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Effect of Sampling Intensity on Precision of Soil and Foliar Data I. Paleudults Derived from Granite

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Analytical results of foliar samples collected at four intensities and soil samples at three intensities were studied. There was no significant difference in the nutrient composition of laminae and petioles sampled at different intensities. In areas on steep terrain, the effect of increasing sampling intensity does not appear to improve the precision of the results.

In contrast to foliar results, variabilities of soil test values are significant. Variations in results are attributed not only to field sampling intensity but also to the methods by which the soil test results are determined.

The need for regular use of fertilisers to increase growth and sustain yields of *Hevea* has been in practice for many years[1–5]. Basic requirements determining the fertiliser needs of rubber are good and reliable soil and foliar analytical data. These will depend on sound sampling techniques.

Currently, the sampling intensities for soil and leaf are one composite soil sample from ten random cores for an area of about 20 ha and one composite leaf sample from thirty random trees over an area of 15–20 ha, respectively. Several studies[6,7] have shown that the precision of laboratory analysis can be improved by proper field sampling techniques. Chang *et al.*[7] showed that the sample size required for a given level of precision was larger in the shale-derived Munchong series soil (a Haplorthox) than that required in the granite-derived Rengam series soil (a typic paleudult). However, more field studies are required to further substantiate these early findings for formulation of appropriate practices in sampling intensity. This paper examines further the effect of field sampling intensity on soil and foliar analytical results with respect to the more homogeneous group of soils derived from granite. Foliar and soil samples from four areas on Rengam series soil (a typic paleudult) sited on different topographical and geographical situations were collected for analysis. For comparison, both the laminae and petioles were analysed. Precision of results in all the cases is discussed and the sampling procedure adopted is evaluated. At this first level of study, soil sampling is confined to the area in the inter-rows, to reflect *in situ* the nutrient resurvey of soils as these areas are expected to be least disturbed by fertiliser inputs. Separate studies involving tree-row samplings are in progress for subsequent evaluations.

EXPERIMENTAL

Four areas on Rengam series soil located on four geographical regions in Peninsular Malaysia were selected for the studies. The four areas experienced different annual rainfall with 275–350 cm for *Area I,* more than 355 cm for *Area II,* 230–255 cm for *Area III* and 255–280 cm for *Area IV.* In addition, there are topographical differences in the areas. Details of the areas are given in *Table 1.* Each area consists of about 30 ha divided into four blocks of about 7.5 ha each. The areas were planted with a uniform well-maintained stand of mature RRIM 600.

Foliar Sampling

Low shade leaves were sampled in the manner described by Chan[2] at four intensities in each

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TABLE 1. DETAILS OF EXPERIMENTAL AREAS

Area	Estate	Location	Soil series	Terrain class (% slope)	Year of planting
I	Changkat Bruas	Bruas, Perak	Rengam	C and D (10% - 30%)	1966
II	Anak Kulim	Kulim, Kedah	Rengam	E and F (50% - 65%)	1966
III	United Malacca Rubber Estates	Malacca	Rengam	B and C (5% - 15%)	1966
IV	Sedenak	Sedenak, Johore	Rengam	C and D (10% - 50%)	1966

of the blocks. The intensities were L_1, L_2, L_3 and L_4 — one composite sample of twelve leaflets per tree from fifteen trees, thirty trees, forty-five trees and sixty trees, respectively. The same sampling procedure was carried out in combined blocks of 15 ha and 22.5 ha in the marked out area. Each sampling intensity was done in six replicates.

Soil Sampling

Soil samples at two depths (0–15 cm and 15–45 cm) were collected from the inter-rows. The intensities of sampling in each block were S_1, S_2, S_3 and S_4 — one composite sample from ten random points, twenty random points and thirty random points, respectively. As for foliar sampling, soil samples were further obtained from combined blocks of 15 ha and 22.5 ha. Each soil sampling intensity was done in three replicates.

In this study, soil samples were collected from the inter-rows to reflect soil nutrient reserves as these areas are expected to be least disturbed by fertiliser inputs. Separate studies are on-going to include investigations involving the areas in the tree rows.

Laboratory Analysis

Petioles and laminae from the leaves were separated, dried at 80°C and ground. The ground plant materials were thoroughly mixed and sub-sampled for analysis[8]; 2 g of the plant material was dry-ashed, dissolved in dilute nitric acid and analysed for P, K, Ca, Mg and Mn. Nitrogen in the plant samples was determined by semi-micro distillation in a Markham apparatus. Elemental compositions of N, P, K, Ca and Mg were calculated as percentages of dry leaf material. The nutrient values in the laminae were further adjusted according to those at optimum leaf age[9].

Soil samples were oven-dried at 55°C, ground to pass through a sieve (<2 mm size) and sub-sampled for analysis[8]. Soil pH was measured with a pH meter on a suspension of soil in distilled water, the soil : water ratio being 2 : 5. Soil organic carbon was determined by Walkley and Black's Titration method and total nitrogen by the Kjeldahl digestion method followed by semi-micro distillation in a Markham apparatus. Acid-extractable cations (K^+, Ca^{2+}, Mg^+) were determined by 6*N* hydrochloric acid extraction and exchangeable cations by leaching with normal neutral ammonium acetate. Soluble P was determined by the Bray and Kurtz II method and total P on perchloric/sulphuric acid digest.

Mean values of soil and foliar samples at each of the sampling intensities together with the standard deviation (±SD) were determined and compared.

RESULTS

Leaf Analysis

Laminae. Mean nutrient values of leaf laminae and standard deviations in the four experimental areas are given in *Tables 2–5*.

TABLE 2. MEAN NUTRIENT VALUES OF LEAF LAMINAE FROM AREAS I AND II ON RENGAM SERIES SOIL

Nutrient[a]	Area I					Area II				
	L_1	L_2	L_3	L_4	Mean	L_1	L_2	L_3	L_4	Mean
7.5 ha										
N	3.50	3.46	3.42	3.39	3.44	3.69	3.63	3.63	3.61	3.64
P	0.27	0.26	0.26	0.25	0.26	0.26	0.26	0.26	0.24	0.26
K	1.85	1.79	1.76	1.75	1.79	1.68	1.64	1.67	1.67	1.67
Ca	0.83	0.84	0.85	0.83	0.84	0.67	0.65	0.66	0.66	0.66
Mg	0.35	0.34	0.34	0.33	0.34	0.23	0.23	0.22	0.23	0.23
Mn (p.p.m.)	224	222	224	225	224	71	78	80	78	77
15.0 ha										
N	3.26	3.28	3.23	3.18	3.24	4.01	3.76	3.74	3.81	3.83
P	0.26	0.26	0.26	0.26	0.26	0.27	0.27	0.27	0.26	0.27
K	1.74	1.70	1.68	1.75	1.72	1.69	1.71	1.67	1.60	1.67
Ca	0.82	0.86	0.85	0.84	0.84	0.61	0.62	0.60	0.62	0.61
Mg	0.32	0.32	0.32	0.32	0.32	0.23	0.24	0.22	0.22	0.23
Mn (p.p.m.)	214	214	216	222	217	81	81	74	80	79
22.5 ha										
N	3.31	3.28	3.33	3.31	3.31	3.86	3.88	3.70	3.74	3.80
P	0.26	0.26	0.26	0.26	0.26	0.26	0.27	0.25	0.26	0.26
K	1.82	1.73	1.70	1.63	1.72	1.61	1.66	1.63	1.64	1.64
Ca	0.72	0.82	0.79	0.88	0.80	0.68	0.64	0.67	0.64	0.66
Mg	0.34	0.33	0.34	0.34	0.34	0.24	0.23	0.22	0.22	0.23
Mn (p.p.m.)	203	219	221	217	215	82	78	78	76	79
Mean	36.70	37.47	37.80	37.96		14.11	14.26	13.97	14.08	

