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Volume based expression of soil variables: Good descriptor of soil-plant interrelationships

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This research compared the gravimetric method of expression of soil nutrient concentration with actual soil volume based expression in terms of yield response using rubber as a test crop. A rubber plantation (planted in year 1989 under a NPK fertilizer trial) was investigated. The experiment was laid out with thirteen treatments in three replications in a randomized block design planted with rubber (Clone RRII 105) at a spacing of 4.9 × 4.9 m. Twenty-four trees formed the main plot and 8 trees were used for measurements of plant related and soil parameters. The treatments included selected combinations of N, P and K; three rates of N (30, 60 and 90 kg ha^{-1} year^{-1}), two rates of P (30 and 60 kg ha^{-1} year^{-1}) and two rates of elemental potassium (20 and 40 kg ha^{-1} year^{-1}) and a control (without fertilizer application). Urea, rock phosphate and muriate of potash were applied as source of elements, N, P and K, respectively. All the nutrients were supplied in two equal splits during April-May and September-October every year. During August 1999, soil samples were collected from all the 39 plots from a depth of 0 to 30 cm. From all these plots rubber latex yield data were also recorded simultaneously at the time of soil sampling. Results revealed that soils vary in plant exploitable actual soil volume (ASV) and its contents. However soil nutrients are not widely expressed on volume basis and gravimetric expression can be misleading when ASV is not known. Soils had different descriptive statistics of variables when expressed in both ways. No gravimetric variables were correlated with rubber yield while volumetric Ca correlated significantly (r = 0.576**). Path analysis showed that log P, log Ca, Mg, log Mn and log Fe had prominent direct effects (0.521, 0.944, 0.454, -0.595 and -0.735, respectively) and variable indirect effects through other variables. However, log Ca only yielded significant correlation with yield even after partial neutralization of direct effect with indirect effects. Path analysis revealed prominent interactions through indirect effects although some correlations (sum of direct and indirect effects) were insignificant and described 57% variability indicating the scope for inclusion of other variables to describe yield. The study provided a lead indicating the merit of volumetric expression over gravimetric expression to explore further as these observations are of practical significance in soils with spatially varied contents of coarse fragments.

Key words: Actual soil volume, expression, nutrient content, path analysis, rubber latex yield.

INTRODUCTION

It is difficult to quantify the plant availability of any soil nutrient when the quantity of fine earth exploited by the roots is not known. For instance, consider two jars (with similar volume), one filled with fine earth (<2 mm fraction of soil) and the other filled with fine earth and gravel in equal proportions. When it is described that the available phosphorus content of soils in these jars is 100 µg g^{-1} soil, can it be construed that the plants grown in these jars receive similar supply of phosphorus over a time? Answer is emphatic 'no' because of the

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Table 1. Details of treatments imposed.

Treatment	NPK contents
T_0	Control
T_1	$N_1P_1K_1$
T_2	$N_1P_1K_2$
T_3	$N_1P_2K_1$
T_4	$N_1P_2K_2$
T_5	$N_2P_1K_1$
T_6	$N_2P_1K_2$
T_7	$N_2P_2K_1$
T_8	$N_2P_2K_2$
T_9	$N_3P_1K_1$
T_{10}	$N_3P_1K_2$
T_{11}	$N_3P_2K_1$
T_{12}	$N_3P_2K_2$

N_1, N_2 and N_3 are 30, 60 and 90 kg N ha^{-1} respectively; P_1 and P_2 are 30 and 60 kg P_2O ha^{-1} respectively; K_1 and K_2 are 20 and 40 kg K_2O ha^{-1} respectively.

difference in the plant root exploitable actual soil volume in the jars.

Most of the literature expresses nutrient concentration in the soils on a weight basis. Literature using a volume-based expression of soil nutrient concentration is limited. Mehlich (1972) expressed soil elements in volumetric terms considering volume weight or bulk density (BD) in order to attain uniformity for comparing analytical results throughout a spectrum of laboratories. Although BD or volume weight based calculation of volumetric soil variables is suggested (USDA, 1999) it is less reliable when spatial variability in BD, which is influenced by coarse fragments, is high.

