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Expression of soil nutrient contents : by weight or volume?

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Abstract

Soil is a three dimensional body and has volume that envelops plant roots. Plant draws its water along with nutrients in volumetric terms. However, seldom soil nutrients are expressed in volumetric terms. This assumes importance when the plant performance in relation to soil nutrients is concerned. The concept of ESV (effective soil volume) needed to be regarded important in devising fertiliser scheduling. Though there won't be any dispute regarding the quantity of fertiliser material that is arrived at after soil analysis (of <2 mm fraction), there would be an imbalance in fertiliser applied if it was not done based on ESV. Average pore space (% volume), particle density (gcc-1) and coarse fragments (% volume), which imply ESV were used to calculate the nutrient elements in volumetric terms. The regression of rubber yield on gravimetric expression was insignificant, whereas, the regression of yield on soil variables in volumetric terms was significant (p = <0.001) with an R2 of 0.638. The significant contributions were made by exchangeable Ca (1.116**), Mg (1.415**) and Mn (-1.653**) to the regression. It was inferred from the study that the expression of soil variables in volumetric terms was more realistic in understanding the soil-plant relationships than gravimetric expression as was revealed by the regressions of yield. It could be ascertained that volumetric terms of soil variables are more reliable since soil is a 3D natural body and plant takes up soil water along with soil nutrients in volumetric equivalents rather than weight based ones.

Key words : Effective soil volume, soil size fractions, fertiliser application, soil nutrients, volumetric expression

Introduction

Soil is a three dimensional body and has volume that envelops plant roots. Plant draws its water along with nutrients in volumetric terms. However, seldom soil nutrients are expressed in volumetric terms. As such no much literature is available on this aspect and about relationships among soil variables expressed volumetrically and plant growth and yield. Although there was a report by Mehlich (1972) who tried to express soil elements in volumetric terms considering volume weight or bulk density, it was aimed at attaining uniformity for comparing analytical results over a spectrum of laboratories. It is an important issue when the plant performance in relation to soil nutrients is concerned since water drawn by the plant along with nutrients is in volumetric terms present in a given soil volume.

It is known that variations do occur in bulk density or volume weight both with in as well between fields. Besides that, the concept of ESV (effective soil volume) needed to be regarded important in devising fertiliser schedules (Rao and Vijayakumar, 2005). Though there won't be any dispute regarding the quantity of fertiliser material that is arrived at after analysis of <2 mm fraction, there would :n excess of fertiliser applied if it was not done based on effective soil volume thus loosing the fertiliser material leading to inefficiency in fertiliser use besides an imbalance within the soil environment surrounding plant roots.

In the light of this information, it would be necessary to regard the issue of expression of soil elements in volumetric terms as related to plant performance to understand the soil-plant relationships. Hence, a work plan was implemented to compare two methods of expression of data on soil nutrient elements measured in an experiment and to find the relationship with yield of rubber.

Materials and Methods

Soil sample collection

Soil samples were collected at a depth of 0-30 cm from 39 plots of a fertiliser trial in Kodumon Rubber Estate, Kerala that was laid out in randomised block design with three replications. The soils of the experimental area were Ustic Kanhaplohumults. There were 13 treatments with selected combinations of nitrogen, phosphorus and potassium i.e. three levels of N (30, 60 and 90 kg ha^{-1} $year^{-1}$), two levels of phosphorus (30 and 60 kg ha^{-1} $year^{-1}$) and two levels potassium (20 and 40 kg ha^{-1} $year^{-1}$) and a control without fertiliser application (Table 1). Polybag plants of clone RRII105 were planted at a spacing of 4.9 x 4.9 m during 1989. The gross plot size was 24 trees with net plot size of 8 trees. Urea, rock phosphate and muriate of potash were applied as source of N, P and K respectively. All the nutrients were supplied in two equal splits during April-May and September-October every year. Mucuna bracteata was maintained as cover crop during the immature phase. All the cultural operations were carried out as per the recommendations of the Rubber Board, India (Punnoose *et al.*, 2000). Soils were air-dried and sieved to pass through 2 mm sieve and stored for analysis.

