the oil palm by Chapman and Gray (4). The first leaf of the main stem of the peanut is taken off at the beginning of flowering, while for the oil palm the first completely expanded but not senescent leaf is chosen. Ten median leaflets of the oil palm leaf, from which are removed the midrib, both ends, and marginal areas, leaving only the middle part of each leaflet, are used for analysis. A medium-sized sample contains the leaves of fifty peanut plants or of twenty-five oil palm trees.

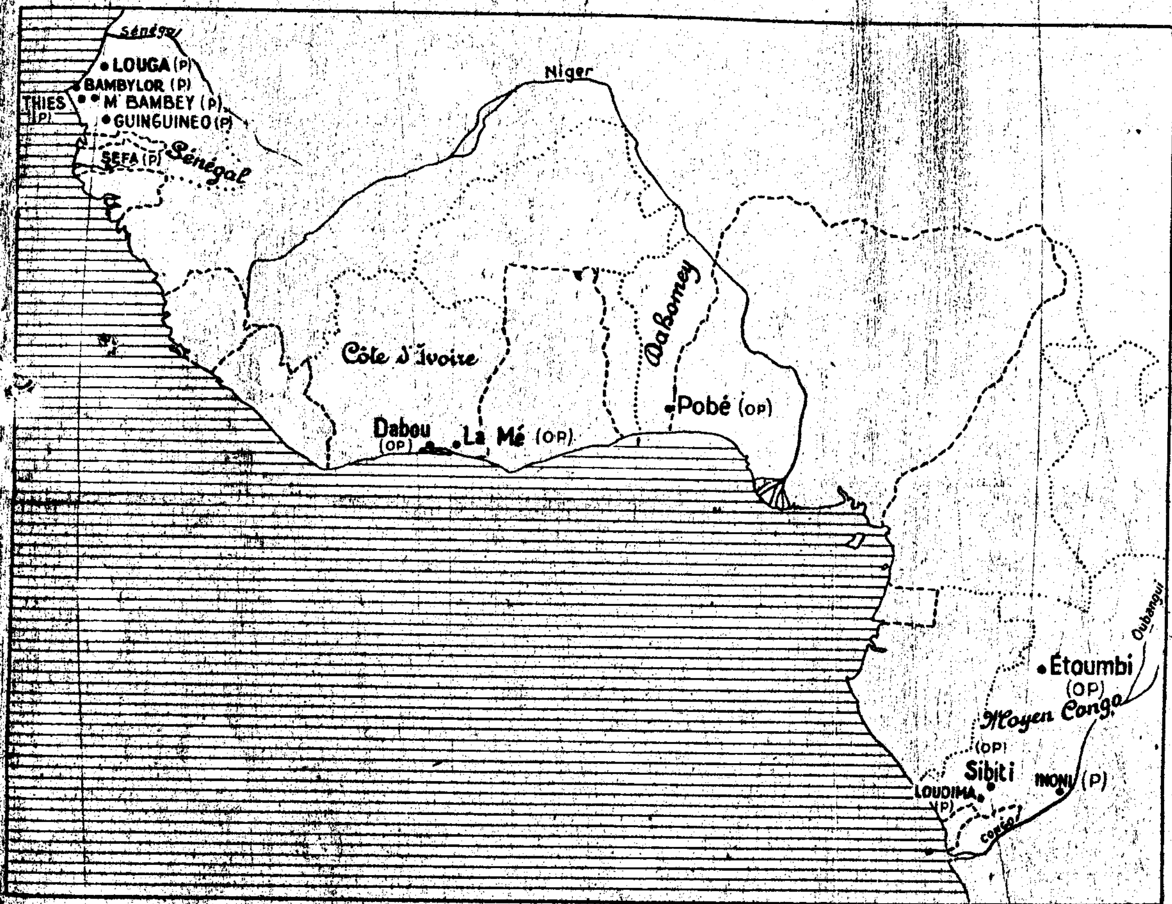

FIG. 1. Location of different experimental fields in Africa. P = Peanut; OP = Oil Palm.

