STALK SODIUM: A USEFUL GUIDE IN INVESTIGATING PROBLEMS OF PLANT NUTRITION

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Summary

The presence of Na in the stalk of sugar cane is shown to be significantly correlated with adequate soil moisture and, if no other growth factors are limiting, stalk elongation. The presence of Na is also shown to be related to optimum N, P and K content of the stalk and its value as a guide to determining, reliably, different levels of soil fertility is considered.

Introduction

Although various techniques of tissue analysis have been adopted in the major sugar cane growing countries of the world to assess the nutritional status of the crop they all have one serious shortcoming, *i.e.*, under conditions of growth stress the concentrations of nutrients decrease markedly. Thus, a low nutrient concentration in the sampled tissue may well be the result of prevailing environmental conditions and not a low nutrient content in the soil. Apart from practical considerations the fact that the chemical analysis of the plant is the ultimate in all plant nutritional studies makes it imperative that such defects, which question the reliability of observed results, be overcome.

Various methods have been proposed to determine when plant growth, and hence nutrient concentration in the sampled tissue, is optimum. With moisture stress being the most serious factor inhibiting plant growth in all sugar cane growing countries, some measure of the amount of moisture which is available to the plant at time of sampling is necessary. Samuels *et al* (5) of Puerto Rico and later Clements (1) of Hawaii used the moisture content of the leaf sheath to correct observed nutrient concentrations. Clements (2) has since gone so far as to express K as a percentage of sheath moisture. Evans (3) of British Guiana has also discussed expressing K on a wet weight basis in preference to a dry weight basis. In Mauritius (4) sampling is only carried out if weekly elongation of primary stalks is greater than 10 cm.

Under South African conditions where sampling is conducted by individual planters none of the above methods would be practical. The position therefore is somewhat undesirable with time of sampling left to the discretion of the individual with his only guide the vague statement that "leaf samples should only be taken when the cane is actively growing".

Outlined below is a technique which could provide the planter with a simple field test to determine when optimum growth conditions prevail and the fertilizer advisory chemist with the assurance that the determined nutrient levels are a true reflection of the fertility status of the soil.

Trends in Plant Nutrient Movement

Over the past twelve months tissue samples have been taken each week from the harvested plots of a growth analysis experiment at Chaka's Kraal. These tissues were considered to represent all constituent above-ground portions of the plant and each has been analysed for the more important plant nutrients. The samples taken included stalks, foliage, trash, meristems, 8-10 internodes, third leaf blades, whole third leaves and 3-6 leaf sheaths. These tissues were analysed for moisture, N, P, K, Ca, Mg and Na and on composite samples of the six replications for Zn, Cu and Mn. Data supplied by the meteorological site of the Research Agronomy Department has permitted a study of the weekly influences of climate on the nutrient composition of the crop to be made. Weekly increments in stalk elongation, crop weights and the moisture contents of the soil have also been provided.

From this mass of data the most interesting observation has undoubtedly been provided by the only element in the above list which is not considered to be an essential plant nutrient, namely Na. In brief, it has been shown that under conditions of adequate soil moisture Na is present in the stalk, and 3-6 sheath samples, while under conditions of somewhat limiting moisture Na is absent. More important is the fact that when temperatures were not limiting plant growth a strong relationship between the presence of Na in the stalk and weekly increment in stalk height was found to exist. Of the tissues displaying these trends the upper tip, or meristem, of the stalk was found to be the most sensitive. The appearance of Na in this tissue was also accompanied by increases in N, P and K concentration. For these studies the meristem was taken as that portion of the stalk above the attachment of the fourth leaf sheath. The relationships between the Na content of the meristem, the moisture content of the soil and stalk height increments over the week preceding sampling are illustrated in Figure 1. Figure 2 indicates the flush of N, P and K to the meristem which accompanies the appearance of Na.

