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SPATIAL VARIABILITY OF AVAILABLE CALCIUM AND MAGNESIUM IN SOILS IN THE RUBBER GROWING REGIONS OF SOUTH INDIA

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Spatial variability in soil properties arises due to parent materials, climate, landscape attributes and anthropogenic factors. Geo-statistical methods are effectively used for preparing geographical distribution maps of soil properties based on limited number of samples collected in soil surveys. Geo-referenced soil samples were collected from rubber growing regions of South India, analysed following standard analytical protocol and available Ca and Mg status were mapped geostatistically using kriging interpolation technique. The study showed that rubber growing soils of south and central Kerala were low in available Ca status, and medium in available Mg status. From Trissur district onwards, available Ca and Mg status showed a gradual increase towards north. In the northern districts, except in Kozhikode, available Ca and Mg status were in the high range in majority of the area. In Wayanad and Kasaragod districts, 100 per cent of the area showed high Mg status. In Karnataka, except in some areas of Dakshin Kannada district, Ca status was high. Almost entire rubber area in Karnataka, Goa and Maharashtra showed high Mg status. The study delineated areas low in Ca and Mg availability which need intervention with respect to Ca and Mg nutrition of rubber plants.

Key words: Available calcium, Available magnesium, Rubber growing regions, South India, Spatial variability

INTRODUCTION

Assessment of spatial variability in soil fertility parameters is important for identifying fertility constraints of a particular region and for effective soil resource management. Spatial variability in soil properties arises due to parent materials, climate and landscape attributes and anthropogenic factors (Brady and Weil, 1996). Global positioning system and GIS are effectively used in recent years for mapping the spatial variability in soil characteristics. Geo-statistical methods are effectively used for preparing geographical

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distribution maps of soil properties based on limited number of samples collected in soil surveys (Behera *et al.*, 2016; Brevik *et al.*, 2016). Kriging simulation technique is used extensively to predict values at un-sampled locations by spatial correlation (Saito *et al.*, 2005; Pereira *et al.*, 2015).

In India, rubber (*Hevea brasiliensis*) was traditionally cultivated in the states of Kerala, Tamil Nadu and parts of Karnataka, and was later extended to Goa, Maharashtra and North-eastern states. It is cultivated in 8,18,000 hectares in India, out of which 5,72,300 hectares is in the traditional area (Rubber Board, 2018). Soils in the traditional rubber growing tract of India are highly weathered and are mostly laterite and lateritic. Red and alluvial soils are also seen in some areas (Karthikakuttyamma *et al.*, 2000). Most of the plantations in India are in the second or third replanting cycle and majority of these areas are to be replanted again with rubber.

Calcium is an essential macronutrient required in moderate amounts for plant growth. In plants, calcium helps in the translocation of carbohydrates and in the formation of healthy cell walls and roots (Hawkesford, 2012). In rubber plantations, Ca is not applied as fertilizer, but it is indirectly added through rock phosphate being the major source of phosphorus fertilizer. Progressive decline in Ca status of soils under repeated rubber cultivation was reported in different studies, which was attributed to the removal of high quantity of Ca by rubber trees (Ulaganathan *et al.*, 2013; Karthikakuttyamma, 1997). Magnesium is also an essential macronutrient for plant growth, which is an ingredient of chlorophyll and helps in the translocation of starch within the plant (Hawkesford, 2012). Application of Mg fertilizer is recommended only during immature phase (1-4 years) of rubber. Among the major nutrients, Mg deficiency is more frequently observed, in young rubber plants (Karthikakuttyamma *et al.*, 2000).

This study is a part of the major project on fertility mapping of soils of the traditional rubber growing tract in South India, conducted to generate a baseline data on soil fertility status, using GIS based interpolation technique. Spatial variability in soil available

Table 1. **Rubber growing area in each district and number of soil samples**

State/District	Area (Ha)	Soil samples (No.)
Tamil Nadu		
Kanyakumari	21948	306
Kerala		
Trivandrum	27657	505
Kollam	38998	766
Pathanamthitta	55845	1101
Alappuzha	4421	52
Kottayam	110724	2099
Idukki	37348	693
Eranakulam	66155	949
Thrissur	15734	270
Palakkad	32119	514
Malappuram	38835	772
Kozhikode	20895	296
Wayanad	7567	157
Kannur	54292	953
Kasargod	25424	423
Karanataka		
Dakhsin Kannada	20413	341
Uduppi	4709	50
Coorg	2395	45
Chikmagalore	2132	23
Shimoga	1589	36
Goa	424	21
Maharashtra	1133	55

