Potassium in Soils of Rubber Plantations

A.K. KRISHNA KUMAR, S.N. POTTY* AND CHANDRA GUPTA

Rubber Research Institute of India,
Regional Research Station, Agartala-799006, Tripura

ABSTRACT

Potassium plays a vital role in the nutrition of Hevea. The need for further refinement of the various aspects of nutrient management with respect to potassium is being felt strongly. This is particularly important in the context of non-traditional regions where Hevea culture will confront stress situations such as prolonged drought, low temperature, high wind-velocity and a soil with a different physico-chemistry. The influence of potassium in moderating these stress effects could be significant and hence has to be accorded top priority. In the quest for higher yield with high input technology and high yielding clones, potassium is one of the nutrient elements which will achieve immense importance and hence the dynamics of this nutrient element in soils under Hevea need to be studied more intensively.

2.0 INTRODUCTION

Importance of the role of potassium in the nutrition of Hevea has been well established and considerable research work has been carried out on this in the various natural rubber producing countries. Potassium plays a vital role in the growth and development of the plant as evidenced by the deficiency symptoms induced and also in governing the yield (Von Uexkull, 1985). Potassium is thought to have influence, direct/indirect, on atex-flow (Pushparajah and Ismail, 1982). High potassium may increase .esistance to wind damage. Pushparajah (1969) showed that potassium improved bark renewal. Samsidar *et al.* (1976) demonstrated that deficiency of potassium not only affected thickness of bark but also the number of latex-vessels. Tajudeen Ismail *et al.* (1980) confirmed the importance of potassium on growth of legumes also. The need for fertilizer application for rubber was felt in 1920's and yield increase upto 70 percent had been reported by the application of nitrogen, due to probably high potassium

*Rubber Research Institute of India, Kottayam-686009, Kerala.

In: Proceedings of Potassium for Plan[t] ... IIo Symposium on

reserves. The early theories however attached only minor importance to potassium nutrition based on the results of a few initial experiments.

Though the crop removal through dry rubber can be regarded as minimal compared to other crops considering the potassium depletion in the soils of the rubber growing tract and also in view of the depletion due to uptake and immobilisation by rubber trees, potassium availability could be a limiting factor. Rubber trees immobilise considerable amount of nutrients and the quantity of potassium immobilised is second only to nitrogen (Table 1). Rubber growing areas are mainly distributed in the tropics and to a lesser extent in subtropics. Soils in these tracts are mostly weathered with low base status and acidic. Buol *et al.* (1975) have estimated that one fourth of the soils in tropics have low potassium status and also

Table 1. *Nutrients immobilised in trees of different ages*

Age (Years)	Nutrients immobilised (Kg ha^{-1})			
	N	P	K	Mg
1	12	1	7	2
6	728	64	311	119
10	1527	143	510	241
33	1779	276	1233	417

Source: (Leong, 1980)

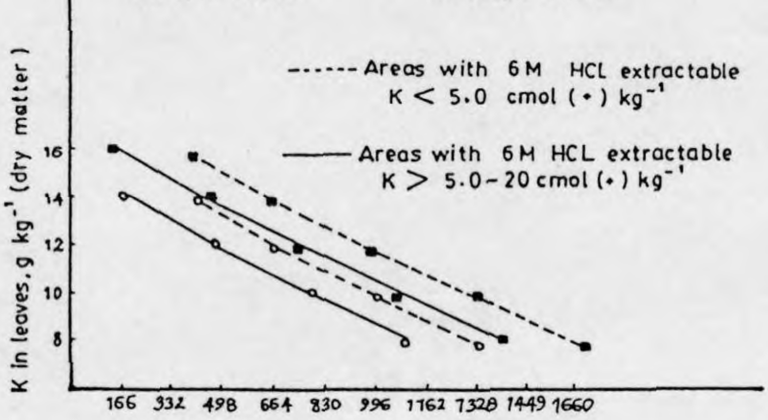

Figure 1. Rates of application of K for mature rubber (Source: Von Uexküll, 1985)

