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FERTILIZATION OF COFFEE IN KONA WITH SPECIAL REFERENCE TO NITROGEN NUTRITION

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For a number of years it has been known that relatively large amounts of fertilizer are required for good coffee production in Kona. Ripperton et al. (10) showed that relatively high rates of potassium and nitrogen application are required. However, these workers could find no beneficial result from applying phosphorus fertilizers to bearing coffee trees. Results reported by Beaumont and Fukunaga suggest the advisability of supplementary nitrogen applications during the months of summer and early fall (1).

The experiment on which this report is based is still in progress. It was designed to determine with greater precision the benefits of supplementary nitrogen applications, the rates of potassium application required, and the effects of frequency of potassium application. Another objective of this experiment has been to seek relationships of leaf composition to growth and yield. In this report are considered some effects of the fertilizer treatments upon yield and certain relationships of nitrogen concentrations in the leaves to yield.

Description of the Experiment

Nursery seedlings were planted in an experimental orchard at the Kona Branch Station in August 1950. Spacing is 8½ x 8½ feet. Each treatment plot consists of four trees in a square configuration. From planting time until the treatments were begun in March 1952 all trees received the same fertilization: ½ pound per tree of 10-5-20 mixed fertilizer in March and June and supplementary applications of ammophos (11-48) in September. Ditches are maintained on all sides of each treatment plot. The depth of these ditches is generally about one foot, but varies somewhat with depth of the top-soil. The experiment consists of six randomized blocks of 12 treatments. An additional treatment (M) is also represented by six plots, but is represented in only five of the randomized blocks. This treatment is not included in computing the variance for the main experiment. Table 1 shows the rates of application for nitrogen and potash equivalent in each treatment and the months when applications were made. Nitrogen was applied in the form of ammonium sulfate. Sulfate of potash was the carrier for potassium. Phosphorus was applied to all trees at the rate of 90 pounds of P_2O_5 per acre each year, half in March and half in June. The phosphate carriers used were treble superphosphate during 1952 and 1953 and superphosphate from March 1954 to March 1956. The treatments as described above were continued from March 1952 until May 1956. A revised schedule of treatments was begun in June 1956. In the new schedule treatments F, I, and L are retained as in the original schedule, with the exception that the main applications are made in February and May instead of March and June. Phosphorus is applied to all trees each February at the rate of 100 pounds of P_2O_5 per acre. It is to be expected that the

Table 1. Rates and months of application for nitrogen and potash

Treatment	Brief description	Annual rates (pounds per acre)		Rates for each application (pounds per acre)			
				Nitrogen (N)		Potash (K_2O)	
		N	K_2O	March and June	Other months[1]	March and June	April and May
A	No K	177	0.0	88.5	-	-	-
B	Low K	177	181	88.5	-	90.5	-
C	Moderate K	177	362	88.5	-	181.0	-
D	Moderate K, high N	354	362	177.0	-	181.0	-
E	Moderate K, N frequent	177	362	38.0	12.6	181.0	-
F	High K	177	724	88.5	-	362.0	-
G	High K frequent	177	724	88.5	-	181.0	181.0
H	Moderate K, high N frequent	354	362	76.0	25.3	181.0	-
I	High K, high N frequent	354	724	76.0	25.3	362.0	-
J	High K frequent, high N	354	724	177.0	-	181.0	181.0
K	High K frequent, high N frequent	354	724	76.0	25.3	181.0	181.0
L	High K, high N	354	724	177.0	-	362.0	-
M	High K, very high N frequent	709	724	152.0	50.6	362.0	-

[1] Other months: an application was made in each of the following months: February, April, May, July, August, September, October, and November.

yield of coffee obtained in the fall of 1956 and early months of 1957 was not materially influenced by the new treatments begun in June 1956 since the fruit had already been formed at that time. Hence, in this report yields obtained for the 1956-1957 harvest season are interpreted in terms of the original treatments. Detailed results for only treatments F, I, and L are reported for the 1957-1958 harvest season, since no significant differences among the new treatments were evident for that season. The 1957-1958 yield data are used, however, in the correlation analysis of the yields.

The pruning system used in this experiment is the 1-2-3-4 multiple vertical system, where it is sought to maintain one vertical branch at each indicated year of age on each tree. This has not been entirely successful in that it is not always possible to get a new vertical started on each tree at the desired time. Hence, there has been some irregularity among the trees. The 1-2-3-4 system was established in 1954. The 1953-1954 harvests are also reported here, although in 1953 the trees each had four verticals, two of which were three years of age and one each at the age of one and two years.

Methods

Leaf sampling and analysis

Leaf sampling on a regular monthly basis was begun in April 1954 although several samplings were made earlier. Leaves of two classes have been sampled. The two classes represent different relative ages. Beginning in May each year recently matured leaves are taken from the fourth internode back from the terminal juvenile leaves on lateral branches. These leaves are referred to as Number 2 leaves through the December sampling. Beginning in January leaves produced during the previous calendar year are referred to as Number 3 leaves. Samplings of each class of leaves were made from May through December each year. In addition Number 3 leaves were sampled from January through April each year. In January, April, and August of each year separate samples were obtained from each plot, four leaves being taken from different sides of each tree. Sampling for the other months of the year was on a treatment basis with each tree being represented by one leaf. Number 2 leaves were taken from the branches expected to bear the major portion of the crop for the following year. Branches to be pruned at the end of the year as well as vertical branches in their first year of age were avoided. Number 3 leaves were taken from branches bearing the major crop during the year of sampling.