[a]Expressed as percentage of oven-dried material unless otherwise stated

TABLE 3. MEAN NUTRIENT VALUES OF LEAF LAMINAE FROM AREAS III AND IV ON RENGAM SERIES SOIL

Nutrient[a]	Area III				Mean	Area IV				Mean
	L_1	L_2	L_3	L_4		L_1	L_2	L_3	L_4	
7.5 ha										
N	3.51	3.38	3.49	3.39	3.44	3.50	3.44	3.51	3.47	3.48
P	0.23	0.24	0.24	0.24	0.24	0.25	0.25	0.25	0.25	0.25
K	1.38	1.31	1.35	1.40	1.36	1.62	1.66	1.66	1.63	1.64
Ca	0.96	0.94	0.96	1.04	0.98	0.84	0.83	0.83	0.83	0.83
Mg	0.35	0.35	0.34	0.35	0.35	0.24	0.23	0.22	0.23	0.23
Mn (p.p.m.)	172	197	201	239	202	96	98	97	97	97
15.0 ha										
N	3.66	3.45	3.32	2.97	3.35	3.77	3.70	3.67	3.63	3.69
P	0.23	0.24	0.24	0.23	0.24	0.23	0.23	0.23	0.23	0.23
K	1.44	1.43	1.49	1.45	1.45	1.60	1.63	1.57	1.59	1.60
Ca	0.97	0.99	0.94	1.00	0.98	0.80	0.76	0.73	0.76	0.76
Mg	0.36	0.36	0.34	0.35	0.35	0.25	0.25	0.25	0.24	0.25
Mn (p.p.m.)	200	188	189	199	194	87	87	90	85	87
22.5 ha										
N	3.80	3.58	3.53	3.48	3.60	3.85	3.67	3.59	3.61	3.68
P	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24
K	1.39	1.48	1.38	1.38	1.41	1.72	1.70	1.72	1.65	1.70
Ca	0.90	0.86	0.91	0.93	0.90	0.77	0.84	0.79	0.77	0.79
Mg	0.37	0.37	0.36	0.33	0.36	0.23	0.22	0.24	0.24	0.23
Mn (p.p.m.)	191	188	202	200	195	89	90	88	88	89
Mean	32.38	32.90	33.95	36.49		16.22	16.37	16.36	16.08	

[a]Expressed as percentage of oven-dried material unless otherwise stated

TABLE 4. STANDARD DEVIATION OF MEAN NUTRIENT VALUES OF LEAF LAMINAE FROM AREAS I AND II ON RENGAM SERIES SOIL

Nutrient	SD (±)							
	Area I				Area II			
	L_1	L_2	L_3	L_4	L_1	L_2	L_3	L_4
7.5 ha								
N	0.150	0.145	0.123	0.125	0.235	0.223	0.189	0.137
P	0.015	0.015	0.010	0.014	0.011	0.019	0.013	0.007
K	0.107	0.080	0.087	0.087	0.086	0.078	0.084	0.084
Ca	0.080	0.077	0.086	0.085	0.081	0.066	0.072	0.055
Mg	0.029	0.022	0.021	0.027	0.031	0.032	0.025	0.024
Mn	29.1	25.0	25.1	22.2	17.1	18.4	16.1	14.4
15.0 ha								
N	0.168	0.183	0.120	0.120	0.198	0.166	0.160	0.191
P	0.012	0.005	0.008	0.006	0.014	0.014	0.013	0.019
K	0.067	0.106	0.069	0.110	0.078	0.079	0.066	0.072
Ca	0.100	0.087	0.069	0.084	0.049	0.020	0.035	0.054
Mg	0.029	0.021	0.016	0.021	0.036	0.047	0.048	0.041
Mn	34.1	21.8	35.4	31.8	16.9	16.1	15.4	13.6
22.5 ha								
N	0.219	0.119	0.112	0.131	0.311	0.229	0.248	0.140
P	0.013	0.010	0.014	0.011	0.008	0.004	0.013	0.014
K	0.087	0.088	0.089	0.160	0.060	0.044	0.090	0.051
Ca	0.080	0.062	0.084	0.070	0.090	0.072	0.121	0.063
Mg	0.029	0.37	0.020	0.025	0.025	0.024	0.034	0.016
Mn	23.0	23.5	24.4	19.2	22.4	17.1	14.4	18.3

TABLE 5. STANDARD DEVIATION OF MEAN NUTRIENT VALUES OF LEAF LAMINAE FROM AREAS III AND IV ON RENGAM SERIES SOIL

Nutrient	SD (±)							
	Area III				Area IV			
	L_1	L_2	L_3	L_4	L_1	L_2	L_3	L_4
7.5 ha								
N	0.129	0.237	0.140	0.280	0.174	0.140	0.128	0.150
P	0.010	0.013	0.007	0.035	0.014	0.011	0.010	0.012
K	0.120	0.089	0.112	0.236	0.091	0.100	0.073	0.092
Ca	0.093	0.062	0.015	0.201	0.066	0.074	0.061	0.059
Mg	0.040	0.028	0.024	0.067	0.025	0.029	0.023	0.023
Mn	20.4	31.8	38.7	51.8	11.8	11.9	12.9	10.2
15.0 ha								
N	0.165	0.228	0.359	0.223	0.146	0.130	0.122	0.111
P	0.014	0.017	0.017	0.010	0.015	0.010	0.018	0.016
K	0.183	0.131	0.149	0.071	0.121	0.118	0.161	0.191
Ca	0.074	0.048	0.076	0.056	0.078	0.046	0.045	0.073
Mg	0.044	0.032	0.033	0.036	0.020	0.020	0.020	0.018
Mn	28.6	18.5	21.5	29. 0	11.1	13.3	7.8	9.8
22.5 ha								
N	0.191	0.284	0.172	0.172	0.129	0.095	0.076	0.088
P	—	0.010	0.010	0.010	0.016	0.011	0.008	0.004
K	0.148	0.095	0.121	0.066	0.121	0.127	0.062	0.105
Ca	0.079	0.071	0.098	0.102	0.051	0.080	0.045	0.073
Mg	0.039	0.037	0.028	0.026	0.017	0.012	0.015	0.013
Mn	33.0	16.9	21.7	32.1	11.4	8.7	8.51	10.8

Differences in the levels of N, P, K, Ca, Mg and Mn in the four areas were evident. Relatively, *Areas I* and *III* appeared to have very high Mn and Mg, with Mn contents exceeding those in *Areas II* and *IV* by as much as 300%. Ca values of the four areas ranged from 0.60% to 1.04% with *Areas I, III* and *IV* having values exceeding the Ca level of 0.6% at optimum leaf age[9]. The differences in leaf age as magnified by their Ca values were attributed to the foliar samplings not being carried out at the same time after commencement of refoliation.

Nutrient contents within each intensity of sampling in the 7.5, 15.0, 22.5 ha plots did not show any marked differences. For each element, differences in values did not vary by more than 8% of the overall mean taken over all the intensities of sampling. Similar observations were noted when comparing values at different plot sizes. In *Area III,* Mn value at intensity L_4 appeared to be markedly higher than that at intensity L_1 in the 7.5 ha plot. This large difference, however, was not shown in other plots.