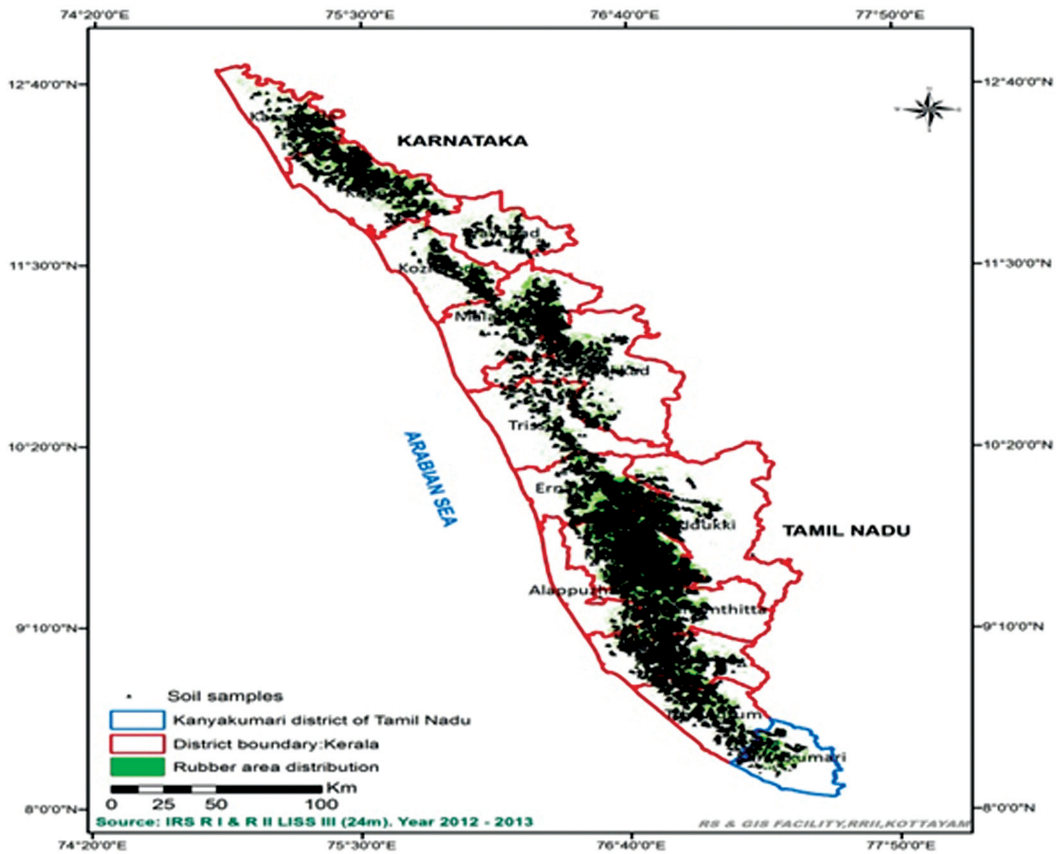

Fig. 1a. Distribution of rubber area and soil sampling sites in Kerala and Tamil Nadu

Ca and Mg is discussed in this paper, so as to delineate the areas with low Ca and Mg availability.

MATERIALS AND METHODS

Study area

Soil samples for mapping of fertility status were collected from rubber growing regions of South India. The study area includes traditional rubber growing tracts stretching from Kanyakumari district of Tamil Nadu in the south to whole of Kerala and southern districts of Karnataka in the north, and also the newly cultivated areas of Konkan region of Goa and Maharashtra. The traditional rubber growing region of Tamil Nadu and Kerala lies between 74^{o} 48' 33.10Ý to 77^{o} 38' 35.43Ý E longitudes and 7^{o} 58' 56.27Ý to 12^{o} 53' 19.11Ý N latitudes, covering a geographic area of 40,550.63 km^{2} (Fig. 1a). The annual rainfall of this area ranges from 2000-5000 mm with an average of 3000 mm. Rubber growing regions of Karnataka lies between east longitudes 74.47^{o} E to 77.64^{o}E and north latitudes 7.98^{o} N to 14.90^{o} N (Fig. 2a). Rubber growing areas in Goa and Sindhudurg district in

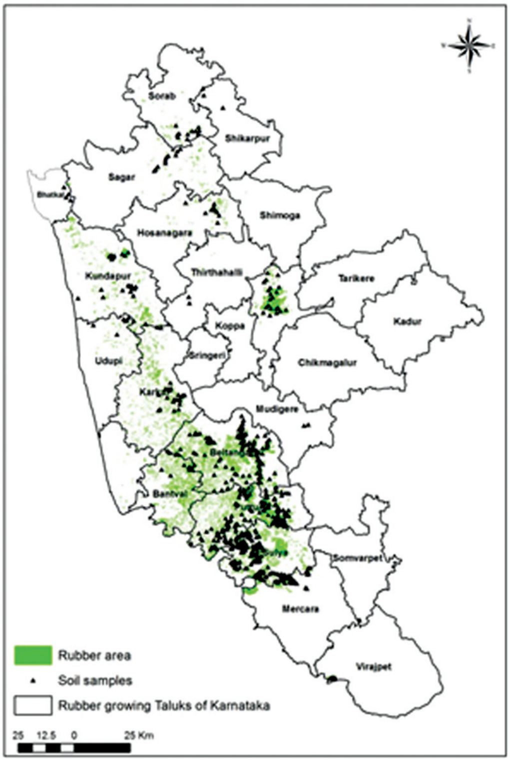

Fig. 1b.Distribution of rubber area and soil sampling sites in Karnataka

Maharashtra falls between 72.64°E to 74.33° E and 14.89° to 20.21° N (Fig. 2b). This area experiences a monsoon climate and average annual rainfall ranges from 2000 to 4500mm. While southern parts of the study area enjoy both south-west and north-east monsoons, in the northern areas, the latter is comparatively weak. From south to north, the dry period extends from two to five months in a year and the rain distribution becomes more uneven. However, the variation in temperature and humidity is not so marked as in the case of rainfall.

Mapping of rubber area using satellite imagery

Survey of India (SoI) toposheets of scale 1:2,50,000 were used to delineate district-wise administrative boundaries, road network and locations of the study area. Indian Remote Sensing Satellite (IRS) Resourcesat I and II and LISS III data for the year 2011, 2012 and 2013 with a spatial resolution of 23.5 x 23.5 m was used for

