TECHNICAL BULLETIN NO. 81 FEBRUARY 1970

CROP LOGGING OF SUGAR CANE: NITROGEN AND POTASSIUM REQUIREMENTS AND INTERACTIONS USING TWO VARIETIES

HARRY F. CLEMENTS

HAWAII AGRICULTURAL EXPERIMENT STATION, UNIVERSITY OF HAWAII

CONTENTS

THE AUTHOR

The author is Senior Plant Physiologist, Emeritus, with the Hawaii Agricultural Experiment Station, University of Hawaii, and also Consulting Plant Physiologist, Retired, with C. Brewer and Company, Ltd.

Two other Technical Bulletins on the growth and nutrition of sugar cane by the author and associates are:

Technical Bulletin No. 18, *Factors Affecting the Growth of Sugar Cane,* 1952 (second printing, 1962) , 90 p.

Technical Bulletin No. 35, *Crop-Logging of Sugar Cane: The Standard Nitrogen Index and the Normal Nitrogen Index,* 1957 (second printing, 1964) , 56 p.

ACKNOWLEDGMENTS

The author wishes to thank the following for the work and care which went into the experiment: Mr. Herbert Gomez, manager of Pepeekeo Sugar Company, the plantation where the experiment was located; Mr. Myron Isherwood, crop control superintendent, who installed the experiment and supervised the crop logging of it; and Mr. Kenneth Kunimitsu, crop control superintendent, who was in charge of the harvesting. Grateful acknowledgment is made to Murrayair, Ltd., for the patience required in making the aerial applications of fertilizers.

The author also wishes to thank Mr. Takashi Nonaka, head of the Crop Log Laboratory, and his staff for the very substantial numbers of analyses reported.

Finally, although all the statistical analyses associated with variance were performed by the author, all the multiple regressions were performed by the Computing Center at the University of Hawaii directed by Mr. Walter Yee, to whom thanks are extended. Words of appreciation also go to students, Misses Bonnie Ching and Marcia Ito, who set up all the data for the computers.

CROP LOGGING OF SUGAR CANE: NITROGEN AND POTASSIUM REQUIREMENTS AND INTERACTIONS USING TWO VARIETIES

HARRY F. CLEMENTS

INTRODUCTION

In Hawaiian sugar cane culture, nitrogen is required in relatively heavy amounts in all fields except those irrigated with waste water from the mills. Where natural rainfall provides the water for unirrigated fields and where mountain surface water or low-potassium pump water is used for irrigation, potash fertilizers are also needed in large amounts.

The system of culture postulated by crop logging (*3, 4*) calls for a series of N applications, sometimes made in combination with K_2O, applied in the ratio of 1 pound of N to 1½ pounds of K_2O. The leaf nitrogen level should be somewhat above the normal (*2*) for the first year and then drop to or below normal toward harvest. The K-H_2O level up to late 1969 was to be maintained at 0.425 or above.

Thirty to 40 pounds of N and 45 to 60 pounds of K_2O per acre are applied along with any phosphate needed directly under the setts ("seed" pieces) at planting time. At 6 to 8 weeks, the first surface application is made consisting of 60 to 80 pounds of N and 90 to 120 pounds of K_2O. At 3½ to 5 months, a similar application is made. Then at 6 to 7 months, a relatively heavy application is made, 80 to 100 pounds of N and 120 to 150 pounds of K_2O. From this point on, the log for that specific crop (*3, 7*) is monitored and should a drop in either material occur, additional applications are made. For normal 24-month crops, at 10 to 12 months of age, a final application is made, levels for which will be determined from the log. If the N level is well above normal (*2*), a final application of 40 to 60 pounds of N and 60 to 90 pounds of K_2O is made. If the N level is normal, 90 pounds of N and 135 pounds of K_2O are called for. If the N level is below normal, as much as 120 pounds of N and 180 pounds of K_2O will be needed, although this would be applied in two equal quantities. Again, even as late as 15 months after planting, depending somewhat on the time of the year, a late though light (45 pounds N and 67 pounds K_2O) application can be made if called for by the log. Thus, total amounts used may range from 290 to 465 pounds of N and from 435 to 698 pounds of K_2O per acre.

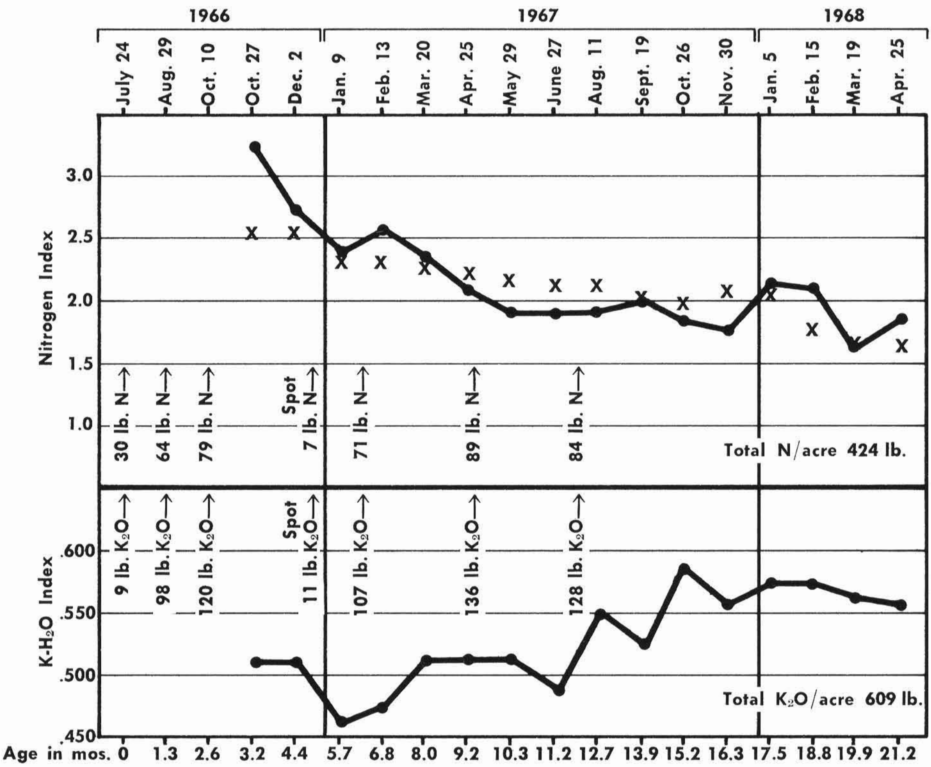

FIG. 1. Nitrogen and potassium indexes copied from the actual crop log of field cane grown adjacent to the experimental area. The crop was controlled by plantation management and the fertilizer applications were guided by the crop log for the field. The *x*'s in the upper portion of the figure represent the normal nitrogen index at each age. The upward pointing arrows indicate the dates on which fertilizers were applied.

In Fig. 1 are shown the N and K-H_2O curves and the actual applications of fertilizers made by plantation management to the commercial cane planted around the experimental cane. Usually the first application to a plant crop is made with the planting machine. The second and third applications are made by hand, by machine, or by water. As soon as the cane has closed in, all subsequent applications are made by water or by airplane.

In the timing of the applications of fertilizer as well as the amounts used, two general thoughts are involved: (i) the crop should be pushed at the start with an abundance of nutrients but (ii) these should be so applied that as harvest approaches, the crop will have exhausted the nutrients and thus begun its ripening cycle.

The first application, most desirably applied with the setts, is a definite aid to the emergence of the shoots. The second application comes at the time when the shoot is fully developed and the buds at its base are stimulated into the development of secondary shoots and the stool. The third application continues the rapid development of the crop toward "closing in" of the field. The fourth application, which should be heavy, comes at a time of maximum growth activity. The final application comes when the crop has already lodged and there is need to resume the rapid growth of the primary as well as secondary shoots and also to stimulate the production of a heavy stand of tertiary stalks (suckers) early enough to permit their full development and maturation. There should be enough N and time to do all these things and yet not so much N that ripening will be prevented from occurring, even in the heavy rainfall areas.

STATEMENT OF OBJECTIVES

Because the general practice outlined above had been in use for many years, it seemed desirable to conduct field experiments to determine its continued validity, and to explore the yield potentials of very high but balanced rates of fertilizer applications where negative soil factors are reduced to a minimum. Furthermore, belief has persisted that N and K-H_2O levels differ for different varieties and what may be normal for one variety may not be for another. Also, it was felt necessary that such experiments be designed to allow direct application to large field operations.

An experiment was installed at Pepeekeo Sugar Company in one of its best low-elevation (360 feet) fields where soil, sunlight, and temperature favored optimum growth. Rainfall at this plantation is high, 233.74 inches during the life of the plant crop (21.9 months). Very rarely is moisture a limiting problem and in the particular field used, drainage is good. The plantation is on the north-facing slope of Mauna Kea on what is locally called the "Hilo Coast."

EXPERIMENTAL DESIGN

To make airplane applications of N and K_2O possible and to use more than one variety, a split-split plot design experiment (*13*) was laid out (Fig. 2). Individual N plots, the main plots, were 0.788 acre in size. The K_2O treatments became the subplots randomized within the main plots and were 45 feet wide to accommodate a single pass of an airplane. Within the K_2O subplots, the variety sub-subplots were randomized. Two guard rows separated the K_2O subplots from each other and a 9-foot aisle separated the varieties within each subplot.

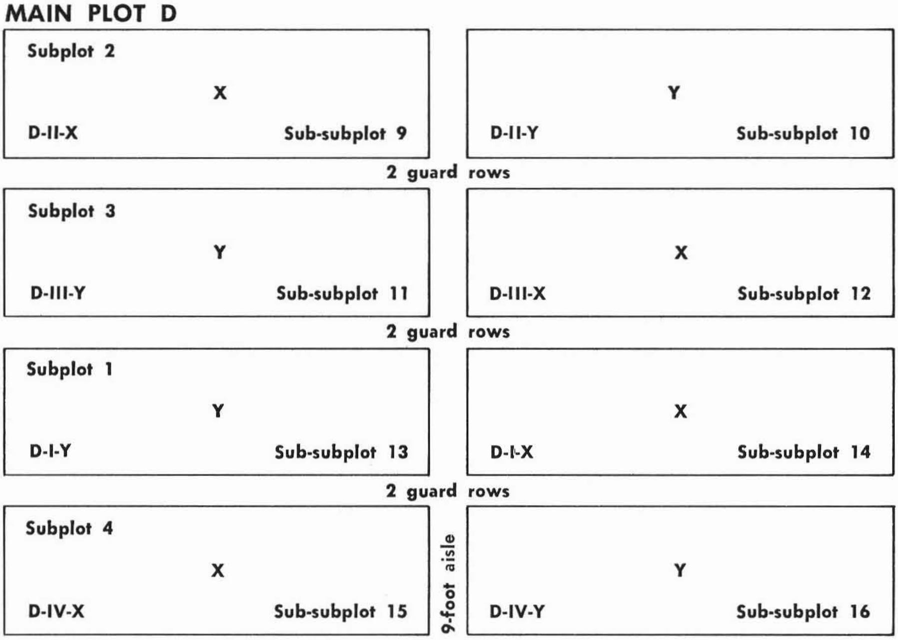

FIG. 2. Detail of one main experimental plot (D) with its 4 subplots (1,2,3,4) and its 8 sub-subplots (X,Y). Numbers 9 through 16 are sub-subplot numbers. Three-member keys are the treatment combinations.

The amounts of N (pounds/acre) used were 150 (A), 300 (B), 450 (C), and 600 (D). The amounts of K_2O were 0 (I), 250 (II), 500 (III), and 750 (IV). Because of the need for simplicity in the experiment, one-fifth of the total amount for each treatment was put on at each date of application. The 450-pound treatment (C) had five applications of 90 pounds each. This was in contrast to normal practice where a smaller amount would have been distributed at the first application, perhaps 30 to 40 pounds, and then on the third application an amount in excess of 90 pounds, perhaps 140 pounds, would have been made. The varieties used were H53-263 (X) and H54-775 (Y), and the setts were treated with a hot fungicide prior to planting. Thus this was a 4 $\times$ 4 $\times$ 2 split-split plot design with two replications. Prior to layout, all of the plots were treated with 3 tons per acre of Hawaiian agricultural calcium metasilicate broadcast over and thoroughly mixed with the soil (*6*). At planting time (August 4, 1966), 600 pounds of P_2O_5 from treble superphosphate was applied to all plots under the setts. One-fifth of the total amount of N and K_2O was applied on each of the following dates: August 30, October 4, and December 13, 1966; and March 7 and July 27, 1967. The first three applications were made by hand and the last two by airplane. Because of the airplane application of N and K_2O, the main plots had to be separated from each other but all were within the same field (Pepeekeo 51), with the same slope, soil type, and rainfall. The whole experiment, although very large, was handled with great care and patience by the plantation and crop log personnel.

Crop log samples were taken from each treatment, or plot, or both 14 times during the 22-month period. Harvesting was carried out from May 29 through 31, 1968.

