MEGAENVIRONMENTS FOR THE COLOMBIAN SUGAR INDUSTRY: CHARACTERISATION AND IMPLICATIONS FOR VARIETAL SELECTION AND CROP MANAGEMENT

Alvaro Amaya, Jorge S. Torres, Rafael Quintero, Carlos A. Luna, Carlos A. Moreno, Alberto E. Palma, Javier Carbonell, Enrique Cortés and Hernando Ranjel. CENICAÑA. Apartado aéreo 9138. Cali, Colombia.

ABSTRACT

The sugarcane-growing area of the Colombian sugar industry is located in a heterogeneous valley with respect to its agroclimatic conditions. This is reflected in the differential sugar production of the varieties in accordance with the environment in which they are planted. This means that there are distinct megaenvironments that require different agronomic practices and varieties. The purpose of this paper is to present progress in the characterisation of megaenvironments for the Colombian sugarcane zone. Information is analysed for soils (orders, series and management groups), soil moisture regimes and water balance. The most important factors that explain the variation in cane and sugar production were determined. The water balance, which is an indicator of the level of moisture available to the crop, and soil management group were the two factors that had the greatest influence on cane and sugar production and, as such, constitute the initial basis for varietal selection and evaluation, as well as for developing agronomic practices. Climatic factors such as rainfall fluctuate over time and space, indicating the importance of considering the temporal nature of climatic factors apart from geographic location in the definition of megaenvironments.

Keywords: Sugarcane, megaenvironments, soil management groups, water balance, soil moisture regimes, production variables.

INTRODUCTION

The cultivation of cane for sugar production in Colombia is concentrated in the geographic valley of the Cauca River, where the natural conditions and the technological level of the crop favour high sugar production per unit of area and time. The characterisation of the soils (IGAC, 1980), as well as their grouping based on their potential management (Quintero & Castilla, 1992), revealed that the geographic valley of the Cauca River is heterogeneous. Likewise, the level of cane and sugar production obtained in commercial fields (Luna et al., 1992a, 1992b; Vivas & Luna 1994a, 1994b; Vivas & Luna, 1996a, 1996b) and in CENICAÑA’s regional trials over the last ten years with the same varieties under different environmental conditions showed that production response is dependent upon the soil, variety, climate and agronomic management (Amaya & Cassalett, 1984; Ranjel & Palma, 1992; CENICAÑA, 1994, 1995).

The competitiveness of the sugarcane sector depends, to a great extent, on technological progress and reduction of unit production costs. Technological progress should focus on precision agriculture, where technology development seeks to maximise profitability under the different conditions. This justifies identifying these conditions, the varieties that adapt best to them and the most desirable agronomic management. This leads to the identification of megaenvironments, for which the specific varieties and agronomic management practices that permit the expression of their greatest production potential are characterised (Gauch & Zobel, 1997).

The agroclimatic zone studies reported in the literature focus on the characterisation of the soil, climate and

1Corresponding author: aamaya@cenicana.org
existing vegetation. Based on these characteristics, the crops with the greatest production potential are identi-
fied. In the case of the Colombian sugar industry, however, this step is unnecessary as we focus on monoculture; we have commercial results and rainfall data for many years; and we also have more specific experimental results and meteorological data. The identification of megaenvironments generates better decision-making elements for crop management and involves rationalisation in the use of resources and, therefore, a reduction in unit production costs. It also contributes to defining the areas representative of commercial exploitation in order to conduct basic research and then extrapolate the results to similar areas. This paper has the following objectives:

1. Characterise the megaenvironments in the Colombian sugarcane area based on the information of the existing soil and climate factors and based on plant response at the experimental and commercial levels.
2. Contribute to a better location of the varietal selection and evaluation sites and to the improvement of the agronomic management of the crop.

MATERIALS AND METHODS

This paper analyses data related to the soil and the climate and relates them to the biological response in cane and sugar production in order to identify the factors that explain, to the greatest possible extent, variations in production. The analyses took into account the soil groupings for the geographic valley of the Cauca River (Quintero & Castilla, 1992), the climatic zoning by water balance (Torres & Cruz, in press) and the response in terms of cane and sugar production obtained in the regional evaluation of varieties in 51 experiments for several cuts (different crops) from 1990-96 and the commercial cane production data for the years 1996-97 at the Central Castilla Sugar Mill.

