EFFECT OF SOIL pH AND BASE STATUS ON THE GROWTH OF YOUNG NATURAL RUBBER PLANTS

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In India, natural rubber (*Hevea brasiliensis*) is cultivated in around 8,27,000 hectares of arable land. Major share of the NR growing regions experiences tropical humid climate and the soils are mainly Ultisols with low base saturation, high exchangeable Al and acidic pH. Studies were conducted to monitor the growth of NR seedlings in soils having three different pH *viz*. 4.4, 5.5 and 7.4 with wide variations in base status in the laboratory condition and in the open-air condition in polythene bags. In the laboratory study, the length and biomass of shoot and root were monitored and in the polythene bags, growth of the plants in terms of shoot diameter, root length, shoot and root biomass at periodic interval (45, 90 and 240 days) were monitored. Growth up to 30 days in the laboratory condition was not affected by soil conditions. In the second experiment, growth measurements on the 45th day indicated no difference between plants grown in soils with three distinctly different pH. However, at 90 days and 240 days significantly lower growth was recorded by plants grown in extremely acidic pH (4.4). Highest growth was recorded by plants grown at pH 7.4. The shoot and root biomass also recorded similar trend. Growth of plants was reduced at extremely acidic pH which may be due to the combined effect of extreme acidity and high Al^{3+} and H^{+} ions and low availability of nutrients warranting soil acidity and specific nutrient management for maintaining soil productivity and good growth of rubber plants.

Key words: Extremely acidic soil, *Hevea brasiliensis*, Natural rubber, Rubber growing soil, Soil pH

INTRODUCTION

Natural rubber (*Hevea brasiliensis*) is a forest tree species of the tropical rain forests in Central and South America. In world over, the natural rubber (NR) producing regions lies between 15^{o} North and South (Thomas and Panikkar, 2000). In the review, Verhege (2010) reported that *Hevea* cultivation is presently between 25^{o} North in Yunnan high lands (China) and 21^{o} South in Brazil. At present, the total NR area in India covers 8.27 lakhs hectares (Rubber Board, 2017) including the traditional as well as the non-traditional rubber growing areas with varying agro-climatic and soil conditions. Major share of the area (more than 85%) is in the traditional region and the the soil is mainly Ultisols (Joseph, 2016). In Kerala, rubber cultivation is extended to Wyanad (high elevation, >700 m) and low temperature areas and the productivity is less compared to the major rubber growing districts.

Soil pH plays major role in nutrient availability and plant adaptations to make a

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suitable environment for growth and productivity (Marschner, 1991). Plant species are sensitive to specific soil pH and its effect is most pronounced when pH conditions reach extreme values (Pattanayak and Sarkar, 2016). Acid soil is a major constraint for crop growth all over the world. About 30-40 per cent of the arable land is acidic (Uexkuell and Mutert, 1995; Pattanayak and Sarkar, 2016). Within the acidic soil, the pH between 3.5 - 4.4, 5.1- 5.5 and 6.6 - 7.3 are extremely acidic, strongly acidic and neutral soil, respectively (Soil Survey Manual, 1993, Hamza *et al.*, 2013). Generally soils of Kerala are acidic with a pH range of 4.5 to 6.2 with poor base status and belong to Ultisols popularly known as laterite and lateritic soils. Soils of the Palghat gap are neutral to alkaline (Chandran *et al.*, 2005). Humid tropical climate with high rainfall and high rate of organic matter decomposition, facilitate the acidification in the soils of Kerala. Each planting cycle of NR ranges from 25-30 years in the traditional belt of cultivation and now it is in the fourth cycle of planting. Our previous studies indicated a shift in the soil pH from strongly acidic to extremely acidic with continuous cultivation of rubber (Joseph, 2016) warranting a close monitoring of the changes in soil properties and growth of plants under extremely acidic soil conditions. Hence, the present study was conducted under confined conditions with sprouted seeds and seedlings to closely monitor the influence of pH on the root and shoot growth in soils having distinctly different pH ranging from extremely acidic to strongly acidic and neutral with wide variation in exchangeable Al and base status.