It can be seen from Figure 1 that Na is present in the meristem (in excess of 0.015 per cent to allow for experimental error) only when the soil moisture is at a value greater than approximately 10 per cent on a weight to weight basis. The Na value on 17/4/62 is the only exception and no logical explanation for this contradiction could be found. The meristem Na time series would appear to be satisfactorily represented by a Markoff process of the first order (the Na content of the meristem in week number three is independent of the concentrations in week number one, c.f. $rx_1x_3=0.4408$: but eliminating the effect of week number two $rx_1, x_3, x_2=0.0718$ N.S.). The soil moisture time series is represented by a Markoff process of the second order (the soil moisture in the third week is still influenced by the first weeks value *c.f.*

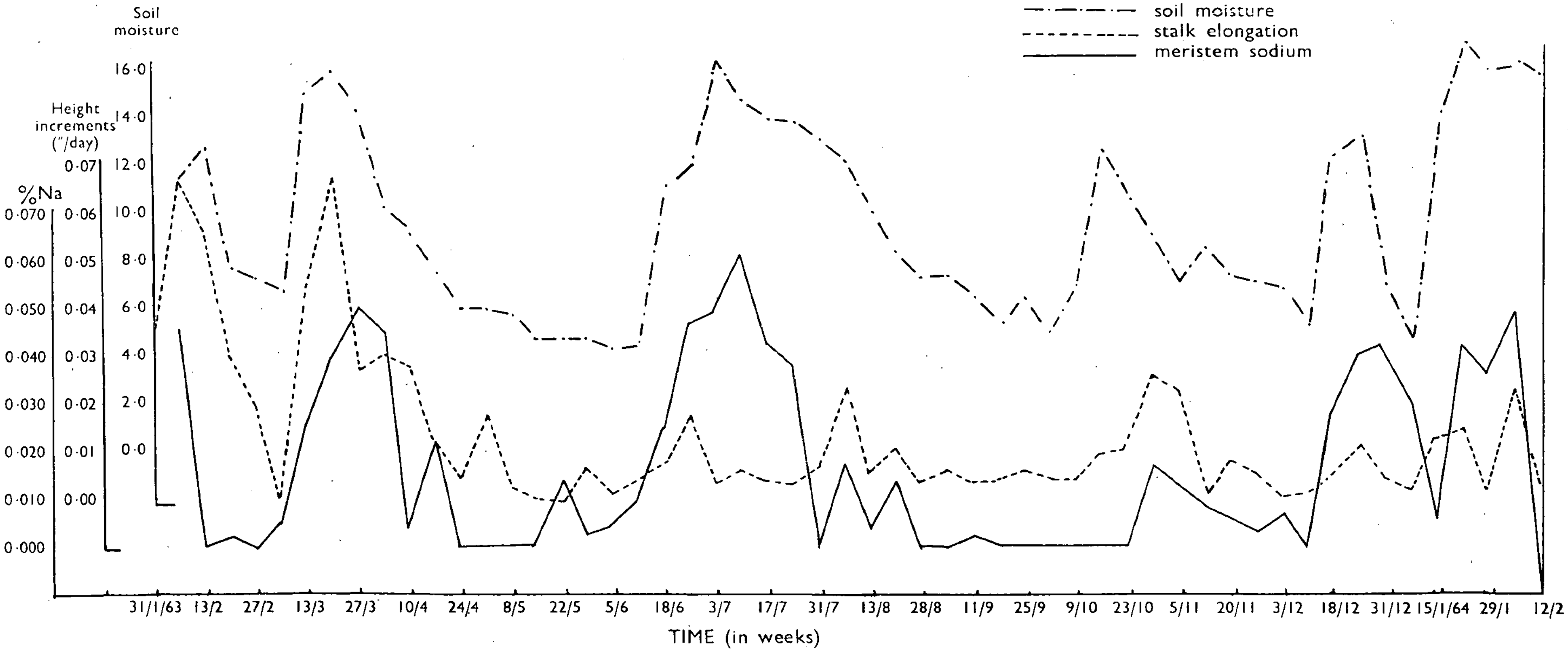

FIGURE 1 : RELATIONSHIP BETWEEN NA CONTENT OF MERISTEM, SOIL MOISTURE AND STALK ELONGATION

$r\,y^1\,y_3=0.3538\dagger$ and $r\,y_1\,y_3\,y_2=0.3146^*$). There is a highly significant correlation between Na content of meristem and soil moisture ($r_1\,y_1=0.6284\ddagger$) but the lagged correlation coefficients of two and three weeks, with soil moisture preceding meristem Na are also significant ($rx_2\,y_1=0.5859\ddagger$ and $rx_3\,y_1=0.3207^*$) but the latter correlation fails to attain significance when the Na serial correlation is taken into account. ($rx_3\,y_1,\ x_2=0.1024$ N.S.) The lagged correlation of one week is reduced in size, but is still significant, if the previous influencing series are eliminated. ($x_4\,y_3,\ x_3\,y_2\,y_1=0.3568\dagger$.)

Weekly growth increments, as with meristem Na, could be represented by a Markoff process of the first order. ($r\,z_1\,z_2=0.6660^*$ but $r\,z_1\,z_3=0.3516$ N.S.) There is a significant lagged correlation of at least one week between meristem Na and growth increment, the two week partial lagged correlation however, was non-significant ($x_1\ z_1=0.1118$; $x_1z_2=0.3193^*$ and $x_1z_3=0.1962$ N.S.). When the growth increments for the winter period are excluded the magnitude of the lagged correlations increases. ($x_1z_1=0.1448$ N.S.; $x_1z_2=0.4204^*$; $x_1z_3=0.4077^*$ and $x_1z_4=0.2416$ N.S.)

Figure 2 illustrates that the presence of Na in the meristem is characterised by optimum levels of N, P and K, or more important, in the absence of Na these values are generally very low. The practical importance of these observations in fertilizer recommendations will be discussed in the following section.

