International Journal of Tea Science
Vol 10 (1&2) 2014

Review Article

Potassium – the key nutrient for tea grown in Latosols of south India: Glimpses of seven decades of potassium research

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Abstract: Potassium (K) is second key nutrient of tea after nitrogen. The N:K2O::2:3 up to fourth year of planting and $N:K_2O$::1:1 in the fifth year was found ideal for young tea. In the pruned year, pruning height at 35-40 cm $N:K_2O$ :: 1:1.67; 50-60 cm $N:K_2O$::1:1.48 and 65-70 cm $N:K_2O$:: 1:1.25 were found optimum. The highest yield under plucking was obtained at $N:K_2O$:: 1:0.83, when N levels varied from 150 to 450 kg/ha. The polyphenols, amino acids and catechins were found higher when $N:K_2O$ ratio varied from 1:0.83 to 1:1. *The P x K interaction was found positive to maintain the linear response to nitrogen.* Synergism was found between Mg and-K_2O levels at higher $N:K_2O$ levels and antagonism at lower $N:K_2O$ levels. Foliar application of two per cent KNO_3 was found better than one per cent each of urea and MOP to provide drought resistance and higher yield. The foliar application of potassium schoenite one to two per cent-was found best K foliar source. The application of 45 K_2O kg /ha/year controlled the infection of red rust caused by the alga. The $N:K_2O$::1:2.5 reduced the infestation of shot hole borer in the pruned year and increases yield. The broadcasting method of K application was found better than placement method in tea soils of south India. Four to six splits of K_2O along with nitrogen was found beneficial to obtain higher productivity. When application of K was withheld, the reduction in yield was ten-twenty per cent in first and second year and progressively declined and led to mortality of bushes. *In conclusion, Potassium is very important for tea crop nutrition. Proper ratio of $N:K_2O$ should be* maintained along with adequate levels of phosphorus and magnesium for sustainable higher productivity of tea in south India.

Keywords: Drought resistance; Kaolinite; Latosols; Key nutrient; Mg x K_2O interaction; $N:K_2O$ Ratios; Potassium nutrition; Tea and Potassium; Potassium and tea quality

Introduction

Potassium is the second key nutrient for tea crop after nitrogen. During earlier decades of tea cultivation, requirement of potassium (K) of tea was mainly met through soil reserves. Later on with the increased productivity through improved genetic, agronomic and management options potassium availability from soil reserves became a limiting factor for economic cultivation of tea. In late forties, the existence of tea was threatened in south India by widespread defoliation and incidence of red rust. The causative factor was recognised as K deficiency.[15]

The significance of K was recognised and since then balanced ratio of $N:K_2O$ has been applied and the productivity of south India has been in the increasing trend. South India can legitimately be proud of its remarkable progress in tea productivity from 654 kg/ha in 1950 to about 2025 kg/ha in 2012-13, an increase of 309.6 per cent in last sixty years. A large number of tea estates have reached the yield level of 2500 kg/ha to 3500 kg/ha and few have reached the yield level of 4000 kg/ha or even more. The nutrient management has indeed played a key role in the increase of tea productivity including adoption of balanced ratio of $N:K_2O$. The significance of nitrogen and potassium fertilizers can be judged from the fact that the growth in consumption of nitrogen, potassium fertilisers and tea productivity have gone up almost together in south India. Potassium is as ephemeral as nitrogen and requires frequent application to maintain available K status against leaching losses and plant uptake.

Due to increase in the prices of muriate of potash (MOP) and sulphate of potash (SOP) in recent years, the recommended $N:K_2O$ ratios are not being maintained in some of the tea estates in south India and if this trend is allowed to continue for next few years, it will affect the productivity of tea and health of tea bushes in the coming years. On the other hand, due to shortage of workers for plucking, continuous cutting by hand shears or mechanical harvesters are being employed round the year including dry period affecting the health of bushes, making drought prone and more susceptible to pest and disease attacks. Under the present situation, the balanced ratio of $N:K_2O$ must be maintained for protection against various stresses. A regular check on deficiency symptoms, tissue concentration coupled with a close watch on yield trends in relation to the rate(s) of application will be useful for

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ISSN: 0972-544X (print)

preventing stagnation and decline in yields and mortality of tea bushes due to K deficiency.