MATERIALS AND METHODS

The study comprises of two experiments *viz.* a laboratory study and a poly bag study conducted at the Rubber Research Institute of India, Kottayam, Kerala, India. In the first experiment, 600 g of soil with three different pH were taken in four trays for each pH and sprouted seeds were planted and grown for 30 days. On the 30th day, twelve uniform plants were uprooted and recorded the height, shoot and root length, fresh and dry weights of shoot and root. In the second experiment, sprouted seeds were planted in polythene bags filled with 10 kg soil in the open-air conditions in the premises of glasshouse. 50 plants were maintained in each treatment. The experiment was designed in completely randomised design with three treatments *viz*. soil with pH 4.4, 5.5 and 7.4. All the plants were maintained with uniform management practices like watering and manual weed control. No fertilizer was applied in any of the treatments. Twelve plants from each treatment were uprooted after 45 days, 90 days and 240 days. Plant diameter, root length, shoots length and shoot /root ratio was measured. Fresh weight and dry weight of shoot (leaf, stem and petiole) and root were recorded and the biomass and per cent dry matter were also estimated. Soil samples were analysed for organic carbon, pH, and available P, K, Ca, Mg, CEC and exchangeable bases as per the standard methodologies outlined in Jackson (1973). Exchangeable Al was estimated following the method described by Kamprath (1970). The data generated from the experiment were statistically analysed (Snedecor and Cochran, 1967)

RESULTS AND DISCUSSION

The initial properties of the three soils are given in Table 1. The soils selected were extremely acidic (pH 4.4), strongly acidic (pH 5.5) and neutral soil (pH 7.4). The organic carbon (OC) was in the medium range in all the three soils. The available P status was in the low range in all the three

Table 1. **Initial properties of the three soils with different pH**

Parameters	Soil with pH 4.4	Soil with pH 5.5	Soil with pH 7.4
Organic carbon (%)	1.13	1.21	1.04
Available P (mg kg^{-1})	20.1	21.9	14.4
Available K (mg kg^{-1})	38.2	47.9	66.0
Available Ca (mg kg^{-1})	42.4	52.4	6066.0
Available Mg (mg kg^{-1})	9.9	18.8	490.0
CEC (cmol(+) kg^{-1})	5.44	8.03	29.1
Exchangeable K (cmol(+) kg^{-1})	1.08	2.5	1.71
Exchangeable Ca (cmol(+) kg^{-1})	0.29	0.71	18.59
Exchangeable Mg (cmol(+) kg^{-1})	0.08	0.31	6.52
Base saturation (%)	33.8	43.8	95.6
Exchangeable Al (cmol(+) kg^{-1})	2.9	1.6	0
Exchangeable acidity (cmol(+)kg^{-1})	2.2	0.85	0.23

soils. At the same time, in the two acidic soils the values were similar and were slightly lower in neutral soil. The available K, Ca, and Mg were comparable in the acidic soils whereas, the available K was high and available Ca and Mg was very high in neutral soil. The exchangeable Al was extremely high in the extremely acidic soil (2.6 cmol(+) kg^{-1}soil) and there was no exchangeable Al content in the neutral soil. The exchangeable Al and exchangeable acidity in strongly acidic soil was less compared to the extremely acidic soil.

