Environmental Effects on Yield and Quality in Three Sugarcane Varieties Grown in Veracruz, Mexico

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Abstract

Two field trials were planted in October 2003 to evaluate the effect of time of harvest on performance by the three main sugarcane varieties in two contrasting locations within the largest sugarcane growing region in México. Trials were harvested at six timings during December 2004-May 2005 harvest season. In the dry zone, cane yield was highest early in the harvest season, i.e. December, through February, while yields declined from March onwards. In contrast, in the humid zone, the harvest season began with low cane yields in December and January, which reached a maximum in February and March, and declined during April and May. In CP 72-2086, reducing sugars showed low values early in the harvest season in the dry zone, which began to increase significantly in March and maintained high values until the end of the harvest season in May. Mex 69-290 recorded high values in December, decreasing in January, through March, and increasing again in April. Mex 79-431 maintained low values from December to March, which increased from April onwards. Main components analysis demonstrated significant effect by location on cane and sugar yields and time of harvest; influence of the environment on varietal yields and confirmed dependence of cane yield on stalk population, stalk length and diameter. Negative correlations between yield components and moisture, reducing sugars and fiber were also found.

1. Introduction

High sugar production depends primarily on the varieties cultivated; improved varieties possessing good adaptability, high insect and disease resistance and high response to input constitutes a key element in increasing sugarcane and sugar yield $unit^{-1}$ area (Santana et al., 2000; Mercado, 1984). Suárez and Bernal (2002) estimated that the use of superior varieties is responsible for 50% of the overall increase in sugarcane yields over the last decades. In reviewing many years of work around the world, Marín and Velásquez (1997) pointed out that high productivity in sugarcane fields demands a rational use of recommended varieties, taking into consideration their characteristics of adaptation, maturity and resistance to insect and disease attack. Thus, it is necessary to establish a program to maintain high level of variety performance by substituting varieties as they lose vigor and yield potential over the years; likewise, producers are commonly advised to keep variety purity, avoiding mixtures of genotypes, which may limit efficient crop and harvest management.

Environmental effects on sugarcane growth and development have been extensively studied in all major producing countries (Arzola, 1997; CENICAÑA, 1995; Creach, 1997; Dillewijn, 1968; Larrahondo et al., 1995). The quality of the sugarcane supplied to the mills depends of a number of factors: variety, soil conditions, climate, water availability, altitude and so on. The harvest process itself may have a large impact on the quality of cut sugarcane (Sánchez, 1993). Proper harvest management practice from the standpoint of the physiology of the plant is extremely important, as it relates to sugar accumulation, degradation and mobilization (Sánchez, 1972). There is ample evidence of varietal differences of maturity and sap quality which the denomination of a given variety as early, intermediate or late is based on, depending on when during its growth its sucrose content in the stalk peaks.

In many sugar factories, the main priority seems to be the urgency to harvest in order to keep the mill supplied at a high pace, regardless of recovery efficiency. High yielding improved varieties, good cropping practice, favorable weather, adequate pest and disease control measures, all is to little avail if harvest is done before or after stalk sucrose is at its high est, the so called industrial maturity. This is the reason why it is so critical to program and control the harvesting process (CENICAÑA, 1995).

Based on these considerations we designed and report herein a study of the impact of the combined effect of environmental factors, designated as location, and timing of harvest on the performance and juice quality of the three main sugarcane varieties used in El Potrero sugar factory in Veracruz.

2. Materials and Methods

Experimental work was carried out in two locations of the El Potrero sugar mill, a dry zone, with annual rainfall below 1100 mm, and a humid zone, with approximately 1900 mm of rainfall. Trials were planted at the two locations in October 2003 and were harvested in six different moments from December 2004 through May 2005.

2.1. Location 1: dry zone

Trial 1 was planted at Barrabas Farm (19º01'6.5" N and 96º33'58.3" W at 260 msl). The climate category at this location is warm-sub-humid. Maximum temperature averages 31.3°C, and minimum temperature 19.6°C with a mean annual temperature of 25.7°C, and a mean annual rainfall of 1085 mm. The trial was planted on a vertisol.