Consistency of procedure is of prime importance in leaf sampling; tissue samples and sampling times must be comparable for valid results.

The samples are dried in Africa and then air mailed to Paris. Comparative chemical analysis in Africa and Paris have shown no important modifications in the samples. The chemical analysis done in Paris are N (semimicro Kjeldahl), P (Lorenz Scheffer), K, Ca, and Mg (Beckman flame spectrophotometer).

The results of the chemical analysis are expressed as elements (N, P, K, Ca, and Mg) on a percentage-dry-weight basis, rather than as oxides as usually done in agronomical papers. Nor did we express the results in milligram atoms as done by Lundegårdh (9) and Prevot (15) since this complicates the calculations, an appreciable factor in thousands of analyses, although this would have been a good method otherwise. A milliequivalent basis, while useful in the comparison of K, Ca, and Mg, is hardly of value when polyvalent ions come into consideration.

Our present conclusions (1952) are based on the results of nine experiments on the peanut and six on the oil palm. For the peanut the experimental designs were of the complex factorial type 3^3 (the three elements N, P, K at three levels 0, 1, 2) or 2^3 (the three elements N, P, K at two levels 0, 1), generally with partial confounding. With the oil palm we had to use experiments already started, and these were of the randomized design.

Experimental Results on Peanut

RESULTS: A typical peanut experiment (18) was performed in 1951 at the Centre de Recherches Agronomiques de M'Bambey (see fig. 1) by MM. Gillier and Orgias, Research Assistants of the Institut de Recherches pour les Huiles et Oléagineux. This was a $3 \times 3 \times 3$ factorial experiment with partial confounding; i.e., eight-one plots arranged in nine sub-blocks of nine plots each. A part of the second order interaction is confounded with block differences. The

CONTINGENCY TABLES

	N_0	N_1	N_2		P_0	P_1	P_2		K_0	K_1	K_2
					Yields in kg per ha ($\pm$ *58.1*) †						
P_0	1936	2201	2220	K_0	2011	2472	2416	N_0	2140	2303	2302
P_1	2449	2634	2440	K_1	2255	2557	2689	N_1	2401	2676	2474
P_2	2377	2716	2647	K_2	2091	2494	2635	N_2	2342	2520	2445
Means ($\pm$ 33.5) ‡	2254	2517	2436		2119	2507	2580		2300	2500	2407
					Leaf elements in % dry wt						
					Nitrogen ($\pm$ *0.058*) †						
P_0	3.67	3.82	3.76	K_0	3.76	3.69	3.63	N_0	3.70	3.68	3.68
P_1	3.72	3.73	3.81	K_1	3.80	3.81	3.71	N_1	3.62	3.81	3.75
P_2	3.67	3.63	3.76	K_2	3.71	3.76	3.71	N_2	3.75	3.84	3.76
Means ($\pm$ 0.034) ‡	3.69	3.72	3.78		3.76	3.75	3.69		3.69	3.78	3.73
					Phosphorus ($\pm$ *0.0078*) †						
P_0	0.137	0.143	0.138	K_0	0.141	0.165	0.161	N_0	0.155	0.153	0.153
P_1	0.156	0.166	0.172	K_1	0.137	0.171	0.169	N_1	0.152	0.164	0.154
P_2	0.169	0.162	0.173	K_2	0.141	0.156	0.173	N_2	0.160	0.160	0.163
Means ($\pm$ 0.0045) ‡	0.154	0.157	0.161		0.140	0.164	0.168		0.156	0.159	0.157
					Potassium ($\pm$ *0.055*) †						
P_0	0.861	0.859	0.864	K_0	0.837	0.826	0.913	N_0	0.899	0.889	0.992
P_1	0.925	0.840	0.877	K_1	0.805	0.837	0.894	N_1	0.835	0.817	0.883
P_2	0.994	0.836	0.871	K_2	0.942	0.980	0.893	N_2	0.841	0.831	0.939
Means ($\pm$ 0.0318) ‡	0.927	0.845	0.871		0.861	0.881	0.900		0.858	0.846	0.938
					Calcium ($\pm$ *0.072*) †						
P_0	2.15	2.33	2.37	K_0	2.22	2.43	2.32	N_0	2.19	2.19	2.30
P_1	2.32	2.52	2.51	K_1	2.29	2.52	2.34	N_1	2.42	2.44	2.34
P_2	2.19	2.36	2.44	K_2	2.34	2.40	2.32	N_2	2.37	2.52	2.42
Means ($\pm$ 0.041) ‡	2.22	2.40	2.44		2.28	2.45	2.33		2.32	2.38	2.35
					Magnesium ($\pm$ *0.059*) †						
P_0	1.16	1.23	1.26	K_0	1.17	1.22	1.23	N_0	1.14	1.23	1.20
P_1	1.21	1.33	1.28	K_1	1.27	1.39	1.28	N_1	1.22	1.36	1.20
P_2	1.19	1.21	1.33	K_2	1.22	1.21	1.23	N_2	1.25	1.35	1.26
Means ($\pm$ 0.034) ‡	1.19	1.26	1.29		1.22	1.27	1.25		1.20	1.31	1.22