Rubber plant (*Hevea brasiliensis* Muell. Arg.) is grown traditionally in Kerala State of India on more than 0.5 million ha. The gravel, the diluents of volume, in the soils under rubber varied from fine (2 to 5 mm diameter) to medium (5 to 20 mm diameter) in size (Soil Survey Division Staff, 1995) and composed mainly of ironstone and laterite (NBSS and LUP, 1999). Approximately 10% of the surveyed soils has less than 15% gravel while 35% of the soils contained 15 to 34% coarse fragments. Fifty-four percent of the area possesses 35 to 60% gravel while 7% area has higher gravel content of 61 to 80% (NBSS and LUP, 1999). It is observed that the gravel exhibited considerable spatial variability even in a small experimental area (Rao and Jessy, 2007). They also noticed that increased coarse fragments negatively influence growth and yield of rubber. For these reasons, it is hypothesized that volume-based expression of soil parameters might improve the understanding of soil-plant relationship because of three-dimensional nature of soils.

Appropriate statistical tools always aid better inferences and use of path analysis is expanding rapidly by practitioners of the biological and agricultural sciences because of the insights this method of analysis generates from correlational structures (Sokal and Rohlf, 1981). Path analysis partitions correlation into direct and indirect effects and differentiates between correlation and causation (Wright, 1934). Williams et al. (1990) suggest a concise format of tables of path analysis coefficients to ease their viewing for picking out important relationships and discerning patterns among subsets of predictor variables. Accordingly, path analysis that partitions a correlation coefficient into direct effect of given variable ‘x’ and indirect effects of it through other variables namely, ‘y’, ‘z’ etc., is used to understand the net effect of selected variables on the response variable. The interpretation of the path coefficients table goes along the row and each row pertaining to a variable for instance, ‘x’, has the underlined direct effect and other values (in the same row) represent its indirect effects via other variables namely ‘y’, ‘z’ etc. (Rao, 2009). Path analysis has been used rather extensively in agronomic studies to study factors affecting plant yield (Basta et al., 1993). However, little knowledge is available on path analysis of soil variables expressed on volume basis. The present study compared the usually followed gravimetric method of expression of soil nutrient concentration with actual soil volume based expression in terms of yield response using rubber as a test crop.

MATERIALS AND METHODS

Soil sampling

A rubber plantation (planted in year 1989 under a NPK fertilizer trial) was considered for the present study. The experiment was laid out with thirteen treatments in three replications in a randomized block design planted with rubber (Clone RRII 105) at a spacing of 4.9 × 4.9 m (Rao and Jessy, 2007). Twenty-four trees formed the main plot and 8 trees were used for measurements of plant related and soil parameters. The treatments included selected combinations of N, P and K; three rates of N (30, 60 and 90 kg ha^{-1} $year^{-1}$), two rates of P (30 and 60 kg ha^{-1} $year^{-1}$) and two rates of elemental potassium (20 and 40 kg ha^{-1} $year^{-1}$) and a control (without fertilizer application) (Table 1). Urea, rock phosphate and muriate of potash were applied as source of elements, N, P and K, respectively. All the nutrients were supplied in two equal splits during April-May and September-October every year. During August 1999, soil samples were collected from all the 39 plots from a depth of 0-30 cm. From all these plots rubber latex yield data were also recorded simultaneously at the time of soil sampling. Soils within the study area (central coordinates were 9° 10’ 05.2” N and 76° 48’ 26.5” E) were Ustic Kanhaplohumults with nearly level slopes within in an undulated terrain with a gentle slope in all directions from approximately the midpoint of the study area.

Determination of soil variables

Actual soil volume (ASV)

The actual soil volume (volume of < 2 mm size fraction), was measured by core sampling and displacement method (Rao and Jessy, 2007). A 33 cm long metal core with a radius of 2.86 cm was driven into the soil to collect soil samples from the midpoints of all experimental plots. The collected portion of <2 mm was separated from the coarse fragments using a 2-mm sieve. The volume of gravel was determined by the displacement method using a water column. The weight of < 2 mm fraction was recorded. The volume occupied by 100 g sieved soil was also determined by displacement method. This volume–weight was used to calculate the ASV of the soil present in the core, which was extrapolated to find out the ASV per tree in m^3 using the dimensions, 4.9 × 4.9 × 0.33 m.

Soil chemical properties

Organic carbon was estimated by wet oxidation method (Walkley and Black) as outlined by Nelson and Sommers (1996). Bray II extractable P was measured by colorimetry (Jackson, 1958). K was estimated by flame photometry while Ca, Mg, Fe and Mn were determined by atomic absorption spectrophotometry using 0.1 M $BaCl_2$ as an extractant (Hendershot and Duquette, 1986). However, available N was not measured.