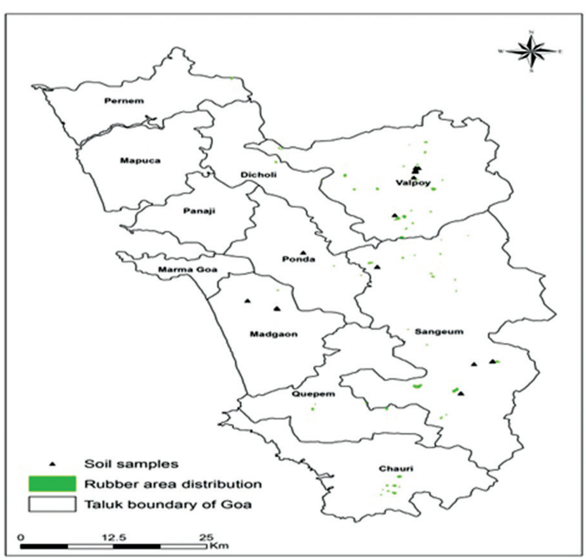

Fig. 1c. Distribution of rubber area and soil sampling sites in Goa

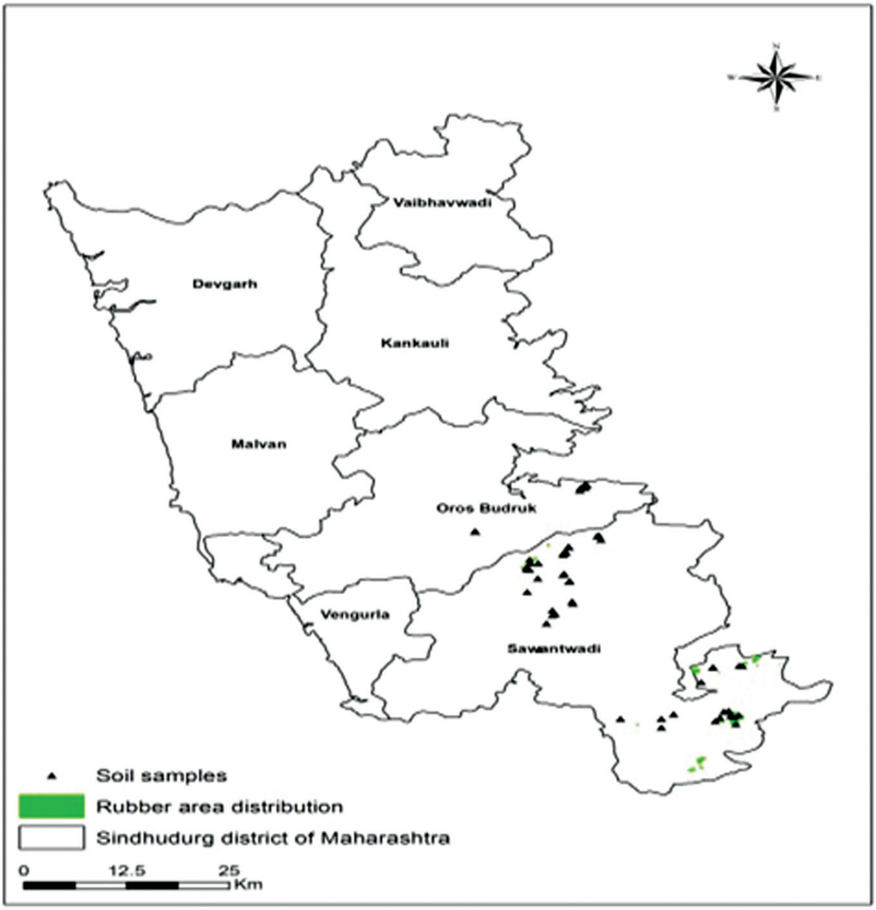

Fig.1d. Distribution of rubber area and soil sampling sites in Maharashtra

mapping rubber plantations across Kerala, Kanyakaumri district of Tamil Nadu, Karnataka, Goa and Maharashtra. Cloud free satellite scenes were procured from National Data Centre (NDC) of National Remote Sensing Centre (NRSC), Indian Space Research Organisations (ISRO) for the study. Detailed ground truth checking was carried out to collect Ground Control Points (GCPs) across rubber growing regions of Kerala, Tamil Nadu, Karnataka, Goa and Maharashtra for validation of rubber holdings mapped using satellite image. District-wise rubber area maps were prepared using ortho-rectified satellite images. Rubber holdings below three years age could not be delineated using LISS III data because of sparse canopy of immature holdings. GIS softwares Rolta Geomatica v 10.3.1 and ArcGIS v 10.1 were used for satellite image processing and analysis.

Soil sample collection

For each 50 ha rubber area, one composite soil sample of 0-30 cm depth was collected. Soil samples were collected from panchayats

Table 2. **Descriptive statistics of available calcium in rubber growing regions of South India**

State/District	Min	Max	Mean	Median	Mode	Kurt	Skew	SD	CV(%)
		mg kg^{-1}							
Tamil Nadu									
Kanyakumari	20.5	783.4	185.7	141.3	331.2	2.6	1.5	145.1	78.2
Kerala									
Trivandrum	3.5	397.8	62.9	45.6	18.6	8.9	2.5	55.2	87.9
Kollam	9.8	881.3	97.5	71.3	86.5	15.6	3.0	84.9	87.1
Pathanamthitta	8.7	835	114.9	90	90	6.2	1.8	86.6	75.3
Alappuzha	22.4	542.9	96.2	62.9	60.3	12.1	3.2	92.4	96.1
Kottayam	4.4	441.4	83.8	75.7	73.5	4.7	4.7	45.1	53.8
Idukki	1.1	482.9	86.9	66.7	115.9	4.4	1.8	64.5	74.2
Ernakulam	10.0	434	98.6	80.5	35.0	3.4	1.7	69.2	70.2
Thrissur	14.05	830.4	212.6	191.5	270.8	4.1	1.6	127.3	59.9
Palakkad	21.8	1365.5	258.2	163.4	123.8	2.7	1.7	242.4	93.9
Malappuram	18.7	837.4	168.7	141.0	191.3	4.3	1.7	112.4	66.6
Kozhikode	1.6	223.8	70.8	63.9	66.3	0.4	0.9	45.9	64.9
Wayanad	61.2	1228.6	270.2	210.0	220.2	5.6	2.2	194.8	72.1
Kannur	6.5	873.5	184.3	155.8	95.7	4.0	1.7	125.4	68.0
Kasaragod	52.2	1032.1	337.8	319.5	370.8	0.9	1.0	186.8	55.3
Karnataka									
Dakhsin Kannada	9.6	484.1	148.1	130.8	35.4	0.7	0.9	85.6	57.8
Uduppi	42.8	602.0	217.5	165.5	117.6	0.4	1.2	157.2	72.3
Coorg	59.4	968.1	235.9	168.5	968.1	7.1	2.6	192.2	81.5
Chickmagalore	147.6	901.9	380.8	398.3	398.3	2.2	1.1	178.7	46.9
Shimoga	153.2	1486.0	427.5	361.9	466.9	5.0	2.1	289.0	67.6
Goa	235.9	929.5	549.9	529.3	521.6	-0.6	0.2	200.9	36.5
Mahararashtra									
Sindhudurg	176.7	1525.9	615.5	568.5	508.9	2.1	1.3	278.4	45.2

with more than 5 per cent area under rubber. Soil samples were collected both from mature and immature rubber areas in the proportion of 4:1, considering that approximately 20 per cent of the total rubber area is in immature phase. For the estimation of coarse fragments and density of fine earth, another set of soil samples (0-30 cm depth) were collected using soil cores of known volume (710.01 cm^3).

