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STUDY OF SOIL-PLANT INTERRELATIONSHIP IN *HEVEA*: A FACTOR ANALYSIS APPROACH

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An understanding of the numerous soil factors affecting soil fertility is a prerequisite to proper management of soils for better growth and yield of *Hevea*. Soil samples collected from 14 sites planted with clone RRII 105 in 1994 spread out in Thrissur district of Kerala State were analysed for pH, organic carbon, available P, exchangeable Ca, Mg, K, Na and Al and DTPA extractable Fe, Mn and Zn. The data subjected to factor analysis using varimax rotation showed that there were two major factors indicating the latent structure, which included soil reaction control factor and P limiting factor. It was seen that the former factor got higher positive loading from exchangeable Ca, Mg, K, and Na while exchangeable Al and DTPA-Zn contributed negatively. The latter factor is regulated positively by pH and Mn and negatively by exchangeable Al and P. Regression analysis of tree volume and factor scores revealed that P limiting factor essentially influences the plant growth.

Key words: Factor analysis, *Hevea brasiliensis* P limiting factor, Soil reaction controlling factor.

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INTRODUCTION

Soil is an important environmental component influencing the establishment, growth and yield of *Hevea brasiliensis*. An understanding of numerous soil factors affecting soil fertility is a prerequisite to proper management of soils for better growth of the rubber plant. Understanding of soil with regard to a crop includes the study of not only the characteristics of the soils but also their influences on the growth of the given crop either directly or indirectly (Rao, 2000).

The rubber plantation industry in India has scientific research support for the last four decades. The crop management practices adopted in India in the initial stages were a first approximation depending on the data generated in other countries, where the research began in the early twenties (Krishnakumar, 1989). For efficient management, there is the definite need for specific recommendations based on the prevailing agro-ecological and agro-climatological conditions of the country.

For such recommendations to come out, data generation and its careful handling for a meaningful interpretation are pre-requisites. In general, correlation studies are taken up to relate a set of parameters of interest, which however, do not reveal the latent structure of the data. Factor analysis is a statistical technique to reduce the number of variables and to detect the structure of the relationship between variables so that the variables can be classified (Thurstone, 1931). However, meagre information is available regarding the use of factor analysis, relating it to rubber cultivation in India. Recently, Rao (2000) reported the use of such multivariate statistical analytical techniques while processing the data on soil.

In the present study, factor analysis was applied to reduce the dimensionality of the data and to understand the behaviour of *Hevea* in different soils. Regression analysis was also done to relate growth in terms of tree volume and factor scores derived after factor analysis.

MATERIALS AND METHODS

Fourteen different sites within the physiographic unit, K11 (Krishnan *et al.*, 1996) spread over Thrissur district of Kerala, planted with the popular clone of rubber RRII 105 in 1994 and maintained under the generally recommended management practices were selected. Soil samples were collected from pits, near the plant base, of 0-30 cm depth from all the 14 sites.

Soil texture (international pipette method) and field capacity (pressure plate method) were determined. Soil pH in 1:2.5 soil water suspensions was measured for all the samples. Organic carbon (OC) was estimated by Walkley and Black method. Exchangeable bases *viz.*, Ca, Mg, K and Na were determined by ammonium acetate method using AAS (for Ca and Mg) and flame photometry (for K and Na). Exchangeable Al was determined in1*N* KCl extracts by using aluminon reagent. DTPA exchangeable Fe, Mn and Zn were estimated by AAS.

From each site, plant height was measured up to the tip of the plants using a foldable aluminium rod with measuring scale and girth was recorded at 10 cm height from the bud union for 25 plants. The tree volume was calculated using a formula of quarter-girth method with a form factor of 0.6.

$$\text{Volume} = (G/4)^2 / H \times 0.6$$

where G = Girth
H = Height

The data were subjected to correlation studies and also to factor analysis with varimax rotation. Multiple regression analysis was done with tree volume as dependent variable and factor scores as independent variables. All the analyses were done using SPSS version 9.0.