that where potassium levels are currently adequate can be shifted to deficiency, if production inputs vary. Excess nitrogen in potassium deficient soils has been reported to depress yield of rubber. Good response to applied potassium has been noticed when applied in conjunction with nitrogen. Though potassium nutrition may not pose problems in newly cleared areas where the content of potassium may be higher, it is sure to pose problems while cultivation of rubber is extended as replantings where in variable depletion due to removal through trees has resulted. The low potassium reserves, poor retention capacity on soils with low cation exchange capacity preponderance of 1:1 clay minerals, dominance of aluminium in the exchange complex, vulnerability for leaching and high input technology especially with high nitrogen through legume cover will further aggravate the problems. Lack of response and even negative response to potassium in some of the earlier trials can be attributed to the fact that these were taken-up in mostly new clearings and with low input management. Though potassium is the major nutrient needed least in low yield agriculture it achieves a dominant position when yields are maximised, particularly in the case of intensively managed plantation crops (Von Uexkull, 1985). Malavolta (1985) has reported that though potassium bearing minerals are universally present, the potassium reserves are either primary or secondary minerals and these in many cases are small which would make sustained prolonged cropping with-out potassium addition difficult. A review of research work done on potassium in soils under Hevea in some of the major natural rubber producing countries is attempted here.

3.0 RESPONSE OF HEVEA TO POTASSIUM

Pushparajah and Guha (1968) showed response of Hevea to potassium depending on soil potassium status. Pushparajah (1977) confirmed that response to potassium was directly dependent on potassium content of soils. Response of Hevea to potassium through residual effect has been reported by Punnose *et al.* (1976) in the red soils of Kerala. Pushparajah and Tan (1972) showed the differential potassium requirement of different clones. Potassium deficiency in rubber has been noted in China which was attributed to the low content of potassium in the soil (Chang *et al.*, 1982). In such soils chlorotic symptoms were reported to be severe when fertilizer nitrogen was applied (He Dian Yung *et al.*, 1963). Die-back symptoms of branch have been noticed in extremely potassium deficient soils of Indonesia and application of potassium fertilizers was observed to restore the crown of trees (Dijkman, 1950).

Increased addition of potassium in Terrarosa soils of Vietnam has been reported to increase yield by increasing P/Mg ratio in the clone Gl-1 which is high in latex magnesium (Beaufils, 1954). Similar observations were made by Rambeaux and Danjard (1963). Increased application of potassium and lowering the quantity of nitrogen before winter increased cold hardness of rubber in China (Huang Zongdao and Zheng Xuegen, 1983).

A balanced nutrition is of utmost importance in rubber. The rubber ecosystem coupled with specific agromanagement practices like maintenance of leguminous ground cover result in a higher input of nitrogen in the soils under Hevea. It has been estimated that through annual leaf fall in plots which are not fertilised about 42 kg of N, 7 kg K_2O and 5.5 kg MgO ha^{-1} are added. The maintenance of legume cover results in adding about 220 kg N and 68 kg K_2O ha^{-1} (*Mucuna bracteata* as cover) after three years under Indian conditions (Kothand-araman *et al.*, 1990). This imbalance in the nutrient inputs also in the long run result in depletion of potassium through consumption.

4.0 POTASSIUM IN SOILS UNDER HEVEA

Major portion of potassium in soils is present in the form of feldspars and micas and the most important of these are orthoclase and microcline feldspars, biotite, muscovite and micaceous clay such as illite. Soil potassium status depends on the amount and form of native potassium and the nature of the exchange complex. Potassium present in the soil is usually classified as non-exchangeable, exchangeable and water-soluble and these forms are in equillibrium.

Distribution of potassium in soils under rubber in Malaysia (Table 2)

Table 2. *Potassium of some common soils under Hevea in Malaysia*

Soil series	Exhange-able K (me $100g^{-1}$ soil)	Cation exchange capacity (me $100g^{-1}$) Soil	Clay fraction	K_2O in clay fraction (%)
Rangam (Typic Paleudalf)	0.14	2.93	11	0.1
Serdang (Typic Paleudalf)	0.10	5.89	21	2.4
Selangor (Sulfic Trop aquept)	0.37	15.96	30	2.0
Kuantam (Tropeptic Haplorthox)	0.10	2.63	12	0.05
Malacea (Plinthic Hplorthox)	0.09	2.65	—	—
Sagamat (Haplic Acrorthox)	0.16	2.05	11	0.06
Batu Anam (Aquoxic Dystropept)	0.12	4.75	—	—
Ulu Tiram (Typic Dystropept)	0.06	2.51	14	0.49

Source: (Soong and Lau, 1977)

shows a wide range. A subsurface enrichment of potassium due to its greater mobility has been reported by Soong and Lau (1977) in the above soils. The exchangeable potassium status of many soil series has been reported to be low which is a result of low cation exchange capacity. Lau and Yap (1972) reported based on studies conducted in Malaysia that leaf potassium correlated with soil potassium status. Aluminium has been reported as the dominant cation in exchange complex and the concentration of Al^{3+} ions determined the availability of potassium. The preferential adsorption of Al^{3+} however decreased at higher potassium concentration. Studying the potassium supplying power of seven soils series under rubber in Malaysia, Yew (1978) reported that the potassium uptake had been highest from Selangor series (Tropaduept) followed by Durian Series (Tropudalf) denoting that there was no response to applied potassium in the soils of above two series. The other five series, Munhong (Tropeptic Haplorthox), Rengam (Typic Paleudalf) and Holyrood (Orthoric Quartzipsamment) warrant potassium fertilizer application. Pushparajah and Ismail (1982) reported that total potassium content was adequate in three of the five soils studied for nutrition of Hevea for a period of time.