Table 1. Details of treatments imposed

Treatment	*NPK contents*	*Treatment*	*NPK contents*
T0	Control	T7	N2P2K1
T1	N1P1K1	T8	N2P2K2
T2	N1P1K2	T9	N3P1K1
T3	N1P2K1	T10	N3P1K2
T4	N1P2K2	T11	N3P2K1
T5	N2P1K1	T12	N3P2K2
T6	N2P1K2		

N1, N2 and N3 are 30, 60 and 90 kg N ha-1 respectively
P1 and P2 are 30 and 60 kg P2O ha-1 respectively
K1 and K2 are 20 and 40 kg K2O ha-1 respectively

Soil analysis

Organic carbon was estimated in the soil samples by wet oxidation method of Walkley and Black as outlined by Nelson and Sommers (1996). Bray II extractable P was measured by colorimetry. 0.1 M $BaCl_2$ was used as an extractant to extract metal cations as suggested by suggested by Hendershot and Duquette (1986). The exchangeable cations measured by this method included Ca, Mg, Na, K, Fe, Mn, Zn and Cu. Exchangeable K and Na were measured by flame photometry while others were estimated by atomic absorption spectrophotometer.

Effective soil volume (ESV)

The effective soil volume from all the 39 plots was measured following the method suggested by Rao and Vijayakumar (2005). An 11 cm long metal core with radius of 2.86 cm was driven in a stepwise sequence to collect soil samples at 0-11, 11-22 and 22-33 cm depth separately from all 39 plots. All the samples collected by core method were air dried and separated coarse fragments from soil using a 2 mm sieve. The volume of coarse fragments was measured by displacement method in a known water column and expressed as percentage volume. The soil material from each core was measured gravimetrically and its particle density was also measured by volume displacement method to calculate the volume of soil (<2 mm fractions). Porosity was determined and expressed as % volume. The effective soil volume per tree in each layer was calculated with the assumed area of 24.01 m2 (4.9 x 4.9 meter spacing) and using the percentage of volume of coarse fragments, soil and pore space in the soil core. The cumulative ESV at the depth up to 33 cm was calculated by summing up ESV at 0-11, 11-22 and 22-33 cm and the data were used for further calculations.

Calculation of soil variables in volumetric terms

Using the average particle density (was measured to be 2.2 gcc^{-1}) and the ESV in each plot, the soil variables measured and expressed on weight basis were converted into volumetric terms. For example, 100 g soil occupied 45.46 cc when the value of particle density 2.2 g cc^{-1} considered and accordingly further calculations could be made. For instance when 'x' g of organic carbon is present in 45.46 cc, its equivalent in 'y'm^3 ESV per tree could be found out. All the soil variables were thus calculated and the data were processed.

Yield data

The rubber latex yield was measured from all eight trees in all the 39 net plots during August, 1999. The plot averages were worked out and used for analysis. Latex volume was expressed in millilitres.

Data analysis

The data were analysed by simple correlation and multiple regression. The software used was SPSS (Statistical Package for Social Sciences) using all the data sets.

Results and discussion

Soil variables

Soil variables expressed in gravimetric terms

The results indicated that all the soil variables varied among replications within a treatment as well as between treatments. The lowest content of organic carbon was measured in T9R3 (90-30-20 NPK) (0.85%) while the highest content was recorded in T3R1 (30-30-40 NPK) (2.49%). In case of Bray II extracted phosphorus, T1R1 (0-0-0 NPK) recorded the lowest content of 0.5 mg100g^{-1} while T10R2 (90-30-20 NPK) recorded the highest content of 11.3 mg100g^{-1}.

0.1 M BaCl2 extracted calcium content varied between 1.38 mg100g^{-1} (T4R3) (30-60-40 NPK) and 8.48 mg100g^{-1} (T10R1) (90-30-20 NPK) while the other divalent Mg registered values ranging from 1.38 (T6R3) (60-30-20 NPK) to 10.52 mg100g^{-1} (T9R3). The contents f monovalent potassium were the minimum in T10R2 (90-30-20) (3.3 mg100g^{-1}) whereas it was found to be highest in T12R2 (90-60-20) with 12.8 mg100g^{-1}. The other monovalent Na was more than the content of K in many plots in general. It ranged from 6.3 mg100g^{-1} (T9R3) (60-60-40 NPK) to 10.8 mg100g^{-1} measured in T12R2 (90-60-20 NPK).