RESULTS AND DISCUSSION

The taxonomy of majority of the soils of the experimental sites appeared to be similar at order level but different at lower levels. The soils belonged to Ustoxic Kanhaplohumults, Ustoxic Dystropepts, Typic Kandihumults (Table 1) with differences in soil particle size and textures, which might influence the field capacity of the soils. It was seen that 13 sites belonged to Ultisols and only one to Inceptisol (NBSS & LUP, 1999). Gravel content, which determines the effective soil volume, varied from 0 to 32.4 per cent in the top 30 cm layer in the study areas (Table 1).

The soils of different sites also varied in chemical properties. Soil pH ranged from 4.4 to 5.9 in the experimental sites (Table 2). A low level of OC (0.3%) was found in Site 3 and a high level (1.71%) was seen in Site 7 indicating the wide range among the soils tested. The available P content was between 8.3 ppm (Site 7) and 49.0 ppm (Site 2).

Wider variations were observed in the exchangeable Ca content from 58 ppm (Site 14) to 448 ppm (Site 5). Similarly, the quantity of exchangeable Mg also showed variation from 15 ppm (Site 14) to 199 ppm (Site 4). Low exchangeable K content (40 ppm) was measured in Site 1 and high (166 ppm) in Site 5. However, unlike other exchangeable bases, exchangeable Na did not show much variation among the soils. The lowest content (33 ppm) was seen in the soil belonging to Site 8 and the highest (53 ppm) in Site 6. Exchangeable Al content showed wide differences. The lowest level (0.2 ppm) of exchangeable Al was measured in Site 11 and the highest (28.7 ppm) in the soil of Site 2.

The DTPA exchangeable elements Fe, Mn and Zn were measured in the soils of all the experimental sites. DTPA-Fe exhibited wide variations in these soils from 43 ppm (Site 4) to 474 ppm (Site 2). Similarly, in the case of DTPA-Mn, a very low of 44 ppm in Site 8 and a high of 321 ppm in Site 1 were noticed. DTPA-Cu showed variations from 2.6 ppm in Site 4 to 52.4 ppm in Site 11. A

Table 1. Physical properties and soil taxonomy of experimental sites

Site No.	Sand	Silt	Clay (%)	Gravel	FC	Taxonomy
1	56.8	11.2	32.0	32.3	25.4	Clayey, kaolinitic, isohyperthermic Ustoxic Kanhaplohumults
2	60.0	9.6	30.4	16.4	20.4	Fine loamy, mixed, isohyperthermic Ustoxic Dystropepts
3	53.6	9.6	36.8	32.4	21.1	Clayey, kaolinitic, isohyperthermic Typic Kanhaplustults
4	52.0	8.0	40.0	22.4	27.3	Clayey, kaolinitic, isohyperthermic Typic Kanhaplustults
5	44.0	9.6	46.4	25.0	22.7	Clayey, kaolinitic, isohyperthermic Typic Kanhaplohumults
6	44.0	12.8	43.2	16.9	27.5	Clayey, kaolinitic, isohyperthermic Typic Kanhaplohumults
7	60.0	12.8	27.2	4.7	28.8	Clayey, kaolinitic, isohyperthermic Ustic Kandihumults
8	47.2	9.6	43.2	19.0	18.7	Clayey, kaolinitic, isohyperthermic Typic Kanhaplustults
9	61.6	8.0	30.4	24.5	18.9	Clayey-skeletal, kaolinitic, isohyperthermic Typic Kanhaplustults
10	55.2	12.8	32.0	9.0	20.4	Fine loamy, mixed, isohyperthermic Typic Kanhaplustults
11	52.0	11.2	36.8	7.4	17.0	Fine loamy, mixed, isohyperthermic, Typic Kanhaplustults
12	47.2	8.0	44.8	22.4	20.5	Clayey, kaolinitic, isohyperthermic Typic Kanhaplustults
13	53.6	8.0	38.4	24.0	19.1	Clayey-skeletal, kaolinitic, isohyperthermic Typic Kanhaplustults
14	52.0	6.4	41.6	0.0	18.0	Clayey, kaolinitic, isohyperthermic Typic Kandihumults

Table 2. Soil properties and tree volume (November 1996)