The content of exchangeable potassium (Table 3) was found to vary widely in soils under Hevea in India (Krishna Kumar, 1989). The distribution of exchangeable potassium was found to occupy 1.81 to 6.01 percent of the cation exchange capacity of the soil. A surface enrichment of exchangeable potassium has been noticed and this is due to litter recycling in the organomineral surface layers. The distribution of exchangeable potassium in the profile shows in general a decreasing trend with depth. The build-up of potassium as reported by Pushparajah *et al.* (1977) in deep layers of Malaysian rubber growing soils was not encountered in soils under Hevea in India. This can be attributed to the clayey texture and illitic component in clay which hold potassium with much tenacity. There was a negative correlation between exchangeable potassium and clay and a positive correlation between exchangeable potassium (neutral 1N NH_4OAc) and available potassium (Morgan's Extract) and exchangeable potassium and cation exchange capacity. However, there was no correlation between total potassium and exchangeable or available potassium in the soils under Hevea in India (Krishna Kumar, 1989).

The available potassium in soils under Hevea determined by Morgan's extract varied from 1.17 to 9.37 mg $100g^{-1}$ soil. The mean available potassium content in the profiles from five rubber growing regions of South Western Coast of India, Kanyakumari, Calicut, Central Kerala, Goa and Karnataka regions are 4.75, 3.7, 4.61, 4.3 and 4.30 mg $100g^{-1}$, respectively. The critical range for soil available potassium is 5-12.5 mg $100g^{-1}$ and the above data suggests that from the nutrition point of view of Hevea the available potassium content is not adequate.

Table 3. *Distribution of potassium in soils under Hevea in India*

Profile/ location	Depth (cm)	pH (H_2O)	C E C (me $100g^{-1}$)	Exchange-able potassium (me $100g^{-1}$)	Available potassium (me $100g^{-1}$) (%)	Total potassium (Na_2CO_3 fusion) (%)
1. Kanyakumari	0-15	4.6	11.83	0.24	7.75	0.56
region	15-30	4.8	8.56	0.13	3.75	0.60
(Paleudalf)	30-70	4.7	9.09	0.12	3.62	0.42
	60-90	4.5	6.36	0.11	2.50	0.37
	90-125	4.6	9.10	0.19	1.25	0.38
	125-150	4.6	8.01	0.16	1.12	0.43
2. Calicut	0-17	4.9	4.73	0.21	3.12	0.71
region	17-30	4.9	3.91	0.18	1.62	0.69
(Paleudalf)	30-50	4.8	3.68	0.27	2.00	1.18
	50-90	4.8	3.55	0.16	1.87	0.60
	90-150	4.8	4.64	0.20	2.25	0.64
3. Central	0-28	4.6	9.74	0.56	9.37	0.95
kerala	28-50	4.7	6.95	0.40	8.62	0.86
(Paleudalf)	50-85	4.7	3.91	0.33	4.87	1.55
	85-125	4.7	5.31	0.27	3.75	0.84
4. Goa	0-13	5.8	18.02	0.64	8.12	0.84
(Paleudalf)	13-35	5.8	12.60	0.47	7.75	0.98
	35-65	5.7	11.83	0.33	6.75	1.07
	65-125	5.7	9.77	0.77	9.25	1.23
	125-150	5.9	6.39	0.28	7.75	1.18
5. Karnataka	0-10	5.4	9.25	0.72	7.25	0.71
(Paleustalf)	10-30	5.0	8.74	0.32	7.62	0.83
	30-75	4.9	7.54	0.20	3.25	0.61
	75-150	5.3	5.54	0.26	1.62	0.79
	150-180	5.4	8.36	0.09	1.25	0.73

Source: (Krishna Kumar, 1989)

5.0 FACTORS AFFECTING AVAILABILITY OF POTASSIUM

In most of the soils under Hevea in the world the mineralogy is dominated by 1:1 minerals (Chan *et al.*, 1977; Ebong *et al.*, 1989; Krishna Kumar, 1989). The potassium potential of the soils in South China is reported to increase with the decrease of kaolinite and hydrous mica in the soil. The potassium supplying power of these soils thus had been found to vary (Chang *et al.*, 1982). Potassium bearing minerals are present as hydrous mica in several soils of People Republic of China and they are difficult to be weathered (Xie *et al.*, 1982).