The growth parameters (shoot length, root length and biomass) of sprouted seedlings for a period of thirty days in the laboratory experiment are given in Table 2. No significant difference in shoot length or root length was observed. There was no significant difference in the shoot, root and total biomass of the seedlings in the three soils in the initial growth and establishment up to 30 days indicating that the extremely low pH or high exchangeable Al level in the extremely acidic soil did not affect the growth of sprouted seeds. The seed endosperm is sufficiently large enough to meet the nutrient requirement for the initial growth which may be one of the reasons. It is interesting to note that the young roots were not affected by the soil environment indicating that the excess H^+ or Al^{3+} might have been complexed or chelated with organic exudates and inactivated at the rhizosphere. Chelation and inactivation of

Table 2. **Growth of seedlings on the 30th day in the first experiment**

Treatments	Shoot length (cm)	Root length (cm)	Number of roots	Biomass (g)		
				Shoot	Root	Total
Soil with pH 4.4	32.8	14.5	27	0.86	0.21	1.07
Soil with pH 5.5	29.9	11.9	21	0.80	0.26	1.06
Soil with pH 7.4	29.1	13.1	26	0.89	0.24	1.13
CD (P=0.05)	NS	NS	NS	NS	NS	NS

Table 3. **Diameter of seedlings at periodic intervals**

Treatments	Diameter (cm)		
	45th day	90th day	240th day
Soil with pH 4.4	3.6	4.9	6.7
Soil with pH 5.5	3.6	6.2	7.9
Soil with pH 7.4	3.8	6.3	9.9
CD (P=0.05)	NS	0.42	0.38

toxic ions at the root surface (Ryan *et al.*, 1993) or at the rhizosphere (Jones, 1998) was reported.

The growth of the seedlings in terms of diameter at three intervals is given in Table 3. There was no significant difference in the diameter of plants at 45 days. However, the diameter at 90 and 240 days was different in the three soils. At the 90th day, the diameter of seedlings in soil with pH 4.4 was less than that in the soil with pH 5.5 and 7.4. Diameter of seedlings in soil with pH 5.5 and 7.4 were on par. At the 240th day also, the diameter of seedlings was different in the three soils and the highest diameter was recorded in pH 7.4 soil followed by pH 5.5 soil. The diameter (Fig. 1) of the plants in each soil steadily increased from 45 days up to 240 days and the rate of diameter increase was different among the three groups from the almost similar diameter on the 45th day. The increase in diameter at 90th day was higher for plants grown in soil having pH 7.4 than pH 5.5.

The shoot and root length in the three soils at three intervals is given in Table 4. Shoot length was not significantly different in the three soils at 45th day. But the shoot length was significantly low at 90 and 240 days in soil having 4.4 pH. Shoot length of plants was on par at pH 5.5 and pH 7.4 soils at 90th and 240th days. A steady increase in shoot length was observed in the three soils (Fig. 2). The highest root length was observed in pH 5.5 both at 90th and 240th day. But the difference in root length between plants grown in soil with pH 5.5 and 7.4 was not significant. The soil with pH 4.4 recorded the