YIELD RESULTS

Analysis of Yields of Cane per Acre, Pol per Acre, and Pol Percent Cane

Variance analysis for the yields of cane, pol, and pol percent cane are shown in Table 1. Because one block was burned prior to harvest and the

TABLE 1. Variance analysis of yield data, mean squares and F values[1]

Source	df	Tons cane per acre		Tons pol per acre		Pol percent cane	
		Mean square	F	Mean square	F	Mean square	F
Block	1	3705.76	47.55**	3.3764	—	23.6439	20.89*
Nitrogen							
N_l	1	7365.12	94.50**	37.06	48.84**	16.0653	14.19*
N_q	1	735.77	9.44^{10}	19.91	26.23*	—	—
N_c	1	23.98	—	0.1015	—	—	—
Error a	3	77.94	—	0.7579	—	1.1318	—
Potassium							
K_l	1	2674.98	29.30**	25.7078	9.47**	—	—
K_q	1	339.48	3.73^{10}	5.7001	—	—	—
K_c	1	120.02	—	0.0526	—	—	—
Interaction							
K_lN_l	1	828.58	9.08*	—	—	—	—
K_cN_q	1	554.40	6.08*	—	—	—	—
Error b	12	91.2983	—	2.71578	—	—	—
Sub-subplots							
Variety (V)	1	18.0625	—	0.2641	—	—	—
Interaction							
VK	3	96.3102	—	0.2964	—	—	—
VN	3	35.1457	—	0.5114	—	—	—
VNK	9	75.7089	—	1.1403	—	—	—
Error c	16	77.5157	—	1.3131	—	—	—

[1]Throughout this bulletin, **implies significance at or beyond the 1% level, *implies significance between the 5% and 1% levels, and superscript 10 implies significance between the 10% and 5% levels. Where significance is lacking, only a blank is found. So far as main effects are concerned, in each case the nature of the regression was determined: l = linear, q = quadratic and c = cubic. For interactions all single degree combinations were analyzed but only the significant ones are reported.

TABLE 2. Yields of cane and pol per acre and pol percent cane

Treat-ments	Tons cane per acre				Mean
	I	II	III	IV	
A	86.1	97.9	97.7	96.4	94.5
B	104.6	104.0	122.9	107.8	109.8
C	112.5	116.5	129.0	126.2	121.0
D	103.6	119.9	126 7	140.8	122.8
Mean	101.7	109.6	119.1	117.8	112.02

Yield criterion: tons cane per acre. Cane yields for nitrogen treatments A,B,C,D by potash treatments, I,II, III, IV. Below, nitrogen and potash treatment results shown separately by variety X or Y. The numbers within the borders reveal the interactions. The main effect data are outside the borders, to the right and at the bottom.

Treatments	X	Y	Mean
A	96.9	92.1	94.5
B	108.6	111.0	109.8
C	121.5	120.6	121.0
D	123.3	122.3	122.8
Mean	112.6	111.5	—

Treatments	X	Y	Mean
I	100.6	102.7	101.7
II	108.3	110.9	109.6
III	123.1	115.1	119.1
IV	118.2	117.3	117.8
Mean	112.6	111.5	—

Treat-ments	Tons pol per acre				Mean
	I	II	III	IV	
A	10.85	12.90	12.33	12.13	12.05
B	12.65	13.35	14.93	14.18	13.78
C	14.53	14.18	15.25	14.30	14.56
D	11.88	13.93	14.42	16.00	14.06
Mean	12.48	13.59	14.23	14.15	13.61

Yield criterion: tons pol per acre. Tons pol per acre for nitrogen treatments A,B,C,D by potash treatments I,II,III,IV. Below, nitrogen and potash treatment results shown separately by variety X or Y. The numbers within the borders reveal the interactions. The main effect data are outside the borders, to the right and at the bottom.

Treatments	X	Y	Mean
A	11.98	12.13	12.05
B	13.69	13.86	13.78
C	14.60	14.53	14.56
D	14.26	13.85	14.06
Mean	13.63	13.59	—

Treatments	X	Y	Mean
I	12.40	12.55	12.48
II	13.48	13.70	13.59
III	14.51	13.95	14.23
IV	14.13	14.16	14.15
Mean	13.63	13.59	—

TABLE 2. Yields of cane and pol per acre and pol percent cane—*continued*

Treat-ments	Pol percent cane I	II	III	IV	Mean
A	12.65	13.28	12.58	12.82	12.83
B	12.12	12.90	12.12	13.12	12.57
C	12.95	12.15	11.93	11.45	12.12
D	11.50	11.62	11.40	11.43	11.49
Mean	12.31	12.49	12.01	12.21	12.25

Yield criterion: pol percent cane. Pol percent for nitrogen treatments A,B,C,D by potash treatments I,II,III,IV. Below, nitrogen and potash treatment results shown separately by variety X or Y. The numbers within the borders reveal the interactions. The main effect data are outside the borders, to the right and at the bottom.

Treatments	X	Y	Mean
A	12.44	13.23	12.83
B	12.63	12.51	12.57
C	12.08	12.16	12.12
D	11.58	11.41	11.49
Mean	12.18	12.33	—

Treatments	X	Y	Mean
I	12.31	12.30	12.31
II	12.49	12.49	12.49
III	11.91	12.10	12.01
IV	12.00	12.41	12.21
Mean	12.18	12.33	—

other was not, the mean square (MS) for block was large. N had a strong, positive, mostly linear influence on yields of cane and pol and a negative influence on pol percent cane. K strongly affected yield of cane and sugar but in Table 1, at least, was without influence on quality. Later it will be shown (Table 3) that K is positively correlated with juice purity although this is hidden in Table 1. The two varieties used, while quite different in appearance, did not affect any of the yield criteria.

Actual yields of cane, pol, and actual pol percent cane values are shown in Table 2 as mean values in the experimental pattern. A, B, C, and D represent the N treatments; I, II, III, and IV the potash treatments; and X and Y the two varieties. Each datum within the large tables is an average of four separate yields—those in the small tables, eight.

Yields of Various Nitrogen Treatments in Relation to Potash Levels

Plotting the yield data for the N treatments against the K_2O treatments results in Fig. 3. At zero K_2O, the first three N treatments step up the yields but a sharp drop occurs for the 600-pound N treatment, especially for

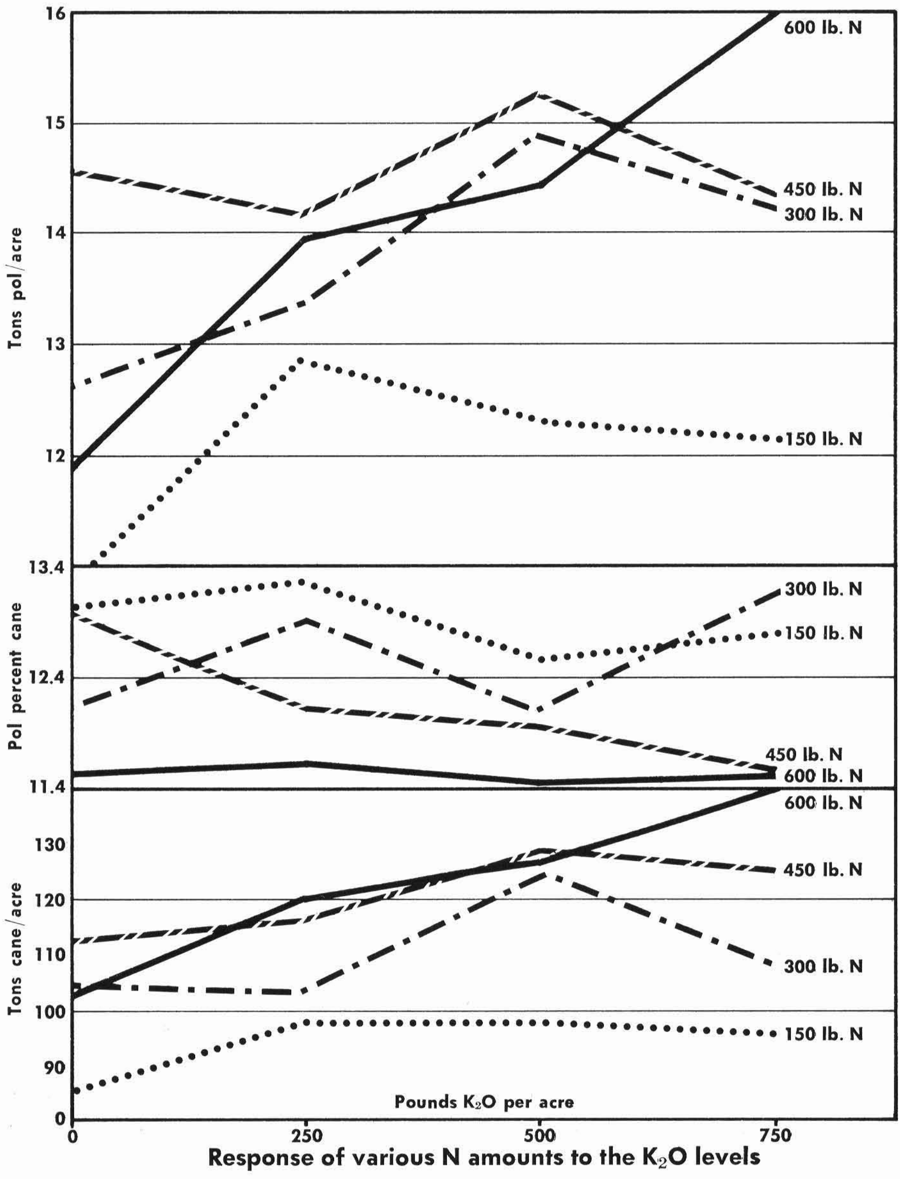

FIG. 3. The influence of selected amounts of nitrogen on yield as affected by the several levels of potash. In the case of tons of pol per acre, note that at 150 pounds of nitrogen, 250 pounds of potash shows maximum yields—higher amounts depress yield. At 300 and 450 pounds of nitrogen, maximum yields are obtained with 500 pounds of potash and again the higher amount, 750 pounds of potash, depressed yields. At 600 pounds of nitrogen, however, all potash treatments arrange themselves in order with the 750-pound treatment giving the highest yield of pol.

pol. Essentially the same relationship holds true for the 250-pound K_2O treatment. At the 500-pound K_2O level, the three high N treatments give rising yields except that the 600-pound N treatment continues below the other two. At the 750-pound K_2O treatment, however, the 600-pound N (D-IV) treatment outproduces all the others, demonstrating the significant interaction shown for cane in Table 1. It should be noted that the quality of treatment D-IV is mediocre, while at the same time the pol yield is the highest.

Yields of Various Potash Treatments in Relation to Nitrogen Levels

Fig. 4 shows TCA (tons cane per acre) and TPA (tons pol per acre) values for each of the four K_2O treatments plotted against each of the N treatments. With 150 pounds of N, only 250 pounds of K_2O shows an increase—and especially for tons pol per acre. Treatments C and D actually show depressions. At 300 pounds of N, however, 500 pounds of K_2O gives a substantial increase over the 250-pound level which again is superior to the zero treatment. The 750-pound treatment again has depressed the yields of both cane and pol. The zero K_2O at 300 pounds N has given as much cane as the 250 pounds K_2O at 300 pounds N. At 450 pounds N, the zero plot, the 250- and 750-pound K_2O treatments all give about the same yield of pol, but 114, 117, and 126 tons of cane, respectively. At this point, apparently, the improved quality of the lower N treatment offsets the gain in cane. Probably there was some residual K_2O in the soil from the previous crop. It is also common knowledge that plant crops may appear to be growing relatively well with a K deficiency showing on the log, but in the following ratoon, the drop in yield often approaches growth failure. At the 600-pound N treatment, the four K_2O treatments take their proper places. The very low yield at 600 pounds N and zero K suggests that perhaps the yield at the 450-pound N level was not true, especially since all corollary data to be presented later also indicate that the yield for C-I is not valid. They also suggest that the very unbalanced condition of N and K_2O is in itself depressing to vegetative growth.

