Potassium in Plantation Crops

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Introduction

The importance of potassium in the Indian agriculture needs no emphasis. It is a key nutrient which is required/removed from the soil in quantities comparable to or more than the nitrogen. Any decline in the soil nutrient pool will have adverse impact on crop productivity. The importance can further be emphasised from the statement of Albrecht (1943), who rightly epitomized that, "Because of the prevalence of its minerals in the lithosphere, of its readily soluble nature, of its readiness to become insoluble and inexchangeable from the colloid, of its movement from the vegetation to the soil through leaching from the tops or exchange from the roots, and of its reserve in the silt and sand minerals to buffer the clay; K is so nomadic that its performances in any particular situation are difficult to interpret". In the nature, the potassium cycle consists of depletion from soil reserve on account of leaching losses beyond root zone, uptake and removal by the crops and addition through release of K from minerals, fertilizers and organic matter and debris. In plants, potassium helps in maintaining ionic balance in the cell, water relations and helps in root development. It is necessary for the formation of sugar, fat and fibrous materials and also favours early bearing. Tandon and Narayan (1990) identified 47 districts in India are deficient in K, whereas 192 is medium and 122 districts high in potassium status. This is based on soil fertility map prepared in 1976. And it is long way since we have come *i.e.* another two decades. Knowing the fertilizer usage with regard to potassium, it can safely be said that now atleast more than 50% of the soils will definitely require K application in order to give optimum crop yields.

Geographical Distribution and Soils Growing Plantation Crops in India

Plantation crops are grown mainly in the states of Kerala, Karnataka, West Bengal, Assam, Tamil Nadu and Andhra Pradesh. These are mostly grown in humid tropical conditions between 20ºN and 20ºS of Equator. However, tea and coffee require comparatively cooler climate. The geographic distribution varies with the crop requirement. Tea is grown in high altitude followed by coffee under hill slopes. Coconut is mainly cultivated in coastal belt of west and east coast of India. The cultivation of rubber is on the hilly slopes of West Bengal, Karnataka, North East, Tamil Nadu and Kerala (Nair *et al.*, 1996).

The plantation crops in general are grown on resource poor soils. The major soil types are laterite, lateritic, red and coastal sand. Apart from these, they are also grown in alluvial, coral and acid sulphate soils. They have poor physical properties and low native fertility. Proper on farm management and adequate moisture availability go a long way in determining the productivity of the crops in these soils. Tandon and Ranganathan (1988) have summarized the general characteristics and range of available nutrients in soils under plantation crops (**Table 1**).

Generally, soils under plantation and spice crops are acidic in reaction. The desirable pH range is 4.5-5.0 for tea, 5.5-6.5 for coffee, 6.0-7.0 for rubber, wide pH range for coconut and for other crops, it is slightly acidic to near neutral in reaction. Some soils under plantation crops are very acidic, thereby; toxicity of aluminum, manganese and iron poses problems in many situations. Tea is tolerant to high levels of aluminum, manganese and iron. However, coffee and cardamom are sensitive to aluminum and manganese toxicity. In such conditions, liming is required. Being high rainfall tract and mainly light textured soils, leaching of nutrients take place, thereby depleting the soil of the precious currencies.

K status of soils: Pillai (1975), based on the ratings of Muhr *et al.* (1963), has reported that all the soil groups of Kerala under coconut are generally deficient in available K and no soil group following under high ratings. Bastin and Venugopal (1986) indicated that the alfisols, which are intensively cultivated for coconut, are generally low to medium in potash status (**Table 2**). Similarly, Rubber, which is extensively grown in red and laterite soils are generally inherently deficient in potassium (Pushpadas and Karthikutty Amma, 1980). Earlier, Palaniswamy *et al.* (1978) reported that rubber growing soils of South India are low to medium in available K status. According to recent studies, majority of rubber growing soils are red ferruginous soils of the order Ultisols and were found to be low to medium in available K status (NBSS & LUP, 1999). Further, to meet the need for area expansion under rubber in the country, large areas were brought into cultivation in non traditional rubber growing states of North East. Most of the areas available were degraded forests, a good portion once subjected to shifting cultivation, thus deprived of precious

Table 1. General characteristics and range of available nutrients in soils under plantation crops

Soil/nutrient characteristics	*Range*	*Remarks/method*
A. General		
pH	3.9-7.0	Varies with rainfall
E.C (dS/m)	0.01-0.3	No salt accumulation
Organic matter (%)	1.0-10.0	Varies with altitude, latitude and cultural practices.
CEC (C molc kg^{-1} soil)	2.0-15.0	More than 50% CEC owing to organic matter
Clay mineral	Predominant Kaolinite	Very low amount of K- fixing clay minerals
Soil texture	Sandy to clay	Varies with rainfall
Soil group	Latosol/Alluvial	Oxisol, Ultisol, Inceptisol and Entisol
B. Nutrient status (ppm)		
N*	0.01-0.05	Alkaline permanganate
P	1-25	Bray & Kurtz – P_2 modified
K	30-250	Morgan's reagent
Ca	400-1500	1M NaCl – NH_4OAc
Mg	25-55	1M NaCl – NH_4OAc
S	23-55	0.1M $CaCl_2$
Zn	0.1-2.0	DTPA
Fe	6.0-12.0	DTPA
Mn	0.2-6.0	DTPA
Cu	0.1-2.0	DTPA
B	0.3-3.8	Water
Si	3-13	1M NaCl

*–%

nutrient reserves to support successful crop production (Krishna Kumar and Potty, 1989). The largest area under arecanut crop is found in the gravelly laterite soils (red clay type) of southern Kerala and Coastal Karnataka, which are poor in bases, K being one of the basic cation. In the maidan tract of Karnataka, arecanut is planted in fertile clay loam soils, which have a large admixture of tank silt particularly in locations where tank irrigation is

Table 2. Available K status in different red soil (alfisols) series of Kerala.

