An empirical relationship between climate, nutrition and nutrient concentrations in banana leaves.

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UNA RELACIÓN EMPÍRICA ENTRE EL CLIMA, LA NUTRICIÓN Y LAS CONCENTRACIONES EN ELEMENTOS NUTRITIVOS EN LAS HOJAS DEL BANANO.

UNE RELATION EMPIRIQUE ENTRE LE CLIMAT, LA NUTRITION ET LES CONCENTRATIONS EN ELEMENTS NUTRITIFS DANS LES FEUILLES DE BANANIER

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RESUME - On a étudié les variations des teneurs en N, P, K, Ca, Mg, Mn, Cu et Zn dans la matière sèche des limbes de bananier, en relation avec la nutrition et les conditions saisonnières pendant trois ans. La plus grande part (70,90 p. 100) de la variation des concentrations foliaires en éléments (C_M) est prise en compte lorsqu'on la relie aux concentrations calculées au voisinage des racines (C_o) et à l'environnement (évaporation potentielle totale E_o pendant les six phyllochrones précédant l'échantillonnage (t) par l'équation

$$C_M = (b_1 + b_2 E_o t \times 10^{-3} + b_3 C_o^{-1})^{-1}$$

où b_1, b_2 et b_3 sont des constantes empiriques.

INTRODUCTION

The interpretation of leaf analysis, widely used in the diagnosis of mineral nutrient problems in horticultural crops, depends on an established relationship between nutrient concentrations in the leaf dry matter and yield. This relationship can be affected by nutritional (other than the nutrient in question) and seasonal factors (ANDREW, 1968 ; BOLLE-JONES, 1975). The success of leaf analysis in bananas has varied because an interaction between stage of plant growth, nutrient availability in the soil and seasonal conditions (MARTIN-PRÉVEL, LACOEUILHE and MARCHAL, 1969 ; TURNER and BARKUS, 1974) makes interpretation difficult. If a relationship between nutrient concentration in the leaf dry matter, nutrient concentration around the roots and seasonal conditions could be established the effect of season on nutrient concentrations in the leaf dry matter and on the nutrient concentration-yield relationship could be explored.

The concentration of a nutrient in a plant can often be related empirically to the concentration in the medium by the rectangular hyperbolae.

$$C_M = (C_{Mmax} + \alpha C_o^{-1})^{-1} \quad \ldots\ldots\ldots\ldots \quad 1.$$

where C_m is the concentration of nutrient in the dry matter, C_{Mmax} is the maximum C_M reached when the concentration in the medium (C_o) is very large, and α is a constant. The effect of environmental factors on C_{Mmax} and α can be assessed (FRIED and BROESHART, 1967) and incorporated into equation 1.

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The relationship between C_M, C_o, environment and plant growth stage was explored in a sand culture experiment using bananas at the Tropical Fruit Research Station, Alstonville, NSW (Lat. 28° 51'S).

MATERIALS AND METHODS

The experiment commenced in January 1970 and was completed in February 1974. Bananas of 'Williams' variety ('Giant Cavendish' group) were grown for three crop cycles in drainage lysimeters.

Lysimeters - Thirty six drainage lysimeters of $1 m^3$ volume (107 cm diameter) were constructed from reinforced concrete pipes set in concrete bases and coated internally with epoxy resin. The volume was about half that available to roots in a field plantation, although bananas will grow satisfactorily in lysimeters of $0.5 m^3$ (MARTIN-PRÉVEL and CHARPENTIER, 1964). The lysimeters were set in the ground so that only 10 cm was above ground level. Each lysimeter was drained with a 12 mm diameter polyvinylchloride pipe placed across the base and penetrating it on one side. A further length of 12 mm pipe attached to the free end of the drainage pipe allowed rapid detection of blockages. Drainage water was collected in plastic bins downhill from the site. The lysimeters were spaced 3.6 x 3.0 m, about half the normal planting density for bananas in New South Wales. From the base upwards each lysimeter contained 15 cm depth of large basalt stones, 5 cm small flat river stones, 10-12 cm crushed gravel and 75 cm river sand.

