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CONTENTS

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CROP-LOGGING OF SUGAR CANE: THE STANDARD NITROGEN INDEX AND THE NORMAL NITROGEN INDEX

Harry F. Clements

INTRODUCTION

The continued use of a carefully chosen index tissue for guiding the nutritional welfare of a crop inevitably leads to the recognition that factors other than supply modify the apparent level of the nutrient in the plant. The leaf nitrogen of sugar cane is no exception to this, but since the level of nitrogen in this tissue does indeed reflect that in the meristem, the chlorenchyma, and storage parenchyma (*1*), it is only reasonable to assume that the same factors which modify the level of the nutrient in the index tissue are having similar influences on the nutrient in these important functional tissues. Hence, what at first seems a shortcoming of tissue diagnosis becomes the basis for the achievement of standardization. While there are those who regard with approval only such studies as can be carried on under carefully controlled conditions, climatic as well as nutritional, it must be clear to everyone that such conditions are not only unnatural for plants, but pretty much useless for the solution of the recurring field problems requiring decisions day by day. And yet the daily need for making estimates of crop requirements under field conditions calls for the reference of the existing conditions to a provable standard.

Clements (*6*) and Clements, Shigeura, and Akamine (*7*) reported on the factors affecting the leaf nitrogen levels of sugar cane (32-8560). The partial regressions are shown in table 1.

TABLE 1. Partial regressions of certain factors on leaf nitrogen

FACTOR	PARTIAL REGRESSION	"t" VALUE
Sheath moisture	+ .6334	29.49**
Age	— .2932	14.28**
Minimum temperature	— .1262	7.06**
Maximum temperature	+ .0858	4.43**
Soil moisture	— .0570	3.55**
Light	+ .0126	.65

$n = 1373$ $R = .832^{**}$ $R^2 = .6922$

It is evident from these measurements that within the ordinary range of nitrogen fertilization the leaf nitrogen levels in field plants are largely the result of the ecological factors which play upon the plant, influencing it as it grows. Of course, it is common experience that each locality in the Islands seems to have its own characteristic nitrogen level.

In 1953, Samuels, Capo, and Bangdiwala (*13*) were the first to capitalize on this characteristic to standardize certain experimental data. The result was that differences in leaf nitrogen readings among experimental plots were "corrected" and greatly increased precision resulted. More recently, Clements (*10*) used the same principle to standardize the phosphorus index.

STATEMENT OF OBJECTIVE

It is the purpose of this paper to explore and evaluate the factors which affect the leaf nitrogen level of sugar cane growing under a wide range of conditions in the Hawaiian Islands with the objective of developing a procedure for standardizing the leaf nitrogen readings. If one or two general equations for standardizing the nitrogen readings of all varieties and all conditions of sugar cane in Hawaii can be developed, then the procedure would be completely objective and useful.

METHODS AND DEFINITIONS

Fortunately, many thousands of sets of data on leaf nitrogen are available locally as a result of the general use of crop-logging procedures. Beginning at about 3–4 months of age and continuing at intervals of 35 days until the crop is harvested (22–30 months), leaf blade and sheath samples are collected following fairly precise procedures (*1, 2, 3, 4, 5, 8*). The total nitrogen level is determined on the chlorenchyma of leaves 3, 4, 5, and 6, counting downward from the spindle leaf as No. 1. The leaf sheaths from these same leaves are used for moisture and total sugar determinations and also for the inorganic nutrients logged—such as potassium, phosphorus, calcium, magnesium, and manganese. When these data are plotted on the log for the field, the maximum and minimum temperatures, and in some cases, light readings are also plotted. For the purposes of the present study the completed logs of numerous fields are the source material. Data are taken from these logs and the statistical methods of multiple regression (*14*) are used since it is evident at once that the factors used have a modifying effect on leaf nitrogen and some at least on one another. In the tables which follow, the partial regressions and their statistical significance ("t") are given. Double asterisks indicate significance beyond the 1 percent level. A single asterisk indicates significance at the 5 percent level and the absence of an asterisk indicates that the statistical significance is below the 5 percent level. At the bottom of each table, the number of data sets is shown by n and the R^2 is shown. The square root of this, of course, yields the multiple correlation R, but when R^2 is multiplied by 100, an estimate of the variation accounted for on a percentage basis is shown (coefficient of determination). Also, in the following tables, whenever data are presented for the first time on a given factor at a given place, the first number after the factor is the mean of the data used and the next two represent the range. The mean and range for leaf nitrogen are given beneath the table title. For *light*, the readings are the average total gram calories per sq. cm. per day for the period prior to the sampling, usually 35 days. For *maximum* temperature, the readings (°F.) are likewise the average of the daily maximum for each of the 35 days and the range is the range in mean maxima for the period. In other words, the range on a daily basis would be larger than shown since the maxima used are the average maxima for the prior period. *Minimum* temperatures are similarly derived.

The *sheath moisture* is the moisture content of sheaths from leaves 3, 4, 5, and 6 expressed as percent of the green weight (*2*). For plant fields, *age* is the age in months at the time of sampling as related to the planting date. For ratoon crops, the starting point is the average harvest date of the previous crop. The average age shown should not be misconstrued as average age of crop at harvest. It is the average age at the sampling dates which begin when the crop is big enough to have the necessary leaves and continue at 35-day intervals until harvest. The *total sugar* level (the Primary Index) (*3*) is the invertase inverted reducing substance content of sheaths 3, 4, 5, and 6 expressed on the dry weight basis. The leaf nitrogen is the total Kjeldahl nitrogen content of the chlorenchyma of leaves 3, 4, 5, and 6 expressed as percent dry basis.

PRESENTATION OF MULTIPLE REGRESSIONS

First, the results will be presented by variety and by area and later various combinations will be used with the ultimate objective of a single, all-inclusive generalization for the important varieties and conditions in Hawaii.

IRRIGATED CANE CULTURE

WAIPIO—VARIETY 32-8560

In table 2 are shown the results of the Waipio 32-8560 study with total sugars displacing soil moisture in table 1.

Judging by the "t" values, the three physiological factors of moisture, age, and total sugars are dominant in their effects on the nitrogen levels of the cane leaf but moisture and total sugars are in turn a rather direct result of the ecological factors (*6, 7*) and plant vigor, a very dominant physiological character which at the moment escapes numerical description. Light shows no significant effect.

In the next set, table 3, light is dropped from the analysis. So far as 32-8560 growing at Waipio is concerned, each of the five factors influences significantly the leaf nitrogen levels. However, were it necessary to deal with five factors each time standardizing a leaf nitrogen reading was called for, the method would be beyond practical use. Hence in another analysis,

TABLE 2. Six partial regressions on leaf nitrogen
(1.517) (1.13–2.25)
Waipio 32-8560

FACTOR	PARTIAL REGRESSION	"t" VALUE
Light (486) (164–778)	— .0360	1.85
Maximum temperature (84.5) (73–93)	— .0810	4.37**
Minimum temperature (65.8) (55–74)	— .0874	4.98**
Total sugars (8.60) (5.1–15.8)	+ .1933	10.68**
Moisture (81.6) (74.1–87.6)	+ .6943	32.47**
Age (13.2) (2.4–24.9)	— .2830	14.43**

n = 1373 R^2 = .7175**

TABLE 3. Five partial regressions on leaf nitrogen
Waipio 32-8560

FACTOR	PARTIAL REGRESSION	"t" VALUE
Maximum temperature	— .0958	5.71**
Minimum temperature	— .0911	5.23**
Total sugars	+ .1827	10.63**
Moisture	+ .7040	33.93**
Age	— .2754	14.35**

n = 1373 R^2 = .7168**

TABLE 4. Four partial regressions on leaf nitrogen
Waipio 32-8560

FACTOR	PARTIAL REGRESSION	"t" VALUE
Minimum temperature	— .1362	8.66**
Total sugars	+ .1729	10.00**
Sheath moisture	+ .6839	33.07**
Age	— .2908	15.13**

n = 1373 R^2 = .7101**

this time dropping out the maximum temperatures, the results are shown in table 4. It is apparent that minimum temperature absorbs practically all of the influence of the maximum temperature shown in the previous table. The values of the R^2's differ only in the third place.

Next, by dropping out the factor of minimum temperature, the results are as shown in table 5.

TABLE 5. Three partial regressions on leaf nitrogen
Waipio 32-8560

FACTOR	PARTIAL REGRESSION	"t" VALUE
Total sugars	+ .1186	7.18**
Sheath moisture	+ .6696	31.69**
Age	— .2746	14.01**

n = 1373 R^2 = .6942**

If instead of minimum temperature, however, total sugars are dropped out, the results are as shown in table 6, producing a very small change in the value of R^2. The partial regressions for minimum temperature and sheath moisture on leaf nitrogen are reduced by the removal of the total sugar factor which seems either to have an interactive influence or is the result of interaction. The effect on R^2, however, is very small.

TABLE 6. Three partial regressions on leaf nitrogen
Waipio 32-8560

FACTOR	PARTIAL REGRESSION	"t" VALUE
Minimum temperature	— .0791	5.21**
Sheath moisture	+ .6049	30.58**
Age	— .2989	15.03**

n = 1373 R^2 = .6889**

TABLE 7. Three partial regressions on leaf nitrogen
Waipio 32-8560

FACTOR	PARTIAL REGRESSION	"t" VALUE
Maximum temperature	— .0421	2.78**
Sheath moisture	+ .6169	31.13**
Age	— .2831	14.29**

n = 1373 R^2 = .6868**

In table 7, maximum temperature is included, and even though the partial regression of maximum temperature on leaf nitrogen has a lower "t" value than did minimum temperature in table 6, the R^2 value is essentially the same. Actually, the last three tables appear to indicate that for prediction purposes were it desirable to have a factor in addition to sheath moisture and age, it would be immaterial which of the three was used, maximum or minimum temperatures or total sugars. Compared with table 2 where all six factors were used and where the coefficient of determination (R^2 x 100) was 71.7 percent, the lowest estimate of any one of the last three tables with only three factors is about 69 percent, or about 3.0 percentage points less, and this difference is not statistically significant.

TABLE 8. Two partial regressions on leaf nitrogen
Waipio 32-8560

FACTOR	PARTIAL REGRESSION	"t" VALUE
Sheath moisture	+ .6119	30.70**
Age	— .2864	14.37**

n = 1373 R^2 = .6827**

Finally, in table 8, only the two dominant factors, age and moisture, are used, and what has been evident all along finally appears in bold conclusion—that these two factors so far as Waipio is concerned will give us about as much information regarding the nitrogen level as we can get by adding any number of other factors, even though several of these are significantly related to leaf nitrogen. The prediction estimate is 68 percent as against 72 percent shown in table 2. Of course, in these data moisture alone shows a simple correlation squared (r^2) of .6349 which is significantly lower than .7175, but which is unusually high for other ecological situations as subsequent data will show. Also, the distortion shown here by the data gives an undue weight to the moisture influence. Such a distortion, while yielding equations useful for Waipio, would in all probability be quite unsatisfactory elsewhere.

EWA—VARIETY 37-1933

Ewa Plantation Company on the island of Oahu contains areas which probably possess the highest-yielding potential of any in the Islands. Although Olokele Sugar Company on the island of Kauai holds the all-time world's record for plantation-wide yield (15.52 TSA in 1955 from 2,087 acres), the over-all average yields at Ewa are substantially reduced by a sizeable area of coral rock fields where yields are some five or six tons of sugar per acre lower than in the deep soil areas. In addition to the difficult substrate, these coral fields are frequently irrigated with water which may contain more than 1,000 ppm of chloride salts. In the deep soil areas, annual averages have approximated 16 tons of sugar per acre. Ewa is a relatively flat plantation with abundant sunlight, low rainfall, and mild winds, and is irrigated with good quality pump water in the area used.

All the data used from actual plantation fields are from those in which the sugar yield was very high; in general for Ewa, 15 tons of sugar per acre or higher. At Ewa, only variety 37-1933 is involved. Crops were chosen over some four years with an effort to obtain crops started in different quarters of the year, plant as well as ratoon. A good set of weather records is kept even though only one weather station is maintained but this is at a central point. In table 9 are shown the partial regressions on leaf nitrogen using six factors. So far as significance is concerned, the alignment of factors is much the same here as for 32-8560 at Waipio, even though the general emphasis is toward age rather than moisture and the size of the regressions of the temperatures is larger, but this is probably brought on by the fact

TABLE 9. Six partial regressions on leaf nitrogen
(1.68) (1.12–2.52)
Ewa 37-1933

FACTOR	PARTIAL REGRESSION	"t" VALUE
Light (552) (315–729)	− .0428	1.73
Maximum temperature (84.2) (78.7–88.8)	− .3034	6.82**
Minimum temperature (64.9) (60.5–70.0)	+ .1750	4.74**
Total sugars (9.2) (5.5–18.2)	+ .1055	6.00**
Sheath moisture (81.8) (72.8–87.7)	+ .3535	15.96**
Age (13.1) (1.8–26.5)	− .5747	25.43**

n = 887 $R^2 = .7890$**

TABLE 10. Five partial regressions on leaf nitrogen
Ewa 37-1933

FACTOR	PARTIAL REGRESSION	"t" VALUE
Minimum temperature	+ .1932	5.46**
Maximum temperature	− .3497	9.80**
Total sugars	+ .1004	5.78**
Sheath moisture	+ .3625	16.81**
Age	− .5747	25.40**

n = 887 $R^2 = .7883$**

that the minimum temperature partial regression is positive. The "t" values for temperatures are at the same general level.

After dropping out light as a factor, the results are as shown in table 10, and as in the case of the Waipio data, there is essentially no effect on R^2.

In table 11 are shown the effects of dropping out minimum temperature which are essentially nil, so far as R^2 is concerned, even though by eliminating it, the partial regression of maximum temperature is substantially changed but without affecting its "t" value.

TABLE 11. Four partial regressions on leaf nitrogen
Ewa 37-1933

FACTOR	PARTIAL REGRESSION	"t" VALUE
Maximum temperature	− .1765	10.66**
Total sugars	+ .0976	5.53**
Sheath moisture	+ .3660	16.70**
Age	− .5803	25.28**

n = 887 R^2 = .7811**

Next, the factor, maximum temperature, is dropped and the results in table 12 show that R^2 has been reduced some .028, but the "t" value of the total sugars has been reduced to the point where it is significant at the 5 percent level only.