With respect to soils, the following factors were taken into account:

1. The order (Mollisols, Vertisols, Inceptisols, Alfisols and Entisols)
2. The soil moisture regime (ustic, udic and aquic) based on the presence/absence of the phreatic level and of the water retained at pressures under 15 bars
3. The potential agronomic management group (groups 1-10) based on taxonomic classification, geomorphological position, soil moisture regime, texture and drainage (external, internal and natural)

Climatic zoning by water balance determines similar zones in the balance between rainfall and crop evapotranspiration, and indicates the periods and water requirements in case of a deficit or surplus of rainfall, as well as the infrastructure required for meeting the deficits or for draining the excess moisture. This zoning is based on rainfall data from 140 stations over a period of at least 10 years and evaporation data for 37 meteorological stations. In accordance with the historical rainfall and evaporation information, water balance isoline gradients were estimated with a probability of 75%. The first approximation characterises 6 climatic water balance zones (based on the historical data for at least 10 years) defined by 200-mm intervals.

For the definition of the megaenvironments, the experimental results of 41 varietal trials harvested in plant and ratoon crops from 1990-96 were related to the water balance that characterises the sites (referred to here as "climatic water balance"). This is different from the water balance isoline that occurred during the experiments (referred to here as "temporary water balance"). The results of the most recent group of variety trials (Series 87: 10 experiments, plant cane) are analysed in terms of both the climatic and the temporal water balances.

The spatial distribution of the climatic water balance zones as well as certain climatic factors (e.g., rainfall, radiation), generated by the meteorological network, were determined with using the geographic information system, GIS.

The determination of the factors that explain the variation of tonnage of cane per hectare (TCH), tonnage of
sugar per hectare (TSH) and sucrose (% cane) and that have a significant effect on the characterisation of the megaenvironments was done using one-way ANOVA models. These models do not take into consideration the interactions among the factors considered; rather they show the individual effect of each factor for each of the response variables. The relationship between the production variables and the factors considered were determined using regression and correlation analyses (SAS programme).

RESULTS AND DISCUSSION

Table 1 shows the explanation of variance in TCH, sucrose (% cane) and TSH for varieties MZC 74-275, CC 85-92 and CC 85-68 with regard to the following factors: soil order, soil moisture regime, potential soil management group and climatic water balance. The explanation provided by the statistical analysis shows the dependence of TCH, sucrose and TSH for the individual factors analysed. In this case the explanation is provided by the coefficient of determination ($R^2$). The most influential factor was the one that had the highest $R^2$ values.

Table 1. Explanation of Variance in TCH, sucrose (% cane) and TSH (ranges of the $R^2$) in relation to four factors. Variety trials, 1990-96.

<table>
<thead>
<tr>
<th>Factor</th>
<th>TCH</th>
<th>Sucrose</th>
<th>TSH</th>
</tr>
</thead>
<tbody>
<tr>
<td>MZC 74-275</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil order</td>
<td>0.03 - 0.19</td>
<td>0.01 - 0.16</td>
<td>0.06 - 0.13</td>
</tr>
<tr>
<td>Soil moisture regime</td>
<td>0.07 - 0.23</td>
<td>0.00 - 0.03</td>
<td>0.04 - 0.22</td>
</tr>
<tr>
<td>Soil management group</td>
<td>0.11 - 0.28</td>
<td>0.03 - 0.09</td>
<td>0.11 - 0.23</td>
</tr>
<tr>
<td>Climatic water balance</td>
<td>0.40 - 0.65</td>
<td>0.05 - 0.25</td>
<td>0.37 - 0.56</td>
</tr>
<tr>
<td>CC 85-92</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil order</td>
<td>0.02 - 0.04</td>
<td>0.03 - 0.10</td>
<td>0.04 -</td>
</tr>
<tr>
<td>Soil moisture regime</td>
<td>0.07 - 0.08</td>
<td>0.01 - 0.05</td>
<td>0.04 - 0.07</td>
</tr>
<tr>
<td>Soil management group</td>
<td>0.01 - 0.16</td>
<td>0.13 - 0.18</td>
<td>0.01 - 0.17</td>
</tr>
<tr>
<td>Climatic water balance</td>
<td>0.27 - 0.60</td>
<td>0.18 - 0.25</td>
<td>0.31 - 0.59</td>
</tr>
<tr>
<td>CC 85-68</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil order</td>
<td>0.05 - 0.12</td>
<td>0.13 -</td>
<td>0.06 - 0.09</td>
</tr>
<tr>
<td>Soil moisture regime</td>
<td>0.15 - 0.54</td>
<td>0.03 - 0.08</td>
<td>0.08 - 0.45</td>
</tr>
<tr>
<td>Soil management group</td>
<td>0.03 - 0.86</td>
<td>0.26 - 0.33</td>
<td>0.05 - 0.85</td>
</tr>
<tr>
<td>Climatic water balance</td>
<td>0.49 - 0.86</td>
<td>0.33 - 0.37</td>
<td>0.44 - 0.85</td>
</tr>
</tbody>
</table>