Soil samples were collected during December 2012 to May 2013. Global Positioning System (GPS Garmin Dakota 20) devices were used for recording location of soil samples. Spatial distribution map of rubber area was overlaid over soil samples of each district in GIS environment for checking the distribution pattern and revisits were made wherever necessary to ensure

Table 3. **Descriptive statistics of available magnesium in rubber growing regions of South India**

State/District	Min	Max	Mean	Median	Mode	Kurt	Skew	SD	CV(%)
		mg kg^{-1}							
Tamil Nadu									
Kanyakumari	6.2	203.5	47.6	35.6	83.2	3.2	1.7	36.1	75.7
Kerala									
Trivandrum	4.1	63.2	19.4	16.6	9.7	1.8	1.3	10.7	55.0
Kollam	4.8	126.1	23.5	19.7	23.0	5.6	1.9	15.3	65.0
Pathanamthitta	3.5	104	19.7	16.6	9.6	6.4	2.0	13.0	66.1
Alappuzha	6	64.1	21.3	19.1	24.1	4.9	1.7	11.5	53.8
Kottayam	3.3	71.6	18.6	16.6	12.1	3.4	3.4	9.3	49.9
Idukki	5	128.7	20.5	17.1	22.4	15.3	3.2	13.6	66.4
Ernakulam	3.0	104.0	20.1	17.0	14.0	4.1	1.5	12.1	60.1
Thrissur	7.9	229.4	55.0	48.2	31.5	3.0	1.4	33.9	61.7
Palakkad	6.6	343.7	67.4	39.6	22.3	2.0	1.6	63.8	94.5
Malappuram	8.2	226.7	44.8	36.2	34.8	4.7	1.7	28.2	63.0
Kozhikode	4.1	81.8	22.5	20.2	17.5	4.8	1.8	11.3	50.3
Wayanad	13.7	185.3	50.7	44.2	32.9	3.3	1.4	27.3	53.7
Kannur	3.7	245.0	49.1	41.2	74.7	3.2	1.5	30.2	61.6
Kasaragod	16.9	216.0	84.5	78.5	93.1	0.1	0.7	41.5	49.2
Karnataka									
Dakhsin Kannada	6.2	102.7	36.6	33.2	34.7	1.8	1.2	17.6	48.1
Uduppi	10.2	119.7	42.3	35.7	24.1	0.7	1.0	24.6	58.2
Coorg	13.8	240.8	63.9	41.0	127.4	4.2	2.0	50.7	79.3
Chickmagalore	16.5	221.9	82.0	69.1	74.3	0.3	1.0	56.6	69.0
Shimoga	26.9	265.9	86.1	66.8	26.9	2.0	1.6	62.6	72.7
Goa	55.7	162.8	108.2	109.1	120.6	-0.8	-0.2	29.6	27.3
Mahararashtra									
Sindhudurg	33.1	234.0	108.8	95.6	33.1	0.7	1.0	48.3	44.4

adequate representation of the entire rubber area (Table 1 and Fig. 1).

Analysis of soil samples

The collected soil samples were air dried, thoroughly mixed, sieved (2 mm) and stored in plastic containers for chemical analysis. Available Ca and Mg in soil samples were extracted using neutral normal ammonium acetate solution, and estimated using Atomic Absorption Spectrophotometry.

Rubber growing soils contain substantial quantity of gravel and it shows considerable spatial variability (NBSS & LUP, 1999). Coarse fragments (mineral particles > 2mm in diameter) in soil samples

Table 4. **Extent of rubber growing area under low, medium and high range of available calcium**

State/district	Area under rubber in each category of available Calcium (%)		
	Low	Medium	High
Tamil Nadu			
Kanyakumari	11	33	56
Kerala			
Trivandrum	100	-	-
Kollam	83	12	5
Pathanamthitta	66	25	9
Alappuzha	76	22	2
Kottayam	87	13	-
Idukki	85	12	3
Ernakulam	87	11	2
Thrissur	9	33	58
Palakkad	15	19	66
Malappuram	16	32	52
Kozhikode	99.7	0.3	-
Wayanad	-	11	89
Kannur	38	35	27
Kasaragod	1	14	85
Karnataka			
Dakhsin Kannada	22	58	20
Uduppi	-	14	86
Coorg	-	7	93
Chickmagalore	-	-	100
Shimoga	-	-	100
Goa	-	-	100
Mahararashtra			
Sindhudurg	-	-	100

were separated by sieving with two mm sieve. Weight of fine earth in each core sample (0-30 cm) was determined. Nutrient content in one hectare was determined based on the weight of fine earth in one hectare soil to eliminate the variability in nutrient stock due to gravel content.

Geostatistical analysis

Normal distribution of the soil nutrients were examined and transformed as appropriate for mapping of spatial variability of the nutrients in GIS platform. Geostatistical software (ArcGIS Geostatistical analyst extension of Environmental System Research Institute) was used to analyse the spatial structure of the data. Geostatistical Analyst derives a surface using the values from the measured locations to predict values for each location in the landscape. Geostatistical analyses involves exploratory spatial data analysis of input samples, calculation and modelling of the surface properties of nearby locations and surface prediction and assessment of results. Kriging interpolation technique (Saito *et al.*, 2005; Pereira *et al.*, 2013) was used for prediction of soil fertility parameters.