In order to assess whether the above Na trends were restricted only to the one site a survey of ten additional sites was carried out. Each site was located on a different soil series which was under commercial cane of widely differing variety and age. The Na contents of three soils varied from 16 to 440 ppm Na. For 35 consecutive weeks duplicate samples for moisture assessment, meristem samples for Na analysis and four stalk measurements for height increments were taken. The results showed that for all 10 sites the same trend between soil moisture and stalk Na held. The relationship between stalk elongation and Na content was not as marked as in the growth analysis experiment but this could probably be attributed to the existance of some other growth inhibiting factors.

Applications to Fertilizer Advice

Since the Na trend has been shown to hold over a variety of commercial sites its possibilities as a guide in determining when conditions are optimum for foliar sampling are immediately apparent. It is known that, apart from actual deficiencies, the two most important factors causing low N, P and K values in the plant are (*a*) climatic conditions which are adverse to plant growth and (*b*) increasing age of the crop. In order to test the ability of the Na concept to eliminate the former, the analytical results of leaves 3, 4, 5 and 6 and 8-10 internode samples from a crop log experiment (BT1/39) containing fertilized and unfertilized plots were considered. Although the 8-10 internode has been shown to be less sensitive than the meristem for the Na test it does serve to indicate the usefulness of the technique. The analytical results for the samples taken during the recommended sampling months are presented opposite:

TABLE I

Analytical Results of 3, 4, 5 and 6 Leaves and 8-10 Internode Samples taken from Fertilized and Unfertilized Plots during the Recommended Sampling Period

1962

Month . . .		March		April		May	
	%	F	U	F	U	F	U
3-6 Leaves	N	1.60	1.53	1.51	1.53	1.52	1.41
	P	0.20	0.18	0.19	0.17	0.17	0.16
	K	0.98	0.85	1.39	1.22	1.25	0.93
	Na	0.070	0.065	0.046	0.041	0.076	0.060
8-10 Internodes	N	0.13	0.16	0.18	0.15	0.18	0.13
	P	0.09	0.05	0.06	0.06	0.06	0.04
	K	1.08	0.89	1.10	1.17	0.97	0.69
	Na	0.013	0.013	0.012	0.011	0.009	0.006