Soil series/Location	*Available potassium status (ppm)*		
	Mean	*Range*	*Rating*
Vellayani (Trivandrum)	23.7	12.1-36.6	Low
Cheriyoor (Quilon)	34.2	12.3-68.1	Low, Medium
Bhavanikkavu (Quilon)	44.4	20.2-75.1	Low, Medium
Beypore (Calicut)	36.8	6.0-112.7	Low, Medium
Chirakkal (Cannore)	40.8	12.1-113.6	Low, Medium
Kunhimangalam (Kasaragod)	19.6	4.5-34.3	Low

practiced (Naidu, 1962). Tea soils in Southern India are classified as Latosols, whereas it is alluvial in Assam and sedimentary type in Darjeeling (Verma, 1997). Despite the diversity of soil type, the tea growing soils are acidic and formed under or exist in high rainfall conditions. The predominant clay mineral being Kaolinite, these soils are low in CEC and bases. Similar conditions exist with regard to soil types in the case of coffee also. In general, it can be stated that soils in which plantation crops are grown are poor to medium in available potassium status.

Potassium Behaviour in Soil

Soils of the Peninsular India are largely sedentary and so their native fertility is dependent on the mineralogical composition. Black, red, alluvial and laterite constitute 56, 34.5, 7.6 and 1.3 per cent of the geographical area in South India, covering 52.4, 31.9, 7.0 and 1.2 million hectares respectively. Potassium saturation of the exchange complex in these soils ranges from 1.0-2.3 in black soils, 1.2-3.7 in red soils, having montmorillonitic clay minerals, 4.4-10.3 in other soils and 3.0-4.4 in laterite (Sekhon and Subba Rao, 1985).

Hameed Khan *et al.* (1982) found that K adsorption was comparatively more and uniform in laterite soils than in red sandy loam, river alluvium and coastal sands cultivated to coconut. The magnitude of the constants K and 1/n and the difference in the values of Freundlich adsorption isotherm was attributed to the contents and nature of clay minerals in these soils. Further, desorption of applied K showed a constant release after third and fourth extraction, irrespective of soil groups. Even after the 8th extraction, a constant release of 1.5 to 2.5 ppm K was removed in two extractions. The soils under the present study were dominated by kaolinite clay minerals, which have no interlattice binding sites for K, and hence cannot hold any non-exchangeable K (Patil *et al.*, 1976). The influence of clay minerals in K supply to the nutrient pool was also indicated by Ramanathan and Krishnamoorthy (1976). In the incubation experiments with different coconut growing soils, highest water soluble K fraction was obtained in sandy soil followed by laterite, red sandy loam and alluvial soils. The exchangeable K fraction was highest in red sandy loam followed by laterite, alluvial and sandy soil. The non exchangeable K fraction was highest in alluvial followed by laterite, red sandy loam and sandy soil (Annual Report. 1997. Central Plantation Crops Research Institute, Kasaragod). This variation in the fractional distribution of K is on account of the variation in the mineralogical constituent of the soil and the initial soil K status.

Nutrient Exhaust

Potassium is usually the least needed major nutrient in low-yield agriculture but climbs into dominant position when yields are maximized (Von Uexkull, 1985). Kanwar (1993) stated that low yield level of 40 nuts / palm / year in case of coconut can be sustained without replenishing the K to the soil, however, at yield levels of 150 nuts, all the K removed must be replenished, and for still higher yields, the application of K from fertilizer sources far exceeds the nutrient removal. In general, these crops have a relatively lower requirement of N and P and higher requirement for K compared to the annuals in the same soil type. The lower N and P demand is due to differences in the root system, asymbiotic N_2 fixation and more frequent mycorrhizal associations. The higher K demand may be due to the coarser root system and midday heat and moisture stress suffered by fully exposed leaves (Von Uexkull, 1985).

The nutrient supply is in general based on the nutrient removal, the losses to which the nutrient is prone to in the environment and the expected crop yield. In general, the nutrient removal by different plantation crops is given in **Tables 3** and **4**. Although variations due to site characteristics will occur, and the nutrient removal at the highest reported yields may differ than those at average yield levels. The data illustrates the importance of maintaining both a favourable nutrient supply and balance for maximizing yields. The potassium is removed in highest quantity in coconut and coffee, in same quantity in arecanut and it is second to nitrogen in case of tea and rubber. The nutrient ratios for N and K for coconut varies from 1.24 to 1.43 for K

Table 3. Nutrient exhaust by coconut palms reported in different countries.

Country	*Yield*	*Nutrients (kg/ha)*						*Ratio Source*
		N	*P*	*K*	*N*	*P*	*K*	
India	175 palms ha^{-1}	97.3	21.0	121.1	1	0.22	1.24	Ramadasan and Lal (1960)
India	40 nuts/palm/ 1.2 t copra (173 palms ha^{-1})	56.0	12.85	70.19	1	0.23	1.25	Pillai and Davis (1963)
Ivory Coast	Hybrid palms (PB 121) 6-7 t copra ha^{-1}	174	20.0	249	1	0.12	1.43	Ouvrier and Ochs (1978)
Sri Lanka	70 palms ha^{-1}	10.2	2.4	12.9	1	0.23	1.26	Nethsinghe (1960)

Table 4. Nutrient removal by plantation crops other than coconut

Crop	*Yield*	*Nutrients (kg/ha)*						*Ratio Source*
		N	P_2O_5	K_2O	*N*	P_2O_5	K_2O	
Coffee	1125 kg coffee	40.0	16.7	60.4	1	0.42	1.51	Turner and Gillbanks (1988)
Tea	1350 kg dried leaves	62.5	10.3	33.9	1	0.17	0.54	Turner and Gillbanks (1988)
Rubber	1928 kg dry rubber	19.1	8.7	18.6	1	0.46	0.97	Turner and Gillbanks (1988)
Arecanut	–	79.0	28.0	79.0	1	0.35	1	Rethinam (1990)

when nitrogen is considered as 1. Phosphorus always maintained a lower profile by recording ratio value of 0.12 to 0.23. Earlier, higher values were reported by Pillai (1919) for K as 1.74 and Patel (1938) as 1.61.

In coconut, besides leaves, inflorescence and nuts, which are removed from the garden, a substantial portion of nutrients is also retained in the growing stem. An adult palm yielding 40 nuts and producing 12-13 fronds in a year absorbed 321 g N, 69 g P, 406 g K, 196 g Ca and 72 g Mg (Pillai and Davis, 1963). The percentage distribution of nutrients in the palms highlights the need for better K management. In tall cultivars, N and P are distributed more or less equally between stem and leaves and the nuts, whereas in hybrid, more of the N and P are utilised for nut production. In case of potassium, irrespective of the cultivars, 78% of the K is removed from the system, when nuts are harvested (**Table 5**).