ASV-based expression of nutrients

Mean volume of 45.46 cc 100 g^{-1} soil (average of soil volume occupied by 100 g of <2 mm fraction of soil collected from 10 experimental plots, which were selected at random), which equaled to a particle density of 2.2 g cc^{-1}, was used for calculations as inter-plot variability in the volume of 100 g fine earth was significant only at third decimal place. Volume-based soil variables were calculated using the mean volume in the following way. For instance, 'x' % of organic carbon meant 'x' grams of organic carbon (OC) present in 45.46 cc (which was the volume occupied by 100 g soil) and accordingly, the corresponding quantity of OC present in 'y' m^3 ASV could be calculated. Likewise all the soil variables were calculated and expressed on the basis of ASV in each plot and the data were analysed and interpreted, as described below.

Yield data

The description of the rubber-plant tapping system followed and details of stage of maturity of rubber trees to initiate tapping etc. were described by Rao and Jessy (2007). The trees attained tapping stage in 1997 (during eighth year of planting) and monthly yield recording commenced from 1998 (corresponding to ninth year of planting) onwards. Tapping system followed was 1/2S d/4, a notation used to designate the exploitation system, which meant tapping from half spiral cut on the trunk once in four days (Vijayakumar et al., 2000). In the present study, the monthly yield recorded during August 1999 was utilized to explore the relation between yield and volume based soil variables.

Data processing

Initially, the identified outliers were replaced by the values calculated by Expectation-Maximisation method (Snedecor and Cochran, 1989), using a missing value analysis technique. Gravimetric extractable P and K were logarithmically transformed while volume based available P, Ca, Mn and Fe were log transformed to fit into normal distribution to proceed with statistical analysis (Tabachnick and Fidell, 2001).

Variance components, Pearson's correlations, multiple and step down regressions were used to explore the relationship between soil variables and rubber latex yield. 39 transformed values (13 treatments × 3 replications) of all variables were included in the statistical analysis instead of means, to consider the variability both between and within treatments. Correlations were partitioned by path coefficient analysis using the concise table format (Williams et al., 1990). The variables included rubber latex yield and volume based OC, log P, log Ca, Mg, K, log Mn and log Fe. All the statistical analyses were performed with SPSS (Statistical Package for Social Sciences) and Excel (for path analysis).

RESULTS

Soil variables

Actual soil volume

The variations in ASV in the experimental plots (replications and treatments), were shown in Figure 1. The important issue in this dataset was that the mean ASV ranged from 3.0 to 3.4 m^3, which amounted to a 13% difference between the lowest and highest values within these experiment plots. But considerable difference of 41% between the lowest (2.7 m^3 in replication 2 of treatment 2) and highest (3.8 m^3 in replication 3 of treatment 8) plots was observed. The standard deviation of ASV in treatment plots ranged from 0.1 to 0.5 highlighting the non-uniform nature of the soil within treatment plots. Variance component analysis of ASV clearly established that error variance due to replications was 23%, which was also considerable.

Chemical variables

Table 2 described the untransformed soil variables expressed on a weight basis. Different sets of minimum and maximum values were observed in gravimetric soil variables. Volume based soil chemical properties showed yet a different kind of distribution of minimum, maximum and standard deviations of course with some commonalities with gravimetric expression (Table 3).

There were differences in variance components of between the two systems of expression. The error variance due to replications in gravimetric OC was 13% while the error variance approached 0% for other measurements. There was no error due to replication in the remaining gravimetric soil variables while it was 6 and 9% in volume-based K and Ca, respectively. There was an insignificant error due to replication (2%) in Fe.

Rubber latex yield

Figure 2 depicted the contents and variations in yield measured in treatment plots. Variance component