2.2. Location 2: humid zone

Trial 2 was planted in the municipality of Atoyac (18°53'42.1" N and 96°47'12.4" W at 511 msl). The climate is warm-humid-regular, with a maximum temperature of 29.73°C, a minimum temperature of 18.99°C and a mean annual temperature of 24.59°C. Mean annual rainfall is 1866 mm. The trial was planted in an acrisol.

2.3. Varieties

The three main varieties grown in the mill area, CP 72-2086, Mex 69-290 and Mex 79-431, were used.

2.3.1. CP 72-2086 (parents: CP 62-374 X CP 63-588)

CP 72-2086 has good germination and tillering, fair trashing, and early and heavy flowering. Mean cane yields of CP 72-2083 were 102 and 90.6 ton ha^{-1} in plant cane and ratoon, respectively (Marin and Velázquez, 1997; Flores, 2001).

2.3.2. Mex 69 290 (parents: Mex 56-476 X Mex 53-142)

Mex 69-290 has recorded fair germination, early tillering, good growth, and fair trashing. Mex 69-290 exhibits scarce flowering, it is suited for regions with irrigation or under rain-fed conditions where annual rainfall reaches 1500 mm or more; best performance has been reported at altitudes ranging from 0 to 800 msl. (Marin and Velázquez, 1997; Flores, 2001).

2.3.3. Mex 79-431 (parents: Co 421 X Mex 57-473)

Mex 79-431 has recorded good germination, tillering, and good agronomic appearance, even under drought. Ratooning is excellent. It exhibits scarce flowering (Marin and Velázquez, 1997; Flores, 2001).

2.4. Trial layout and treatments

A sub-split plot factorial arrangement (2 x 3 x 6) was used in a randomized block design with four replicates. The experimental plots consisted of six rows 12 m long, spaced at 1.15 m for a total plot area of 82.8 m^2 with a net plot of four central 12 m long rows equivalent to 55.2 m^2. Experimental factors under study were the following:

a) Location: dry zone (L1) and humid zone (L2)
b) Variety: CP 72-2086 (V1), Mex 69-290 (V2) and Mex 79-431 (V3)
c) Month of harvest: December (M1), January (M2), February (M3), March (M4), April (M5) and May (M6)

2.5. Measurements

Temperature and rainfall were measured at intervals throughout the trials. Soil fertility variables (organic matter, total nitrogen, potassium, phosphorus, micronutrients, clay, silt and sand contents, acidity and base exchange capacity) were measured to a depth of 30 cm at the two locations. Sugarcane germination percentage, stalk length, stalk diameter and population density at six months of age and prior to each harvest date were recorded, as well as cane yield, stalk fiber and moisture; juice purity, brix and reducing sugars, sucrose (pol) and theoretical sugar yield ha^{-1} at harvest were determined according to standard methods (IMPA, 1983). Data were analyzed by ANOVA, regression and main components analyses using the SAS system for Windows, release 6.12 (SAS Institute Inc. 1989-1996) and the Main Components Analyses was done after Pla (1986), and Bilodeau and Brenner (1999) without repeated analyses of data.

2.6. Climate

In the humid zone (trial 2), rainfall was 1162 mm greater than that of the dry one (trial 1) (Table 1). Such abundance of water supply naturally suggests the opportunity for better sugarcane growth in the former than the latter, and therefore higher potential cane yields and less deterioration from untimely harvesting, which was one of the factors under study in both zones.

Total rainfall in the humid zone over the period considered was almost twice the rain in the dry zone over the same period; concomitantly maximum, mean and minimum temperatures in the dry zone were higher than those of the humid zone by 1.62°C, 1.11°C and 0.61°C, respectively.

2.7. Physical-chemical characteristics of the soils

The physical-chemical characteristics of the soils at the two locations (data not shown) were adequate for sugarcane cultivation, but in the case of the dry zone, a greater number of growth limiting factors were present (Arcia, 1997), as indicated by low phosphorus and potassium content as well as an intermediate organic matter content, which implied the need for supplementary applications of these nutrients to the soil for sugarcane production.