Site No.	pH	OC (%)	N (%)	Av.P (ppm)	Exchangeable elements (ppm)					DTPA extractable elements (ppm)				Volume dm^3
					Ca	Mg	K	Na	Al	Fe	Mn	Cu	Zn	
1	4.8	1.17	0.16	12.5	149	46	40	38	12.5	171	321	52.4	2.5	9.5
2	4.4	0.81	0.12	49.0	86	20	45	35	28.7	474	130	9.3	4.5	14.3
3	5.2	0.30	0.10	15.0	250	78	73	38	10.2	112	178	4.1	1.5	8.5
4	4.6	0.66	0.10	10.0	320	199	154	51	11.6	43	201	2.6	2.0	9.4
5	5.5	1.50	0.14	11.2	448	143	166	39	3.6	137	293	4.0	3.5	7.6
6	5.5	0.51	0.09	16.6	388	159	101	53	1.7	116	258	18.9	2.5	10.7
7	4.9	1.71	0.22	8.3	395	46	148	39	10.4	160	65	38.5	3.0	13.3
8	4.8	0.57	0.11	41.7	106	24	81	33	24.2	95	48	3.1	13.0	18.6
9	5.3	1.05	0.11	21.6	230	83	83	36	12.5	182	44	4.7	1.5	13.0
10	5.5	0.78	0.11	12.5	286	110	38	41	2.9	333	305	6.1	2.5	10.3
11	5.9	0.66	0.07	12.5	356	136	78	40	0.2	184	255	27.5	3.5	9.7
12	5.3	0.78	0.10	13.3	176	69	51	35	11.2	87	228	4.2	18.0	8.8
13	5.0	0.78	0.12	12.5	78	26	52	34	21.7	124	234	22.2	4.0	13.3
14	4.8	0.75	0.09	17.4	58	15	60	34	22.9	79	151	14.7	4.0	11.4

low Zn content of 1.5 ppm (Sites 3 and 9) and high quantity of 18 ppm in Site 12 were recorded. The calculated tree volume ranged from 7.6 dm^3 in Site 5 to 18.6 dm^3 in Site 8.

The correlation coefficients are given in Table 3 indicating the relationships between the tree volume and the soil properties measured in all the 14 sites. The tree volume in the test sites showed a significant positive correlation (0.715**) with available P. The relationship between tree volume and exchangeable Al also was positive and significant (0.674**). Among the negative relationships, the correlation of tree volume with exchangeable Mg (-0.583*) and with DTPA-Mn (-0.721**) were significant.

Among soil properties, the correlation between available P and exchangeable Al was positive and significant (0.682**). According to Kirkby and Nye (1986), the dissolution of phosphate rock is very sensitive to pH. It was also seen that the soil pH is influenced by exchangeable Al and hence the negative relation between exchangeable Al and soil pH (-0.823**). The dissolution of Al bound P also releases Al thus leading to a positive correlation between available P and exchangeable Al. Karthikakuttyamma *et al.* (1991) also reported that Al bound P was positively correlated with available P in some rubber growing soils. Bolan and Hedley (1990) observed that increased soil acidity could increase the P adsorptive capacity of soils with pH dependent changes. This could also increase the dissolution of rock phosphate by removing P released from the phosphate rock. As could be anticipated, the relationship among the exchangeable bases was positive. Exchangeable Al has a negative correlation with exchangeable Ca, Mg and Na.

The data were subjected to factor analysis to study the latent structure and also to reduce the dimensionality of the data (Table 4). The effects of the derived factors were tested by multiple regression analysis using factor scores and tree volume as inputs, the results of which are in given in Table 5. A total of four factors were identified and only the first two were retained as they together contributed about 60 per cent to the variability.

It was clearly seen that the first factor was associated with exchangeable Ca, Mg, Na, K, Al and Zn, characterized by higher factor loadings (0.714, 0.837, 0.709, 0.901, –0.491 and –0.532 respectively), which are known to influence the soil reaction as could be seen in the correlation analysis. It appeared that this first factor might be ruling the soil environment by regulating the soil pH, which determines the solubility of several minerals. But interestingly, the soil pH itself did not contribute a high loading on this factor. This factor has highest Eigen value of 4.886, which could be called "soil reaction control factor" explaining a large portion of the variability (44.4%) among the soils (Table 4).