Experimental design - The experiment was a completely randomized 3 K x 3 Mg x 2 Mn factorial experiment with two replications. Treatments were 1.46, 2.92 and 14.60 g K ; 0.24, 0.48 and 2.40 g Mg ; and 1.38 and 13.80 g Mn lysimeter^{-1} 2 weeks^{-1}. The highest amounts of K and Mg and the lower amount of Mn represent control treatments and are subscripted as K_1, Mg_1 and Mn_1. The remaining treatments are $\frac{1}{5}$ and $\frac{1}{10}$ of control for K and Mg and ten times control for Mn. The K_1, Mg_1 and Mn_1 treatments are one quarter the amounts used by MARTIN-PRÉVEL and CHARPENTIER (1964) ; this dilute solution produced satisfactory growth in preliminary experiments. Other nutrients (g 2 weeks^{-1}) were applied as follows : 27.7 g NO_3, 2.3 g P, 6.9 g Ca, 18.6 g SO_4, 0.24 g Na, 3.9 g Cl, 0.06 g Fe, 0.71 g Zn, 4.05 g BO_3, 0.36 g Cu, 0.77 g Mo_7O_{24}. The nutrients were dissolved in 9 litres of water and applied each 2 weeks. During the 13 days between treatments tap water was applied so that some water drained from each lysimeter each day. When rain fell irrigation water was withheld for 24 hours. The tap water contained 0.76 ± 0.13 mg l^{-1} K, 1.45 ± 0.09 mg l^{-1} Mg and 0.13 ± 0.05 mg l^{-1} Mn. Rain was assumed to contain negligible amounts of nutrients. The river sand contained 19.5 ppm exchangeable K, 121 ppm exchangeable Mg and 5.5 ppm exchangeable Mn and had a pH of 6.3.

Planting material was obtained using a micropropagation technique (TURNER, 1968). Lateral buds were pregerminaled in a glasshouse and after planting received only tap water for two weeks. The plants were grown for three crop cycles. Suckers were removed when about 30 cm high. The third cycle developed without a ratoon sucker attached.

Plant samples and analysis - Leaf samples were taken in March, June, September and December of each year commencing March 1970 and ending March 1972. The central 15 cm portion of each lamina half of the third youngest leaf from the top of the plant was taken on each occasion. The plant parts were dried at 60°C for 48 hours and the concentrations of N (Kjeldhal method with selenium catalyst), P (autoanalyser), K, Ca, Mg, Mn, Cu and Zn (atomic absorbtion spectroscopy, LEECE and SHORT, 1967) measured in the dry matter. The effects of sampling date and treatment were examined using the analysis of variance.

Estimation of nutrient concentrations around the roots (C_o) - The concentration of nutrients in the solution around the roots was taken as

$$C_o = M_1 \, W^{-1} \quad \ldots\ldots\ldots\ldots \quad 2.$$

were M_1 is the mass of the element within the lysimeter and W is the water volume in the lysimeter at field capacity. W was 95 l. On any day M will be a function of three factors - addition of nutrients to the lysimeter , removal of nutrients from the lysimeter by leaching and by plant uptake of nutrients. Nutrients were added on the first day of each two weekly period. On subsequent days the nutrient was assumed to move in a band down the sand column until more than 95 l of water had passed through the drainage outlet. It was then assumed to have been leached out. Drainage analyses suggested that the band was diffuse and that the nutrients mixed within the whole lysimeter.

Plant uptake was calculated with regard to two factors. Firstly, the amount of water evaporated by the plant would indicate the amount of nutrient brought to the root surface by convective flow. Secondly, the amount of nutrient present in the plant would show how much of this was absorbed. The total nutrient uptake by the plant (M_p) was measured at the end of the experiment and nutrient uptake rate (R_p) was expressed as

$$R_p = M_p \, . \, E_p^{-1} \quad \ldots\ldots\ldots\ldots \quad 3.$$

where E_p is the quantity of water evaporated by the plant during its growth. The quantity of nutrient removed from solution by plant uptake (U) for each day was

$$U = R_p \, . \, (E_T - E_S) \quad \ldots\ldots\ldots\ldots \quad 4.$$

where E_T is the total amount of water evaporated from the lysimeter for the day and E_S is the estimated water loss from the sand surface. The mass of any nutrient in the lysimeter (M_l) on any day, d, will be

$$M_{ld} = M_{l(d-1)} + M_{lT} - M_D - U \quad \text{............. 5.}$$

where $M_{l(d-1)}$ is the mass of nutrient present on the previous day, M_{lT} is the nutrient added in treatments, M_D is the nutrient leached from the lysimeter and U is plant uptake.

