RELATIONSHIP BETWEEN GROWTH AND UPTAKE DYNAMICS IN SUGARCANE

P.F. Chabalier

CIRAD/IRAT-97487 Saint-Denis Cedex, Réunion

ABSTRACT

The correlative relationship between growth, expressed as an increase in dry matter (DM) or volumetric index (a non-destructive growth indicator); and the uptake of mineral elements (notably N, P and K) was studied in a three level nitrogen fertilization experiment. The element dilution curves from the leaves and stalk differ by the element and vary depending on the N treatment. When the level of nitrogen nutrition required for growth is provided, there is a dilution described by the relationship: N % = DM^b, where the dilution coefficient (b) is close (b = 0.33) to corresponding values published for other crops. The generality of this relationship for optimal nutrient content could enable one to formulate real level diagnosis for nitrogen nutrition of a cane field, independent of environmental conditions and of the age of the cane. These relationships could equally be used in already developed growth models such as EPIC-AUSCANE.

Key words: Sugarcane, growth, nutrition, allometric relationships, fertilization, diagnosis.

INTRODUCTION

A primary goal of mineral nutrition studies is to establish the critical concentrations of each nutrient required for optimum growth. Different methods of foliar diagnosis have been adapted to specific crops and conditions of crop areas. These diagnoses are always empirical, subject to standardization constraints, and must be related to a locally established reference. Indeed, the mineral composition of an organ depends upon its position (age) on the plant and the developmental phase when the sample was taken. There is, therefore, a need to define the conditions of sampling and to use adapted references. The acquisition of a local scale through the progressive accumulation of available references remains a constant objective of plant nutrition research.

Attempts to improve (Bowen) and to simplify analyses by ratios as with DRIS (Beaufils, Meyer) have met limited success. Ratios give rela-
tionships which depend on the physiological age of the sample tissue; the
aging of the leaf is accompanied by divergent rates of change of certain
mineral element concentrations (Ca and N, for example). Also, ratios do not
necessarily decrease variety differences in the luxuriant use of certain ele-
ments: DRIS remains therefore a method which requires local calibration.

A ten-year series of experiments in the Reunion have failed to prove the
superiority of DRIS compared to more classic methods of plant nutrition
diagnosis. However, the use of different methods for analyzing plant nutrition
do provide means to confirm diagnoses. The ranking of deficiencies identi-
cified by DRIS and a good correlation of the sum of the indexes to the yield
leads to efficient application of information obtained from available data.

Another goal of nutrition studies is to quantify the relationship between
growth and nutrient level, with the aim of defining relatively simple general
rules of mineral element use. Practical application of the knowledge of these
relationships lead to superior methods of nutritional diagnosis; and the
incorporation of this knowledge to the growth models.

At present, most growth models, e.g. EPIC-AUSCANE-CERES, use a model
of nitrogen mobilization based on a very empirical dilution law. Nitrogen
deficiency is defined by a stress index, obtained by comparing the availability
of N in the system to the theoretical needs of the plant established from existing
nutrition trial data. Example of simulation carried out on three theoretical
nitrogen concentrations introduced in the crop parameters is shown (Figure 1 A&B).
The N stress index can reduce growth if it is less than other stress indexes (water, temperature, etc.) Stress index varies from
no stress (0) to most severe stress (1).

![Figure 1](image-url)

**FIGURE 1.** Nitrogen content of stalks as a function of day in the
crop cycle (A) and dry matter production (AUSCANE
simulation) (B).
However, recent studies first carried out on forage grasses (Lemaire and Salette, Salette and Lemaire), then on other plants, have shown that the nitrogen content of plants can be linked to the quantity of dry matter produced by the relationship \( N\% = a(DM)^b \) where \( N\% \) is the nitrogen content, \( DM \) is the dry matter, and \( a \) and \( b \) are constants.

For an unrestricted level of nitrogen (\( N_s \)), applied to C4 plants, workers report the particularly reliable relationship:

\[
N\% = 3.7 \times (DM)^{0.32} + 0.35
\]

This allometric relationship \( b = 0.33 \) can be explained by the simple relationship between surface and volume of the leaves metabolizing the nitrogen (Greenwood). The different coefficients \( a \) observed can be attributed to the difference in nutrient use efficiency, between C3 and C4 classes of photosynthesis.