Standard error for individual results: †.
Standard error for means: ‡.

treatments, all combinations of the three elements N, P, and K at three levels, are as follows:

N_0	0	P_0	0	K_0	0
N_1	37.5 kg/ha	P_1	75 kg/ha	K_1	37.5 kg/ha
N_2	75 kg/ha	P_2	150 kg/ha	K_2	75 kg/ha

N applied as ammonium sulfate;
P applied as dicalcium phosphate;
K applied as potassium chloride.
ha = hectare.

All applications were made as side-dressing five centimeters from the row and five centimeters deep. The variety used was the 24-11 strain of M'Bambey, a runner type. The results are given in tables I, II, and III.

DISCUSSION: For abbreviation we shall indicate the treatments by N_T, P_T, and K_T, and the leaf contents by N_L, P_L, K_L, Ca_L, and Mg_L.

The yields (table I) show a predominating influence of P_T, a lesser effect of N_T, and a small effect of K_T, being just within the 0.05 significant level. However, when there is a highly significant correlation between yield and P_L (0.01 level of significance, table III), there is no such correlation between yield and N_L or K_L. There is even a tendency for a negative correlation between yield and K_L. These relationships are

TABLE II

LINEAR AND CURVATURE EFFECTS OF THE FERTILIZER TREATMENTS (N_T, P_T, K_T) ON LEAF CONTENTS (N_L, P_L, K_L, Ca_L, Mg_L) AND ON YIELD

	Linear effect						Curvature effect					
	Yield	N_L	P_L	K_L	Ca_L	Mg_L	Yield	N_L	P_L	K_L	Ca_L	Mg_L
N_T	+182 **	+0.10 *	+0.007	−0.056	+0.21 **	+0.10 *	−345 **	+0.02	+0.002	+0.107	−0.14	−0.04
P_T	+461 **	−0.07	+0.028 **	+0.039	+0.04	+0.03	−316 **	−0.06	−0.021 *	−0.000	−0.30 **	−0.08
K_T	+107 *	+0.04	+0.001	+0.080	+0.03	+0.01	−294 **	−0.13	−0.005	+0.106	−0.09	−0.20 *
Standard error	± 47.4	±0.048	±0.0063	±0.0451	±0.059	±0.048	± 82.2	±0.083	±0.010[illegible]	±0.0781	±0.101	±0.083

Linear effect of $N = N_2 - N_0$.
Curvature effect of $N = N_2 - 2N_1 + N_0$.