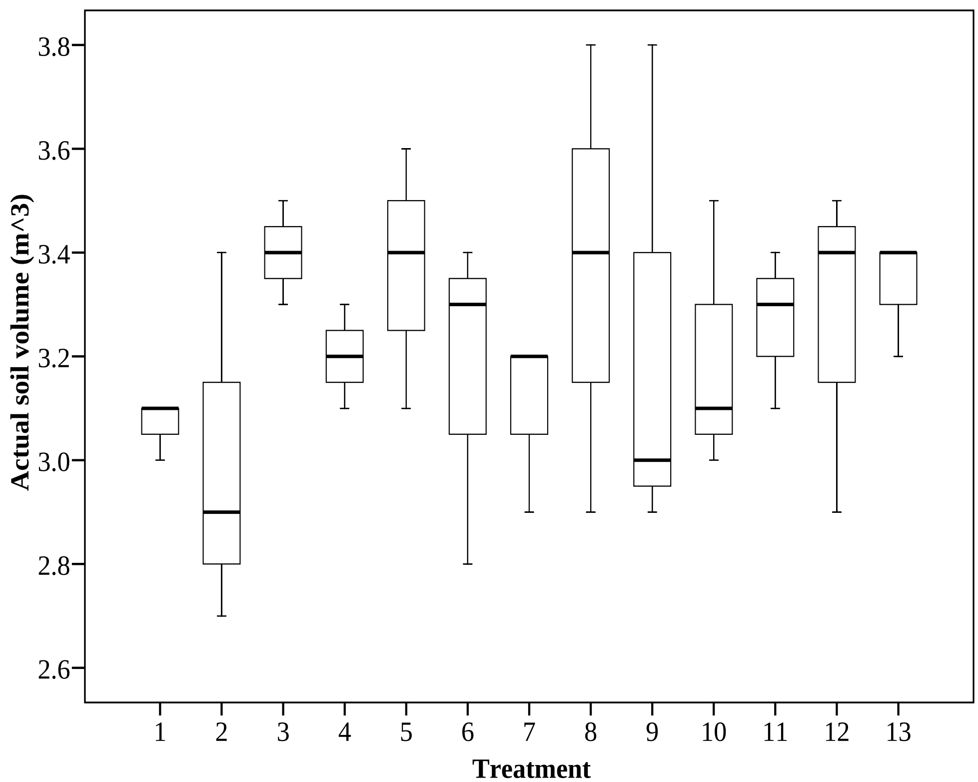

Figure 1. Actual soil volume (m^3) in experimental plots.

analysis highlighted the impact of treatments on yield (98% variance) while the error variance was only 2%. However, the univariate analysis of variance of yield by GLM (general linear model) procedure indicated that treatments had no impact at all on the rubber latex yield ($p = 0.691$).

Inferences from statistical analysis

Correlation studies

None of the gravimetric soil variables showed any significant relation (by Pearson correlation) with response variable while volumetric Ca (log Ca) influenced the yield (0.576^{**}) (significant at 1% level). Though there were different pairs of correlated variables in both systems of expression, it is beyond the scope of this paper to describe them.

Path analysis

The concise format of path coefficient table showed direct effect (underlined coefficient) of a variable and its indirect effects (off diagonal coefficients) through other predictor variables on the response variable, when read horizontally (Table 4). In the present exercise only large path coefficients were interpreted because of the magnitude. A coefficient of correlation is a sum of the direct effect of a variable and its indirect effects through other predictor variables on the response variable and also that the direct effects are the standardized partial regression coefficients. Log P had its direct effect (0.521) on the rubber latex yield with additive indirect effects through log Ca (0.272) and Mg (0.113). However, the opposite indirect effects through log Mn (-0.572) and log Fe (-0.234) were large and nullified the direct effect with almost nil indirect effects via OC and K, resulting in an insignificant correlation between log P and rubber yield ($r = -0.010 + 0.521+ 0.272 + 0.114 +0.038 -0.572 – 0.234 = 0.129$).

Log Ca had a larger direct effect (0.944) on yield with lesser to modest indirect effects through log P, log Mn and log Fe (0.150, -0.214 and –0.358, respectively) and ignorable indirect effects through OC, Mg and K (-0.005, 0.033 and 0.027, respectively). Although there was a partial neutralization of the direct effect by its opposite indirect effects, the resultant correlation was significant (0.576^{**}). In spite of its large direct effect (0.454), the correlation of Mg with yield however, was rendered insignificant ($r = 0.108$) because of nullification of direct effect by its opposite indirect effects through log Fe (-0.405), log Mn (-0.146), log P (0.131) and log Ca (0.069)

Table 2. Descriptive statistics of soil variables expressed gravimetrically.