Leaves were weighed and dried at 70°-75° C. in a forced draft immediately after sampling. The total nitrogen including nitrate nitrogen was determined on the dried and ground samples by the Kjeldahl method (8). Nitrogen is expressed on a starch-free dry weight basis, since considerable differences in nitrogen values can result from variations in starch if total dry weight is used as the basis of expression.

For estimation of starch the leaf samples are ground to pass a 60-mesh screen. The method of McCready *et al.* (6) is used for the estimation. It is found that a certain small amount of anthrone reactive material which is not starch is extracted with the perchloric acid. However, the quantity of this material is relatively constant. Correction for this non-starch material is made by use of a regression equation based on a comparison of the method of McCready *et al.* with that of Pucher *et al.* (9). The latter method, although more precise, is much more tedious and time-consuming. The regression equation used is based on analysis of each of 79 coffee leaf samples by each method. The leaf samples used included approximately equal numbers of Number 2 leaves and Number 3 leaves and represented all months of the year. No influence of leaf age or season of the year was found on the non-starch anthrone active fraction nor on the regression. The regression equation is: $Y = .8786 X - 1.426$ where X is the glucose equivalent obtained by the method of McCready *et al.* and Y is the estimated starch. This relationship accounts for 99.6 percent (i.e. $r^2 = .996$) of the variance in starch among the samples. Confidence intervals for values of starch estimated from several values of X were calculated as described by Ezekiel (4):

Selected values of X	Estimated starch	Confidence range for estimated starch at 5 percent level
2.00	0.33	0.22 to 0.44
5.00	2.97	2.88 to 3.06
10.00	7.36	7.26 to 7.43
15.00	11.75	11.65 to 11.85
20.00	16.15	16.00 to 16.29
25.00	20.54	20.34 to 20.74
30.00	24.93	24.68 to 25.19

Size index

Twice each year, at pruning time in February or March and again in August, the circumference of each vertical branch on each tree is measured at the first internode above the point of its emergence from the stump. The sum of the squared circumferences of all verticals is used as an index of tree size. This measure has the same dimension as the cross-sectional area which is frequently correlated with yield (2). The size index for February or March is the one used in this report.

Experimental Results

Coffee yields

Yield data are shown in table 2. The three-year means represent the years during which the trees of all treatments were on the 1-2-3-4 pruning system. Four-year means are also shown. These include the 1953-1954 harvest season when each tree had two verticals three years of age and one vertical each of one and two years of age. As will be seen, little difference in interpretation would arise from the use of either column of means. Variance analysis of the yield data for four years gives the results shown in table 3. As noted earlier only treatments A-L were included in this analysis. Very highly significant differences are shown for blocks, treatments, years, and for the interaction of years and blocks. Differences between pairs of treatment means were tested by the procedure of Duncan (3) using the error terms of table 3 and that derived from a separate variance analysis of the three-year means.

In table 4 the treatments are arranged to facilitate comparisons between mean yields which were obtained as a result of differences in annual rates and frequencies of potassium application under three separate regimes of nitrogen fertilization. Treatments A, B, C, and F represent a series with increasing rates of potassium application under conditions where only 177 pounds of nitrogen per acre were applied each year in two applications. Treatment G received the same annual rates of nitrogen and potassium applications as F but received its potassium in four applications instead of two. Among the three-year means in this series only differences between treatments A and G and between B and G exceed that required for significance at the 5 percent level. Among the four-year means differences between A or B and C or G all exceed the 5 percent level of significance. At a higher annual rate of

Table 2. Coffee yields in an experimental orchard at the Kona Branch Station

Treatment	Brief description	Annual rates of fertilization (lb./acre) K₂O	N	Yield (number of 100 lb. bags of cherry coffee per acre) 1953-1954[1]	1954-1955	1955-1956	1956-1957	1957-1958	Three-year mean[1]	Four-year mean[1]
A	No K	0	177	161.7	131.5	126.7	131.1	-	129.8	137.8
B	Low K	181	177	162.6	130.4	145.2	112.5	-	129.4	137.7
C	Moderate K	362	177	197.4	150.7	168.3	137.7	-	152.2	163.5
D	Moderate K, High N	362	355	178.3	168.9	158.0	138.8	-	155.2	161.0
E	Moderate K, N frequent	362	177	178.8	157.2	168.2	136.7	-	154.0	160.2
F	High K	724	177	189.4	155.4	152.8	121.5	185.1	143.2	154.8
G	High K, freq.	724	177	188.9	169.4	159.5	135.1	-	154.7	163.2
H	Moderate K, High N frequent	362	355	170.5	156.8	169.3	136.1	-	154.1	158.2
I	High K, High N frequent	724	355	201.7	173.6	199.0	168.4	192.9	180.3	185.7
J	High K frequent, High N	724	355	184.7	153.3	150.4	152.9	-	152.2	162.1
K	High K frequent, High N frequent	724	355	184.7	148.6	161.9	139.6	-	150.0	158.7
L	High K, High N	724	355	181.6	170.9	158.6	123.9	172.9	151.1	158.8
M	High K, Very High N frequent	724	709	203.9	179.2	189.3	167.1	-	178.5	184.9
Mean				183.9	157.4	162.1	138.6		152.7	160.5

[1] The three-year mean excludes 1953-1954 yield, since the final 1-2-3-4 pruning system had not been established in 1953. The system in 1953 was 1-2-3-3. Yields for 1957-1958 are excluded from both means, since only three of the treatments described here are included.