Daily concentrations of nutrients were averaged to provide a mean concentration present for each weekly period.

Environment of sampled leaves - The climatic conditions experienced by the leaf were taken over a six phyllochrons (a phyllochron is the time between the appearance of successive leaves) beginning three phyllochrons before leaf emergence and ending three phyllochrons after emergence, when the leaf lamina was sampled. During this period 90 percent of the increase in leaf area and weight takes place (BARKER, 1969 ; TURNER, 1971).

Meteorological data were collected on a lawn 150 m from the experimental site. Weekly potential evaporation (E_o) was calculated from the tables of McCULLOCH (1965). The environmental conditions during the growth of each leaf were taken as E_ot, where t is the duration of six phyllochrons in days and E_o is the mean daily potential evaporation rate.

Analyses of leaf nutrient concentration data - Using the analysis of variance the effects of treatments and sampling dates on leaf nutrient concentrations were estimated. These data were then combined and double reciprocal plots of C_o against C_M for the nutrients N, P, K, Ca, Mg, Mn, Cu and Zn were made. Using multiple regression techniques the importance of E_ot, crop cycle and plant growth stage were assessed. The ratio of leaf number produced (n) to total leaf number (Σ n) provided an estimate of plant growth stage. Crop cycles (c) were labelled 1, 2 and 3 in chronological order.

RESULTS

Potassium deficiency changed the concentrations of all elements except Zn in the leaf 3 dry matter (table 1). Magnesium was changed most (45 percent increase) and nitrogen the least (6 percent increase). The concentration of Mn, K and P decreased by 30, 29 and 8 percent respectively. Potassium deficiency increased Ca (16 percent) and Cu (8 percent) concentrations.

Magnesium deficiency decreased Mg concentration by 24 percent and slightly reduced N and P concentrations (4 percent). It increased Mn concentrations by 18 percent (table 1).

High Mn increased Mn concentration in direct proportion to supply (10.1 x) and Cu concentration by 9 percent. High Mn supply decreased the concentrations of Zn (33 percent), Mg (14), Ca (13), K(8) and N (2).

Time of sampling significantly affected the concentration of nutrients in the leaf 3 dry matter (table 1). The concentrations of all elements showed significant differences between dates. Some elements, such as nitrogen, varied seasonally (Figure 1) with low values in March samples and high values in September. Other elements (e.g. potassium) changed from date to date but within year seasonal effects were less marked (Figure 2).

The magnitude of the effects of sampling dates (40-60 percent) on the concentrations of nutrients was much greater than the effect of K or Mg deficiency (table 1). Interactions between treatments and sampling dates were significant for dates x potassium for all elements except Cu and for dates x Mn for all elements except N, P and K. The dates x Mg interaction was not significant for any element. This was interpreted as a variation in the effect of K and Mn treatments between dates, for example the effect of K deficiency on N concentration varied with the sampling date (Figure 1). The effects were more apparent after the fourth sample.

The relationship between C_o and C_M was satisfactorily described by a rectangular hyperbola (Figure 3), the relationship being

$$C_M = (b1 + b2\, E_o t \times 10^{-3} + b3\, C_o^{-1})^{-1} \quad \text{............. 6.}$$

Equation 6 accounted for a minimum of 73 percent and a maximum of 91 percent of the variation in C_M (table 2). The reciprocal of the function ($b1 + b2\, E_ot \times 10^{-3}$) represented C_{Mmax} in equation 1. Thus a change in E_o was reflected in C_{Mmax}. Leaves which grew during the winter (September samples) had higher values of E_ot than those which grew during summer (March samples). This was caused by the greater proportional increase in t during the winter even though E_o was reduced. E_ot increased the C_{Mmax} of N, P, Ca, Mg, Mn and Cu but reduced it for K and Zn. Plant ontogeny significantly improved the relationships for P and crop cycle was significant for Mg, Cu and Zn (table 2).

