities for each of these places. For instance, in Piracicaba region soils with high level of aluminum are very common (alic soils), therefore, the selected materials in this condition have greater possibilities of being tolerant to higher aluminum levels on the soil. In this same region, climatic condition favors rust disease occurrence. So, Piracicaba region propitiates unfavorable environment to selection of tolerant genotypes for this disease.

As a result of this breeding strategy, the *Instituto Agronômico de Campinas* has released since 2004 twelve sugarcane regional cultivars with a more specific adaptation profile, in order to include regions that were poorly contemplated by current sugarcane breeding programs, like surrounding regions of Mantiqueira and Assis. For next few years, varieties originally developed for “cerrado” areas will be released by all sugarcane breeding programs, bringing considerable gains on varieties currently cultivated.

In order to define a cultivar regarding its agronomic response profile, it is necessary to better understand the productive environments and the individual performance of the genotype. This has permitted introduction of new sugarcane cultivars more suitable to different production environments associated to the type of agricultural management and harvesting time during production. Such specificity allows exploring at maximum the genetic potential of new cultivars in different production sites.

An example of varietal recommendation is presented in Table 2. Cultivars are recommended for harvest time and type of production environment.

TABLE 2 Management recommendation of sugarcane cultivars, according to production environment criteria, responsiveness and harvest season.

	Environment			**Responsiveness**			**Season**		
	Superior	**Medium**	**Inferior**	**Resp.**	**Rustic**	**Estable**	**Autumm**	**Winter**	**Spring**
CTC 1	■	■		■			■		
CTC 2		■	■		■	■		■	■
CTC 3	■			■					■
CTC 4	■			■				■	■
CTC 5	■	■		■			■		
CTC 6	■	■		■		■		■	■
CTC 7	■	■		■			■		
CTC 8		■				■		■	■
CTC 9	■	■		■		■	■	■	
IAC 86-2210	■	■				■	■		
IAC 87-3396		■	■		■	■		■	
IAC 91-2195		■				■	■		
IAC 91-2218	■			■				■	
IAC 91-5155		■	■		■	■		■	■
IACSP 93-6006		■				■		■	
IACSP 93-3046	■	■	■		■	■		■	■
IACSP 94-2094		■	■		■			■	■
IACSP 94-2101	■			■				■	■
IACSP 94-4004	■	■		■		■		■	
PO 88-62		■		■		■		■	
RBT 72454	■	■				■	■	■	
RB 835054	■	■		■		■		■	■
RB 845210		■				■		■	
RB 855113	■			■					■
RB 855156		■	■		■		■		
RB 855453	■	■		■			■		
RB 855536	■	■		■		■		■	■
RB 867515		■	■	■		■		■	■
RB 92579	■	■		■		■		■	■
RB 925211	■	■		■		■	■	■	
RB 925268	■	■		■		■		■	■
RB 925345		■	■		■	■	■	■	
RB 928064	■					■		■	
RB 935744	■	■		■		■		■	■
SP 80-1816	■	■		■		■		■	
SP 80-1842		■				■	■	■	
SP 80-3280	■	■		■				■	
SP 81-3250	■	■		■		■	■	■	
SP 83-2847		■	■		■	■		■	

(continues)

	Environment			Responsiveness			Season		
	Superior	**Medium**	**Inferior**	**Resp.**	**Rustic**	**Estable**	**Autumm**	**Winter**	**Spring**
SP 83-5073									
SP 84-1431									
SP 84-2025									
SP 86-42									
SP 86-155									
SP 87-365									
SP 89-1115									
SP 90-1638									
SP 90-3414									
SP 91-1049									

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