Table 5: Proportion of nutrient removed in nuts and in stem and leaves of two cultivars of Coconut

Cultivar	*Part of palm*	*Nutrients*		
		N	*P*	*K*
West Coast Tall	Stem + leaves	49	50	22
	Nuts	51	50	78
PB 121	Stem + leaves	38	25	22
	Nuts	62	75	78

Sources: Pillai and Davis (1963), Ouvrier and Ochs (1978)

Crop Response to K Application

A. Coconut: Coconut has unique feature among the plantation crops in that it flowers and fruits through out the year. Hence, adequate water and nutrients should be maintained during the entire period. Proper nutrition during early stages has a profound influence on yields during the productive lifetime of the species. Foale (1968) reported that nutrient contribution by endosperm to the growing seedling decreased from 4th month after germination, suggesting that the young seedlings are actually in short supply of nutrients for major part of their one year growth in the nursery when seedbed is not adequately supplied with nutrient. Though, food reserves where adequate as far as carbon compounds and nitrogen were concerned (Harris, 1970), potassium uptake was more and the experiments indicated the advisability of applying potassium. Application of balanced fertilizers consisting of N, P, K, Ca and Mg to the nursery seedlings improved the vigour and quality of seedlings (Nelliat *et al.*, 1976). The seedlings obtained from seednuts collected from palms manured with K displayed better vigour and growth than those obtained from unmanured plots (Nelliat, 1973).

Young palms: On an average one leaf is produced every month and this leaf remains on the palm for at least 3 years. In young immature trees, lack of K results in shortening of the lifespan of leaves, decreased leaf size and reduced rate of leaf production. This extends the immature phase and the trees grown under such conditions will not commence before 10-12 years of age, whereas palms receiving adequate nutrition will start bearing from 3-4 years from field planting itself. Thus, the importance of K is not only for the faster development and vigorous growth, but also for reducing the prebearing period (Smith, 1968). The palms, which received adequate nutrition from the beginning, produced more yield than those supplied after maturity. In coconut experiments in the Ivory Coast (Fremond and Ouvrier, 1971), the effect of applying K and the time of field planting was compared to withholding K applications until the age of bearing (**Table 6**). The later practice was decidedly inferior for all palms. Similarly, palms fertilized with KCl and N or NP from transplanting time in an inland-upland area of Philippines recorded initial flowering in less than four years and significantly higher nut and copra production than those palms, which did not receive KCl (Mendoza and Prudente, 1979). In a sandy loam soil at Kasaragod, palms which received 1.0 kg N and 1.5 kg K_2O flowered first (Nelliat, 1978).

Table 6. Timing effects of first potash fertilizer application on the performance of young coconut palms

Year	*Characteristics observed*	*Time of K application*	
		From field planting	*From bearing age only*
1956	No. of fronds	8.89	7.69
1958	Length of frond (cm)	256	233
1959	Girth (cm)	124.1	105.4
1960	No. of fronds (one yr)	11.7	10.7
1962	Kg copra ha^{-1}	2,560	272
1966	Kg copra ha^{-1}	2,480	2,272
1970	Kg copra ha^{-1}	–	2,096
1961-1970	Cumulative yield (kg ha^{-1})	17,344	12,704

Adult palms: The potassium levels influence the yield and yield attributing characters in coconut. Menon and Pandalai (1958) on reviewing the work of various workers has summarised that coconut responded positively to potassium application and K had beneficial effect on copra production compared to nitrogen which had an adverse effect. This further reflects the importance attached to potassium in coconut nutrition. Continuous mining from a limited area depletes K from the feeding zone and as the K pool also cannot restore much K needed by the coconut palm, which has a heavy demand for potassium, there is a need for evolving a more suitable way of K management. Report of John and Jacob (1959) on extensive fertilizer demonstration studies involving 24,000 coconut trees in the west coast of India lends support to the above contention. They indicated that application of additional dose of potash and higher doses of NPK resulted in increased yield where standard dose failed to elicit adequate response in farmer's field.

Application of 340 g N, 340 g P_2O_5 and 680 g K_2O/palm/year improved the nut yield by 35% and copra out turn by 44% in the cultivator's gardens where the palms were hitherto unmanured. Further, where response to fertilizer application was not observed, significant increase was obtained when K level was raised to 900 g K_2O/palm/year (John and Jacob, 1959). In a 3^3 NPK factorial experiment on sandy loam soil at Kasaragod, higher level of N had an adverse effect on copra content while K levels showed positive response (Muliyar and Nelliat, 1971). Further, they reported that potassium improved all the nut characters studied *viz*. weight of whole nut, weight of husked nut, volume of husked nut and copra weight per nut, whereas nitrogen had an adverse effect. The palms yielding less than 60 nuts annually, the optimum dose of N ranged between 400-650 g and that of potash between 890 and 1210 g per palm per year. In a long term fertilizer experiment in red loam soil, Wahid *et al*. (1988) recorded significantly higher nut yield with potassium application. Besides early bearing was also achieved with increased levels of K application. The yield was 7, 68 and 77 nuts $palm^{-1}$ $year^{-1}$ in the 21st year after planting under no fertilizer, 450 g K_2O and 900 g K_2O $palm^{-1}$ $year^{-1}$ respectively.

In a recent study In Veppankulam in Tamil Nadu potash response to coconut in soils adequately supplied with potassium has been established (**Table 7**) (AICRPP, 2000).

The relationship between CEC of roots, yield and cationic concentration in soil and plant of different yield groups of the cv. West Coast Tall (Wahid *et al.*, 1974) showed that K contents of both soil and plants were positively correlated with yield and CEC was negatively correlated with yield as well as leaf K content, emphasizing the importance of K in increasing the nut yields. They also suggested that leaf potassium level was affected by a combined level of (Na + Ca + Mg). The impact of interaction on critical levels of (Na + Ca + Mg) is indicated as 0.75 to 0.82% as satisfactory levels. The study also suggested that a critical level of 0.8 to 1.0% (Frond 14) proposed by IRHO workers is applicable to Indian conditions.