In summary, applying large amounts of K_2O when only 150 pounds of N was used failed to increase the cane tonnage and tended to decrease the pol yield. In the same vein, using high levels of N without corresponding increases in K_2O tended to give reduced cane, as well as sugar, yields. Large applications of N clearly depress pol percent cane (quality), while there appears no relationship between quality and K_2O application (*see below*). So far as quality is concerned, there is an element of risk in applying large amounts of N but much less risk in applying large amounts of K_2O. Considering that the spread of yields between the 10.85 tons of pol for low N

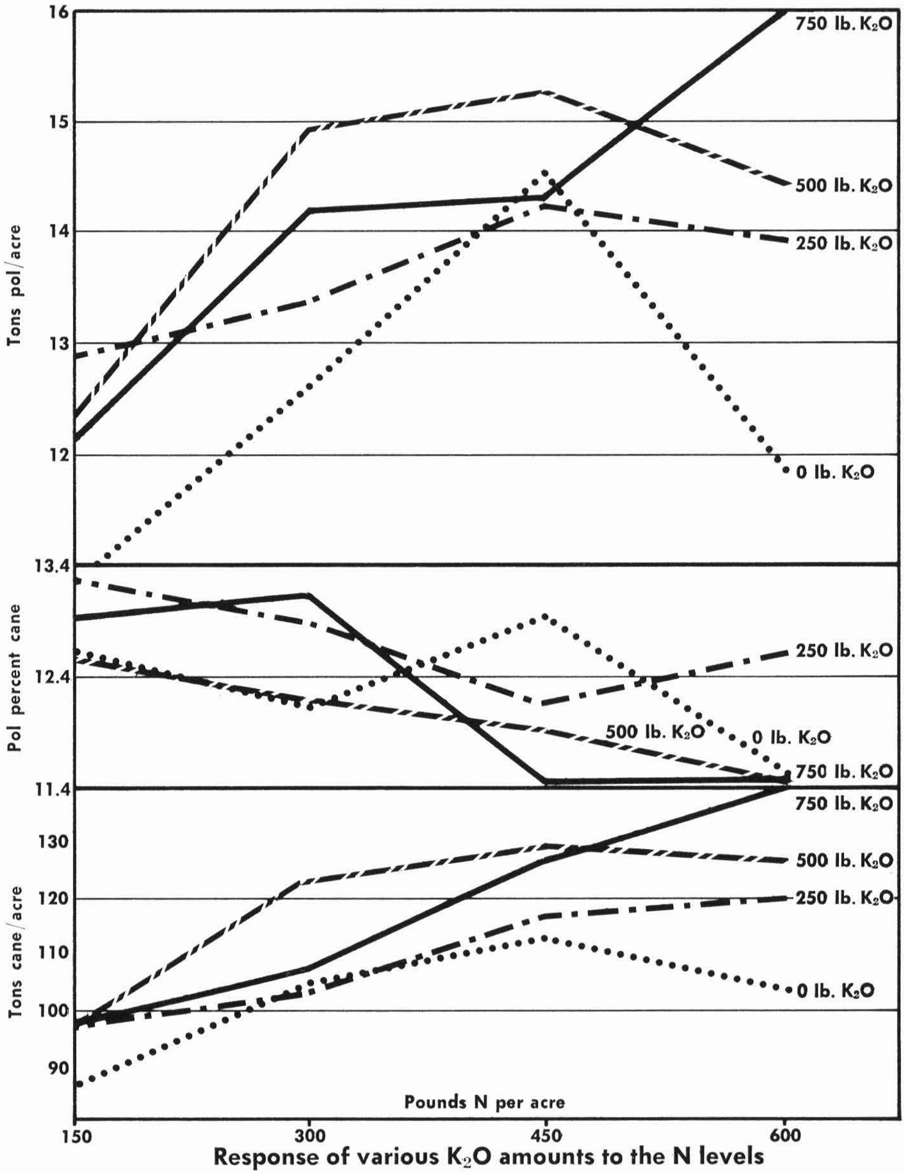

FIG. 4. The influence of selected amounts of potash on yields as affected by the several levels of nitrogen. At zero, 250, and 500 pounds of potash, maximum yields of pol are obtained with 450 pounds of nitrogen, but at 750 pounds of potash, maximum yields are obtained with 600 pounds of nitrogen.

and low K_2O (A-I) and 16.00 tons for the high (D-IV), there is much gain to be realized from using high but balanced fertilization rates, especially since each 100 pounds of N from urea adds only $9.34 at 1969 price levels to the per acre cost and 100 pounds of K_2O, only $5.33. For example, the pol data in Table 2 show 15.25 tons for treatment C-III (450 pounds N and 500 pounds K_2O), 14.30 tons for C-IV (450 pounds N and 750 pounds K_2O), 14.42 tons for D-III (600 pounds N and 500 pounds K_2O), and 16.00 tons for D-IV (600 pounds N and 750 pounds K_2O). (Were the yield of C-I at 14.53 tons pol to be considered valid, the N was 450 pounds and the K_2O zero.) The maximum differences are 150 pounds of N and 750 pounds of K_2O, costing $14.01 for the N and $39.98 for K_2O or a total of $53.99 per acre, which would represent the value of less than one-half ton of pol. The maximum differences among the four valid yields C-III and C-IV and D-III and D-IV are 150 pounds of N and 250 pounds K_2O and represent $14.01 and $13.33 or a total of $27.34, the value of less than one-fourth ton of pol. Quite obviously, even from the economic viewpoint, the top yield of 16 tons of pol is worth achieving with additional fertilizer if it can be done regularly. It is evident, however, that in this nutrient control area, considerable need for sophistication exists if full advantage is to be taken of yield increase potentials without suffering losses because of quality.

Effect of Nitrogen and Potassium on Purity

Unfortunately, because of the unburned harvest of the second block, a large amount of leafy trash material was chopped up with the cane for quality determination. This resulted in a considerable lowering of the purity. The only significance which developed was a rather strong negative regression on the N treatments, but no regression on the K treatments. In order to take advantage of the data available, however, the purities for block I only are shown in Table 3. The purity regression for K is posi-

TABLE 3. Purity values, by treatment, but only for block I

Treatments	I	II	III	IV	Mean
A	87.6	90.9	89.5	91.6	89.9
B	88.4	88.7	88.8	90.6	89.1
C	90.0	89.0	91.1	89.9	90.0
D	86.8	87.3	87.7	87.6	87.4
Mean	88.2	89.0	89.3	89.9	—

tive and significant and that on N is negative and significant, although only at the D level is the drop decisive. The highest purity is 91.6 for A-IV

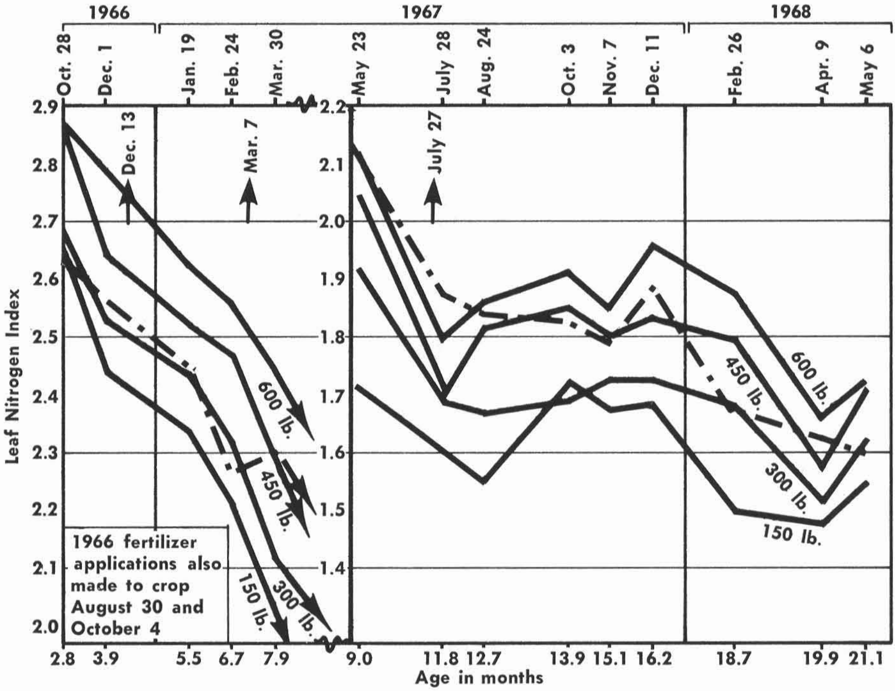

FIG. 5. The actual leaf nitrogen index curves for variety H53-263, plotted from readings taken at various times throughout the crop season. Each curve is for a particular nitrogen treatment but with all four potash treatments included. Upward pointing arrows indicate dates of fertilizer applications. The broken line is the normal nitrogen index for the highest yielding crops of H53-263 as grown at Pepeekeo. Note broken scale.

and the next for C-III. The overall best purity is for the C treatment of N and the IV treatment for K. A certain caution, however, is needed. There might develop the idea that excessive applications of K are therefore desirable. This is not so. When the K levels in the plant are excessively high, the purities are lowered thereby. In the boiling house at the sugar mill as the final crystallizations are being effected, not only is the recovery of sucrose lowered, but the K, usually as KCl, becomes so concentrated that it crystallizes and in the centrifuge these small crystals become wedged among the large sucrose crystals making most difficult the elimination of the final molasses.

CROP LOG DATA FOR LEAF NITROGEN AND SHEATH POTASSIUM

Leaf Nitrogen

In Fig. 5 and 6 are shown the leaf nitrogen readings for H53-263 and H54-775, respectively, taken from the middle of leaves 3, 4, 5, and 6 and expressed

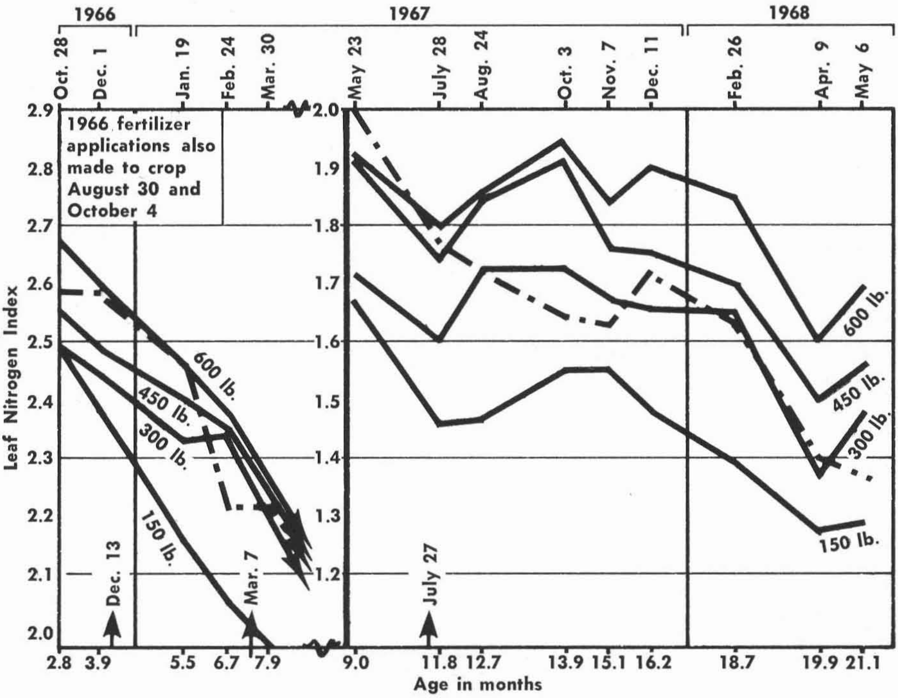

FIG. 6. The actual leaf nitrogen index curves for variety H54-775, plotted from readings taken at various times throughout the crop season. Each curve is for a particular nitrogen treatment but with all four potash treatments included. Upward pointing arrows indicate dates of fertilizer applications. The broken line is the normal nitrogen index for the highest yielding crops of H54-775 as grown at Pepeekeo. Note broken scale.

as percent of the dry matter. Each point on a curve represents an average of 16 separate samples and determinations and each includes the N levels at all four levels of K. The normal points are those calculated for the respective variety from data taken from the highest yielding crops at Pepeekeo. The four N treatments resulted in distinct levels of N in the plant throughout the cycle. Except for treatment D-IV, as already noted in Tables 1 and 2, the C treatment gave maximum yields and as can be seen in Fig. 5 and 6, the pertinent curves stay fairly close to the "normal." Through March 30, and after August 24, the C and D treatments remain above normal, and A and B below, with the C treatment following most closely. From May 23 through July, all treatments drop below normal, but after the final application on July 23, the levels again resume their proper positions. The drop below normal during the March to May period probably represents the effect of low soil temperatures and also the start of rapid growth because of favorable air temperatures. Evidence for this appears again the next spring,

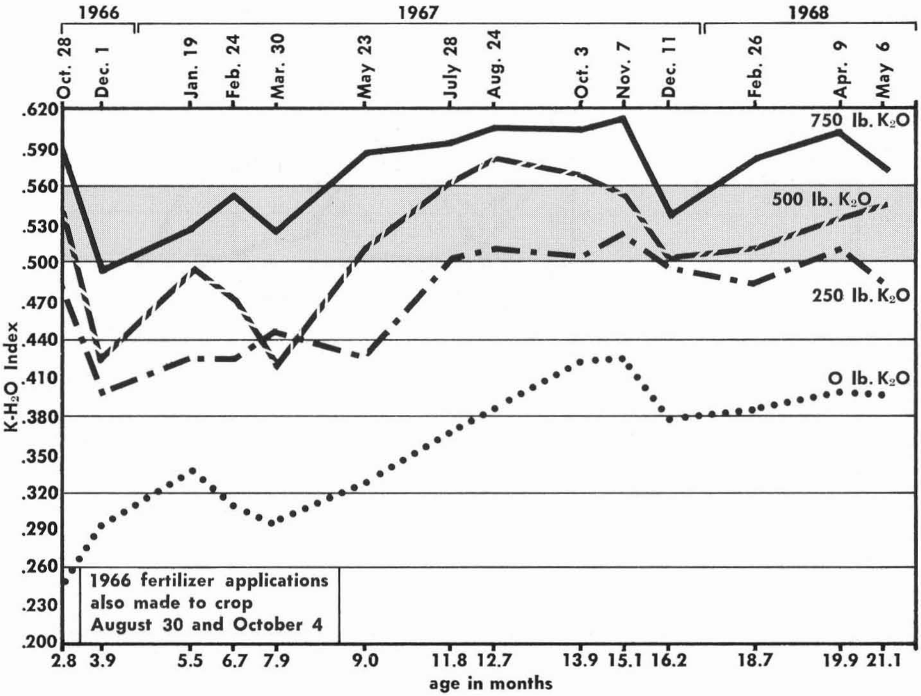

FIG. 7. The actual potassium index curves for variety H53-263, plotted from readings taken at various times throughout the crop season. The shaded area shows the range within which potassium levels are adequate if nitrogen fertilization is correct. Upward pointing arrows represent dates of fertilizer applications.