3. Results and Discussion

3.1. Performance of agronomical and quality variables at harvest

Analyses of variance of agronomical variables (cane popula tion density, cane length, cane diameter and yield) and quality variables (fiber, moisture, reducing sugars, sucrose and tons of sugar ha^{-1}) at harvest were carried out (data not shown) as well as the corresponding comparison of means for the most significant interactions.

3.2. Sugarcane yield

Highly significant differences between locations and among varieties, months of harvest and for the interactions location by variety and location by month of harvest were shown by ANOVA (data not shown). In comparing the means of these main effects and their interactions (Table 1), it was evident that cane yields were significantly higher in the humid zone than in the dry zone in all three varieties under study. This clearly demonstrates the effect of location on the performance of the varieties and confirms reports by Mariotti (1987) in Argentina, Ghaderi, et al. (1980) in India and Bernal (1986) in Cuba. By reviewing the interaction location by month of harvest, it can be noticed that in the dry zone, cane yield was highest early in the season in December, January and February, while from March onwards there was a decline in cane yield, which became significantly lower in April and May. In contrast, in the humid zone, the cane yield trend was towards low yields in December and January which then increased to a maximum in February and March to later decrease during April and May. These observations underline the importance of taking into consideration the characteristics of location to optimize harvest scheduling (Milanés et al., 2007). As Peña et al. (2001) concluded, the use of new superior varieties well adapted to specific locations constitutes one of the main tools for increasing yield potential and reducing the negative impact of variety fatigue over time. This imposes the need to implement a planting and harvesting program if one is to attain better harvests.

3.3. Percentage of reducing sugars

Highly significant differences were determined between locations, varieties, months of harvest and the interactions location by variety, location by month of harvest and location by variety by month of harvest in percent reducing sugars. By comparing the means of these main effects and their interactions it can be observed that reducing sugars (Figure 1) show a different time curve for each variety. Thus, for example, CP 72-2086 recorded low reducing sugar values at the beginning of the harvest season, which increased significantly in March, and maintained these values until the end of the harvest season in May. These observations suggest that CP 72-2086 should

Table 1: Comparison between means of the most important significant interactions at harvest

No.	Location x variety interactions		Location x variety x month of harvest interactions	
		Cane yield (t ha^{-1})		Reducing sugars (%)
1	L_1 x V_1 (Dry zone)	49.94^{b}	L_1 x V_1 x M_1	0.297^{b}
2	L_1 x V_2 (Dry zone)	46.36^{b}	L_1 x V_1 x M_2	0.285^{b}
3	L_1 x V_3 (Dry zone)	48.84^{b}	L_1 x V_1 x M_3	0.507^{b}
4	L_2 x V_1 (Moist zone)	118.64^{a}	L_1 x V_1 x M_4	0.883^{ab}
5	L_2 x V_2 (Moist zone)	126.91^{a}	L_1 x V_1 x M_5	1.070^{ab}
6	L_2 x V_3 (Moist zone)	137.73^{a}	L_1 x V_1 x M_6	1.407^{a}
Standard error		21.19	L_1 x V_2 x M_1	0.617^{ab}
Locality x month of harvest			L_1 x V_2 x M_2	0.288^{b}
1	L_1 x M_1 (Dry zone)	56.42^{c}	L_1 x V_2 x M_3	0.240^{b}
2	L_1 x M_2 (Dry zone)	56.46^{c}	L_1 x V_2 x M_4	0.507^{b}
3	L_1 x M_3 (Dry zone)	52.35^{c}	L_1 x V_2 x M_5	0.797^{ab}
4	L_1 x M_4 (Dry zone)	47.48^{cd}	L_1 x V_2 x M_6	0.873^{ab}
5	L_1 x M_5 (Dry zone)	40.78^{d}	L_1 x V_3 x M_1	0.470^{b}
6	L_1 x M_6 (Dry zone)	36.77^{d}	L_1 x V_3 x M_2	0.407^{b}
7	L_2 x M_1 (Moist zone)	122.50^{b}	L_1 x V_3 x M_3	0.273^{b}
8	L_2 x M_2 (Moist zone)	129.43^{ab}	L_1 x V_3 x M_4	0.500^{b}
9	L_2 x M_3 (Moist zone)	132.73^{ab}	L_1 x V_3 x M_5	1.003^{ab}
10	L_2 x M_4 (Moist zone)	136.15^{a}	L_1 x V_3 x M_6	1.067^{ab}
11	L_2 x M_5 (Moist zone)	124.01^{b}	Standard error	0.812
12	L_2 x M_6 (Moist zone)	129.55^{ab}		
	SE	11.50		