Petioles. Total N, P, K, Ca, Mg and Mn contents of petioles and their standard deviations are tabulated in *Tables 6–9.* Values of N, P and Mg in petioles were significantly lower than those in the laminae. However, the petioles had higher K, Ca and Mn. The Mn contents in the petioles were so high that in some cases, the values were four times more than those in the laminae. As for laminae, nutrient contents of petioles in the four sites were different. Comparing nutrient values in the various plot sizes, Mn content showed the most variability. Mn values in plots in *Areas II, III* and *IV* differred and the differences could be as high as 20% of the overall mean calculated for the complete plot. Values of N, P, K, Ca and Mg at intensities of L_1, L_2, L_3 and L_4 did not appear to show much variation. These variations seldom exceeded more than 10% of the mean values. Contrary to what were obtained for N, P, K, Ca and Mg, Mn values at L_1, L_2, L_3 and L_4 were relatively inconsistent and also showed greater variations.

Soil Analysis

Mean results of some soil chemical analyses are shown in *Tables 10* and *11.* Values of exchangeable cations by neutral *N* ammonium acetate extraction and acid-extractable cations by 6*N* hydrochloric acid extraction are not presented here as widely differing values were obtained within the three plot sizes in each of the experimental areas. Standard deviations of mean values at each sampling intensity were high and tended to exceed 20%–30% of the mean. These observations persisted with repeated analyses.

Soil pH, C, N, soluble P (available P) and acid-extractable P (total P) in all the four areas fell within narrow ranges of 4.08 – 4.38, 0.76% – 1.77%, 0.12% – 0.21%, 5.0 – 8.9 p.p.m., and 139 – 197 p.p.m., respectively. The comparatively low values were typical of soils, like the Rengam series soil which is of granite origin. With the exception of *Area IV* which has Mn content of more than 150 p.p.m., all the other areas had mean soil Mn of less than 50 p.p.m. Values of soil pH, N, available P, total P and Mn in the 7.5, 15 and 22.5 ha plots in all the experimental areas were in close agreement. Similarly, no significant differences could be inferred when the intensities were increased from S_1 to S_3. In *Area III* where the terrain was of *Class E* and *Class F* (50%–65% slopes), values at intensity S_3 were not much affected when compared to those of S_1.

The variability of results for sub-soils (15–45 cm) generally followed that of the top-soils. Comparatively, lower values of available and total P, N and Mn contents were obtained.

DISCUSSION

The current procedure[2] of leaf sampling consists of collecting one composite low shade leaf sample (twelve leaflets per tree) taken from thirty randomly chosen trees over an area of 15–20 ha. Subsequently, Chang *et al.*[7] showed that this procedure was quite adequate for homogenous soils like the Rengam series soil but required further studies to refine its application under different soil conditions. The effects of sampling size on foliar results from areas

TABLE 6. MEAN NUTRIENT VALUES OF PETIOLES FROM AREAS I AND II ON RENGAM SERIES SOIL

Nutrient[a]	Area I					Area II				
	L_1	L_2	L_3	L_4	Mean	L_1	L_2	L_3	L_4	Mean
7.5 ha										
N	1.06	1.02	1.02	1.01	1.03	1.26	1.32	1.27	1.23	1.27
P	0.17	0.17	0.17	0.17	0.17	0.20	0.19	0.19	0.19	0.19
K	1.89	1.98	2.02	1.97	1.97	1.68	1.67	1.60	1.62	1.64
Ca	0.80	0.85	0.90	0.86	0.85	0.75	0.76	0.74	0.74	0.75
Mg	0.17	0.16	0.17	0.17	0.17	0.10	0.10	0.10	0.10	0.10
Mn (p.p.m.)	512	555	576	568	553	205	224	229	229	222
15.0 ha										
N	0.98	0.91	0.99	0.99	0.97	1.46	1.41	1.42	1.37	1.42
P	0.18	0.18	0.17	0.17	0.18	0.22	0.19	0.19	0.19	0.20
K	2.05	2.20	2.29	2.13	2.17	1.92	1.70	1.72	1.52	1.72
Ca	0.84	0.88	0.86	0.84	0.86	0.92	0.85	0.85	0.79	0.85
Mg	0.17	0.17	0.17	0.16	0.17	0.12	0.11	0.11	0.11	0.11
Mn (p.p.m.)	488	531	514	514	512	294	284	263	279	280
22.5 ha										
N	0.96	1.03	1.02	1.01	1.01	1.40	1.39	1.34	1.32	1.36
P	0.14	0.17	0.15	0.16	0.16	0.19	0.18	0.19	0.19	0.19
K	2.01	2.06	2.13	2.15	2.09	1.70	1.69	1.67	1.67	1.68
Ca	0.73	0.74	0.73	0.76	0.74	0.91	0.93	0.91	0.90	0.91
Mg	0.17	0.17	0.17	0.17	0.17	0.11	0.11	0.11	0.10	0.11
Mn (p.p.m.)	504	553	575	552	546	283	286	286	274	282
Mean	84.24	91.76	93.22	91.48		44.16	44.81	43.91	44.11	

[a]Expressed as percentage of oven-dried material unless otherwise stated

TABLE 7. MEAN NUTRIENT VALUES OF PETIOLES FROM AREAS III AND IV ON RENGAM SERIES SOIL

Nutrient[a]	Area III					Area IV				
	L_1	L_2	L_3	L_4	Mean	L_1	L_2	L_3	L_4	Mean
7.5 ha										
N	1.14	1.12	1.12	1.09	1.12	1.18	1.09	1.11	1.11	1.12
P	0.13	0.14	0.13	0.14	0.14	0.19	0.19	0.18	0.18	0.19
K	1.42	1.45	1.46	1.46	1.45	1.90	1.87	1.78	1.81	1.84
Ca	0.80	0.95	0.96	0.99	0.93	1.19	1.19	1.18	1.21	1.19
Mg	0.15	0.17	0.17	0.18	0.17	0.15	0.15	0.15	0.16	0.15
Mn (p.p.m.)	647	645	683	702	669	443	413	434	447	434
15.0 ha										
N	1.04	0.94	0.93	0.97	0.97	1.18	1.18	1.19	1.19	1.19
P	0.14	0.13	0.13	0.13	0.13	0.16	0.18	0.17	0.17	0.17
K	1.59	1.47	1.49	1.49	1.51	1.74	1.84	1.84	1.88	1.83
Ca	1.10	1.00	1.02	1.06	1.05	1.15	1.22	1.12	1.27	1.19
Mg	0.17	0.16	0.16	0.16	0.16	0.16	0.17	0.17	0.16	0.17
Mn (p.p.m.)	800	762	767	783	778	441	472	470	460	461
22.5 ha										
N	1.15	1.20	1.11	1.06	1.13	1.17	1.17	1.14	1.16	1.16
P	0.15	0.14	0.14	0.14	0.14	0.19	0.18	0.16	0.18	0.18
K	1.51	1.56	1.50	1.50	1.52	2.02	1.88	1.75	1.86	1.88
Ca	1.25	1.23	1.17	1.11	1.19	1.28	1.30	1.21	1.40	1.30
Mg	0.20	0.20	0.19	0.18	0.19	0.18	0.16	0.16	0.16	0.17
Mn (p.p.m.)	883	837	829	819	842	461	486	469	504	480
Mean	130.11	125.33	127.26	128.65		75.49	76.93	77.02	79.16	

