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THE NITROGEN CONTENT OF SUGARCANE AS INFLUENCED BY MOISTURE AND AGE

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INTRODUCTION

There is an intimate, dynamic relationship between the moisture content, the age, and the nitrogen content of the various parts of the sugarcane plant. This relationship must be taken into consideration for the precise evaluation of the fertilizer needs of the sugarcane plant by the use of foliar-diagnosis techniques.

The relationship between the factors nitrogen, moisture, and age have been mentioned in the literature, separately, or in various combinations. However, the close association of these three factors has not been thoroughly explored, nor has their bearing on foliar analysis been sufficiently stressed.

Clements has taken these factors into consideration in his work on crop-logging. He used the moisture in the elongating cane sheath as his moisture index (7)[2]; for after numerous analyses of all parts of the cane plant, the sheath was found to be most reflective of the moisture changes in the plant. Clements used the nitrogen content of the elongating cane leaves as his nitrogen index (8). He accounted for the influence of age of the sample by specifying lower levels of both nitrogen and moisture as the age of the plant increased.

Borden touched upon the moisture-nitrogen relationships in cane in his work with the nitrogen fertilization of sugarcane (3). He showed that the moisture content of sugarcane increased as the nitrogen level increased.

Howe (9) in a critical examination of crop logging in Hawaii, mentioned many factors which might influence the leaf-nitrogen content of the cane. He stated that nitrogen is directly related to sheath moisture and inversely related to age. The relationship for leaf nitrogen-sheath moisture-age

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[2] Numbers in parentheses refer to Literature Cited, p. 12.

was developed separately for variety 37-1933 and for a grouping of varieties H.109 and 32-8560. For both varieties, similar curves were obtained for nitrogen as related to age, and straight lines for nitrogen as related to sheath moisture. Three dimensional curves were developed to present the relationship among the three factors: Leaf nitrogen, sheath moisture, and age.

The purpose of this paper is to evaluate critically the nitrogen–moisture–age relationship, and to show how it may be applied quantitatively in establishing a sound foliar-diagnosis program for sugarcane grown in either humid or irrigated areas.

NITROGEN AND MOISTURE

In seeking the relationship between foliar analysis and crop yield in sugarcane, controlled field experiments were carried out by the staff of the Agricultural Experiment Station of the University of Puerto Rico. Yearly data taken from plots which had received the same fertilizer and cultural treatments showed marked variations in leaf-nitrogen values from year to year. An example of this is given in table 1, presenting data from a combined variety-fertilizer experiment carried out at Arecibo on Coloso silty clay (10).

In this experiment, the 125-pound nitrogen-per-acre treatment gave highly significant yields of sugar per acre over the no-nitrogen treatment. In general, for the 5 crops, the use of 125 pounds of nitrogen per acre in excess of 125 pounds of nitrogen per acre did not give additionally significant increases in yield. On this basis, the level of nitrogen in the leaves at the 125-pound nitrogen-per-acre treatment might be selected as the leaf-nitrogen level associated with an optimum application of nitrogen as regards sugar yield per acre. However, it can be seen in table 1 that for the second ratoon, the leaf-nitrogen content was 1.64 percent; for the third ratoon it jumped to 1.76, and for the fourth ratoon it dropped to 1.43. From these values, it is impossible to decide what this leaf-nitrogen level should be. It is obvious that all leaf-nitrogen values are very high for the third, lower for the second, and very low for the fourth ratoon. As the same fertilizer and cultural treatments were used for all crops, these fluctuations were for the most part caused by differences in climate. The climatic factor can be divided into temperature, light, and rainfall. The seasonal variations in temperature and light were not recorded for this experiment and corrections could not be made for these.

The influence of rainfall on the variation of nitrogen in the leaf was determined by using the rainfall data for the area. In figure 1, A, the rainfall for the period from the time of cutting of the previous ratoon crop to the taking of the leaf sample has been plotted against the percentage of nitrogen in the leaves. The regression coefficient for the equation of the relationship was significant for the mean of the four varieties. The equation obtained was:

$$Y = 0.96 + 0.021\ X$$

where Y is the percentage of nitrogen in the leaf on a dry-weight basis, and X is the rainfall in inches from the time of cutting the previous ratoon

TABLE 1.—*Nitrogen content as percentage dry weight of leaves of sugarcane*[1] *grown at different nitrogen levels,*[2] *with and without correction for rainfall*