Means in each column followed by different letters are significantly different (Duncan $_{0.05}$)

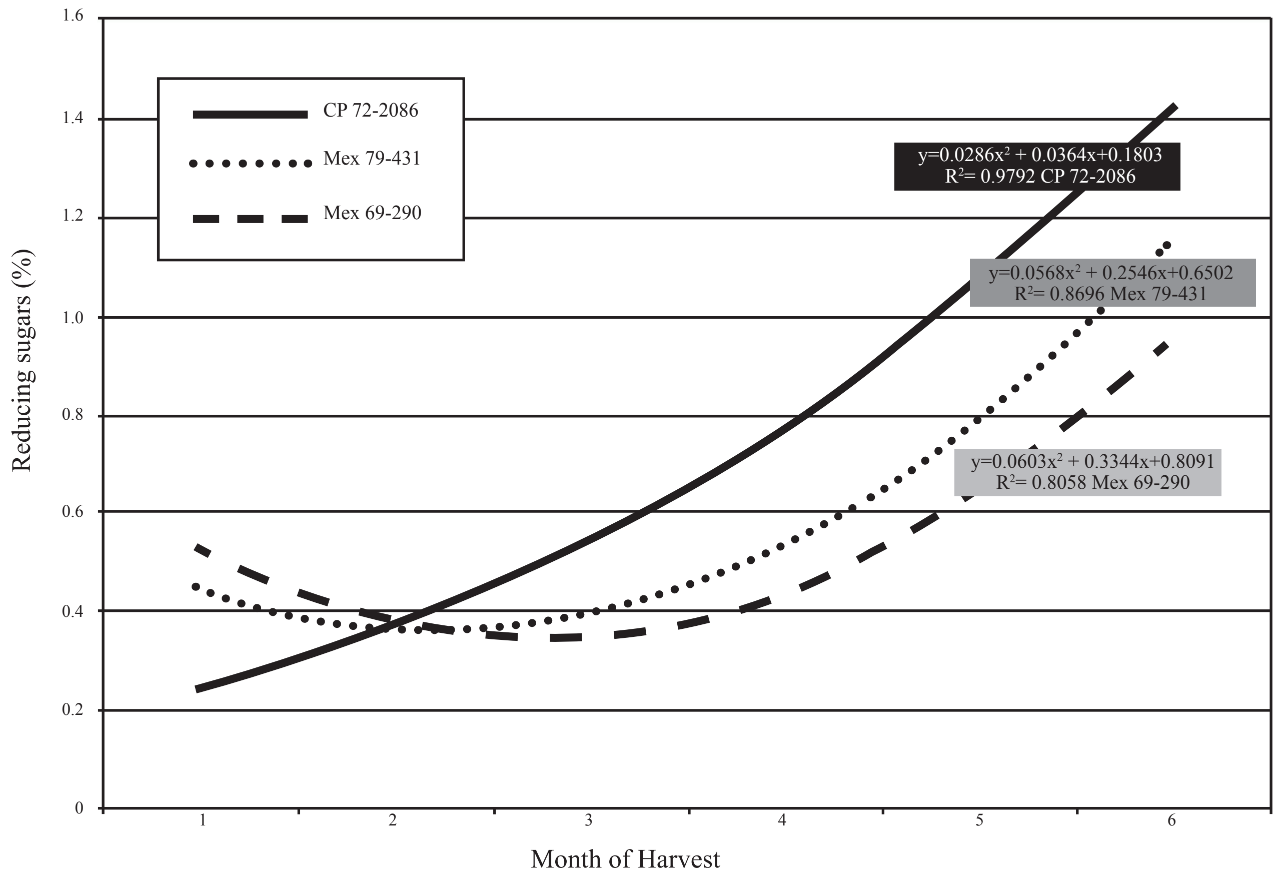

Figure 1: Variation in reducing sugar content over time in three varieties studied in the dry zone

be harvested at the beginning of the harvest season to finalize before March, while Mex 69-290 should be harvested preferably during the months of January, February and March. Similar findings were reported by CENICAÑA (1995) in Colombia, which allowed varieties to be classified for their peak sugar content, anywhere from 9 to 14 months of growth.

3.4. Main components analyses: components and eigenvectors

The first four components extracted more than 90% of the total variation of the assessed matrix, and the two first reached 72.72% (Table 2). Consequently, it should be sufficient to work with the information extracted by these two components. In the first component the important variables included: location, cane yield, stalk population, stalk length, stalk diameter, fiber content, reducing sugars, sucrose and tons of theoretical sugar ha^{-1}. In the second component, important variables included: juice purity and cane moisture with opposite signs, i.e. with contrary effects, as expected. It is worth noting that the variables associated with yield components had the same sign as did location, hence the large effect of the former on cane yield. On the other hand, the effect of reducing sugars was contrary to that of sucrose, almost with the same values of components, but with opposite signs; similar results were reported by Bernal (1986) and Milanes et al. (2007).

3.5. Relationships and importance of variables

The correlation circle (Figure 2) suggests that effects of sugarcane yield components were directly opposite to the effect of fiber and reducing sugars, while sucrose and juice purity were, as expected, associated and opposite to stalk moisture. Supplementary variables show little importance, except location, also in this case related to the cane yield components.