This article is a compilation and highlights of research work done on different aspects of potassium nutrition including soil potassium, K interaction with nitrogen and other nutrients, K in stress, pests and diseases management of last seven decades by various researchers at UPASI Tea Scientific Department, UPASI Tea Research Foundation, Tea Research Institute, Valparai=Tamil Nadu. This compilation is to update the knowledge various aspects of K nutrition with due emphasis on maximizing crop productivity in Red and Lateritic soils (Latosols) of south India and enhancement of quality and flavor of Made tea. This has become imperative to meet the challenges of rising labour and inputs costs for making the south Indian tea industry viable and attractive.

Potassium is a Key Nutrient for Tea Nutrition

Potassium (K^+) is larger in size among the mineral cations required by plants. Its dehydrated radius is 0.133 mm. It is univalent cation found in the largest concentration (100-200 m *M* K) in the plant cell sap and so it is called as "master cation." [52] Potassium (K^+) is free ion (not bound to any constituent) and mobile in plants. Potassium is essential in mitochondrial and cell membrane permeability, plays vital roles in enzymes activation, water relation (osmotic regulation), energy relations, translocation of assimilates, photosynthesis, protein and starch synthesis.[22]

The young tea leaves and buds contain more K than older leaves suggesting the higher physiological demand of K by the flush shoots. In general, the higher concentration of K is thought to be necessary in young growing tissues for the maintenance of optimum turgor needed for cell elongation and possibly for cell division.[21] In addition to young leaves, the nonlignified stems and petioles are also rich in K. Potassium in plants is very mobile and circulates freely.[17] Its main transport direction is towards the meristematic tissues. Often under K deficiency, K from older leaves is redistributed to these younger tissues, resulting in deficiency symptoms in the older leaves. Before the appearance of visible symptoms in the margins and tips of older tea leaves, there is reduction in growth rate.[41]

The uptake and transport of K^+ to younger leaves is thus favoured in plants well supplied with N. The high uptake rate of K^+ infers that it is a strong competitor in the uptake of other cation species. Their absorption rate is especially enhanced when the K uptake is low. On the other hand K uptake and retention in plant cells are also competitively affected by H^+, Ca^{++}, Mg^{++} and Na^+.[8] A further typical feature of K is its high content in the phloem sap, as the solute of the phloem sap can be translocated both upwards (acropetal) and downwards (basipetal) in the plant, long distance transport of K can readily take place. Because K is indispensable for biochemical and biophysical reactions in the tissue, it should be supplied and maintained at optimum rates for the production of the highest economic yield.

Hunger Signs and Deficiency Symptoms of Potassium

When potassium is inadequate with lesser and lesser availability, the bush adjusts itself by putting forth lesser growth of flush shoots till the critical level is reached beyond which the growth cannot be further without self injury and then deficiency symptoms set in. Up to this stage, the crop passes through the stage of hidden hunger, when the crop can be easily revived to normal health by balanced application of potash. Hidden hunger stage can be identified by following symptoms: [41]

- Gradual reduction in yield, which is not easily recognizable, since the seasonal variations in yield are superimposed on this variation.
- Bushes suffer more in the drought and lose their capacity to withstand it.
- Bushes become more susceptible to diseases and pests.
- Pruned bushes fail to recover satisfactorily.

When potassium starved plants can not reduce their yield further, deficiency symptoms appear in the following sequence:

- Pronounced marginal and lamina necrosis on mature leaves. (Figure 1)
- Premature leaf fall, leaving a crown of young foliage at the top.
- Development of thin and twiggy wood.
- Defective growth of the bush, which does not respond to nitrogenous fertilisers resulting in absence of new flush growth.
- Ultimately death of bushes in the field creating vacant patches.

The deficiency of K is one of the factors that weakens tea plant, thus predisposing it to the attack by red rust caused by the algae Cephaleuros parasiticus (Karst). This malady could be corrected by applying the recommended levels of K.