April 9. The markedly higher leaf nitrogen during the first 7 to 8 months as compared with the remainder of the crop are usual and reflect the close relationship among tissue moisture, N, and K. As the plant becomes older its dry matter builds up and the moisture level drops as does the N level, but, of course, the K level rises.

Sheath Potassium

In Fig. 7 and 8 are shown the K-H_2O index readings, throughout the entire crop cycle, in relation to the four K_2O treatments. Tables 1, 2, and 3 have shown there was a response to K_2O and that this was mostly linear, although there was a small drop at the highest level. There was no effect of variety nor was there any effect on quality, except as noted above for purity. Heretofore, the "critical" level was considered to be 0.425. Following this experiment, however, it seems that the amount of K_2O to use will be that amount needed to keep the K_2O level between 0.5 and 0.6. The difficulty

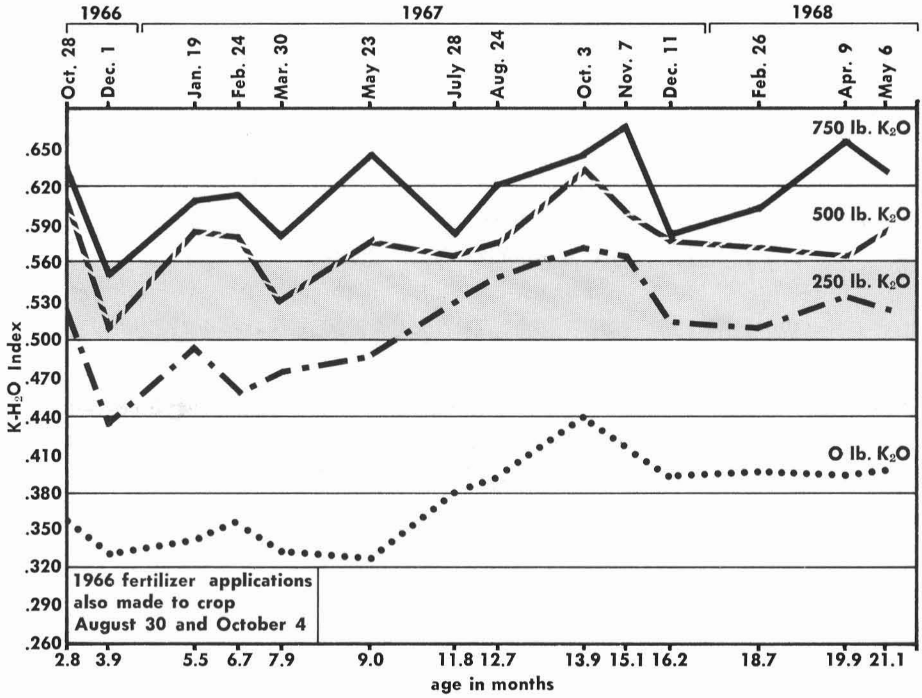

FIG. 8. The actual potassium index curves for variety H54-775, plotted from readings taken at various times throughout the crop season. The shaded area shows the range within which potassium levels are adequate if nitrogen fertilization is correct. Upward pointing arrows represent dates of fertilizer applications.

of achieving this will be determined at least partly by the amount of N needed to keep the leaf nitrogen index at normal. In this experiment the very highest N application combined with the very highest K_2O to give the highest cane and pol yield, although at a reduced quality.

Normal Nitrogen Curve

In an earlier report (*2, 7*), it was shown that the normal nitrogen (NN) curve based on tissue moisture and age is essentially the same for all the cane varieties used in Hawaii. While some varieties may have had higher or lower apparent levels of N, this was related to their moisture levels. The NN for the two varieties, H53-263 and H54-775, when collected on August 24, 1967 was reported at 1.88 and 1.82 percent, respectively. This difference was significant ($F = 7.53^*$). The sheath moistures for the same collection were 81.54 and 80.59 percent ($F = 7.80^*$). The actual leaf nitrogen readings were 1.72 and 1.73, only slightly different but both below the

NN. Now the NN shown above is that calculated for record yields of 44-3098, an old variety now being displaced. The equation obtained was:

$$\text{For 44-3098} \quad NN = 0.05885\, \underset{\text{Sheath } H_2O}{X_1} - 0.02270\, \underset{\text{Age}}{X_2} - 2.5931 \tag{1}$$

The NN curves for the two varieties used in the experiment were calculated according to these equations:

$$\text{For H53-263} \quad NN = 0.09738\, \underset{\text{Sheath } H_2O}{X_1} - 0.02835\, \underset{\text{Age}}{X_2} - 5.8212 \tag{2}$$

$$\text{For H54-775} \quad NN = 0.07875\, \underset{\text{Sheath } H_2O}{X_1} - 0.02652\, \underset{\text{Age}}{X_2} - 4.2727 \tag{3}$$

For a comparison of the NN derived from each of these three equations, Table 4 gives the ages and sheath moistures for X and Y varieties as taken for the C treatments and the average of the K_2O treatments.

TABLE 4. Calculation of normal nitrogen levels

Age, months	H53-263 Moisture	H54-775 Moisture	Normal nitrogen by equation 1		2	3
			X	Y	X	Y
2.8	88.2	87.2	2.53	2.48	2.60	2.59
3.9	88.1	87.5	2.50	2.47	2.56	2.59
5.5	87.1	86.6	2.41	2.38	2.44	2.46
6.7	85.2	84.4	2.27	2.22	2.26	2.21
7.9	86.1	84.8	2.29	2.22	2.30	2.21
9.0	84.0	83.2	2.15	2.10	2.10	2.03
11.8	82.0	81.4	1.96	1.93	1.87	1.77
12.7	81.9	81.2	1.94	1.90	1.84	1.73
13.9	82.0	80.7	1.92	1.84	1.82	1.64
15.1	82.1	80.8	1.90	1.82	1.79	1.62
16.2	83.7	82.2	1.96	1.88	1.89	1.72
18.7	81.8	82.0	1.80	1.81	1.67	1.63
19.9	81.7	80.0	1.76	1.66	1.63	1.40
21.1	81.7	80.0	1.74	1.64	1.60	1.37

Comparing the NN readings for X in the first column, calculated with the standard 44-3098 formula, with those in the third column, calculated with the formula for variety X, shows remarkably similar readings for the period during which active fertilization is going on. During the second year, however, the departures vary up to 0.10 percentage points. Considering that these readings are from a field experiment sampled by regular field crews, and processed by the field laboratory, it might be considered unnecessary to try for greater precision. However, leaf nitrogen readings are generally very precise. Now comparing the NN in the second column, the NN for variety Y calculated from the 44-3098 formula with column 4, the NN calculated with formula (3) for variety Y, greater discrepancies are apparent. During the first year, the discrepancies vary from 0.01 to 0.12 percentage points but during the second year, from 0.16 to 0.27 percentage points.

Even though the NN's during the first year are very similar, it is a simple and practical matter to have an NN formula for each variety, since once a variety reaches commercial standing several crop logs for it already exist. These would be for record crops, otherwise the variety would have been discarded. If calculations are made for only the two dominant factors other than supply affecting leaf nitrogen, sheath moisture, and age and if only four or five logs exist, the calculation can be done manually. For the convenience of the Crop Control Superintendents, a complete array of two- and three-member equations for NN for all the important varieties at each of several plantation areas throughout the State is given in the Appendix. These were obtained by assembling all the crop logs for the record yields by field in each of the areas listed.

The essential data were put on cards and included (i) the green weight of the sheath sample collected each time, (ii) the maximum, minimum temperatures and light readings (where available) for the 35-day intervals, (iii) the sheath moisture, (iv) age in months, (v) leaf nitrogen and (vi) the K-H_2O readings. Fortran programming was followed in its step-wise regression manner and the first two most important factors which appeared make up the two-member equations and when the next one appeared, the three-member equations developed. In general, tissue moisture and age are the dominant first two factors. The third factor varies considerably.

INFLUENCE OF EXPERIMENTAL TREATMENT ON VARIOUS INDEXES

In this section, a detailed examination of the crop log data for the experiment will be made, using the analytical results from five plot-by-plot collections as the source material. Although nine other collections were made, they were not on a plot-by-plot basis. While useful for general guidance, they could not be analyzed statistically.

Leaf Nitrogen Index

In Table 5 are shown the statistical data for the leaf nitrogen (LN) index. In each case a complete variance analysis was made including not only the

TABLE 5. F values for leaf nitrogen, as affected by the experimental treatments

Source	12/1/66 3. 9 months	1/19/67 5.5 months	7/28/67 11.8 months	8/24/67 12.7 months	10/3/67 13.9 months
N_l	30.49*	37.99**	49.81**	86.16**	743.12**
N_q	—	—	—	7.75[10]	—
N_c	—	—	—	—	32.64**
K_l	4.80*	—	—	—	—
N_qK_q	—	—	5.55*	—	—
V	14.50**	23.17**	—	—	—
VN_l	—	—	7.22**	—	15.81**
VN_q	—	—	—	—	18.56**
VN_cK_l	—	—	—	—	8.28*
Leaf N (avg)	2.54	2.41	1.67	1.72	1.78
CV (%)	6.2	5.7	7.1	6.2	1.9

main effects but all the possible interactions as well. In order to save space, however, only those effects which achieved significance will be reported. These are the F values. Below are given the average leaf nitrogen readings by date and also the percent coefficient of variability (CV).

In Table 6 are shown the actual leaf nitrogen indexes for the October 3, 1967, collection. These are arranged according to experimental groups and

TABLE 6. Leaf nitrogen indexes, percent dry matter of leaves 3, 4, 5 and 6 (October 3, 1967, collection)

Treatments	I	II	III	IV	Mean
A	1.62	1.67	1.65	1.60	1.63
B	1.73	1.74	1.72	1.65	1.71
C	1.90	1.81	1.92	1.89	1.88
D	1.87	1.93	1.90	2.01	1.93
Mean	1.78	1.79	1.79	1.79	—

Treatments	X	Y	Mean
A	1.72	1.55	1.63
B	1.69	1.73	1.71
C	1.85	1.91	1.88
D	1.91	1.94	1.93
Mean	1.79	1.78	—

Treatments	X	Y	Mean
I	1.81	1.75	1.78
II	1.80	1.78	1.79
III	1.80	1.79	1.79
IV	1.77	1.80	1.79
Mean	1.79	1.78	—

as averages for each. Thus, each value in the top NK table represents the average of four separate samplings and analyses. Each of the overall means shown to the right and below for the NK table represents 16 separate samplings, and the two means at the bottom of the NV and KV tables represent 32 separate samplings.

The overwhelming influence on the leaf nitrogen index is, of course, the amount of N used as fertilizer. K_2O fertilization did not affect the leaf nitrogen except at 3.9 months of age. Varieties showed influence as main effects only during the 3.9- and 5.5-month collections. However, there is a rather clear difference in the VN regressions—Y showing a strong linear regression with N while X tends to show a quadratic regression for this one collection. Had there been an irrigation treatment involved, the N readings would have been greatly affected (*2*), since N and moisture show very strong influences on each other. Also, as shown at the bottom of Table 5, age has a very strong effect. The CV values show the degree of precision possible in field experiments involving N.

Potassium Indexes

In Table 7 are shown results of variance analysis for the five plot-by-plot collections. K is shown in two ways, as the K index which is the K content of the sheaths expressed as a percent of the sugar-free dry weight and as the K-H_2O index which is the K content of sheaths 3, 4, 5, and 6 expressed as a percent of the sheath-tissue moisture. It is apparent from the F values that the K-H_2O index is more sensitive than the K index and, in view of the lower CV, more reliable also. Either one can be used with good effect, however.

In Table 8 are shown the detailed K-H_2O data for the October 24, 1967, collection. It was noted earlier that the K treatment did not affect leaf nitrogen. In contrast, the K-H_2O, especially once the crop is well closed in, is markedly and always negatively affected by the N treatment. This is true whether K is reported as percent moisture or percent dry matter. Part of the explanation lies in the fact that N caused heavier growth resulting in greater demand and dilution of K. For example, in Table 8 the K-H_2O for A-I and D-I is 0.446 and 0.322. The one is 72 percent of the other. Yet from Table 2, the yields of cane for these plots were 86.1 and 103.6 tons per acre, respectively. The one is 83 percent of the other. Another factor here involves the general effects that each fertilizer treatment has on increasing the tissue moisture level. Since the K-H_2O is expressed on moisture, a further reduction would be expected.