The content of manganese extracted by barium chloride was found lower in T9R3 (60-60-40 NPK) (0.05 mg100g^{-1}) while highest content was registered in T6R3 (60-30-20 NPK) and T11R2 (90-30-40 NPK) (0.14mg100g^{-1}). The other redox metal Fe in general was high in content among the designated micronutrients measured. It ranged from 1.66 mg100g^{-1} measured in T10R2 (90-30-20 NPK) to 4.6 mg100g^{-1} found in T3R2 (30-30-40 NPK). Interestingly, both minimum and maximum contents of Zn content were found in the same treatment and ranged from 34 mg100g^{-1} (T5R1) (30-60-40 NPK) to 256 mg100g^{-1} (T5R2) (30-60-40 NPK). T5R1 (30-60-40) recorded the lowest content of Cu (90 mg100g^{-1}) while T9R3 (60-60-40 NPK) registered highest content of 516 mg100g^{-1}.

Soil variables expressed in volumetric terms

The ESV was lowest in T2R2 (30-30-20 NPK) with 2.7 m^3 while highest volume was found in T8R3 (60-60-20 NPK) and T9R3 (60-60-40 NPK), which measured 3.8 m^3. It could be seen that variability in ESV among treatments as well as replications was evident leading to error variance in this experimental field . With regards to soil variables expressed in volumetric terms, the content of organic carbon was found be least in T9R3 (60-60-40 NPK) with 70 kg in 3.8 m^3 while the highest content was observed in T3R1 (30-60-20 NPK), which was 184 kg in 3.4 m^3. The Bray II extracted P content was minimum in T1R1 (0-0-0 NPK) with 34 g in 3.1, m^3 whereas a maximum content of 758 g in 3.0 m^3 was seen in T10R2 (90-30-20 NPK).

Exchangeable calcium when expressed in volumetric terms recorded lowest in T1R1 (0-0-0 NPK) with 1947 g in 3.1 m^3 while maximum was calculated for plot T9R1 (60-60-40 NPK), which was equivalent to 28125 g in 2.9 m^3. The other divalent base, Mg recorded lowest content of 72 g in T11R2 (90-30-4- NPK) in 3.1 m^3. The highest Mg content of 534 g in 3.8 m^3 was recorded in plot T9R3 (60-60-40 NPK). Monovalent base, K registered the least content in T5R1 (30-60-40 NPK) (53 g in 3.1 m^3) and T11R2 (90-30-40 NPK) (53 g in 3.1 m^3) whereas it was highest in T12R2 (90-60-20 NPK) with 300 g in 3.4 m^3. It was found that the contents of Na were more than K as was seen in the contents expressed by weight basis also. The minimum content of exchangeable Na was recorded in T1R1, which was 39 g in 3.1 m^3 ESV while the maximum content was recorded in T10R2 with 943 g in 3.0m^3 ESV.

The contents of Mn were lowest in T6R3 (60-30-20 NPK) with 3.0 mg in 2.8 m^3 while maximum content was measured in T13R2 (90-60-40 NPK) with 72 mg 3.4 m^3 of ESV. It was seen that the contents of Fe were more than any other micronutrient element measured like in the case where elements were expressed by weight. It ranged from 34 mg in 3.1 m^3 of ESV that was found in T11R2 (90-30-40 NPK) to that was observed in T9R3 (60-60-40 NPK) (406 mg in 3.8 m^3 of ESV). Exchangeable Zn contents varied between 1.0 mg in 3.0 m^3 of ESV seen in T10R2 (90-30-20 NPK) to 18 mg in 3.4 m^3 of ESV in T5R2 (30-60-40) and in 2.9 m^3 of ESV in plot T8R1 (60-60-20 NPK). The Cu contents were ranging from 6.0 mg in 3.1 m^3 in plot T5R1 (30-60-40 NPK) to 49.0 mg in 3.4 m^3 in T13R2 (90-60-40 NPK).

