Research Article
Journal of Plantation Crops, 2014, 42(2): 175-184

Geospatial variability of soil and climate on performance of rubber (*Hevea brasiliensis* Muell. Arg.) in traditional region of India

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(Manuscript Received: 03-01-14, Revised: 11-03-14, Accepted: 25-03-14)

Abstract

Natural rubber is grown in traditional region of India in varied soil and climate conditions. Earlier efforts to relate soil-site condition on performance of rubber were based on observation of few locations. Geospatial analysis of soil and climate variation helps to delineate constraint areas for site specific management. Kanyakumari district of Tamil Nadu and Kasaragod district of Kerala having contrasting soil and climate condition in traditional region of rubber cultivation were selected to study the effect of soil and climate on rubber performance. Soil OC, available P and K in Kanyakumari was in medium range whereas in Kasaragod soil OC was in high range, available P and K in low range. In Kanyakumari district major rubber growing area was under low elevation (0-100 m) and slope below 5-10 per cent compared to low to medium(100-200 m) elevation and slope above 5-10 per cent in Kasaragod. Annual rainfall distributed uniformly in Kanyakumari compared to unimodal rainfall distribution observed in Kasaragod. As a result Moisture Adequacy Index (MAI) in Kanyakumari during December to March was good to poor whereas in Kasaragod it was poor to very poor. Length of growing period was more in Kanyakumari compared to Kasaragod as a result performance of rubber with respect to growth and yield was better in Kanyakumari than Kasaragod. Factor analysis showed that soil health (OC) and cation (Ca and Mg) factors showed significant role in performance of rubber in Kanyakumari, whereas in Kasaragod only topographic factors *i.e.*, elevation showed significant role in rubber performance.

Keywords: Climate, geospatial variability, rubber, SMU, water balance

Introduction

Soil is characterized by high degree of spatial variability due to combined effect of physical, chemical and biological processes that operate at different intensities and at different scales. Rubber growing soils in the world are no exception to this. Considerable work has been done in India as well as other rubber growing countries to understand, characterize and classify the rubber growing soils. Grouping of large number of soil series into few management groups based on distinct soil properties helps to prioritize and focus the issues related to management and fertility problems. Based on variability in properties among the 62 soil series mapped (NBSS and LUP, 1999). Naidu *et al*. (2008) delineated the land areas that has uniform capability for rubber production and grouped the soils of rubber growing areas into seven soil management units (SMU).

Climate is an important ecological factor as the soil characters to great extent are dictated by climate in which they occurs. Soil characterization, grouping and mapping will be relevant only when attempts were made to relate with the performance of crop. Earlier attempt to relate soil-site condition to performance of rubber (Karche *et al.,* 1995; Rao *et al.*, 2002) were at global or macro level. There is a need for integrated analysis of soil and climate

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for site specific management, so as to increase productivity without further horizontal expansion of area to meet the growing demand of rubber. Utility of integrated analysis of soil and climate using GIS has been proved elsewhere (Pratummintra and Kesawapitak, 2002; Dansagoonpan *et al.*, 2004) but no such studies were conducted in India. Such studies help to identify the constraints at micro level and develop suitable site specific management practices.

Materials and methods

Study area consisted of two districts, *viz.* Kanyakumari (8.08^o to 8.58^o N latitude and 77.1^o to 77.59^o E longitudes) representing traditional region and Kasaragod (12.04^o to 12.80^o N latitude and 74.86^o to 75.43^o E longitudes) representing non-traditional region. Soil management unit (SMU) map of both districts were colour scanned, geo-referenced and vectorised to bring into GIS (Fig. 1). Soil management unit 1 to 7 with increasing order of limitation of depth, gravel content and soil OC were grouped into three categories; good (SMU 1&2), moderate (SMU 3&4) and poor soil (SMU 5-7). Holdings of uniform management with RRII 105 clone of 10-15 years old and S/2 d2 system of tapping were selected giving due representation to SMUs in both districts. A total of 74 holdings in Kanyakumari and 63 holdings in Kasaragod were selected and geographical location of holdings was recorded using hand held GPS. Number of holdings in each SMU and their geographical distribution is given in Table 1 and Figure 1.