Effect of Cessation of K_2O levels

The cardinal role of potash in maintaining the health, even ensuring survival of the tea bush was diagnosed by the UPASI Scientific Department in the late forties. At that time, tea bushes started dying extensively and the occurrence of unknown virus disease was suspected as the cause. Classic experiments revealed that tea bushes were dying because of potash starvation.

Old Devarshola, 3x 3 x 3 NPK factorial experiment, where three levels of nitrogen (0, 44.8, 89.6 kg/ha), three levels of phosphorus (0,22.4,44.8 kg/ha) and three level of potash (0,22.4,44.8 kg/ha) in all possible combinations was reviewed.[28] That experiment was initiated in 1940 and conducted for 14 years to study the effect of different levels of manuring on yield and was continued for another seven years to find out the effect of cessation of manuring. The experimental results showed that continual withholding of potassium progressively reduced the yielding capacity of tea plants (Table 1).

From the data it appeared that the effect of potassium on crop reduction was felt from year one onwards and it was cumulative over the years. In the first year, the crop yields declined to the extent of 17 per cent by complete withholding of K, compared to the plots received 44.8 K_2O kg/ha and at the end of year 14, the crop reduction in plots that received no potassium was 32 per cent.[30] However the visual symptoms of K deficiency on tea plants were observed only after six years. It was found that when 25 per cent reduction was done on K rates, the per cent reduction in the first, second and third year each was 5 to 10 per cent and in the fourth year increased to 10 to 20 per cent. But when K was completely withheld, the per cent reduction increased from 10 to 20 during first and second years respectively and 15 to 25 per cent in the third year. [30] (Table 2)

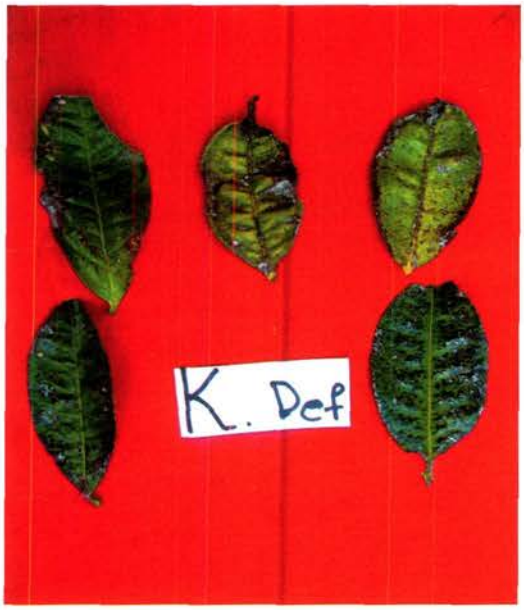

Fig. 1: Marginal and lamina necrosis on mature leaves showing potassium deficiency.

Table 1: Effect of Withholding Potassium on Tea Yields 3 x 3 x 3 NPK trial Devarshola, 1940/1953

Year	Maximum possible yield (%)		
	44.8 K_2O kg/ha	22.4 K_2O kg/ha	0 K_2O kg/ha
1940/41	91	83	72
1941/42	93	85	72
1942/43	92	85	71
1943/44	93	81	66
1944/45	94	81	65
1945/46	94	85	69
1946/47	94	83	67
1947/48	94	80	62
1948/49	94	78	62
1949/50	97	80	61
1950/51	95	81	61
1951/52	95	81	59
1952/53	95	81	58

Source: Ranganathan [30]

Table 2: Estimated Reduction in Tea Crop on Withholding NPK Fertilisers

Nutrient	% Reduction in crop estimates						
	Complete with holding			25 % Reduction in rates			
	First year	Second year	Third year	First year	Second year	Third year	Fourth year
N	25 to 30	40 to50	50 to 55	5 to 10	10 to 20	10 to 20	10 to 20
P	-	-	10 to 20	-	-	-	5 to 10
K	10 to 20	10 to 20	15 to 25	5 to 10	5 to 10	5 to 10	10 to 20
NPK *	35	46	60	10	15	15	23

*Minimum reduction expected based on per cent yield concept

Source: Ranganathan [30]