Crop	Results when indicated quantities of nitrogen were applied, in pounds per acre		
	0	125	250
A: *Without correction for rainfall*			
	Percent N	*Percent N*	*Percent N*
Second ratoon	1.43	1.64	1.84
Third ratoon	1.59	1.76	1.83
Fourth ratoon	1.21	1.43	1.43
Mean of 3 crops	1.41	1.61	1.70
B: *Corrected for rainfall*[3]			
	Percent N	*Percent N*	*Percent N*
Second ratoon	1.35	1.56	1.76
Third ratoon	1.38	1.55	1.62
Fourth ratoon	1.36	1.58	1.53
Mean of 3 crops	1.36	1.56	1.64

[1] Mean of 4 varieties: P.O.J. 2878, P.R. 903, M. 275, and M. 317.

[2] All plots received phosphoric acid and potash at rates of 300 lbs. of P_2O_5 and K_2O per acre, respectively.

[3] All nitrogen values corrected to a basis of 20 inches of rainfall for the period from cutting of the previous ratoon crop to the time of leaf sampling. Actual rainfall values in inches were 24, 30, 13 for the corresponding periods of the second, third and fourth ratoons, respectively.

crop to time of sampling. Thus, for every 10 inches of rain falling in the period from the previous harvest to leaf-sampling time, there was a mean increase of 0.21 percent of nitrogen in the leaf sample.

To determine whether rainfall 1 week prior to leaf-sampling time influenced the leaf nitrogen, these factors were plotted graphically (fig. 1, B). The relation obtained was also significant. One inch of rain during the week prior to sampling increased the leaf nitrogen 0.33 percent.

On the basis of 20 inches of rain for the period from the time of planting or cutting to the time of taking the leaf sample, the nitrogen values of table 1 were adjusted to eliminate the effect of variation in rainfall. The adjusted data are given also in table 1. When the data are compared, it is seen that

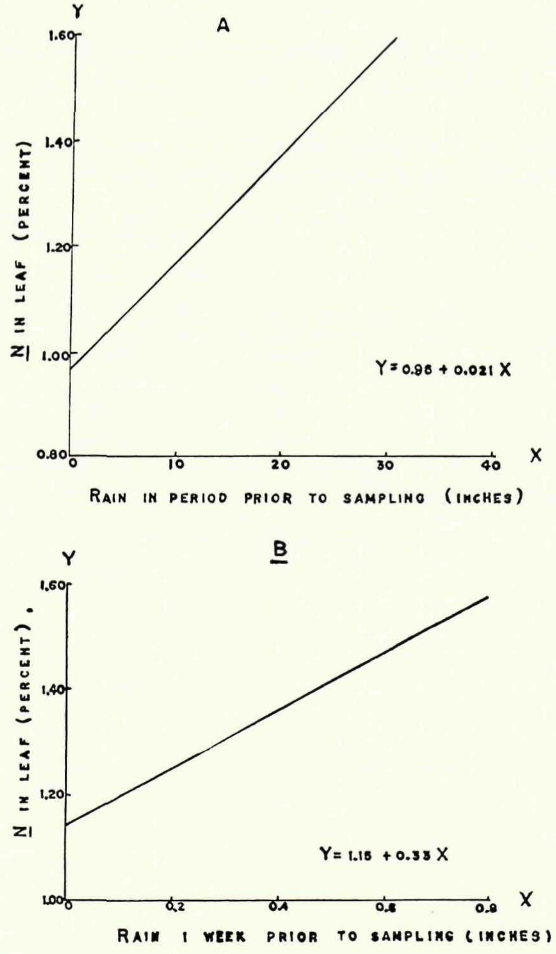

FIG. 1—A. Rainfall during the period from time of cutting previous ratoon crop to the taking of the leaf sample, as compared with percentage nitrogen in the leaf; B, rainfall during the period a week prior to leaf sampling, as compared with percentage nitrogen in the leaf.

the correction for rainfall has adjusted the values for the different years to about the same levels.

It is apparent from these data that increases in rainfall produce higher nitrogen levels in the sugarcane leaf. However, rainfall is but a gross measurement of a more precise factor—the moisture content of the plant. It is obvious that, if more accurate adjustments of the variation of the nitrogen content of the cane sample were to be made, the moisture content of the sample taken must be considered. Unfortunately, there were no data available concerning the moisture content of the leaf samples for which nitrogen had been determined. However, excellent data are available in the literature from the extensive work of R. J. Borden in Hawaii.