Girth (cm) and tapping panel dryness (TPD) percentage of 100 rubber trees was recorded from the selected holdings and composite surface soil sample (0-30 cm) was collected. Monthly yield data was collected from each holding and expressed rubber yield as g tree^{-1} tap^{-1}. Soil samples were analysed for organic carbon (OC), available P, K,

Table 1. Number of holdings selected for study in Kanyakumari and Kasaragod district

SMU group	Kanyakumari	Kasaragod
SMU 1& 2	32	31
SMU 3&4	19	23
SMU 5, 6 and 7	23	9
Total	74	63

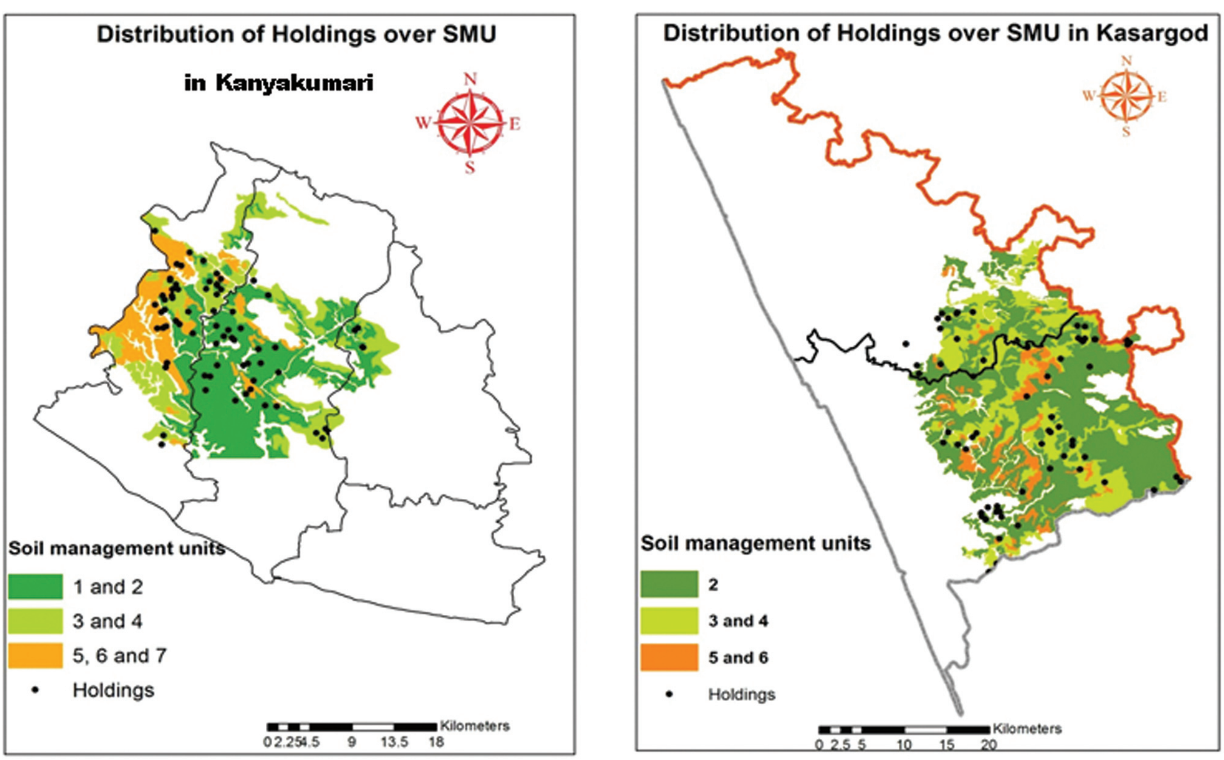

Fig. 1. Distribution of holdings over SMU in study area

Ca and Mg content following standard methods and were rated into low, medium and high using standard ratings. Soil core sample was collected to estimate gravel content (vol %). Field capacity (FC) and wilting point (WP) were determined following the pressure plate method and available water holding capacity (AWC) was estimated and expressed as mm m^{-1} after correcting for gravel content. Holdings point database was created in GIS using GPS readings and linked soil, yield and holdings details. Using advanced spaceborne thermal emission and reflection radiometer (ASTER) digital elevation model (DEM), topographic parameters like slope and elevation were derived for rubber growing areas of both the districts.

Monthly rainfall readings for 2011-12 were collected from the available weather stations in both districts. In order to get better spatial distribution of rainfall observations, daily rainfall readings derived from TRMM 3B42 version 7 at 0.25 x 0.25 degree grid data were also downloaded to fill the spatial gaps *(http://disc2.nascom.nasa.gov/Giovanni/tovas/ TRMM_V7.3B42_daily.shtml).* Using point rainfall data, spatial continuous map were developed using kriging interpolation technique in ArcGIS. Monthly water balance in the soil was estimated following the Thornthwaite-Mather's book keeping method (Thornthwaite and Mather, 1955) using the ArcGIS water balance toolbox (Dyer, 2009). Inputs used for this are raster image of rainfall, PET and AWC. Using the outputs from monthly water balance, monthly moisture adequacy index (MAI = actual evapo-transpiration (AET)/PET x 100) was calculated to assess the adequacy of moisture availability. Monthly MAI values were grouped into four categories namely, excellent (> 75 %), good (50-74 %), poor (24-49%) and very poor (< 24 %) (Krishnan, 1971) to identify the period and areas facing moisture stress. Analysis of variance was used to compare the significance of difference among the SMU within district and two sample 't' test was used to compare the significance of difference between districts. Moran index was calculated using ArcGIS to assess the spatial clustering of soil nutrient distribution.