RESULTS AND DISCUSSION

Descriptive statistics

Available calcium status of soil samples was categorized as low (<100 ppm), medium (100-150 ppm) and high (>150 ppm). Descriptive statistics showed wide variability in Ca status in the rubber growing regions of South India, and an increasing trend was observed in Ca status from south towards north (Table 2). In Kanyakumari district, soil available Ca status ranged from 20.5 to 783.4 mg $kg^{-1}$with a mean value of 185.7 mg kg^{-1}. In samples collected from Trivandrum district of Kerala, available Ca status ranged from 3.5 to 397.8 mg kg^{-1} with a mean value of 62.9 mg kg^{-1}. In Kollam district, available Ca status ranged from 8.7 to 835.3 mg kg^{-1} with a mean value of 97.5 mg kg^{-1}. Variability was higher in other districts of Kerala, *viz.* Pathanamthitta, Alappuzha, Kottayam, Idukki, Eranakulam, Trissur, Palakkad, Malappuram, Kozhikode,

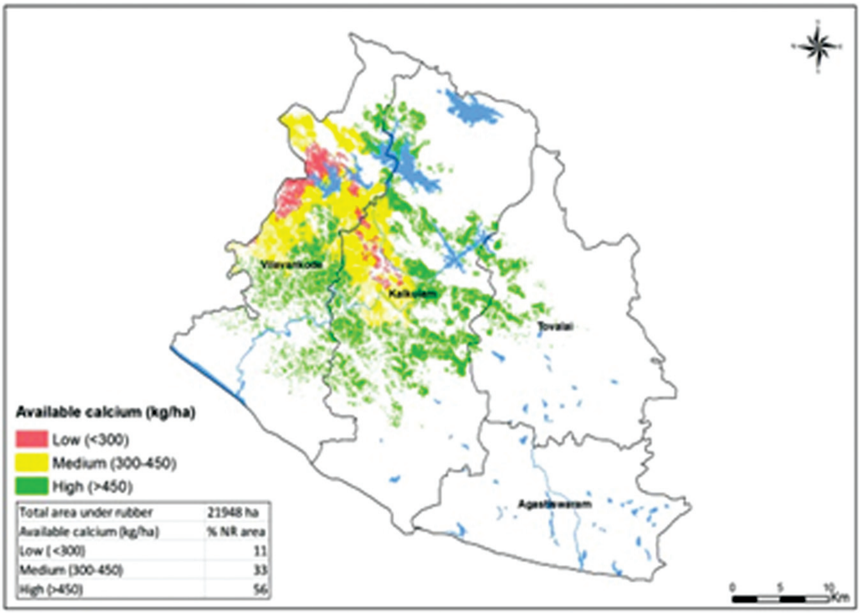

Fig. 2a. Spatial variability of available calcium in Kanyakumari district of Tamil Nadu

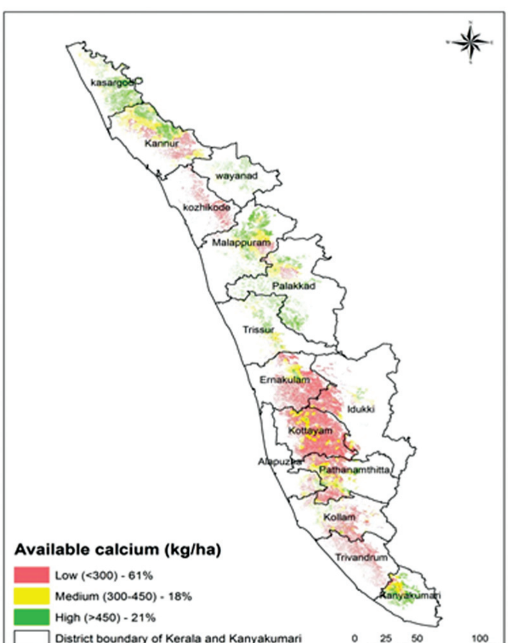

Fig. 2b. Spatial variability of available calcium in rubber growing regions of Kerala

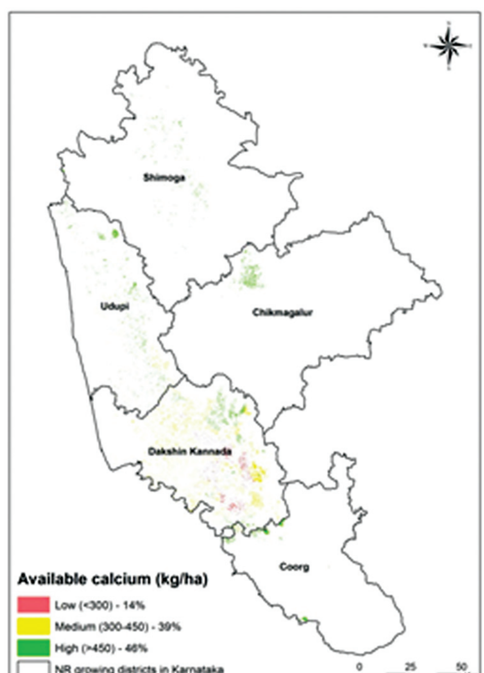

Fig. 2c. Spatial variability of available calcium in rubber growing regions of Karnataka

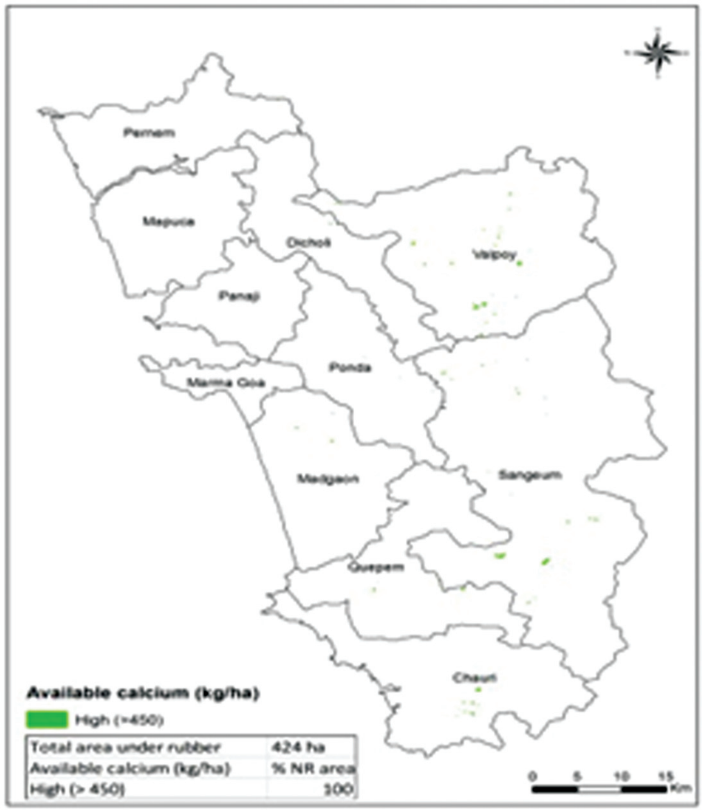

Fig. 2d. Spatial variability of available calcium in rubber growing regions of Goa

Wayanad, Kannur and Kasaragod. From Trissur district onwards, soil available Ca status showed an increasing trend and mostly in the 'high' range in northern districts of Kerala.