Table 3. Variance analysis of coffee yields during four years

Source	Degrees of freedom	Mean square	F	Level of significance
Total	287			%
4-year aggregate	71			
Blocks (B)	5	2,811.438	5.78	0.5
Treatments (T)	11	1,620.714	3.33	0.5
Error (a)	55	486.209		
Years (Y)	3	11,345.93	7.99	0.5
Y X T	33	221.93	1.12	n.s.
Y X B	15	1,419.66	7.16	0.5
Error (b)	165	198.23		

Table 4. Effects of potassium variables upon yields under three conditions of nitrogen fertilization

Treatment	Potassium application				Coffee yields cwt. cherry/acre	
	Lb. K_2O per acre each year	No. of K applications each year	Lb. N per acre each year	No. of N applications each year	3-year mean	4-year mean
A	0	-	177	2	129.8	137.8
B	181	2	177	2	129.4	137.7
C	362	2	177	2	152.2	163.5
F	724	2	177	2	143.2	154.8
G	724	4	177	2	154.7	163.2
D	362	2	355	2	155.2	161.0
L	724	2	355	2	151.1	158.8
J	724	4	355	2	152.2	162.1
H	362	2	355	10	154.1	158.2
I	724	2	355	10	180.3	185.7
K	724	4	355	10	150.0	158.7

nitrogen supply, applied in two applications no improvement in yield resulted from increasing the potassium supply from 360 pounds to 724 pounds per acre (treatments D and L), or increasing the frequency of potassium application at the higher rate (treatment J). However, when nitrogen was supplied at the rate of 355 pounds per acre in frequent applications, there was a significant increase in yield resulting from an increase of potassium supply from 362 pounds to 724 pounds of K_2O per acre (the difference between treatments H and I is significant at the 5 percent level for both three-year and four-year means). This improvement in yield was only obtained, however, when the potassium was applied in two applications. When applied in four applications (treatment K) yields were significantly lower than when it was applied in two (treatment I).

Since an annual rate of 724 pounds of K_2O per acre in two applications gives higher yield than any other of the potassium regimes included in this experiment, comparisons among treatments having this regime but having different nitrogen regimes are shown in table 5. Whether three-year or four-year means are used, the difference between treatments F and I is significant at the 1 percent level and the difference between L and I at the 5 percent level. Comparison of treatments F and L shows there was no discernible benefit derived from increasing the annual rate of nitrogen supply from 177 to 355 pounds per acre as long as it was applied in two applications. Increasing the number of applications, however, resulted in a large increase in yield. Although treatment M was not included in the statistical analysis because this treatment was not represented in one of the randomized blocks, it is evident that yields in this treatment were very similar to those in treatment I. It seems reasonable to conclude from the yields for this treatment that no significant benefit is to be expected from rates of nitrogen supply higher than 355 pounds per acre under the conditions of this experiment.

Table 5. Effects of nitrogen variables upon yields under conditions of high potassium fertilization at a frequency of two applications per year

Treatment	Nitrogen application		Coffee yields cwt. cherry/acre	
	Lb. N per acre each year	No. of N applications each year	3-year mean	4-year mean
F	177	2	143.2	154.8
L	355	2	151.1	158.8
I	355	10	180.3	185.7
M	709	10	178.5	184.9

It will be recalled that the analysis of variance for the yield data shows highly significant differences among the mean yields for years (table 3). Among the mean yields for the several seasons of harvest (see table 2), the Duncan test shows comparisons between 1953-1954 yield and each of the other means to be significant. It will be recalled that the final pruning system had not been established in 1953 and each tree had two verticals three years of age that year. This is undoubtedly the main factor accounting for higher yields for the 1953-1954 harvest. Among the other yearly differences, that between 1955-1956 and 1956-1957 is statistically significant at the 5 percent level. The three treatments which were continued through the 1957-1958 harvest (F, I, and L, see table 2) each yielded much more coffee in 1957-1958 than in 1956-1957. Leaf nitrogen concentrations during the flowering season are related to these differences as will be indicated.

Leaf nitrogen

As noted from table 5, supplementary applications of nitrogen resulted in a large increase in yield. This response occurred at each harvest season (table 2), although it was greater in some seasons than others (compare treatments F and I for example). To illustrate the influence of supplementary nitrogen applications upon the concentration of nitrogen in the leaves at various seasons of the year, nitrogen values for treatments F and I are plotted in figure 1. From these plots it can be seen that response to the supplementary nitrogen applications was in the months of November 1954 through March 1955 for leaves formed in 1954. Leaves formed in 1955 showed clear response for the months of November 1955 through April 1956. For 1956 leaves the response was not as consistent as for the earlier years but increases in nitrogen values in response to supplementary applications were found for October and December of 1956 as well as for January and February 1957. Comparisons of nitrogen