More striking was the effect due to omission of potassium on mortality of tea bushes. The number of mortality of bushes rose to 45 per cent in the plots, which received no potash for 12.5 years. The corresponding figures of mortality of bushes for 22.4 kg and 44.8 K_2O kg /ha/ annum were 20 per cent and 4.0 per cent only.[12]

The experiment clearly brought out the essentiality of potassium for tea manuring. Continuous skipping and/or inadequate applications of K leads to debilitation of bushes and their yielding capacity is very much reduced.[13, 28,30] Regular application of potassium helps in the arresting mortality of bushes, which follows every drought and every prune[13] and also to delay the senescence of leaves. [5,13] Potassium also helps in maintaining peak crop over prolonged period and in obtaining a better distribution of crop. Another feature of these experiments was the indication that the response to nitrogen was greater in the presence of potash than in its absence. At present with high rate of nitrogen application, the reduction in yield on withholding K will be more pronounced. Adequate application of potassium is necessary for getting optimum response from N and P fertilisers. [28,29]

Effect of Cessation of NPK fertilisers

Tea responds well to manuring and adversely reacts to withholding or reducing the rates of NPK application. Experiments were carried out to determine the effect of cessation of manuring.[14] The plots were manured with $N:P_2O_5:K_2O$::89.6:44.8:44.8 kg/ha respectively for four cycles (fourteen years) from 1940. Manuring was stopped at the end of fourth cycle (fourteenth year) and observations were continued for two more cycles (seven years). The yield data collected in the above experiment are given in Table 3. Comparison of first, second and third year yields before and after cessation of manuring indicated that yields were adversely affected by withholding fertiliser application. The yields were reduced from 18.4 to 34.9 per cent in the cycle following the cessation and from 45.0 per cent to 60.7 per cent in the subsequent cycle. [30] It is worth mentioning that it had taken four cycles to build up the yield level with balanced NPK manuring, while it had taken only three years to bring it down to the threshold level.

Results of Devarshola experiments (1940-59) were summarized and the estimated reduction in crop by withholding the major nutrients separately and in combination were shown in (Table 2). The data clearly indicated that 25 per cent reduction in NPK fertiliser rates had reduced the yield by 10 per cent in first year, 15 per cent each in second and third year and 23 per cent in fourth year. When NPK fertilisers were completely withheld, the yield reduction was 35, 46 and 60 per cent during first, second and third years respectively. [30] At present, with high rate of fertiliser usage, the effect of cessation of NPK manuring will be more pronounced and will prove disastrous and should be avoided.

Characteristics of Tea Soils of South India and its Relation with Potassium Nutrition

In south India, tea is grown in Red and Lateritic (Latosols) soils in the humid regions of western ghats, which runs in north west to south east direction parallel and close to the west coast of Peninsular India, at latitudes between 8^0 and 13^0 N and elevation ranges from 300 to 2500 m above mean sea level.[2] The annual rainfall ranges between 900 and 7500 mm. The western facing of the mountain range receives the complete spell of south west monsoon rains, while the eastern facing receives north east monsoon rains. In between these, there are areas, which receive rain from both the south west and north east monsoons.[35] Drought period varies from three to five months.

Tea soils of south India are sedentary and derived mostly from parent material such as granites, gneiss, sand stones and basalt. The soils belong to order Oxisols and Ultisols according to soil taxonomy. Oxisols are strongly weathered mineral soils of the humid tropics dominated by the Kaolinite and sesquioxide rich deep

Table 3: Effect of Cessation of Manuring 3 x 3 x 3 NPK trial Devarshola 1940/ 53 and 1953/59

Stage in the pruning cycle	Yield Made tea (kg/ha)				
	Before cessation of manuring			After cessation of manuring	
	Second cycle	Third cycle	Fourth cycle	Fifth cycle	Sixth cycle
First year	392	562	675	552	265
Second year	734	717	839	593	466
Third year	707	693	1085	712	441