Salgado (1951) suggested importance of nut water analysis in the diagnosis of nutrient deficiency of palms and attempted manurial recommendation. An account of nutrient content of tender coconut water at different stages of the development of the nuts (Kamala Devi and Velayudham, 1978) indicated abundance of potassium at maturity stage of 8 month (**Table 8**). The distribution of total sugars 0.8 to 5.6% and potash content favours tender

Table 7. Response of coconut to application of potash (Selected treatments) – Veppankulam, Tamil Nadu

Sl.No.	*Treatment*	*Plant nutrient (%) (Frond 14)*		*Soil available nutrients (ppm)*		*Yield nuts/palm*
		N	*K*	*N*	*K*	
1	$N_0P_0K_0$	0.91	0.81	164	84	108
2	$N_0P_0K_1$	1.28	0.92	173	99	126
3	$N_1P_0K_1$	1.26	0.96	170	102	149
4	$N_0P_0K_2$	0.98	0.99	144	118	134
5	$N_1P_0K_2$	1.26	1.10	179	122	154
6	$N_1P_1K_1$	1.26	0.96	174	108	159
7	$N_2P_2K_2$	1.62	1.20	276	135	201

Table 8: Changes in nut water composition during development of coconut (West Coast Tall)

Age of nut (month)	*Volume of water (ml)*	*pH*	*Total sugars (%)*	*N*	*P*	*K*
					mg l^{-1}	
4	75	3.5	0.8	32	48	1113
6	310	4.7	3.3	195	118	5320
8	230	5.5	5.6	432	186	7300
10	145	5.9	3.4	336	140	3260
12	100	6.1	1.8	299	108	3181

coconut to be considered as a health drink. They also observed least difference among cultivars.

B. Tea: Tea essentially signifies two/three leaves and a bud of the shrub *Camellia* L. spp. processed differently to give black, green or oolong tea. The most important operation in tea culture is the plucking of the succulent shoots at appropriate intervals for the manufacture of commercial tea. The plucking is done throughout the year in the Southern India and for about 150-270 days in Assam. Potassium is the second most important nutrient after nitrogen required for tea (Ranganathan and Natesan, 1985). K is involved in promoting the translocation of carbohydrates to the young shoots that are harvested periodically. Visual symptoms of K deficiency on tea plants was observed six years after withholding K application but yield decrease was noticed in the very first year. The yield reduction was 17% in the first year and became 32% in the 13th year of withholding K application compared to the plots receiving 40 kg K_2O ha^{-1} (Ranganathan, 1970a). Ranganathan and Narayanan (1974) has quite candidly put forth that since the release of K from the soil source is inadequate in relation to plant needs, K is best applied in as many doses as possible in relation to crop requirements and the most practical way is to apply the same with every nitrogen application.

In the mid sixties, in North East India, K was applied as the maintenance dose. The application of N alone at 200 and 300 kg ha^{-1} depressed the tea yield. This was due to the accumulation of high theanine (4%) in the feeder roots and application of 224 kg K ha^{-1} reduced it (Dev and Bajaj, 1988). Results of NPK trial in NE India on mature tea conducted in different estates showed that for sustaining yield of 2300 kg ha^{-1} the required K was 80-140 kg K_2O ha^{-1} which increased to 160 kg K_2O ha^{-1}, when the yields were raised to 3500 kg ha^{-1} or higher along with required N and P (Biswas and Chakravartee, 1992). Sharma and Sharma (1995) have reported after 16 years of experiment, a yield increase of 74.4%, 32.8% and 40.5% with N90, P39 and K33 respectively as compared to control. The highest yield increase was recorded with N180P78K33.

Ranganathan (1981a) showed that the efficiency of fertilizer applied K decreased with increasing yields probably because of limitation of transport processes within soil (**Table 9**). At high yield levels especially during the peak growing seasons, the K demand is very high. The demand can possibly be met by increasing the K^+ concentration in the soil solution, thereby effectively facilitating the diffusion process (Ranganathan and Natesan, 1985).

Pruning is an important cultural activity in tea cultivation. Tea in the

Table 9: Per cent utilization of applied K and K demands, during peak cropping period at different yield levels

Yield level (kg ha^{-1} $year^{-1}$)	*Utilization of applied K (%)*	*K demand during peak seasons (g ha^{-1} day^{-1})*
1000	80	250
2000	80	500
3000	75	750
4000	65	1000

pruned year mobilizes large quantities of nutrients within a short period for the formation of sound and healthy frames and sufficient foliage to start the cycle for yield exploitation. Natesan *et al.* (1984b) found significant response to K fertilization in the pruned year on the crop harvested both in the pruned year and in the subsequent years. With the increasing K levels applied in the pruned year, there is a significant crop increase for the same level of fertilizer usage in the subsequent years of the cycle. Over the cycle, applying 166 and 116 kg of K ha^{-1} obtained 12 and 6% more crop in the pruned year respectively compared to 66 kg K ha^{-1}.

C. Coffee: Coffee being a perennial crop continuously produces berries and fresh wood for the succeeding crop. The crop requirement of K is high during the development of coffee berries and is maximum during their ripening. The nutrient removal by the berries in the two important cultivated varieties of coffee has been estimated at 34 kg N, 5 kg P_2O_5 and 45 kg K_2O per hectare in arabica and 35 kg N, 7 kg P_2O_5 and 89 kg K_2O in robusta (Nelliat, 1978). The nutrients required for building up the berries are twice the quantity of nutrients removed by the berries. In another study on crop nutrient removal, Alwar *et al.* (1991) have estimated that 6000 kg of ripe fruits removes approximately 40 kg N, 5.33 kg P_2O_5 and 52 kg K_2O.

According to Sharma (1967), in the field trials laid out in different arabica estates (Chettahalli soil) for a period of 5 years, the highest yield was recorded with NPK at 100-30-40 kg ha^{-1} in which N was applied in three installments. Chandrappa and Krishnamurthy (1969) reported that maximum economic dose of NPK was 160-120-160 for arabica coffee. In a series of field trials, Mathew *et al.* (1971) found that the yield increased with the NPK dose up to 299-150-200 kg ha^{-1} though the rise was marginal above the level of 160-120-160. The most effective proportion of N to K_2O appeared to be 1:1.