Yield

The latex yield was found ranging from 93 ml as was measured in plot T8R1 (60-60-20 NPK) to 315 ml observed in plot T9R1 (60-60-40 NPK). Like in other soil variables, there was variation in yield parameter also among replications and between treatments.

Relationships between yield and soil variables

The regression of yield on soil variables expressed in gravimetric terms was attempted and the regression was found to be nonsignificant ($p = 0.263$) with an R^2 value of 0.293. Considering this nonsignificance of regression equation further analysis was not performed on this data set.

Table 2 indicated that the regression of rubber latex yield on soil variables expressed in volumetric terms was significant (p = 0.000) with an R^2 value of 0.638. This multiple regression equation showed that the coefficients of Ca, Mg and Mn significantly contributed to the regression equation. The coefficients were 1.116 (p = 0.000), 1.415 (p = 0.036) and -1.653 (p = 0.002) for Ca, Mg and Mn, respectively.

Table 2. Regression of rubber yield on soil variables expressed in volume terms

	Unstd. Coefficients		Std. Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	28.87	53.89		0.536	0.596
OC	0.24	0.18	0.246	1.331	0.194
Av. P	13.65	101.13	0.095	0.135	0.894
Ca	6.49	1.20	1.116	5.429	0.000**
Mg	409.63	185.63	1.415	2.207	0.036**
K	-117.43	115.44	-0.222	-1.017	0.318
Na	-9.29	81.90	-0.078	-0.113	0.910
Mn	-3067.25	921.98	-1.653	-3.327	0.002**
Fe	-188.14	185.62	-0.465	-1.014	0.319
Zn	-792.80	972.62	-0.122	-0.815	0.422
Cu	861.16	487.99	0.326	1.765	0.089

** Significant at 1%

R^2 = 0.638

In a study, Rao (2005) proved the advantage of using 0.1 M BaCl2 as an extractant of soil nutrients, which regressed well with the rubber plant growth when compared to neutral normal ammonium acetate that was used routinely in acid soils too. Same 0.1 M barium chloride was used as an extractant for measuring metal cations, Ca, Mg, K, Na, Mn, Fe, Zn and Cu (as was suggested by Hendershot and Duquette (1986) in the present study also. The advantage with this extractant was that a single solution was used for measuring all the metal cations. More over the field pH is simulated (pH of extractant was 4.8) during extraction process that is normally found in the rubber growing soils of Kerala. While the criticism against use of NN NH4OAc in acid soils is in place, the results of Rao (2005) hinted that there is a need to replace neutral normal ammonium acetate with 0.1 M BaCl2 to simulate the plant uptake at field conditions i.e. at field pH.

It was found that there were variations in the effective soil volume between as well as within treatment plots, which sounded that the error variance component would be higher. To get the expected results of fertiliser application, it is needed to consider effective soil volume to device the fertiliser application method like number of splits, quantity in each split etc. (Rao and Vijayakumar, 2005) not only in advisory services but also in the experimental plots.

It could be noticed that in majority of instances there were differences and similarities (in minor instances) between two kinds of expressions, with reference to plots in which minimum and maximum contents were measured. Similarities included the content of organic carbon and available P when expressed in both ways i.e. T9R3 recorded the minimum while T3R1 recorded the maximum in case of OC in both systems of expression. Similar observation was made in case of available P also. In some instances there were similarities in plots where maximum contents were measured and expressed in both ways. It was possible because of the inherent differences in the calculation methods. Weight based expression was a straight case of calculation, which did not consider the ESV whether it was similar or dissimilar in the experimental plots. Whereas volume based expression included ESV for calculation hence the results were different from those expressed gravimetrically.

Though there was variability in yield even among replications and between treatments. However, the analysis of variance did not show any significance of treatment effect. Hence, further analysis for treatment comparison was not performed.

However, the regression of yield on soil variables expressed in terms of weight did not yield any significant result with an R^2 value of 0.269. Interestingly, the regression of rubber latex yield on soil variables expressed in volumetric terms was a significant (p = 0.000) one with an R^2 value of 0.638, which indicated that about 64 per cent of variability was explained by the soil variables expressed in volume terms. The significant regression coefficients were of (Ca 1.116), Mg (1.415) and Mn (-1.653) in the equation. In an earlier study, Rao *et al* (2002) reported the negative impact of Mn on plant growth by means of correlation studies as well as factor analysis where "P Limitation Factor" played an important role in the growth process, which was accentuated by manganese. The contribution by Ca and Mg in this regression was interesting and note worthy.