Components 1 and 2 have been displayed for individuals plotted on a chart: grouping of the 108 studied individuals into two large groups (Figure 3) associated to each of the two studied locations is quite apparent, which again adds to the large impact of location on the performance of the sugarcane crop.

4. Conclusion

Differential yield response and reducing sugar content over harvest season among varieties demonstrates need to consider location characteristics to optimize harvest scheduling. Main components analysis showed significant effects by location on sugarcane and sugar yields, time of harvest, and environmental impact on varietial yields. Varietal performance was largely dependent on specific conditions prevailing at each location and on harvest scheduling. Overall, results suggest that at the sites involved in these experiments, CP 72-2086 should be harvested before March; Mex 69-290 should be harvested from January,

Table 2: Eigenvectors, eigenvalues and main components of variables and individuals studied

Parameters and variables	Components			
	1	2	3	4
Eigenvalues	6.003814	1.995072	1.228785	0.687575
Percentages	54.58	18.14	11.17	6.25
Cumulative values	54.58	72.72	83.89	90.14
Location (L)	-0.911	-0.268		
Variety (B)	-0.097	-0.227		
Harvest (C)	0.147	-0.022		
Replicates (REP)	0.032	0.015		
Cane yield (REN)	-0.949	-0.238		
Stalk population (NT)	-0.748	-0.012		
Stalk length (AT)	-0.934	-0.247		
Stalk diameter (DIA)	-0.835	-0.200		
Brix	-0.669	0.488		
Fibre (FIB)	0.751	0.312		
Moisture (HUM)	-0.249	-0.769		
Purity (PUR)	-0.234	0.566		
Reducing sugars (RED)	0.654	-0.346		
Sucrose (PLS)	-0.687	0.680		
Theoretical sugar ha^{-1} (RAT)	-0.974	-0.010		