Treatment	Statistics	OC %	Ca	P	Mg	K	Mn	Fe
			µg g^{-1}soil					
	Min.	1.4	16	5	21	42	2	17
1	Max.	1.5	28	30	26	47	3	30
	SD	0.1	6	14	3	03	1	7
	Min.	1.7	19	12	21	47	2	26
2	Max.	2.1	55	29	31	54	3	42
	SD	0.2	19	9	6	04	1	8
	Min.	1.1	26	12	22	55	2	30
3	Max.	2.5	32	94	51	101	5	46
	SD	0.7	3	43	16	23	2	8
	Min.	1.5	14	20	25	39	2	21
4	Max.	2.1	37	22	27	55	3	30
	SD	0.3	12	1	1	09	1	5
	Min.	1.1	34	18	21	43	2	18
5	Max.	2.2	35	48	34	62	3	36
	SD	0.6	1	17	7	10	1	10
	Min.	1.5	18	16	14	43	1	23
6	Max.	1.6	28	26	39	73	4	28
	SD	0.1	5	6	13	15	2	3
	Min.	1.4	27	23	20	65	2	37
7	Max.	2.5	33	35	31	83	3	45
	SD	0.6	3	6	6	10	1	4
	Min.	1.4	22	41	15	51	1	31
8	Max.	2.0	31	60	36	68	4	36
	SD	0.3	5	10	11	09	2	3
	Min.	0.9	27	32	22	57	2	19
9	Max.	1.6	54	89	33	90	3	34
	SD	0.4	15	29	6	18	1	8
	Min.	1.6	16	32	23	33	2	17
10	Max.	1.8	30	73	44	59	4	27
	SD	0.1	7	23	11	15	1	5
	Min.	1.3	18	8	14	35	1	20
11	Max.	1.9	31	18	31	51	3	24
	SD	0.3	7	6	9	08	1	2
	Min.	1.7	28	20	16	35	2	21
12	Max.	2.1	47	89	24	58	2	33
	SD	0.2	10	35	4	12	0	6
	Min.	1.0	30	19	27	56	3	24
13	Max.	2.3	49	52	41	75	4	28
	SD	0.7	10	17	8	10	1	2

Table 3. Descriptive statistics of soil properties expressed based on actual soil volume.

Treatment	Statistics	OC	Ca	P	Mg	K	Mn	Fe
		kg*		g*			mg*	
1	Min.	95	2.0	34	106	66	5	45
	Max.	103	7.7	206	122	80	7	71
	SD	5	3.0	95	8	7	1	13
2	Min.	101	2.8	70	102	91	6	62
	Max.	136	12.1	186	153	125	19	146
	SD	19	4.8	58	29	17	7	42
3	Min.	81	2.8	89	107	105	7	77
	Max.	184	7.7	221	131	227	15	112
	SD	53	2.6	75	12	61	4	19
4	Min.	100	2.6	142	122	65	4	61
	Max.	151	10.5	159	138	129	10	82
	SD	26	4.0	10	8	34	3	12
5	Min.	74	6.1	123	105	53	8	66
	Max.	166	9.0	364	174	153	14	83
	SD	46	1.5	136	35	51	3	9
6	Min.	94	4.3	99	74	74	3	35
	Max.	118	5.2	188	197	128	12	112
	SD	13	0.5	51	63	27	5	39
7	Min.	94	7.4	148	99	122	6	83
	Max.	159	9.0	243	156	225	11	137
	SD	33	0.8	50	29	58	3	30
8	Min.	103	3.3	285	74	85	4	51
	Max.	167	6.2	497	182	155	9	145
	SD	32	1.4	117	55	35	3	48
9	Min.	70	6.7	214	110	81	7	61
	Max.	101	8.2	368	171	158	9	80
	SD	17	0.8	87	31	41	10	10
10	Min.	106	3.5	221	113	59	6	60
	Max.	132	6.8	496	224	122	9	104
	SD	13	1.6	151	56	34	2	23
11	Min.	93	5.8	55	72	53	4	34
	Max.	134	7.8	129	154	107	10	84
	SD	21	1.0	41	43	27	3	25
12	Min.	125	6.2	153	76	79	6	45
	Max.	156	9.2	560	114	108	13	87
	SD	17	1.7	206	21	15	4	24
13	Min.	75	10.2	141	131	81	9	80
	Max.	161	14.5	394	207	184	16	111
	SD	45	2.3	128	41	58	4	16

* per ASV.