[a]Expressed as percentage of oven-dried material unless otherwise stated

TABLE 8. STANDARD DEVIATIONS OF MEAN NUTRIENT VALUES OF PETIOLES FROM AREAS I AND II ON RENGAM SERIES SOIL

Nutrient	SD (±)									
	Area I				Mean	Area II				Mean
	L_1	L_2	L_3	L_4		L_1	L_2	L_3	L_4	
7.5 ha										
N	0.085	0.075	0.057	0.056	0.068	0.148	0.168	0.105	0.089	0.128
P	0.019	0.017	0.012	0.013	0.015	0.022	0.028	0.024	0.017	0.023
K	0.192	0.098	0.114	0.155	0.140	0.142	0.098	0.113	0.077	0.108
Ca	0.121	0.115	0.118	0.076	0.108	0.141	0.131	0.144	0.098	0.129
Mg	0.027	0.022	0.020	0.015	0.021	0.023	0.017	0.019	0.015	0.019
Mn	104.0	132.6	93.0	95.3	106.2	21.4	52.9	57.2	42.9	43.6
15.0 ha										
N	0.051	0.109	0.073	0.051	0.071	0.109	0.117	0.127	0.106	0.115
P	0.017	0.010	0.008	0.014	0.012	0.034	0.030	0.026	0.028	0.030
K	0.149	0.138	0.160	0.178	0.156	0.224	0.220	0.282	0.159	0.221
Ca	0.106	0.097	0.041	0.072	0.079	0.220	0.124	0.154	0.158	0.164
Mg	0.027	0.020	0.013	0.012	0.018	0.019	0.015	0.023	0.022	0.020
Mn	87.0	64.0	70.0	62.0	70.8	60.7	45.5	39.5	20.5	41.6
22.5 ha										
N	0.047	0.039	0.049	0.037	0.043	0.106	0.119	0.115	0.087	0.107
P	0.034	0.010	0.014	0.003	0.015	0.019	0.018	0.017	0.016	0.018
K	0.177	0.158	0.099	0.119	0.138	0.097	0.080	0.111	0.091	0.095
Ca	0.088	0.062	0.080	0.064	0.074	0.191	0.190	0.160	0.202	0.186
Mg	0.017	0.020	0.023	0.014	0.019	0.021	0.025	0.013	0.011	0.018
Mn	58.0	67.0	106.0	31.0	65.5	67.8	70.6	59.8	67.0	66.3
Mean	13.90	14.70	14.99	10.51		8.41	9.47	8.77	7.31	

TABLE 9. STANDARD DEVIATIONS OF MEAN NUTRIENT VALUES OF PETIOLES FROM AREAS III AND IV ON RENGAM SERIES SOIL

Nutrient	SD (±)									
	Area III				Mean	Area IV				Mean
	L_1	L_2	L_3	L_4		L_1	L_2	L_3	L_4	
7.5 ha										
N	0.110	0.082	0.073	0.070	0.084	0.088	0.055	0.060	0.073	0.069
P	0.025	0.014	0.009	0.011	0.015	0.023	0.020	0.013	0.017	0.018
K	0.227	0.124	0.099	0.098	0.137	0.151	0.118	0.091	0.114	0.119
Ca	0.200	0.085	0.082	0.113	0.120	0.106	0.114	0.089	0.124	0.108
Mg	0.021	0.013	0.017	0.018	0.017	0.026	0.015	0.019	0.020	0.020
Mn	151.8	91.1	110.2	102.4	113.9	82.1	67.8	66.2	71.1	71.8
15.0 ha										
N	0.103	0.122	0.153	0.114	0.123	0.084	0.058	0.050	0.057	0.062
P	0.026	0.017	0.026	0.020	0.022	0.036	0.014	0.010	0.019	0.020
K	0.201	0.181	0.176	0.110	0.167	0.393	0.079	0.112	0.122	0.177
Ca	0.094	0.186	0.095	0.082	0.114	0.236	0.126	0.085	0.079	0.132
Mg	0.028	0.040	0.030	0.024	0.031	0.040	0.020	0.016	0.017	0.023
Mn	110.7	63.7	61.4	72.3	77.0	123.2	74.0	64.9	74.4	84.1
22.5 ha										
N	0.064	0.116	0.082	0.079	0.085	0.070	0.050	0.064	0.030	0.054
P	0.010	0.017	0.026	0.020	0.018	0.026	0.019	0.021	0.015	0.020
K	0.101	0.110	0.127	0.173	0.128	0.110	0.158	0.128	0.095	0.123
Ca	0.102	0.122	0.114	0.079	0.104	0.149	0.186	0.196	0.144	0.169
Mg	0.020	0.026	0.026	0.024	0.024	0.019	0.025	0.020	0.014	0.020
Mn	172.1	98.6	89.2	82.2	110.5	72.7	71.3	62.8	60.5	66.8
Mean	24.22	14.15	14.55	14.33		15.53	11.90	10.83	11.50	

TABLE 10. MEAN RESULTS OF CHEMICAL ANALYSES OF TOP-SOILS FROM AREAS I AND II AND STANDARD DEVIATION VALUES

Nutrient	Area I				Area II			
	S_1	S_2	S_3	Mean	S_1	S_2	S_3	Mean
7.5 ha								
pH	4.29 (0.08)	4.29 (0.10)	4.23 (0.12)	4.27 (0.10)	4.31 (0.03)	4.31 (0.06)	4.29 (0.05)	4.30 (0.05)
Org. C (%)	1.12 (0.14)	1.11 (0.13)	1.11 (0.12)	1.11 (0.13)	1.42 (0.16)	1.52 (0.14)	1.63 (0.09)	1.52 (0.13)
Total N (%)	0.13 (0.01)	0.13 (0.02)	0.13 (0.01)	0.13 (0.01)	0.17 (0.02)	0.18 (0.02)	0.19 (0.01)	0.18 (0.02)
Avail. P (p.p.m.)	5.31 (0.70)	5.35 (0.64)	5.70 (0.60)	5.45 (0.65)	6.84 (1.11)	7.06 (1.11)	6.81 (0.69)	6.90 (0.97)
Total P (p.p.m.)	142 (14)	142 (13)	143 (11)	142 (13)	181 (11)	185 (11)	186 (7)	184 (10)
Mn (p.p.m.)	55 (12)	54 (10)	56 (10)	55 (11)	40 (10)	39 (3)	39 (3)	39 (5)
15.0 ha								
pH	4.18 (0.09)	4.14 (0.05)	4.16 (0.05)	4.16 (0.06)	4.16 (0.05)	4.18 (0.08)	4.12 (0.04)	4.15 (0.06)
Org. C (%)	1.24 (0.10)	1.22 (0.08)	1.20 (0.07)	1.22 (0.08)	1.63 (0.11)	1.76 (0.15)	1.77 (0.16)	1.72 (0.14)
Total N (%)	0.14 (0.01)	0.14 (0.01)	0.13 (0.02)	0.14 (0.01)	0.20 (0.01)	0.21 (0.01)	0.21 (0.01)	0.21 (0.01)
Avail. P (p.p.m.)	6.50 (1.40)	6.00 (0.25)	6.10 (0.35)	6.20 (0.67)	8.10 (2.09)	7.60 (1.50)	7.60 (2.23)	7.77 (1.94)
Total P (p.p.m.)	145 (12)	146 (9)	142 (5)	144 (9)	176 (19)	181 (20)	172 (16)	176 (18)
Mn (p.p.m.)	51 (5)	50 (4)	45 (5)	49 (5)	42 (7)	44 (6)	43 (7)	43 (7)
22.5 ha								
pH	4.19 (0.10)	4.29 (0.06)	4.38 (0.07)	4.29 (0.08)	4.26 (0.14)	4.06 (0.05)	4.12 (0.07)	4.15 (0.09)
Org. C (%)	1.02 (0.15)	1.04 (0.10)	1.08 (0.08)	1.05 (0.11)	1.68 (0.08)	1.60 (0.10)	1.63 (0.08)	1.64 (0.09)
Total N (%)	0.12 (0.01)	0.13 (0.01)	0.13 (0.01)	0.13 (0.01)	0.20 (0.01)	0.19 (0.01)	0.20 (0.01)	0.20 (0.01)
Avail. P. (p.p.m.)	5.75 (0.89)	5.88 (0.35)	5.88 (0.83)	5.84 (0.69)	8.88 (3.33)	7.88 (1.27)	6.88 (1.45)	7.88 (2.02)
Total P (p.p.m.)	139 (11)	145 (7)	152 (9)	145 (9)	167 (13)	173 (11)	168 (13)	169 (12)
Mn (p.p.m.)	48 (5)	51 (3)	51 (4)	50 (4)	46 (4)	45 (5)	47 (3)	46 (4)

Figures within brackets are values of standard deviation (SD).