Month . . .		November		December		January	
	%	F	U	F	U	F	U
3-6 Leaves	N	1.47	1.38	1.53	1.30	1.55	1.43
	P	0.16	0.15	0.16	0.14	0.16	0.15
	K	0.90	0.80	0.84	0.73	0.84	0.67
	Na	0.134	0.127	0.066	0.057	0.051	0.049
8-10 Internodes	N	0.27	0.21	0.27	0.21	0.18	0.14
	P	0.04	0.03	0.04	0.04	0.05	0.03
	K	0.92	0.93	0.64	0.66	0.80	0.56
	Na	0.011	0.014	0.002	0.002	0.008	0.005

1963

Month . . .		February		March		April	
	%	F	U	F	U	F	U
3-6 Leaves	N	1.38	1.30	1.29	1.30	1.28	1.26
	P	0.16	0.14	0.17	0.17	0.16	0.15
	K	0.80	0.63	0.91	0.83	0.74	0.65
	Na	0.054	0.049	0.057	0.055	0.037	0.038
8-10 Internodes	N	0.14	0.12	0.14	0.14	0.13	0.13
	P	0.04	0.03	0.05	0.05	0.05	0.04
	K	0.57	0.43	0.60	0.61	0.48	0.46
	Na	0.000	0.000	0.013	0.013	0.000	0.000

F—Fertilized; U—Unfertilized.

By studying these results it can be seen that at three sampling dates the Na content of the 8-10 internodes fell below 0.005 per cent.

As with the meristem data presented in Figure 2 these months are also characterised by low N, P and K values with K results being the most marked. This relationship is more clearly illustrated if we plot nutrient concentrations in leaves and 8-10 internodes against Na content of the latter.

Since 3, 4, 5 and 6 leaves are not used in practice to estimate nutrient requirements, arbitrary critical levels have been taken and imposed on the above figures. The levels below which fertilizer applications would be considered necessary for 8-10 internodes are