The application of K_2O, of course, largely determined the K-H_2O levels, although each additional increment gives a smaller incremental increase in the tissue level. As seen in Table 7, the effect is mostly linear, although

TABLE 7. F Values for the K index and the K-H_2O index, as affected by experimental treatments

Source	12/1/66 3.9 months		1/19/67 5.5 months		7/28/67 11.8 months		8/24/67 12.1 months		10/3/67 13.9 months	
	K index	K-H_2O	K index	K-H_2O	K index	K-H_2O	K index	K-H_2O	K index	K-H_2O
N_l	32.91**	22.71*	—	—	—	469.92**	28.60*	84.56**	—	27.11**
N_q	—	—	—	—	—	—	—	—	6.06*	—
N_c	33.16*	—	—	—	—	12.50*	—	—	—	—
K_l	156.66**	120.95**	278.79**	379.61**	200.56**	301.36**	307.56**	228.00**	110.42**	221.26**
K_q	7.64*	—	14.76**	26.62**	12.00**	44.21**	8.42*	24.94**	11.86**	18.37**
K_c	—	—	8.14*	—	—	—	—	—	—	—
N_lK_q	—	—	—	19.76**	—	—	—	—	—	—
N_qK_l	—	—	—	—	—	5.18*	—	4.49[10]	—	—
K_q	—	—	—	—	—	—	6.42*	—	—	—
V	7.51*	30.25**	—	—	16.26**	—	8.42**	—	—	20.38**
VK_c	—	5.55**	—	—	—	—	—	—	—	—
VK_q	—	4.62*	—	—	—	—	—	—	—	—
VN_l	—	—	—	—	—	—	13.18**	29.82**	—	—
VN_q	—	—	—	—	—	—	—	10.15**	—	—
Index level	3.33	.428	3.32	.475	2.44	.510	2.51	.523	2.54	.548
CV	12.91	12.75	10.00	7.50	10.50	6.90	8.52	8.15	10.65	7.08

TABLE 8. K-H_2O indexes on August 24, 1967

Treatments	I	II	III	IV	Mean
A	0.446	0.568	0.663	0.698	0.594
B	0.391	0.552	0.596	0.621	0.540
C	0.391	0.548	0.539	0.566	0.511
D	0.322	0.446	0.518	0.567	0.463
Mean	0.388	0.529	0.579	0.612	—

Treatments	X	Y	Mean
A	0.576	0.612	0.594
B	0.532	0.549	0.540
C	0.495	0.527	0.511
D	0.478	0.449	0.463
Mean	0.520	0.534	—

Treatments	X	Y	Mean
I	0.385	0.391	0.388
II	0.509	0.549	0.529
III	0.582	0.577	0.579
IV	0.577	0.620	0.612
Mean	0.520	0.534	—

the top treatments give less than proportional increases resulting in the quadratic regressions shown. NK interactions, if they occur at all, are weak.

The two varieties showed different reactions to K_2O in only two of the five cases cited. In only one case (Table 7) was there a VN interaction, rather clearly discernible also in Table 8.

As was seen in Fig. 7 and 8, the K-H_2O is generally low at the start of the young crop, which is generally high in moisture, but builds up as the crop ages. This, together with experience, shows the need for early K_2O applications and probably a reduction later on. A drought also greatly affects the K-H_2O and for two reasons: first, because of reduced growth, the K accumulates and second, because of the reduced moisture, the apparent concentration rises. This is one of the big advantages of using the K-H_2O rather than the K index. The latter is expressed on dry matter which increases strikingly during a drought. This in turn reduces the apparent K index well below deficiency levels. Yet there is an excess of dry matter and a deficiency of moisture and not K. The CV for K-H_2O is somewhat higher than that noted for leaf nitrogen, but once the crop is closed in, it is acceptable.

Efforts at using N/K, K/N ratios or K $\times$ N products resulted usually in less clarity and precision. Ratios have been very popular with French workers (*10, 11*) as well as others. The N/K ratio is commonly in use but where N and K are supplied as fertilizers in adequate amounts, both the N and K indexes rise together. It is conceivable that at deficiency levels, an N/K ratio might exist which could be duplicated at high levels, and yet growth at the same ratios would be distinctly different. Because of the rising and falling together, it seems more reasonable to multiply the two values. Here very decisive spreads can be had. However, analysis shows lower significance for this combined index than for each of the two indexes taken separately. Data showing these relationships are presented in Table 9 taken from the October 3, 1967, collection.

TABLE 9. Main effect comparisons of various possible K indexes, F values (October 3, 1967, collection)

Source	K index	K-H_2O	N × K-H_2O	N/K	K/N
N_l	—	27.11*	—	127.43**	102.58**
N_q	6.06[10]	—	—	—	—
N_c		—	—	—	—
K_l	110.42**	221.26**	109.04**	165.44*	11.82**
K_q	11.86**	18.37**	9.88**	22.06**	—
K_c	—	—	—	—	—
V	—	20.38**	17.99**	13.38**	—
CV (%)	10.65	7.08	10.04	8.48	31.07

The F values for the various ratios and products show that the N × K-H_2O essentially neutralizes the N effect while the K/N ratio minimizes the K effect. The N/K ratio gives a relative balance between the two and therefore may have some value in diagnosis, although as the K level rises the ratio drops. Since leaf nitrogen and K-H_2O taken alone show most clearly the various relationships, nothing seems to be gained by using ratios.

Application of Indexes to Yield Responses

The four highest cane yields were obtained with treatments D-IV, C-III, D-III, and C-IV, in that order. The K-H_2O readings fell in the 0.5 to 0.6 range, which clearly shows the desired levels to be maintained. K-H_2O levels higher than this are to be found where N levels are clearly below normal, and levels below this are associated with N above normal and K actually deficient. Thus, in Table 10 are shown three groups of data arranged as for the NK table. In the top group are the average leaf nitrogen indexes for the three main collections; in the second group are shown the NN obtained by using the actual moisture and age of each of the two varieties for each treatment group and applying the NN equation specific to each. Finally in the lowest grouping are the departures from normal for each treatment. C-IV and D-IV show no departure, demonstrating that N was neither a limiting nor an excessive factor so far as growth was concerned. C-II and C-III are

TABLE 10. Leaf nitrogen, normal nitrogen and departures from normal
(Top cane yields underscored)

Treatments	Leaf nitrogen I	II	III	IV
A	1.58	1.57	1.55	1.53
B	1.65	1.69	1.68	1.70
C	1.81	1.75	1.87	1.83
D	1.84	1.82	1.84	1.97

Treatments	Normal nitrogen I	II	III	IV
A	1.64	1.65	1.71	1.71
B	1.65	1.76	1.74	1.76
C	1.69	1.76	1.86	1.83
D	1.72	1.78	1.81	1.97

Treatments	Leaf nitrogen departures from normal nitrogen I	II	III	IV
A	—0.06	—0.08	—0.16	—0.18
B	+0.02	—0.07	—0.06	—0.06
C	+0.15	—0.01	+0.01	0.00
D	+0 12	+0 04	+0 03	0.00

within —0.01 of normal and B-I is within +0.02 of normal. From A-I to A-IV and B-II to B-IV, N is in deficient supply. N is in excess from B-I to D-I, pointing to some other deficiency factor—in this case, K. From D-I to D-IV, N is in diminishing excess down to the balance in D-IV. B-I and B-II show small excesses for the low K levels but mild deficiencies for the higher K levels.

In Table 11 are shown the average of the K-H_2O for the same three collections. Thus, each datum is an average of 12 separate samplings and analyses. Deficiencies and excesses stand out clearly.

Just as A-I to A-IV showed increasing deficiencies in N, so they showed strikingly increasing excesses in K as the K_2O applications increased. In other words, the K was not being used because of the N deficiencies. From A-I to D-I, the deficiencies were severe, restricting the utilization of the N applied. C-II, while about normal in N, was somewhat below optimum in

TABLE 11. K-H_2O readings, average of three collections (Top cane yields underscored)

Treatments	I	II	III	IV
A	0.445	0.570	0.656	0.690
B	0.405	0.552	0.589	0.615
C	0.268	0.513	0.559	0.563
D	0.344	0.476	0.518	0.564

K. D-II showed a slight excess of N but its K-H_2O was below optimum. C-III, C-IV, D-III, and D-IV, which had the four heaviest cane tonnages, had two factors in common: their N levels were normal and their K-H_2O ranges were from 0.518 to 0.564. It may therefore be concluded that under conditions of adequate moisture, where the N level is normal, that 0.518 to 0.564 percent of K of the tissue moisture is adequate for maximum growth where all other factors are normal. Where the K-H_2O level is above this range, deficiencies in other factors are indicated (notably moisture and N or both). Where the K-H_2O levels are below this range, various degrees of K deficiency exist. In view of these rather precise data, there seems little need for using ratios.

Tissue Moisture

Since growth has been influenced by both N and K, it can be anticipated that tissue moisture also will be affected. In Table 12 are shown the effects on tissue moisture noted in the experiment. In crop logging, tissue moisture

TABLE 12. Tissue moisture as influenced by experimental treatments, F values

Source	12/1/66 3.9 months	1/19/67 5.5 months	7/28/67 11.8 months	8/24/67 12.7 months	10/3/67 13. 9 months
N_1	5.82^{10}	11.21*	39.84**	––	8.09^{10}
K_1	24.79**	53.99*	52.37**	23.86**	4.92*
K_q	6.89*	––	7.83*	5.0^{10}	––
N_1K_1	––	––	7.83*	5.09*	––
V	––	5.96*	29.22**	7.80*	29.58**
VK_q	6.67*	––	––	––	5.70*
VN_1K_q	8.08*	––	––	––	––
VN_qK_1	5.00*	––	––	––	––
Sheath H_2O	87.6	86.5	81.5	81.1	80.8
CV (%)	0.70	0.77	1.19	1.7	1.19

is the moisture content of leaf sheaths 3, 4, 5, and 6 expressed as percent of the green matter. All three treatments, as well as some interactions among them, affect moisture levels. Data in Table 13 show the general effects. These are averages of the three main collections. Comparing these data now with pol percent cane data in Table 2 reveals one rather striking thing—although K_2O treatments affect tissue moisture exactly the same as do the N treatments (80.2 to 81.9 percent in each case), only the N treatments have significantly affected quality, showing that quality in this high-rainfall area is essentially a matter of juice purity and not Brix. Pol percent cane declined steadily from 12.83 percent for the low treatment to 11.49 percent for the high, while for the K_2O treatments there was an inconsistent change from 12.01 to 12.21 percent. Although variety Y had a lower moisture content, which is very significant statistically, it did not show a significant difference in quality.

TABLE 13. Tissue moisture levels by treatment, percent green weight

Treatments	I	II	III	IV	Mean
A	79.8	79.9	80.6	80.6	80.2
B	79.9	81.1	81.0	81.3	80.8
C	80.4	81.2	82.4	82.1	81.5
D	80.7	81.4	81.7	83.6	81.9
Mean	80.2	80.9	81.4	81.9	—

Treatments	X	Y	Mean
A	81.0	79.5	80.2
B	81.3	80.4	80.8
C	82.0	81.1	81.5
D	82.6	81.2	81.9
Mean	81.7	80.6	—

Treatments	X	Y	Mean
I	81.1	79.3	80.2
II	81.6	80.2	80.9
III	81.9	80.9	81.4
IV	82.2	81.6	81.9
Mean	81.7	80.6	—

Green Weight of Sheath Samples

Sheaths 3, 4, 5, and 6 make up the crop log samples analyzed for everything but N. The weight of the 20 sheaths making up a sample has come to be used as a criterion of growth. Of interest, then, is the susceptibility of this index to change by treatments which have significantly affected yield. In Table 14 are the variance data and in Table 15 the average green weights for the three final collections.

Since the size of the sheath is determined at least in part by the size of stem, which is a varietal characteristic, then obviously also the size of the

TABLE 14. Green weights of sheaths as influenced by treatments, F values

Source	12/1/66 3.9 months	1/19/67 5.5 months	7/28/67 11.8 months	8/24/67 12.7 months	10/3/67 13.9 months
N_l		—	6.39[10]	5.53[10]	37.24**
N_q	9.19[10]	—	—	—	—
N_c	—	—	—	—	11.41*
K_l	40.66**	52.55**	35.82**	28.04**	18.43**
K_q	—	6.87*	16.39**	—	—
K_c	—	—	7.16*	—	—
N_lK_l	9.08*	—	—	—	—
N_lK_q	—	—	8.90*	—	—
N_qK_l	—	4.80*	—	—	—
N_qK_q	—	—	17.44**	—	—
N_cK_q	—	—	—	—	11.70**
V	195.23**	115.59**	400.93**	2318.4**	1053.00**
VN_l	8.60**	—	—	29.82**	—
VN_q	5.17*	—	—	10.15**	—
VK_l	—	—	—	13.13**	—
VK_q	—	—	—	5.66*	—
VK_c	—	—	—	—	14.99**
VN_lK_l	—	—	—	8.20*	—
VN_qK_l	—	—	—	15.66**	—
VN_cK_c	—	—	—	5.44*	—
VN_lK_c	—	—	—		5.07
Green wts. (avg)	289.00	359.00	327.00	320.00	294.00
CV (%)	7.71	6.2	6.7	2.8	4.7

sheath is a varietal characteristic, as is clearly shown in the next table. The green weights of the sheaths clearly show the effects of N as well as K_2O treatments, paralleling rather well the actual cane yields shown in Table 2 and justifying the use of the sheath weight within a variety as indicative of growth being made. In fact, judging by the interaction, the green weights are more sensitive to nutrition than the cane yields. The bigger the stalk and the greater the elongation of stalk the larger will the sheath be and the greater its green weight.