It could also be seen that the availability of P was associated with factor 2 and

Table 3. Coefficients of correlation between tree volume and soil properties

	Volume	pH	Av.P	Ca	Mg	Na	Al
Av.P	0.715**	-0.471					
Ca	-0.490	0.581*	-0.527				
Mg	-0.583*	0.480	-0.461	0.779**			
K	-0.171	0.053	-0.314	0.732**	0.564*		
Na	-0.399	0.201	-0.371	0.654*	0.846**		
Al	0.674**	-0.823**	0.682**	-0.856**	-0.763**	-0.596*	
Mn	-0.721**	0.421	-0.507	0.256	0.429	0.353	-0.542*

** $P \leq 0.01$; * $P \leq 0.05$

Table 4. **Factor analysis of soil data (November 1996)**

Soil properties	Communality	Factor 1	Factor 2	Factor 3	Factor 4
pH	0.742	0.106	0.851	0.014	-0.078
OC	0.931	-0.055	0.029	0.957	0.108
Av.P	0.733	-0.257	-0.683	-0.31	0.324
Exch. Ca	0.904	0.714	0.472	0.412	-0.044
Exch. Mg	0.912	0.837	0.438	-0.089	-0.105
Exch. K	0.937	0.709	-0.106	0.552	-0.343
Exch.Na	0.897	0.901	0.226	-0.185	-0.011
Exch. Al	0.940	-0.491	-0.822	-0.144	0.045
DTPA - Fe	0.887	-0.178	-0.092	-0.032	0.920
DTPA - Mn	0.674	0.094	0.773	-0.195	0.174
DTPA - Zn	0.609	-0.532	-0.069	-0.188	-0.535
Eigen value		4.886	1.688	1.345	1.246
% variance		44.4	15.3	12.2	11.3

other soil variables were either influencing it or being influenced. The second factor has got an Eigen value of 1.688, which explained 15.3 per cent of the variability among the soils. It had positive loadings of soil pH and DTPA-Mn (0.851 and 0.773 respectively) indicating closer correlation of these two with the second factor. The second factor had negative loading by available P (-0.683) and exchangeable Al (-0.822). This factor could be named as P limiting factor because of the fact that DTPA-Mn and increasing soil pH reduced the availability of P and also that increasing exchangeable Al has a positive role in enhancing the P availability. The antagonism between Mn and P is possible because of formation of a complex of Mn and P thus inactivating the P uptake. According to Kabata-Pendias and Pendias (1992), the interaction of Mn and P may be cross-linked with Fe and P antagonism.

The factor scores of all the 14 sites were calculated and were included in the multiple regression to understand the influence of the factor scores on the plant performance. The results of the regression are presented in Table 5. It was observed that the availability of P had significant influence on plant growth as indicated by tree volume. The coefficient for P limitation factor obtained in multiple regression analysis of factor scores and tree volume indicated that elimination of the P limitation factor had a positive influence on growth. Only one factor was found significantly related to plant growth, which showed that P was limiting by reasons like inherent deficiency of P or antagonism in P availability, availability of soil moisture, soil temperature or a combination of the above (Rao, 2000).

Factor analysis attempts to identify the underlying variables or factors that explain the pattern of correlation within a set of observed variables. Factor analysis is often

Table 5. **Multiple regression analysis of factor scores and tree volume**

Variables	Unstandard Coefficient B	Standard Error	Standard Coefficient Beta	t	Significance **
(Constant)	11.303	0.606		18.641	0.000
Factor 1	-0.860	0.629	-0.292	-1.368	0.205
Factor 2	-2.080	0.629	-0.707	-3.305	0.009
Factor 3	0.089	0.629	-0.030	-0.142	0.890
Factor 4	0.138	0.629	0.047	0.219	0.832

$R^2 = 0.588$

used in data reduction to identify a small number of factors that explain most of the variance observed in a much larger number of manifested variables. It can also be used to generate hypotheses regarding causal mechanisms or to screen variables for subsequent analysis. In the present study, factor analysis could extract two factors (soil reaction control factor and P limitation factor) that are not measured directly and which could explain the variability in the data to a large extent. Such information could not be revealed by correlation studies. Hence it would be appropriate to apply factor analysis identifying the underlying factors when a large set of data from several soils is considered instead of limiting the analysis to simple correlation studies. In the present study, data pertaining to the growth of trees in the first two years only is considered which form a limitation. However, the usefulness of factor analysis is extracting the key factors which contribute to most of the variance is evident.

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