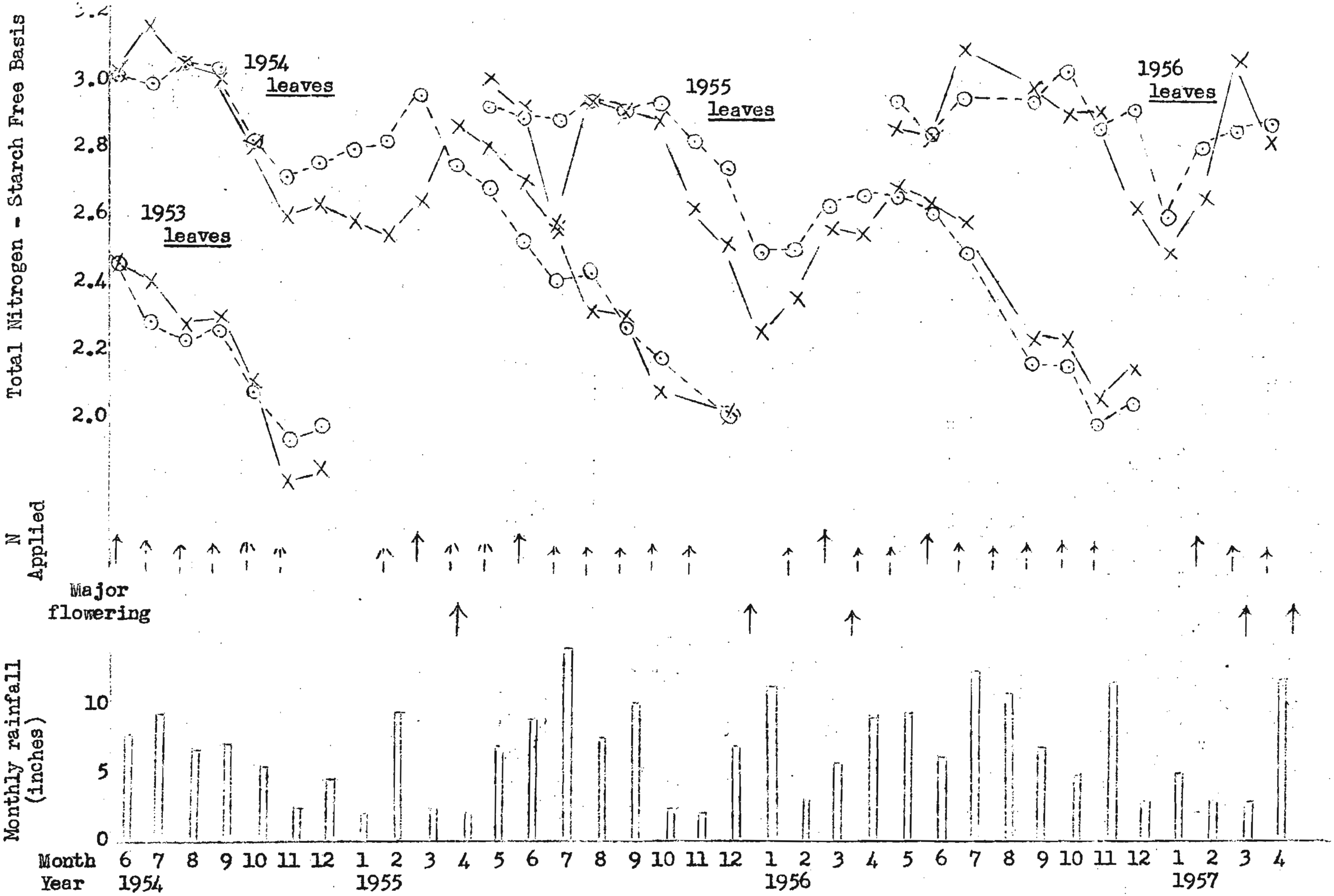

Figure 1. Nitrogen concentrations in coffee leaves taken at monthly intervals from treatments F, X; and I, ⊙. Nitrogen applications for treatment F were at the rate of 88.5 pounds per acre each March and June of 1954, 1955, and 1956, and February 1957. Treatment I received 76 pounds per acre each March and June of 1954, 1955, and 1956 and in February 1957 with supplementary applications of 25.3 pounds at the months indicated by the small arrows. Times of major flowering and total monthly rainfall are also shown.

Table 6. Nitrogen concentrations in coffee leaves during early months of 1955 and 1956

Treat-ment	Potassium applied		Nitrogen applied		Nitrogen - percentage of starch-free dry matter									
	Lb. K_2O per acre each year	No. of applications each year	Lb. N per acre each year	No. of applications each year	1955					1956				
					Jan.	Feb.	Mar.	Apr.	Mean	Jan.	Feb.	Mar.	Apr.	Mean
A	0	-	177	2	2.61	2.72	2.48	2.77	2.65	2.32	2.46	2.70	2.59	2.52
B	181	2	177	2	2.63	2.46	2.56	2.83	2.62	2.31	2.43	2.63	2.65	2.51
C	362	2	177	2	2.70	2.44	2.54	2.87	2.64	2.36	2.37	2.66	2.67	2.52
E	362	2	177	10	2.55	2.53	2.64	2.92	2.66	2.36	2.46	2.83	2.57	2.56
F	724	2	177	2	2.60	2.56	2.66	2.89	2.68	2.29	2.49	2.59	2.57	2.49
G	724	4	177	2	2.66	2.56	2.51	2.90	2.66	2.33	2.41	2.62	2.60	2.49
D	362	2	355	2	2.61	2.49	2.63	2.97	2.68	2.44	2.51	2.54	2.71	2.55
L	724	2	355	2	2.51	2.60	2.71	2.85	2.67	2.51	2.54	2.47	2.79	2.58
J	724	4	355	2	2.70	2.67	2.82	2.88	2.77	2.39	2.55	2.64	2.69	2.57
H	362	2	355	10	2.82	2.87	2.60	2.95	2.81	2.55	2.51	2.71	2.69	2.62
I	724	2	355	10	2.81	2.83	2.97	2.77	2.85	2.51	2.52	2.65	2.68	2.59
K	724	4	355	10	2.56	2.87	2.90	2.85	2.80	2.53	2.58	2.61	2.78	2.63
M	724	2	709	10	2.64	2.79	2.95	2.94	2.83	2.65	2.62	2.67	2.87	2.70

levels among years during winter and early spring months show a lower value for each treatment in the 1955-1956 season than was the case in either 1954-1955 or 1957-1958.