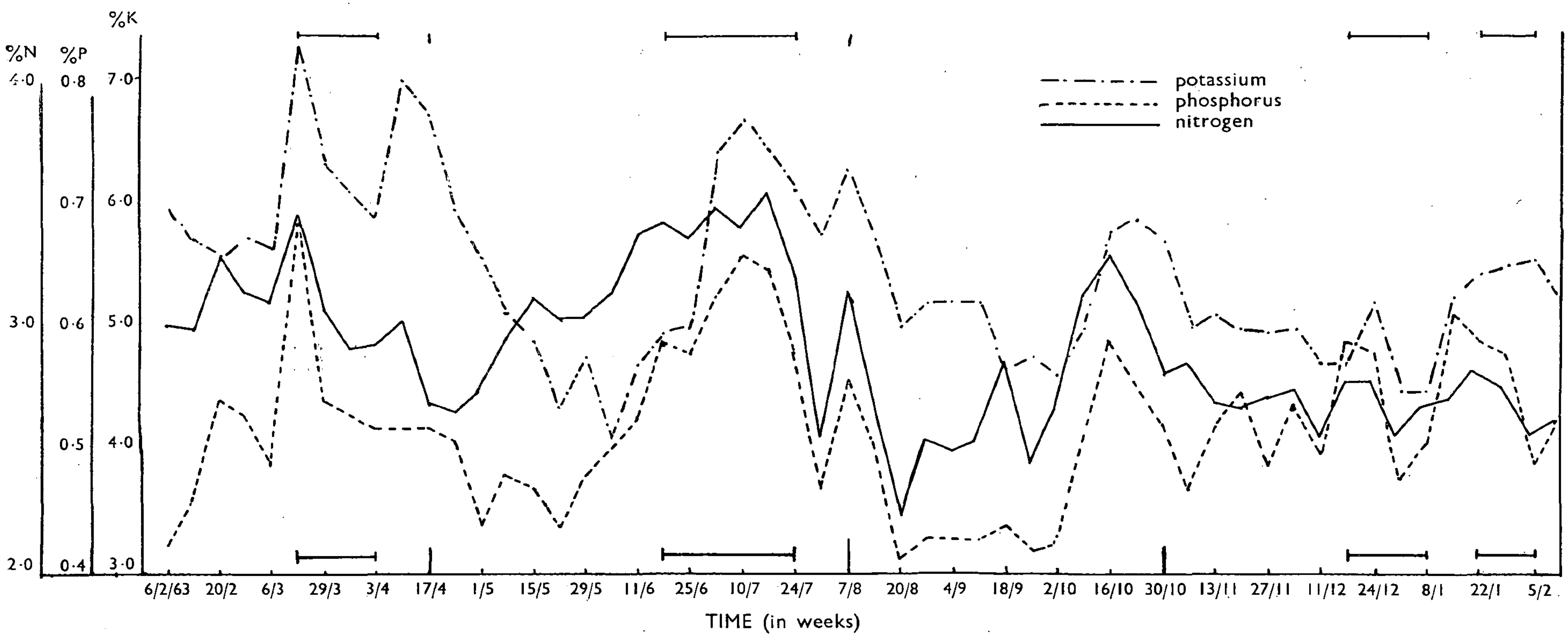

FIGURE 2 : FLUCTUATIONS IN N,P AND K CONCENTRATIONS IN MERISTEM

also demarcated. These levels are 1.45% N, 0.16% P and 0.90% K for leaves and 0.15% N, 0.04% P and 0.60% K for 8-10 internodes. The critical Na level has been marked at 0.005% Na instead of at zero to allow for experimental error. Since the object of the Na index is to limit the error of recommending fertilizer to fields where it is not required a comparison between the existing and proposed methods has been carried out to determine whether the new approach is in fact more reliable. In accordance with existing methods, any value falling to the left of the critical level lines in Figures 2 and 3 would be indicative of the need for more fertilizer. By the new technique only those points falling to the left of this line but above the 0.005% Na level would indicate a nutrient deficiency. The number of fertilized plots which would be incorrectly diagnosed by the two methods are tabled below. The total number of fertilized plots considered was eighteen.

TABLE II

Number of Fertilized Plots incorrectly Diagnosed by the Present as compared to the Recommended Technique

	Number of Incorrect Predictions					
	N		*P*		*K*	
	Present	*Proposed*	*Present*	*Proposed*	*Present*	*Proposed*
Leaf results .	8	4	3	1	10	3
% error . .	44.4	22.2	16.7	5.6	55.6	16.7
Stalk results .	6	3	1	0	5	0
% error . .	23.3	16.7	5.6	0.0	27.8	0.0

It can be seen from the above table that the number of incorrect predictions has been considerably reduced by applying the new method. This is particularly true for the 8-10 internode where the average per cent error for all three major nutrients is only 5.6 per cent. The results from the growth analysis experiment have also shown that the concentrations of N, P and K in the stalk are much more closely associated with the Na content of the stalk than are the N, P and K contents in the leaves. In order to permit planters to be able to assess when optimum sampling conditions prevail a rapid field test is at present being perfected whereby if one drop of juice from a meristem which contains Na is squeezed into the test solution a coloured precipitate will be formed. The presence of a large excess of K over Na in this tissue, however, is causing some difficulty in finalising the test. A more accurate quantitative analysis can be conducted in the laboratory on meristem samples, taken together with the third leaves, prior to the routine determination. Unreliable samples could then be detected and sampling repeated at a later date. For third leaf lamina data there is a fairly close relationship between N content and the presence of Na in the stalk. Unfortunately, however, the movements of P and K in the leaf are far more delayed than in the stalk. This means that the Na trend in the stalk may be complete before increased concentrations in P and K are observed. Although this lag is not as pronounced during the summer months the trend does indicate that the Na test cannot be applied effectively to leaves. This is borne out by the results in table I, which indicate that if the Na test is to be adopted, some portion of the stalk rather than a leaf will give more reliable results. Such a development would also mean the sampling and chemical analysis of one tissue only. Although the 8-10 internode is already recognised as a tissue which is sensitive to differences in soil fertility it was felt that the meristem would be a more practical tissue for the following reasons:

(i) samples could be taken from very young cane,

(ii) the concentration of nutrients, including Na, are greater than in any other part of the plant thus permitting a wider range of values and

(iii) sampling of the stalk tip is easier than separating out the 8-10 internodes.