Increasing plant age reduced C_{Mmax} for phosphorus and increasing crop age reduced C_{Mmax} for magnesium. Crop cycle increased the C_{Mmax} for Cu and Zn.

DISCUSSION

The differences in nutrient concentrations between sampling dates was large compared with those due to treatment effects. The type of variation shown in Fig. 1 and 2 was similar to that observed by TURNER and BARKUS (1974)

Table 1 - Effect of sampling dates (averaged over all treatment) and treatments (averaged over all sampling dates) on the concentration of nutrients in leaf III dry matter.

Tableau 1 - Effet des dates d'échantillonnage (moyenne de tous les traitements)et des traitements (moyennes de toutes les dates) sur les concentrations des éléments dans la matière sèche de la feuille III.

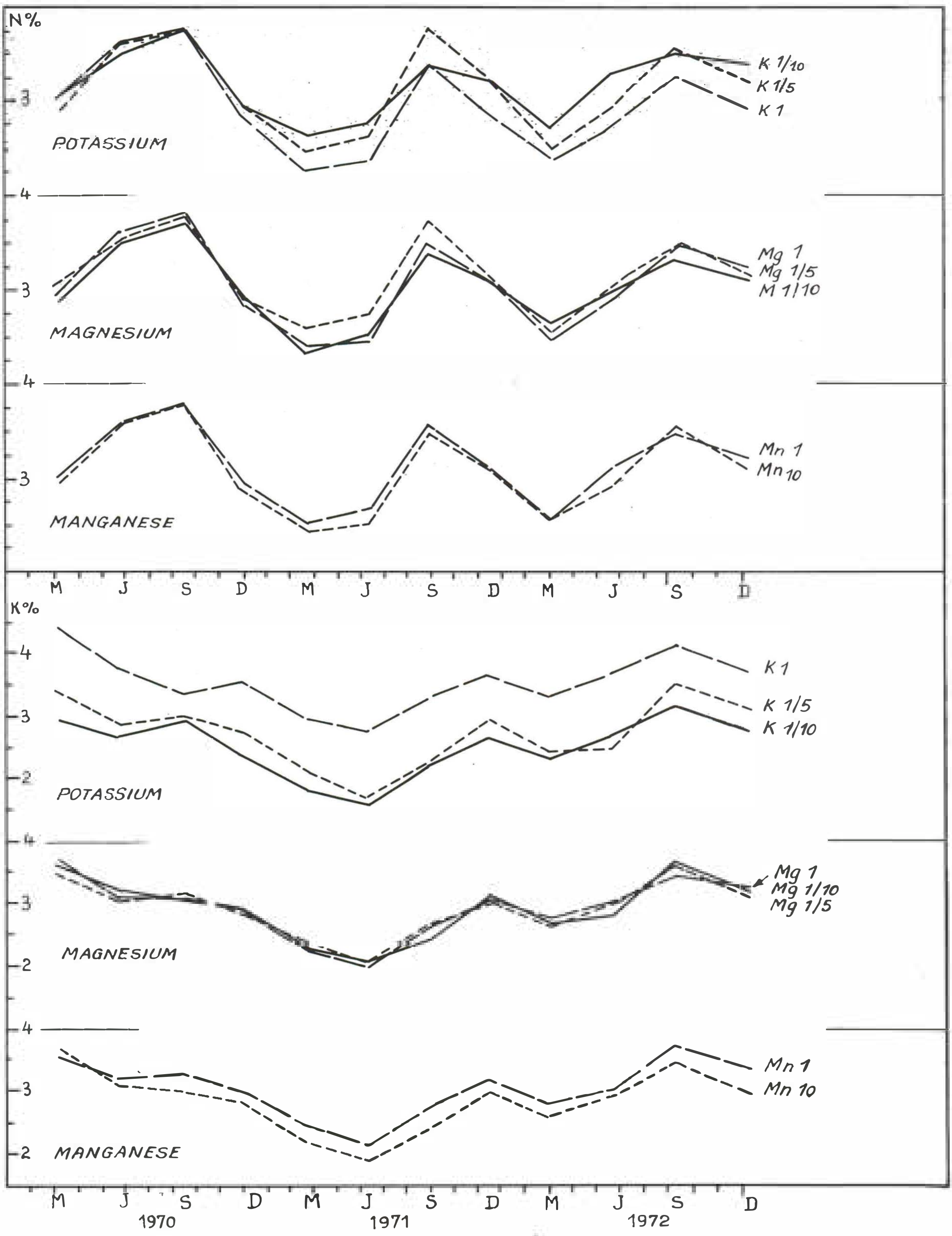
Cuadro 1 - Efecto de las fechas de muestreo (promedios de todos los tratamientos) y de los tratamientos (promedios de todas las fechas) en las concentraciones de los elementos en la matera seca de la hoja III.