In the rubber growing soils of India appreciable illite in degraded form has been reported to be present and illite was the second dominant mineral which calls for attention from nutritional point of Hevea. The amount of exchangeable potassium in soils directly available to plants is related to clay content and on the intensity of mineral decomposition of soils rich in illite and montmorillonite (Sekhon, 1982). There was a negative correlation between exchangeable potassium and clay in the rubber growing soils of India. The available potassium in these soils showed a negative correlation with available magnesium also denoting that higher magnesium in soils will affect the availability of potassium. In soils under Hevea in Malaysia soil potassium availability was greatly affected by presence of Al^{3+} ions (Singh, 1970). Adsorption isotherms of these soils revealed that Al^{3+} ion was strongly preferred to K^{+}.

In India the rubber cultivation is extended to non-traditional region such as in the North Eastern Region where the physico-chemistry of the soil is quite different from that in the traditional regions. In soils of Tripura, appreciable amount of illite has been recorded. The available potassium status of these soils has not been satisfactory (Krishna Kumar and Potty, 1989) and good response to applied potassium has been reported (Krishna Kumar and Potty, 1990).

The availability of potassium in the soil to plants depend on soil moisture content and the concentration of available potassium in the soil. Increase in soil moisture has been found to increase exchangeable potassium in soils under *Hevea* in India (Table 4). The level of exchangeable potassium depended on the dose of fertilizer applied. However, magnesium has been shown to depress available potassium. Soils inherently rich in magnesium need high application of potassium to maintain satisfactory level. The uptake of potassium is affected by soil moisture content as evidenced by the latex potassium content (Table 4). To sustain a satisfactory level of uptake during dry periods, high potassium application would be required and also in the presence of magnesium a higher dose of potassium is required to keep up the uptake. The study above conducted by Krishna Kumar (1989) also revealed that a higher soil potassium during dry period helped in maintaining a better plant water status.

6.0 INFLUENCE OF POTASSIUM FERTILIZERS ON SOIL POTASSIUM STATUS

Addition of potassium fertilizers has been reported to improve the exchangeable potassium status of the soil (Pushparajah *et al.*, 1975). Application of potassium fertilizers has also been found to modify the available potassium status as well as favour plant growth (Potty *et al.*, 1976). Bolton (1960) reported large increase in soil exchangeable potassium due to KCl application. However, lowering of pH caused by addition of ammonium sulphate reduced exchangeable potassium. Application of

Table 4. *Influence of soil-moisture on soil exchangeable K, K-uptake and yield of rubber*

Months	Soil moisture (%)	$N_0P_0K_0Mg_0$			$N_{30}P_{30}K_{30}Mg_0$			$N_{30}P_{30}K_{30}Mg_{30}$			$N_{30}P_{30}K_{60}Mg_0$		
		Soil exch. K (me $100g^{-1}$)	Latex K (%)	Yield (ml)	Soil exch. K (me $100g^{-1}$)	Latex K (%)	Yield (ml)	Soil exch. K (me $100g^{-1}$)	Latex K (%)	Yield (ml)	Soil exch. K (me $100g^{-1}$)	Latex K (%)	Yield (ml)
Dry													
Feb.	22.25	0.152	0.410 (47.83)*	78	0.262	0.397 (46.08)*	67	0.260	0.387 (48.12)*	135	0.412	0.512 (39.94)*	157
March	22.15	0.096	0.395 (34.78)*	86	0.212	0.307 (37.05)*	65	0.208	0.345 (41.78)*	115	0.375	0.508 (36.51)*	144
April	21.05	0.085	0.380 (41.36)*	69	0.200	0.400 (47.65)*	40	0.298	0.275 (50.15)*	31	0.312	0.392 (49.25)*	85
Wet													
August	36.65	0.307	0.467 (32.30)*	185	0.387	0.417 (37.51)*	225	0.365	0.407 (34.71)*	540	0.610	0.536 (29.74)*	546
Sept.	32.70	0.292	0.372 (36.97)*	110	0.317	0.412 (39.80)*	204	0.300	0.387 (33.27)*	403	0.325	0.456 (37.66)*	420
Oct.	32.55	0.240	0.301 (35.34)*	228	0.310	0.375 (35.40)*	180	0.292	0.376 (34.27)*	394	0.192	0.401 (33.45)*	430