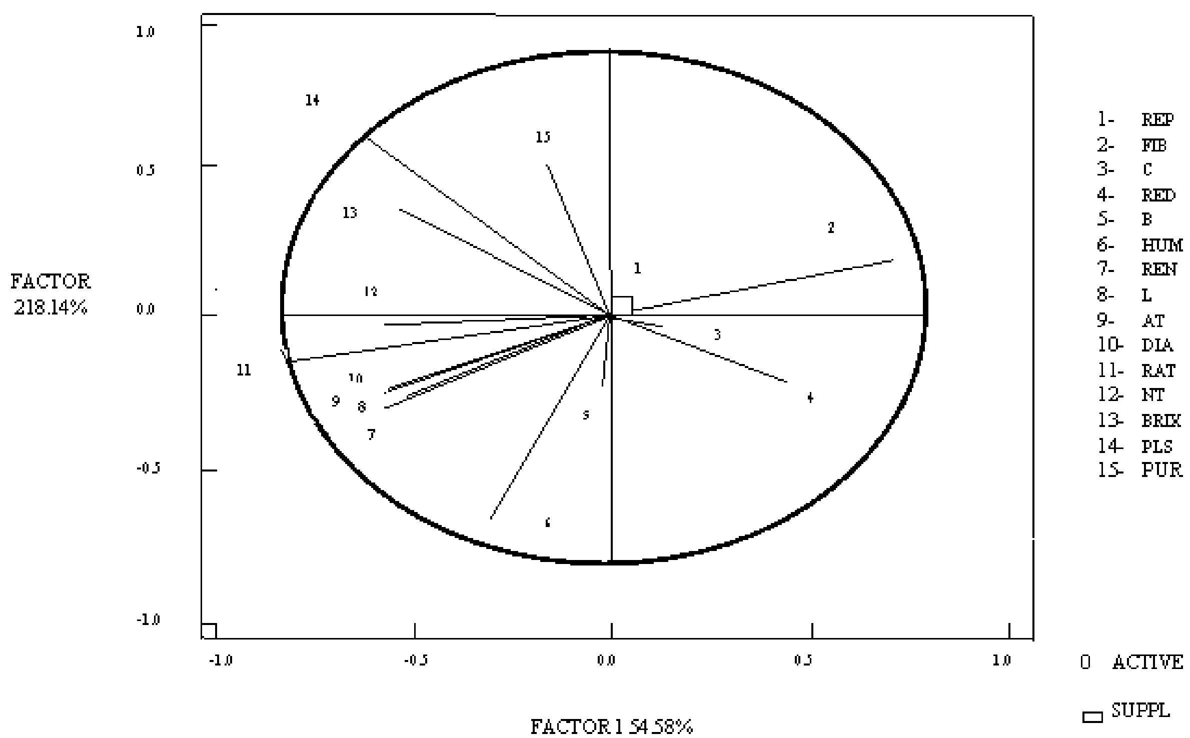

Figure 2: Correlation circle (represented are the 15 considered variables, according to their relative importance in the first and second components)

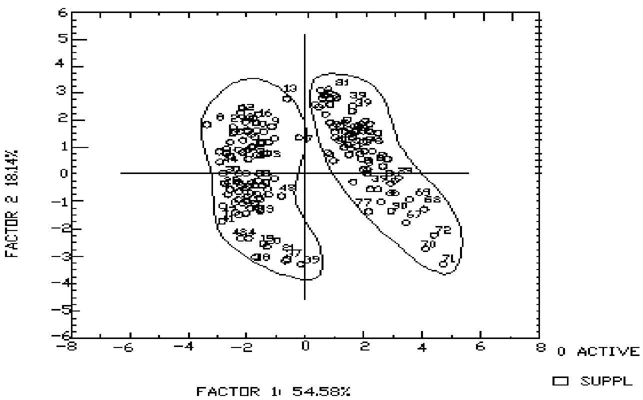

Figure 3: Behavior of individuals in the first and second components in accordance to the relative impact of location and harvest timing on both components

through March; while Mex 79-431 would be best harvested during February and March.

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