It is therefore necessary to determine the efficiency of the meristem to detect different levels of soil fertility.

Referring again to figure 2 it is seen that certain intervals have been designated. These areas represent those sampling intervals, in addition to 17/4/63, 7/8/63 and 30/10/63 when more than 0.015% Na was found in the meristem. These would be considered valid sampling dates and in general N, P and K values are at the optimum. Those periods in which climate is adversely affecting nutrient content would be avoided.

In order to assess whether the meristem could be expected to be as sensitive as the third leaf blade in determining different levels of soil fertility the correlation coefficients for N, P and K between these tissues were calculated. Forty-seven sets of observations from cane of varying ages were used. The correlation coefficients for N, P and K contents of meristem and leaves were 0.5030, 0.5709 and 0.5908, respectively. All these values were significant at the 1 per cent level.

Next, samples of third leaf blades and meristems were taken from a 3 by 3 by 3 fertilizer experiment of the Tongaat Sugar Company. The fertilizer levels applied were equivalent to 0, 100 and 200 lb. per acre of N, P_2O_5 and K_2O. The mean analytical results for each level (9 plots) are presented in Table 3.

It is immediately apparent from these results that nutrient composition of the meristem is indeed sensitive to differences in soil fertility. It is also obvious that the ranges in nutrient content, between the highest and lowest treatments, are far greater in the meristem than in the leaf. Such wider ranges, would, in addition to limiting the magnitude of errors introduced during chemical analysis, permit the advisory chemist to assess more accurately whether observed results indicate low, medium or high levels of soil fertility. At present further experiments to indicate the possibilities of using the meristem as a sampling tissue are being undertaken. These studies include varietal differences, age effects and the type and number of meristem tissue required per unit area to give the most reliable results.