Figures in bracket indicate total solids
Source: (Krishna Kumar, 1989)

potassium chloride over a period of seven years in North East India, showed marked increase in soil available potassium. Raising the quantity of potassium fertilizer from 20 Kg to 40 Kg per hectare during the above period resulted in an increase of available potassium level from 5.93 to 10.93 mg $100g^{-1}$ (Annual report, Rubber Research Institute of India, 1988-89). In another field experiment undertaken in Tripura by the Rubber Research Institute of India, no increase in available soil potassium has been noticed when a higher dose of nitrogen was applied along with a higher potassium fertilizer dose. Though the growth of Hevea plants was found to be increased in the above case a subsoil depression of available potassium has been noticed at third year (Krishna Kumar and Potty, 1990) possibly due to higher uptake by both rubber plants and luxurient leguminous ground cover coupled with higher fixation by illite component in the exchange complex. Addition of potassium fertilizers also reduces the available magnesium status of soil and leaf magnesium percentage. In the People's Republic of China where rubber is grown on Oxisols low in potassium, the application of potassium fertilizer had a significant effect on yield and latex stability (Liang, 1982).

Application of potassium fertilizer had been reported to increase the 6 N HCl acid extractable potassium in soils with lattice clays (Pushparajah and Ismail, 1982). They also reported that in soil with a mixture of Kaolinite and Goethite an increase in exchangeable potassium was accompanied by a similar increase in acid extractable potassium.

7.0 LOSSES OF POTASSIUM FROM SOIL

Potassium because of its high mobility is vulnerable to leaching losses. The leaching loss depends on the soil-texture, nature of adsorption complex, presence of Al^{3+} forms and rate of potassium fertilizer applied and rainfall and its distribution. Most soils under Hevea have a mineralogy dominated with 1:1 type minerals with a preponderance of Al^{3+} and fall in high rainfall regions. Studies conducted in Lysimeter (Bolton, 1968; Soong, 1973; Sivanadyan, 1974; Pushparajah *et al.*, 1977 and Pushparajah *et al.*, 1974) suggest that the loss is appreciable. Though the quantity of fertilizer applied to rubber is only 270 Kg per hectare in the first year considering the fact that is over an area of 0.006 hectare makes the effective rate 40 tonnes per hectare and this leads to heavy leaching (Sivanadyan, 1974). Studies indicated that in general the retention of applied potassium was only 60 to 70 percent in soils under Hevea. It has also been noted that potassium fertiliser, when applied with urea is better retained than when applied with ammonium sulphate. Leaching of potassium was observed to be rapid in acid soils.

8.0 SOIL TEST METHODS FOR POTASSIUM IN RUBBER PLANTATION

Soil test methods form the basis of fertilizer recommendation. The steps involved in developing a soil test include selecting an extractant, correlating the amount of nutrient extracted with the amount taken up by plant and calibrating the test value in terms of its effects on yield (Corey, 1987). Though the soils under Hevea have appreciable amount of total potassium, the plant available potassium is limited. As per the Glossary of Soil Science (SSSA, 1987) available nutrients are defined as 'Nutrient ions or compounds in forms which plants can absorb and utilise in growth.' Though there is no mention of the rate at which it is absorbed, the same also is important.

The general terms used in the context of forms of potassium are exchangeable potassium, available potassium and total potassium. The assessment of potassium status of soils under rubber in Malaysia has been confined for the determination of exchangeable and total potassium and had been correlated with soil potassium and leaf potassium status (Lau and Yap, 1972). While boiling 6 N hydrochloric acid for a period of one hour is employed for determining total potassium (only a portion is extracted), neutral normal ammonium acetate is used to determine exchangeable potassium in Malaysia. Singh and Talibudeen (1969) extended the hypothesis of Schoefield (1947) to the estimation of potassium in rubber growing soils of Malaysia. Intensity and quantity measurements were made by a single equilibration method using 0.01 N $AlCl_3$. The study indicate that potassium status of soils under rubber in Malaysia could be obtained from Quantity/Intensity relationship using aluminium chloride. Further, studies indicated that exchangeable acid extractable Quantity/Intensity values for soil potassium appeared to be correlated with leaf potassium (Lau and Yap, 1972). They also reported that buffering capacity did not give any plant analytical value. Use of cation exchange resin has been tried in Malaysia (Soong and Lau, 1977) and it is reported that this can extract more than neutral normal ammonium acetate.