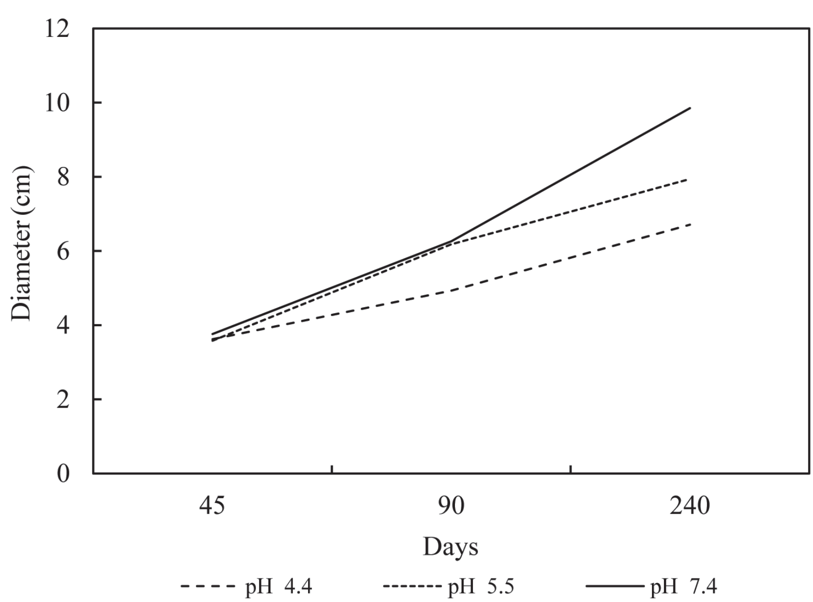

Fig. 1. Comparison of diameter from 45th to 240th day in the three soils

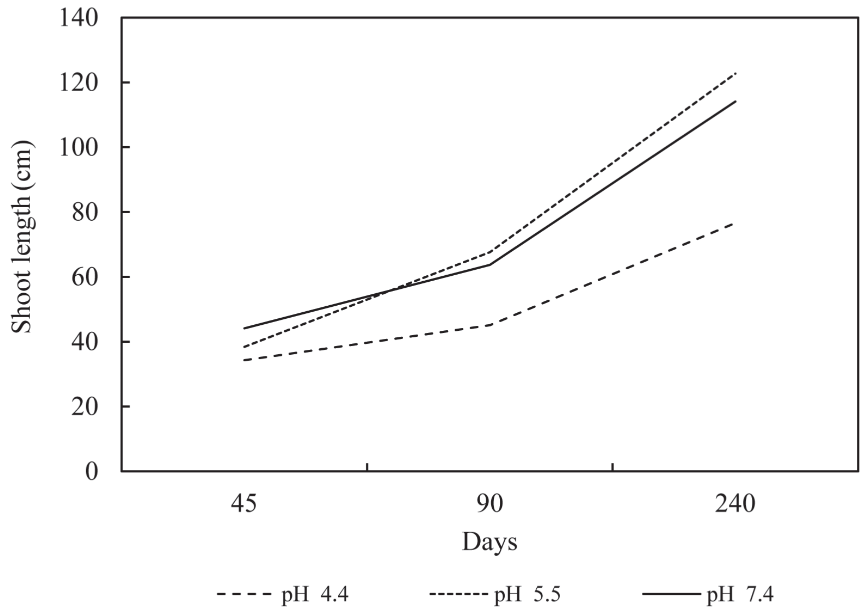

Fig. 2. Comparison of shoot length from 45[th] to 240[th] day in the three soils

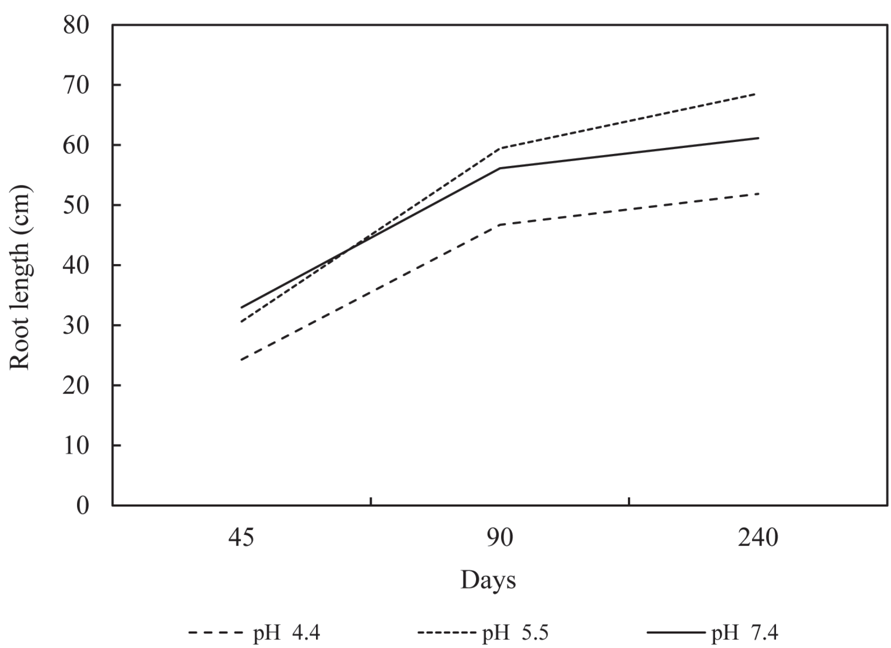

Fig.3. Comparison of root length from 45[th] to 240[th] day in the three soils

Table 4. **Shoot and root length of seedlings at periodic intervals**

Treatments	Shoot length (cm)			Root length (cm)		
	45th day	90th day	240th day	45th day	90th day	240th day
Soil with pH 4.4	34.3	45.1	76.6	24.3	46.7	51.9
Soil with pH 5.5	41.2	67.6	122.7	30.6	59.4	68.6
Soil with pH 7.4	44.0	63.7	114.1	33.0	56.1	61.1
CD(P=0.05)	NS	6.3	7.1	3.1	4.0	9.1

lowest root length than the other two soils in all the three time intervals and was significantly lower than the values recorded in soils with pH 5.5 and 7.4. There was a steady increase of root length from 45th to 240th day (Fig. 3).

The shoot, root and total biomass in the three soils at different interval is given in Table 5. There was no significant difference in shoot, root and total biomass at 45th day as that of the biomass at 30th day in laboratory study which indicates that the initial growth was not influenced by the different soil conditions. However, the shoot, root and total biomass at 90th day showed a significant difference in the three soils. Highest shoot biomass was recorded in pH 7.4 soil followed by pH 5.5 soil. However, the root biomass was higher in plants grown in soil with pH 5.5 than soil with pH 7.4 and the lowest shoot, root and total biomass was recorded in pH 4.4 soils. At the 240th day, the shoot, root and total biomass in pH 5.5 and pH 7.4 were on par and here also the lowest values were recorded for plants grown in pH 4.4 soil. The changes in shoot biomass (Fig. 4) and root biomass (Fig. 5) in each soil recorded a steady increase from 45th day up