Borden, using various nitrogen fertilizer levels on a plant cane and two ratoons of variety 32-8560 attempted to associate leaf-punch nitrogen samples with yields. The values obtained by Borden are given in the first six columns of figures of table 2. It can be seen that, as for the Puerto Rican data, there is a fluctuation of nitrogen with each crop. Because of this fluctuation, especially the low values of the first ratoon, Borden encountered difficulty in selecting a nitrogen level in the leaf which was associated with optimum yields. If we use the moisture content of the sugarcane at the time of sampling (sheath-or leaf-moisture values for the three crops were not available) as a means of correcting for nitrogen variations in the leaf, we obtain the values given in the last three columns of table 2. The regression of moisture of the cane on leaf nitrogen was highly significant. The equation obtained for the correction of nitrogen was:

TABLE 2.—*The use of cane moisture to correct leaf-blade nitrogen content*[1]

Crop	Moisture in cane when using—			Nitrogen in leaf-punch samples when using—			Nitrogen in leaf-punch samples corrected for moisture, when using—		
	0 N	100 lbs.N	160 lbs.N	0 N	100 lbs.N	160 lbs.N	0 N	100 lbs.N	160 lbs.N
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Plant cane	72.1	74.3	74.3	0.98	1.36	1.46	1.06	1.32	1.42
First ratoon	70.5	72.5	73.6	.90	1.22	1.38	1.07	1.28	1.38
Second ratoon	73.4	75.1	76.2	1.05	1.36	1.53	1.06	1.27	1.38

[1] The data for the percentage moisture in cane and original nitrogen leaf-punch data are from Borden (1 to 3).

Corrected nitrogen = actual nitrogen − 0.0541 (actual percentage moisture content of cane) + 3.978

The corrected values show very little fluctuation when compared with the original data, and the low values of the first ratoon become comparable to those of the other two crops. The use of moisture for the correction of leaf nitrogen explained 94 percent of the random variation of the leaf-nitrogen values.

In table 3, a comparison is made using another set of data taken from two plant crops grown under a nitrogen fertilizer test by Borden (4, 5). For these data the correction for moisture was made by using leaf-sheath moisture. The corrected values are given in the last two columns of table 3. Leaf-blade moisture values have been found also to be correlated with the nitrogen content of the leaf, but this relationship is 20 percent less precise than the one for sheath moisture and nitrogen content of blade. The resultant equation of sheath moisture and blade nitrogen was very highly significant; 95 percent of the variation in nitrogen content was explained by

TABLE 3.—*The use of leaf-sheath moisture to correct leaf-blade nitrogen content*[1]

Treatment in pounds of nitrogen per acre	Moisture in leaf sheath in—		Nitrogen in leaf-punch sample in—		Nitrogen in leaf-punch sample corrected for moisture in—	
	1945	1948	1945	1948	1945	1948
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
0	77.4	77.4	1.12	1.08	1.22	1.18
100	79.7	76.7	1.35	1.12	1.23	1.28
160	79.6	77.6	1.46	1.23	1.35	1.31
220	80.4	78.8	1.51	1.32	1.33	1.29

[1] The data for the percentage moisture in leaf sheath and original nitrogen leaf-punch data are from Borden (4, 5).

TABLE 4.—*The variation of sugarcane leaf-sheath moisture for varieties*

Variety	Moisture content of leaf sheath, dry-weight basis	Variety	Moisture content of leaf sheath, dry-weight basis
	Percent		*Percent*
Barbados 37-161	84.36	P.O.J. 2878	85.20
Barbados 34-104	82.55	Mayagüez 336	85.43
Central Aguirre 38-200	82.84		

Least significant difference between means of varieties—
At the 1-percent level: 1.15
At the 5-percent level: 0.84

variations in sheath moisture. The equation obtained for the correction of leaf-blade nitrogen for sheath moisture for the two crops was:

Corrected nitrogen = actual nitrogen − 0.0934 (actual percent moisture in sheath) + 7.330

Preliminary work on leaf-sheath moisture and nitrogen relationships has shown that some varieties exhibit differences in their sheath-moisture content when grown under the same moisture conditions. The sheath-moisture content of several varieties is given in table 4. There are significant differences in the sheath-moisture content of some of the varieties. Barbados 34-104 and Central Aguirre 38-200 had lower leaf-sheath moisture values and Mayagüez 336 and P.O.J. 2878 higher values.