* Significant at 5%.
** Significant at 1%.

shown in figure 2, where the main effects are plotted against yields and leaf contents. The results indicate that P is the principal deficient element and that, on the basis of this experiment, a fertilizer formula with a predominating proportion of P should be recommended.

positive correlation $P_L:K_L$ not as a correlation of absorption capacity but rather as an improvement in the physiological condition of the plant, due to the favorable action of the most deficient element, P. These more favorable physiological conditions would tend to increase accumulation ability.

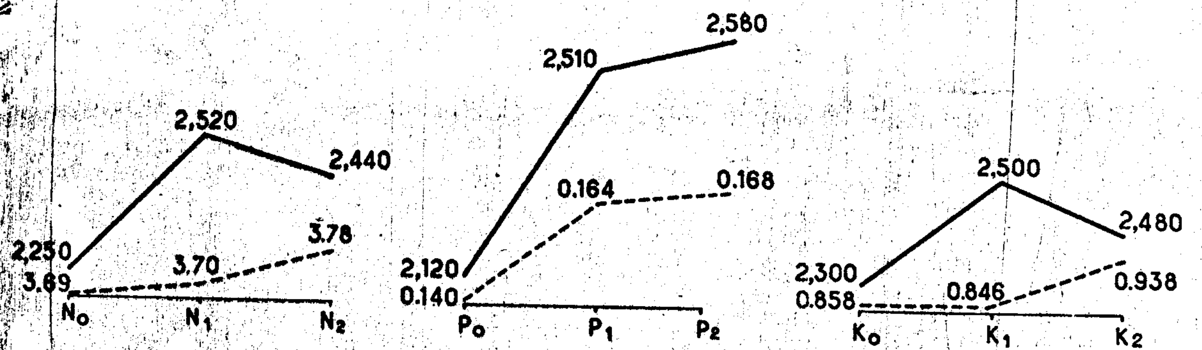

FIG. 2. Main effects of N, P or K on yields (unshelled nuts kg/ha) and leaf contents (gm % dry weight) of N, P or K. 1 cm represents a signicant difference at 5% between main effects.

The favorable effects of K_T and N_T upon yields may act indirectly. For example, the favorable effect of K_T might be associated with the uptake of P, as there is a significant (0.05) positive correlation between K_L and P_L (table III). However, this does not seem to be the case, for it can be seen that K_{T2} tends to act the opposite way in the presence of P_{T1}. For instance, we see (table I) that K_{T2} increases K_L from 0.837 to 0.980 (significant) and decreases P_L from 0.171 to 0.156 (significant). We interpret the

The correlation between N_L and P_L, although positive, is not significant (table III). This is related to the strong negative correlation between N_L and K_L along with the positive correlation between K_L and P_L.

It is possible that the favorable effect of N_T is partially related to the increase in Ca_L and Mg_L due to this treatment (tables I and III). As a matter of fact, we find a highly significant correlation between yield and Ca_L or Mg_L, which would seem to indicate a favorable effect of Ca and Mg, a point to be investigated later.

TABLE III

CORRELATIONS

Between	Yield	P_L	K_L	Ca_L	Mg_L
N_L	+0.1233	+0.0690	−0.4464 **	+0.5763 **	+0.5797 **
P_L	+0.8096 **	.....	+0.2658 *	+0.0760	−0.0347
K_L	−0.1880	.....	.....	−0.6521 **	−0.7575 **
Ca_L	+0.6641 **	.....	.....	.....	+0.8713 **
Mg_L	+0.5390 **	.....	.....	.....	.....

* Significant at 5%. ** Significant at 1%.

The main results of this experiment can be summarized as follows:

P ===Yield

K====N====Ca====Mg

The solid lines show relations between yield and treatments and dotted lines correlations between elements.

General Survey of Experiments

Results: Lack of space prevents us from presenting complete results of each analysis; however, we have summarized them in table IV (peanut) and table V (oil palm) by giving only the results with and without the favorable treatment. Also, for comparison, we have included some data of Chapman and Gray (4), recalculated on a basis of percentage of dry weight.