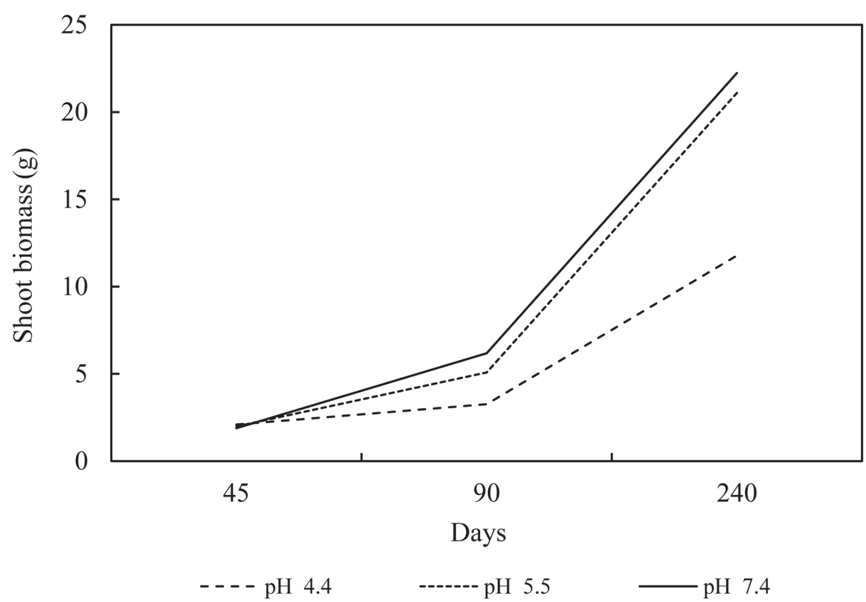

Fig. 4. Comparison of shoot biomass from 45th to 240th day in the three soils

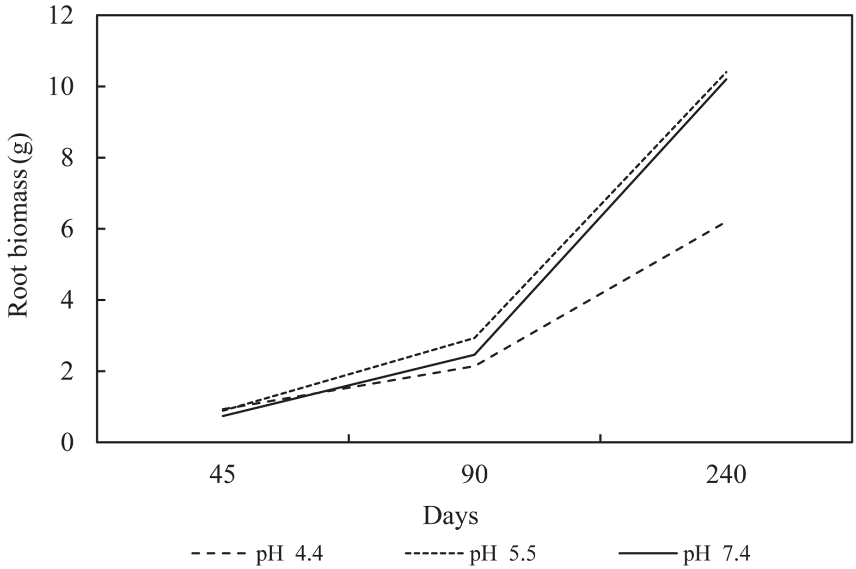

Fig. 5. Comparison of root biomass from 45th to 240th day in the three soils

to 240th day. The changes from 90th to 240th day were very high compared to 45th and 90th days and a lower increase was observed in 4.4 pH soil. The shoot/root ratios in the three soils (Table 6) at 90th day were significantly different and highest ratio was recorded by plants grown in pH 7.4 soil. This might be due to the significantly high shoot biomass recorded in pH 7.4 soil during the 90th day. Similar pattern of growth of rubber seedlings was reported by Correia *et al.* (2017). Though shoot biomass was very high, a corresponding increase in root biomass was not recorded and hence the shoot /root ratio was high in pH 7.4 soil. However, when it reached 240th day the shoot/root ratio recorded similar values in all the three soils. It was inferred from this observation that there were some changes according to the soil conditions to

Table 6. **Shoot/root ratio of seedlings at periodic intervals**

Treatments	45th day	90th day	240th day
Soil with pH 4.4	2.28	1.53	1.91
Soil with pH 5.5	2.39	1.74	2.03
Soil with pH 7.4	2.63	2.54	2.22
CD (P=0.05)	NS	0.13	NS

Table 5. **Shoot, root and total biomass of seedlings at periodic intervals**

Treatments	45th day			90th day			240th day		
	Shoot	Root	Total	Shoot	Root	Total	Shoot	Root	Total
Soil with pH 4.4	2.1	0.9	3.0	3.3	2.1	5.4	11.8	6.2	18.0
Soil with pH 5.5	2.0	0.9	2.9	5.1	2.9	8.0	21.1	10.4	31.5
Soil with pH 7.4	1.9	0.7	2.6	6.2	2.5	8.7	22.2	10.2	32.4
CD (P=0.05)	NS	NS	NS	0.4	0.2	0.5	2.1	1.5	3.4

Table 7. **Effect of soil pH and base status on the nutrient concentration in shoot on 240th day**

Nutrient	Soil pH 4.4	Soil pH 5.5	Soil pH 7.4	CD (P=0.05)
N (%)	1.31	1.18	1.38	NS
P (%)	0.05	0.19	0.22	0.03
K (%)	0.74	0.85	1.03	0.19
Ca (%)	0.71	1.03	1.29	0.22
Mg (%)	0.23	0.22	0.19	NS
Zn (mg kg^{-1})	30	47	38	8
Cu (mg kg^{-1})	30	23	19	6
Fe (mg kg^{-1})	537	278	187	208
Mn (mg kg^{-1})	189	149	107	36
Al (mg kg^{-1})	1643	343	171	58