The existence of a stable reference equation for the entire plant or an organ, representative of the critical nitrogen level of the whole plant would allow the user of particularly simple diagnoses since no empirically determined correction is required for the phenological stage of sampling. This diagnosis would be more reliable for metabolized elements (N-P-S) than for others. For example, any point on the graph (\( N_s = a \) function of \( DM \)) would enable one to judge the adequacy of nitrogen nutrition of the crop depending on whether the value is above or below the \( N_s \) curve. Another use of this relationship would be a more precise model of the mineral uptake by sugarcane for growth models, e.g., AUSCANE.

We present here the first study of the relationship between the growth of sugarcane and the dynamics of mineral element uptake in the Réunion.

**MATERIALS AND METHODS**

The experimental treatments were conducted at Bras-Panon, Reunion (21°7'S) in 1989-1990. Fields were located on the east side of the island at an elevation of 70 m. The soil is characterized as a Fluvent-type recent basaltic alluvials, but the superficial layer (0-20 cm) has Dystrandept characteristics (pH water = 5.3, P. Olsen = 600 ppm).

The experimental design was a complete randomized block containing 3 treatments (levels of nitrogen) and 3 replications. The experiment was conducted on the first-ratoon fo a plant crop of cultivar R-570 harvested in February 1989. Following harvest, the field was fertilized with a complete 18-7-30 (N-P-K) at the rate of 1000 kg/ha. in March, heavy rains (750 mm)
Nitrogen and leached the soil. Treatments with levels of additional nitrogen, \( N_0 = 0 \) kg/ha; \( N_1 = 110 \) kg/ha and \( N_3 = 220 \) kg/ha were made as two equal applications on April 10 and June 1.

Growth was monitored by sampling every 15 days measuring the number of stalks, height of stalks and basal diameter of stalks in a area of 1.5 m² (1m² sample). Then every stalk was harvested and divided into 3 parts: the stalk from the base up to the attachment of the sheath of the top visible dewlap (TVD) leaf, the leaf blade of the TVD leaf, and the remaining green leaf blades above the TVD and below. Each plant sample was weighed, dried at 75°C in a forced air oven, ground in a plant mill and analyzed for N, P, K, Ca and Mg with a flame atomic absorption photometer. Data were summarized, analyzed by simple statistics and used in a nonlinear regression analysis (Jollivet and Tomassone).

RESULTS

Evaluation of dry matter

Growth phase normally ends at about 270 days. Tillering reaches maximum at about 100 days with 50 stalks/m. then rapidly decreases to stabilize at around 180 days to 15 stalks/m. The decrease in number of stalks was accompanied by a rapid increase in height of the remaining stalks. The general growth model was on the average (up to 300 days): DM in mg/ha (total) = 0.19t-13.3 \((r^2 = 0.93)\) \((t = \text{No. days of cycle})\). DM yield is approximately 40 mg/ha with a difference between No and \(N_1, N_2\) which are equivalent (Figure 2).

\[ \text{DM} = 0.19t - 13.3 \]

\[ r^2 = 0.93 \]

\[ t = \text{No. days of cycle} \]

\[ \text{DM yield} = 40 \text{ mg/ha} \]

FIGURE 2. Rate of dry matter accumulation (kg/ha) at different times during the crop cycle in response to 3 levels of nitrogen applied.
To estimate the rate of growth with a non-destructive method, we used as an indicator the volumetric index \( I_v = nHd^2 \), where \( H \) = height, \( d \) = diameter, \( n \) = number of stalks per 1 meter row. The correlations obtained with measured DM were: DM total kg/ha = 200 \( I_v \)–2900 \( (r^2 = 0.94) \); DM stalk kg/ha = 172 \( I_v \)–4420 \( (r^2 = 0.92) \).

The volumetric index proved to be a reliable estimate of the dry matter produced. The \( I_v \) avoids sampling manipulations which cost time and contribute to measurement errors.

**Mobilization of mineral elements**

**Nitrogen**

In the leaves the concentrations decrease slightly from day 100 to day 220, then rapidly decrease at the end of the cycle (Figure 3). The concentrations in the leaf No. 1 (TVD) are superior to those in leaves 1-2-3 and the effect of N treatments is more noticeable. In the stalks, the decrease is of an exponential type and the effect of N treatments is significant.