TABLE 12. Three partial regressions on leaf nitrogen
Ewa 37-1933

FACTOR	PARTIAL REGRESSION	"t" VALUE
Total sugars	+ .0473	2.62*
Sheath moisture	+ .3561	15.31**
Age	− .5747	23.57**

n = 887 R^2 = .7529**

Dropping the total sugars and re-entering maximum temperature, the results in table 13 indicate that in this set of data, maximum temperature exerts a greater influence on leaf nitrogen than total sugars.

In table 14, minimum temperature replaces maximum temperature and the general effect is an improvement over that exerted by total sugars as shown in table 12. However, of three factors in the Ewa data, maximum temperature shows the greatest influence although the total effect on the

TABLE 13. Three partial regressions on leaf nitrogen
Ewa 37-1933

FACTOR	PARTIAL REGRESSION	"t" VALUE
Maximum temperature	— .1520	9.37**
Sheath moisture	+ .3378	15.59**
Age	— .6251	28.61**

n = 887 R^2 = .7735**

TABLE 14. Three partial regressions on leaf nitrogen
Ewa 37-1933

FACTOR	PARTIAL REGRESSION	"t" VALUE
Minimum temperature	— .0995	5.95**
Sheath moisture	+ .3418	15.35**
Age	— .6163	27.42**

n = 887 R^2 = .7606**

TABLE 15. Two partial regressions on leaf nitrogen
Ewa 37-1933

FACTOR	PARTIAL REGRESSION	"t" VALUE
Sheath moisture	+ .3421	15.06**
Age	— .5985	26.35**

n = 887 R^2 = .7510**

R^2 is not substantial as can be seen in table 15, since here the coefficient of determination is 75.1 percent while including all five factors increases this only to 78.8 percent.

In general, at Ewa, maximum temperatures are more influential on the level of leaf nitrogen of 37-1933 than either minimum temperature or total sugars. Light has no significant direct effect. The two dominant factors, as in the case of the Waipio data with 32-8560, are again sheath moisture and age, but while there was an unbalance of these factors at Waipio in favor of sheath moisture, the unbalance at Ewa is the other way. For the practical objective of this research, neither situation is entirely desirable.

HAWAIIAN COMMERCIAL & SUGAR CO.—CENTRAL MAUI

The Central Maui area, although locally described as a valley, is really a low elevation saddle connecting Haleakala, a 10,000-foot mountain on the east, with the older West Maui mountains on the west. The area given over to sugar cane ranges from perhaps 25 feet above sea level to a maximum of some 700 feet. All the cane is irrigated—some with surface water drained from the high-rainfall country east of the central cane-producing area, and the remainder with potash-rich water pumped at several points throughout the area. Atmospheric conditions include very bright sunlight, high maximum temperatures, particularly in the Kihei area, low humidities, very high wind velocities at least during part of the year, and low rainfall. Without irrigation at least part of the area would approach semi-desert conditions. Perhaps because the dehydrative elements of weather are dominant, it seems impossible to overirrigate (*9, 15*). It is quite likely that climatically this area represents the highest sugar-producing potential in the Islands, but awaits a variety which can maintain high moisture levels despite the high winds.

As at Ewa, data from Hawaiian Commercial and Sugar Company were taken from high-yielding fields. At this plantation two varieties are important, 37-1933 and 38-2915. Several crop years are involved, and an effort was also made to include data from crops started in the various seasons of each year.

CENTRAL MAUI—VARIETY 37-1933

In table 16, the partial regressions of the same six factors are reported. Now, perhaps because Central Maui differs from Ewa and Waipio on Oahu in its clearer and generally much drier and windier atmosphere, it perhaps is not surprising that moisture and sunlight seem more important. Here all the factors have some effect on the leaf nitrogen level, but the effect of minimum temperature is less strong than the others. In general, the brighter the sunlight and the warmer the temperature, the lower is the

TABLE 16. Six partial regressions on leaf nitrogen
(1.63) (1.02–2.41)
Central Maui 37-1933

FACTOR	PARTIAL REGRESSION	"t" VALUE
Sunlight (569) (277–794)	− .0742	4.44**
Maximum temperature (80.9) (68–93)	− .0629	4.05**
Minimum temperature (65.4) (54–74)	− .0346	2.37*
Total sugars (9.93) (5.1–21.1)	+ .0759	4.91**
Sheath moisture (81.3) (71.7–88.0)	+ .4106	16.39**
Age (13.79) (2.1–27.4)	− .5141	20.97**

n = 1145 R^2 = .7771**

leaf nitrogen level. The dominant influences continue to be moisture and age.

In table 17, all the factors except sunlight are reported; and even though sunlight had a significant effect on leaf nitrogen levels, its removal from the complex has reduced the R^2 only slightly, since its effects were largely assumed by the maximum and minimum temperatures.

TABLE 17. Five partial regressions on leaf nitrogen
Central Maui 37-1933

FACTOR	PARTIAL REGRESSION	"t" VALUE
Maximum temperature	— .0881	6.03**
Minimum temperature	— .0489	3.39**
Total sugars	+ .0603	3.97**
Moisture	+ .4236	16.88**
Age	— .5012	20.46**

$n = 1145$ $R^2 = .7732$**

Dropping maximum temperature reduces but slightly the R^2 value, as shown in table 18.

TABLE 18. Four partial regressions on leaf nitrogen
Central Maui 37-1933

FACTOR	PARTIAL REGRESSION	"t" VALUE
Minimum temperature	— .0611	4.21**
Total sugars	— .0502	3.28**
Moisture	+ .4411	17.44**
Age	— .4825	19.54**

$n = 1145$ $R^2 = .7660$**

TABLE 19. Three partial regressions on leaf nitrogen
Central Maui 37-1933

FACTOR	PARTIAL REGRESSION	"t" VALUE
Total sugars	+ .0469	3.04**
Moisture	+ .4518	17.82**
Age	— .4738	19.10**

$n = 1145$ $R^2 = .7623$**

In table 19, it is apparent that very little has been lost in the size of R^2 by reducing to three factors. It has been interesting to observe the gradual ascendency of influence by sheath moisture as the factors have been dropped out, one by one.

Finally, in table 20, only the two factors are shown and even though each of the six factors shown in table 16 had a significant effect on the leaf nitrogen, the R^2 of .7771 is not significantly better than .7604 displayed by the two factors, sheath moisture and age. In this set of data the distribution of influence between the two dominant factors appears beautifully balanced, and is much more desirable from the applicability viewpoint than that shown for Ewa (table 15) where age was dominant and for Waipio (table 8) where moisture was dominant.

TABLE 20. Two partial regressions on leaf nitrogen
Central Maui 37-1933

FACTOR	PARTIAL REGRESSION	"t" VALUE
Sheath moisture	+ .4246	17.83**
Age	— .4960	20.83**

n = 1145 R^2 = .7604**

CENTRAL MAUI—VARIETY 38-2915

At Hawaiian Commercial and Sugar Company, a second variety, 38-2915, is used over a substantial part of its area and seems at times better adapted to

TABLE 21. Six partial regressions on leaf nitrogen
(1.64) (0.78–2.45)
Central Maui 38-2915

FACTOR	PARTIAL REGRESSION	"t" VALUE
Sunlight (562) (214–768)	— .0269	1.45
Maximum temperature (82.4) (68–97)	— .0833	4.54**
Minimum temperature (63.6) (51–75)	— .0554	3.13**
Total sugars (10.7) (5.1–20.0)	+ .1223	5.49**
Sheath moisture (82.0) (72.2–87.5)	+ .4765	14.72**
Age (14.2) (2.3–27.5)	— .4855	16.81**

n = 872 R^2 = .7485**

the area than 37-1933. Logs of crops involving this variety were also available and a similar study was undertaken. The influences of the six factors are shown in table 21 and when compared with the analysis for 37-1933 (table 16), the suggestion at least can be injected at this point that the leaf nitrogen is less a varietal characteristic than it is an eco-physiological one. The two varieties are quite different in appearance and in their moisture relations, and even though 38-2915 gives the observer the impression of being a high moisture and a high nitrogen cane, while 37-1933 is a "good juice" cane, yet their nitrogen levels appear at this point at least to be subject to the same modifying factors and in about the same way.

Dropping out the sunlight factor, the analysis is reported in table 22, with essentially no reduction of R^2.

TABLE 22. Five partial regressions on leaf nitrogen
Central Maui 38-2915

FACTOR	PARTIAL REGRESSION	"t" VALUE
Maximum temperature	— .0877	4.84**
Minimum temperature	— .0580	3.30**
Total sugars	+ .1186	5.36**
Sheath moisture	+ .4815	14.95**
Age	— .4787	16.78**

n = 872 R^2 = .7479**

Dropping out maximum temperature (table 23) results in a sufficient realignment of the other values to leave R^2 practically unchanged.

TABLE 23. Four partial regressions on leaf nitrogen
Central Maui 38-2915

FACTOR	PARTIAL REGRESSION	"t" VALUE
Minimum temperature	— .0667	3.75**
Total sugars	+ .0970	4.42**
Sheath moisture	+ .4891	15.01**
Age	— .4605	16.09**

n = 872 R^2 = .7411**

Dropping minimum temperature results in the values shown in table 24. Thus far, dropping out the three factors of climate has reduced the estimate by only 1.2 percentage points.

TABLE 24. Three partial regressions on leaf nitrogen
Central Maui 38-2915

FACTOR	PARTIAL REGRESSION	"t" VALUE
Total sugars	+ .0974	4.40**
Sheath moisture	+ .5110	15.82**
Age	— .4404	15.54**

n = 872 R² = .7369**

Finally, in table 25, are shown the values for the two dominant factors alone and when compared with similar data in table 20 representing 37-1933, the partial regressions are almost the same. In fact, the similarity is so great that it is evident that the variety is not of much consequence so far as directly determining the characteristic nitrogen level, but whatever the part played by the variety appears to be by way of its moisture characteristics.

TABLE 25. Two partial regressions on leaf nitrogen
Central Maui 38-2915

FACTOR	PARTIAL REGRESSION	"t" VALUE
Sheath moisture	+ .4239	16.42**
Age	— .4944	19.15**

n = 872 R² = .7310**

TABLE 26. Six partial regressions on leaf nitrogen
(1.63) (0.78–2.45)
Central Maui 37-1933 and 38-2915

FACTOR	PARTIAL REGRESSION	"t" VALUE
Sunlight (566) (214–794)	— .0421	3.44**
Maximum temperature (81.5) (68–97)	— .0772	6.53**
Minimum temperature (64.6) (51–75)	— .0453	3.97**
Total sugars (10.25) (5.1–21.1)	+ .0837	6.65**
Sheath moisture (81.6) (71.7–88.0)	+ .4372	22.97**
Age (13.98) (2.1–27.5)	— .5002	27.58**

n = 2017 R² = .7586**

CENTRAL MAUI—VARIETIES 37-1933 AND 38-2915

In table 26 are shown the partial regressions using both varieties and all six factors. It seems very evident from the "t" values and from the R^2 that combining the data from the two varieties has not altered the estimate possibilities. In view of this similarity only the two-factor analysis is shown and this in table 27.

TABLE 27. Two partial regressions on leaf nitrogen
Central Maui 37-1933 and 38-2915

FACTOR	PARTIAL REGRESSION	"t" VALUE
Sheath moisture	+ .4329	25.16**
Age	— .4876	28.34**

n = 2017 $R^2 = .7440$**

NORMAL AND STANDARD NITROGEN DEFINITIONS AND EQUATIONS

The equations for the Normal Nitrogen Index and for the Standard Nitrogen Index follow. The Normal Nitrogen Index can be defined as the Nitrogen Index which represents the average index for a given sheath moisture and given age for crops which have given outstanding yields over a few years and is obtained by:

$NN = .04122\ X_1 - .02212\ X_2 - 1.42077$ where

NN is the Normal Nitrogen Index; X_1 is the actual moisture level of the sheath at the time of sampling; and X_2 the age of the crop at the time of sampling.

The Standard Nitrogen Index (SNI), however, is somewhat different. It tells what an actual Leaf Nitrogen Index would be were the sheath moisture and age something other than observed. This equation is:

$SNI = N_1 + .04122\ (M_2 - M_1) - .02212\ (A_2 - A_1)$

where N_1 is the leaf nitrogen observed
M_2 the desired sheath moisture
M_1 the actual sheath moisture
A_2 the desired age
A_1 the actual age

A table may be prepared for each of these equations. Thus, for normal nitrogen at Hawaiian Commercial and Sugar Company, a table can be prepared for all possible moistures from 73.0 to 90.0 percent with intervals of 0.5 percent and ages from 2.0 to 28.0 months with intervals of 0.5 months. When a leaf sample has been collected for nitrogen, the moisture content of the sheath sample is determined. Even before the nitrogen sample returns from the laboratory, the Normal Nitrogen Index can be plotted since the moisture and age are both known. Usually it is indicated on the log with a red cross or small circle. When the actual nitrogen figure returns from the laboratory, that is plotted as a point and is connected with the previous actual nitrogen (see later). Whether it is above or below or at the normal nitrogen will determine whether or not fertilizer should be applied.

A table can also be prepared for the Standard Nitrogen Index if one wishes to standardize all readings at a single moisture and single age. The table can be prepared to indicate how much of a correction should be added to or subtracted from N_1 to standardize it for the actual moisture and age. To be sure, if one chose to standardize all nitrogen readings to a constant moisture of say, 85.0 and an age of 6.0 months, the equation then takes on a modified form so as to eliminate the need for repetitious calculations.

Thus:

$$SNI = N_1 + .04122\ (85.0 - M_1) - .02199\ (6.0 - A_1)$$

$$\text{or } SNI = N_1 - .04122\ M_1 + .02199\ A_1 + 3.3718$$

Actually, while this is the form used for standardizing phosphorus (*10*), it is too limited in scope to be completely useful for nitrogen. The practical need in nitrogen nutrition is for a variety of moistures and ages and hence the more general equation is needed, but again a table can be constructed based on the differences $(M_2 - M_1)$ and $(A_2 - A_1)$. The extremes might be −10 percent to +10 percent for moistures, −20 months to +20 months for ages. The resulting answers would be added to or subtracted from the N_1 to give the Standard Nitrogen reading.

PIONEER MILL CO.—VARIETIES 37-1933 AND 38-2915

Pioneer Mill Company is located on the western and southern slopes of the West Maui mountains which, like the Kihei area southwest of Haleakala, is a very hot and dry area. Normal winds are perhaps less severe than in the central valley. Were it not for the very rocky lands and somewhat less than adequate water supply this is potentially as high a yielding area as any in the Islands.

A similar study was made of 37-1933 and 38-2915 at Lahaina, but only four factors were used. The analysis for 37-1933 is given in table 28, for 38-2915 in table 29 and for both in table 30.