S_1, S_2, S_3 = One composite sample from ten, twenty and thirty random points respectively.

TABLE 11. MEAN RESULTS OF CHEMICAL ANALYSES OF TOP-SOILS FROM AREAS III AND IV AND STANDARD DEVIATION VALUES

Nutrient	Area III			Mean	Area IV			Mean
	S_1	S_2	S_3		S_1	S_2	S_3	
7.5 ha								
pH	4.26 (0.08)	4.20 (0.09)	4.20 (0.05)	4.22 (0.07)	4.25 (0.09)	4.26 (0.03)	4.28 (0.07)	4.26 (0.06)
Org. C (%)	1.18 (0.09)	1.14 (0.08)	1.17 (0.13)	1.16 (0.10)	1.51 (0.09)	1.53 (0.13)	1.57 (0.12)	1.54 (0.11)
Total N (%)	0.14 (0.01)	0.14 (0.01)	0.14 (0.02)	0.14 (0.01)	0.18 (0.01)	0.17 (0.01)	0.18 (0.02)	0.18 (0.01)
Avail. P (p.p.m.)	6.40 (0.65)	7.20 (1.15)	6.75 (0.59)	6.78 (0.80)	6.04 (0.05)	5.88 (0.59)	6.08 (0.56)	6.00 (0.40)
Total P (p.p.m.)	177 (23)	182 (18)	182 (18)	180 (20)	178 (17)	172 (12)	175 (13)	175 (14)
Mn (p.p.m.)	41 (4)	42 (3)	41 (2)	41 (3)	174 (49)	150 (21)	165 (35)	163 (35)
15.0 ha								
pH	4.36 (0.07)	4.30 (0.11)	4.19 (0.10)	4.28 (0.09)	4.20 (0.01)	4.21 (0.03)	4.21 (0.03)	4.21 (0.02)
Org. C (%)	0.87 (0.26)	0.76 (0.28)	1.20 (0.23)	0.94 (0.26)	1.50 (0.09)	1.50 (0.13)	1.47 (0.16)	1.49 (0.13)
Total N (%)	0.14 (0.01)	0.16 (0.01)	0.16 (0.01)	0.15 (0.01)	0.17 (0.01)	0.17 (0.01)	0.15 (0.02)	0.16 (0.01)
Avail. P (p.p.m.)	6.25 (0.46)	6.90 (0.64)	6.38 (0.52)	6.51 (0.54)	5.25 (0.43)	5.25 (0.43)	5.25 (0.43)	5.25 (0.43)
Total P (p.p.m.)	154 (5)	197 (62)	182 (55)	178 (41)	173 (1)	167 (1)	175 (1)	172 (1)
Mn (p.p.m.)	39 (7)	36 (6)	42 (5)	39 (6)	152 (1)	141 (1)	152 (1)	148 (1)
22.5 ha								
pH	4.09 (0.18)	4.08 (0.05)	4.08 (0.22)	4.08 (0.15)	4.35 (0.13)	4.25 (0.07)	4.12 (0.04)	4.24 (0.08)
Org. C (%)	1.27 (0.06)	1.27 (0.08)	1.15 (0.08)	1.23 (0.07)	1.53 (0.11)	1.55 (0.09)	1.56 (0.15)	1.55 (0.12)
Total N (%)	0.13 (0.01)	0.14 (0.01)	0.13 (0.01)	0.13 (0.01)	0.16 (0.01)	0.16 (0.01)	0.16 (0.01)	0.16 (0.01)
Avail P (p.p.m.)	6.75 (0.71)	6.62 (0.74)	6.12 (0.35)	6.50 (0.60)	5.38 (0.99)	5.00 (0.29)	5.25 (0.83)	5.21 (0.70)
Total P (p.p.m.)	187 (22)	158 (9)	160 (16)	168 (16)	175 (14)	173 (11)	177 (8)	175 (11)
Mn (p.p.m.)	41 (5)	38 (4)	37 (3)	39 (4)	146 (20)	161 (12)	152 (13)	153 (15)

Figures within brackets are values of standard deviation (SD).

S_1, S_2, S_3 = *One composite sample from ten, twenty and thirty random points, respectively.*

with different terrains and in different geographical regions were thus further studied.

Comparison of mean values given in *Tables 2* and *3* showed no significant differences between the four intensities of leaf sampling for most of the nutrients analysed. Although *Areas I - IV*, are located on different slope classes, no significant differences were obtained. Of particular interest are *Areas I* and *II*. The slopes are steep and foliar sampling over the entire area was difficult. In addition, all the four areas were located in widely different geographical regions in Peninsular Malaysia. The fact that variability of means at L_1, L_2, L_3 and L_4 was small, suggested that the intensity of sampling was not influenced by the location of the areas even though the areas were situated in widely different climatic zones.

Figures 1 and *2* show the mean coefficient of variation (CV) in relation to intensity of sampling; CV of Mn was high and the highest value appeared to be in *Area II*. Total Mn contents in leaves in *Area II* were generally small and this could possibly account for the high CV. As the intensity of sampling L_1 was increased to L_4, there appeared to be no improvement in the precision of analysis, with CV, for N, P and K remaining below 10% in almost all the areas. Problems arising out of sampling in steep areas and the selection of suitable leaves (of similar leaf age), could possibly give rise to the large variation in Ca and Mn values. Other factors contributing to the high CV could be due to laboratory error[6].

Coefficients of variation at intensity L_1 were comparable to those at L_4. These small differences in CV as well as the mean values suggest that foliar sampling in areas on homogenous soils can be carried out at lower intensity, *viz.* 15 trees/15 ha, when the availability of good leaves is scarce or when the leaves are at a position too high to be sampled.

Mean values of nutrient contents in petioles did not show significant variations. However, CV of replicate samples showed that the determination of nutrients in petioles could not be done at a higher precision than those of the laminae *(Figures 3* and *4)*. Despite higher K, Ca and Mn values, the mean CV ranged from 5.8% - 11:7%, 8.6% - 21.4%, 11.2% - 20.7% compared with 4.0% - 10.8%, 6.4% - 12.9%, 10.6% - 24.1% for laminae. A significant improvement in the precision of results was noted when the intensity of sampling was increased from L_1 to L_4, contrary to what was obtained for laminae. This effect is most pronounced in *Areas I* and *II* with slopes of 10% - 65%. Yew and Pushparajah[10] found that K in petioles and leaf stalks were the most sensitive in gauging the nutritional status of rubber. When the collection of good leaf laminae samples is not possible as a result of severe leaf diseases and irregular wintering, Yew and Pushparajah[10] showed that petioles could be used as alternative tissues for determining the nutrient requirement of rubber. When petioles are used as alternative tissues, the intensity of sampling is increased so that the accuracy and precision of results are not affected.