Table IV

General Peanut Results—Leaf Analysis

Location	Number of replicates	Treatment	N	P	K	Ca	Mg	N/P	K + Ca + Mg	Yields Kg/ha	Yields %
			% of dry weight								
Sénégal											
Thiès 1950	27	(–)	4.46	0.483	0.534	0.83	0.86	9.2	2.22	574	100
		K	4.31	0.395	0.652	0.75	0.71	10.9	2.11	819	143
Séfa 1950	27	(–)	4.65	0.165	1.61	1.16	0.489	28.2	3.26	1580	100
		P	4.75	0.194	1.49	1.35	0.605	24.5	3.44	2040	129
Séfa 1951	27	(–)	4.58	0.179	2.14	1.79	0.725	25.6	4.65	1654	100
		P	4.84	0.256	1.99	1.93	0.847	18.9	4.73	2082	126
Bambey 1951	27	(–)	3.76	0.140	0.861	2.28	1.22	26.9	4.36	2119	100
		P	3.69	0.168	0.900	2.33	1.25	22.9	4.60	2500	122
Bambylor 1951	27	(–)	3.42	0.153	0.776	1.96	1.13	22.3	3.87	1801	100
		P	3.34	0.176	0.774	2.06	1.23	19.0	4.03	2248	125
Louga 1951	20	(–)	2.91	0.168	1.66	1.24	0.403	17.3	3.30	976	100
		N	2.76	0.156	1.63	1.33	0.410	17.7	3.37	1210	124
Guinguinéo 1951	20	(–)	4.36	0.240	1.18	2.23	1.06	18.2	4.47	1556	100
		K	4.31	0.235	1.24	2.27	1.08	18.3	4.59	1840	118
French Congo											
Loudima 1951	27	(–)	3.21	0.139	2.25	2.40	0.305	23.1	4.95	2227	100
		Mg	3.17	0.142	2.23	2.42	0.344	22.3	4.99	2324	104
Inoni 1951	18	(–)	3.48	0.228	1.90	1.18	0.409	15.3	3.49	1139	100
		Ca	3.70	0.209	1.82	1.16	0.555	17.7	3.53	1209	106

Discussion: It should be pointed out that all favorable treatments of both the peanut and the oil palm increased the leaf content of the same element, except at Inoni and Louga. The Inoni experiment gave no significant results, and the Louga exception, discussed in another paper (18), is related to the very low level of N in the soils which had not been corrected by fertilizer application (50 kg of ammonium sulfate per hectare). This would be a case of being in the "minimum percentage" range, according to Macy (10).

So, the treatment that increases yield also corrects deficiency of the element in the leaf. Once more the validity of foliar diagnosis for finding mineral deficiencies in soils is confirmed. In a recent experiment with the peanut Bouyer (2) failed to find such a relation; however, both his leaf sampling and experimental design were quite different from ours.

Critical levels: We give to the critical level a practical goal and *define it as the concentration of the element in the leaf (dry weight basis) above which a yield response from the element in the fertilizer is unlikely to occur.*

This concept is of a major importance for practical use, as rightly pointed out by Ulrich (20), because it allows advising manures which will give the most economic returns.

Critical levels are indicated by N_c for N_L, P_c for P_L, and K_c for K_L. To determine them we use either a direct or an indirect method.

The *direct method* consists of comparing yield response to leaf analysis.

For N_c of the peanut, for instance, we found the following values for N_L in the plots without N_T and for the yield response to the application of nitrogen:

	N_L	Yield response to the application of nitrogen
Louga (1951)	2.91	+ 24% **
Bambylor (1951)	3.36	+ 16% **
Bambey (1951)	3.69	+ 12% **
Guinguinéo (1951)	4.27	0
Thiès (1950)	4.42	+ 5%
Séfa (1950)	4.60	+ 2%
Séfa (1951)	4.70	+ 1%

We see that the yield responses decrease as N_L increases from 2.91 to 4.27.