The green weights can be used also in irrigation experiments as the criteria of growth. They do not apply so well in P_2O_5 experiments or perhaps in any other experimental treatment which results in substantially increased numbers of stalks per unit area. In most cases where positive response to P_2O_5 was recorded, very significant but negative effects on green weights followed, reflecting the greater stalk population and the resulting crowding.

TABLE 15. Green weights of samples by treatment, average of three
(Four top cane yield treatments underscored)

Treatments	I	II	III	IV	Mean
A	280.7	297.7	290.0	313.9	295.6
B	281.2	315.0	327.6	307.5	307.8
C	298.0	326.5	332.5	332.9	322.5
D	296.1	330.6	334.3	352.9	328.5
Mean	289.0	317.4	321.1	326.8	—

Treatments	X	Y	Mean
A	344.6	246.4	295.6
B	362.9	252.8	307.8
C	378.5	266.4	322.5
D	388.9	268.1	328.5
Mean	368.7	258.4	—

Treatments	X	Y	Mean
I	341.4	236.5	289.0
II	371.7	263.2	317.4
III	380.2	261.8	321.1
IV	381.6	272.0	326.8
Mean	368.7	258.4	—

Total Sugars of Sheath

The level of total sugars in the sheaths (percent dry matter) has, along with tissue moisture, been very useful in reflecting the well-being of the plant or fitness to a particular environment (*5*). Where the level is high, the plant is growing less well than could be expected by the energy available. Where the level is low, growth tends to be more rapid than justified by good quality. Variance data are given in Table 16 and actual levels in Table 17. A high level, however, does not mean high-level storage of sucrose in the

TABLE 16. Variance data for total sugars, F values

Source	12/1/66 3.9 months	1/19/67 5.5 months	7/28/67 11.8 months	8/24/67 12.7 months	10/3/67 13.9 months
N_l		8.73^{10}			
N_q	9.20^{10}			20.56*	
N_c	11.80*				
K_l	187.11**	355.10**	229.40**	148.48**	61.29**
K_q	13.13**	19.89**	26.92**	8.49*	
K_c			11.42**	24.40**	
N_lK_l			4.77*		
V	49.36**	27.92**	18.30**	12.78**	24.70**
Total sugars (avg)	8.02	7.21	8.70	9.60	9.20
CV (%)	9.1	13.8	7.2	12.2	7.3

TABLE 17. Total sugars of the sheaths by treatment, percent dry matter (average of three)

Treatments	I	II	III	IV	Mean
A	10.5	9.3	8.4	8.2	9.1
B	10.9	8.7	8.5	7.6	8.9
C	11.2	9.4	8.2	8.0	9.2
D	11.8	9.5	8.8	7.9	9.5
Mean	11.1	9.2	8.5	7.9	—

Treatments	Y	X	Mean
A	9.5	8.7	9.1
B	9.4	8.4	8.9
C	9.6	8.8	9.2
D	9.9	9.1	9.5
Mean	9.6	8.7	—

Treatments	X	Y	Mean
I	11.5	10.7	11.1
II	9.8	8.7	9.2
III	8.9	8.0	8.5
IV	8.3	7.5	7.9
Mean	9.6	8.7	—

stalk or vice versa. It indicates the balance existing between growth and carbohydrate utilization and between carbohydrate production and translocation. In general, lowering the moisture level raises the total sugars. It is probable that because K deficiencies markedly lower tissue moisture, they raise the total sugar level. N deficiencies, however, also lower tissue moisture but usually raise the total sugars even though slightly. A more common reaction is that as the increased N is associated with deepening greenness of the leaves, that as N thus stimulates photosynthesis, there is an actual rise in the total sugar production and hence sheath level. The data in the tables verify these points: (i) N is positively, though weakly, related to total sugar levels, (ii) K is negatively related to the total sugar levels, and (iii) since the total sugar level reflects the well-being of the plant, it is not surprising that the two varieties differ. Even though the difference is small, it is highly significant throughout.

In an effort to determine the usefulness of the primary index (total sugars of the sheath), crop logs of record yields for each field on three large plantations were assembled and the total sugar levels were analyzed using Fortran. Growing conditions varied from the very hot, irrigated, high-yielding Olokele area through a medium climate, high-rainfall Hilo location to the cool, high-elevation, unirrigated Pahala section. The total df was 8743. The analysis is in Table 18 arranged in the order of importance determined by the computers.

TABLE 18. Total sugars analysis, partial regressions and simple correlation

Factor	Partial regression	Simple correlation
Sheath H_2O	—0.8532	—0.4274
Leaf nitrogen	+0.2190	—0.0889
K-H_2O	—0.2193	—0.1131
Maximum temperature	—0.4081	—0.3503
Age	—0.3353	—0.0370
Green weight	+0.1665	—0.0802
Minimum temperature	+0.0391	—0.2333

R^2 = .5029** F value=1262.62** df = 7 and 8735

Because the plantations did not have adequate measurements of sunlight, this factor could not be included. Actually sunlight gives a strong positive correlation as well as partial regression on the total sugar level. However, despite this, the total sugar level (primary index) is very useful in diagnosing the fitness of the crop to its environment.

Amplified Phosphorus Index

The Amplified Phosphorus Index (API) represents a combination reading (*1, 7*). The P content of the sheath is standardized to a common moisture and total sugar level and that of the fifth mature internode is expressed as percent dry matter. Two representative values obtained, for example, could be 0.085 and 0.030 percent, respectively. The two members are then treated as whole numbers and multiplied ($85 \times 30 = 2550$). The product is the API. It has been very useful for guidance in fertilization. Variance data and API readings are shown in Tables 19 and 20. Only the three main collections are included, since the stem tissue was not available earlier. It

TABLE 19. Variance data for API, F values

Source	11.8 months	12.7 months	13.9 months
N_l	114.00**	96.07**	49.54**
N_q	23.44**	40.71**	13.81*
K_l	20.65**	——	5.63*
V	——	6.30*	8.77**
VN_l	——	5.52*	——
API (avg)	3736	3687	3814
CV (%)	25.1	26.67	23.1

TABLE 20. API readings by treatment

Treatments	I	II	III	IV	Mean
A	5614	5460	5044	4947	5266
B	4495	3123	3369	3342	3582
C	3502	3114	2829	2739	3046
D	3807	3005	2566	2975	3088
Mean	4355	3676	3452	3501	—

Treatments	X	Y	Mean
A	5956	4576	5266
B	3772	3392	3582
C	3109	2984	3046
D	3194	2982	3088
Mean	4008	3483	—

Treatments	X	Y	Mean
I	4543	4166	4355
II	3980	3371	3676
III	3819	3085	3452
IV	3690	3311	3501
Mean	4008	3483	—

will be noted that the CV percentages are very high. As Gowing has shown (*9*), transforming the data to square roots or logs greatly reduces this, if it is cogent to do so. However, where greater precision is needed, the best approach is to collect samples made up of more stalks.

To avoid any possibility of a P deficiency, 600 pounds of P_2O_5 was applied under the setts at planting time. This amount greatly exceeds, in the order of 10 times, the amount actually absorbed by the crop. Soil fixation in the experimental area is very high, but once root development is strong, the crop obtains adequate supplies. To insure good root development (*6*), 3 tons of calcium metasilicate per acre was applied and rotovated into the soil. Thus, the data in Tables 19 and 20 should represent direct effects rather than just variation due to dilution by growth. The dominant influence on P absorption is N and the influence is strongly negative, mostly linear but showing curvilinear trends as well. K fertilization is also negative but not strongly significant. The varieties also vary in their abilities to absorb P. In view of the strong negative effects which N has on P uptake, it is very essential that wherever a crop is to be forced with high amounts of N, appropriate levels of P be maintained. For example, the treatments which gave the highest cane tonnages, D-III, D-IV, C-III, and D-IV, had API readings just above the critical level, which is in the 2400 to 2500 range.

Calcium

Although Ca (Ca content as percent sugar-free dry matter of the sheaths) is an essential element, its function is satisfied at relatively low levels of the element. By far the greatest role is that of offsetting toxicity effects of soil elements *(6, 7)*. Thus, maintaining high levels is desirable if maximum yields are to be obtained. The calcium metasilicate treatment as well as the use of monocalcium phosphate should have maintained adequate Ca indexes. Ca index levels between 0.17 and 0.20 are adequate for Ca as a nutrient and Tables 21 and 22 show the effects of treatment.

TABLE 21. Variance data for the calcium index, F values

Source	12/1/66 3.9 months	1/19/67 5.5 months	7/28/67 11.8 months	8/24/67 12.7 months	10/3/67 13.9 months
N_l	25.14*	——	27.87*	40.70*	56.09**
N_q	——	——	——	——	23.08*
K_l	79.02**	76.08**	87.78**	72.61**	54.20**
K_q	——	21.89**	8.89*	9.81**	——
K_c	——	——	7.48*	——	——
V	——	91.91**	49.70**	142.51**	——
VN_l	4.71*	——	——	——	——
VK_l	4.47*	4.28*	——	——	——
VN_lK_l	——	——	——	——	7.28*
VN_lK_q	——	——	4.59*	——	——
Ca index (avg)	0.405	0.398	0.303	0.302	0.285
CV (%)	8.8	10.1	12.3	8.5	9.2

TABLE 22. Calcium indexes by treatment

Treatments	I	II	III	IV	Mean
A	0.309	0.274	0.233	0.219	0.259
B	0.331	0.309	0.296	0.281	0.304
C	0.367	0.340	0.330	0.305	0.336
D	0.345	0.310	0.296	0.299	0.313
Mean	0.338	0.308	0.289	0.276	——

Treatments	X	Y	Mean
A	0.240	0.277	0.259
B	0.274	0.334	0.304
C	0.302	0.368	0.335
D	0.286	0.339	0.313
Mean	0.277	0.330	——

Treatments	X	Y	Mean
I	0.317	0.359	0.338
II	0.276	0.341	0.308
III	0.265	0.313	0.289
IV	0.245	0.307	0.276
Mean	0.276	0.330	——

The overall effect of N treatment, as in other plants *(8, 10, 12)*, is the enhancement of Ca absorption, for the most part in linear fashion, but partially quadratic. Conversely, the effect of K_2O treatment is strongly negative, also mostly linear with some curvilinear effects. This is a fortunate situation and emphasizes the need for synchronized fertilization with both N and K if the Ca status is to remain acceptable. Ca builds up where N applications are not balanced with K, and drops off markedly where K is applied excessively without N. But comparing the A-I treatment with the D-IV, Ca is shown as not being affected. Varieties again show different absorption abilities for Ca, with 54-775 (Y) being able to absorb much more than 53-263 (X), perhaps explaining to some degree why the former does better in the more acid, high-elevation soils.

Magnesium

Mg index levels (Mg content as percent sugar-free dry matter of the sheaths) are becoming more and more critical in several high-rainfall areas such as that in which this experiment was performed. While 0.085 percent Mg is considered adequate, many crop log readings are lower. Part of this is due to the use of higher purity fertilizers and part to the lack of Mg fertilization. The responses of the Mg index to the treatments in this experiment are shown in Tables 23 and 24. The levels shown are below the 0.085 tentative level, although C-IV and D-IV are at the standard. Quite obviously, a general application of Mg should have been made. Although the same general relationships hold for Mg as for Ca, the positive effect for N is less marked for Mg, as is also the negative effect for K. For K, only at the two low N levels is there a consistent downward regression.

TABLE 23. Variance data for magnesium, F values

Source	12/1/66 3.9 months	1/19/67 5.5 months	7/28/67 11.8 months	8/24/67 12.7 months	10/3/67 13.9 months
N_l	—	—	—	15.40*	—
K_l	70.77**	64.93**	5.51*	26.86**	27.67**
K_q	—	11.76**	11.92**	13.25**	—
N_lK_l	—	6.80*	7.32*	—	—
V	—	10.78**	8.74**	—	—
VK_l	—	—	15.93**	—	6.02*
VN_lK_l	—	—	8.13*	—	—
$VN K_l$	—	—	—	—	4.71*
Mg index (avg)	0.144	0.135	0.102	0.081	0.057
CV (%)	13.6	9.2	9.3	10.6	13.7

TABLE 24. Magnesium Index levels, by treatment

Treatments	I	II	III	IV	Mean
A	0.083	0.073	0.073	0.071	0.075
B	0.088	0.075	0.070	0.069	0.076
C	0.098	0.088	0.075	0.085	0.086
D	0.097	0.078	0.074	0.084	0.083
Mean	0.092	0.078	0.073	0.077	—

Treatments	X	Y	Mean
A	0.080	0.070	0.075
B	0.078	0.073	0.076
C	0.089	0.082	0.086
D	0.087	0.079	0.083
Mean	0.084	0.076	—

Treatments	X	Y	Mean
I	0.101	0.082	0.092
II	0.083	0.073	0.078
III	0.074	0.071	0.073
IV	0.076	0.078	0.077
Mean	0.084	0.076	—

At the two higher N treatments, the effect of K on Mg is curvilinear. The varieties also show a weaker reaction, and opposite to that for Ca, as might be anticipated.