Results and discussion

Soil and topography

Kanyakumari and Kasaragod showed significant difference in their soil physical and chemical properties (Table 2). Mean soil OC, available P and K in Kanyakumari soil was in medium range, whereas, in Kasaragod soil OC was in high range, available P and K in low range. However, soil available Ca and Mg was in high range in both the districts. Similar trend was noticed in distribution of samples over different classes (Table 2). Soil OC and available Mg showed significant spatial clustering as indicated by Moran Index indicating spatial variation (Table 2). Similarly, available Ca in Kanyakumari and gravel content in Kasaragod showed significant spatial variation. Extent and spatial distribution of SMU in both the districts showed significant variation between the districts (Fig. 1). The difference in soil nutrient content could be attributed to the difference in their land forms as well their parent materials. Soils of Kanyakumari are grouped under the *khondalite* land forms whereas soils of Kasaragod are grouped under the *charnockite* and *laterite* landforms. (NBSS and LUP,1999). *Khondalite* and *laterite* are the major rock types observed in Kanyakumari compared to extensive *charnockite* rock observed in Kasaragod district.

A major soil forming factor in rubber growing area is climate (NBSS and LUP, 1999). Because of distinctly different climate observed in the two districts, the genesis of soil might have occurred differently, leading to difference in their basic physical and chemical properties (Table 2). High available Ca and Mg in rubber growing soils has been reported from Malaysia and Cambodia (Pushparajah, 1969; de Geus, 1973). In general, available P was low to medium in rubber growing soils and this is in conformity with the findings of Osodeke and Kamalu (1992) and NBSS&LUP (1999). The reason might be due to the dominance of kaolinite and goethite in soil clay.

Topography of rubber growing area in both the districts differed. In Kanyakumari district major rubber growing area (70%) was under the low elevation (0-100 m), whereas in Kasaragod 43 per cent area was under 0-100 m and 39 per cent under 100-200 m elevation indicating the higher elevation area in Kasaragod compared to Kanyakumari. In Kanyakumari district the major rubber growing area (80%) was under the slope below 5-10 per cent whereas in Kasaragod district rubber area was spread over all slope class with large area between

Table 2. Descriptive statistics of soil parameters

Parameter	District	Mean	Two sample 't' test	No. of samples in range Low	Medium	High	Moran Index
OC (%)	Kanyakumari	1.3	12.82 *	11	49	14	0.37 *
	Kasaragod	3.0		0	3	60	0.32 *
Available P (mg kg^{-1})	Kanyakumari	19.9	4.37 *	37	21	16	0.11
	Kasaragod	4.7		57	6	0	0.05
Available K (mg kg^{-1})	Kanyakumari	100.4	6.71 *	8	51	15	0.10
	Kasaragod	56.2		33	30	0	0.13
Available Ca (mg kg^{-1})	Kanyakumari	237.3	3.29 *	3	15	56	0.20 *
	Kasaragod	343.6		0	4	59	0.06
Available Mg (mg kg^{-1})	Kanyakumari	63.9	4.91 *	2	12	60	0.18 *
	Kasaragod	142.1		1	0	62	0.45 *
pH	Kanyakumari	4.8	11.05 *				0.08
	Kasaragod	5.3					0.18
Gravel (%)	Kanyakumari	8.2	1.96 *				0.10
	Kasaragod	6.6					0.25 *
Available water content (mm m^{-1})	Kanyakumari	47.6	0.27				
	Kasaragod	46.8					

* Significant at 0.05 level

the slope classes of 5-10 and 15-25 per cent indicating higher slopy area in Kasaragod compared to Kanyakumari.

Climate

Annual total rainfall distribution showed a distinct pattern in Kanyakumari and Kasaragod districts (Fig. 2). In Kanyakumari, uniform distributed annual total rainfall of 1228.1 mm was received against the potential evapotranspiration (PET) demand of 1749.5 mm leading to an annual deficit of 546.4 mm and surplus of 8.7 mm (Table 3 and Fig. 2). On the other hand in Kasaragod unimodal annual rainfall of 3461.7 mm was received against the PET of 1770.1 mm leading to annual deficit of 589.8 mm and 2281.4 mm rainfall as surplus, which was 65.9 per cent of annual rainfall. This clearly indicates the tight water balance situation existing in Kanyakumari district. Monthly water balance showed deficit rainfall in both the districts during December to March period and this is evident from Figure 2. However the severity of deficit was more in Kasaragod (524 mm) compared to Kanyakumari (380 mm) district. This result is in conformity to Rao *et al.* (1990) who reported less intensity of moisture stress or water deficit in southern region and severe in northern part of traditional regions of rubber cultivation.