NITROGEN AND AGE

In general, as the cane plant grows older, except for the brief initial growing period of a few months, its nitrogen content decreases. When foliar diagnosis is used in humid areas where crop ages at harvest average but 1 year, there is usually but one sampling at a cane age of 3 months.

TABLE 5.—*The influence of sampling age on the nitrogen content of sugarcane leaf-blade samples at different ages (dry-weight basis) for 4 varieties*

Variety and age of sample (months)	Results when indicated quantities of nitrogen were applied, in pounds per acre				Nitrogen difference[1]
	0	62	125	185	
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
P.R. 903					
3	1.13	1.60	1.37	1.59	0.46
6	1.29	1.23	1.34	1.57	.28
10	1.38	1.33	1.27	1.39	.01
P.R. 904					
3	1.16	1.49	1.56	1.50	.34
6	1.39	1.44	1.49	1.55	.16
10	1.44	1.39	1.36	1.45	.01
M. 275					
3	1.26	1.20	1.53	1.52	.26
6	1.20	1.28	1.38	1.50	.30
10	1.22	1.28	1.20	1.26	.04
P.O.J. 2961					
3	1.35	1.51	1.62	1.61	.26
6	1.25	1.31	1.49	1.54	.19
10	1.52	1.48	1.45	1.42	.10

[1] Difference between 0 and 185 pounds of nitrogen-per-acre treatment.

The selection of a cane age of 3 months for Puerto Rican foliar diagnosis in humid areas is based upon data obtained at several ages of sampling. The differences obtained are shown in table 5. The greatest difference in leaf-nitrogen content between treatments (0 to 185 pounds of nitrogen per acre) was found at 3 months and the lowest at 10 months.

For cane at crop ages of 18 months to 2 years in irrigated areas, fertilization may be extended for a longer period. In these cases, leaf samples are usually taken at intervals as for the crop-logging system of Clements. However, when leaf samples are taken at various cane ages correction must be made for the influence of age on the nitrogen content of the samples taken.

In figure 2 the influence of age on sheath nitrogen is plotted from data taken on irrigated cane on the southern coast of Puerto Rico. The nitrogen content of the leaf-sheath samples decreased with increasing age. The first six samplings taken when the cane ages ranged from 6 to 10 months showed a significant linear relationship with nitrogen; however, the last three samplings, 7 to 9, did not reveal this tendency. The later samplings showed