Other Indexes

In addition to the data already presented, the following materials together with their mean values were determined (all in ppm except sulphur and silica as percent of the dry matter) : molybdenum (0.35) , copper (22.0) , zinc (25.0), boron (2.0) , manganese (255.0) , sulphur (0.319) , silica (2.22) and sheath aluminum (9.0). None of these was significantly affected by treatment except Cu, which showed a positive linear regression with K ($F = 44.09^{**}$) and Mn, which showed some responses to all three treatments but these were very inconsistent. The levels shown are all normal for sugar cane except for Mn which is high, only about 10-14 ppm being normal.

DISCUSSION AND SUMMARY

It develops that nitrogen and potassium were both very much needed in the particular locality of the experiment. When considering only the major effects, the recommended applications were 450 pounds of N and between 300 and 450 pounds of K_2O. However, on the basis of interactions observed in this experiment, the highest rates of application of both gave the highest actual yield, showing that despite the extraordinarily heavy applications, there is no assurance that even higher levels might not have given even higher yields. Limitations of yields were experienced where leaf nitrogen readings were above normal, due not so much to excess N but to too little K. Where leaf nitrogen was below normal, K-H_2O was high, pointing to lack of utilization. Leaf nitrogen, as measured, is not a nutrient but a measure of the leaf protoplasm itself. Where supplies of N are high, associated with adequate water for protoplasm dispersal, a sufficiency of K and other solutes in the water to maintain the proper dispersal and abundant sunlight for maximum carbohydrate production, maximum yields can be realized. In part, this end may be achieved by generous phosphorus supplies as well as calcium which as calcium metasilicate would not only provide for all the Ca needed as a nutrient but also for the elimination of soil toxicities. The exploration of very much higher levels is certainly indicated, particularly in higher energy environments.

The concept that there is a single critical (*14*) level for N could not be verified here. The critical level for N is a function of tissue moisture and crop age and obviously varies throughout the crop. The critical level for K with the high rates of fertilization was above that formerly considered adequate. Perhaps this indicates that as N levels within the plant are raised even higher, there will be more tissue moisture calling for more K, not only to maintain what are considered normal K-H_2O levels now, but pointing to newer critical levels as well.

The use of N/K or K/N ratios or K $\times$ N products so popular (*11, 12*) in some areas added only confusion in the interpretation of the sugar cane growth data. The leaf nitrogen index, expressed as percent of the dry matter, and K, expressed as percent of the sheath tissue moisture, gave high sensitivities to treatment as determined statistically. With these points in mind, it is worthwhile examining Fig. 1 again and deciding whether the fertilization program was entirely proper. In the overall requirements of the field, 424 pounds of N and 609 pounds of K_2O were applied which checks rather well with the experimental means. The high yield for D-IV, however, was produced by 600 pounds of N and 750 pounds of K_2O. Up until 5 to 7 months of age (Fig. 1) the leaf nitrogen was considerably above normal and the K-H_2O was not adequate. The point suggests itself that since the plant did absorb the N that considerably more K_2O should have been applied during this period. During the 9- to 13-month period, more N might have been applied which in turn might have called for better utilization of K_2O after the 15-month period.

Summary

1. Maximum yields of cane and pol were achieved with the highest levels of N and K, pointing to the possible existence of still greater yield possibilities. At the highest yields apparent, quality suffered, however. The two varieties used gave essentially the same yield.

2. The crop log data showed that where the leaf nitrogen was above normal the K-H_2O was deficient and where leaf nitrogen was below normal showing N deficiency the K-H_2O rose. A balance could be achieved by using less K but maximum yields would not be realized unless the N level was raised to normal, perhaps then also requiring additional K.
3. Where the crop log data showed the leaf nitrogen index to be above normal, the K-H_2O data were below their normal levels. Correction is by way of K fertilization which when effected might well reduce the leaf nitrogen to normal or even below, thus calling also for more N.
4. During the first year of the crop, the NN's for each variety were very similar whether derived from equations specific to each variety or from a common one. However, because of the simplicity of developing equations for each variety in each area, a large number of such equations was developed for each of the several varieties at each of several sugar cane areas in the State.
5. There were many secondary effects of the treatments:
   (a) Although there was no influence of K treatment on leaf nitrogen, N rather strongly depressed the apparent K-H_2O, probably entirely a matter of dilution because of growth and tissue moisture enhancement.
   (b) Tissue moisture levels were enhanced by N and K treatments and there was a small but significant varietal effect.
   (c) The green weights of the sheath samples were sensitive to all three major treatments and to numerous interactions, showing them to be a good measure of growth in this type of experiment.
   (d) The total sugar level of the sheaths (the primary index) was very sensitive to K and variety but less so to N.
   (e) P was strongly depressed by N and less so by K. Varietal differences were significant.
   (f) While tissue Ca was strongly depressed by K fertilization, it was also strongly enhanced by N. Thus the Ca index for the low-low N and K treatment was about the same (0.309 vs. 0.299) as for the high-high treatment. Mg was similarly affected though less strongly.
   (g) Cu was positively affected by K treatment. However, S, SiO_2, Mo, Zn, B, Mn and sheath Al were not affected.
6. The fact that yield differences for the two varieties did not occur and the fact that in a number of cases involving nutrients there were varietal differences suggest that varietal responses to particular levels may be the same but that while adequate levels are more readily

achieved by some varieties than by others, this fact does not become proof that the critical ranges differ.

7. Finally, the need for exploration of higher fertilizer intensities is pointed up, emphasizing that such an effort can only be successful if the plant's well-being is followed very carefully and provided for en-route to the desired end.

LITERATURE CITED

(1) CLEMENTS, HARRY F. 1955. La absorcion y distribucion del fosforo en la planta de cana de azucar. Agronomica Tropical 5: 3–25. (Transl. by Dr. S. Horowitz.)

(2) ________. 1957. Crop logging of sugar cane: the Standard Nitrogen Index and the Normal Nitrogen Index. Hawaii Agr. Exp. Sta. Tech. Bull. No. 35. 56 pp.

(3) ________. 1961. Crop logging of sugar cane in Hawaii. Plant Analysis and Fertilizer Problems (Amer. Inst. Biol. Sci.). Pp. 131–147.

(4) ________. 1964. Foundations for objectivity in tissue diagnosis as a guide to crop control. Plant Analysis and Fertilizer Problems. (Amer. Soc. Hort. Sci.). Pp. 90–110.

(5) ________and T. KUBOTA. 1943. The Primary Index, its meaning and application to crop management with special reference to sugar cane. Hawaiian Planters' Rec. 47: 257–297.

(6) ________, E. W. PUTMAN, and JOHN R. WILSON. 1967. Eliminating soil toxicities with calcium metasilicate. Hawaiian Sugar Technol. 1967 Rep. P. 43–54.

(7) ________, ________, and GLADYS L. N. YEE. 1968. Tissue analysis—the basis of crop logging and crop control. Hawaii Coop. Ext. Serv. Misc. Pub. No. 51. P. 17–32.

(8) EMMERT, FRED H. 1961. The bearing of ion interactions in tissue analysis results. Plant Analysis and Fertilizer Problems (Amer. Inst. Biol. Sci.). Pp. 231–243.

(9) GOWING, DONALD P. 1968. Transforming data in the evaluation of tissue analyses for micronutrients. Proc. Amer. Soc. Hort. Sci. 92: 721–725.

(10) JOHANSEN, C., D. G. EDWARDS, and J. F. LONERAGAN. 1968. Interactions between potassium and calcium in their absorption by intact barley plants. I. Effects of potassium on calcium absorption, and II. Effects of calcium and potassium concentration on potassium absorption. Plant Physiol. 43: 1717–1726.

(11) PREVOT, P., and M. OLLAGNIER. 1954. Peanut and oil palm foliar diagnosis interrelations of N, P, K, Ca, Mg. Plant Physiol. 29: 26–34.

(12) ________and________. 1961. Law of the minimum and balanced mineral nutrition. Plant Analysis and Fertilizer Problems (Amer. Inst. Biol. Sci.). P. 257–277.

(13) SNEDECOR, GEORGE W. 1956. Statistical methods. 5th ed. Iowa State College Press, Ames. xiii + 534 pp.

(14) ULRICH, ALBERT. 1964. The relative constancy of the critical nitrogen concentration of sugar beet plants. Plant Analysis and Fertilizer Problems (Amer. Soc. Hort. Sci.). Pp. 371–391.

APPENDIX

Normal Nitrogen Equations by Variety and Area

Kilauea, Kauai. This partially irrigated plantation is the northernmost in the State. Although elevations are not high, it is a cold area with troublesome soils. The number in parentheses following the variety designation represents the number of items used, and the R^2 that actually obtained for the whole array of factors. All of those reported are very highly significant, although some are much more significant than others.

H49-3533 (527) $R^2 = .7821$

$$NN = .06756\,X_1 - .03221\,X_2 - 3.39986$$

(X_1 = H_2O; X_2 = Age)

$$NN = .054171\,X_1 - .03748\,X_2 - .024353\,X_3 - .31879$$

(X_1 = H_2O; X_2 = Age; X_3 = Maximum Temperature)

H39-7028 (1016) $R^2 = .7515$

$$NN = .07039\,X_1 - .02695\,X_2 - 3.5704$$

(X_1 = H_2O; X_2 = Age)

$$NN = .05653\,X_1 - .03024\,X_2 - .014011\,X_3 - 1.4444$$

(X_1 = H_2O; X_2 = Age; X_3 = Minimum Temperature)

H53-263 (265) $R^2 = .7244$

$$NN = .15242\,X_1 + .05508\,X_2 - 11.2829$$

(X_1 = Moisture; X_2 = Total Sugars)

$$NN = .11525\,X_1 - .01988\,X_2 + .04010\,X_3 - 7.79958$$

(X_1 = H_2O; X_2 = Age; X_3 = Total Sugars)

H51-2279 (175) $R^2 = .7396$

$$NN = -.02641\,X_1 - .05136\,X_2 + 4.1598$$

(X_1 = Minimum Temperature)

$$NN = +.05282\,X_1 - .02366\,X_2 - .03175\,X_3 - .66618$$

(X_1 = H_2O; X_2 = Minimum Temperature; X_3 = Age)

H50-7209 (133) $R^2 = .8031$

$$NN = .13181\, X_1 - .02591\, X_2 - 7.2390$$
H_2O Minimum Temperature

$$NN = .10620\, X_1 - .02904\, X_2 - .01481\, X_3 - 4.7529$$
H_2O Minimum Temperature Age

H52-4610 (124) $R^2 = .6149$

$$NN = .09165\, X_1 - .02186\, X_2 - 4.3398$$
H_2O Minimum Temperature

$$NN = .05444\, X_1 - .02186\, X_2 - .02265\, X_3 - .9808$$
H_2O Minimum Temperature Age

H49-5 (113) $R^2 = .8198$

$$NN = -.03919\, X_1 - .06904\, X_2 + 5.3495$$
Minimum Temperature Age

$$NN = -.5797\, X_1 - .03880\, X_2 - .06589\, X_3 + 5.5545$$
K-H_2O Minimum Temperature Age

Olokele, Kauai. Olokele is on the south slopes of Kauai, is wholly irrigated, and is a very warm, high-yielding area.

H37-1933 (1863) $R^2 = .8138$

$$NN = .05311\, X_1 - .02990\, X_2 - 2.0718$$
H_2O Age

$$NN = .05163\, X_1 - .03113\, X_2 - .01588\, X_3 - .86601$$
H_2O Age Minimum Temperature

H52-4610 (74) $R^2 = .7670$

$$NN = .07318\, X_1 - .01909\, X_2 - 4.1106$$
H_2O Age

$$NN = .07330\, X_1 - .02060\, X_2 - .02407\, X_3 - 2.4773$$
H_2O Age Minimum Temperature

H49-3533 (157) $R^2 = .8343$

$$NN = .04866\,X_1 - .03519\,X_2 - 1.8530$$
X_1 = H_2O, X_2 = Age

$$NN = .04317\,X_1 - .03681\,X_2 - .02586\,X_3 + .35225$$
X_1 = H_2O, X_2 = Age, X_3 = Minimum Temperature

H50-2036 (174) $R^2 = .7543$

$$NN = .06893\,X_1 - .03277\,X_2 - 3.3148$$
X_1 = H_2O, X_2 = Age

$$NN = .06268\,X_1 - .03721\,X_2 - .02984\,X_3 - .7388$$
X_1 = H_2O, X_2 = Age, X_3 = Minimum Temperature

H57-5174 (39) $R^2 = .8358$

$$NN = .041089\,X_1 - .02467\,X_2 - 1.2658$$
X_1 = H_2O, X_2 = Age

$$NN = .04481\,X_1 - .02941\,X_2 - .03139\,X_3 + .59663$$
X_1 = H_2O, X_2 = Age, X_3 = Minimum Temperature

H50-7209 (1157) $R^2 = .8240$

$$NN = .06356\,X_1 - .03247\,X_2 - 2.90782$$
X_1 = H_2O, X_2 = Age

$$NN = .06262\,X_1 - .03451\,X_2 - .02645\,X_3 - 1.0282$$
X_1 = H_2O, X_2 = Age, X_3 = Minimum Temperature

Wailuku, Maui. This is a low-elevation plantation on the east facing slopes of the west Maui mountains, is wholly irrigated, and is capable of moderately high yields.