Nitrogen values for each treatment are shown for the periods between January and April of 1955 and 1956 in table 6. Treatments H, I, K, and M had higher nitrogen values on the average than the other treatments, although within each treatment there were fluctuations from one month to the next. The yield differences among treatments H, I, K, and M noted above (tables 4 and 5) were not associated with corresponding differences in leaf nitrogen. Nitrogen values were generally higher in all treatments during early months of 1955 than during the same period in 1956.

Relationships of Leaf Nitrogen to Yield

In an attempt to determine whether the leaf nitrogen for any particular month is best related to coffee yield, correlation coefficients were determined as shown in table 7. The yield for each season except that of 1957-1958 was significantly correlated with nitrogen in the leaves obtained at least one of the months during winter and spring. The month involved in the significant correlation was near a time of major flowering in each case. The major flowering which led to the 1954-1955 yield was in March and April of 1954. Unfortunately, nitrogen data are not available for February or March of 1954; however, the April nitrogen was significantly correlated with yield. The first major flowering leading to the 1955-1956 fruit production was on April 6, 1955. Flowering continued in flushes during April and May. It is noted that leaf nitrogen values for March and April were significantly correlated with yield. The 1956-1957 yield was relatively low. The peak harvest was relatively early. An early flowering followed a Kona storm on December 20 and 21, 1955, but the main flowering in this experiment was late in March 1956. Table 7 shows a significant correlation between leaf nitrogen for January 1956 and 1956-1957 yield. There was a major flowering in March 1957 and extremely profuse flowering in April. The lack of significant correlation between

Table 7. Correlation coefficients[1] for relationships of leaf nitrogen for several months of winter and spring to yields obtained the following fall and winter

	N, 1953 leaves with 1954-1955 yield	N, 1954 leaves with 1955-1956 yield	N, 1955 leaves with 1956-1957 yield	N, 1956 leaves with 1957-1958 yield
December N	+.4365	-	+.5280	-
January N	+.5486	+.4331	+.6162*	+.2416
February N	-	+.3584	+.5130	+.2500
March N	-	+.6639*	+.2257	-.1159
April N	+.6464*	+.5963*	+.4432	-.0350
Mean N:				
Jan. and Feb.		+.4482	+.6125*	+.3419
Mar. and Apr.		+.7038**	+.6339*	-.1782
Jan.-Apr.		+.6681*	+.6472*	+.1972

[1] Correlation coefficients required for significance at 11 degrees of freedom are 0.553 at the 5 percent level and 0.684 at the 1 percent level (11).

leaf nitrogen and 1957-1958 yield may be related to the fact that leaf nitrogen in all treatments was relatively high in March and April 1957 (see table 6). Furthermore, there was relatively little variation in leaf nitrogen among treatments for those months.

Although the above observations suggest a relationship between leaf nitrogen at flowering time and yield, it is hardly to be expected that the nitrogen value for one particular month will give the best correlation with yield. Since flowering is hardly ever limited to a single month at the Kona Branch Station, and the harvest season extends over a period of five or six months. It is perhaps more reasonable to look for relationships between the mean nitrogen level during the main flowering season and yield. Table 7 shows that higher correlation coefficients are usually obtained when the leaf nitrogen values for two or four months are averaged.

A considerable proportion of the variance in yield among seasons can also be accounted for by the leaf nitrogen during the flowering season. Data for 1955-1956, 1956-1957, and 1957-1958 harvest seasons were combined and subjected to correlation analysis. Results of these analyses are shown in table 8. Highly significant simple correlations with yield are obtained whether mean nitrogen values for January and February, March and April, or for January through April are used. The size index is not correlated significantly with yield when used as the only independent variable. However, the size index contributes significantly in accounting for variance unaccounted for by leaf nitrogen when used as an additional

Table 8. Simple correlation coefficients, coefficients of determination and significance of correlations of yields with leaf nitrogen concentrations and the tree size index for three harvest seasons

Independent variables	Correlation coefficient (r)	Coefficient of determination ($\bar{R}^2$)[1]	F value for last factor added[2]	Significance[3]
Simple correlations:				
Mean N, Jan. and Feb. (N_{1-2})	.7398			**
Mean N, Mar. and Apr. (N_{3-4})	.8455			**
Mean N, Jan. through Apr. (N_{1-4})	.8378			**
Size index (X)	.1037			n.s.
Multiple correlations:				
N_{3-4}, X		.7543	5.76	*
N_{3-4}, N_{1-2}		.7188	-	n.s.
N_{3-4}, N_{1-2}, X		.7859	6.33	*
N_{1-4}, X		.7680	12.82	**

[1] Coefficient of determination: the squared multiple correlation coefficient adjusted for number of observations and factors (4).

[2] F values obtained for reduction in variance remaining unaccounted for by addition of the last factor to the equation (11).