The productivity level of majority of the coffee growers in Kerala is below the national average. This was attributed to low fertilization and the soil being acidic having low potash status (Swarupa and Shekara, 1995). In the fertilizer trials with 12 year old coffee (cv. S 795), amongst the 16 NPK combinations, NPK treatment applied at the rate of 160:90:120 kg ha^{-1} gave the highest berry yield (8.3 t/ha) (Stalin *et al.*, 1991). In a study conducted in 40 small coffee estates of Chikmagalur zone growing arabica coffee, it was observed that yield and soil test based N, P and K application rates were significantly and positively correlated. A significant positive correlation was found between yield and available K in these acidic sandy loam and sandy clay loam soils. Addition of 1 kg each of N, P and K increased clean coffee yield by about 6 kg (Jayarama *et al.* 1993).

D. Rubber: Rubber is mainly grown in laterite and lateritic soils. Research on K needs started quite late. Since, the harvested product consisted of hydrocarbon, the earlier theories on mineral nutrition considered the nutrient demand for rubber to be small (Von Uexkull, 1985). This theory was supported by earlier researches, where little or no response to K application was observed. von Uexkull (1970) showed that very little potassium was actually removed with latex (about 0.6 kg K per 100 kg dry rubber) and excess of potassium sometimes depressed growth and yield. Later on, increase in yield potential, depletion of K from soil nutrient pool and better understanding of the plant nutrient needs have made K essential for fertilizer recommendation. Pushparajah (1977) calculated total K^+ removed over 30 year period (25 year tapping) at 451 kg K ha^{-1}. The amount of K immobilized in the trees (removed at the time of replanting) greatly exceeds the amount drained with the latex. On a medium K soil, the amount immobilized has been estimated at 1400 kg K ha^{-1} (Lim, 1978).

Application of potassium in amounts of 50 and 100 kg ha^{-1} increases the latex yield. The increase is more marked and persistent with higher amounts (Nelliat, 1978). Potty *et al.* (1976) found that the optimum requirement of NPK for seedling nursery was 500, 250 and 100 kg ha^{-1} N, P_2O_5 and K_2O respectively for obtaining maximum number of vigorous, healthy and buddable seedlings. Based on the field experiments they suggested a fertilizer schedule of 40 kgN, 40 kg P_2O_5 and 16 kg K_2O ha^{-1} for immature rubber and 30 kg N, 30 kg P_2O_5 and 30 kg K_2O ha^{-1} for mature rubber.

Punnose *et al.* (1978) reported that application of K @ 100kg ha^{-1} significantly increased the yield from fourth year of tapping and continued till seventh year of tapping. According to Sivanadyan *et al.* (1975) lack of K during early stages of plant growth limits the active leaf area and reduces the photosynthetic activity resulting in slow girth increment and prolonged immaturity period. However, Abdul Kalam *et al.* (1980) observed that application of K @ 60 kg ha^{-1} suppressed the girth increase at four and five and half years after planting. Pushparajah *et al.* (1975) have reported that K significantly improved the bark thickness (bark regeneration), phloem thickness, size and number of latex vessels per unit bark. He also correlated higher percentage of tapping panel dryness with higher levels of K application. Further, three year study conducted to investigate the response of mature rubber tree (clone RRIM 600) to different K levels in a laterite soil showed an increase in the volume of latex and dry rubber yield upto 60 kg K_2O ha^{-1} (Mercykutty Joseph *et al.* 1996). However, dry rubber content was not influenced by K application.

E. Arecanut: Arecanut is an important commercial crop of humid tropics in India. It is generally grown in laterite soils, which are acidic in nature and have low nutrient retention capacity. The soils are low to medium in K. A series of fertilizer experiments were conducted in arecanut growing areas in Karnataka (Vittal), Kerala (Peechi and Palode), West Bengal (Mohitnagar) and Assam (Kahikuchi). The results of these agronomic trials (Khader 1990) indicated the optimum requirement of potash to be 140 g $palm^{-1}$ $year^{-1}$ and that of nitrogen and phosphorus as 100 g N and 40 g P_2O_5. In some of the centres N-K interaction was found to be significant on yield increase. Recent results with high yielding varieties like Mangal, Srimangala and Sumangala indicated no significant yield difference amongst varieties. However, significant yield differences were observed among fertilizer levels. Highest chali yield (5269 kg ha^{-1}) was obtained at fertilizer level 200 : 80 : 280 g of N, P_2O_5 and K_2O respectively compared to 3981 kg ha^{-1} for the existing general recommendation (Annual Report 1997, Central Plantation Crops Research Institute pp. 66).

Long Term Impact of Fertilization on Nutrient Status

Hameed Khan *et al.* (1986) reported that after 18 years of coconut growth, the control (Mo) plot analyzed 19 ppm available K where as it was 55 and 70 ppm in M_1 and M_2 treatments, respectively. Potassium levels in the control and treated plots decreased with depth. Further, Reddy *et al.* (2001) after 32 years of fertilization observed that the available soil potassium content was 66 ppm in M_0 plot under rainfed condition, which increased, to 202 ppm and 318 ppm with M_1 and M_2 levels of fertilizer application at 0-25 cm soil depth. Under irrigation, a reduction in soil available K was observed in M_1 and M_2 plots (**Table 10**). Application of potassic fertilizers raised the leaf K levels to 1.14% (M_1) and 1.25% (M_2) compared to 1.07% in M_0 under rainfed condition. Under irrigation, leaf K content was 1.07% under M_1 and 1.20% under M_2 compared to 0.90% under M_0. Application of K fertilizer at M_1 level was found to maintain K content of leaves above critical level (0.8 to 1.0%). This suggests that doubling the K levels had little effect indicating that rates beyond 830 g K (1000g K_2O) per years are probably not needed. Thus a soil available

Table 10: Long term effect of fertilization on available potassium status of red sandy loam soils (*Arenic Paleustult*) at different soil depth (cm)

Fertilizer level	*Av. K (ppm)*			
	Irrigated condition		*Rainfed condition*	
	0-25	*25-50*	*0-25*	*25-50*
M_0 (No fertilizer)	79	38	66	66
M_1 (500g N: 218g P: 833g K palm^{-1} year^{-1})	110	69	202	153
M_2 (1000g N: 437g P: 1667g K palm^{-1} year$^{-1)}$	212	129	318	235

Source: Reddy *et al.* (2000).