Sampling date		N	P	K	Ca	Mg	Mn	Cu	Zn
		percent					ppm		
1970	Mar	2.98	0.29	3.58	0.74	0.50	1864	11.6	38
	Jun	3.56	0.25	3.11	0.96	0.59	2000	9.0	34
	Sep	3.77	0.26	3.09	1.03	0.46	3698	10.3	33
	Dec	2.91	0.19	2.89	0.69	0.45	2482	9.3	26
1971	Mar	2.45	0.18	2.29	0.69	0.29	2777	8.3	26
	Jun	2.58	0.21	2.01	1.39	0.46	3767	7.4	24
	Sep	3.52	0.26	2.56	1.73	0.57	5013	14.5	45
	Dec	3.09	0.17	3.06	0.69	0.30	3222	12.6	45
1972	Mar	2.55	0.21	2.66	0.67	0.21	3719	12.9	49
	Jun	3.17	0.25	2.92	0.92	0.26	3567	19.5	49
	Sep	3.27	0.29	3.55	1.29	0.34	4622	15.7	86
	Dec	3.09	0.23	3.15	0.93	0.26	4757	15.9	91
LSD 0.05		0.13	0.015	0.17	0.13	0.038	751	1.4	19
0.01		0.17	0.019	0.23	0.17	0.050	987	1.8	25
Nutrient level									
K/10		3.14	0.22	2.49	1.02	0.45	2737	12.9	38
K/5		3.13	0.25	2.69	1.03	0.41	3721	11.9	55
K 1		2.97	0.24	3.53	0.88	0.31	3913	11.9	43
Mg/10		3.02	0.23	2.90	1.00	0.35	3664	12.3	46
Mg/5		3.14	0.23	2.89	0.96	0.36	3590	12.5	47
Mg 1		3.08	0.24	2.92	0.97	0.46	3117	11.9	43
LSD 0.05		0.06	0.007	0.09	0.07	0.019	376	0.7	10
0.01		0.09	0.010	0.11	0.09	0.025	493	0.9	13
Mn 1		3.11	0.23	3.02	1.04	0.42	571	11.7	39
10 Mn		3.05	0.23	2.79	0.91	0.36	6343	12.8	52
LSD 0.05		0.05	0.006	0.07	0.05	0.016	307	0.6	8
0.01		0.07	0.008	0.09	0.07	0.021	403	0.7	10

in the field in this environment. The relationship shown in equation 6 could therefore be useful in understanding the contribution of C_o and E_ot to variation in C_M in the field. Given the E_ot for any sampling date and the results of a leaf analysis the mean C_o, as experienced by the plant, could be determined. This would be better than a chemical soil test since it would have the advantage of assessing nutrient available to the plant and could be better than a direct reliance on nutrient concentrations in leaves as is most commonly used (HEWITT, 1955 ; BOLAND, 1974 ; MESSING, 1974).

The negative value of the b_2 constant (table 2) was caused by nutrients accumulating in leaves with higher E_ot values, K and Zn were exceptions. Zinc was present in the sprays used to control Sigatoka leaf diseases from December to March each year which could account for the slightly higher concentrations in the summer. No explanation is apparent for high K concentrations.