[3] Significance of simple correlation coefficient for equations involving only one independent factor. For multiple regression equations, significance of F values in preceding column. Symbols used: n.s., not significant; *, 5 percent level; **, 1 percent level.

variable. The highest proportion of variance in yield is accounted for when the nitrogen levels in January and December are treated as a separate factor in addition to March and April nitrogen and the size index. However, this relationship accounts for very little more variance than can be attributed to the two factors: January through April nitrogen and size. Use of the two nitrogen means as separate factors does show that by far the more important factor for the three years involved was the nitrogen during March and April. The partial regression lines for yield on March-April nitrogen and on January-February nitrogen are shown in figures 2 and 3, respectively. The multiple regression equation is: $Y = 46.1832\ N_{1-2} + 108.7611\ N_{3-4} + .323,78\ X - 354.55$. Where Y = estimated yield, N_{1-2} = mean leaf nitrogen in January and February preceding the harvest season, N_{3-4} = mean leaf nitrogen in March and April, and X = the size index.

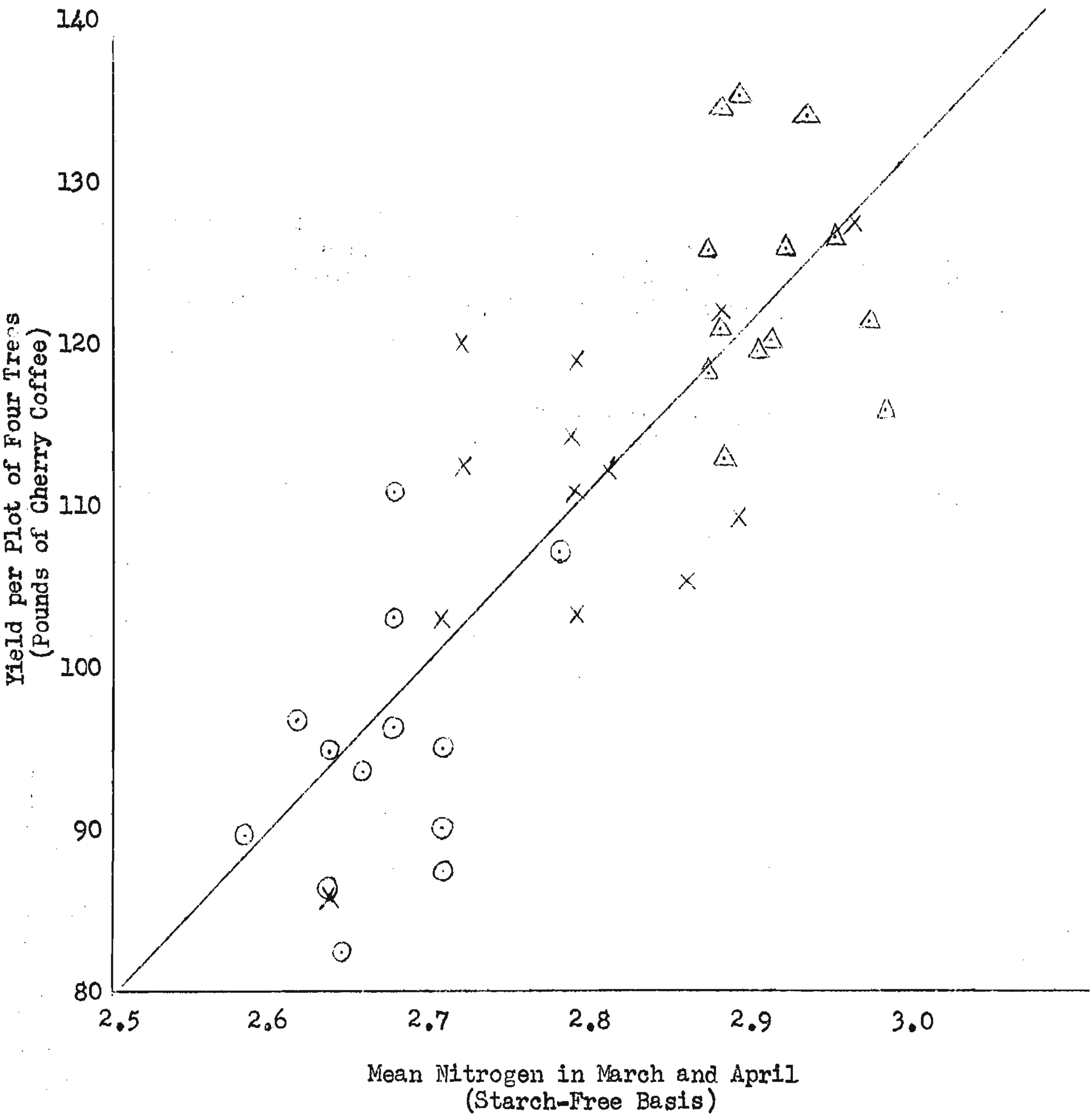

Figure 2. Partial regression of yield on mean nitrogen in March and April for the 13 treatments during three harvest seasons. Plots represent deviations from the multiple regression equation. X, 1955-1956 season; ⊙, 1956-1957; ⚠ 1957-1958.