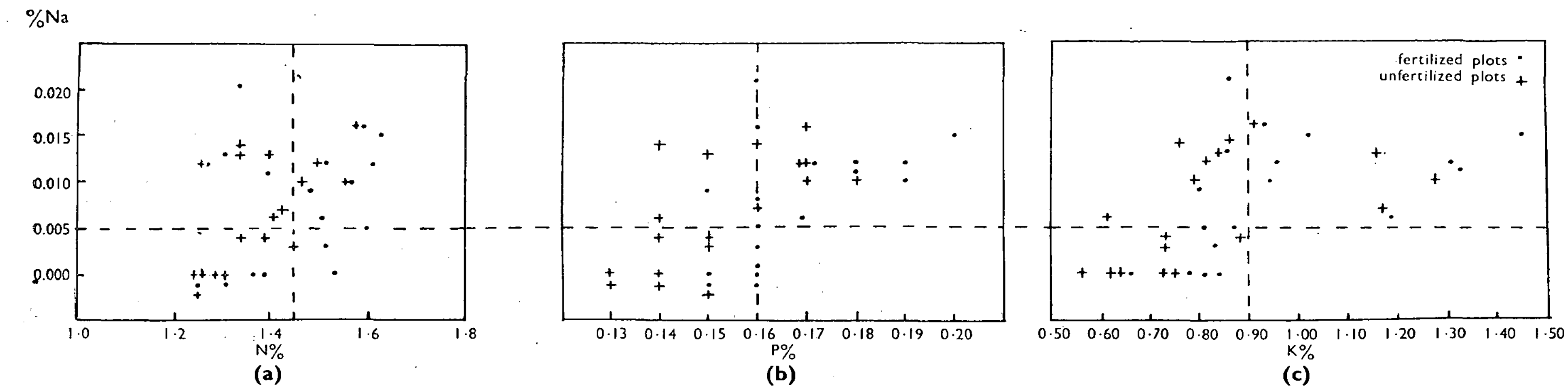

FIGURE 3 : THE RELATIONSHIP BETWEEN NA CONCENTRATION IN 8-10 INTERNODES AND N,P AND K CONCENTRATION 3, 4, 5 AND 6 LEAVES

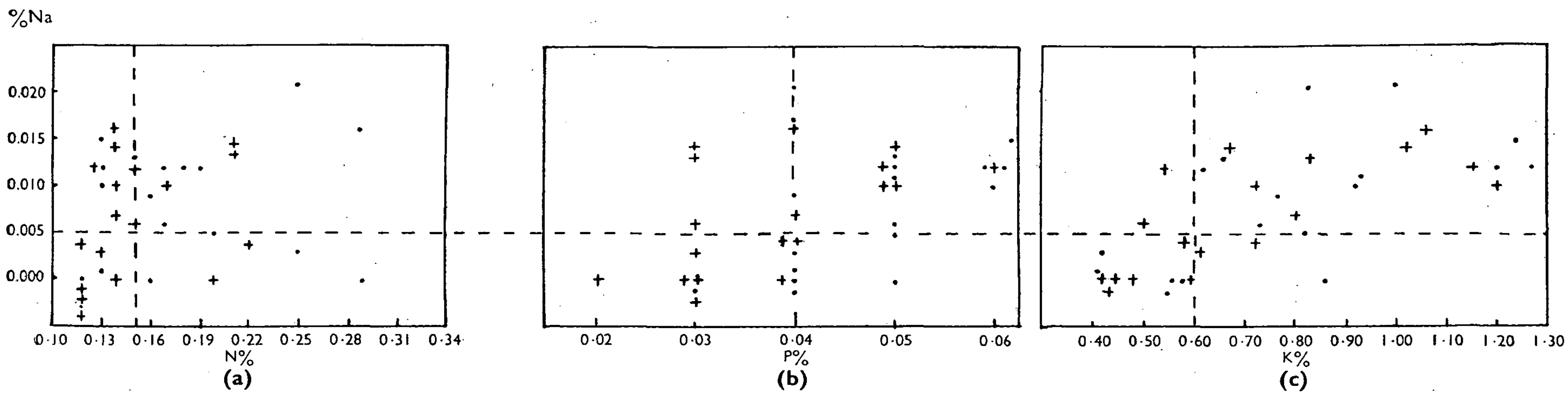

FIGURE 4 : THE RELATIONSHIP BETWEEN CONCENTRATIONS OF NA N,P AND K IN 8-10 INTERNODES

TABLE 3

Comparison of Percentage N, P aud K in Third Leaf Lamina and Meristem Samples from a 3^3 Factorial Experiment.

	N% at Nitrogen Levels			
	0	1	2	Range
Third Leaf Blades . .	1.57	1.69	1.75	0.18
Meristem	2.15	2.58	2.76	0.61

	P% at Phosphorus Levels			
	0	1	2	Range
Third Leaf Blades . .	0.21	0.25	0.26	0.05
Meristem	0.40	0.58	0.63	0.23

	K% at Potassium Levels			
	0	1	2	Range
Third Leaf Blades . .	0.88	1.06	1.15	0.27
Meristem	5.04	7.04	7.55	2.51

Conclusions

From the results presented, the "actively growing period" of sugar cane (if no other growth factors are inhibiting) occurs approximately one week after an effective rainfall and is maintained for about the next three weeks. Unfortunately, the actively growing period does not necessarily coincide with optimum nutrient concentrations in the third leaf lamina under South African conditions. In contrast, the concentrations of nutrients in the stalk are at, or very nearly at. their optimum during such periods of optimum growth. The stalk therefore would be a more reliable tissue to use for determining when nutrient levels are optimum. Furthermore the planter will be able to check on whether such conditions prevail by a simple spot test and a quantitative test for stalk Na will provide the fertilizer advisory chemist with an additional check on the validity of the sample. Such increases in reliability, coupled with the fact that stalk tissues are already used in other countries for assessing levels of soil fertility, indicates that serious consideration should be given to some portion of the stalk being adopted as the basis for routine fertilizer advisory work. Of the various portions of the stalk tested to date the upper tip is apparently the most suitable,

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Mr. du Toit (in the chair): This paper is a result of an interdepartmental co-operative experiment which included the growth experiment at Chaka's Kraal. It has lead to a research project and a fundamental discovery which may have a big effect on our analytical laboratory. By this new method the laboratory can ascertain whether or not the leaf sample has been taken at a time of active growth and sufficient moisture supply.