Moisture adequacy index (MAI) was estimated for both the districts to assess the adequacy of moisture and to identify the stress period (Fig. 3). In Kanyakumari district, moisture adequacy was poor for two months (January and March) but in Kasaragod, moisture adequacy was very poor for three months (January to March). This result agrees with that of Rao and Vijayakumar (1992) who reported severe moisture stress for 4-6 months in

Table 3. Annual water balance (mm)

Parameters	Kanyakumari	Kasaragod
Rainfall	1228.06	3461.65
Potential Evapotranspiration	1794.48	1770.10
Actual Evapotranspiration	1249.52 (69 % PET)	1180.28 (66.7 % PET)
Deficit	546.45 (30 % PET)	589.82 (33 % PET)
Surplus	8.72 (0.7% RF)	2281.38 (65.9% RF)

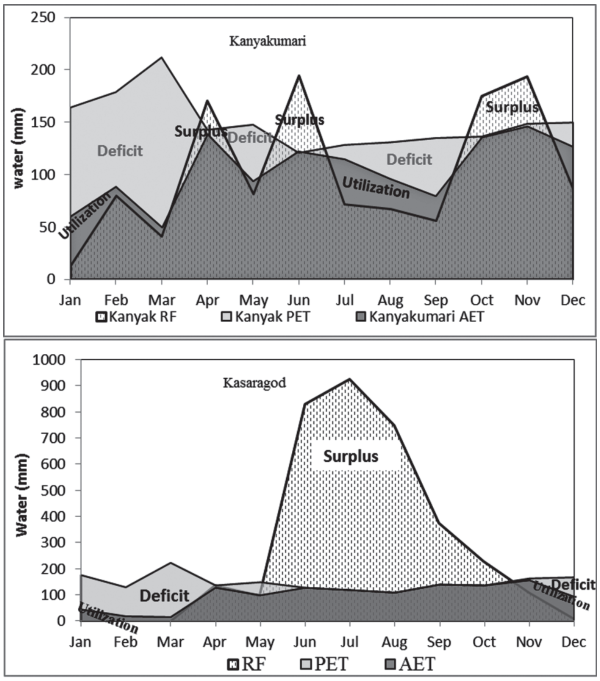

Fig. 2. Water balance of Kanyakumari and Kasaragod districts

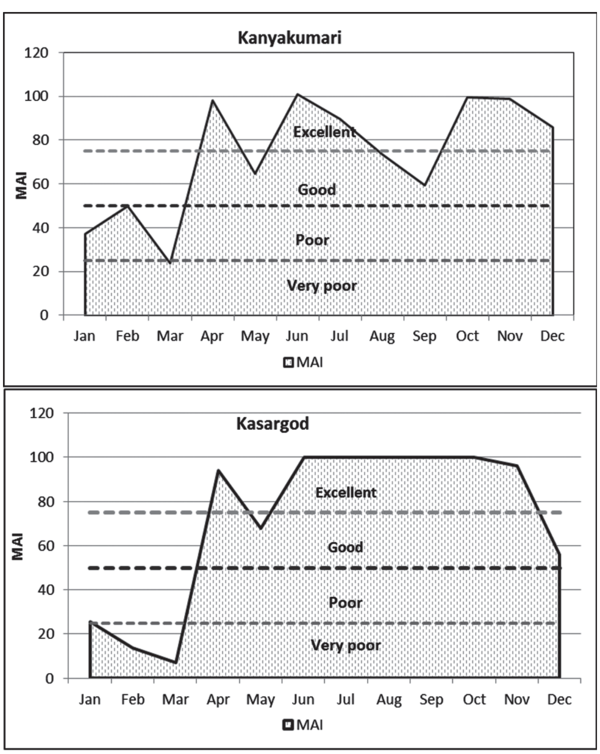

Fig. 3. Moisture adequacy index of Kanyakumari and Kasaragod districts

non-traditional rubber growing regions (above 10^0N), even where annual rainfall was sufficient. Moisture stress during December to March varied spatially in both the districts (Fig. 4). In Kanyakumari, moisture stress was seen only in southern part of the district whereas central part of district showed no moisture stress. But in Kasaragod district, moisture stress free area was not at all seen during December to March and intensity of stress was more in south-western part of the district (Fig. 4). All previous attempts to assess the water balance of rubber growing region were based on point weather data and no report of spatial analysis was available. Previous studies grouped the entire southern region and in particular Kanyakumari belt of rubber growing area in India as mild or no moisture stress and northern region as moisture stress area (Rao *et al*., 1990; Rao *et al*., 1993). Spatial analysis in the present study helped to delineate the specific area with and without moisture stress within a district, which was not reported so far.