The Rubber Research Institute of India follow the use of Morgan's extract in a soil: extractant ratio, 1:5 for the estimation of available potassium (Karthikakutty Amma, 1977). An available potassium content of 5-12.5 mg $100g^{-1}$ is the critical range of available potassium fixed for the soils under rubber in India. Exchangeable potassium extracted by normal ammonium acetate and available potassium extracted by Morgan's extract correlated in the rubber growing tract of South Western Coast of India (Krishna Kumar, 1989) and there was no correlation between total potassium and exchangeable/available potassium.

9.0 FERTILIZER RECOMMENDATION

The Pre-World War II yields which were in the range of 250 to 500 kg dry rubber per hectare has risen to 1500 to 2000 kg per hectare per year with a further potential upto 6000 Kg per hectare per year upto 7000 kg per hectare per year as estimated by Corley (1980). The increased yield, the immobilisation which in a medium soil has been estimated as 1400 kg per hectare (Lim, 1978), the extra removal through stimulation which disproportionately increase potassium removal through latex and the fact that rubber is grown in poorer soils warrant high input of potassium fertilizer. Fertilizer recommendations are largely based on leaf and soil analysis and clonal differences in potassium requirement is also taken into account. Von Uexküll (1985) has suggested a diagonistic criteria following Pushparajah and Ismail (1982) as illustrated in the figure. The recommendation suggested is for 1500 kg dry rubber per hectare per year and for additional higher yield potassium at the rate of 10 to 12 kg per hectare (K) for every 100 kg rubber has to be applied.

The Rubber Research Institute of India recommends K_2O at the rate of 4, 16, 20 and 16 kg. per hectare during immature phase, for first, second, third and fourth year, respectively. The dose however is increased to 24 kg per hectare at fifth year upto tapping where no legume cover has been established (Nitrogen being 60 kg per hectare) and 30 kg per hectare (Nitrogen being also 30kg. per hectare) where legume cover has been established.

In the North Eastern India which is a non-traditional rubber growing region, the dose of potassium for the first four years of immaturity is 14, 25, 35 and 25 kg potassium per year respectively, for first to fourth year (Krishna Kumar and Potty, 1989). Taking into consideration the physico-chemical aspects and also the stress condition prevailing, further work on potassium is required to evolve a suitable recommendation. The impact of prolonged latex flow during winter period on potassium depletion also need to be studied in depth.

REFERENCES

Beaufils, E.R. (1954) Contribution to the study of mineral elements in field latex. *Proceedings of the Third Rubber Technology Conference*, London 1953 pp 87-88.

Bolton, J. (1960) The response of Hevea to fertilizers on a sandy latosol. *Journal of the Rubber Research Institute of Malaya*. 16(4): 178-190.

Bolton, J. (1968) Leaching of fertilizers applied to a latisol on lysimeters. *J. Rubber Res. Inst. Malays.* **20**: 274.

Buol, S.W., Sanchez, P.A., Cote, R.B. Jr., and Granger. (1975) Soil fertility capability classification. p 126-141. *In Soil management in tropical America. Proc. CIAT Seminar,* February, 1974. North Carolina State University, Raleigh.

Chan, H.Y., Pushparajah, E., Mohd. Nordinbin, Wan Dand., Wong, C.B. and Zainol Eusof (1977) Parent material and soil formation. *In Soils Under* Hevea *in Peninsular Malaysiá and their Management.* Ed. by E. Pushparajah and L.L. Amin. 1-19. Rubber Res. Inst. Malaysia, Kuala Lumpur.

Chan, Xie Jian., Tong, Mao Ma., Lin Du Cheng and Xing, Cheng Ji. (1982) Potassium status and potassium fertilizer requirement of soils in tropical and subtropical regions of China. *In Phosphorus and Potassium in the Tropics* Ed. E. Pushparajah and Sharifudeen. A Hamid. *Kuala Lumpur Malaysia Soc. of Soil Sci.:* 113-126.

Corey, R.B. (1987) Soil test procedures: correclation. *In Soil Testing: Sampling, Correlation, Calibration and Interpretation.* ed. J.R. Brown. Soil Science Society of America, Inc. Madison, Wisconsin, U.S.A. p 15-22.

Corley, R.H.V. (1980) Oil palm and coconut. *In symposssium on potential productivity of field crops under different environments.* International Rice Research Institute, Los Banos, Philippines.