TABLE V

GENERAL OIL PALM RESULTS—LEAF ANALYSIS

LOCATION	AGE	TREATMENT	NUMBER OF REPLICATES	N	P	K	Ca	Mg	N/P	K+Ca+Mg	YIELDS	
				% OF DRY WEIGHT							KG/HA	%
POBÉ (Dahomey)	Nursery	..	5	3.63	0.220	1.80	0.650	0.470	16.5	2.92	No production	
	2-year-old trees	(–)	5	2.78	0.168	0.[illegible]7	0.700	0.540	16.5	1.94	No production	
		K		2.75	0.171	[illegible]8	0.721	0.432	16.1	2.23		
	20-year-old trees	(–)	6	2.54	0.167	[illegible]499	0.932	0.651	15.2	2.08	4730	100
		K		2.64	0.171	0.872	0.776	0.470	15.4	2.12	6830	147
DABOU (Ivory Coast)	20-year-old trees	(–)	5	3.01	0.193	0.496	0.589	0.318	15.6	1.40	3100	100
		K		2.83	0.180	0.765	0.756	0.286	15.7	1.31	9350	302
SIBITI (French Congo)	7-year-old trees	Healthy	11	2.80	0.162	1.38	0.457	0.230	17.3	2.07	No records	
		Unhealthy		2.53	0.158	1.54	0.412	0.202	16.0	2.15	No records	
ETOUMBI (Moyen Congo)	20-year-old trees	Control	6	2.81	0.1[illegible]4	0.91	0.530	0.118	15.3	1.56	3920	100
		NPK		2.95	0.189	1.21	0.562	0.114	15.6	1.89	4210	107
		NPK+Mg		2.98	0.[illegible]97	1.13	0.577	0.135	15.1	1.84	5520	141
MALAYA (from Chapman)												
Experiment 1		(–)		2.26	0.128	1.01	....	....	17.6	...	Not pub.	100
		P		2.45	0.153	0.96	....	....	16.0	...	Not pub.	193
Experiment 2		(–)		2.58	0.239	0.560	0.960	0.376	10.8	1.90	Not pub.	100
		K		2.73	0.247	1.09	0.832	0.329	11.1	2.25	Not pub.	168

The N_c has been approximated to $N_c = 4.00$. The same reasoning applies to other critical-level values.

The *indirect method*, or examination of special cases, may also give some information. For instance, at Dabou K_T (which increases yield 200%) lowers N_L from 3.01 to 2.83. In Malaya (Chapman) this same K_T with a yield increase of 90% brings N_L from 2.58 up to 2.73. Thus, the N_c may be situated around 2.70. Similar reasoning may be used in other cases.

Summarizing, we propose the following critical levels:

Peanut	Oil palm
$N_c = 4.00$	$N_c = 2.70$
$P_c = 0.20$	$P_c = 0.15$
$K_c = 1.20$	$K_c = 1.00$

These critical levels should be considered approximate; they will probably have to be modified in the course of further experiments involving varietal and climatic influences. However, it is interesting to point out the similarity of the K_c of the oil palm in Chapman's experiments in Malaya and our experiments in different African regions.

Interrelations of elements: While the critical levels are of major importance they do not, of course, tell us the whole story. In order to understand some experimental results more fully it is necessary to consider the interrelationships of the different elements.

Ratios between elements: The N_L/P_L ratio is surprisingly constant. For the oil palm (table V) it is about the same in seedlings, young or old trees (Pobé); also, it is about the same in such different conditions as Malaya and Africa. Its value is about 16 and, in a general way, a favorable treatment brings it down or up when it is lower or higher than 16 in the control.