Length of growing period (LGP) estimated from monthly water balance showed that LGP in Kanyakumari was 303 days compared to 244 days in Kasaragod district. This was in conformity with Karche *et al.* (1995) who reported 330 days LGP for Kulasekharam area of Kanyakumari and 240 days of LGP for Kanhangad area of Kasaragod. Expressing a similar view, Naidu *et al*. (2008) estimated 5-6 months dry period for Kasaragod district based on LGP.

Performance of rubber

Mean girth of rubber in Kanyakumari (63.4 cm) was significantly (p=0.05) higher compared to mean girth of rubber in Kasaragod (58.81 cm). Seventy per cent of the holdings in Kanyakumari had girth above 60 cm, whereas 65 per cent of holdings in Kasaragod had girth less than 60 cm (Fig. 5). Rubber needs a well distributed rainfall without any marked dry season (Vijayakumar *et al*., 2000). Non-uniform rainfall distribution with long dry period and short LGP resulted in comparatively less girth in Kasaragod compared to Kanyakumari. This result is in conformity with the previous works (Karche *et al.,* 1995; Dea *et al*., 1996; Thanh *et al*., 1997; Wijesuriya *et al*., 2010) which highlighted the importance of well distributed rainfall with short dry period from major rubber growing countries in

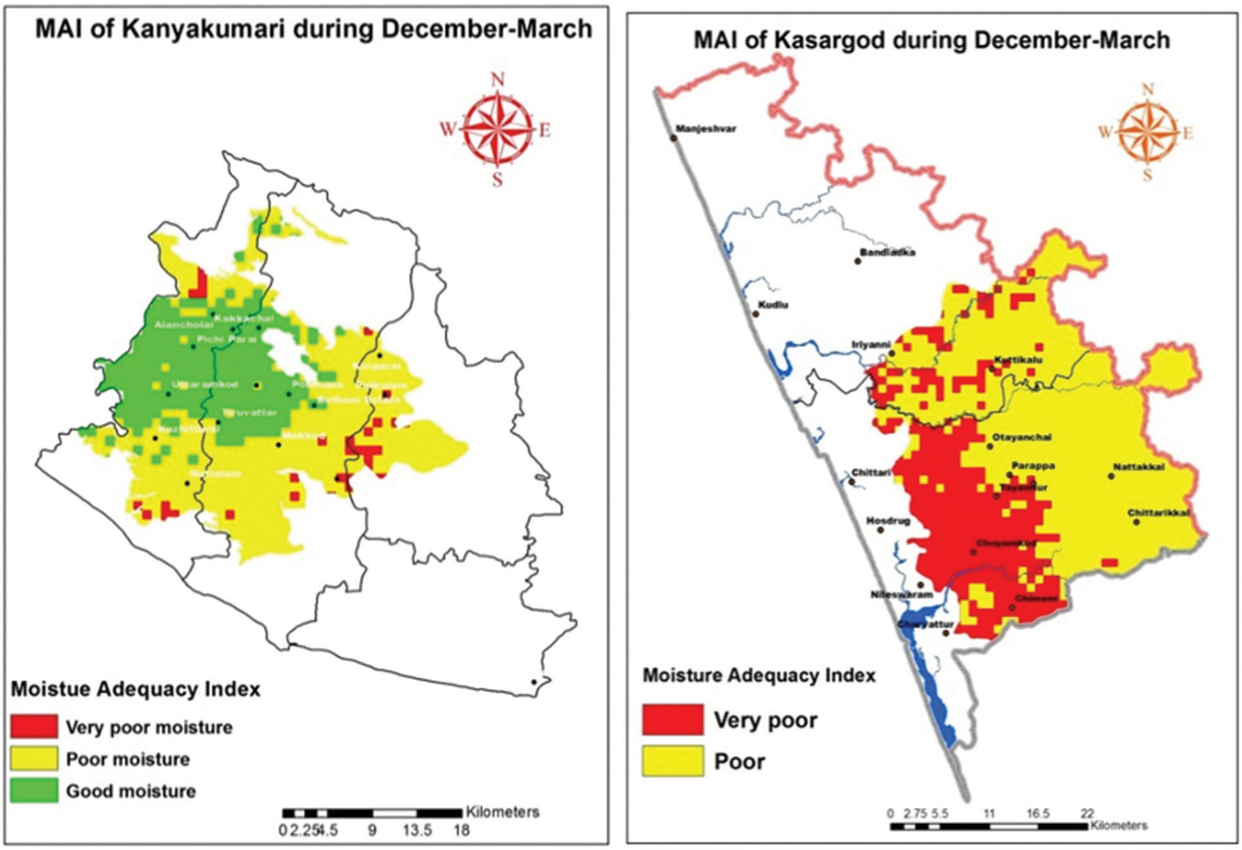

Fig. 4. Moisture adequacy index of Kanyakumari and Kasaragod during December - March