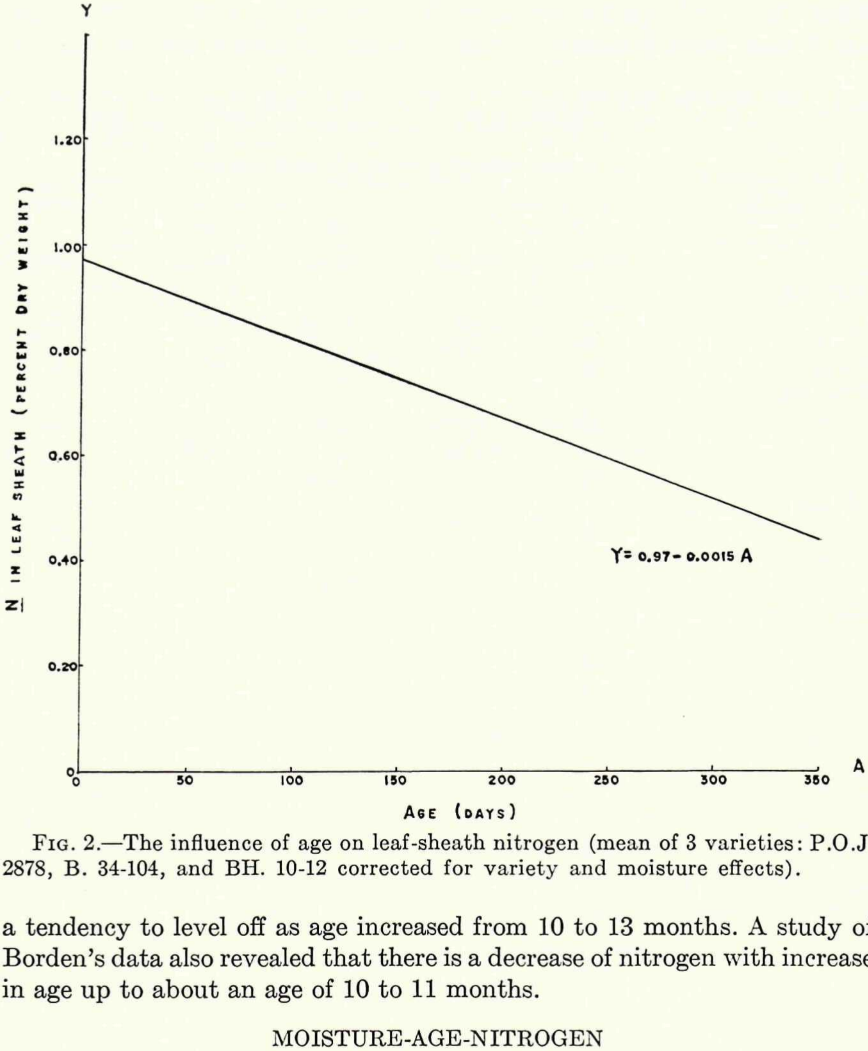

FIG. 2.—The influence of age on leaf-sheath nitrogen (mean of 3 varieties: P.O.J 2878, B. 34-104, and BH. 10-12 corrected for variety and moisture effects).

a tendency to level off as age increased from 10 to 13 months. A study of Borden's data also revealed that there is a decrease of nitrogen with increase in age up to about an age of 10 to 11 months.

MOISTURE-AGE-NITROGEN

Although we have devoted a section to moisture and nitrogen and one to age and nitrogen, for purposes of clear presentation, in practice these three factors—moisture, age, and nitrogen, are intimately related and all are operative at the same time. Moisture variations show the greatest influence on nitrogen. However, age is an important factor, if the sampling periods occur in the early portion of the curve where the decrease in nitrogen due to age is rapid, and if the time between samplings is normally greater than 2 months.

TABLE 6.—*Actual vs. adjusted nitrogen content of sugarcane leaf sheaths*[1]

Variety and field location	Nitrogen content of leaf sheath, dry weight-basis		
	Actual value	Adjusted value	Adjustment
	Percent	*Percent*	
P.O.J. 2878			
Destino 14-15	0.53	0.46	−0.07
	.42	.42	0
	.35	.47	+.12
Juana Diaz 56	.54	.47	−.07
	.42	.49	+.07
B 34-104			
Destino 54	.56	.61	+.05
	.66	.64	−.02
Destino 55	.66	.75	+.09
	.93	.71	−.22
BH 10-12			
Carmen 14	.62	.51	−.11
	.43	.43	0
Carmen 15	.52	.51	−.01
	.56	.50	−.06
Paso Seco 55	.68	.58	−.10
	.63	.59	−.04
Paso Seco 56	.59	.49	−.10
	.53	.51	−.02

[1] Calculations based on following equations:

P.O.J. 2878: $Y' = Y + 0.00210\ (A\text{-}250) - 0.0125\ (B\text{-}84.99)$

B 34-104 : $Y' = Y + 0.00119\ (A\text{-}219) - 0.0820\ (B\text{-}86.17)$

BH 10-12 : $Y' = Y + 0.00063\ (A\text{-}258) - 0.0230\ (B\text{-}81.51)$

where Y' is the adjusted leaf-sheath nitrogen, Y the actual leaf-sheath nitrogen, A the age of sample in days, and B the percentage moisture content of the leaf-sheath sample.

It may be felt that the evaluation of moisture and age only on nitrogen does not include all of the main factors which might influence the nitrogen content in the leaf sample. However, a study of data taken from cane growing on the irrigated southern coast of Puerto Rico, revealed that the variation of age and moisture with nitrogen explained over 95 percent of the random nitrogen variation. This left but 5-percent residual error to be attributed to such sources as soil and temperature differences. Clements, in a study of the factors influencing leaf nitrogen (6), found that sheath moisture showed the greatest dominant influence, and then age, maximum and minimum temperatures, and soil moisture also had some influence, but the latter three not nearly as much as did sheath moisture and age.