In the State of Karnataka, available Ca status was comparatively lower in soils of Dakshin Kannada district compared to Udupi, Coorg, Chikmagalore and Shimoga districts. Considering the entire study area, the highest available Ca status was observed in soil samples from Sindhudurg district of Maharashtra which ranged from 176.7 to 1525.9 mg kg^{-1} with a mean value of 615.5 mg kg^{-1}. In rubber growing areas of Goa also, soil available Ca status was in the high category and the values ranged from 235.9 to 929.5 mg kg^{-1} with a mean value of 549.9 mg kg^{-1}.

Available Mg status was categorized as low (<10 mg kg^{-1}), medium (10-25 mg kg^{-1}) and high (>25 mg kg^{-1}) (Karthikakuttyamma *et al*., 2000). As in the case of available Ca, wide variability was observed in the availablel Mg status also in rubber growing soils of South India (Table 3). In Kanyakumari district of Tamil Nadu, soil available Mg status ranged from 6.2 to 203.5 mg kg^{-1} with a mean value of 47.6 mg kg^{-1}. In the State of Kerala, there is a gradual increase in available Mg status from south to north, which is more prominent from

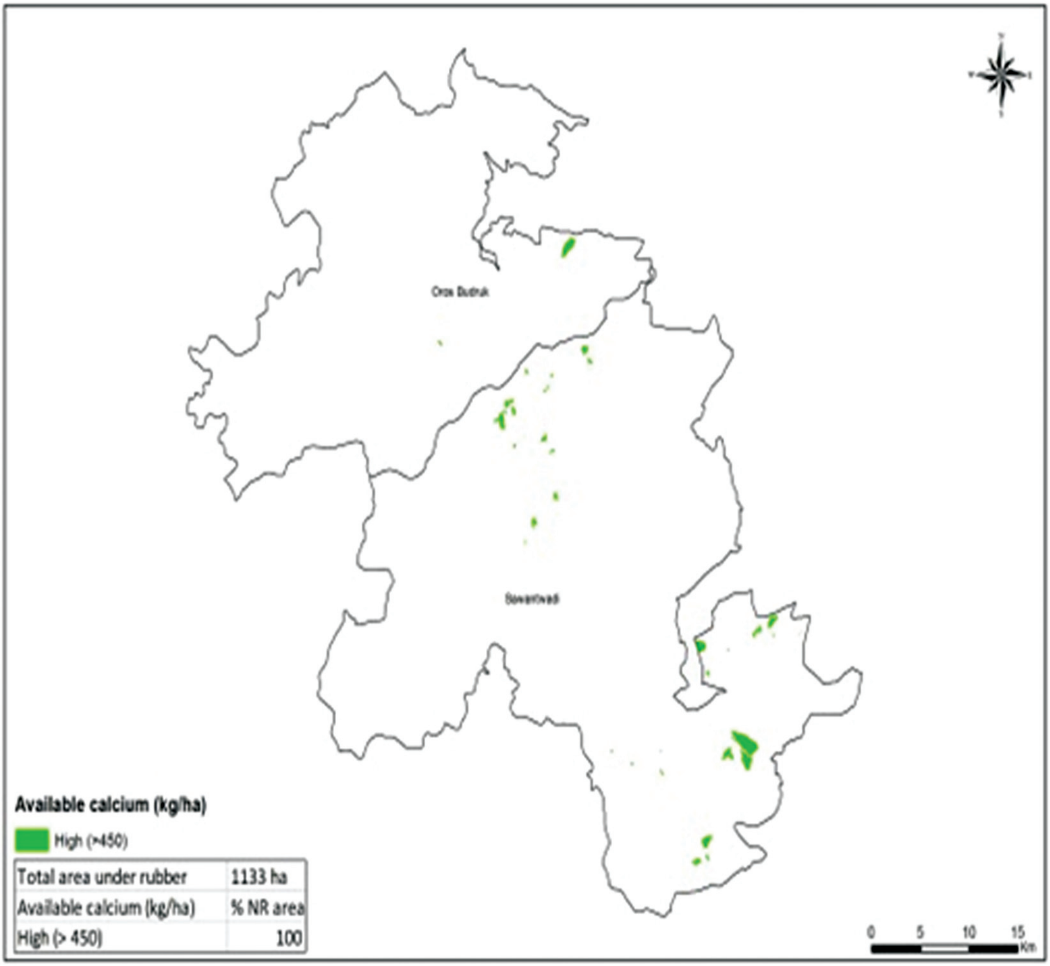

Fig. 2e. Spatial variability of available calcium in Sindhudurg district of Maharashtra

Trissur district onwards. In samples from Kasaragod district, Mg status ranged from 16.9 to 216.0 mg kg^{-1} with a mean value of 84.5 mg kg^{-1}. In rubber growing districts of Karnataka also, available Mg status was in the high range. In samples collected from Goa, Mg status was still higher and ranged from 55.7 to 162.8 mg kg^{-1} with a mean value of 108.2 mg kg^{-1}. In the rubber growing areas of Maharashtra also, very high available Mg status was observed which ranged from 33.1 to 234.0 mg kg^{-1} with a mean value of 108.8 mg kg^{-1}.