the world. Under harsh environment, decreased plant growth resulting in delayed maturity has been reported from India (Sethuraj *et al*., 1989; Chandrasekhar *et al*., 1996; Devakumar *et al*., 1998), Thailand (Rantala, 2006), Cote d Ivorie (Dea *et al*., 1996) and Sri Lanka (Wijesuriya *et al*., 2010).

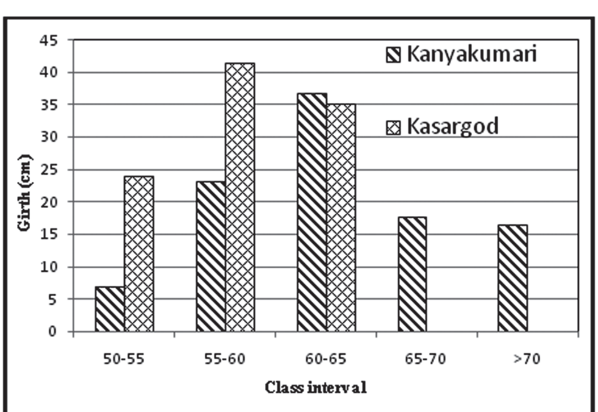

Fig. 5. Histogram of rubber girth in Kanyakumari and Kasaragod

Variation in rubber girth among SMU was analyzed by one way ANOVA and is presented in Table 4. Rubber girth varied significantly among SMU groups in Kanyakumari district with SMU 1-2 and 3-4 recording significantly higher girth compared to SMU 5-7. However, girth did not differ significantly between SMU 1-2 and 3-4. In Kasaragod district girth did not differ significantly among the SMU groups.

Average per tree rubber yield (g tree^{-1} tap^{-1}) during different periods did not differ significantly between two districts, except during December to

Table 4. Variation in rubber girth (cm) as influenced by SMU

SMU groups	Kanyakumari	Kasaragod
1 and 2	64.77 [a]	58.5 [ns]
3 and 4	64.57 [a]	58.4
5,6 and 7	60.53 [b]	58.7
Mean	63.48	4.07
S.Em	0.68	0.5

Table 5. Rubber yield variation between two districts at different periods during 2011-12

District	Dec-Mar. yield ($g\ tree^{-1}\ tap^{-1}$)	Feb -May yield ($g\ tree^{-1}\ tap^{-1}$)	June-Sept. yield ($g\ tree^{-1}\ tap^{-1}$)	Oct - Jan. yield# ($g\ tree^{-1}\ tap^{-1}$)	Average yield# ($g\ tree^{-1}\ tap^{-1}$)	Annual yield ($kg\ ha^{-1}\ year^{-1}$) #
Kanyakumari	43.2	30.16	39.91	40.85 (1.61)	36.59 (1.57)	1779.1 (3.22)
Kasaragod	37.3	31.37	42.88	40.0 (1.60)	37.70 (1.58)	1472.7 (3.15)
't' Test	2.36*	0.65	1.16	0.44	0.50	3.30*

log_{10} transformed; * Significant at 0.05; figures in the parenthesis are transformed data

March period (Table 5). Average per tree per tap rubber yield during December to March was significantly high in Kanyakumari compared to Kasaragod. The annual total yield differed significantly between two districts with Kanyakumari (1779.1 kg ha^{-1} $year^{-1}$) recording significantly higher annual yield than Kasaragod (1472.71 kg $ha^{-1}yr^{-1}$). Rubber yield variation among SMU in each district are presented in Tables 6 and 7.

In Kanyakumari per tree rubber yield showed significant variation among the SMU only during February to May period (Table 6). During February to May period SMU 5-7 recorded significantly low per tree yield compared to SMU 3-4 but on par with SMU 1-2 (Table 6). Annual rubber yield did not show significant variation among SMU in Kanyakumari (Table 6). In Kasaragod, per tree rubber yield during different period as well as annual yield did not show significant variation among the SMU (Table 7). Soil moisture is the balance between water supply and demand. Rainfall in Kasaragod district showed imbalance in rain water supply with 66 per cent rainfall as surplus (*i.e.*, loss). Because of non-uniform rainfall distribution and undulating terrain observed in Kasaragod, even SMU 1-4 having good soil depth and low gravel content could not hold much soil moisture during summer. This is clearly evident from more soil moisture deficit observed in Kasaragod during December to March despite more area under SMU 1-4 compared to Kanaykumari. This might be the reason why in Kasaragod SMUs did not significantly influence the growth and yield of rubber.