This ratio is less constant in the peanut (table IV); however, it tends toward a certain value under a

TABLE VI

PEANUT—RATIOS BETWEEN N AND P

LOCATION	TREATMENT	N:P	TREND OF N:P	YIELD INCREASE
Thiès	(–)	9.2	↓	+43%
	K	10.9		
Inoni	(–)	15.3	↓	+ 6%
	Ca	17.7		
Louga	(–)	17.3	↓	+24%
	N	17.7		
Guinguinéo	(–)	18.2	↓	+18%
	K	18.3		
			N:P = 20	
Bambylor	P	19.0	↑	+25%
	(–)	22.3		
Loudima	Mg	22.3	↑	+ 4%
	(–)	22.9		
Séfa 51	P	18.9	↑	+26%
	(–)	25.6		
M'Bambey	P	22.9	↑	+22%
	(–)	26.9		
Séfa 50	P	24.5	↑	+29%
	(–)	28.2		

TABLE VII

ESTIMATE OF BEST ELEMENTS RATIOS IN LEAVES

	PEANUT	OIL PALM
N : P	20.0	16.0
N : K	3.5	3.0
N : Ca	*	3.0
N : Mg	5.0–6.0	9.0
P : K	0.20	0.20
P : Ca	0.10–0.15	0.20
P : Mg	0.3	0.5–0.75
K : Ca	1.0	2.0
K : Mg	2.0	2.0
Ca : Mg	2.0	2.0–2.5

* Difficult as yet to determine.

favorable treatment. There seems to be an optimum N_L/P_L ratio around 20 (table VI).

Similar calculations have been made for other ratios, which are summarized in table VII.

Of course, these "optimal" ratios are still quite rough and rather indicate a range of ratios toward which favorable treatments will converge. Nevertheless, they may be useful in analyzing deficiencies. When a ratio found in a leaf sample differs greatly from these values, the divergence may be attributed to the numerator and/or the denominator, and the deficiency may thus become evident. For instance, in Thiès, $P_L/K_L = 0.582$ is about three times the "optimal" ratio. The figures show clearly that this is due to both a high P_L and a low K_L, so the suggestion to apply K_T is made. The same reasoning applies to Séfa 1951, where $P_L/K_L = 0.083$ (a value much too low) would point to an application of P_T. Experimental results confirm these predictions.

So, these values are a means of checking the conclusions drawn from the critical-level values. *They are especially useful in regions where no experimental fertilization data are available.*

Correlations between elements: The ten possible correlations between N, P, K, Ca, and Mg have been calculated. The most interesting ones can be seen in table VIII.

We have seen that the N_L/P_L ratio is surprisingly constant in the oil palm, which is explained by the strong positive correlation found in all cases. Correlations are also positive in the peanut, although not so highly significant. On the other hand, K_L, Ca_L, and Mg_L are linked together. The correlation between K_L and Ca_L or K_L and Mg_L are negative while the correlations between Ca_L and Mg_L are positive. Thus, the analyzed elements could be, broadly speaking, subdivided into two large classes: N and P could be termed the "protoplasmic class," while the other elements could be termed the "basic elements class."

It should be pointed out that the sum $K_L + Ca_L + Mg_L$ (table IV) for the peanut increases approximately as the yields (see fig. 3), and may be used to estimate the general soil exhaustion in available bases.

TABLE VIII

SIGN, VALUE AND SIGNIFICANCE OF THE CORRELATIONS BETWEEN PROTOPLASMIC ELEMENTS N, P AND BASIC ELEMENTS K, Ca, Mg, IN PEANUT AND OIL PALM EXPERIMENTS