TABLE 28. Four partial regressions on leaf nitrogen
(1.62) (0.89–2.44)
Lahaina 37-1933

FACTOR	PARTIAL REGRESSION	"t" VALUE
Maximum temperature (82.9) (76–89)	− .1613	4.43**
Minimum temperature (64.7) (60–69)	+ .0220	.61
Sheath moisture (81.1) (72.2–87.8)	+ .4787	12.55**
Age (12.8) (2.4–26.0)	− .4637	12.17**

n = 362 R^2 = .7747**

TABLE 29. Four partial regressions on leaf nitrogen
(1.64) (0.83–2.72)
Lahaina 38-2915

FACTOR	PARTIAL REGRESSION	"t" VALUE
Maximum temperature (80.4) (74–86)	+ .0292	.55
Minimum temperature (64.3) (60–69)	+ .0081	.15
Moisture (81.5) (71.3–90.1)	+ .3877	11.20**
Age (13.40) (2.5–27.1)	— .5117	8.50**

n = 273 R^2 = .6517**

TABLE 30. Four partial regressions on leaf nitrogen
(1.64) (0.83–2.72)
Lahaina 37-1933 and 38-2915

FACTOR	PARTIAL REGRESSION	"t" VALUE
Maximum temperature (81.8) (74–89)	— .1122	3.77**
Minimum temperature (64.6) (60–69)	+ .0331	1.12
Sheath moisture (81.3) (71.3–90.1)	+ .4249	14.51**
Age (13.06) (2.4–27.1)	— .4943	16.82**

n = 635 R^2 = .7124**

TABLE 31. Two partial regressions on leaf nitrogen
Lahaina 37-1933 and 38-2915

FACTOR	PARTIAL REGRESSION	"t" VALUE
Sheath moisture	+ .4366	14.80**
Age	— .4787	16.22**

n = 635 R^2 = .7040**

At Lahaina, as at Puunene, the varietal effects seem of no consequence so far as the leaf nitrogen level is concerned. Only age and sheath moisture are dominant although maximum temperature has a significant influence although its total effect in contributing to a higher prediction is very small as is indicated by table 31, where only the two dominant factors are shown. It is rather striking how similar the partial regressions are to those gathered at Puunene and shown in table 27.

The Normal Nitrogen Equation for the two varieties at Lahaina is

$$NN = .04690 \underset{\substack{\text{Sheath}\\ \text{Moisture}}}{X_1} - .02639 \underset{\text{Age}}{X_2} - 1.83115$$

and the Standard Nitrogen Equation is

$$SNI = N_1 + .04690 \underset{\substack{\text{Sheath}\\ \text{Moisture}}}{(M_2 - M_1)} - .02639 \underset{\text{Age}}{(A_2 - A_1)}$$

WAILUKU SUGAR CO.—VARIETY 37-1933

Wailuku Sugar Company is located on the east-facing slopes of the West Maui mountains. Weather conditions are somewhat similar to those in the central valley except that there is an almost constant cloud layer which reduces the direct sunlight particularly during the afternoon. Reflected light, however, is very high.

Only a few data were available from Wailuku and the partial regressions are shown in table 32.

TABLE 32. Two partial regressions on leaf nitrogen
(2.06) (1.63–2.86)
Wailuku 37-1933

FACTOR	PARTIAL REGRESSION	"t" VALUE
Sheath moisture (82.7) (76.5–87.8)	+ .4362	6.30**
Age (9.80) (2.8–17.3)	— .4547	6.57**

n = 97 R^2 = .6794**

OLOKELE SUGAR CO.—VARIETY 37-1933

Olokele Sugar Company is located on generally southern slopes on the island of Kauai and is one of the highest-yielding plantations in the Territory.

Some 37-1933 data from Olokele were available and the results are shown in table 33.

TABLE 33. Two partial regressions on leaf nitrogen
(1.75) (0.98–2.86)
Olokele 37-1933

FACTOR	PARTIAL REGRESSION	"t" VALUE
Sheath moisture (81.4) (71.3–87.2)	+ .4685	15.30**
Age (14.46) (2.9–27.7)	— .4545	14.84**

n = 317 R^2 = .7468**

WAIALUA AGRICULTURAL CO.—VARIETY 37-1933

Some variety 37-1933 data were also available from Waialua and these are shown in table 34.

TABLE 34. Two partial regressions on leaf nitrogen
(1.61) (1.04–2.55)
Waialua 37-1933

FACTOR	PARTIAL REGRESSION	"t" VALUE
Sheath moisture (80.5) (70.3–87.4)	+ .2668	26.03**
Age (13.88) (1.4–27.9)	— .6144	11.30**

n = 541 R^2 = .6999**

UNIRRIGATED CANE CULTURE

ISLAND OF HAWAII CONDITIONS—VARIETY 44-3098

So far, only data from irrigated plantations have been presented. The unirrigated conditions on the island of Hawaii are in marked contrast. Here variety 44-3098 is being grown for the most part under conditions of excessive rainfall.

Data were available from Hilo Sugar Co., Onomea Sugar Co., Pepeekeo Sugar Co., Hakalau Sugar Co., Paauhau Sugar Co., Hawaiian Agricultural Co., and Hutchinson Sugar Co. The first four are on the eastern and northern slopes and have very high annual rainfall reaching as much as 200 inches in some of the higher elevations. Associated with such heavy rainfall is a great deal of cloudiness, but since the air is very clean, when the sun does shine it is very strong. Soils here are acid and very thoroughly leached.

Paauhau is also on the northern slopes of the island but at a distance from the heavy rainfall area. The middle and upper elevations are wet enough to produce cane without irrigation, but at the lower level irrigation is required during part of the year.

The remaining two companies are on the southern slopes of the island of Hawaii. Cane here is grown from less than 1000-foot elevation to over 3000 feet. At the low elevations recurring droughts are a severe hazard to the growing of cane, but at the higher elevations rainfall is heavy, reaching as much as 150 inches in wet years.

Except for Paauhau, conditions at these Hawaii plantations are quite the opposite of those on Maui. The air is cool, moist, and generally quiet. Sets of data were obtained from each of these plantations as follows: Hakalau, 273; Pepeekeo, 307; Onomea, 312; Hilo, 355; Paauhau, 188; Pahala, 444; and Naalehu, 395; for a total of 2274 all from the island of Hawaii. In table 35 is given the analysis of five factors; unfortunately, reliable sunlight data were not available. The data, however, show the same kind of influences.

The two overwhelming influences are again sheath moisture and age. Minimum temperature seems strong although along similar lines as heretofore.

TABLE 35. Five partial regressions on leaf nitrogen
(1.85) (0.97–2.92)
Island of Hawaii 44-3098

FACTOR	PARTIAL REGRESSION	"t" VALUE
Maximum temperature (76.5) (66–86)	+ .0252	1.61
Minimum temperature (61.6) (50–70)	— .1587	10.85**
Total sugars (8.51) (3.0–28.0)	+ .0931	6.27**
Sheath moisture (81.3) (71.7–88.3)	+ .5611	30.65**
Age (14.99) (2.0–34.8)	— .4544	31.52**

n = 2274 $R^2 = .7452^{**}$

In table 36 the analyses are recast with only four factors, with essentially no change in the value of R^2. Dropping minimum temperature results in table 37, where the effect has been a decrease of .018 in the value of R^2.

TABLE 36. Four partial regressions on leaf nitrogen
Island of Hawaii 44-3098

FACTOR	PARTIAL REGRESSION	"t" VALUE
Minimum temperature	— .1436	12.78**
Total sugars	+ .0885	6.07**
Sheath moisture	+ .5522	31.61**
Age	— .4623	34.04**

n = 2274 $R^2 = .7449^{**}$

TABLE 37. Three partial regressions on leaf nitrogen
Island of Hawaii 44-3098

FACTOR	PARTIAL REGRESSION	"t" VALUE
Total sugars	+ .1257	8.50**
Sheath moisture	+ .6207	36.07**
Age	— .4124	30.64**

n = 2274 $R^2 = .7265^{**}$

In table 38, where total sugars are dropped and minimum temperature re-entered, the R^2 is essentially restored to the original level shown in table 35. The Normal Nitrogen equation for this three-factor analysis is:

$$NN = \underset{\substack{\text{Minimum}\\ \text{Temperature}}}{-.01165\ X_1} + \underset{\substack{\text{Sheath}\\ \text{Moisture}}}{.05395\ X_2} - \underset{\text{Age}}{.02495\ X_3} - 1.4421$$

and, of course, the Standard Nitrogen equation would be:

$$SNI = \underset{\substack{\text{Actual}\\ \text{Leaf Nitrogen}}}{N_1} - \underset{\substack{\text{Minimum}\\ \text{Temperature}}}{.01165\ (T_2 - T_1)} + \underset{\substack{\text{Sheath}\\ \text{Moisture}}}{.05395\ (M_2 - M_1)} - \underset{\text{Age}}{.02495\ (A_2 - A_1)}$$

TABLE 38. Three partial regressions on leaf nitrogen
Island of Hawaii 44-3098

FACTOR	PARTIAL REGRESSION	"t" VALUE
Minimum temperature	− .1573	14.16**
Sheath moisture	+ .4803	37.13**
Age	− .4891	37.79**

$n = 2274$ $R^2 = .7407^{**}$

TABLE 39. Two partial regressions on leaf nitrogen
Island of Hawaii 44-3098

FACTOR	PARTIAL REGRESSION	"t" VALUE
Sheath moisture	+ .5240	40.00**
Age	− .4450	33.95**

$n = 2274$ $R^2 = .7178^{**}$

Dropping the minimum temperature (table 39) results in a change of R^2 from .7407 to .7178 or from R of .861 to .847, which drop reaches significance at the 5 percent level.

The Normal Nitrogen equation for the two factors is:

$$NN = \underset{\substack{\text{Sheath}\\ \text{Moisture}}}{.05885\ X_1} - \underset{\text{Age}}{.02270\ X_2} - 2.59310$$

and the Standard Nitrogen equation

$$SNI = \underset{\substack{\text{Actual}\\ \text{Leaf Nitrogen}}}{N_1} + \underset{\substack{\text{Sheath}\\ \text{Moisture}}}{.05885\ (M_2 - M_1)} - \underset{\text{Age}}{.02270\ (A_2 - A_1)}$$

Actually, considering the very large range of conditions existing in the area where 44-3098 grows, it seems an exceptionally high correlation has been observed. The individual r's between leaf nitrogen and the factors of sheath moisture and age are +.758 and −.721, respectively, and the corresponding r^2 would be .5746 and .5198 leaving no doubt that both factors are involved in getting a multiple correlation (R) of .847.

Finally, several of these sets of data can now be combined to determine the extent of the generalization we can enjoy. In the first of these combinations the data from variety 37-1933 will be assembled from all the areas which were presented above, but since only age and moisture data were available for some of these, only these two factors will be used. The 37-1933 data from Ewa, Waialua, Olokele, Lahaina, Puunene, and Wailuku will be used. The results are shown in table 40.

TABLE 40. Two partial regressions on leaf nitrogen
All 37-1933 data

FACTOR	PARTIAL REGRESSION	"t" VALUE
Sheath moisture	+ .4012	37.46**
Age	— .5015	46.83**

$n = 3349$ $R^2 = .7113^{**}$ $R = .843^{**}$

The value of R^2 continues to be relatively high and compares with .7510 at Ewa alone (table 15); .760 at Puunene (table 20); .750 at Lahaina; .679 at Wailuku (table 32); .700 at Waialua (table 34); and .747 at Olokele (table 33). The conclusion seems justified that a single equation can be used for variety 37-1933 under the range of conditions where it is grown in Hawaii. The Normal Nitrogen equation for 37-1933 as it is grown under Hawaiian irrigated conditions is as follows:

$$NN = \underset{\text{Sheath Moisture}}{.04195\ X_1} - \underset{\text{Age}}{.02453\ X_2} - 1.4222$$

The Standard Nitrogen equation becomes:

$$SNI = N_1 + .04195\ (M_2 - M_1) - .02453\ (A_2 - A_1)$$ where N_1 is the actual leaf nitrogen, M_2 the desired moisture level, M_1 the actual moisture level, A_2 the desired age, and A_1 the actual age.

ALL VARIETIES—IRRIGATED AND UNIRRIGATED

ALL IRRIGATED AREAS—VARIETIES 32-8560, 37-1933, 38-2915

Next, all the data resulting from the three main irrigated varieties, 32-8560, 37-1933, and 38-2915, are combined and the results are as shown in table 41. The dominant factors continue to be sheath moisture and age with total sugars and temperatures following, but sunlight seems to exert no significant influence. The R^2 of .7282 compares very favorably with the R^2 of .7175 for 32-8560 alone, .7890 for Ewa's 37-1933, and .7586 for Puunene's combined 37-1933 and 38-2915. The corresponding R's are 854 for the three varieties, .847 for 32-8560, .888 for Ewa, and .870 for Puunene. While the actual differences appear small, combining the three varieties results in a better R than was had for 32-8560 alone, but significantly poorer than for Ewa alone as well as for Puunene.

TABLE 41. Six partial regressions on leaf nitrogen
Three varieties—Irrigated conditions
32-8560, 37-1933, and 38-2915

FACTOR	PARTIAL REGRESSION	"t" VALUE
Sunlight	+ .0041	.44
Maximum temperature	— .1257	14.57**
Minimum temperature	— .0741	8.66**
Total sugars	+ .1957	21.56**
Sheath moisture	+ .5360	44.51**
Age	— .3949	33.81**

$n = 4277$ $R^2 = .7282^{**}$

In table 42, maximum temperature is included with sheath moisture and age.

TABLE 42. Three partial regressions on leaf nitrogen
32-8560, 37-1933, and 38-2915

FACTOR	PARTIAL REGRESSION	"t" VALUE
Maximum temperature	— .1233	14.39**
Sheath moisture	+ .4600	38.15**
Age	— .4356	21.52**

$n = 4277$ $R^2 = .6900^{**}$

For later comparison, the Normal Nitrogen equation is:

$$NN = \underset{\substack{\text{Maximum}\\\text{Temperature}}}{-.00760\ X_1} + \underset{\substack{\text{Sheath}\\\text{Moisture}}}{.04525\ X_2} - \underset{\text{Age}}{.01853\ X_3} - 1.20807$$

Inasmuch as the 32-8560 data result from numerous measurements on relatively few crops and, further, since the R for 32-8560 was lower than for the other varieties, 32-8560 is dropped from the analysis in table 43. The resulting R value of .873 is not significantly different from that at Puunene .870, or that at Ewa .888.