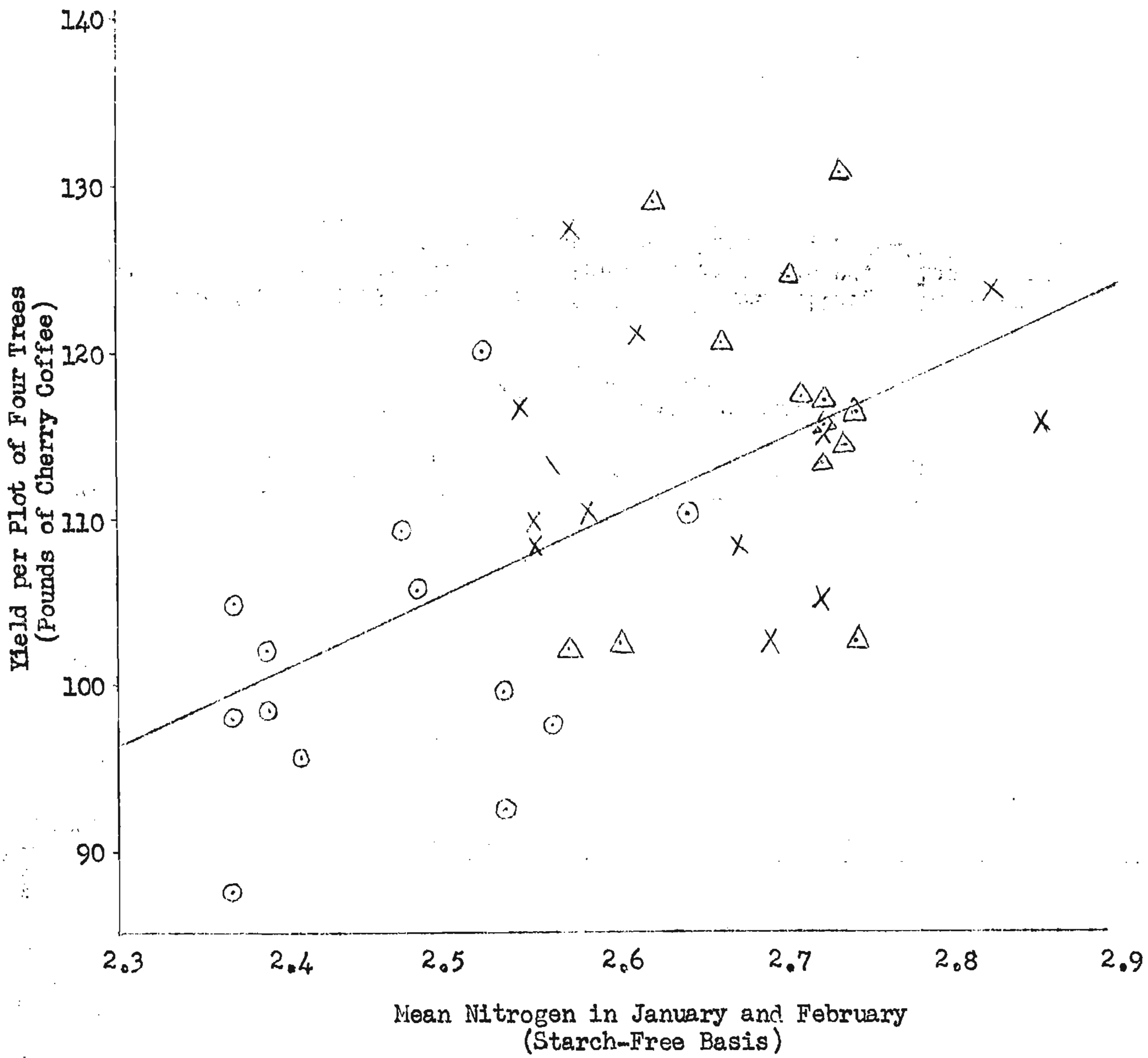

Figure 3. Partial regression of yield on mean nitrogen in January and February for 13 treatments during three harvest seasons. Plots represent deviations from the multiple regression equation. X, 1955-1956 season; ⊙, 1956-1957 season; △, 1957-1958 season.

Discussion and Conclusions

It is evident from the results presented above that a large proportion of the variance in yield among treatments and harvest seasons in this experiment can be accounted for in terms of leaf nitrogen during the flowering season. However, there remains a considerable proportion of variation not accounted for in these terms. Insufficient application of potassium resulted in reduced yields in treatments A and B, but results from the entire potassium series (treatments A, B, C, and F) are complicated by relatively low leaf nitrogen values during the flowering season. In the new series of treatments begun in June 1956, supplementary nitrogen applications are provided for all trees of the potassium series. It is to be hoped that more definitive results for potassium will be obtained from this new series of treatments.

Yield results not readily interpretable in terms of leaf nitrogen are found in comparisons of treatments H or K with treatment I. All three of these treatments received supplementary nitrogen applications (table 1). The three also had generally comparable leaf nitrogen values during the early months of 1955 and 1956 (table 6). Yet, treatment I had consistently higher yields than the other two (table 2), and the same differences between treatments were statistically significant for the three- and four-year means. Treatment H had less total potassium applied than treatments I or K. However, the latter two treatments had the same annual quantities of potassium applied, the only difference being that I had its potassium in two equal dosages in March and June; whereas, in K the potassium was applied in four equal dosages in March, April, May, and June. These results suggest that in treatments H and K insufficient potassium was supplied in March. Leaf potassium results show no clear response to higher March application of potassium, although there is some indication of response in the Number 2 leaves in May and June. However, these results are not sufficiently consistent to warrant a detailed report at this time. It may be concluded that the conditions under which supplementary nitrogen applications result in increases in yield are somewhat specific with reference to the regime of potassium fertilization.

No attempt has been made here to make a definitive analysis of the factors determining leaf nitrogen levels during the flowering season, although it is evident that frequency of nitrogen application is one factor. Other factors probably include the rainfall pattern and the magnitude of the coffee crop developing and maturing on the trees during the period when flower buds are developing for the next crop. A considerable quantity of nitrogen is present in the coffee cherries (10). Hence, it is reasonable to seek an influence of size of crop upon leaf nitrogen concentrations. The relatively low leaf nitrogen values for the early months of 1956 (figure 1 and table 6) may be attributed in part to the relatively high and late yields in the 1955-1956 harvest season. By contrast, leaf nitrogen values in the early months of 1957 were higher and 1956-1957 yields lower and earlier.