1/MZC 74-275: Series 84 & 85, plant cane and two ratoon crops; Series 86, plant cane
2/CC 85-92: Series 85, plant cane and two ratoon crops; Series 86, plant cane
3/CC 85-68: Series 85, plant cane and two ratoon crops; Series 86, plant cane

The climatic water balance is the factor that best explains the variance in TCH and TSH for the three varieties evaluated, followed by the soils management group. For varieties MZC 74-275 and CC 85-92, the dependence of TCH and TSH on the function of the climatic water balance is almost double that generated by the soils management group.

For sucrose (% cane), the explanation of the model for each of the factors is very low, indicating that factors other than those evaluated in this study—for example, other climatic variables and agronomic management (e.g., age, cut, planting date, opportuneness of the irrigation)—can affect variation in sucrose content to a greater extent. Therefore, the results and discussion focus primarily on TCH.
A greater dependence of TCH on the climatic water balance in relation to the other factors considered in this study makes it possible to concentrate the analysis on such factor as the initial element in the determination of the megaenvironments. Figure 1 shows the relationship between TCH and the climatic water balance for the three aforementioned varieties when the analysis considered only the experiments that had three cuts and excluded two sites that had performances different from the trends of the majority of the experiments. One period of time covering several cuts (three in this case) made it possible to consider a water balance representative of a time period closer to that determined for the climatic water balance than when only one cut was considered. For all three varieties, there was a tendency towards greater TCH when the water balance tended towards a deficit.

Figure 1. Relationship between TCH and the climatic water balance for the varieties MZC 74-275, CC 85-92 and CC 85-68 evaluated in variety trials in plant cane and two ratoons.

The greatest response in terms of TCH when there is limited water available for the crops in zones that have traditionally had an excess of water was confirmed by the greatest increases in TCH that the sugar industry had after the drought (1992-93) in the southern and northern zones of the cane-growing area of the Cauca River Valley; and that corresponds to zones where the climatic water balance has the greatest probabilities of excess water. The percent increase in TCH from 1991-93 was 15 and 18%, respectively, in the southern and northern zones vs 10% for the central zone (Vivas & Luna, 1994-1996).
The foregoing indicates that in periods of drought, there is a greater response in cane production in zones that tend to have excess moisture; whereas in periods of normal rainfall, the higher cane production occurred in zones with a tendency towards moisture deficit. This reflects, to a certain extent, the current situation in the Cauca River Valley with respect to the availability of water for the crop given the fact that the sugar industry has the infrastructure prepared for irrigating rather than for draining; and under deficit conditions, it is possible to diminish the water stress in the plant in a more timely fashion.

TCH in relation to the climatic water balance for the three varieties in the Series 85 experiments tended to decrease with excess water. Nevertheless, variety CC 85-92 had the highest production of the three varieties and this was higher even in environments where the water balance was in excess: whereas variety CC 85-68 was most sensitive to conditions of excess water, reflected in decreasing tonnages, which can be seen in the slopes and intercepts of Figure 1. The former shows the differential response of the varieties in relation to the climatic water balance factor and the possibility of characterising more suitable varieties in accordance with said factor.

The experimental response was validated with information from commercial plantations. The relationship between TCH and the climatic water balance was determined based on 1373 observations of the Central Castilla Sugar Mill during 1996-97, which included different varieties, cuts and ages (Figure 2). The response of TCH with respect to soil moisture availability shows once again the trend towards higher production under water-deficit conditions with a similar range of variance, whether under conditions of excess water or a moisture deficit. The foregoing agrees with the experimental results presented here.

![Climatic water balance diagram](image)

Figure 2. Relationship between TCH and the climatic water balance at the Central Castilla Sugar Mill. 1996-1997. N = 1373.