Table 8. **Effect of soil pH and base status on the nutrient concentration in root on 240th day**

Nutrient	Soil pH 4.4	Soil pH 5.5	Soil pH 7.4	CD (P=0.05)
N (%)	0.91	0.65	0.68	NS
P (%)	0.15	0.16	0.18	0.04
K (%)	0.58	0.56	0.70	NS
Ca (%)	0.52	0.46	0.55	NS
Mg (%)	0.23	0.18	0.18	NS
Zn (mg kg^{-1})	30	52	33	9
Cu (mg kg^{-1})	39	76	40	14
Fe (mg kg^{-1})	3476	6205	8369	1120
Mn (mg kg^{-1})	112	102	82	NS
Al (mg kg^{-1})	3085	3057	1800	77

favour a particular growth pattern in the case of shoot/root partitioning and can be attributed to biomass allometry for new flushes of leaf and branches as reported earlier (Templeton, 1968; Sethuraj, 1985; Shafar *et al.*, 2017).

Plants grown in pH 5.5 soils with less base status attained comparable growth with pH 7.4 soil having extremely high base status indicating that pH 5.5 is favourable for growth of rubber seedlings even though the base nutrients were less compared to pH 7.4. Shafar *et al.* (2017) reported that when pH value reaches to 5.0, the Al in the soil solution undergoes precipitation to unreacted gibbsite and becomes less toxic. In acid mineral soils, the limitation such as increase of H^+ and Al^{3+} toxicity and impaired root growth restricts the plant growth. Among the two acidic soils, the growth is affected in extremely acidic pH (4.4) than the strongly acidic pH (5.5) soil. Marschner (1991) and Pan *et al.* (1989) reported that when exchangeable Al was high, not only the fresh root formation is affected but also the shoot growth hindered due to release of cytokinin content from roots along with the starvation for water and necessary nutrients. Also Cronan (1991) observed that when Al was high, it replaces the Ca and Mg from the exchange positions of the roots and decreased its uptake and this seriously affect the plant growth in terms of reduced cambium growth and girth increment (Shortle and Smith, 1988). The leaf and root growth and functions also will be affected (Raynal *et al.*, 1990). Shamshuddin and Fauziah (2010) reported that at higher concentration of Al, growth retardation is resulted due to the lack of tolerance to Al and acidity. These can be attributed as the reasons for poor growth in soil with pH 4.4 compared to the soil with pH 5.5 and the neutral soil (pH, 7.4). The highest growth in pH 7.4 also can be of the same reason of high Ca and Mg and the favourable pH of the soil medium in the present study. Incorporation of ground basalt which when dissolves increases the Ca supply can avoid the toxic effects of Al (Alva *et al.*, 1986; Shafar *et al.*, 2017) indicates the beneficial effect of high Ca content in the soil solution. Rubber is

Table 9. **Effect of soil pH and base status on the total uptake of nutrients by rubber seedlings on the 240th day**

Nutrient	Uptake (g plant^{-1})			CD(P=0.05)
	Soil with pH 4.4	Soil with pH 5.5	Soil with pH 7.4	
N	214	316	375	90.2
P	16.1	56.0	66.0	9.9
K	123	237	301	44.3
Ca	141	267	342	55.2
Mg	41.1	64.1	61.6	10.2
Zn	0.54	1.54	1.18	0.21
Cu	0.59	1.28	0.82	0.20
Fe	28.0	70.2	89.1	15.8
Mn	2.87	4.23	3.19	0.81
Al	38.6	39.2	22.2	4.5

performing well in strongly acidic soils but soils with extremely acidic pH along with higher exchangeable Al and H^+ ion concentration retards the growth. Also, growth of rubber plants is superior in soil with pH 7.4 having high status of Ca and Mg indicating its wide adaptability.