![Figure 3](image)

**FIGURE 3.** Concentration of stalk nitrogen as a function of dry matter accumulated in the stalks and level of nitrogen applied.

The mobilizations increase up to 250 days, which is the date at which the foliar surface has reached its maximum (LAI max). The mobilizations by the leaves stabilize around 150 days then continue in the stalks.

The phenomenon of dilution is more noticeable in the stalks (Figure 3) than in the leaves (Figure 4). The dilution coefficients are different for each treatment:
Negatives coefficients on No  $\bar{N} = 0.92 \text{ (DM)}^{0.53}$  
N1  $\bar{N} = 1.23 \text{ (DM)}^{0.39}$  
N2  $\bar{N} = 1.27 \text{ (DM)}^{0.35}$  

The coefficients for N1 and N2 are close to those published by Lemaire and Salette (0.33) for the satisfaction curve in nitrogen Ns. The dilution is greater when there is a nitrogen deficiency (0.53).

**FIGURE 4.** Concentration of leaf nitrogen as a function day in the crop cycle in response to 3 levels of nitrogen.

**Phosphorus**

In the leaves the concentrations are quite stable up to day 200, then rapidly fall (Figure 5). The N treatments have a significant action (No > N1 and N2) on the concentrations of the TVD. In the stalks, the concentration of P follows a decreasing exponential law.

**FIGURE 5.** Average concentration of leaf phosphorus as a function of day in the crop cycle in response to 3 levels of nitrogen.
Mobilizations regularly increase on the cycle with the effect of nitrogen treatments (N1 and N2 > No).

The dilution phenomenon in the stalk (Figure 6) is very high at the start of the cycle (P % goes from 0.15 % to 0.05 % in 50 days.) From day 150, the concentrations vary little. The dilution coefficient is 0.44 which is larger than that of nitrogen.

**FIGURE 6.** Average concentration of stalk phosphorus as a function of stalk dry matter in response to 3 levels of nitrogen.

**Potassium**

Fluctuating variations of concentrations can be observed in the leaves which seem to be linked to the water consumption of the plant (Figure 7) and to the lixiviation of the soil. The effect of N treatments is significant at the beginning of the cycle. The decrease of concentrations after 200 days follows a similar pattern of N and P concentrations. In the stalks, the concentrations decrease following an exponential law. They fall from 4 % at the beginning of the cycle to 0.5 % at the end.

Mobilizations stabilize at around day 150 and vary according to the treatments:

- N0 = 170 u
- N1 and N2 ≥ 200 u
Dilution in the stalks (Figure 8) is very high ($b = -0.95$) with a speed of 0.3% per ton of sugarcane produced up to 12 mg of DM (approximately 150 days).

**Calcium and magnesium**

The dilution phenomena of calcium (Figure 9) and magnesium (Figure 10) are similar to that of potassium.
PLANT PHYSIOLOGY

FIGURE 9. Average concentration of stalk calcium as a function of stalk dry matter in response to 3 levels of nitrogen.

FIGURE 10. Average concentration of stalk magnesium as a function of stalk dry matter in response to 3 levels of nitrogen.

DISCUSSION

The dilution phenomenon is common for all the elements. It is more noticeable in the stalks than in leaves. In fact, due to a relative stability of concentrations in the leaves between 50 and 200 days, the dilution is less. For the whole plant, the dilution is intermediate and becomes progressively similar to that of the stalk at the end of the cycle.

A stalk can be used as a sample organ because it possesses all the characteristics required for a sample use, including a fairly precise estimation of dry matter produced by measuring the volumetric index (Tables 1,2).
Several types of phenomena can be distinguished:

- High dilution in K (Figure 8)
- Moderate dilution in Ca-Mg (Figures 9 and 10)
- Low dilution in N-P (Figures 3 and 6)

It seems that, at a satisfaction level for nitrogen, a dilution coefficient can be found in the region of 1/3 as quoted by Lemaire and Salette which corresponds to a general allometric rule between nitrogen and the fresh weight of the matter produced. We dispose therefore of a relationship of a general nature which, upon confirmation, would allow several types of practical applications.

Considering the vast quantity of biomass produced by sugarcane, it would be interesting for diagnosis purposes to use the substitution variable Iv instead of the measured biomass. The relationships would be found in Table 2.