So far, then, it appears that varieties at a given place do not differ in the factors affecting the nitrogen level. Also, different varieties in different irrigated situations do not differ in the factors affecting the nitrogen levels.

TABLE 43. Six partial regressions on leaf nitrogen
Ewa 37-1933 and Puunene 37-1933 and 38-2915

FACTOR	PARTIAL REGRESSION	"t" VALUE
Sunlight	— .0648	6.36**
Maximum temperature	— .0661	6.68**
Minimum temperature	— .0421	4.42**
Total sugars	+ .0862	8.47**
Sheath moisture	+ .4043	27.63**
Age	— .5331	37.33**

n = 2904 R² = .7625** R = .873**

In table 44 is given the analysis for the maximum temperature, moisture, and age.

TABLE 44. Three partial regressions on leaf nitrogen
Ewa 37-1933 and Central Maui 37-1933 and 38-2915

FACTOR	PARTIAL REGRESSION	"t" VALUE
Maximum temperature	— .0778	8.29**
Sheath moisture	+ .3857	28.19**
Age	— .5455	39.66**

n = 2904 R² = .7519**

The three-factor equation for Normal Nitrogen is:

$$NN = -.00489 \underset{\substack{\text{Maximum}\\ \text{Temperature}}}{X_1} + .03789 \underset{\substack{\text{Sheath}\\ \text{Moisture}}}{X_2} - .02436 \underset{\text{Age}}{X_3} - .71102$$

In table 45, the two-factor analysis is shown.

TABLE 45. Two partial regressions on leaf nitrogen
Ewa 37-1933 and Central Maui 38-2915 and 37-1933

FACTOR	PARTIAL REGRESSION	"t" VALUE
Sheath moisture	+ .4009	29.22**
Age	— .5261	38.35**

n = 2904 R² = .7460**

The two-factor Normal Nitrogen equation for the two irrigated varieties grown at these two places is as follows:

$$NN = .03938 \underset{\substack{\text{Sheath}\\ \text{Moisture}}}{X_1} - .02350 \underset{\text{Age}}{X_2} - 1.2470$$

The Standard Nitrogen equation is:

$$\mathrm{SNI} = N_1 + \underset{\text{Sheath Moisture}}{.03938\ (M_2 - M_1)} - \underset{\text{Age}}{.02350\ (A_2 - A_1)}$$

Now we come to the extremes of ecological conditions and proceed to combine the 44-3098 growing in the high-rainfall areas with the varieties grown under irrigated conditions. Since sunlight records were not available for the 44-3098 data, only the five factors will be considered and the results are shown in table 46. The factors of moisture and age continue to be the most dominant ones but maximum temperature here where the contrast in environment conditions is far greater than we have experienced before assumes a very important role, and, of course, has a negative partial regression. The R^2 of .700 is significantly lower than that for Ewa ($R^2 = .788$) and that for Hawaii's 44-3098 alone ($R^2 = .745$). The corresponding R's are .837, .887, and .863, respectively. However, the actual R's are sufficiently close to justify the conclusion that even for the complete extremes of ecological conditions in the Territory, the leaf nitrogen levels are subject to the same factors in about the same way irrespective of the varieties currently used.

TABLE 46. Five partial regressions on leaf nitrogen
Ewa, Central Maui, and Hawaii
37-1933, 38-2915, and 44-3098

FACTOR	PARTIAL REGRESSION	"t" VALUE
Maximum temperature	— .2275	27.08**
Minimum temperature	— .1247	15.46**
Total sugars	— .0456	5.57**
Sheath moisture	+ .3390	33.00**
Age	— .5370	55.56**

n = 5178 $R^2 = .7000$**

TABLE 47. Three partial regressions on leaf nitrogen
Ewa, Central Maui, and Hawaii
37-1933, 38-2915, and 44-3098

FACTOR	PARTIAL REGRESSION	"t" VALUE
Maximum temperature	— .2985	37.31**
Sheath moisture	+ .3827	37.44**
Age	— .5064	48.73**

n = 5178 $R^2 = .6882$**

In table 47 the analysis is given without total sugars and minimum temperature, resulting in no significant change in R^2. The "t" values indicate a very good balance in the values for each of the three factors. While it will probably be better for each general sugar cane area in the Territory to use an equation more specific to itself (see p. 31ff), yet there is value in an over-all equation, and for these three factors the Normal Nitrogen equation is:

$$NN = \underset{\substack{\text{Maximum}\\ \text{Temperature}}}{-.01960\ X_1} + \underset{\substack{\text{Sheath}\\ \text{Moisture}}}{.04219\ X_2} - \underset{\substack{\text{Age in}\\ \text{Months}}}{.02531\ X_3} + .22292$$

where X_1 is the maximum temperature (average for the period preceding the sampling). The range in maximum temperature in these data was from 65° to 94° F. with a mean of 79.3°; X_2 is the sheath moisture with a range of 71.4–87.8 and a mean of 81.4; and X_3 is the age in months at the time the sample was taken—the range was 1.8–33.3 and the mean 14.3.

A Standard Nitrogen Index can be obtained by the use of this equation:

$$SNI = N_1 - .01960\ (T_2 - T_1) + .04219\ (M_2 - M_1) - .02531\ (A_2 - A_1)$$

where N_1 is the actual nitrogen reading

T is the average maximum temperature for the sample period

M the sheath moisture at the time of sampling

A the age at the time of sampling.

The subscript 2 is the value to which standardizing is desired and the subscript 1 is the actual value in each case.

In table 48 minimum temperature is used in place of maximum. It seems fairly clear not only from the reduced R^2 but also the smaller "t" value of 28.12, as compared with 37.31 in table 47, that the maximum temperature is more dominant on leaf nitrogen levels than is minimum.

TABLE 48. Three partial regressions on leaf nitrogen
Ewa, Central Maui, and Hawaii
37-1933, 38-2915, and 44-3098

FACTOR	PARTIAL REGRESSION	"t" VALUE
Minimum temperature	− .2352	28.12**
Sheath moisture	+ .3881	36.00**
Age	− .4788	44.18**

n = 5178 R^2 = .6568**

In table 49, total sugars are entered as the third factor, which gives the R value of .785 and is significantly poorer than when either maximum or minimum temperatures were used.

Finally, only moisture and age are used; the results are shown in table 50.

TABLE 49. Three partial regressions on leaf nitrogen
Ewa, Central Maui, and Hawaii
37-1933, 38-2915, and 44-3098

FACTOR	PARTIAL REGRESSION	"t" VALUE
Total sugars	$-$ .1293	13.28**
Sheath moisture	$+$ .3680	29.12**
Age	$-$ .4620	39.22**

$n = 5178$ $R^2 = .6174^{**}$ $R = .785^{**}$

TABLE 50. Two partial regressions on leaf nitrogen
Ewa, Central Maui, and Hawaii
37-1933, 38-2915, and 44-3098

FACTOR	PARTIAL REGRESSION	"t" VALUE
Sheath moisture	$+$ .4468	39.33**
Age	$-$ .4121	36.27**

$n = 5178$ $R^2 = .6043^{**}$

The multiple correlation here is significantly lower than that shown with maximum temperatures, but for those who might be interested in a single Normal Nitrogen equation for the whole Territory based on three dominant varieties, it is:

$$NN = \underset{\substack{\text{Sheath}\\ \text{Moisture}}}{.04925\ X_1} - \underset{\text{Age}}{.02059\ X_2} - 1.98674$$

SUMMARY OF EQUATIONS

Perhaps the best way to summarize this section is to assemble the various equations for Normal Nitrogen and for Standard Nitrogen.

THREE-FACTOR EQUATIONS FOR NORMAL NITROGEN

Three Irrigated Varieties (Table 42)

$$NN = \underset{\substack{\text{Maximum}\\ \text{Temperature}}}{-.007597\ X_1} + \underset{\substack{\text{Sheath}\\ \text{Moisture}}}{.04525\ X_2} - \underset{\text{Age}}{.01853\ X_3} - 1.20807$$

Ewa and Central Maui 37-1933 and 38-2915 (Table 44)

$$NN = \underset{\substack{\text{Maximum}\\ \text{Temperature}}}{-.004889\ X_1} + \underset{\substack{\text{Sheath}\\ \text{Moisture}}}{.03789\ X_2} - \underset{\text{Age}}{.02436\ X_3} - .71102$$

Island of Hawaii 44-3098 (Table 38)

$$NN = -.01165 \underset{\substack{\text{Minimum}\\ \text{Temperature}}}{X_1} + .05395 \underset{\substack{\text{Sheath}\\ \text{Moisture}}}{X_2} - .02495 \underset{\text{Age}}{X_3} - 1.4421$$

Ewa, Central Maui, and Hawaii (Table 47)

$$NN = -.01960 \underset{\substack{\text{Maximum}\\ \text{Temperature}}}{X_1} + .04219 \underset{\substack{\text{Sheath}\\ \text{Moisture}}}{X_2} - .02531 \underset{\text{Age}}{X_3} + .22292$$

TWO-FACTOR EQUATIONS FOR NORMAL NITROGEN

Puunene 37-1933 and 38-2915 (Table 27)

$$NN = .04122 \underset{\substack{\text{Sheath}\\ \text{Moisture}}}{X_1} - .02212 \underset{\text{Age}}{X_2} - 1.4208$$

Lahaina 37-1933 and 38-2915 (Table 31)

$$NN = .04690 \underset{\substack{\text{Sheath}\\ \text{Moisture}}}{X_1} - .02639 \underset{\text{Age}}{X_2} - 1.8312$$

All 37-1933 data (Table 40)

$$NN = .04195 \underset{\substack{\text{Sheath}\\ \text{Moisture}}}{X_1} - .02453 \underset{\text{Age}}{X_2} - 1.4222$$

Ewa and Central Maui 37-1933 and 38-2915 (Table 45)

$$NN = .03938 \underset{\substack{\text{Sheath}\\ \text{Moisture}}}{X_1} - .02350 \underset{\text{Age}}{X_2} - 1.2470$$

Island of Hawaii 44-3098 (Table 39)

$$NN = .05885 \underset{\substack{\text{Sheath}\\ \text{Moisture}}}{X_1} - .02270 \underset{\text{Age}}{X_2} - 2.59310$$

Ewa, Central Maui, and Island of Hawaii (Table 50)

$$NN = .04925 \underset{\substack{\text{Sheath}\\ \text{Moisture}}}{X_1} - .02059 \underset{\text{Age}}{X_2} - 1.98674$$

THREE-FACTOR EQUATIONS FOR STANDARD NITROGEN

Three Irrigated Varieties (Table 42)

$$SNI = N_1 - .007597 \underset{\substack{\text{Maximum}\\ \text{Temperature}}}{(T_2 - T_1)} + .04525 \underset{\substack{\text{Sheath}\\ \text{Moisture}}}{(M_2 - M_1)} - .01853 \underset{\text{Age}}{(A_2 - A_1)}$$

Ewa and Central Maui 37-1933 and 38-2915 (Table 44)

$$\text{SNI} = N_1 - .004889 \underset{\substack{\text{Maximum}\\ \text{Temperature}}}{(T_2 - T_1)} + .03789 \underset{\substack{\text{Sheath}\\ \text{Moisture}}}{(M_2 - M_1)} - .02436 \underset{\text{Age}}{(A_2 - A_1)}$$

Island of Hawaii 44-3098 (Table 38)

$$\text{SNI} = N_1 - .01165 \underset{\substack{\text{Minimum}\\ \text{Temperature}}}{(T_2 - T_1)} + .05395 \underset{\substack{\text{Sheath}\\ \text{Moisture}}}{(M_2 - M_1)} - .02495 \underset{\text{Age}}{(A_2 - A_1)}$$

Ewa, Central Maui, and Island of Hawaii (Table 47)

$$\text{SNI} = N_1 - .01960 \underset{\substack{\text{Maximum}\\ \text{Temperature}}}{(T_2 - T_1)} + .04219 \underset{\substack{\text{Sheath}\\ \text{Moisture}}}{(M_2 - M_1)} - .02531 \underset{\text{Age}}{(A_2 - A_1)}$$

TWO-FACTOR EQUATIONS FOR STANDARD NITROGEN

Puunene 37-1933 and 38-2915 (Table 27)

$$\text{SNI} = N_1 + .04122 \underset{\substack{\text{Sheath}\\ \text{Moisture}}}{(M_2 - M_1)} - .02212 \underset{\text{Age}}{(A_2 - A_1)}$$

Lahaina 37-1933 and 38-2915 (Table 31)

$$\text{SNI} = N_1 + .04690 \underset{\substack{\text{Sheath}\\ \text{Moisture}}}{(M_2 - M_1)} - .02639 \underset{\text{Age}}{(A_2 - A_1)}$$

Ewa and Central Maui 37-1933 and 38-2915 (Table 45)

$$\text{SNI} = N_1 + .03938 \underset{\substack{\text{Sheath}\\ \text{Moisture}}}{(M_2 - M_1)} - .02350 \underset{\text{Age}}{(A_2 - A_1)}$$

Island of Hawaii 44-3098 (Table 39)

$$\text{SNI} = N_1 + .05885 \underset{\substack{\text{Sheath}\\ \text{Moisture}}}{(M_2 - M_1)} - .02270 \underset{\text{Age}}{(A_2 - A_1)}$$

Ewa, Central Maui, and Island of Hawaii 37-1933, 38-2915, and 44-3098 (Table 50)

$$\text{SNI} = N_1 + .04925 \underset{\substack{\text{Sheath}\\ \text{Moisture}}}{(M_2 - M_1)} - .02059 \underset{\text{Age}}{(A_2 - A_1)}$$

APPLICATION OF THE CONCEPT OF NORMAL NITROGEN

The application of the concepts of "Normal Nitrogen" and "Standard Nitrogen" can now be developed. As discussed on the first page of this bulletin, the actual level of nitrogen in the chlorenchyma of the young leaf blade is affected by factors other than supply of nitrogen in the soil. Inasmuch as the growing cane top is an organization of many tissues actively metabolizing and carrying on the principal functions of the plant it is not surprising that nutrient levels within these tissues should be modified by internal as well as external factors. But as shown in the previous section, the most dominant of these are sheath moisture and age with maximum temperature being an additional factor useful in reconciling widely differing ecological habitats.