The effects of sampling intensity on chemical soil test results are shown in *Tables 12* and *13;* pH, C and N appeared to have consistently lower coefficients of variation for all sampling intensities. Mean CV for available P, total P and Mn are erratic. Reports of cross-check exercises[11] showed that available P, total P, exchangeable and acid-extractable cations had very high inter-laboratory variability with mean CV of 100% for exchangeable and acid-extractable cations. Due to the large variations, these parameters were classified as 'problem' parameters. Even for a homogenous soil like the Rengam series soil, the precision of chemical soil tests could not be improved by merely increasing the field sampling intensity. Laboratory errors alone contribute significantly to the inconsistencies of the results. Compared with other soils, the Rengam series soil is more homogenous. However, within itself, soil heterogeneity still exists.

Where management inputs are maintained at a high level as in the areas studied, it is anticipated that variations may be due to the inherent soil chemical properties. If the inherent chemical properties are uniform, variation of mean values would be at a minimum and this was demonstrated by the good agreement in soil test values for all the intensities of sampling.

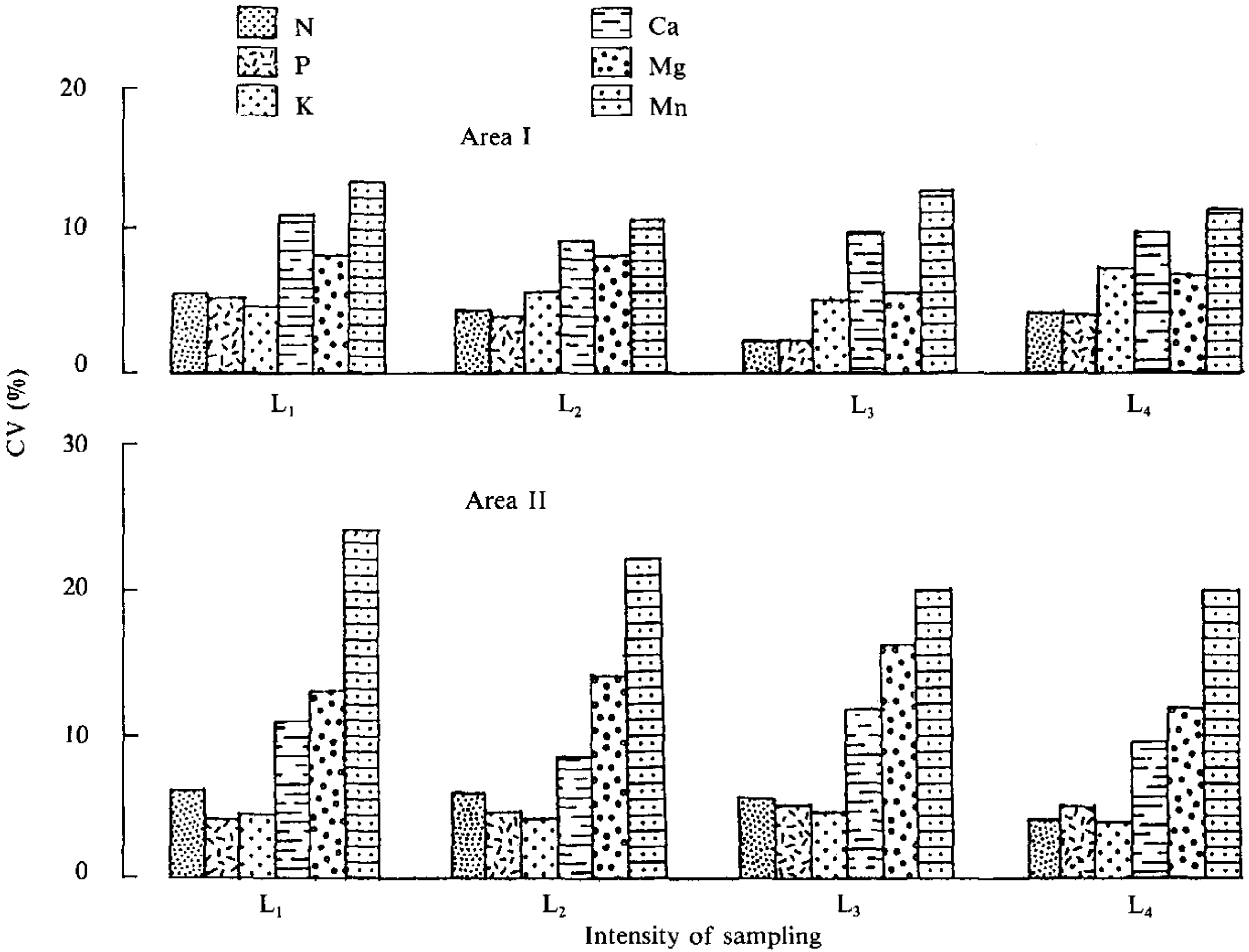

Figure 1. Mean coefficients of variation in relation to intensity of sampling of leaves in Areas I and II.