Mr. Glover: The meristem is a good choice for sampling as it is the last place to suffer stress. I would like to know if values change in a high sodium soil or if they maintain their relative proportions?

Mr. Bishop: Of the ten soils studied, sodium content varied from 16 to 440 ppm., the latter being at a salt lagoon on the Natal Estates where water, also at 440 ppm. was flooding the field. The test still worked well. Incidentally, the only time I have ever found sodium absent in the leaves was in a plant from a brack soil with a sodium content of over 2,000 ppm. The sodium flushes appear to be the result of the soil almost coming to field capacity.

Regarding the meristem, it also shows much higher contents for zinc, copper and manganese.

Mr. du Toit: The meristem composition must, however, be correlated with actual yield experiments. The meristem is known to be very high in nutrients and in particular zinc, but concentration is not the final criterion and yield must also be considered.

Dr. Brett: In connection with what you were saying, Mr. du Toit, the point is that in Table 3 the range for the leaf blades is 0.18, which is nearly a fifth; for the meristem it is nearly a third.

Mr. Wyatt: These findings should be very useful. I suggest that we who supply samples to the Experiment Station should in future assist this work by submitting leaf and meristem samples, at the same time giving rainfall information for the preceding month.

Dr. Cleasby: This is an extremely interesting method of tissue analysis. May I point out that in Table 3 although a wide range of difference is shown, this particular experiment, at Tongaat, has never responded to potash. Is meristem analysis being used overseas, or are they working on it?

Mr. Bishop: It has not been used, probably because it is undoubtedly easier to strip the leaf lamina for a sample.

Mr. Hill: Will meristem, as opposed to leaf sampling, cause greater damage to the plant?

Mr. Bishop: There was no appreciable deterioration on these experimental plots, in fact, from the number of shoots coming out from the eye below the one cut off, there appears to be a case for pruning sugar cane.

Please do not think that at this stage a change from leaf to meristem sampling is being recommended. We have in fact struck a snag at Chaka's Kraal, where there is a variety nitrogen trial, and there was a sharp response between variety and nitrogen in one instance. The results were switched in this experiment by taking a measured length of meristem, the top inch, instead of taking from the attachment of the fourth leaf and results were more consistent.

Dr. Sumner: Mr. Bishop has suggested a scheme to Professor Orchard and myself for tracing the movement of sodium from the meristem into the soil, using radio-active sodium 22 with an ordinary radiographic technique.

Mr. Bishop: Assuming that sodium is in fact being lost from the plant, some force which is capable of pulling sodium against the transpiration stream must be operating. Since sodium lost from the stalk is not being found in any other above-ground part of the plant, the influencing force is probably found below ground level. The most obvious source of this force is the colloidal fraction of the soil.

According to the Donnan, and other theories involving movement of ions into the soil solution, in a dilute system monovalent ions are released from the clay plates more readily than higher valency ions. As the soil system dries out (becomes more concentrated) the reverse occurs, i.e., higher valency ions tend to be released from, and monovalent ions attracted to, the clay plates.

Therefore as the soil is moistened sodium is available to the plant but as the system dries out the position is reversed and sodium movement is towards the clay plate. With sodium playing no physiological role in the plant the movement could be influenced solely by this force in the soil.

Professor Orchard: This work appears to be very promising at the moment but I think it is essential that it should be calibrated against the results of other experiments, against the known responses of a soil. It does not justify at this stage throwing over a well tried system.

What is interesting is the theoretical explanation, according to the laws of physical chemistry, of the behaviour of the sodium in relation to the other ions in the plant. If figures obtained can be correlated with these theoretical considerations then the importance of the work will be tremendous and of very wide application and could lead to a new understanding of plant nutrition.

Mr. Glover: I am not satisfied that the soil is the sink for the sodium. There is a big sink in the plant itself and sodium is an in-going cation. Everything is stored in the meristem, it is a protected area, and sodium could be drained from there to any other part of the plant suffering stress. It is easier to accept this than that the sodium is going into the soil through the roots, but further tests should determine this.