Coffee yields can be affected at several stages of development beginning with the growth of new branches on which the cherries are to be borne. Other stages include initiation and growth of flower buds, flower opening, and fruit set. Any of a number of factors can limit development at each of these stages. In heavily bearing trees considerable quantities of nitrogen, potassium, and carbohydrate materials are moved from the vegetative parts of the tree into the fruit (10), resulting in low concentrations of these materials in the leaves (2). Inadequate supply of one or more of these materials may result in restricted growth of new branches. That trees producing a heavy crop may have limited growth of lateral branches has been adequately demonstrated (1, 2). It is reasonable to expect, and indicated by cursory observation, that bud development may be similarly affected, particularly when the time of heavy demand by the developing crop coincides with, or only slightly precedes, the time of flower bud initiation and growth. Climatic factors such as rainfall, sunlight, and temperature undoubtedly play a part in bud development, but these relationships have not been elucidated in detail. Major flowerings are observed to occur after heavy rains which are preceded by dry periods. The observations of Mes (7) show, however, that the flower buds must reach a certain stage of development before they open. After development of the buds a drenching of the branches is generally required before flowers open in large numbers.

Climatic conditions in Kona representing patterns where dry periods are followed by heavy rains may occur throughout the months of winter and spring, but there is considerable variation from year to year (figure 1). Such a pattern may occur within a single month and in this event would not be illustrated adequately by the monthly rainfall data of figure 1.

The complexity of factors involved in time and intensity of flowering in relation to coffee yield is illustrated by the 1956-57 harvest season. An early flowering occurred in late December 1955 (see figure 1). Here, a very dry period in October, November, and early December was followed by a storm December 20-21. For the trees in this experiment, this was not the major flowering, because sufficient flower buds had not developed to the necessary stage at this time. A considerable portion of the 1955-56 crop was still maturing on the trees in December 1955. A major flowering occurred in late March 1956 associated with a dry period early in March followed by heavy rains. However, total yields for the 1956-1957 crop were low compared to those for other years (table 2). These low yields appear to be associated with relatively low nitrogen values for March and April of 1956 as compared with nitrogen values for the same months of 1955 and 1957. Frequent applications of nitrogen under the appropriate potassium regime (treatments I and M) were partially effective in maintaining yields in the 1956-1957 crop (table 2).

The relationships of leaf nitrogen to yield (figures 2 and 3) suggest that the process frequently limited by insufficient nitrogen in this experiment is one of nitrogen to late bud development and/or fruit set, since leaf nitrogen at the time of flowering or immediately preceding flowering appears better related to yield than leaf nitrogen two or three months before the major flowering. Detailed studies of flower bud development and fruit set are required, however, to determine this question finally.

It may be of interest to compare the yields from this experiment with yields reported for certain farms in the Kona area. Keeler _et al._ (5) have recently reported yield data from 15 farms in Kona for the 1955-1956 crop year. In table 9 are shown yields and quantities of fertilizer used on the four farms having the highest yields as reported by these workers and comparable data from certain treatments in the present experiment for the same crop year. For this comparison data from table 2 have been converted to estimates of parchment coffee yield by assuming four pounds of cherry coffee to be equal to one pound of parchment. The total fertilizers for the experiment are calculated on the basis of ammonium sulfate, muriate of potash, and superphosphate. The fertilizer used on each of the farms had the formula 10-5-20. It is evident that even among the four farms which had the highest yield there was considerable variation. The only treatments of the experiment which resulted in yield higher than the farm with the highest yield (farm No. 3) were treatments I and M. In obtaining the higher yield in treatment I, however, considerably more total fertilization was used.

Table 9. A comparison of yields and rates of fertilization obtained in this experiment with yields from several farms in Kona for the 1955-1956 crop year

Source of data	Yield: Pounds of parchment coffee per acre	Fertilizer: Pounds per acre
Keeler *et al.* (5, tables 10 and 11)		
Farm No.		
3	4,499	2,339
5	4,000	1,600
14	3,814	2,000
9	3,157	2,182
Present study, table 2		
Treatment No.		
I	4,975	3,302
M	4,733	4,992
L	3,965	3,302
D	3,950	2,698
A	3,168	1,252

Suggestions for Practical Applications

The correlation analyses of yield data in this experiment clearly suggest the desirability of having high leaf nitrogen values during the flowering season. Comparisons of yield data among treatments H, I, and K lead to the suggestion that a heavy application of potassium fertilizer should be made early in the year. At the Kona Branch Station the major flowering usually occurs in March and April. On the basis of the results in this study it is suggested that the first major fertilization for localities having the same flowering behavior should be made in February or even late January. In addition, the results indicate that two applications of nitrogen during the year are an insufficient number to assure high yields. Treatment I represents a fertilizer regime on which a practical recommendation can be based. It is very likely that similar yields could be obtained with less fertilizer than was used in this treatment, however. Hence, although there was a significant yield response when treatment I is compared with treatment H (table 4), treatment I received 724 pounds of K_2O equivalent as compared to 362 pounds for H. Very likely the optimal quantity lies somewhere between these two figures. It may be that 500 pounds is sufficient, for example. The revised experimental plan begun in June 1956 provides for further study of this question. Likewise, it is probably not necessary to apply nitrogen 10 times a year as was done in treatment I. Six or even four times may be sufficient. However, this may depend upon the locality where the coffee is grown.

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