When relating the response in cane production to the water balance, it might be more advantageous to use the climatic water balance (determined with historical data) than the temporal water balance, (registered during the crop cycle). Specific temporal water balances (e.g., those obtained for only one cut under conditions of excess rainfall) concentrate the production responses around the reduced range of the temporal water balance, making it impossible to discriminate TCH trends. This occurred with the response in TCH for varieties...
MZC 74-275, CC 85-92 and CC 85-68, evaluated in the plant crop of the ten Series 87 regional trials (1995-96). When the TCH of the plant crop was related to the climatic water balance, there was a tendency for higher tonnages under moisture-deficit conditions in 2 of the 3 varieties (Figure 3). This did not occur when the TCH of the same plant crop was related to the temporal water balance for the crop cycle (Figure 4), where high rainfall prevailed in the majority of the sites during the crop cycle. The foregoing indicates that under temporal conditions of water stress (excess, in this case), other factors such as the physico-chemical characteristics of the soil may account better for the response in TCH. Differences in cane production are found in soils of the same management group in fertilisation experiments with variety MZC 74-275, where no fertiliser was applied. The variation in production was, in that case, due to differences in organic matter content and the availability of K in the soil (Quintero et al, 1996).

![Figure 3. Relationship between TCH and the climatic water balance for varieties MZC 74-275, CC 85-92 and CC 85-68 evaluated in variety trials in plant cane. 1995-1996](image-url)
The foregoing indicates that specific climatic changes (e.g., excess rainfall in a given year) have a different impact on the production response of the varieties in the different soil management groups (Figure 4). When longer time periods are considered (Figure 1) or information is available from an ample range of environments (Figure 2), however, the production responses depending on the climatic water balance factor are more consistent because climatic variables can change quite rapidly in short periods of time, resulting in contrasting effects in production (Figure 4); whereas the variations in the geographic space are more gradual (Figure 1). This leads us to consider two types of megaenvironments: spatial megaenvironments that can be more permanent and megaenvironments that are more sporadic. In the case of the geographic valley of the Cauca River, the foregoing results suggest that spatial megaenvironments dependent on the climatic water balance consistently define the trends in the response in TCH better than the temporal megaenvironments defined by the temporal water balance.

Figure 4. Relationship between TCH and the temporal water balance for MZC 74-275, CC 85-92 and CC 85-68 evaluated in variety trials in plant cane. 1995-1996

Information on the climate complements that of the environment in which the plant develops and facilitates understanding production changes. The cane production data in the plant crop for the varieties of ten Series 87 regional trials were compared with the climatic variables generated at the nearest meteorological station. Table 2 gives the correlations between TCH vs radiation, temperature, rainfall and estimated evapotranspiration for three stages of crop development: 1 to 3 mo., 3 to 9 mo. and 9 mo. to harvest. Despite having data from only 10 sites and during only one crop cycle and some climatic variables can be related, it was noted that the association between TCH and each of the variables depended on the varieties and, to a certain extent, the stage of development. Thus, the correlations between TCH and rainfall during the rapid growth stage (3-9 mo.) were negative (range of -0.50 to -0.74) in 9 of the 13 varieties; while in the 4 other varieties, there was no such association. The correlation between TCH and rainfall for variety CC 85-68 was negative (-0.64); while there
was none for CC 85-92 and MZC 74-275. This result is in accordance with the aforementioned trend for this variety's having the lowest TCH under conditions of excess water. The correlations between TCH and radiation showed the same trend for 5 of the 13 varieties (range of -0.51 to -0.67) in the first stage of development. For more conclusive results with respect to the effect of the climate on production, more data are required. Nevertheless, with this type of association it is possible to identify varieties whose TCH is less sensitive to certain temporal factors.

Table 2. Correlations (x1/100) between TCH and 4 climatic variables for the Series 87 varieties, plant crop, 1995-96.