Equation 6 satisfactorily fitted data for nutrients which were not changed in the treatments. The variation in C_o caused by leaching and plant uptake was sufficient to give a suitable range of C_o.



Figures 1 and 2. Effect of K and Mg deficiency and high Mn on the concentration N (fig. 1) or K (fig. 2) in leaf III dry matter over 12 samples dates.

Figures 1 et 2. Effet de déficience en K et Mg et d'un haut niveau de Mn sur la concentration de N (fig. 1) ou de K (fig. 2) dans la matière sèche de la feuille III à 12 dates d'échantillonnage.

Figuras 1 y 2. Efecto de deficiencias de K y Mn y de un nivel alto de Mn sobre la concentración de N (fig. 1) o de K (fig. 2) en la matera seca de la hoja III a 12 fechas de muestreo.

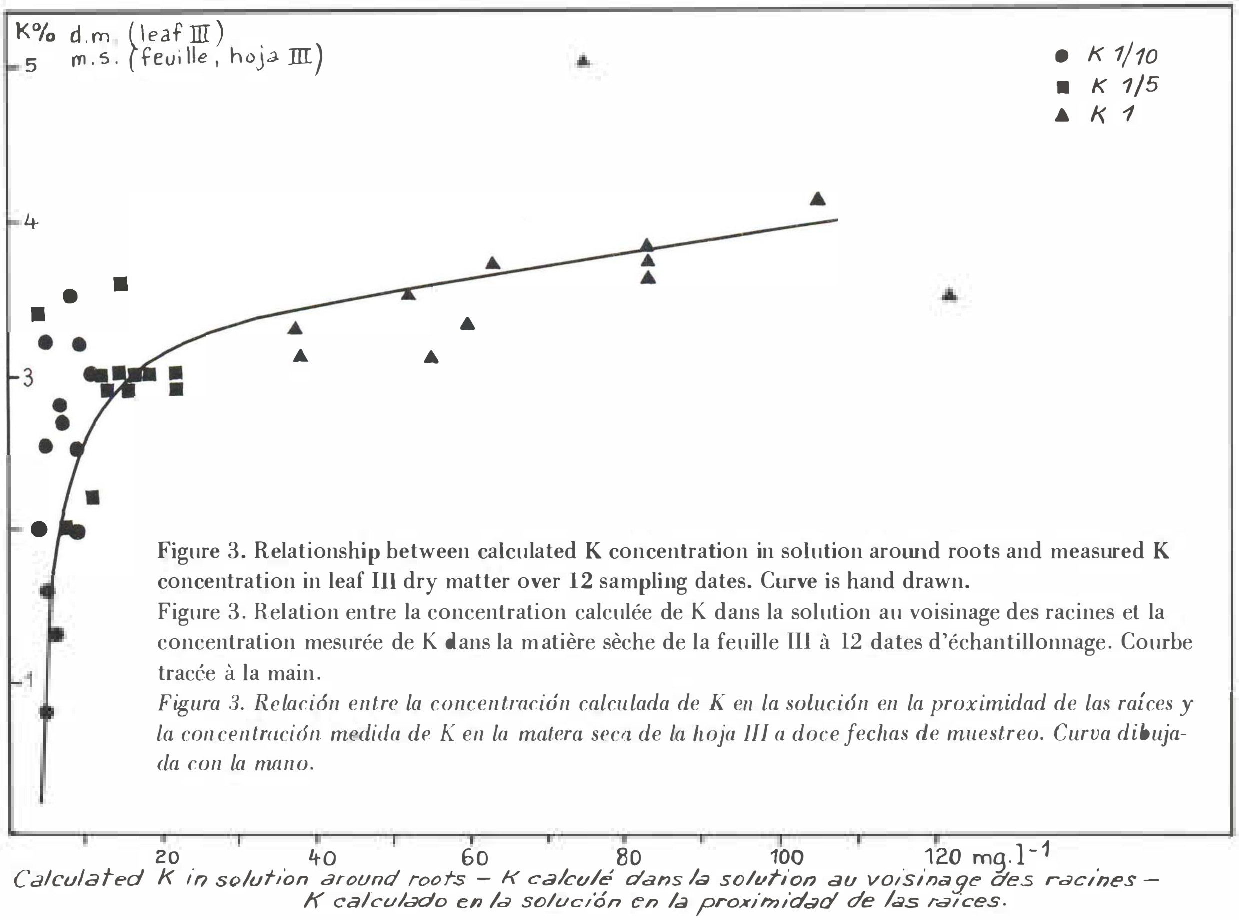


Figure 3. Relationship between calculated K concentration in solution around roots and measured K concentration in leaf III dry matter over 12 sampling dates. Curve is hand drawn.
Figure 3. Relation entre la concentration calculée de K dans la solution au voisinage des racines et la concentration mesurée de K dans la matière sèche de la feuille III à 12 dates d'échantillonnage. Courbe tracée à la main.
Figura 3. Relación entre la concentración calculada de K en la solución en la proximidad de las raíces y la concentración medida de K en la matera seca de la hoja III a doce fechas de muestreo. Curva dibujada con la mano.

The seasonal changes in C_M in this experiment were largely accounted for by changes in C_o, E_o and t. If similar relationships hold in the field the effect of environment could be included in the interpretation of banana leaf analysis. It would be possible to determine whether C_M was low because of low C_o or because of seasonal conditions or both. Such information would influence fertilizer recommendations made to growers.

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UNE RELATION EMPIRIQUE ENTRE LE CLIMAT, LA NUTRITION ET LES CONCENTRATIONS EN ELEMENTS NUTRITIFS DANS LES FEUILLES DE BANANIER