When a crop is sampled for crop-logging, the primary objective is to determine the state of the plant's nutrition and when the tissue is analyzed, the grower needs to know whether the resulting data are normal or too high or too low. With cation nutrients such as potassium, calcium, magnesium, etc., it seems that a straight line can be drawn across the page of the log at the appropriate level and if the nutrient is maintained at or above this line the nutrition of the plant is satisfied. With nitrogen, however, the matter is much more complicated and hence a different approach is needed. For a given plantation the appropriate Normal Nitrogen equation is selected and in order to avoid the repetition for the simple though annoying calculations each time, a table is constructed, developed from the equation and showing the normal nitrogen level for all the combinations of age (from 2.0 to perhaps 30.0 months) and sheath moisture (from 90.0 down to 73.0 percent). To illustrate the use first on a specific problem basis a few actual cases may be cited.

Example 1. A field of 44-3098 planned to be harvested at 36.0 months is sampled at 23.0 months of age and has a sheath moisture of 82.5. The normal nitrogen is 1.74. The actual nitrogen index is 1.50. Here, fertilization is called for since there is still more than a year of time to go before harvest.

Example 2. A field of 44-3098 is in an area where a temporary drought prevails. The leaf nitrogen reads 1.15, sheath moisture 74.2, and the age is 12.3 months. Is the low nitrogen level due to drought or is there an actual deficiency? Normal nitrogen would be 1.49. Hence the drought even though severe is less a factor than is the nitrogen deficiency.

Example 3. A field at 9.7 months shows 84.0 moisture and leaf nitrogen of 2.03. Normal nitrogen would be 2.13. Field is close to normal although on the low side.

Example 4. At one of the Kau plantations, leaf nitrogen was extremely high, nearly 3.0, but at 5.9 months there was a sharp "drop" to 2.4. The inclination was to put on more fertilizer. But at 5.9 months and a sheath moisture of 81.2, normal nitrogen was 2.00.

Another use which can be made of the normal nitrogen readings has to do with nitrogen experiments such as the one currently under way at Hawaiian Commercial and Sugar Company. At the time the plots were about 9 months old the analytical results were as reported in table 51. The question is, what is the normal nitrogen for the observed moistures? These are

TABLE 51. Hawaiian Commercial & Sugar Co. data

TREATMENTS POUNDS N PER ACRE	LEAF NITROGEN AV.	SHEATH MOISTURE AV.	NORMAL NITROGEN	
			FOR OBSERVED MOISTURE	FOR THE HIGH MOISTURE
200	1.66	81.71	1.75	1.82
400	1.81	82.24	1.77	1.82
600	1.86	82.75	1.79	1.82
800	1.96	82.97	1.80	1.82
1000	1.93	83.46	1.82	1.82

given in one column. It is clear that, at this sampling, only the 200-pound treatment gives less than a normal nitrogen reading, but the second question is, what should the reading be if we had the highest moisture for maximum growth at this stage? If we take the highest average block moisture of 83.46, the normal nitrogen would be 1.82 which would then show the 200-pound treatment 0.16 below, the 400-pound treatment .01 below, and the remaining above. It appears then that thus far in the experiment applying nitrogen at the rate of 400 pounds satisfies the requirements.

The commonest use for normal nitrogen, of course, is in connection with normal logging of fields. As practiced on the plantations, the normal nitrogen reading is plotted on the logs as a red cross and the crosses are not connected with solid lines. Several examples are shown in figures 1–6. The crop logs shown are records of actual crops and all but one were excellent crops for the areas. Although in this publication, the normal nitrogen levels are plotted as black X's about the leaf nitrogen curve, the concept was not used in the guidance of these particular crops since the crops were well on their way to harvest by the time the normal nitrogen equations were developed.*

All of the nitrogen equations developed show the very strong effect which the moisture level has on the nitrogen level. The normal nitrogen and standard nitrogen equations emphasize this relationship. Thus, the nitrogen curve shown in figure 4 is very high, not only because more nitrogen was applied than needed but also because the ecological situation is such as to favor a high moisture status. Now, of course, for vigorous growth this high moisture is desirable, but it is clear that this situation if continuing indefinitely is not conducive to the formation and storage of sugar. On irrigated plantations where ripening is possible by withholding water this is not undesirable during the early part of the crop, but on unirrigated plantations where ripening cannot be effected, the growth of

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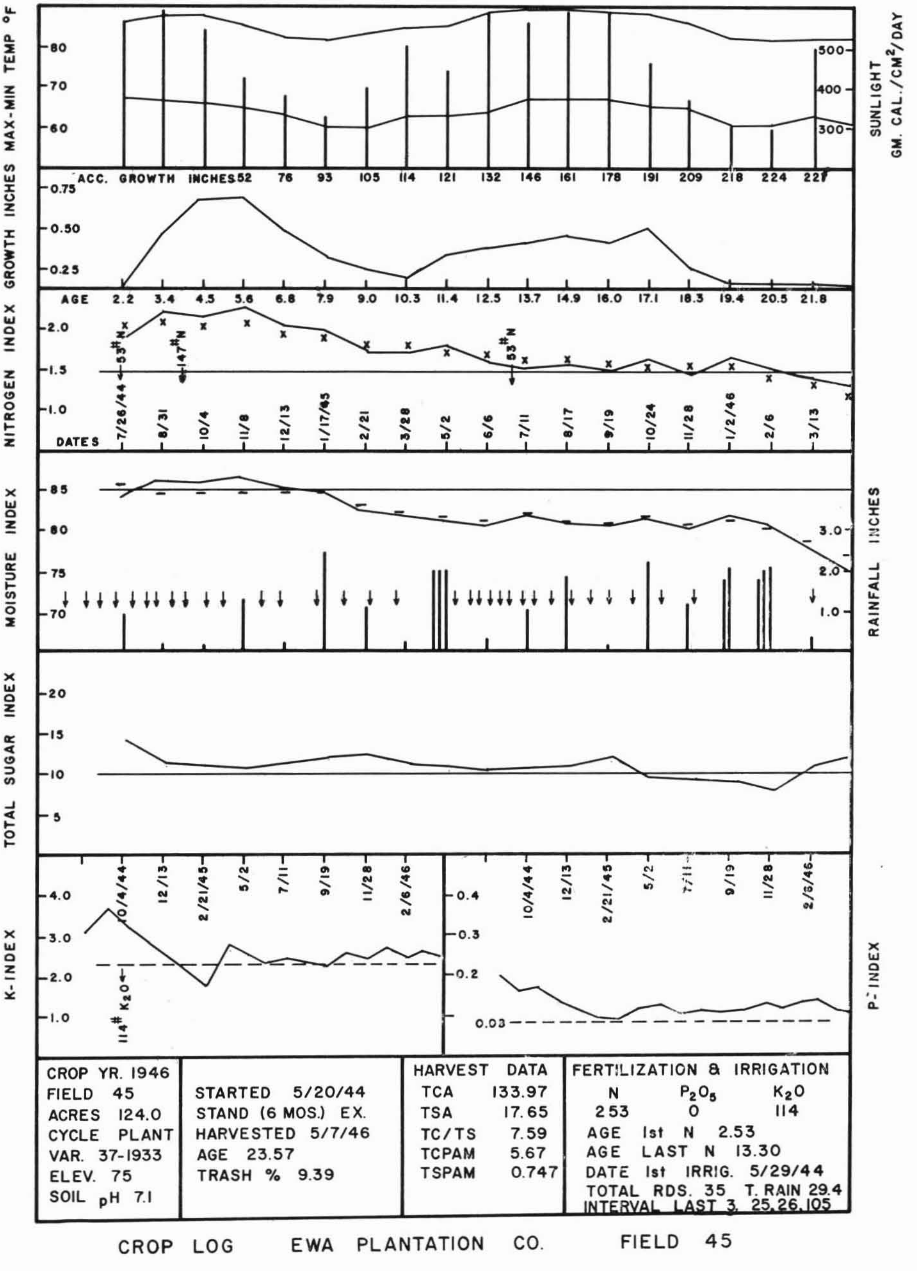
*It is suggested that the reader complete the text to page 49 before going over figures 1–6.



CROP YR. 1946 FIELD 45 ACRES 124.0 CYCLE PLANT VAR. 37-1933 ELEV. 75 SOIL pH 7.1	STARTED 5/20/44 STAND (6 MOS.) EX. HARVESTED 5/7/46 AGE 23.57 TRASH % 9.39	HARVEST DATA TCA 133.97 TSA 17.65 TC/TS 7.59 TCPAM 5.67 TSPAM 0.747	FERTILIZATION & IRRIGATION N 253 · P_2O_5 0 · K_2O 114 AGE 1st N 2.53 AGE LAST N 13.30 DATE 1st IRRIG. 5/29/44 TOTAL RDS. 35 T. RAIN 29.4 INTERVAL LAST 3 25,26,105

CROP LOG EWA PLANTATION CO. FIELD 45

FIGURE 1.

the cane plant under conditions of continuously high moisture and high nitrogen (*11, 12*) and relatively low radiation results in large cells of low dry matter content and hence low sugar content. Where the normal nitrogen is based on a high moisture content at least partly induced by excessive nitrogen, then obviously even the so-called "normal" nitrogen will be abnormally high.

On the other hand, where because of nitrogen deficiency and lack of vigor (figure 6), the normal nitrogen while above the actual nitrogen, is so slightly above that the difference does not adequately represent the degree of distress experienced by the crop. What is needed is a moisture standard on which the normal nitrogen level can be based and which is distinctive for the variety and the field where the plant is growing. The use to be made of the moisture standard would be in studies of the extreme cases such as shown for figures 4 and 6.

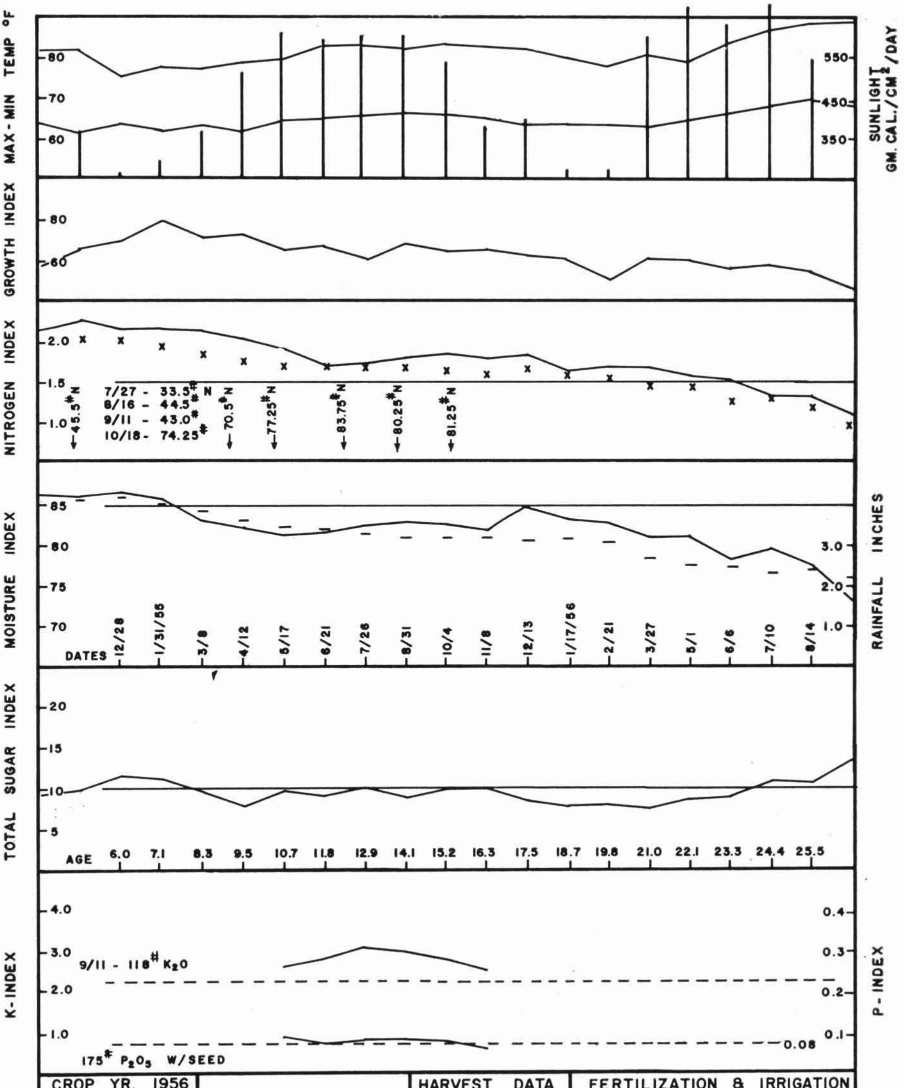
NORMAL MOISTURE DATA AND EQUATIONS

The factors which affect the moisture level of 32-8560 are given in table 52.

Here, leaf nitrogen exerts the greatest influence on the moisture level but it is clear that all the factors of environment play important parts as well as the variety itself. If we are to develop a moisture level which we can use for determining what level of nitrogen we desire, then we should determine this without reference to nitrogen. Hence, in table 53 are shown the six factors and their influence on tissue moisture.

FIGURE 1. The crop log shown in figure 1 is for the very first commercial field size crop of 37-1933 grown at Ewa and harvested May 7, 1946. Here, with a minimum fertilization (253 lb. N, 0 lb. P_2O_5, and 114 lb. K_2O) one of the highest yields was obtained, achieving a tons-sugar-per-acre-month of 0.747. This, then, is a case of an excellent new variety unimpeded in its development by the host of deterrents which attach themselves to a new variety as its history lengthens and which ultimately drag it down into the so-called varietal decline.

Plotted as X's in the Nitrogen Index space, the normal nitrogen readings reveal a generally high nitrogen curve during the first 6.8 months, but after that a very close approximation of the two indices. Nitrogen fertilization practices of today would call for an earlier application (the first application was made July 26, 1944, at 2.53 months) with perhaps two later applications of 70–80 pounds each instead of the one of 147 pounds. The second-season application today would have been considerably larger, especially for a field to be harvested in May, and on irrigated plantations such as Ewa where ripening control can be so effectively done (*4*). It is surely evident, however, not only from the actual yield, but also from the goodness of fit of the two nitrogen indices that not much improvement on this log can be expected.



CROP YR. 1956		HARVEST DATA	FERTILIZATION & IRRIGATION
FIELD 501	STARTED 6/28/54	TC/A 132.27	N P$_2$O$_5$ K$_2$O
ACRES 175.1	STAND (6 MOS)	TS/A 17.66	633.25 175.75 118
CYCLE PLANT	HARVESTED 9/14-21/56	TC/TS 7.49	AGE 1st N 1.2
VAR. 37-1933	AGE 26.68	TSPAM 0.662	AGE LAST N 15.3
ELEV. 304-470	TRASH % 24.16	BRIX 20.71	DATE 1st IRRIG. 6/28/54
		POL 18.23	TOTAL RDS. 41.28 T. RAIN 57.26
		PURITY 88.03	

HAWAIIAN COMMERCIAL & SUGAR CO., LTD., CROP LOG FIELD 501

FIGURE 2.