Factor analysis using soil, climate and topography factors was done to extract the

Table 6. Average yield and annual rubber yield as influenced by SMU in Kanyakumari district

SMU	Average yield ($g\ tree^{-1}\ tap^{-1}$) during					Annual yield
	Dec-Mar.	Feb -May #	June-Sep.	Oct to Jan #	Mean #	($kg\ ha^{-1}$)
1 & 2	42.3	27.7 (1.44)[ab]	38.96	41.26(1.61)	35.9(1.55)	1817.5
3 & 4	48.5	33.4 (1.53)[b]	45.97	47.0 (1.66)	42.9(1.63)	1737.3
5 – 7	39.9	24.5 (1.39)[a]	36.21	38.9 (1.58)	33.4(1.52)	1617.0
Mean	43.2	28.18 (1.45)	39.91	40.74(1.61)	36.3(1.56)	1739.0
CD (p= 0.05)	NS	*	NS	NS	NS	NS

Log_{10} transformed; figures in the parenthesis are transformed data; NS = not significant

Table 7. Rubber yield during different period as influenced by SMU in Kasaragod district

SMU	Average yield ($g\ tree^{-1}\ tap^{-1}$) during					Annual Yield #
	Dec-Mar	Feb -May	June-Sep	Oct to Jan $	Mean yield $	($kg\ ha^{-1}$)
1 & 2	37.4	31.63	41.00	42.3 (6.50)	38.19 (6.18)	1318.3 (3.12)
3 & 4	36.2	31.43	44.32	39.6 (6.29)	37.82 (6.15)	1288.3 (3.11)
5- 7	42.1	29.82	46.28	42.9 (6.55)	42.12 (6.49)	1445.4 (3.16)
Mean	37.3	31.37	42.88	41.2 (6.42)	38.4 (6.2)	1318.3 (3.12)
CD (p=0.05)	NS	NS	NS	NS	NS	NS

Log_{10} transformed; $ square root transformed; figures in parenthesis are transformed data; NS = not significant

components which influence the rubber performance in both the districts. Results of factor analysis are presented in Tables 8-11. Factor analysis in Kanyakumari extracted three components namely water balance factor, soil cation factor and soil health factor explaining the 83 per cent variance together (Table 8). Soil health factor showed significant positive correlation with girth of rubber (r = 0.46) and average per tree rubber yield (r = 0.51) and average per tree rubber yield during different periods (Table 9). Soil cation factor showed significant negative correlation with per tree rubber yield during June-Sep (r = -0.31) and girth of rubber (r = -0.29). Water balance factor did not show significant correlation with girth, tapping panel dryness (TPD) and yield of rubber. Under the uniform climate condition, soil could exert considerable influence on rubber yield (Chan *et al.*, 1972). Hence in Kanyakumari district only soil component, *i.e.,* soil cation and soil OC influenced the rubber growth and yield. Soil cation factor with high positive loading from available Ca and Mg showed significant negative correlation with girth of rubber and rubber yield during June-September indicating the adverse effect of high level of Ca and Mg observed in the soil. In the present study, available Mg content showed significant negative relation with rubber growth and yield. Reports of negative effect of high level of available Mg on rubber growth (Fairfield, 1950; Boltejone, 1954; Punnoose,1993) and rubber yield (RRIM, 1964; Punnoose, 1993) were reported earlier. Soil pH of Kanyakumari was slightly more acidic, as a result more chance of P fixation by the abundant aluminium present in acidic condition. Soil OM forms a complex with active Al ions present in soil solution leading to less P fixation. This way soil OC not only acts as source and sink of nutrients, but it helps in balancing the cation thereby making essential elements available to plants. This might be the reason for the growth and yield of rubber showing significant correlation with soil health factor having positive loading from soil OC.

Table 8. Loading of different variables into factor components in Kanyakumari district

Variables	Component		
	Water balance factor	Soil cation factor	Soil health factor
Available Ca	-0.29	0.88	0.16
Available Mg	-0.07	0.94	-0.08
Bulk density	0.75	-0.03	-0.42
Organic carbon	-0.08	0.08	0.94
Annual rainfall	0.77	-0.25	0.44
Annual deficit	-0.84	0.21	0.08

Extraction method: Principal Component Analysis.
Rotation method: Varimax with Kaiser Normalization.