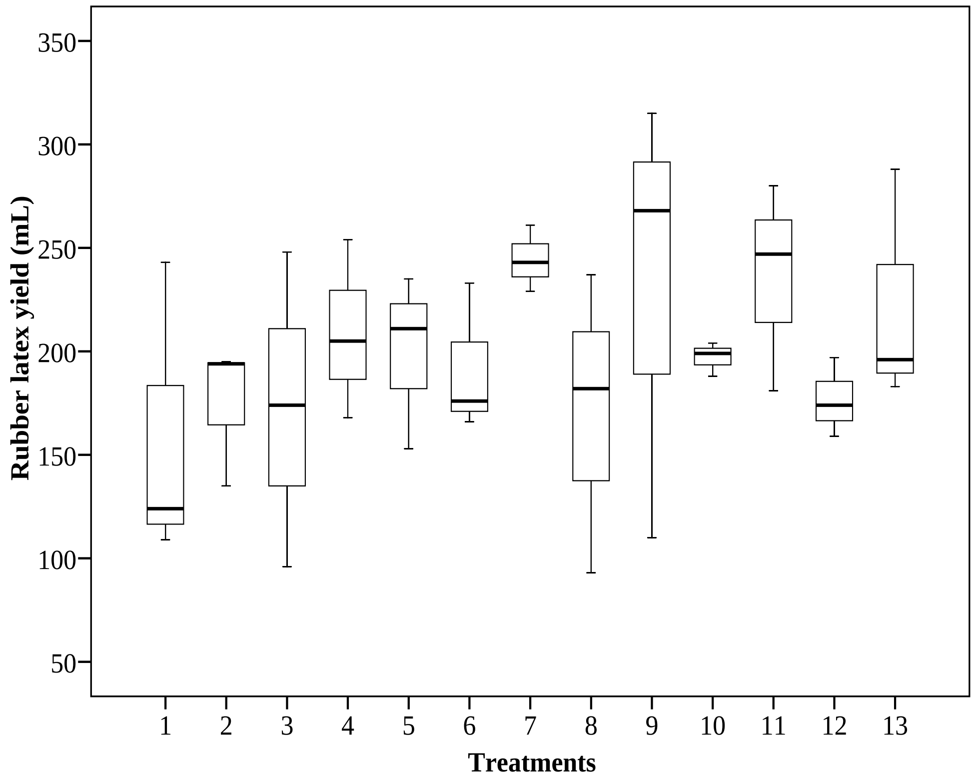

Figure 2. Rubber latex yield (mL) measured in treatments.

Table 4. Direct and indirect effects of volume based soil variables on rubber yield.

Soil variables	OC	Log P	Log Ca	Mg	K	Log Mn	Log Fe	r
OC	-0.037	0.138	0.129	-0.069	0.084	-0.118	0.020	0.147
Log P	-0.010	0.521	0.272	0.113	0.038	-0.572	-0.234	0.129
Log Ca	-0.005	0.150	0.944	0.033	0.027	-0.214	-0.358	0.576**
Mg	0.006	0.131	0.069	0.454	0.000	-0.146	-0.405	0.108
K	-0.025	0.161	0.209	0.000	0.124	-0.181	-0.161	0.126
Log Mn	-0.007	0.501	0.340	0.111	0.038	-0.595	-0.261	0.126
Log Fe	0.001	0.166	0.460	0.250	0.027	-0.212	-0.735	-0.042
R^2 =	0.569							
Residual =	0.431							

coupled with minor indirect effects via OC and K.

Increased Mn content showed its prominent negative direct effect on the rubber yield (-0.595) with an additive negative indirect effect of log Mn through log Fe (-0.261). However, this effect was neutralized by its opposite indirect effects through log P (0.501), log Ca (0.340) and Mg (0.111) thus leading to an insignificant coefficient of correlation between rubber yield and log Mn (r = 0.126). In spite of a prominently large direct effect of log Fe on yield (-0.735) with an additive indirect effect through log Mn (-0.212), the correlation coefficient was almost zero because of neutralization by opposite indirect effects through Ca (0.460), Mg (0.250) and log P (0.166). The predictor variables included in the path model described only 57% of variance indicating the scope for inclusion of some other influential variables also to describe the variability.

DISCUSSION

Error control in experimentation

The results clearly established that the replication plots were not uniform with reference to actual soil volume. A difference of 41% between replications cannot be ignored while all the experimental plots are supposed to be uniform. Variance component analysis also highlighted the non-uniform nature of soil in experimental plots and it is necessary to control this error variance. Probably, certain statistical tools, like multilevel analysis might be of use to understand error control (Snijders and Bosker, 1999) although not tested in this study.