Spatial variability in available calcium status in rubber growing regions of South India

The spatial variability in soil available Ca status was delineated by kriging interpolation technique (Table 4, Fig. 2a to 2e). In Kanyakumari district of Tamil Nadu,

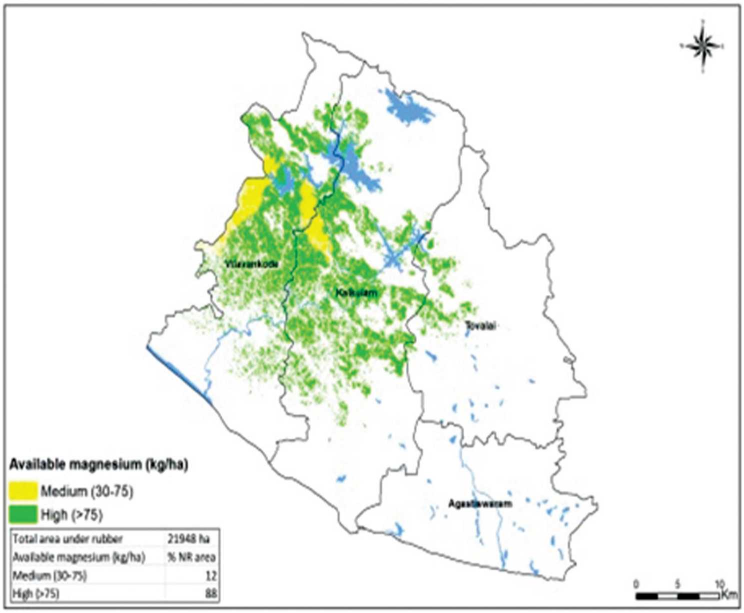

Fig. 3a. Spatial variability of available magnesium in Kanyakumari district of Tamil Nadu

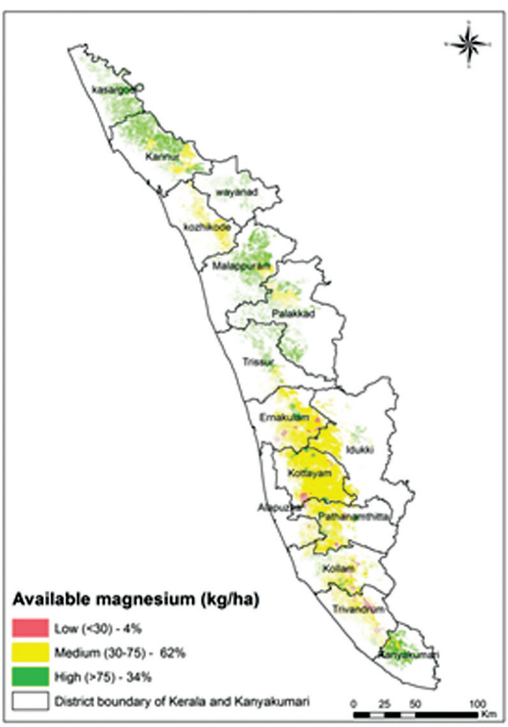

Fig. 3b. Spatial variability of available magnesium in rubber growing regions of Kerala

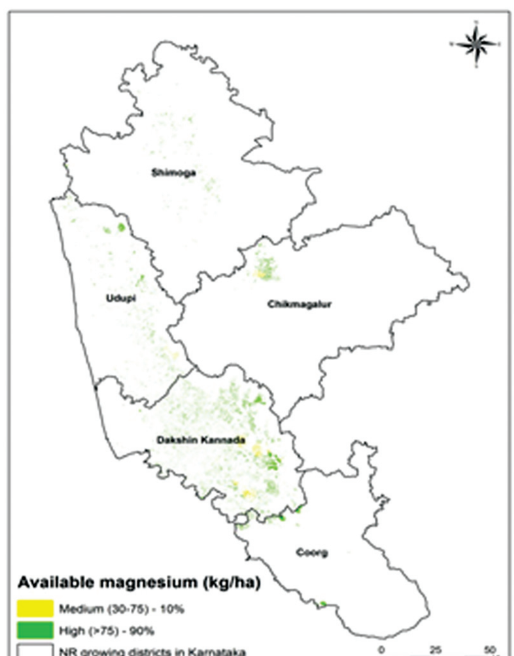

Fig. 3c. Spatial variability of available magnesium in rubber growing regions of Karnataka

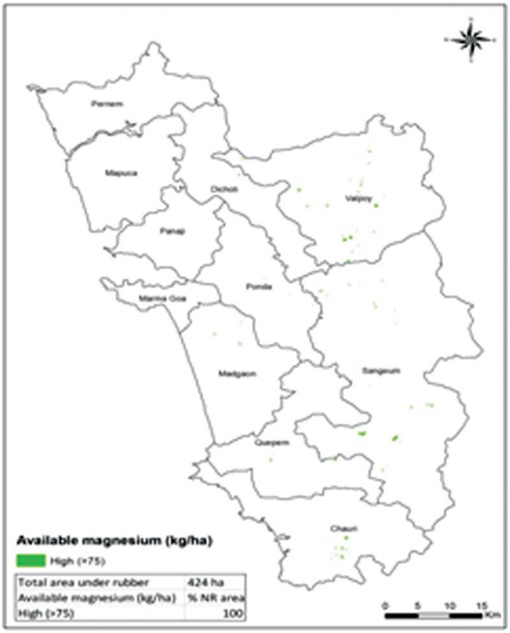

Fig. 3d.Spatial variability of available magnesium in rubber growing regions of Goa

89 per cent area had adequate calcium status, with 56 per cent area in the high category and 33 per cent area in the medium category (Fig. 2a). Spatial variability of available Ca in rubber growing regions of Kerala is shown in Figure 2b. In Trivandrum and Kozhikode districts, 100 per cent of rubber area showed low Ca status. In Kollam district, 83 per cent area was in low status, 12 per cent in medium and five per cent in high Ca status. In Pathanamthitta, Alappuzha, Kottayam, Idukki and Eranakulam districts also, majority of the area was in low Ca status. In Trissur district, 58 per cent of the area is in high Ca status, 33 per cent area in medium, and only nine per cent area showed low calcium status. From Trissur district onwards, available Ca status showed a gradual increase towards north. In Palakkad, Malappuram, Wayanad and Kasaragod districts, majority of the area showed high calcium status.