Ebong T, Eshett and Omutei, J.A.I. (1989) Potential for rubber (*Hevea brasiliensis*) cultivation on the basaltic soils South Eastern Nigeria: Climatic, pedo chemical and mineralogical considerations. *Indian Journal of Natural Rubber Research* **2**(1): 18.

He dian-Yuan *et al (1963)* The chlorosis of rubber trees in relation to potassium nutrition as quoted in the book Phosphorus and Potassium in the tropics. Ed. E. Pushparajah and Sharifuddin, A. Hamid. *Kuala Lumpur. Malaysian Soc. of Soil Sci.:* 117.

Huang Zongdao and Zheng Xuegen. (1983) Rubber cultivation in China. *Proc. RRIM Planter's conference:* 31-42.

Karthikakutty Amma, M. (1977) Comp. *Plant and Soil Analysis - Laboratory Manual.* Rubber Res. Institute of India Kottayam.

Kothandaraman, R., Jacob Mathew; Krishna Kumar, A.K.; Kochuthresiamma Joseph; Jayarathnam K. and Sethuraj, M.R. (1990) Comparative efficiency of *Mucuna bracteata* D.C. and *Pueraria phaseoloides* Benth on soil nutrient enrichment, microbial population and growth of Hevea *Indian J. Nat. Rubb. Res.* **2**(2): 147-150.

Krishna Kumar, A.K. (1989) *Soils Under Hevea in India: A Physical Chemical and Mineralogical study with a reference to Soil Moisture Cation Influence on yield of hevea brasiliensis* Ph.D. Thesis, Indian Institute of Technology, Kharagpur.

Krishna Kumar, A.K. and Potty, S.N. (1990) Response of Hevea planted as polybag plants to fertilizers during immature phase in soils of Tripura. *Indian Journal of Natural Rubber Res.* 2(2): 143-146.

Lau. C.H. and Yap, W.C. (1972) Evaluation of various soil K-indices in relation to nutrition, growth and yield of Hevea brasiliensis. *Proc. 2nd ASEAN soil conf. Diakarta* 2: 239.

Liang, Deyin. (1982) Effect of potassium fertilization on commercial crops. *ESCAP News Brief* 5(4): 6-11.

Lim, T.S. (1978) Nutrient uptake by clone PRIM 600 in relation to soil influence and fertilizer needs. *In Proc. Rubber Res. Inst. Malaysia Planters Conference* 17-19 Oct. 1977 Kuala Lumpur p 166-185.

Malavolta, E. (1985) Potassium status of tropical and subtropical region soils. In *Potassium in Agriculture* Ed. Robert D Munson. American Society of Agronomy, Crop Science Society and Soil Science Society of America Inc. USA p 163-200.

Leong, N.S. (1980) Some views on the reliability of foliar diagnosis for rubber. *In Proceeding Conference on Classification and Management of Tropical Soils. 1977.* Ed. K.T. Joseph, Kuala Lampur, *Malaysian Soc. of Soil Sci.* 319-323.

Potty, S.N., Abdulkalam, M., Punnoose, K.I. George, C.M. (1976) Response of Hevea to fertilizer application in relation to soil fertilizer characters. *Rubber Board Bull.* 13(3): 48-54.

Punnoose, K.I., Potty, S.N., Abdul Kalam, M., Karthikakutty Amma, M. and Mathew, M. (1978) Studies on direct and residual effect of nitrogen, phosphorus and potassium on the growth and yield of rubber in red loam soils of South India. *Proc. of the Plantation Crop Symposium. I Kottayam.* 1978.

Pushparajah, E. and Guha, M.M. (1968) Fertilizer response to *Hevea brasiliensis* in relation to soil type and leaf nutrient status *trans. 9th Int. Cong., Soil Science* Adelaide.

Pushparajah, E. (1969) Response in growth and yield of *Hevea brasiliensis* to fertilizer application on Rengam Series Soils. *J. Rubb. Res. Inst. Malaya* 21: 165.

Pushparajah, E. and Tan, K.T. (1972). Factors influencing leaf nutrient levels in rubber. *Proc. Rubb. Res. Inst. Malaya Plr's Conf.* Kuala Lumpur. 1972. 140.

Pushparajah, E. Sivanadyan, K and Yew, F.K. (1974) Efficient use of fertilizers. *Proc. Rubb. Res. Inst. Malaya Plr's Conf.* Kuala Lumpur. 102.

Pushparajah, E., Soong, NK., Yew, F.K. and Zainol Eusof (1975) Effect of fertilizers on soils under Hevea. *Proc. Int. Rubb. Conf. Kuala Lumpur* 54: 27.