TABLE 52. Seven partial regressions on sheath moisture
Waipio 32-8560

FACTOR	PARTIAL REGRESSION	"t" VALUE
Leaf nitrogen	+ .6464	30.97**
Maximum temperature	+ .2409	12.15**
Age	— .1825	8.81**
Light	— .1721	6.72**
Relative humidity	+ .1245	6.46**
Soil moisture	+ .0800	5.20**
Wind velocity	+ .0727	3.54**

n = 1373 R^2 = .7157** R = .846**

On most plantations, however, records of wind, relative humidity, and soil moisture are either not kept, or are not complete and reliable. Hence, in table 54, the Waipio moisture levels are related to four of the factors: age, sunlight, and maximum and minimum temperatures. It seems that where the supply of water to the roots is not limiting, the variety's moisture level will be modified only by the age of the crop (which is probably simply a corollary of the height of the plant), by sunlight which is the input of energy, and by the elements of temperature, the prevailing energy

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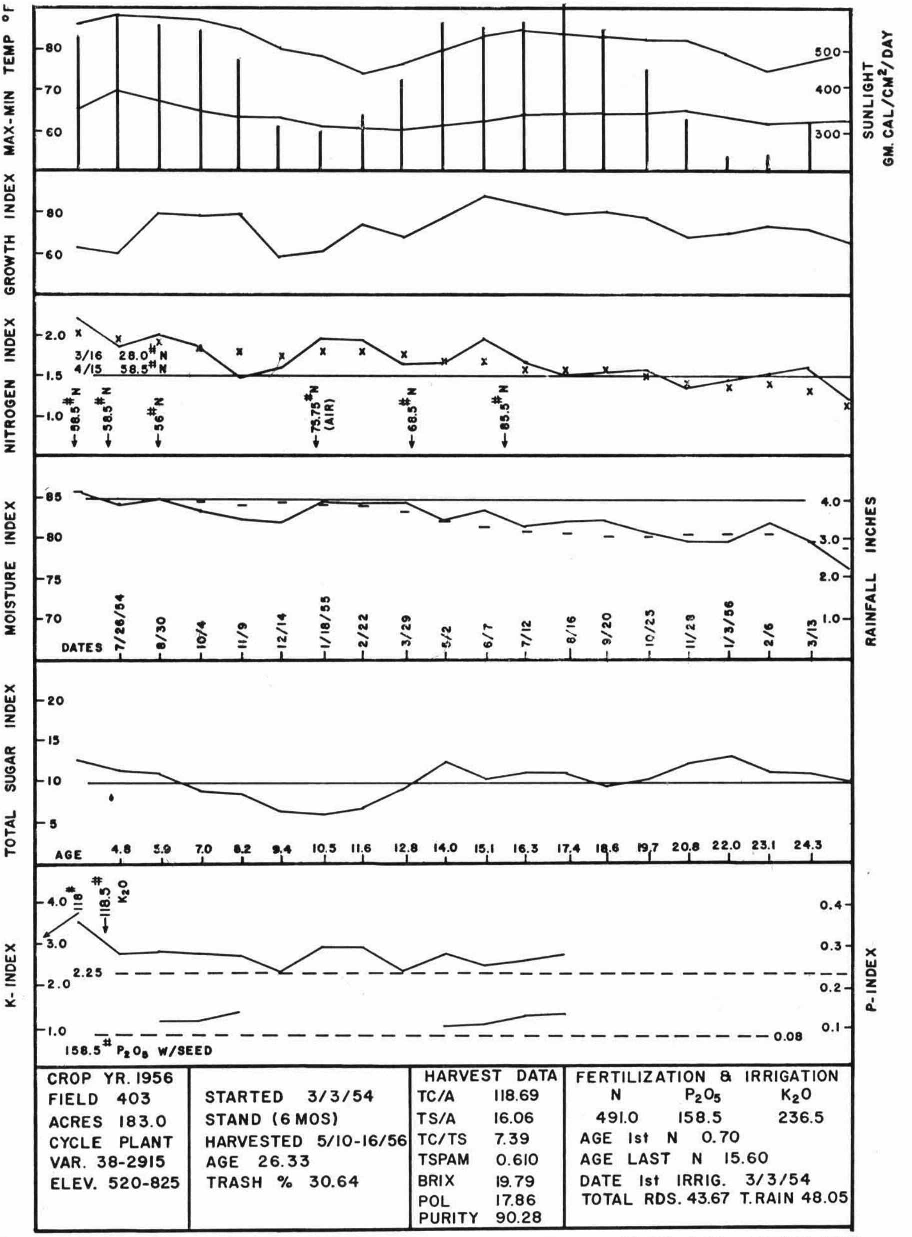
FIGURE 2. At Hawaiian Commercial & Sugar Co., a very excellent yield of sugar was obtained from 37-1933 in 1956, ten years after the first harvested crop shown in figure 1. Here the tons-sugar-per-acre of 17.66 was the same as that at Ewa, but since the crop was nearly three months older the sugar-per-acre-month yield was 0.662 tons. Here the total fertilization was 633 lb. N, 118 lb. K_20, and 175 lb. P_20_5.

This crop as it appears is an excellent example of overfertilization with nitrogen, but since it was done in an area where ripening control can be effected, juice quality can still be very good (*8*), although a TC/TS value of 7.49 for Central Maui, in the opinion of the author, cannot be considered excellent. Comparing the actual nitrogen with the normal nitrogen shows excessive nitrogen levels throughout. Perhaps the very high readings early in the crop are not without merit since a crop of this nutritional state will have broader and more numerous leaves which will contribute to closing-in the field sooner, but it is questionable from this vantage point whether the application of 70.5 pounds of nitrogen in March needed to go on so soon, and most likely one of the three, perhaps the last one of the second-season applications of 80 pounds should have been omitted altogether.



HAWAIIAN COMMERCIAL & SUGAR CO., LTD., CROP LOG FIELD 403

FIGURE 3.

TABLE 53. Six partial regressions on sheath moisture
Waipio 32-8560

FACTOR	PARTIAL REGRESSION	"t" VALUE
Light	− .4047	12.45**
Age	− .6277	31.95**
Maximum temperature	+ .3539	10.51**
Minimum temperature	− .1097	3.82**
Humidity	+ .0291	1.16
Wind velocity	+ .1434	4.18**

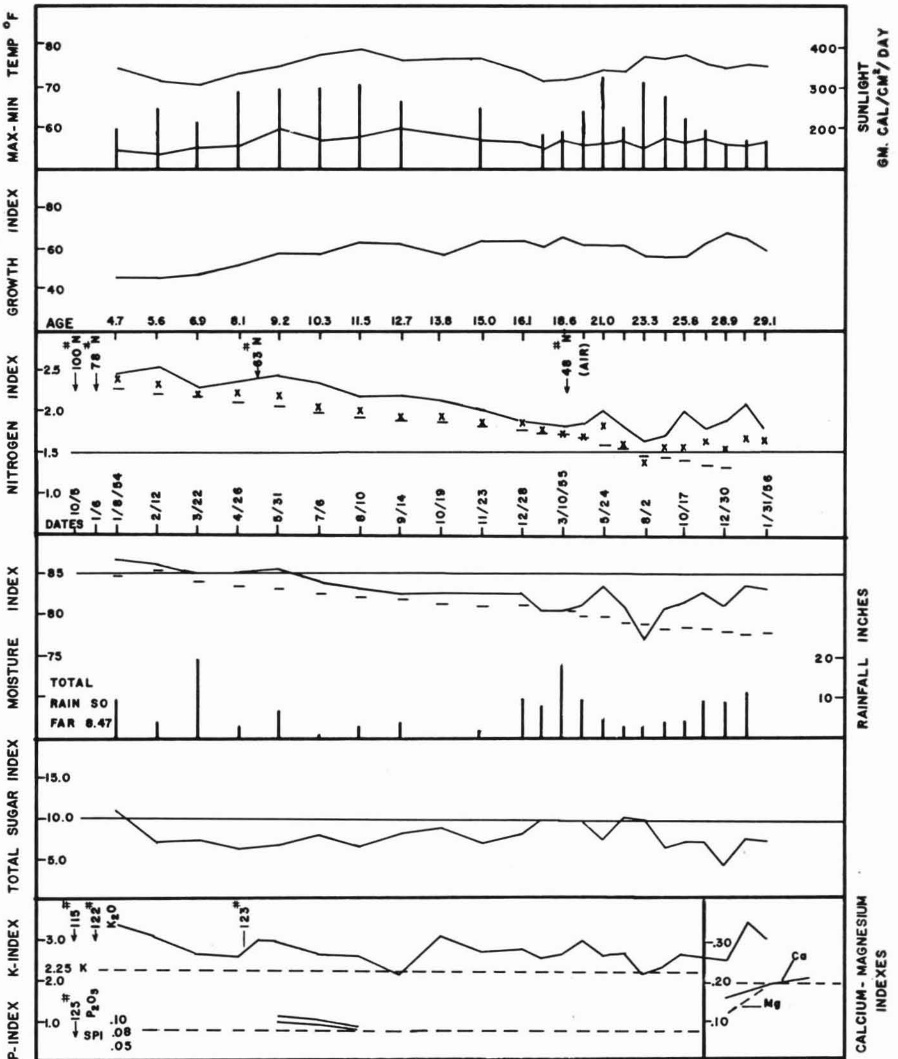
$n = 1373$ $R^2 = .5150^{**}$

TABLE 54. Four partial regressions on sheath moisture
Waipio 32-8560

FACTOR	PARTIAL REGRESSION	"t" VALUE
Sunlight	− .3303	14.66**
Age	− .6443	33.78**
Maximum temperature	+ .2530	10.80**
Minimum temperature	− .0364	1.62

$n = 1373$ $R^2 = .5082^{**}$

FIGURE 3. This crop log shows another excellent yield, but this one with variety 38-2915 at Hawaiian Commercial & Sugar Co. The total fertilization here was 491 lb. N, 158 lb. P_20_5, and 236 lb. K_20. The yields of 16.06 tons-sugar-per-acre and 0.610 tons-sugar-per-acre-month were considered excellent for the field and the variety. The field is in an area of the plantation subject to occasional shortages of irrigation water. The normal nitrogen and actual nitrogen indices compare more favorably than in the previous log, but there is a serious drop in the actual readings below normal, and this was the result of greatly extended intervals between irrigations during October and November, 1954. An aerial application of 76 pounds of nitrogen was made to hasten the restoration of color to the field when there was the assurance of winter rains. The two second-season applications were certainly justified on the basis of the low nitrogen index and/or the high total sugar level at a time when water was available.



STARTED 8/24/53
STAND (6 MOS) GOOD
HARVESTED 1/28/56
AGE 29.1 MONTHS
TASSEL 1st YR. NONE

TCA	159.81
TC/TS	13.34
TSA	11.98
TCPAM	5.33
TSPAM	0.399

FERTILIZATION
SOIL pH 6.1

N	P_2O_5	K_2O
289	125	360

AGE 1st N 1.4 MOS.
AGE LAST N 18.9 MOS.
TOTAL RAIN 171.5 INCHES

HAWAIIAN AG. FIELD 465 ACRES 101.76 ELEV. 1950-2800
CROP YR. 1956 VAR. 44-3098 CYCLE 1st RAT.

FIGURE 4.

TABLE 55. Four partial regressions on sheath moisture
Ewa 37-1933

FACTOR	PARTIAL REGRESSION	"t" VALUE
Sunlight	— .3051	8.47**
Age	— .6402	26.07**
Maximum temperature	+ .2735	4.02**
Minimum temperature	— .0734	1.29

n = 887 R^2 = .4953**

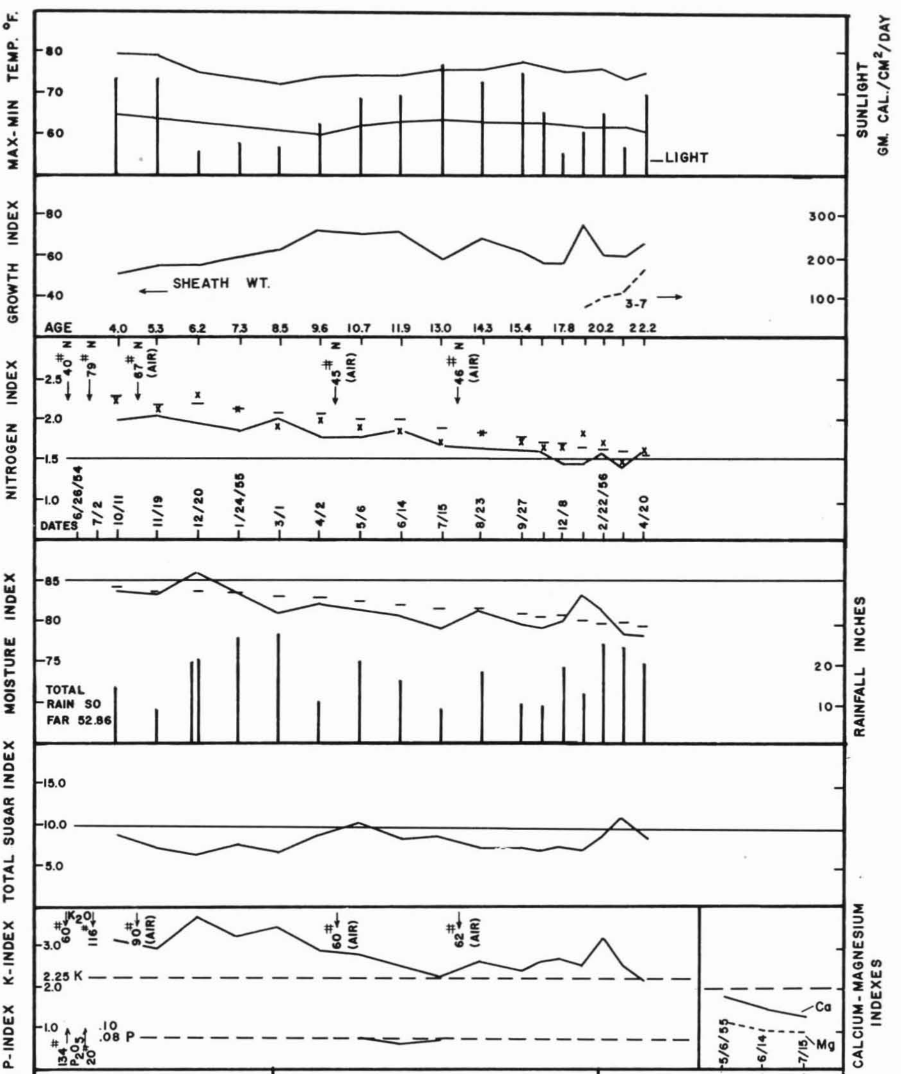
level of the atmosphere. There should, of course, be a measure of the evaporation potential of the environment, but these additional factors of relative humidity and wind are not generally measured at plantations.