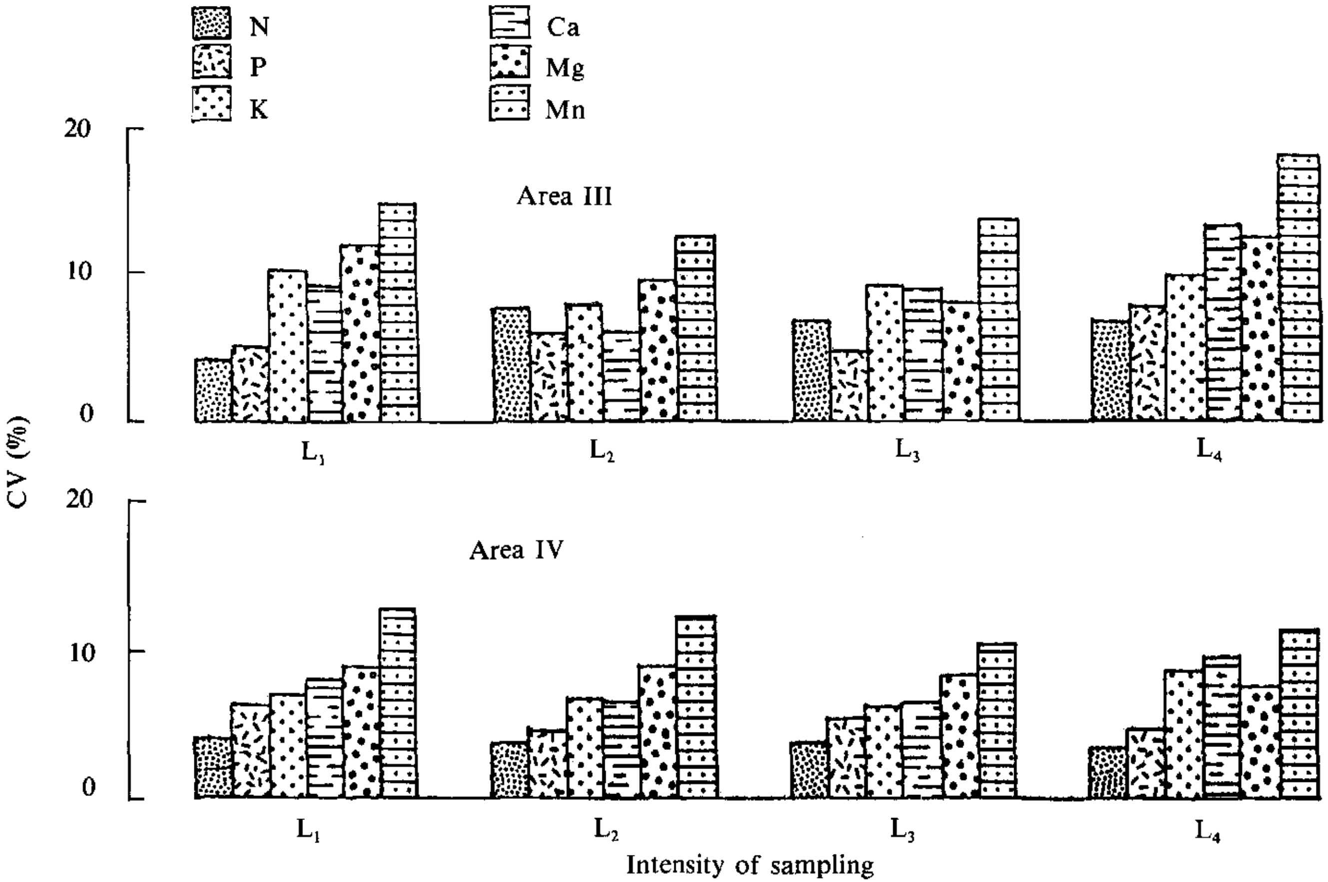

Figure 2. Mean coefficients of variation in relation to intensity of sampling of leaves in Areas III and IV.

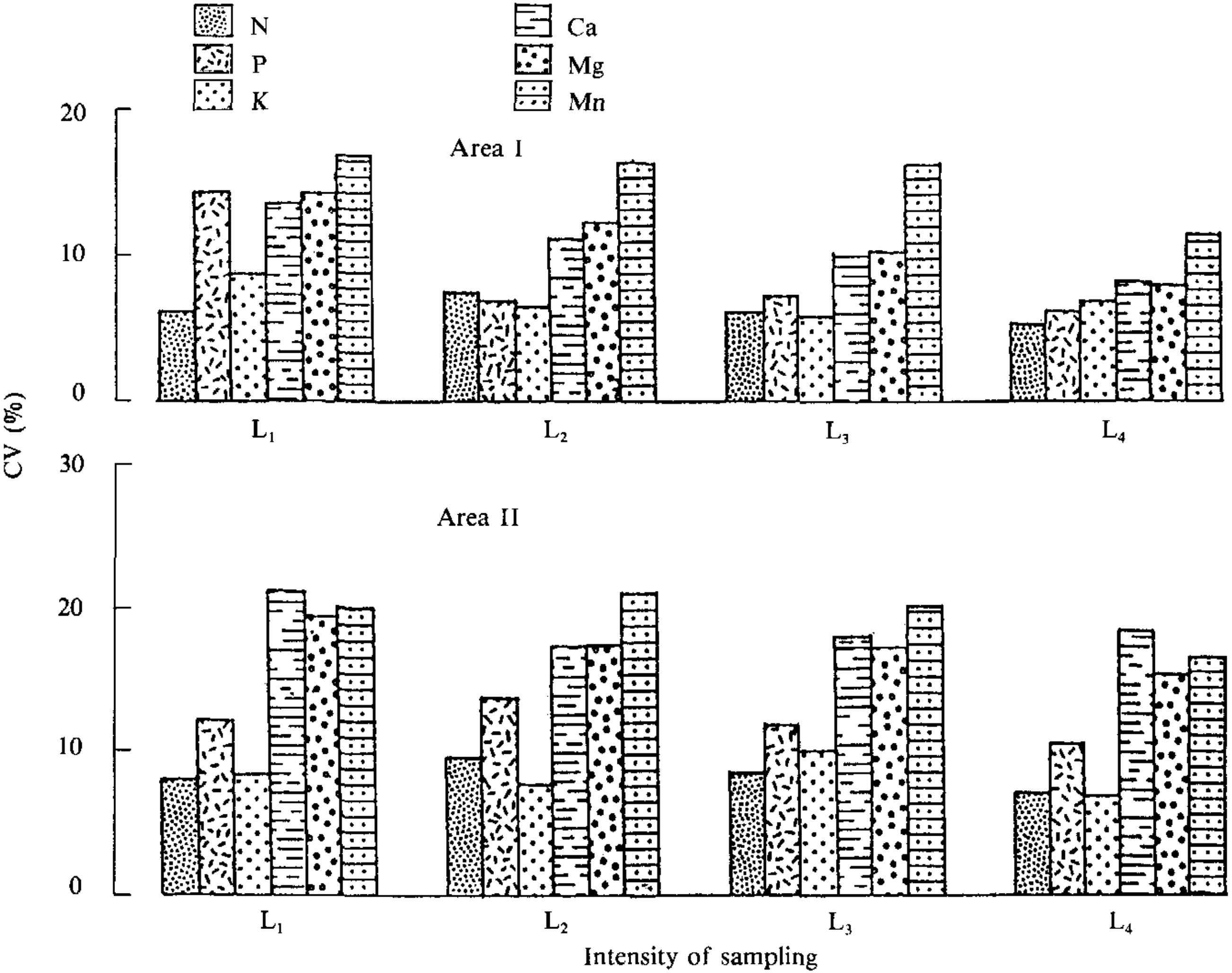

Figure 3. Mean coefficients of variation in relation to intensity of sampling of petioles in Areas I and II.