<table>
<thead>
<tr>
<th>Stage(1^j)</th>
<th>Varieties(3^j)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MZC 92 68 66 117 231 251 409 434 473 474 479 505</td>
<td></td>
</tr>
<tr>
<td>RAD(3^j)</td>
<td>1</td>
</tr>
<tr>
<td>Tmax</td>
<td>1</td>
</tr>
<tr>
<td>Tmed</td>
<td>1</td>
</tr>
<tr>
<td>RAIN</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>-64</td>
</tr>
<tr>
<td>3</td>
<td>-48</td>
</tr>
<tr>
<td>ETP(4^j)</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>58</td>
</tr>
</tbody>
</table>

---

**CONCLUSIONS**

The climatic water balance (based on the historic characterisation of the rainfall and evaporation) is the factor on which cane production depends to the greatest extent. Accordingly, the climatic water balance will be considered initially as the primary factor in defining the megaenvironments.

The soils management group was the second in importance in explaining differences in cane production; however, this explanation was less consistent than the climatic water balance. Under conditions of excess moisture, cane production was not clearly correlated with the soils management group.
The results of this research are preliminary. Nevertheless, they form the basis for making progress in the knowledge of the factors that determine production. This, in turn, will provide the bases for defining the proposed megaenvironments with greater precision, the technology for each one of them and orientate the regional location of varieties, both at the experimental and commercial levels.

REFERENCES


NICHOS AGROECOLÓGICOS PARA LA INDUSTRIA AZUCARERA COLOMBIANA: CARACTERIZACIÓN E IMPLICACIONES PARA LA SELECCIÓN DE VARIEDADES Y EL MANEJO AGRONÓMICO DEL CULTIVO.


RESUMEN

El área cañera del área azucarera colombiana se encuentra localizada en un valle heterogéneo respecto a sus condiciones agroclimáticas. Lo anterior se refleja en producciones diferenciales de azúcar de acuerdo con el ambiente donde se siembren. Esto indica que existen diferentes nichos agroecológicos para los cuales se requieren diferentes prácticas agronómicas y diferentes variedades. El objetivo de este trabajo es presentar los avances en la caracterización de nichos agroecológicos para la zona azucarera colombiana. Se analizó la información de suelos (órdenes, conjuntos y grupos de manejo), regímenes de humedad e isobalance hídrico. Se determinaron los factores más importantes que explican la variación en producción de caña y azúcar. El isobalance hídrico, el cual es un indicativo del nivel de humedad que dispone el cultivo y el grupo de manejo de suelos, son los dos factores que más explican la variación en producción de caña y azúcar y como tal son la base inicial para la selección y evaluación variedades de variedad y desarrollar prácticas agronómicas. Factores climáticos como la precipitación son fluctuantes en el tiempo y espacio e ilustra cómo en la definición de los nichos es conveniente considerar la temporalidad de los factores climáticos aparte de la ubicación geográfica.

Palabras Claves: Caña de azúcar, nichos agroecológicos, grupos de manejo de suelos, isobalance hídrico, regímenes de humedad del suelo, variables de producción

MEGAENVIRONNEMENTS” POUR L’INDUSTRIE SUCRIERE COLOMBIENNE: CARACTERISATIONS ET IMPLICATIONS POUR LA SELECTION VARIETALE ET LA CONDUITE DES CULTURES


RÉSUMÉ

La zone de culture de la canne de l’industrie sucrière colombienne est située dans une vallée aux conditions agroclimatiques très éloignées de l’environnement dans lequel elles sont plantées. Il existe donc des “mega-environnements” distincts qui requièrent des pratiques agronomiques et des variétés différentes. L’objectif de cette communication est de présenter les progrès réalisés dans la caractérisation de ces “mega-environnements” de la zone cannière colombienne. Les variables prises en compte sont pour les sols leur classification et leurs groupes par mode de gestion et pour l’eau l’évolution de l’humidité et le bilan hydrique défini par des isolignes. Les facteurs les plus importants qui expliquent la variation de la production de canne et de sucre ont été déterminés. Le bilan hydrique qui est un indicateur du niveau d’humidité disponible pour la culture et les groupes de sols par mode de gestion sont les deux facteurs qui ont le plus d’impact sur la production de canne et de sucre. Ils constituent donc une base de référence pour la sélection et l’évaluation variétale de même que pour le développement de pratiques agronomiques. Les facteurs climatiques tels que les chutes de pluie sont très fluctuants en fonction du temps et de l’espace ce qui montre l’importance de considérer la nature temporelle des facteurs climatiques séparément de la localisation géographique dans la définition des “mega-environnements”.

Mots clés: canne à sucre, “mega-environnements”, groupes de sol par mode de gestion, bilan hydrique, régime d’humidité des sols, variables de production.