Pushparajah, E. (1977) Nutrition and fertilizer use in *Hevea* and associated covers in Peninsular Malaysia - a review. *J.Rubb. Res. Inst. Sri Lanka* **54**: 270-83.

Pushparajah, E, Ng Siew Kee and Ratnasingam, K. (1977) Leaching losses of nitrogen, potassium and magnesium on Peninsular Malaysian soils. *Proc. Conf. Fer. Chem. Trop. Soils. Kuala Lumpur.* 121.

Pushparajah, E., Tan K.H. and Soong, N.K. (1977) Influence of covers and fertilizers and management on soil. *In Soils under* **Hevea** *in Peninsular Malaysia and Their Management.* Ed. E. Pushparajah and L.L. Amin. *Rubber Research Inst. Malaysia, Kuala Lumpur.*

Pushparajah, E. and Tajudeen Ismail (1982) Potassium in rubber cultivation. *In Phosphorus and Potassium in the Tropics.* Ed. By E. Pushparajah and Sharifuddin A. Hamid. *Kuala Lumpur Malaysian Soc. of Soil Sci.*: 293-313.

Rambeaux, J. and Danjard, J.C. (1963) Teneronge basaltiqul et nutrition de l' Hevea dans pes conditions ecologiques dn Cambodge opuse. Tech. Inst. Res. Caoutch Cambodge No. 2/63.

Rubber Research Institute of India. (1960) Annual Report. 1988-1989.

Samsidar Hanzah, Abdul Azziz Mahmood, Sivandyan, K and Gomez B.T. (1976) Effects of mineral deficiencies on bark. anatomy of Hevea brasiliensis. *proc. Int. Rubb. Conf. Kuala Lumpur.* **2**: 165.

Schofield, R.K. (1947) A Ratio Law governing the equillibrium of cations in the soil solution. *Proc. llth Int. cong. Pure and appl. Chem. Lond* **3**: 257.

Sekhon, G.S. (1982) Potassium and its use in the tropics. *In Phosphorus and Potassium in the Tropics* Ed. E. Pushparajah and Sharifuddin, A. Hamid. *Kuala Lumpur. Malaysian Soc. of Soil Sci.*: 285-292.

Singh, M.M. (1970) Exchange Reactions of Potassium, Magnesium, Aliminium in some Malayan soils. Ph.D. thesis, University of Malaya. As quoted in the book *Soils under Hevea and their Management in Peninsular Malaysia* Ed.E. Pushparajah and L.L. Amin *Rubber Research Institute of Malaysia, Kuala Lumpur.*

Singh, M.M. and Talibudeen, O. (1969) Thermodynamic assessment of the nutrient status of rubber growing soils. *J. Rubb. Res. Inst. Malays* **21**: 240.

Sivanadyan, K. (1974) Lysimeter studies on the efficiency of some potassium and nitrogenous fertilizer on two common soils in West Malaysia. *Proc. 2nd ASEAN Soils Conf. Jakarta* **11**: 177.

Soil Science Society of America. (1987) Glossary of soil science terms. Soil Science Society of America. Madison, W.I.

Soong, N.K. (1973) Effect of nitrogenous fertilizer on growth of rubber and leaching losses of nutrients. *J. Rubb. Res. Inst. Malaya* **23**(5): 273.

Soong. N.K. and Lau, C.H. (1977) Physical and Chemical properties of soils. In Soils Under Hevea in Peninsular Malaysia and their Management. Ed. E. Pushparajah and L.L. *Amin. Rubber Research Institute of Malaysia Kuala Lumpur.* 1.

Tajuddin Ismail., Chin Siew Lock and Pushparajah, E. (1980) Improving efficiency of legume covers for increased nitrogen returns. *Proc. Legumes Tropics.* pp 403-414. University Pertanian, Malaysia, Serdang 1979.

Templeton, J.K. (1969) Where lies the yield Summit for Hevea? *Plant Bull. Rubber Res. Inst. Malays.* **104**: 220-226.

Von Uexkull, H.R. (1985) Potassium nutrition of some Tropical plantation crops. *In Potassium in Agriculture Soil Science Society of America Madison,* USA. p. 929-954.

Xie, J.C. M.T. Ma, C.L. Du and J.X. Chen (1982) K supplying power and K fertilizer requirements of the main rice soils of China. *Potash Rev.* Subject 4, 76th Suite: 1-5.

Yew, F.K. (1978) Potassium-supplying power of seven soils under rubber. *J. Rubb. Res. Inst. Malaysia* **26**(1): 13-20.