**TABLE 2.** Dilution of the elements in function of the volumetric index measured N % stalk = a (Iv)².

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Treatments</th>
<th>N0</th>
<th>N1</th>
<th>N2</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td></td>
<td>7.24</td>
<td>6.00</td>
<td>6.62</td>
</tr>
<tr>
<td>b</td>
<td></td>
<td>0.71</td>
<td>0.55</td>
<td>0.54</td>
</tr>
<tr>
<td>r²</td>
<td></td>
<td>0.83</td>
<td>0.85</td>
<td>0.85</td>
</tr>
</tbody>
</table>

The correlations are not quite as good as those obtained with a measured biomass, and some precision is lost. However, much time is saved in manipulation. The relationships would also need to be generalized to determine the coefficients a and b.
The study of the dilution of elements in the DM produced by sugarcane shows that certain organs are more prone than others to this phenomenon.

The choice of using a stalk is better for the following reasons: the law of dilution of elements are described by a simple model; it enables characterization of the DM produced using a reliable indicator, IV, and the manipulation is easier than with leaves for taking samples for analysis.

The first results are encouraging enough to look for and establish more general relationships. However, the establishing of a general relationship of dilution in an element for a satisfaction level must be validated in a sufficient number of situations.

This leads to interesting perspectives: in matters of nutrition diagnosis, the method would be more practical because it would not depend on any hypothesis on the phenological stage of sampling and the equation used unique and independent of regional calibrations. Also, in the field of growth modelization, an accurate knowledge of the dilution laws, hence the mobilizations of the nutrients, would improve the reliability of the models already in use.

REFERENCES

LE RAPPORT ENTRE LA CROISSANCE ET LA DYNAMIQUE DE L'ABSORPTION DES ELEMENTS NUTRITIFS PAR LA CANNE A SUCRE

P.F. Chabaler
CIRAD/IRAT 97487, Saint-Denis Cedex, Réunion

RESUME

Des essais de fumure avec trois doses d'azote ont permis d'établir des corrélations entre la croissance exprimée en matière sèche (MS) ou par l'indice volumétrique (index de croissance non-destructif) et la consommation d'éléments minéraux (notamment le N, P et K). Les courbes de dilution pour les éléments nutritifs présents dans les feuilles et les tiges diffèrent pour chaque élément, et varient selon le taux d'azote. Lorsqu'un rapport d'azote requis par la plante est réalisé, il est accompagné d'une dilution décrite par N% = DM* où le coefficient de dilution (b) est proche de 0,33 des valeurs qui correspondent à d'autres cultures. La possibilité de déterminer cette relation pour la recherche de l'optimum nutritif permettra de formuler un vrai diagnostic afin d'envisager la fumure azotée d'un champ de cannes, indépendamment des conditions du milieu, et de l'âge de la canne. Ces relations pourraient être également appliquées à des modèles de croissance déjà développés tels que l'EPIC-AUSCANE.

Mots clef: Canne à sucre, croissance, nutrition, elongation, fumure, diagnostic.
RELACIÓN ENTRE LAS DYNAMICA DE CRECIMIENTO Y LA CAPACIDAD DE TOMAR LOS NUTRIENTES DE SUERO EN LA CAÑA DE AZÚCAR

P.F. Chabalier

CIRAD/IRAT, 97487 Saint-Denis (Cédex) Réunion

RESUMEN

La relación correlativa entre el crecimiento o desarrollo expresado como el aumento en materia seca (DM) o índice volumétrico (indicador de crecimiento no destructivo), y la capacidad de tomar los nutrientes minerales del suelo, (principalmente N, P y K) fue estudiada en experimentos con 3 niveles de nitrógeno. Las curvas de diluciones de elementos en las hojas y tallos diferían entre los elementos, y variaban de acuerdo con el tratamiento de nitrógeno. Cuando se le provee a la planta el nitrógeno suficiente, existe una dilución que da la relación: $N\% = DM^b$, donde el coeficiente de dilución ($b$) casi corresponde ($b=0.33$) a los valores conocidos para otro tipo de cosecha. Las generalidades de esta relación nos puede permitir formular los requisitos de nitrógeno en un campo dado de caña de azúcar, independientemente de condiciones ambientales y de caña. Estas relaciones también se pueden utilizar en modelos conocidos tales como el EPIC-AUSCANE.