Les variations de teneurs en éléments nutritifs des limbes de bananier ont été étudiées en relation avec la fourniture de K, Mg et Mn et les conditions saisonnières. On a fait pousser pendant trois ans des bananiers de cultivar 'Williams' (groupe 'Giant Cavendish') dans des lysimètres à drainage remplis de sable. Des échantillons constitués des

UNA RELACIÓN EMPÍRICA ENTRE EL CLIMA, LA NUTRICIÓN Y LAS CONCENTRACIONES EN ELEMENTOS NUTRITIVOS EN LAS HOJAS DEL BANANO

Las variaciones de los contenidos en elementos nutritivos de los limbos del banano han sido estudiadas en relación con el suministro de K, Mg y Mn y las condiciones estacionales. Se cultivaron durante tres años bananos 'Williams' (grupo 'Giant Cavendish') en lisímetros con drenaje llenos de arena. Se tomaron muestras constituidas por los 15 cm

Table 2 - Values of constants in relationship between nutrient concentration in the leaf (C_M), nutrient concentration around the roots (C_o) and environment (E_ot) described by the equation $C_M = (b_1 + b_2 E_ot \times 10^{-3} + b_3 C_o^{-1})^{-1}$

Tableau 2 - Valeurs des constantes dans la relation entre la concentration de l'élément dans la feuille (C_M), la concentration de l'élément au voisinage des racines (C_o) et l'environnement (E_ot) décrite par l'équation $C_M = (b_1 + b_2 E_ot \times 10^{-3} + b_3 C_o^{-1})^{-1}$

Cuadro 2 - Valores de las constantes en la relación entre la concentración del elemento en la hoja (C_M), la concentración del elemento en la proximidad de las raíces (C_o) y el ambiente (E_ot) descrita por la ecuación $C_M = (b_1 + b_2 E_ot \times 10^{-3} + b_3 C_o^{-1})^{-1}$

Element	Constant				Comments*
	b_1	b_2	b_3	r^2**	
N	0.289	-0.153 ± 0.069	5.62 ± 0.95	0.81	
P	3.788	-1.363 ± 1.198	8.55 ± 1.99	0.78	1
K	-0.142	0.456 ± 0.297	1.14 ± 0.16	0.73	
Ca	1.718	-2.085 ± 1.872	13.15 ± 11.62	0.80	
Mg	2.780	-4.026 ± 1.020	2.18 ± 0.52	0.77	2
Mn	6.009	-11.82 ± 8.24	58.81 ± 5.17	0.86	
Cu	0.069	-0.014 ± 0.049	2.19 ± 0.64	0.76	3
Zn	0.013	0.007 ± 0.011	0.92 ± 0.14	0.91	4