K (1N NH_4OAc) content of 50-60 ppm (0.128 to 0.153 me 100g^{-1}) is adequate for maintaining sufficiency levels in coconut. Manicot *et al.* (1979) reported that .015 to 0.20 me 100g^{-1} (59-78 ppm) and Loganathan and Balakrishnamoorthy (1980) suggested that 0.13 me 100g^{-1} (51 ppm) of exchangeable K is sufficient for satisfactory growth of coconut palm.

In another long term studies in littoral sandy soil at Kasaragod, the available potassium status of the soil (0-100 cm depth) increased from 50.17 ppm at K_1 level (750g K_2O/palm/year) to 95.94 at K_2 level (1250g K_2O/palm/year) to 105.56 at K_3 level (1750g K_2O/palm/year) (Reddy *et al.*, 1999). This shows a near sufficiency level for available K in the soil. Thus, a statement by Biddappa *et al.* (1993) that a soil available K content of 50-60 ppm is adequate for maintaining the sufficiency levels in coconut appears to be true. Joseph and Wahid (1997) has observed that the application of muriate of potash resulted in a large increase in K reserves in soil to a depth of 100 cm. The increase in K content was nearly 200 ppm within this depth. Relatively less accumulation of K was noticed in the 0-50 cm root zone than below it.

A desorption equilibrium model was prepared for laterite and red sandy loam soils for computation of the amount of K_2O palms^{-1} needed to raise the available potassium content of soil to a desired level. Though Hameed Khan *et al*. (1986) have indicated 50-60 ppm of available K as a desired level (based on its reflect on plant K and yield), however, in the present study, 80 ppm available K (1N NH_4OAc) was assumed as the base value in the coconut basin to maintain a plant content of 0.8-1.0% (Annual report, 1985). To regulate satisfactory release of K for coconut, a ready reckoner table was prepared to guide the level of K_2O to be applied per palm (**Table 11**). It was observed that the potential buffering capacity (PBC^K) of laterite and red sandy loam soil with reference to potassium was different and hence the amount of K to be applied is less for laterite soil compared to red sandy loam to sustain available K content at 80 ppm.

No permanent or long term manurial experiment is in progress on tea, except a few aimed at studying the effect of skipping of nutrients (Gopalasundaram and Yusuf, 1989). Long term fertilizer experiments conducted else where, with the tea grown on red soils have identified strong positive yield responses to both potassium and magnesium, and have indicated critical soil levels of 0.1 N H_2SO_4 extractable K and Mg, of about 21 and 15 mg/100g respectively. Strong antagonistic effects between these metals and various cations (K, Mg, Ca, NH_4) and liming were found to reduce the availability in both the cases (Godziashvili and Peterburgsky, 1985). Ranganathan and Narayanan (1975), found that the uptake of nutrients especially cations was highest between pH 4.5 to 5.0 whereas at pH levels

Table 11: Dosage of K required for laterite and red sandy loam soil to raise the soil test value of K to any predetermined level (g K_2O palm/year)

Soil test value	*80*	*70*	*60*	*50*	*40*	*30*	*20*	*10*
Laterite Soil								
0	1514	1238	1062	885	708	531	354	177
10	1238	1062	885	708	531	354	177	0
20	1062	885	708	531	354	177	0	
30	885	708	531	354	177	0		
40	708	531	354	177	0			
50	531	354	177	0				
60	354	177	0					
70	177	0						
80	0							
Red sandy loam soil								
0	2087	1826	1565	1305	1043	782	522	260
10	1826	1565	1305	1043	782	522	260	0
20	1565	1305	1043	782	522	260	0	
30	1305	1043	782	522	260	0		
40	1043	782	522	260	0			
50	782	522	260	0				
60	522	260	0					
70	260	0						
80	0							

above and below this range, the uptake was adversely affected. Ranganathan (1981a) showed that the efficiency of K decreases with decrease in soil pH (**Table 12**). This arises from the decrease in binding strength of K ions on the soil clay complex with the increase in soil acidity. Also the leeching losses of K increases markedly with a decrease in pH < 5.0. In East Africa, Wilson (1975a) from a series of 10 experiments showed that responses to K fertilizer leading to improved efficiency from N fertilization occurred where the soil pH is 4.9 or lower.

Raju and Deshpande (1985) studied the influence of long term application of chemical fertilizers on the soil health and nutrient status of coffee leaves. Continued use of fertilizers led to significant decline in soil pH from 6.63 (control) to 5.30 (highest fertilizer level – 495:374:495 kg NPK ha^{-1}). Buildup in available K status of the soil was observed with the fertilization. The foliar K level increased with fertilization from 1.71% in the control plot to 2.28% at higher level of fertilizer application.

Pushpadas *et al.* (1974) found that after 14 years of NPK application in rubber plantation, the available K status in the soil was raised by K application. As the soil fertility status was medium to high in the plots, the leaf N, P and K content were above critical limits and hence were unaffected by NPK application. In another long term experiment, the soils after 60 years of cropping were evaluated for their morphological properties and nutrient status (Karthikakuttyamma *et al.* 1998). In comparison to the adjoining natural forests, the morphological properties were not significantly affected, the total N and K status decreased and the P status increased. The study concludes the need for higher dose of N and K and a reduction of P fertilizer. Philip *et al.* (1993) observed a buildup of available K and P in the soil after 10 years of cropping period. Foliar K level also increased with K application but critical level could only be attained after K application of more than 40 kg ha^{-1}.

Table 12. Efficiency of fertilizer applied K and N at different soil pH

Soil pH	*Efficiency**	
	K	*N*
5.2	80	90
5.0	70	100
4.8	60	100
4.5	50	90

*Assuming efficiency of K= 100 at pH 5.5 to 6.6; N = 100 at pH 4.8 to 5.0

Nutrient Interaction in the System

The interaction of potassium with level of other nutrient is more important than that of with the qualitative factors like form of fertilizer, method and date of application, crop variety, etc. Several studies have revealed strong interactions of potassium with other nutrient elements like Ca, Mg, Na and N. Smith (1969) opinioned that the critical level of K is operated when nitrogen was at sufficient level and suggested N: K ratio of 2.25 when N level was less than 1.8 per cent in coconut. Experiments conducted at Ratnagiri in Maharastra (AICCAIP, 1983) have indicated that the response to higher level of N (750 g N palm^{-1} year^{-1}) application was manifested only in the presence of potassium. In the absence of K fertilizer, response was noticed only upto the lower level of N (375 g). Anil Kumar and Wahid (1989) found that application of muriate of potash increased available K and organic carbon status of soil. The effect of soil K was N-dependent as revealed from the significant N x K interaction. Higher rates of ammonium sulphate led to reduction in exchangeable K. They observed accumulation of K in lower depths in contrast to the observations recorded by Hameed Khan *et al.* (1986) in red sandy loam.