The influence of moisture and age on nitrogen in the cane plant is so dominant that we may use these two factors to adjust the nitrogen content of the tissue sample. With the equation obtained from the study of age and moisture on leaf-sheath nitrogen in irrigated cane from the southern coast of Puerto Rico, leaf-sheath nitrogen was adjusted using only sheath-moisture and age data. This information compared with actual values is given in table 6. It can be seen that there is very good consistency among the adjusted values.

This again serves to show that a proper evaluation of moisture and age in foliar-diagnosis work with sugarcane will allow the worker to obtain nitrogen values which can safely be used to decide whether a deficiency of nitrogen exists and the cane should be fertilized. When these nitrogen values are corrected for moisture and age, most of the variation to be encountered is eliminated, and a true picture of the nitrogen status of the cane plant can be obtained.

SUMMARY

Moisture and age have a dominant influence on the nitrogen content of the sugarcane plant. A study of these factors revealed the following:

1. The nitrogen content of the leaf sample varied from year to year, despite constant cultural and fertilizer treatments.

2. A correction of nitrogen content for moisture eliminated the majority of the fluctuation of nitrogen in the leaf samples.

3. In most cases, leaf-sheath moisture and leaf-blade moisture gave the best correction for nitrogen variation, but rainfall variation could be used as a correction factor.

4. The nitrogen content of the leaf sample increased with increasing moisture content of the tissue; this increase was linear.

5. The nitrogen content of the leaf tissue decreased with increasing age of the cane plant. Thus a decrease in nitrogen is approximately linear to an age of about 10 to 11 months for sugarcane in Puerto Rico. After 11 months the decrease tends to level off. This relationship was also observed for Hawaiian data.

6. The factors of moisture and age appear to be the most dominant in influencing the nitrogen content of the cane-leaf sample. A correction for

both moisture and age in the leaf samples taken, in many cases explained over 90 percent of the variation of the nitrogen in the sample.

7. Adjusted leaf-sheath nitrogen values were obtained from an equation using sheath moisture and age of sample. The adjusted values were in very close agreement.

RESUMEN

Los propósitos principales de este trabajo han sido: evaluar críticamente la relación entre las concentraciones de nitrógeno y agua del tejido vegetal de la caña de azúcar, y demostrar cómo se puede usar esta relación cuantitativa para determinar los requisitos del abonamiento de esta cosecha, mediante el análisis químico de la hoja.

Los datos que se presentan en este artículo demuestran que la concentración del nitrógeno en la hoja de la caña de azúcar guarda estrecha relación con la concentración de agua en la hoja. Esta concentración de nitrógeno puede usarse como un índice para determinar el grado de suficiencia o deficiencia, respecto a la alimentación de la caña, en cuanto a este elemento nutritivo.

El conocimiento que se tenga del contenido de agua en la hoja para corregir el análisis de nitrógeno, será de ayuda para hacer más exacto este sistema de análisis, de modo que se pueda decidir si es o no conveniente hacer a la cosecha una aplicación de abono nitrogenado, según lo demuestre el análisis de las hojas.

De este trabajo se pueden derivar las siguientes conclusiones:

1. El ajuste de la concentración de nitrógeno en las hojas de la caña, verificada a base de las variaciones del contenido de agua de las hojas analizadas, elimina la mayor parte de la variación casual que ocurre cuando se analizan distintas muestras de hojas representativas de una determinada serie de condiciones de crecimiento.

2. Cuando se hace uso de un factor tan sencillo como es la lluvia, desde la cosecha previa hasta que se toma la muestra, y aún la de la semana anterior a la toma de ésta, se puede corregir el contenido de nitrógeno, aunque no con la exactitud que puede hacerse cuando se determina la humedad de la misma muestra que se analiza para nitrógeno.

3. La concentración de nitrógeno de la hoja de la caña tiende a aumentar en forma de relación rectilínea, según aumenta la humedad en el tejido.

4. La concentración de nitrógeno, también, es afectada por la edad del tejido, pero si se toman las muestras de hojas cuando las plantas tienen una edad uniforme, es posible eliminar la influencia de este factor. Además, se pueden fijar con precisión los límites críticos de la concentración de nitrógeno en la hoja, a distintas edades de la planta.

5. Los ajustes hechos a base de la edad y contenido de humedad eliminaron más del 90 por ciento de la variación casual del nitrógeno en las muestras de cada una de distintas variedades de caña cultivadas bajo condiciones similares de clima, suelo y manejo en el campo.

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