The nutrient concentration of the shoot on the 240th day of growth in three different soils having distinctly different pH and base status is provided in Table 7. Except for N and Mg all other nutrients recorded significant difference among the three soils. The P concentration was extremely low in soil having pH 4.4. It was on par in soil with pH 5.5 and 7.4. At extremely low pH (4.4), the availability and absorption is limited probably by the high P fixation as reported earlier (Ulaganathan *et al.*, 2005). Regarding K, the values were on par between the two acidic soils and significant difference was recorded with soil having 7.4 pH. Regarding Ca, the values were significantly different between two acidic soils with the extremely acidic soil recording the lowest value. However, the values were on par between pH 5.5 and 7.4. Even with very high available Ca level in pH 7.4 soil the concentration of Ca in the shoot was on par with the values recorded by plants grown in soil with pH 5.5. The Ca concentration in the plant increases with age and probably as the time advances there is more likely chance of increasing the Ca concentration with increased availability in the soil. Zinc concentration was significantly different between the three soils and the highest value was recorded in extremely acidic soil with pH 4.4. Increased Zn availability in extremely acidic soil may be the reason for this (Shuman, 1977). Regarding Cu, Fe, Mn and Al significant difference was recorded among the three soils. As reported in the literature, increased concentration of these ions under extremely acidic soil conditions might have promoted the uptake and highest concentration was recorded in soil with pH 4.4. The Fe concentration was on par between soils having pH 5.5 and 7.4.

Effect of soil pH and base status on the nutrient concentration of roots at the 240th day is given in Table 8. No significant difference was recorded in the concentration of N, K, Ca and Mg between the three soils which is in contrary to the general expectation that the plants grown in soil with pH 7.4 and very high base status will be having high concentration of the cations especially in K, Ca and Mg. But in the roots there was no difference between the three soils. However, in shoot, difference was recorded for K between the soils with pH 5.5 and 7.4. Iron concentration in the roots was very high for soil with pH 7.4. Higher concentration of Fe in the neutral soil (pH 7.4) compared to the extremely acidic soil (pH 4.4) is a significant observation and this might be affecting the uptake and accumulation of other nutrient elements affecting the balance among them.

The total uptake of nutrients by the plants on the 240th day is presented in Table 9. Uptake of nutrients being a derived value, calculated from the concentration and biomass, the treatment effect on the concentration and biomass is reflected. Differences were significant on the uptake of all the nutrients among the treatments. Nitrogen uptake was significantly lower in soils with pH 4.4 and was on par between soils with pH 4.4 and 5.5. Similar observation was recorded for P also. Regarding uptake of K, values were significantly different between soils with pH 5.5 and 7.4 and between soils with pH 4.4 and 5.5. For N, P K, Ca and Mg, highest uptake was recorded for soils with pH 7.4. Regarding Zn, Cu, Fe and Mn highest uptake was recorded by plants grown in soils with pH 5.5 and the lowest value was recorded by plants grown in soils with pH 4.4. Aluminium uptake was significantly lower in soils with pH 7.4 and the values were on par for soils with pH 4.4 and 5.5.

CONCLUSION

The soil pH and base nutrient status significantly influenced the growth of rubber seedlings. The growth of rubber plants was poor in extremely acidic soils with pH 4.4. Strongly acidic soil (pH 5.5) was favourable for rubber plants and recorded better growth. Neutral soil with very high base nutrient status recorded the highest growth of rubber seedlings indicating that the very high levels of Ca and Mg in the soil is not adversely affecting the growth of rubber seedlings. Rather it was found favourable for attaining improved growth. Root length was significantly lower in extremely acidic soil which in turn affected the uptake of nutrients and growth of plants. The study clearly indicated that when soil conditions especially pH, Al^{3+} and H^+ ion contents exceeds certain limit; the growth of rubber plants will be affected. Hence, necessary management practices is to be adopted from the initial stage in these soils to improve plant growth, particularly for attaining the specified girth within seven years which is the pre-requisite for opening the trees for tapping.

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