H49-3533 (30) $R^2 = .8625$

$$NN = .10596\,X_1 - .00113\,X_2 - 6.3560$$
X_1 = H_2O, X_2 = Light

$$NN = .04723\,X_1 - .00127\,X_2 - .03379\,X_3 - .98569$$
X_1 = H_2O, X_2 = Light, X_3 = Age

H57-5174 (33) $R^2 = .9382$

$$NN = .05573 \underset{H_2O}{X_1} - .03643 \underset{Age}{X_2} - 2.2688$$

$$NN = .04414 \underset{H_2O}{X_1} - .03880 \underset{Age}{X_2} - .02117 \underset{\text{Maximum Temperature}}{X_3} + .3870$$

H38-2915 (86) $R^2 = .9320$

$$NN = +.07139 \underset{H_2O}{X_1} - .03835 \underset{Age}{X_2} - 3.4322$$

$$NN = .07010 \underset{H_2O}{X_1} - 04798 \underset{Age}{X_2} + .57994 \underset{K\text{-}H_2O}{X_3} - 3.51755$$

H37-1933 (307) $R^2 = .8519$

$$NN = .06670 \underset{H_2O}{X_1} - .02450 \underset{Age}{X_2} - 3.2587$$

$$NN = .05594 \underset{H_2O}{X_1} - .02780 \underset{Age}{X_2} - .000479 \underset{Light}{X_3} - 2.1278$$

H50-7209 (2268) $R^2 = .8336$

$$NN = .08563 \underset{H_2O}{X_1} - .02286 \underset{Age}{X_2} - 4.8941$$

$$NN = .07181 \underset{H_2O}{X_1} - .02777 \underset{Age}{X_2} - .000613 \underset{Light}{X_3} - 3.3680$$

Hilo-Onomea, Hawaii. This is wholly unirrigated, on the north-northeast slopes of Mauna Kea, and has deep Hydrol Humic soils and very high rainfall.

H53-263 (58) $R^2 = .9064$

$$NN = .05329 \underset{H_2O}{X_1} - .04137 \underset{Age}{X_2} - 1.80369$$

$$NN = +.06383 \underset{H_2O}{X_1} - .03442 \underset{Age}{X_2} - .00569 \underset{\text{Green Weight}}{X_3} - 2.3274$$

H53-1447 (126) $R^2 = .8723$

$$NN = .05849\,X_1 - .03032\,X_2 - 2.4849$$
H_2O Age

$$NN = .06775\,X_1 - .02458\,X_2 - .00402\,X_3 - 3.0094$$
H_2O Age Green Weight

H44-3098 (167) $R^2 = .7211$

$$NN = .01379\,X_1 - .04854\,X_2 + 1.6161$$
H_2O Age

$$NN = .01443\,X_1 - .04319\,X_2 - .00648\,X_3 + 1.8611$$
H_2O Age Green Weight

H49-5 (1971) $R^2 = .8372$

$$NN = .06419\,X_1 - .03740\,X_2 - 2.8266$$
H_2O Age

$$NN = .06722\,X_1 - .03756\,X_2 + .67425\,X_3 - 3.40266$$
H_2O Age K-H_2O

Pepeekeo-Hakalau, Hawaii. A wholly unirrigated plantation on the north-facing slopes of Mauna Kea, has deep as well as shallow Hydrol Humic Latosolic soils and excessive rain.

H49-5 (2995) $R^2 = .8381$

$$NN = .07287\,X_1 - .03481\,X_2 - 3.5851$$
H_2O Age

$$NN = .07286\,X_1 - .03537\,X_2 - .01760\,X_3 - 2.43627$$
H_2O Age Minimum Temperature

H53-1447 (99) $R^2 = .7494$

$$NN = -.001376\,X_1 - .04927\,X_2 + 3.2547$$
Light Age

$$NN = -.001223\,X_1 - .04398\,X_2 + .02135\,X_3 + 1.31930$$
Light Age H_2O

H54-775 (203) $R^2 = .8549$

$$NN = .07875\,X_1 - .02652\,X_2 - 4.2717$$
$$\quad\quad H_2O \quad\quad\quad Age$$

$$NN = .08854\,X_1 - .02752\,X_2 + 1.02725\,X_3 - 5.69482$$
$$\quad\quad H_2O \quad\quad\quad Age \quad\quad\quad K\text{-}H_2O$$

H53-263 (549) $R^2 = .8271$

$$NN = .09738\,X_1 - .02835\,X_2 - 5.82120$$
$$\quad\quad H_2O \quad\quad\quad Age$$

$$NN = .09433\,X_1 - .02638\,X_2 - .00713\,X_3 - 5.00476$$
$$\quad\quad H_2O \quad\quad\quad Age \quad\quad\quad \text{Green Weight}$$

H44-3098 (391) $R^2 = .7955$

$$NN = .05476\,X_1 - .03121\,X_2 - 1.96694$$
$$\quad\quad H_2O \quad\quad\quad Age$$

$$NN = .05374\,X_1 - .03213\,X_2 - .02391\,X_3 - .33654$$
$$\quad\quad H_2O \quad\quad\quad Age \quad\quad\quad \text{Minimum Temperature}$$

Paauhau, Hawaii. This partially irrigated plantation is on the north facing slopes of Mauna Kea, the lower elevations being warm but the upper elevations cold.

H44-3098 (40) $R^2 = .9271$

$$NN = .06154\,X_1 - .02466\,X_2 - 2.66670$$
$$\quad\quad H_2O \quad\quad\quad Age$$

$$NN = .09244\,X_1 - .01528\,X_2 + .03868\,X_3 - 5.5796$$
$$\quad\quad H_2O \quad\quad\quad Age \quad\quad\quad \text{Total Sugars}$$

H42-2772 (263) $R^2 = .7131$

$$NN = .05160\,X_1 - .02054\,X_2 - 2.04262$$
$$\quad\quad H_2O \quad\quad\quad Age$$

$$NN = .05464\,X_1 - .01913\,X_2 - .00299\,X_3 - 2.0792$$
$$\quad\quad H_2O \quad\quad\quad Age \quad\quad\quad \text{Green Weight}$$

H50-7209 (221) $R^2 = .8736$

$$NN = .06944\ X_1 - .02993\ X_2 - 3.27160$$
X_1: H_2O; X_2: Age

$$NN = .05153\ X_1 - .03253\ X_2 - .02742\ X_3 - 1.5533$$
X_1: H_2O; X_2: Age; X_3: Total Sugars

H54-775 (107) $R^2 = .8562$

$$NN = .06581\ X_1 - .02872\ X_2 - 3.10500$$
X_1: H_2O; X_2: Age

$$NN = .06748\ X_1 - .02847\ X_2 - .001242\ X_3 - 3.15704$$
X_1: H_2O; X_2: Age; X_3: Green Weight

H49-5 (220) $R^2 = .8511$

$$NN = .05878\ X_1 - .04414\ X_2 - 2.28974$$
X_1: H_2O; X_2: Age

$$NN = .05280\ X_1 - .04694\ X_2 - .02002\ X_3 - .44062$$
X_1: H_2O; X_2: Age; X_3: Minimum Temperature

Pahala, Hawaii. A partially irrigated plantation on the south slopes of Mauna Loa, capable of carrying crops for as much as 48 months.

H50-7209 (144) $R^2 = .7532$

$$NN = .04568\ X_1 - .02415\ X_2 - 1.26050$$
X_1: H_2O; X_2: Age

$$NN = .05294\ X_1 - .02228\ X_2 - .03377\ X_3 + .15278$$
X_1: H_2O; X_2: Age; X_3: Minimum Temperature

H52-246 (48) $R^2 = .4682$

$$NN = -.02054\ X_1 - .00494\ X_2 + 2.74493$$
X_1: Age; X_2: Green Weight

$$NN = -.01966\ X_1 - .00640\ X_2 - .03445\ X_3 + 5.4270$$
X_1: Age; X_2: Green Weight; X_3: Maximum Temperature

H52-1609 (49) $R^2 = .8752$

$$NN = .07686 \underset{H_2O}{X_1} - .01863 \underset{\text{Age}}{X_2} - 4.05043$$

$$NN = .07458 \underset{H_2O}{X_1} - .01684 \underset{\text{Age}}{X_2} - .00693 \underset{\text{Green Weight}}{X_3} - 3.3404$$

H53-1447 (123) $R^2 = .8016$

$$NN = .07028\, X_1 - .02236\, X_2 - 3.4366$$

$$NN = .07405 \underset{H_2O}{X_1} - .02360 \underset{\text{Age}}{X_2} + .58763 \underset{K\text{-}H_2O}{X_3} - 4.04179$$

H32-8560 (48) $R^2 = .7850$

$$NN = .03968 \underset{H_2O}{X_1} - .01958 \underset{\text{Age}}{X_2} - .96091$$

$$NN = .04526 \underset{H_2O}{X_1} - .01984 \underset{\text{Age}}{X_2} - .00355 \underset{\text{Green Weight}}{X_3} - 1.16731$$

H52-1518 (50) $R^2 = .7885$

$$NN = .12702 \underset{H_2O}{X_1} - .01211 \underset{\text{Green Weight}}{X_2} - 7.7086$$

$$NN = .13138 \underset{H_2O}{X_1} - .01041 \underset{\text{Green Weight}}{X_2} + .03462 \underset{\text{Maximum Temperature}}{X_3} - 10.77100$$

H46-564 (95) $R^2 = .7769$

$$NN = .04820 \underset{H_2O}{X_1} - .02398 \underset{\text{Age}}{X_2} - 1.61178$$

$$NN = .05162 \underset{H_2O}{X_1} - .02319 \underset{\text{Age}}{X_2} - .00672 \underset{\text{Green Weight}}{X_3} - 1.32480$$

H49-5 (1999) $R^2 = .8038$

$$NN = .07107\ \underset{H_2O}{X_1} - .02096\ \underset{Age}{X_2} - 3.48253$$

$$NN = .07540\ \underset{H_2O}{X_1} - .02032\ \underset{Age}{X_2} - .00451\ \underset{Green\ Weight}{X_3} - 3.49656$$

H44-3098 (3753) $R^2 = .7631$

$$NN = .05429\ \underset{H_2O}{X_1} - .01973\ \underset{Age}{X_2} - 1.99463$$

$$NN = .05546\ \underset{H_2O}{X_1} - .01841\ \underset{Age}{X_2} - .00627\ \underset{Green\ Weight}{X_3} - 1.74539$$

H41-3340 (937) $R^2 = .7669$

$$NN = .06089\ \underset{H_2O}{X_1} - .02566\ \underset{Age}{X_2} - 2.58922$$

$$NN = .06439\ \underset{H_2O}{X_1} - .02517\ \underset{Age}{X_2} - .00273\ \underset{Green\ Weight}{X_3} - 2.65362$$

Naalehu, Hawaii. Like Pahala, a partially drought ridden plantation on the south slopes of Mauna Loa, capable of carrying crops for as much as 44 months.

H49-5 (499) $R^2 = .8076$

$$NN = .06647\ \underset{H_2O}{X_1} - .02704\ \underset{Age}{X_2} - 3.05667$$

$$NN = .07255\ \underset{H_2O}{X_1} - .02285\ \underset{Age}{X_2} - .00934\ \underset{Green\ Weight}{X_3} - 2.9162$$

H52-246 (46) $R^2 = .7999$

$$NN = -.02226\ \underset{Age}{X_1} - .00662\ \underset{Green\ Weight}{X_2} + 2.78575$$

$$NN = .04199\ \underset{H_2O}{X_1} - .01283\ \underset{Age}{X_2} - .01139\ \underset{Green\ Weight}{X_3} - .51957$$

H41-3340 (912) $R^2 = .8339$

$$NN = .07029\,X_1 - .02893\,X_2 - 3.3164$$

H_2O Age

$$NN = .07679\,X_1 - .02537\,X_2 - .00514\,X_3 - 3.46843$$

H_2O Age Green Weight

H44-3098 (3098) $R^2 = .7032$

$$NN = .05557\,X_1 - .01971\,X_2 - 2.0849$$

H_2O Age

$$NN = .06011\,X_1 - .01359\,X_2 - .01105\,X_3 - 1.91963$$

H_2O Age Green Weight

UNIVERSITY OF HAWAII
COLLEGE OF TROPICAL AGRICULTURE
HAWAII AGRICULTURAL EXPERIMENT STATION
HONOLULU, HAWAII

HARLAN CLEVELAND
President of the University

C. PEAIRS WILSON
Dean of the College and
Director of the Experiment Station

WALLACE C. MITCHELL
Acting Associate Director of the Experiment Station