This variation is natural and should be taken into account to improve the fertilizer use efficiency for uniform realization of yield throughout the rubber plantation. However, there is no method of elimination of such error variance at field level. Hence Rao and Vijayakumar (2005) suggested application of fertilizer material to rubber plantation based on the effective soil volume (ESV). According to their technique, fertilizer rate would be based upon soil retention capacity. Probably ASV-based application fertilizer helps in the quantitative description of chemical reactions, which determines the availability of applied fertilizers to plants. In addition, it increases the use efficiency, reduces loss of valuable fertilizer materials and lowers possible chemical pollution due to excess fertilizer application.

Yield relations

The small error variance in yield due to replications (2%) was because of more than 300 mm of rainfall normally received during August. It is unlikely that there is any limitation on the availability of soil moisture, the determinant of latex flow (Devakumar et al. 1988; Chandrasekhar, 1994) and dissolved nutrients, irrespective of similar or dissimilar ESV or ASV in the experimental plots. However, Rao and Jessy (2007) observe that the annual yield (of 1999) in the same experimental field has error variance due to replications approaching 19%, which is likely a function of rainfall during all months, including the ones with low rainfall, influencing the moisture availability in the plots differing in ESV.

Better interpretation

Although the interpretation of the path coefficient table would have been limited to partitioning of only significant correlations, the description included other variables too because some of the insignificant correlations had large direct effects and indirect effects. It is the unique advantage of path coefficient analysis to unravel the latent structure of the data. Analysis showed that the regression on rubber yield on log Mg, log Ca and log Fe was statistically significant (Latex yield = -0.037 OC + 0.454 Mg + 0.124 K + 0.521 log P + 0.944 log Ca – 0.595 log Mn – 0.735 log Fe). The underlined path coefficients are also the standardized partial regression coefficients. However, multiple regression analysis did not extract any information regarding indirect effects of predictor variables, which the path analysis did. This was the basic reason to use this statistical tool to partition the correlation into direct and indirect effects and to understand the process of neutralization of these effects. Probably, the indirect effects of a variable through remaining prediction variables can be construed as interaction effects, which neither the regression nor correlation analysis indicated. As sufficient literature is already available on the nature of interactions among different chemical ions under different situations and soils the discussion was limited to the utility part of the path analysis tool.

The results of path analysis called for inclusion of some more critical variables (as R^2 = 0.569) to explain the variability in yield further. In another exercise, Rao (2009) used path analysis tool while studying the influence of dynamic soil properties, which are consequent to variations in climate, on the growth of rubber plants and realized the utility of such tool. Path analysis certainly is a useful tool in understanding the correlation and causation and the inferences may help in identifying management solutions in handling the complex chemistry associated with soil. However, caution is to be exerted in the interpretations of path analysis since the analysis can only be used to interpret the structural consequences of the normal equation hypothesis, the analysis cannot generate the hypothesis. Providing the causal hypothesis is the responsibility of the researcher (Williams et al., 1990).

Conclusions

The results of the present study emphatically indicated two important things namely the advantage of volume-based expression of soil variables and the utility of path analysis in understanding the latent structure of the data. The volume based expression, which is close to the reality, described the yield relationship in better terms like the correlation between log Ca and rubber latex yield while none was realized with gravimetric soil variables. However, further studies are necessary based on the lead provided by the present preliminary study to ascertain the impact of the ASV and volume based variables over a given duration considering the example of two jars described earlier. Though data on gravel content are available, the use is limited to soil survey and evaluation to identify land capability classes (LCCs). Generally, LCC may be of help in decision-making process but certainly is of less significance when farmers use land regardless of the capability. However, farmers' need for proper fertilizer management in rubber production in such a terrain with variable ASV suggested that studies using volume-based measurements are necessary. It is shown that more of fine root activity in rubber is confined to the surface layer (Jessy, 2004) that suggested a sampling depth of 0 to 30 cm. Depth of sampling is important because of the concept of effective foraging space (EFS) (Wahid, 2000), defined as the soil cylinder around the plant that accounts for 80% or more root activity, which also indicates ESV foraged by the majority of roots. Additional observations on bulk density, particle density and coarse fragments may not cost much but certainly contribute much to the understanding of soil in relation to plant. The utility of the path analysis is clear as it facilitated the understanding of the partition of correlation in to respective direct and indirect effects and the net result of neutralization effects, which give information about the possible interactions that serve as a guide for effective soil resource management.

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