	NUMBER OF RESULTS	NP		KCa		KMg		CaMg	
		+	–	+	–	+	–	+	–
Peanut									
SENEGAL									
Thiès (1950)	[illegible]	0.20			0.10		0.21	0.30 **	
Séfa (1950)	[illegible]	0.10			0.64 **		0.66 **	0.07	
Séfa (1951)	[illegible]	0.59 **			0.47 **		0.74 **	0.65 **	
Bambey (1951)	[illegible]	0.07			0.65 **		0.76 **	0.87 **	
Bambylor (1951)	[illegible]		0.02	0.09			0.38 **	0.42 **	
Louga (1951)	[illegible]	0.68 **			0.08	0.22		0.51 **	
Guinguinéo (1951)	[illegible]	0.18			0.32 *		0.43 **	0.66 **	
FRENCH CONGO									
Loudima (1951)	[illegible]	0.05			0.50 *		0.72 *	0.22 *	
Inoni (1951)	27	0.29			0.31		0.24	0.08	
Oil Palm									
DAHOMEY									
Pobé 2-year-old trees	25	0.65 **			0.11		0.62 **	0.39	
20-year-old trees	48	0.22 *			0.62 **		0.83 **	0.55 **	
IVORY COAST									
Dabou 20-year-old trees	35	0.64 **			0.06		0.31	0.05	
FRENCH CONGO									
Sibiti 7-year-old trees	21	0.52 *			0.65 **		0.48 *	0.09	
Etoumbi 20-year-old trees	48	0.51 **		0.09			0.02	0.62 **	

* Significant at 5%.
** Significant at 1%.

\+ = positive correlations.
– = negative correlations.

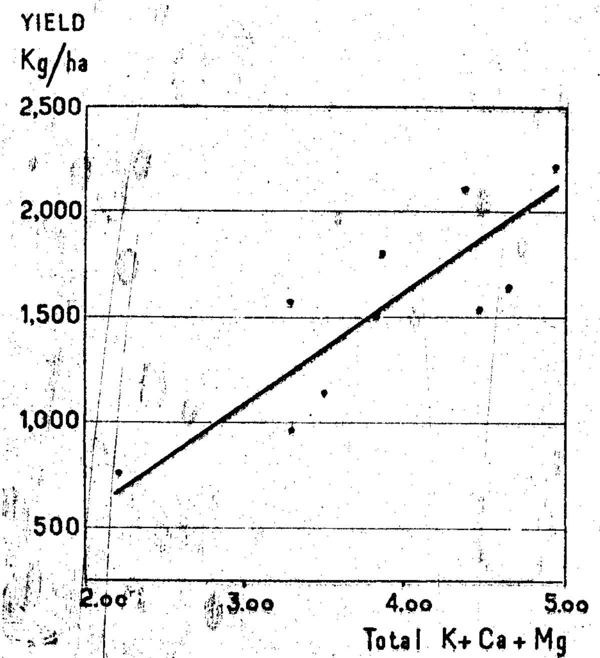

FIG. 3. Relation between the yield and the sum of the basic cation in the leaf of the peanut.

In the oil palm (table V) this sum is rather constant, around 2.0.

It is interesting to note that, although the favorable treatment may greatly increase K_L (i.e., Pobé: K_L goes up from 0.499 to 0.872), the sum is changed by only a very small amount (Pobé: from 2.08 to 2.12). This is well explained by the antagonisms between Ca_L, Mg_L, and K_L. At Dabou these antagonisms do not reach the significant level; the sum of the elements increased more (from 1.40 to 1.81) and there was concomitant increase of both K_L and Ca_L. So, we see that when the sum does not reach 2.0 the antagonism between K_L and Ca_L or between K_L and Mg_L disappear.

Summary

Detailed results of a typical peanut experiment are reported to show the method used in foliar diagnosis. General results are given for the peanut and oil palm, and from these results critical levels of N, P, and K are approximated for both plants. Interrelations of elements are discussed from the standpoints of the ratios and correlations between N, P, K, Ca, and Mg. Correlations between N and P are generally positive; correlations between K and Ca or K and Mg are negative, while correlations between Ca and Mg are positive. In the oil palm such correlations may disappear when the sum K + Ca + Mg is lower than 2.0.

The elements thus far analyzed have been subdivided into two large classes: the "protoplasmic class" for N and P, and the "basic elements class" for K, Ca, and Mg.

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