Manciot *et al.* (1979) reported that there exist strong antagonisms between K-Ca, K-Mg and K-Na in coconut. Often, Mg level in the tissue decreased consequent upon high fertilization. Application of potassium led to a significant drop in the content of Ca, Mg and Na in the leaf (**Table 13**). Further, magnesium fertilization is beneficial only when the K is adequate in supply or the K deficiency is corrected. The results showed that Mg application had a beneficial effect on the copra yield only if K fertilizers were also applied. Similarly higher levels of K manuring increased the yield only in the presence of Mg. In fact, higher levels of K application had a depressive effect on copra yield in the absence of Mg fertilization. Wahid *et al.* (1974) demonstrated the antagonistic effect of combined level of Na, Ca and Mg on K in the palms when judged through foliar analysis. Coomans (1977) observed that

Table 13. Effect of KCl application on the nutrient concentrations in the coconut leaf.

KCl appln. (kg palm^{-1} year^{-1})	*Nutrient content (%)*					
	N	*P*	*K*	*Ca*	*Mg*	*Na*
Control	1.80	0.091	0.20	0.495	0.567	0.166
5	1.75	0.097	0.98	0.507	0.188	0.294
10	1.74	0.094	1.38	0.401	0.159	0.234
15	1.74	0.097	1.55	0.392	0.125	0.181

application of K had induced the Mg deficiency in coconut hybrids, but Mg application had no effect on leaf K level. However, Brunin (1970) reported that in Tall cultivars when the leaf K levels were between 0.7 and 1.2%, application of high rates of Mg significantly reduced K contents. The results of the experiments conducted at CPCRI, Kasaragod in red sandy loam and lateritic soils have shown that application of NPK fertilizer without Mg showed significant reduction in leaf Mg content (Khan *et al.*, 1986).

The N-K interaction in tea is well established. It is well known that lack of K limits the yield response to N. When N: K_2O ratio is adequate, the assimilation of K_2O in relation to N is highest in the roots followed by twig, wood, flush shoot and foliage. Thus, the requirement of K_2O in relation to N are important for young tea plants and in pruned year. The optimum N-K ratios for tea in Southern India, based on the interaction effects are 1:0.83 for nursery plants, 1:0.83 to 1:1.25 (depending on soil pH and K availability) for young tea, 1:1.25 to 1:1.66 (depending on the type of prune) for mature tea in the pruned year following pruning and 1:0.415 to 1:0.83 (depending on the source of N and yield level) for mature tea other than in the pruned year (Ranganathan, 1982; Ranganathan and Natesan, 1983). Depending upon the height of pruning, irrespective of the source of N, N: K_2O should be maintained at 1:2 for pruning below 45 cm height, 2:3 for pruning between 45-60 cm and 1:1 for cut across at and above 60 cm (Verma, 1997).

Cropping System

Nutrient management in the cropping system is a difficult task owing to the interplay of various factors viz. crop requirements, differential crop responses, crop residue additions and soil environment. It is therefore necessary to study the system as a single unit. In intensive cropping system with tree crops, the application of fertilizers according to the estimated requirement for each crop is certainly not the most efficient and economic way of utilizing the native and applied nutrients (Oelsligle *et al.*, 1976). Bench mark data on total nutrient demand, nutrient removal in harvested and non harvested products and the rate of nutrient accumulation during ontogeny are needed for each species in a multicropped system to arrive at answers on rate, time, source and placement of various nutrients (Nair, 1979).

The importance of intensive cropping lies in the nutrient economy, as the extensive cover in the plantation floor increases the plant cycling fraction of nutrients (**Table 14**). The direct percolation loss of 113.8 kg K/ha in a pure stand of coconut is reduced to 54.5 kg K in the case of crop combination. The better exploitation/exploration of the soil volume by roots in crop combination may possibly reduce the loss of nutrients through percolating water. The annual increase of nutrients in soil stores especially for N and K clearly indicates the advantage of intensive cropping in nutrient economy.

In Coconut based HDMSCS experiment at Kasaragod, an annual nutrient

Table 14. Annual fluxes of nutrients in a 30 year old coconut plantation with 5 year old cocoa as mixed crop.

Sl.No.	*Nutrient fluxes (kg ha^{-1} yr^{-1})*	*N*	*P*	*K*
Input				
1.	Precipitation	2.3	4.8	5.0
2.	Fertilizer for coconut	175.0	49.0	348.0
3.	Fertilizer for cocoa	35.0	6.1	40.7
4.	Total (1 + 2 + 3)	212.3	59.9	393.7
Output				
5.	Coconut parts*	153.5	11.6	85.0
6.	Cacao beans	9.0	2.0	4.7
7.	Percolation (4-5-6-11-14)	8.9	0.0	274.7
8.	Total (5+6+7)	171.4	13.6	364.4
Increments				
9.	Coconut (stem and roots)	3.5	0.5	3.0
10.	Cacao (stem and roots)	9.0	1.8	9.0
11.	Total (9+10)	12.5	2.3	12.0
Plant cycling fraction				
12.	Coconut-washout	0.0	0.0	151.0
13.	Cacao-washout	0.0	0.0	69.2
14.	Cacao-fallen leaves	28.4	2.7	17.3
15.	Total (12+13+14)	28.4	2.7	237.5
16.	Total uptake (5+6+11+15)	203.4	18.6	339.2
17.	Soil stores (4-8-11)	28.4	44.0	17.3

*includes nuts, leaves, spathes and rachis
Source: Khanna and Nair (1977)

budget and balance of N, P, K, and Mg was worked out for three consecutive years (Bavappa *et al.*, 1986). It was observed that while there has been no build up of N and Mg, the levels of P and K doubled by the third year. In fact, there was a depletion of N and Mg. However, there appears to be displacement of Mg from its exchange sites due to heavy input of K^+ and NH_4^+ fertilizers resulting in leaching of Mg (Ochs and Ollagnier, 1977).