In Kasaragod, factor analysis extracted three components namely water balance factor, rainfall factor and topographic factor (Table 10). Topographic factor showed significant positive correlation with average per tree rubber yield (r = 0.3), annual yield (r =0.32) and per tree rubber

Table 10. Loading of different parameters into the factor components in Kasaragod district

Variables	Component		
	Water balance factor	Rainfall factor	Topographic factor
Annual actual Evapotranspiration	0.81	-0.11	0.37
Annual surplus	-0.09	0.99	-0.11
Annual rainfall	0.23	0.96	0.04
Annual deficit	0.87	0.18	-0.31
Annual potential evapotranspiration	0.99	0.09	-0.09
Elevation	-0.29	-0.01	0.86
Slope	0.17	-0.05	0.86

Table 9. Correlation of rubber yield, girth and Tapping panel dryness with factor components in Kanyakumari district

Component	Average yield ($g\ t^{-1}\ t^{-1}$)	Annual total yield ($kg\ ha^{-1}\ yr^{-1}$)	Average per tree yield($g\ tree^{-1}\ tap^{-1}$) during			Girth	TPD
			Feb-May	Jun-Sep	Oct-Jan		
Water balance factor	-0.05	0.14	-0.08	-0.07	0.01	0.12	0.19
Soil cation factor	-0.21	-0.20	-0.22	-0.31 **	-0.15	-0.29 *	-0.11
Soil health factor	0.51 **	0.17	0.46 **	0.46 **	0.49 **	0.46 **	0.20

** Significance at 0.01 levels; * Significance at 0.05 levels

Table 11. Correlation of rubber yield, girth and Tapping panel dryness with factor components in Kasaragod district

Component	Average yield	Annual yield	Feb-May yield	Jun-Sep Yield	Oct-Jan Yield	Girth	TPD
Water balance factor	0.09	0.19	-0.08	0.01	0.11	0.12	-0.06
Rainfall factor	-0.04	0.03	-0.04	0.08	-0.21	-0.13	-0.01
Topography factor	0.30 *	0.32 *	0.28 *	0.12	0.33 **	-0.08	0.12

** Significance at 0.01 levels; * Significance at 0.05 levels

yield during February-May (r = 0.28) and Oct-Jan (r = 0.33) (Table 11). All other components did not show significant correlation with rubber growth as well as rubber yield.

For any crop to perform better, climate is the pre-requisite. Topographic factors like, slope, aspect and elevation are reported to have profound influence on performance of rubber (Chan *et al*., 1972). Because of changes in climatic condition associated with altitudinal gradient, altitude acted as a modifier, and hence, elevation mediated climate effect showed influence on rubber performance under the uneven distributed rainfall, long dry period and moisture stress observed in the Kasaragod rubber ecosystem. With concentrated and uneven distributed rainfall condition observed in Kasaragod, increase in slope helps to maintain good drainage condition and hence slope also showed significant positive influence on rubber performance in Kasaragod. Because of this reason, significant rubber growing area was under high elevation (200-300 m) and slope (>10-15%) compared to Kanyakumari. Chan *et al*. (1974) reported increase in girth and yield with increase in slope up to 26 per cent due to better drainage. Rao and Jose (2003) reported the influence of physiography slope on fertility capability classification of soil under rubber. Unlike Kanyakumari, soil OC and cation factor failed to dominate in the Kasaragod rubber ecosystem. This might be due to the fact that soil OC in Kasaragod was at high level compared to Kanyakumari. Under heavy and concentrated rainfall condition, all exchangeable cations are leached down from profile (Joseph *et al*., 2008), so despite of high level of Ca and Mg observed in Kasaragod, cation factor did not show dominant negative effect on rubber performance.

Conclusion

Under the favourable climatic condition observed in Kanyakumari, soil factors like soil OC, available Ca and Mg showed limitation on rubber performance. Hence there is a need to maintain soil OC by adopting good agricultural practices and also suitable measures to reduce the negative effect of excess calcium and magnesium on rubber performance. On the other hand under the unfavourable climate condition observed in Kasargod, soil factor did not show significant influence on rubber performance, thus indicating the need of favourable climate condition for any soil to express its full potential. Under the uneven distributed rainfall, long dry period and moisture stress observed in the Kasargod, elevation mediated climate modification showed influence on rubber performance. This was clearly evident from the large rubber area distributed on high elevation compared to Kanyakumari district. In low elevated areas of Kasaragod adequate soil and water conservation measures are required to store the excess rainfall received over short period to reduce the moisture stress during dry period and increase the growing period. This highlights the importance of integrated approach for site suitability analysis and also to evolve a site specific management practices to improve the performance of rubber.

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