There is, of course, a very substantial reduction in the value of R^2, but using three factors, sunlight, maximum temperature, and age, gives a practical solution and a highly significant multiple correlation of .712.

In table 55, a similar analysis of 37-1933 at Ewa is shown. The value of R^2 is about the same as for Waipio; in fact, there is a rather strong similarity between this table and the one for 32-8560 at Waipio. The three factors—sunlight, age, and maximum temperature—yield as much information as when minimum temperature is included.

In table 56, a similar analysis is given for 37-1933 growing in Central Maui.

FIGURE 4. This crop log is from a field of 44-3098 grown at a high elevation at Hawaiian Agricultural Co. The area is cool, cloudy, and generally wet. No irrigation is practiced. At the age of 29.1 months a heavy cane yield of about 160 tons of cane per acre was obtained, but which yielded only 11.98 tons of sugar per acre and 0.399 tons-sugar-per-acre-month. Again for the area this is not a poor yield, but quite clearly something needs to be done if at all possible to improve the quality of the cane. The fertilization totals were 289 lb. N, 125 lb. P_20_5, and 360 lb. K_20. Throughout the entire crop the nitrogen index was considerably above the normal. Hence, this seems to be the point of attack upon the problem. This plantation now is following a policy of less nitrogen as well as potash. An effort is being made to bring the actual nitrogen index closer to the normal and to apply the last nitrogen not less than 12 months before harvest and preferably 15 months. This type of crop in this area, in the opinion of the writer, is a classic example of the unbalanced carbohydrate-nitrogen relationship (*11, 12*).



STARTED 6/11/54
STAND (6 MOS) EX
HARVESTED 5/31/56
AGE 23.5 MONTHS
TASSEL 1st YR. V. LIGHT

TCA	119
TC/TS	10.1
TSA	11.79
TCPAM	4.77
TSPAM	0.472

FERTILIZATION
SOIL pH 5.6

N	P_2O_5	K_2O
277	154	387

AGE 1st N 0.5 MOS.
AGE LAST N 13.2 MOS.
TOTAL RAIN 365 INCHES

PEPEEKEO SUGAR CO. FIELD 14B ACRES 70.0 ELEV. 450′
CROP YR. 1956 VAR. 44-3098 CYCLE 1st RAT.

FIGURE 5.

TABLE 56. Four partial regressions on sheath moisture
Central Maui 37-1933

FACTOR	PARTIAL REGRESSION	"t" VALUE
Sunlight	— .1331	6.77**
Age	— .8038	46.44**
Maximum temperature	— .0476	2.48*
Minimum temperature	— .0313	1.74

n = 1145 R^2 = .6586**

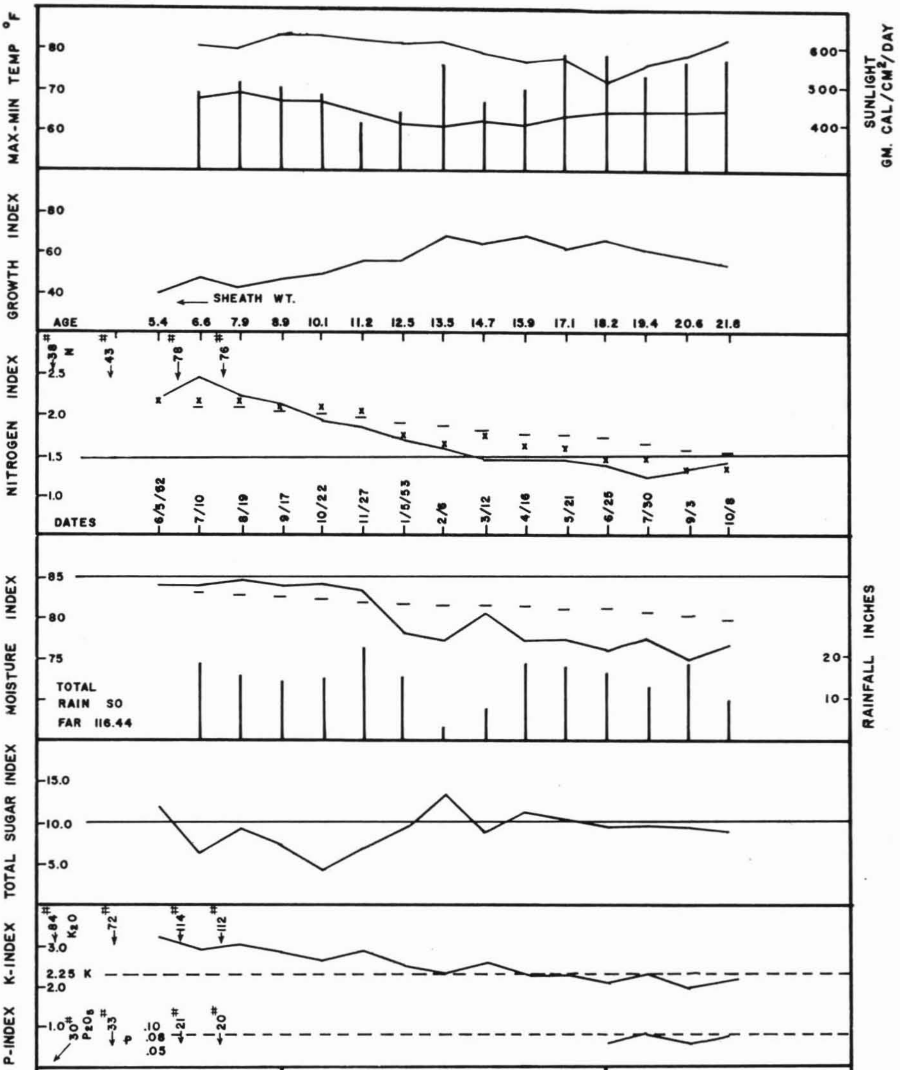
Here a considerably improved R^2 is realized and again the three factors, sunlight, age, and maximum temperature, are the ones giving significant information.

TABLE 57. Four partial regressions on sheath moisture
Ewa and Central Maui 37-1933

FACTOR	PARTIAL REGRESSION	"t" VALUE
Sunlight	— .1567	9.50**
Age	— .7468	51.82**
Maximum temperature	+ .0127	.79
Minimum temperature	— .0139	.90

n = 2032 R^2 = .5830**

FIGURE 5. The crop log here is again for variety 44-3098, but grown at Pepeekeo on the north slopes of the island of Hawaii where rainfall is excessive, 365 inches of rain having fallen during the life of the crop. The total fertilization was 277 lb. N, 154 lb. P_20_5, and 387 lb. K_20. The yield of sugar per acre, 11.79, was practically the same as that shown in figure 4, but was obtained in fewer months; hence, the tons-sugar-per-acre-month yield was 0.472, and this yield was obtained for about 30 tons less cane per acre. Comparing the actual nitrogen with the normal nitrogen reveals in general that the actual was below normal throughout. Here is the kind of crop which probably could have used more nitrogen earlier in its cycle. The total application during the first 10 months, 186 pounds, was a little short perhaps. The two aerial applications were well timed. With current practice the early applications would have totaled about 220 pounds and where the second-season leaf nitrogen was so far below the normal N the first application would have been 67 lb. instead of 45 lb. However, such logs as this should help to convince growers that excellent crops are not necessarily those with heavy nitrogen fertilization; in fact, heavy nitrogen fertilization may give heavy crops, but costly ones to harvest and transport.



STARTED 12/26/51
STAND (6 MOS) POOR
HARVESTED 10/1953
AGE 22 MONTHS
TASSEL 1st YR. V. LIGHT

TCA	76.81
TC/TS	12.23
TSA	6.28
TCPAM	3.49
TSPAM	0.285

FERTILIZATION
SOIL pH

N	P_2O_5	K_2O
235	104	362

AGE 1st N WITH SEED
AGE LAST N 7.5 MOS.
TOTAL RAIN 322.82 IN.

HAKALAU SUGAR CO. FIELD 11-2 ACRES 49.0 ELEV. 800
CROP YR. 1953 VAR. 44-3098 CYCLE PLANT

FIGURE 6.

It is of interest to determine whether a moisture curve can be assigned to a variety irrespective of the site or whether each area should work out its own moisture relationships. In table 57, the data for 37-1933 for Ewa and Central Maui are combined.

Here the two dominant influences are sunlight and age; temperatures within the range experienced are not significant.

For the time being, at least, it will probably be better to consider sheath moisture at each place as somewhat distinctive. Until more complete weather data are available at more places a definitive analysis of factors affecting moistures can be only partially complete.

The factors affecting the sheath moisture level of 38-2915 in Central Maui are shown in table 58. Both maximum and minimum temperatures exert significant influences here.

TABLE 58. Four partial regressions on sheath moisture
Central Maui 38-2915

FACTOR	PARTIAL REGRESSION	"t" VALUE
Sunlight	— .1421	6.28**
Age	— .7707	35.32**
Maximum temperature	— .1082	4.80**
Minimum temperature	— .1107	5.03**

$n = 872$ $R^2 = .5957^{**}$

Finally, in table 59 are shown the factors affecting sheath moisture of variety 44-3098 on the island of Hawaii. Unfortunately, here completely adequate sunlight data are not available and while the R^2 is highly significant, one wishes for a higher coefficient of determination. The two important factors are age and maximum temperature.

FIGURE 6. The crop log shown here is for variety 44-3098 grown under the cultural practices now considered poor. While this particular log is from Hakalau, it in no way reflects on management since there were many such logs available along the Hilo coast. The yield of 77 tons of cane per acre, and a very poor quality, resulted in a yield of 6.25 tons of sugar per acre, and 0.285 tons-sugar-per-acre-month. The crop reveals a phosphate deficiency, improper application of the 104 lb. of P_20_5 which were used, and a very low nitrogen curve beginning at 10.1 months of age. Potash also became deficient too early. All of these deficiencies contributed to make the moisture level abnormally low throughout the second year despite very heavy rainfall. Conditions such as these brought on the use of aerial fertilization shown as second-season applications on the previous logs.

TABLE 59. Three partial regressions on sheath moisture
Island of Hawaii 44-3098

FACTOR	PARTIAL REGRESSION	"t" VALUE
Age	— .5927	34.23**
Maximum temperature	— .2753	11.64**
Minimum temperature	— .0203	.88

n = 2274 $R^2 = .3561^{**}$

The equations for Normal Moisture for each variety at each place now follow:

Waipio 32-8560

$$\text{NMo} = \underset{\text{Sunlight}}{-.00666\,X_1} - \underset{\text{Age}}{.23973\,X_2} + \underset{\substack{\text{Maximum}\\ \text{Temperature}}}{.15820\,X_3} + 74.66273$$

Ewa 37-1933

$$\text{NMo} = \underset{\text{Sunlight}}{-.008145\,X_1} - \underset{\text{Age}}{.25789\,X_2} + \underset{\substack{\text{Maximum}\\ \text{Temperature}}}{.19131\,X_3} + 73.60162$$

Central Maui 37-1933

$$\text{NMo} = \underset{\text{Sunlight}}{-.00408\,X_1} - \underset{\text{Age}}{.38809\,X_2} - \underset{\substack{\text{Maximum}\\ \text{Temperature}}}{.03318\,X_3} + 91.6721$$

Central Maui 38-2915

$$\text{NMo} = \underset{\text{Sunlight}}{-.00311\,X_1} - \underset{\text{Age}}{.35834\,X_2} - \underset{\substack{\text{Maximum}\\ \text{Temperature}}}{.06794\,X_3} + 94.4073$$

Island of Hawaii 44-3098

$$\text{NMo} = \underset{\text{Age}}{-.26949\,X_1} - \underset{\substack{\text{Maximum}\\ \text{Temperature}}}{.08068\,X_2} + 91.4796$$

These various equations represent an initial attempt at setting up a moisture curve characteristic of a variety grown in a particular place. As time goes on, continuing studies should give a better approximation. To accomplish this requires an accumulation of crop-log data obtained from high-yielding crops and associated with accurately recorded weather data, including radiation, temperature records, and evaporation data. Such studies may well reveal that completely satisfactory moisture levels may be characteristic of the variety for each month of the year and will need no continuing collection of weather data. At any rate, on the crop logs shown (figures 1–6), short dashes in the sheath moisture space indicate the moisture levels calculated from the appropriate moisture equation. It is evident that the high-yielding, good quality crops have actual moisture levels very near to the normal and, hence, the normal nitrogen levels obtained from the "normal" moisture levels are practically the same as those obtained from the actual moisture; hence, they are not indicated on the logs.

The logs shown in figures 4 and 6, however, have the normal nitrogen obtained from the actual moistures shown with an X and the normal nitrogen obtained from the normal moisture is shown with a horizontal dash. Thus, for the high cane, poor quality crop, the actual nitrogen is indeed excessive and for the poor crop, the shortage of nitrogen is accentuated. (The reader is now prepared for figures 1–6.)

APPLICATION OF THE CONCEPT OF STANDARD NITROGEN

The uses made of the Standard Nitrogen Index are of another kind. If a field experiment is undertaken, the nitrogen level of the crop may be affected even though nitrogen is not one of the variables. For example, in table 60 are data for a collection of log samples from a phosphorus and potassium factorial experiment.

TABLE 60. Data from a phosphorus and potassium experiment—Paauhau

PLOT	SHEATH MOISTURE	TOTAL SUGARS	LEAF N	SNI	K-INDEX
AK	79.9	11.3	2.05	2.17	.82
AL	81.4	9.8	2.11	2.15	2.78
AM	82.1	7.3	2.17	2.16	2.52
BK	80.8	12.4	2.10	2.17	.98
BL	81.4	9.6	2.18	2.22	2.05
BM	82.0	8.7	2.24	2.24	2.56
CK	79.7	12.0	1.85	1.99	.68
CL	81.7	10.0	2.09	2.11	2.05
CM	82.0	7.4	2.04	2.04	2.75

The overwhelming variable in the experiment is potassium, but the nitrogen levels also vary and, apparently, in the same way as potassium. Other studies indicate that while potassium and nitrogen do vary together, they vary thus because each has the same effect on moisture and that it is by way of tissue moisture that the two indices are related. Hence, the question to answer now is not what is the normal nitrogen reading for the observed moisture, but rather what would the N reading be for the plots were the moisture readings the same, say 82.0?