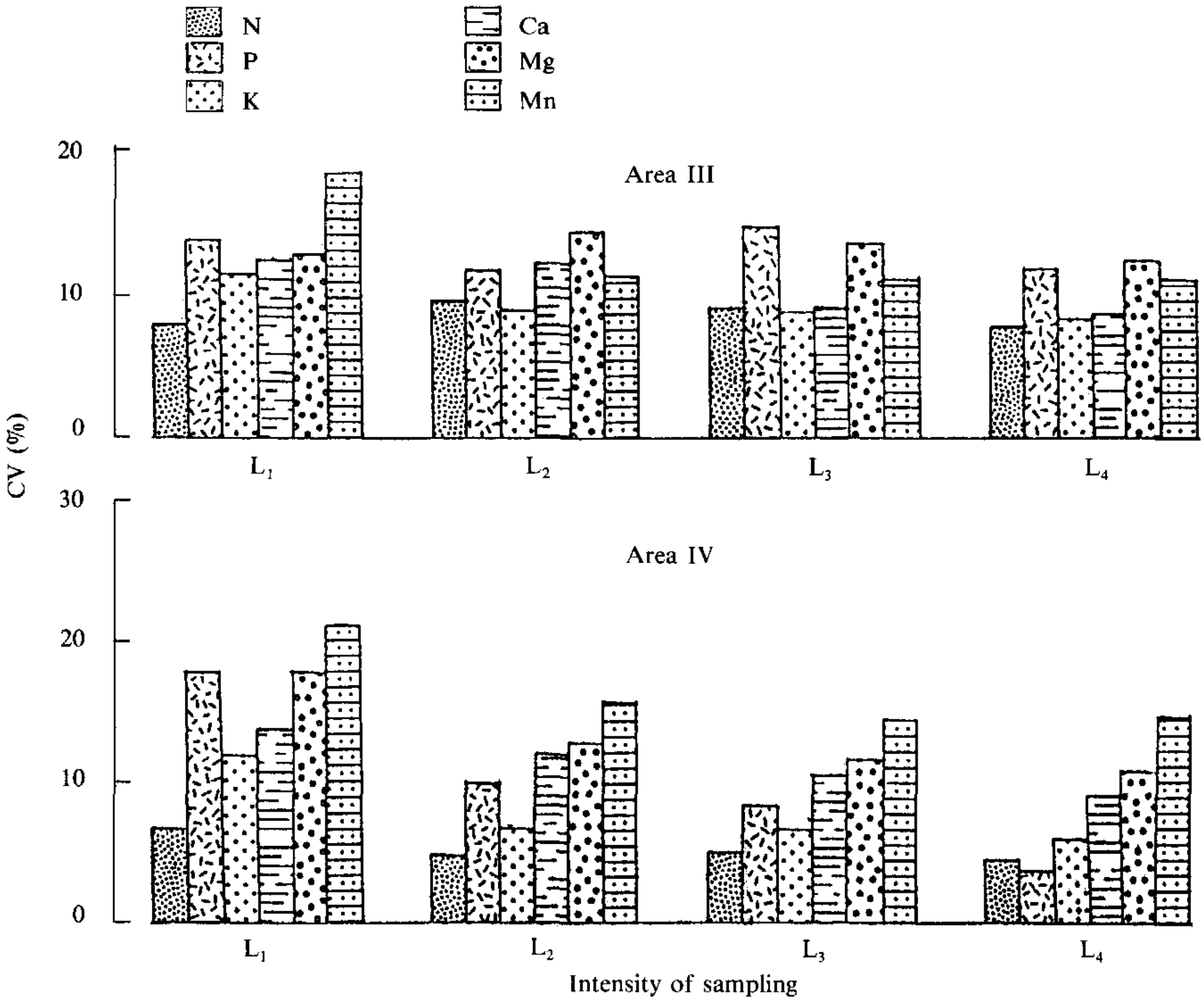

Figure 4. Mean coefficients of variation in relation to intensity of sampling of petioles in Areas III and IV.

TABLE 12. MEAN COEFFICIENT OF VARIATION OF SOIL CHEMICAL ANALYSIS (TOP-SOIL) IN AREAS I AND II

Nutrient	CV (%)							
	I				II			
	S_1	S_2	S_3	Mean	S_1	S_2	S_3	Mean
7.5 ha								
pH	1.9	2.3	2.8	2.3	—	1.4	1.2	1.3
Org. C (%)	12.5	11.7	10.8	11.7	11.3	9.2	5.5	8.7
Total N (%)	7.7	15.4	7.7	10.3	11.8	11.1	5.3	9.4
Avail. P (p.p.m.)	13.2	12.0	10.5	11.9	16.2	15.7	10.1	14.0
Total P (p.p.m.)	10.0	8.9	7.5	8.8	5.9	5.9	3.8	5.2
Mn (p.p.m.)	22.0	18.6	18.4	19.7	12.1	6.8	7.7	8.9
15.0 ha								
pH	2.1	1.2	1.2	1.5	1.2	1.9	1.0	1.4
Org. C (%)	8.4	6.6	5.8	6.9	6.7	8.5	9.0	8.1
Total N (%)	7.1	7.1	15.4	9.9	5.0	9.5	4.8	6.4
Avail. P (p.p.m.)	21.5	4.2	5.7	10.5	25.8	19.7	29.3	24.9
Total P (p.p.m.)	8.5	6.2	3.6	6.1	10.5	10.9	9.3	10.2
Mn (p.p.m.)	9.8	7.4	10.5	9.2	16.6	13.0	16.5	15.4
22.5 ha								
pH	2.4	1.4	1.6	1.8	3.3	1.2	1.7	2.1
Org. C (%)	14.7	9.6	7.4	10.6	4.8	6.3	4.9	5.3
Total N (%)	8.3	7.7	7.7	7.9	5.0	5.2	5.0	5.1
Avail. P (p.p.m.)	15.5	6.0	14.1	11.9	37.5	16.1	21.1	24.9
Total P (p.p.m.)	7.9	4.9	5.6	6.1	7.7	6.2	7.6	7.2
Mn (p.p.m.)	11.2	5.5	6.9	7.9	9.8	10.0	7.4	9.1
Mean	10.3	7.6	8.0		11.2	8.8	8.4	

TABLE 13. MEAN COEFFICIENT OF VARIATION OF SOIL CHEMICAL ANALYSIS (TOP-SOIL) IN AREAS III AND IV

Nutrient	CV (%)							
	III				IV			
	S_1	S_2	S_3	Mean	S_1	S_2	S_3	Mean
7.5 ha								
pH	1.9	2.1	1.2	1.7	2.1	0.7	1.6	1.5
Org. C (%)	7.6	7.0	11.0	8.5	6.0	8.5	7.6	7.4
Total N (%)	7.1	7.1	14.3	9.5	5.6	5.9	11.1	7.5
Avail. P (p.p.m.)	10.2	16.0	8.7	11.6	10.8	10.0	9.2	10.0
Total P (p.p.m.)	12.8	9.7	11.5	11.3	9.7	7.1	7.3	8.0
Mn (p.p.m.)	9.9	6.9	5.8	7.5	28.3	14.0	21.4	21.2
15.0 ha								
pH	1.6	2.6	2.4	2.2	0.2	0.7	0.7	0.5
Org. C (%)	29.9	36.8	19.2	28.6	6.0	8.7	10.9	8.5
Total N (%)	7.0	6.3	6.3	6.5	5.9	5.9	13.3	8.4
Avail. P (p.p.m.)	7.4	9.3	8.2	8.3	8.2	8.2	8.2	8.2
Total P (p.p.m.)	26.9	31.2	30.3	29.5	—	—	—	—
Mn (p.p.m.)	16.9	17.2	11.9	15.3	—	—	—	—
22.5 ha								
pH	4.1	1.2	5.4	3.6	3.0	1.6	1.0	1.9
Org. C (%)	4.7	6.2	7.0	6.0	7.2	5.8	9.6	7.5
Total N (%)	7.7	7.1	7.7	7.5	6.3	6.3	6.3	6.3
Avail. P (p.p.m.)	10.5	11.2	5.7	9.1	18.5	5.8	15.8	13.4
Total P (p.p.m.)	12.0	6.0	10.2	9.4	7.8	6.6	4.9	6.4
Mn (p.p.m.)	12.2	10.1	8.6	10.3	13.8	7.4	8.3	9.8
Mean	10.6	10.8	9.7		8.7	6.5	8.6	

CONCLUSION

Mean N, P, K, Ca and Mg contents of laminae and petioles sampled at intensities of 15, 30, 45 and 60 trees for 7.5, 15.0, and 22.5 ha plots do not show significant differences. Precision of results is not enhanced even though there is an increase in the intensity of sampling. For rubber grown on more homogenous soils and in areas where the level of management input is high, mean leaf values are unlikely to show high variability. Based on the above studies, it can be recommended that sampling size can be reduced to fifteen trees without significant loss in reliability of results. Thus, this measure can be adopted for areas where sampling is difficult as a result of steep terrain, irregular 'wintering', high incidence of leave diseases, and, 'self-pruning' habits of some of the recently developed precocious clones resulting in insufficient amount of good representative leaves for sampling.

When petioles are used for assessing nutritional requirement of rubber, a higher level of intensity of sampling should be used.

Of all the chemical soil tests studied, soil pH, organic carbon and nitrogen appeared to be the least variable. Based on these results, the current practice of collecting one composite sample from ten random points over an area of 15 ha for the determination of pH, organic carbon and nitrogen is sufficient. Values for soluble and total P, exchangeable and acid-extractable cations and total Mn showed significant variability. Increasing the sampling intensity does not improve the precision of test results. Arising from this, variability of results from laboratory analysis merits further investigation.

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