** - all significant at / tout significatif à / todo significativo à los } P = 0.01

* - ontogeny ($N/\Sigma n$) or crop cycle (c) / ontogénie " ou cycle de culture " / ontogenia " o ciclo de cultivo " } significant

1 : $b_1 = 2.174 \pm 0.678 (n/\Sigma n) + 2.701$ where - où - donde $(n/\Sigma n) = 0.5$

2 : $b_1 = 1.114 \pm 0.119\, c + 1.672$ where - où - donde c = 1

3 : $b_1 = -0.019 \pm 0.005\, c + 0.089$ where - où - donde c = 1

4 : $b_1 = -0.008 \pm 0.0012\, c + 0.022$ where - où - donde c = 1.

15 cm centraux des deux côtés du limbe de la feuille en position III (position I = plus jeune feuille déroulée) ont été prélevés en mars, juin, septembre et décembre des années 1970 à 1972. On a mesuré les concentrations (C_M) de N, P, K, Ca, Mg, Mn, Cu et Zn dans la matière sèche du limbe. Les concentrations en éléments au voisinage des racines (C_o) ont été estimées en tenant compte des quantités absorbées par la plante, de la lixiviation et du volume d'eau retenu par le sable. L'évaporation potentielle totale (E_o) subie par la feuille durant les six phyllochrones précédant l'échantillonnage (t) a été utilisée comme mesure de l'environnement.

Les traitements K, Mg et Mn ont influé sur les concentrations en éléments, mais la variation d'une date d'échantillonnage à l'autre a été plus grande que les effets des traitements. L'effet de C_o, E_o et t sur C_M a été décrit par la relation :

$$C_M = (b_1 + b_2 E_ot \times 10^{-3} + b_3 C_o^{-1})^{-1}$$

où b_1, b_2 et b_3 sont des constantes.

centrales de los dos lados del limbo de la hoja en posición III (posición I = la hoja más joven desarrollada) en Marzo, Junio, Septiembre y Diciembre de los años 1970 a 1972. Se han medido las concentraciones (C_M) de N, P, K, Ca, Mg, Mn, Cu y Zn en la materia seca del limbo. Las concentraciones de los elementos en la proximidad de las raíces (C_o) han sido estimadas teniendo en cuenta las cantidades absorbidas por la planta, la lixiviación y el volumen de agua retenido por la arena. La evaporación potencial total (E_o) sufrida por la hoja durante los seis filocrones precedentes al muestreo (t) ha sido utilizado como medida del ambiente.

Los tratamientos K, Mg y Mn han influido en las concentraciones de elementos, pero la variación de una fecha de muestreo a otra ha sido más grande que los efectos de los tratamientos. El efecto de C_o, E_o y t sobre C_M ha sido descrito por la relación.

$$C_M = (b_1 + b_2 E_o t \times 10^{-3} + b_3 C_o^{-1})^{-1}$$

donde b_1, b_2 y b_3 son constantes.

Pour N, K, Ca et Mn l'équation donne satisfaction. Pour P, le stade de croissance de la plante (nombre de feuilles produites) est important. Pour Mg, Cu et Zn, le cycle de culture affecte significativement la relation. Ces effets ont été incorporés par modification de b_1.

La relation empirique entre C_M, C_o, E_o et t permettra de calculer l'importance du climat lors de l'interprétation des analyses foliaires sur bananier.

Para N, K, Ca y Mn la ecuación es satisfactoria. Para el P, el estado de crecimiento de la planta (número de hojas emitidas) es importante. El ciclo de cultivo afecta significativamente la relación para el Mg, Cu y Zn. Estos efectos han sido incorporados por modificación de b_1.

La relación empírica entre C_M, C_o, E_o y t permetirá estimar la importancia del clima en la interpretación del análisis foliar en banano.

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