There is always a necessity to regard the EFS (Effective Foraging Space) when the advantage of ESV (Effective Soil Volume) is to be realised. The concept of 'effective foraging space' (EFS) is introduced to delineate lateral and vertical soil space of intense root activity around the plant. Effective foraging space of a plant is defined as the soil cylinder around the plant that accounts for 80 % or more of root activity. Based on the measured and/or available information Wahid (2000) grouped different plant species into 16 classes, though the list did not include rubber. However, there is some available literature with reference to root activity of rubber measured by both physical and isotope methods.

Soong *et al.* (1971) observed that maximum root activity was within 3.7 m radius from tree base. Soong (1976) in the evaluation of the vertical distribution of feeder roots found that in most soils the greatest root proliferation was in the top soil and the proliferation decreased rapidly with depth. The results also showed significant changes in feeder root development at certain seasons. Chong-Qun (1984) stated that for rubber trees of 10-15, 25-30, 50-55 cm girth, the highest root activity was found at the lateral distances of <30, 50-80 and 100-150 cm respectively from the tree trunk. Samarappuli *et al.* (1996) reported that feeder root density was significantly different between lateral distances from base of the rubber plant and in their vertical distribution with the highest percentages of roots being in surface soil layers, 0-10, 10-20 in the region of 120 cm circle. The amount of feeder roots in the surface soil was more than 75% of total feeder roots at that depth.

Joseph (1999) maintained that more than 90 % of root activity in one year rubber is confined to a depth of 25 cm. In two year rubber, highest activity was noticed at 50 cm followed by 100 cm distance. The effect of depth of application was also significant and 50 cm depth recorded maximum recovery of radio label. During third year, maximum recovery of soil applied 32P was obtained from a lateral distance of 50 cm followed by 100 and 150 cm. Srinivasan et al (2004) noticed that the soil zone lying within 3 m lateral distance and 30 cm depth accounted for almost 70 % of the total roots in the rubber trees studied. Similarly, Jessy (2004) found that more than 60 % fine roots were within 0-10 cm depth followed by more than 20 % at 10-30 cm followed by more than 7 and 2 % at 30-60 and 60-90 cm depth respectively.

Salam and Wahid (1993) stated that certain environmental parameters can influence the physical and functional dimensions of plant root system to varying degrees apart from genetic control over root system. The size of EFS is viewed as the resultant of interaction between the plant and its ambient ecological conditions, which would mean that EFS of a plant species in a particular soil type may not necessarily be the same in another soil type. Consequently, a plant species may have to be classified differently depending on the soil type (Wahid ,2000). However, in the present study, an area of 4.9 x 4.9 m (recommended spacing) is considered, for all reasons and consideration of 30 cm depth is supported by the available literature, to determine the EFS (Wahid , 2000) though the available literature mentioned varied lateral distances of active roots of rubber,

The present study also highlighted the impact of non-applied elements viz. Ca (though it really was not applied but was added as a chemical constituent of rock phosphate), Mg and Mn, the concept of which was not given any thought in the agronomic research of rubber cultivation in India or elsewhere. Plant nutrition needs to be understood not with respect to applied nutrients alone but also with regard to non-applied elements, which are coexisting in the soil system, to help management of any crop for that matter.

The interpretation of the results of the present study showed the utility of expression of the soil variables in volumetric terms that helped understanding the soil-plant relationship when compared to the same variables expressed in gravimetric terms. The results also highlight about the storage of the soil nutrients in a given ESV, which is also EFS at a given point of time. The dynamics of soil nutrients in a given ESV can possibly be studied temporally to understand the soil-plant interrelationships, which are 24 x 7 phenomena, in realistic terms. The additional information from this study was about the impact of non-applied elements on the plant performance as a result of addition of graded levels of fertiliser material, which might have caused fluctuations in the concentration of these non-applied elements. It suggested research in holistic manner to understand the impact of both applied and non-applied soil nutrients expressed in volumetric terms on plant performance.

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