Studies on coconut based cropping system involving clove, pineapple and banana as components of the system at Kasaragod have revealed that the treatment, one-third of the recommended dose of fertilizers was observed to be on par with the treatment, full dose of recommended fertilizers upto 14 years without any biomass recycling in the system. Later on, slight yield decline was observed and to offset this decline, the fertilizer levels have to be raised to two-third of the recommended dose. However, availability of biomass of around 12.7 t – 18.2 t per hectare in the system for recycling under various treatments was assessed. This biomass if recycled can enhance the productivity and sustenance of the system (**Table 15**). Studies are in progress at Kasaragod.

Points to Ponder

The reserves of potassium in the plantation growing soils are lower due to low CEC and higher amounts of 1:1 clay type, mainly Kaolinite, which have very low K fixation capacity. Since, K is required in many physiological functions but does not form part of plant structure, huge investments are required in terms of K currency to meet the crop requirement. Secondly, it

Table 15. Potential for nutrient recycling in coconut based cropping system at Kasaragod.

Treatments	*Biomass for recycling (t/ha/year)*	*Nutrient recycling (kg/ha)*		
		N	*P*	*K*
Full	18.196	110.30	13.46	225.10
Two-third	18.497	104.10	10.83	213.50
One-third	16.043	87.10	9.44	187.50
One-fourth	14.133	68.10	10.21	134.20
One-fifth	12.832	58.50	7.04	119.90
Control	12.667	56.40	6.72	108.10

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can be considered a mobile capital investment highly capable of being recycled but also susceptible to loss in tropical soils. The ability of K to be reused in this sense is unmatched by any other macronutrient. Accomplishing efficient recycling requires a thorough understanding and management of K dynamics (Vilela and Ritchey, 1985). This requires efforts to enhance the CEC of the soil and reduce soil solution level K^+ to match the required rate of uptake at any given time and increase the amount of time during which K is held in above ground plant materials.

Perennial crop based cropping system can solve some of these problems. In the cropping system, there is more mining of the nutrients from different layers and the K reaches the above ground layer. When the older leaves begin to senesce, the K that is not translocated to economic produce is water-soluble and subject to elution by rainfall and this is deposited on the soil surface and can be effectively taken up by the main and component crop.

The escalation of prices of fertilizers and consequent upon reduction in the subsidy in recent years, fertilizers in the optimum quantity are not applied to the crops creating a wide imbalance especially of N: K ratios in the system affecting productivity of the crops. Plantation crops produce large quantities of biomass viz. husk, dried leaves, coir dust (by product of coir industry), pruning, coffee husk, tea wastes, shedding, oil palm bunch wastes etc. which can be effectively converted into acceptable organic manures. The quantity of on farm waste available for recycling in the plantation sector is furnished in **Table 16**. Nair *et al.* (1996) made an attempt to work out total quantity of nutrient supply that is potentially available through plantation wastes (**Table 17**). The amount of nutrient supplied would be in the order of 9.2 x 10^4 t N, 1.2 x 10^4 t P_2O_5, 6.3 x 10^4 t K_2O annually by 2000 AD.

Further, crop residues contain the remnants of nutrients after the plant has transferred its absorbed nutrients to its economic produce (about 75% of absorbed N and P, 50% of S and 25% of absorbed K) (Tandon, 1991). Thus, crop residues are more important sources of potash as compared to nitrogen and phosphorus. In case of coconut, it was observed that husk accounted for 67 percent of the potassium and 85 per cent of chlorine. This indicates the considerable reduction in fertilizer requirement which can be achieved by leaving the husk in the field where it is quickly broken down, releasing the locked up nutrients to be recycled (Ouvrier and de Taffin, 1985). One hundred husks will be able to provide 1 kg of potash apart from 270 g N and 150 g P_2O_5 in the same period (Jothimani, 1994). Effect of husk burial will be observed from third year onwards and beneficial effect lasts for 5-6 years. Even green manuring in the coconut basin would be better. The nutrients viz. potassium and phosphorus hitherto unavailable to coconut at surface layer will be taken up by green manure crops and made available to coconut on decomposition of the green manure in the basin.

Even though nitrogen is the most important nutrient vis a vis K, and, N being universally deficient, is a common nutrient in the fertilizer schedule. The plantation crops growing soils being acidic are generally deficient in magnesium. The Mg deficiency does not result solely from low soil content of exchangeable Mg but from antagonism wherein K^+ ions are easily taken up

Table 16. Availability of on farm wastes/byproducts in plantation sector in India.

Crop waste	*Quantity available*
Coconut (excluding coir pith)*	11.2 million t
Areca leaves	0.13 million t
Areca rachis	0.08 million t
Areca husk	0.22 million t
Cocoa shed leaves	360.03 t
Cocoa pruning	12056.33 t
Cocoa pod husk	32900 t
Coir pith	7.5 million t
Coffee husk	0.18 million t
Tea waste	0.22 million t

*Includes spadices, bunch wastes, sheath, inflorescences and husks
Source: Biddappa *et al.* 1996

Table 17. Quantity of nutrient supplied by organics and that anticipated ('000 t).

Crop Waste	*Growth rate (%)*	*Present (2000 AD)*			*2025AD*		
		N	P_2O_5	K_2O	*N*	P_2O_5	K_2O
Coconut	7.3	79.15	7.6	49.45	460.72	44.24	287.85
Arecanut	3.4	6.84	3.74	9.14	15.78	8.63	21.08
Cocoa	11.6	1.04	0.319	2.88	16.17	4.96	44.77
Oilpalm	8.6	0.0035	0.0007	0.0096	0.024	0.0049	0.066
Coffee	2.1	4.71	0.233	1.223	7.92	0.392	2.06
Total		91.74	11.89	**62.7**	500.61	58.23	**355.83**

by the plant and so reduce the diffusion of the heavier hydrated Mg^{2+} ions. Hence, in many of the fertilizer schedule, magnesium supplementation is advocated.

Climatic factors and synchronized crop requirements influence the yield potential and yield of the crop. Even small differences in management levels right from the time of field planting will have tremendous influence on crop yield and fertilizer response. Because of the complexity of the factors, the interactions between K nutrition, soil management and climate are to be properly understood.

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