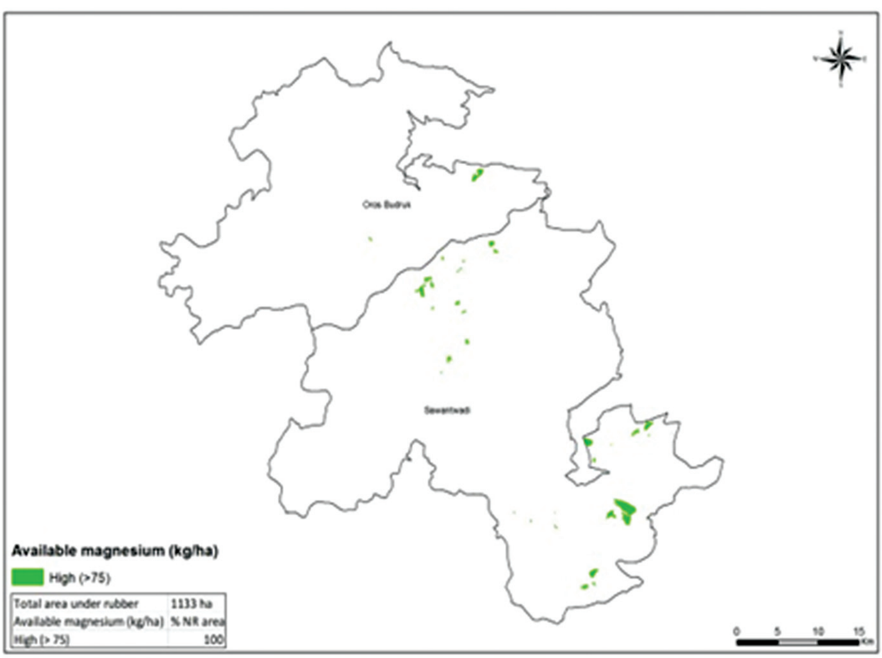

Fig. 3e. Spatial variability of available magnesium in Sindhudurg district of Maharashtra

Table 5. **Extent of rubber growing area under low, medium and high category of available magnesium**

State/district	Area under rubber in each range of available magnesium (%)		
	Low	Medium	High
Tamil Nadu State			
Kanyakumari	0	12	88
Kerala State			
Trivandrum	19	79	2
Kollam	9	72	19
Pathanamthitta	4	91	5
Alappuzha	10	84	6
Kottayam	4	93	3
Idukki	-	94	6
Ernakulam	7	87	6
Thrissur	-	26	74
Palakkad	-	24	76
Malappuram	-	13	87
Kozhikode	-	99.7	0.3
Wayanad	-	0.5	99.5
Kannur	-	23	77
Kasaragod	-	-	100
Karnataka State			
Dakhsin Kannada	-	12	88
Uduppi	-	5	95
Coorg	-	-	100
Chickmagalore	-	15	85
Shimoga	-	-	100
Goa	-	-	100
Mahararashtra			
Sindhudurg	-	-	100

In the state of Karnataka, except in some regions of Dakshin Kannada district, Ca status was high in most of the rubber areas (Table 4). Spatial variability of available Ca in rubber growing regions of Karnataka is shown in Figure 2c. Considerable spatial variability in Ca status was observed in Dakshin Kannada district, with 22 per cent area in low, 58 per cent area in medium and 20 per cent area in high Ca status. In general, available Ca status was high in other rubber growing districts of Karnataka, *viz*. Udupi, Coorg, Chickmagalore and Shimoga, with 85-100 per cent of the area in the high category. In Goa and Maharashtra (Fig. 2d and 2e, respectively), 100 per cent rubber area showed high calcium status. The spatial variability in Ca status shows the difference in parent materials, as management practices in rubber plantations are almost uniform.

Spatial variability in available magnesium status

The spatial variability in available Mg status, delineated by krigging interpolation technique is shown in Table 5 and Figure 3a to 3e. In Kanyakumari district of Tamil Nadu, 88 per cent of the area was in high and 12 per cent area was in medium status with respect to available Mg (Fig. 3a). Spatial variability of available Mg in rubber growing regions of Kerala is shown in Figure 3b. In south and central Kerala, *viz*. Trivandrum, Kollam, Pathanamthitta, Alappuzha, Kottayam, Idukki and Eranakulam districts, majority of the area (about 72-95%) showed medium status with respect to available Mg. From Trissur onwards, a shift towards high Mg status was observed. In the northern districts of Kerala, except in Kozhikode district, Mg status was in the high range in majority of the area. In Kozhikode district, almost entire area was in medium Mg status. In Wayanad and Kasaragod districts, 100 per cent of the rubber growing areas showed high Mg status.

Spatial variability of available Mg status in rubber growing regions of Karnataka, Goa and Maharashtra are shown in Figure 3c, 3d and 3e, respectively. Almost entire rubber area in Karnataka, Goa and Maharashtra recorded high Mg status.

CONCLUSION

Spatial patterns of available Ca and Mg status of soils in the rubber growing regions of South India were delineated through systematic soil sample collection, analysis and mapping with geostatistical techniques. Soils of Kanyakumari district of Tamil Nadu showed sufficient in Ca and Mg with entire area in the high or medium status. In general, rubber growing soils of south and central Kerala were low in available Ca status, and medium in available Mg status. From Trissur district onwards, available Ca and Mg status showed a gradual increase towards north. In the northern districts, except in Kozhikode, available Ca and Mg status were in the high category in majority of the rubber area. In Wayanad and Kasaragod districts, 100 per cent of the area showed high magnesium status. Except in some areas of Dakshin Kannada district, Ca status was high in most of the rubber growing areas in Karnataka. In Karnataka, Goa and Maharashtra almost entire rubber area recorded high Mg status. The study identified areas low in Ca and Mg which need intervention with respect to Ca and Mg nutrition of rubber plants.

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