The equation is:

$$\mathrm{SNI} = N_1 + .05885\ (M_2 - M_1) \quad - \quad .02270\ (A_2 - A_1)$$

Since age is not being varied, the substituted equation for plot AK becomes:

$$\mathrm{SNI} = 2.05 \ + \ .05885\ (82.0 - 79.9) \quad - \quad .02270\ (0) = 2.17$$

The SNI values are inserted in the table and what seemed like a trend disappears.

But perhaps the most important place to use the Standard Nitrogen Index is in setting up experimental data for variance analysis. Here, data from an Hawaiian Commercial and Sugar Company nitrogen experiment will be used first (table 61). Three forms of nitrogen, aqua ammonia, urea, and nitrate of soda, and five amounts, 200, 400, 600, 800, and 1000 pounds, make up the factorial experiment, with four replicates. The experiment will be harvested late in 1957 but the data for one 35-day collection will suffice for illustration. The variety is 37-1933.

TABLE 61. Data from nitrogen experiment
Hawaiian Commercial and Sugar Co.

FORM	LEAF NITROGEN	SHEATH MOISTURE	AGE IN MONTHS	SNI
		200-POUND TREATMENT		
Aqua	1.73	82.2	8.45	1.70
	1.64	81.7	8.54	1.63
	1.54	81.2	9.10	1.57
	1.47	81.7	9.13	1.48
Urea	1.56	79.6	8.48	1.64
	1.57	82.2	8.48	1.54
	1.78	83.0	9.10	1.73
	1.56	81.1	9.13	1.59
Nitrate	1.83	82.5	8.45	1.79
	1.70	80.6	8.54	1.74
	1.76	82.3	9.10	1.74
	1.80	82.4	9.13	1.78
Means	1.66	81.71 ± .27		1.66
		400-POUND TREATMENT		
Aqua	1.97	84.1	8.45	1.88
	1.80	82.0	8.54	1.80
	1.89	82.7	9.10	1.88
	1.88	83.6	9.13	1.83
Urea	1.78	81.5	8.45	1.80
	1.63	81.7	8.48	1.65
	1.73	82.4	9.10	1.73
	1.67	81.3	9.13	1.72
Nitrate	1.88	81.9	8.45	1.89
	1.98	83.8	8.54	1.91
	1.94	81.2	9.10	1.99
	1.60	80.7	9.17	1.67
Means	1.81	82.24 ± .32		1.81
		600-POUND TREATMENT		
Aqua	1.71	80.1	8.45	1.81
	1.83	83.9	8.54	1.77
	1.89	82.8	9.10	1.89
	1.89	83.0	9.17	1.89
Urea	1.78	82.3	8.45	1.79
	1.94	83.9	8.54	1.89
	1.81	82.4	9.10	1.83
	1.79	84.0	9.17	1.75
Nitrate	1.78	82.1	8.48	1.80
	2.03	83.7	8.54	1.98
	1.94	82.4	9.10	1.96
	1.98	82.4	9.17	2.00
Means	1.86	82.75 ± .32		1.86

TABLE 61. Data from nitrogen experiment *(continued)*

FORM	LEAF NITROGEN	SHEATH MOISTURE	AGE IN MONTHS	SNI
		800-POUND TREATMENT		
Aqua	2.00	82.6	8.45	2.01
	1.94	83.8	8.48	1.90
	1.92	83.4	9.10	1.91
	1.96	83.3	9.17	1.95
Urea	1.93	83.4	8.48	1.90
	1.81	82.2	8.48	1.83
	1.94	82.4	9.13	1.97
	1.96	84.0	9.17	1.93
Nitrate	2.03	83.0	8.48	2.02
	2.08	82.3	8.54	2.10
	1.96	82.3	9.13	2.00
	1.99	82.9	9.17	2.00
Means	1.96	82.97 ± .18		1.96
		1000-POUND TREATMENT		
Aqua	1.97	84.3	8.48	1.93
	1.97	84.6	8.48	1.92
	1.85	83.7	9.13	1.85
	1.94	82.7	9.17	1.98
Urea	2.03	83.7	8.45	2.01
	1.95	83.6	8.54	1.94
	2.01	83.9	9.13	2.00
	1.83	82.3	9.17	1.89
Nitrate	1.83	82.0	8.45	1.88
	2.00	84.1	8.54	1.97
	1.96	83.9	9.13	1.95
	1.83	82.7	9.17	1.87
Means	1.93	83.46 ± .24	8.812	1.93

Included in table 61 are the leaf nitrogen values as they come from the crop-log chemical laboratory. The next two columns are the sheath moisture and age. Ages vary because the samples could not all be gathered on one day but were collected in part June 19, 20, and 21, 1956, and in part July 2, 3, and 5. Here then we need to standardize the actual readings not only with reference to moisture but also with reference to age.

The equation for calculating the standard nitrogen applicable here is:

$$SNI = N_1 + .04122\ (M_2 - M_1) \quad - \quad .02212\ (A_2 - A_1)$$

where as before N_1 is the actual nitrogen, M_2 the desired moisture, and M_1 the actual moisture; A_2 the desired age and A_1 the actual age.

In an experiment involving a nutrient which in itself significantly affects the sheath moisture, the mean sheath moisture of the particular treatment will be used as the desired M_2. Thus, the forms of nitrogen, aqua, urea, and nitrate of soda, show average sheath moistures of 82.9, 82.6, and 82.5, respectively, indicating no effect of form on sheath moisture, but the amounts show the characteristic effects on sheath moisture. Hence, the desired moisture for the 200-pound plots, irrespective of form, is 81.71, for the 400-pound, 82.24, etc., up to the 1000-pound treatment, 83.46. The desired age in this collection (A_2) is the average for all the plots; namely, 8.812 months.

With these data, then, and the actual figures as shown in the sets of data, the SNI is calculated for each plot and entered in the column under SNI. Were there many experiments to be undertaken in which the SNI is needed, a table can be set up in which the various combinations of moisture differences ($M_2 - M_1$) ranging from -10 to perhaps $+10$, and ages ($A_2 - A_1$) ranging from -10 to $+10$ months, each factor varying by a half point, can be calculated so that one number in each case is added to or subtracted from N_1.

VARIANCE ANALYSIS OF LEAF NITROGEN

Variance analysis can now be undertaken to determine the relative reliability and sensitivity of the two indices, the leaf nitrogen, and Standard Nitrogen Index data as shown in table 62.

TABLE 62. Analysis of variance for leaf nitrogen data shown in table 61

SOURCE OF VARIATION	DEGREES OF FREEDOM	MEAN SQUARE	F VALUE	F NEEDED	SIGNIFICANCE
Total	59				
Blocks	3	.00870	1.11	2.83	n.s.
Forms	2	.04292	5.47	5.15	**
Amounts	4	.16687	21.27	3.80	**
Interaction	8	.01489	1.90	2.17	n.s.
Error	42	.00785			

Coefficient of variation 4.80 percent.

Summary

LEAF NITROGEN INDICES BY TREATMENT

FORM	200 LB.	400 LB.	600 LB.	800 LB.	1000 LB.	MEAN
Aqua	1.595	1.885	1.830	1.955	1.933	1.840
Urea	1.618	1.703	1.830	1.910	1.955	1.803
Nitrate soda	1.773	1.850	1.933	2.015	1.905	1.895
Means	1.662	1.813	1.864	1.960	1.931	

Least significant differences needed for .01 and .05 percent levels:
For forms .076 and .057, respectively.
For amounts .098 and .073, respectively.

Least significant differences needed for significance among the forms are .0757 and .0566 for .01 and .05 percent levels, respectively. Thus, nitrate shows to advantage over the urea form *at this stage,* but the difference between nitrate and aqua escapes significance at the .05 percent level and no significance exists between urea and aqua.

Least significant differences needed for amounts are .0978 and .0731, respectively. Thus, each of the amounts 400, 600, etc., is highly significantly higher than the 200-pound treatment.

The 600-pound treatment is not significantly higher than the 400-pound, but each of the 800- and 1000-pound treatments is highly significantly higher than the 400-pound treatment. The 800- and 1000-pound treatments are significantly higher than the 600-pound treatment. Finally, the 800- and 1000-pound treatments are not different.

Interaction does not exist at significant levels. The coefficient of variation is 4.80 percent indicating reliability of considerable degree.

VARIANCE ANALYSIS OF STANDARD NITROGEN

The variance analysis of the same collection will now be undertaken but using Standard Nitrogen Index as reported in the data above.

TABLE 63. Analysis of variance for standard leaf nitrogen data shown in table 61

SOURCE OF VARIATION	DEGREES OF FREEDOM	MEAN SQUARE	F VALUE	F NEEDED	SIGNIFICANCE
Total	59				
Blocks	3	.005904	1.25	2.83	n.s.
Forms	2	.049852	10.51	5.15	**
Amounts	4	.16856	35.52	3.80	**
Interaction	8	.00989	2.08	2.17	n.s.
Error	42	.00474			

Coefficient of variation 3.73 percent

Summary

STANDARD NITROGEN LEVELS BY TREATMENT

FORM	200 LB.	400 LB.	600 LB.	800 LB.	1000 LB.	AVERAGE
Aqua	1.595	1.848	1.840	1.943	1.920	1.829
Urea	1.625	1.725	1.815	1.908	1.960	1.807
Nitrate soda	1.763	1.865	1.935	2.030	1.920	1.903
Means	1.661	1.813	1.863	1.960	1.933	

Least significant differences for forms .0589 and .0440, respectively.
Least significant differences for amounts .0763 and .0570, respectively.

Forms. At this stage, nitrates effect highly significantly higher Standard Nitrogen Index readings than either urea or aqua. Although aqua seems somewhat superior to urea, the difference is not significant.

Amounts. Each of the amounts above 200 pounds results in highly significant increases in the nitrogen levels. The 600-pound treatment fails to show a significant difference over the 400-pound, but the 800- and 1000-pound treatments result in highly significant increases over the 400-pound treatment. The difference between the 800-pound treatment and the 600-pound is highly significant and the 1000-pound treatment is significantly higher than the 600-pound treatment. The difference between the 800- and 1000-pounds is not significant.

Interaction. Again interaction fails to reach significant levels, although more nearly so than where the leaf nitrogen was used. It seems, at least, that there is a suggestion that the 200-pound treatment of aqua is relatively less effective than the heavier treatments.

The general effect of standardizing the leaf nitrogen readings in these data has been to increase the precision by decreasing the error. Clearly, the averages of the nitrogen readings for the treatments were not affected but the mean variance error was reduced from .0078 to .0047 resulting in considerably higher F values (for forms 10.51 vs. 5.47 and for amounts 35.52 vs. 21.27).

ONOMEA—AMOUNTS OF NITROGEN EXPERIMENT

In the nitrogen experiment just reported the moisture conditions of the experiment on the field were rather well controlled and so the over-all standardization was simple with very small changes in the nitrogen readings. In the following experiment, however, at Onomea, the raw data for the detail of one collection are shown not only for leaf N, but also for the moistures (table 64). Also, the Standard Nitrogen Index is shown, basing the SNI on the average moisture for each treatment and using the 44-3098 standard nitrogen equation developed from table 39:

$$\text{SNI} = N_1 + .05885\ (M_2 - M_1)\ -\ .02270\ (A_2 - A_1)$$

Here the age cancels out since all the plots were sampled on the same day.

TABLE 64. Onomea nitrogen experiment

PLOT NO.	LEAF N	SHEATH MOISTURE	SNI
1A	1.24	75.5	1.21
2B	1.18	71.8	1.21
3C	1.56	78.2	1.28
4D	1.72	77.0	1.69
5A	1.39	75.7	1.35
6B	1.23	72.8	1.20
7C	1.13	70.0	1.33
8D	1.68	77.5	1.62
9A	1.22	73.9	1.28
10B	1.06	72.3	1.06
11C	1.30	71.9	1.39
12D	1.65	75.0	1.74

Variance analysis for leaf N is as follows:

The F value for treatment is 9.07 and is significant. The D treatments show highly significantly higher readings than any of the other treatments.

The F value for SNI reading is a highly significant 25.79. Furthermore, not only are the D treatments highly significantly higher than the others, but C is also significantly higher than B.

At harvest, the yields of cane were as follows:

PLOTS	POUNDS N PER ACRE	TONS CANE PER ACRE	TONS POL PER ACRE
A	120	61.7	7.7
B	195	61.3	7.0
C	300	88.1	10.7
D	600	116.5	14.1

Variance analysis shows a highly significant ($F = 12.93$) effect of treatment. The LSD's for TCA are 25.2 and 38.2, respectively. Thus, D is significantly higher than C and highly significantly higher than A and B, and C is significantly higher than A and B, a rather good parallel to the results of the SNI variance.

SUMMARY

1. In order to provide improved means of interpreting the leaf nitrogen readings in crop-logging of sugar cane, a study of factors affecting the leaf nitrogen level of cane was undertaken and included irrigated cane grown under conditions at Waipio, Ewa, and Waialua, on the island of Oahu; Olokele, on the island of Kauai; Puunene, Paia, Lahaina, and Wailuku, on the island of Maui; as well as unirrigated cane grown at Hilo, Onomea, Pepeekeo, Hakalau, Paauhau, Pahala, and Naalehu, on the island of Hawaii.

2. The irrigated varieties used were 32-8560, 37-1933, and 38-2915. The unirrigated variety was 44-3098.

3. Pertinent crop-log data were taken from crop logs from those plantations and were submitted to the statistical method of multiple regression. Partial regressions on leaf nitrogen were determined for radiation, maximum and minimum temperatures, the total sugar level of the sheaths (Primary Index), sheath moisture, and age.

4. In general, of the factors studied, sunlight affects the leaf nitrogen readings the least while age and sheath moisture are dominant.

5. For both irrigated and unirrigated cane, the two factors, age and moisture, give as high a coefficient of determination as any combination of three or more factors, even though each of the other factors had partial regressions on leaf nitrogen which were significant. But where both irrigated and unirrigated cane are combined into a single study, including the entire range of ecological conditions found in the Territory, it is necessary to add the factor maximum temperature to obtain the most completely satisfactory coefficient of determination.

6. Equations are presented for normal nitrogen as well as for standard nitrogen for each of the varieties and the various areas in the Territory where cane is grown.

7. The application of the normal nitrogen concept to actual plantation conditions is described in detail.

8. The application of the concept of the standard nitrogen concept to experimental methods is described.

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