Source: Ranganathan [30]

subsurface horizon (Oxic horizon). Most Oxisols have brick red colour but some are yellow or grey in colour. Ultisols developed due to advance stage of weathering and characterized by clay enriched sub-surface argillic horizon. These soils are base poor mineral soils of humid region developed under high rainfall and forest vegetation. These soils are subjected to heavy rainfall hence intensively leached. When leaching continues under warmer condition, bases like calcium, magnesium, sodium and potassium (Ca, Mg, Na and K) are washed out by percolating water leaving behind silica, iron and aluminium. The iron and aluminum under oxidised condition form sesquioxides (Fe and Al Oxides) impart red colour to these soils. The process is known as Laterization and the soils so formed are described as Lateritic or Latosols.[2] The colour ranges from dark red through yellowish red to strong brown (10 R - 2.5YR hues). It is red when iron oxides are predominantly Haematite and yellow or brown, when they occur mainly as Geothite. The major constraints of such soils are as follows:

- Coarse and gravelly nature of soils results in low water holding capacity thus less water available to plants and restricted rooting depth.
- Surface crusting and compaction leading to increased runoff accompanied by soil erosion.
- Acidic condition of soil and high level of aluminum
- Fixation of added phosphatic fertilisers
- Nutrients deficiencies, especially of potassium, calcium, magnesium, zinc and boron.

The major problems of the Red and Lateritic soils of the hilly regions are the intense rain leading to severe erosion due to steep slopes coupled with rolling topography. The conservation strategy is contour cultivation along with contour drainage in the soils with flat lands, contour bunds up to 6 per cent slope, graded bunds at 6 to 10 per cent slope, graded trenches at 10 to 16 per cent slope and bench terracing at 15 to 33 per cent slope were found to reduce run off from 5 to less than 2 per cent and soil loss from 30 to 50 tonnes / ha to less than 0.5 tonnes /ha. [58] Lands above 33 per cent slope should not be brought under plantation crops such as tea, coffee and spices. If tea is cultivated above 33 per cent slope, it is desirable to have appropriate soil conservation measures with proper maintenance to minimise erosion. It is desirable to break the length of slope at every ten meters by establishing vegetative barriers of one meter width consisting of hardy grasses of local shrubs. Both biological and mechanical measures are to be employed either in combination or individually for conservation of valuable surface soil. [58]

Kaolinite is predominant clay mineral and hence potassium fixing capacity is low. Kaolinite is 1:1 type clay mineral, which is made up of one tetrahedral (silica) sheet combined with one octahedral (alumina) sheet and held together by oxygen anions, which are mutually shared by silicon and aluminium cations in their respective sheets. These layers in turn are held together by hydrogen bonding. Consequently, the lattice is fixed and no expansion ordinarily occurs between layers when the clay is wetted. Cations and water do not enter between the structural layers of the particle [50]. The effective surface of Kaolinite is thus restricted to its outer external surface area and there is little isomorphic substitution in this mineral and thus it has low capacity to absorb cations. Electro-ultrafiltration (EUF) analysis of K desorbed at 20^{0}C and 80^{0}C has substantiated that Illite, expanded Illite and or Montmorillonite type clay mineral are negligible in these soils.[25] Only in localized patches in Nilgiris, Kaolinite mixed with Illite clay mineral are found.

The texture of the tea soils is sandy loam, loam, clay loam, clay and heavy clay. The pH of tea soils varies from 3.5 to 6.0. Tea plants require acidic soils having pH between 4.5 and 5.5 but certain tolerant varieties can establish growth at higher pH levels; such upper limit is between pH 6.0 and 6.5.[41] However, better utilization of nutrients is at pH 4.5 to 5.0 in many countries. Tea also grows well at pH below 4.5 but at such low pH nutrients supply can become limiting. The water holding capacity varies from 52 to 80 per cent, infiltration rate varies from 5 to 25 mm/hr and storage capacity of 30 cm soil varies from 2.5 to 5.5 cm.[59] The Cation exchange capacity (CEC) is generally low and is in the range of 4 to 12 meq/100 g soil depending on their clay and organic matter contents.[28] Nearly 50 per cent of CEC is due to soil organic matter [39]. The average release of K from weathering of soil estimated to be equivalent to 3mg/kg (ppm) per month.[31] In majority of the tea area in south India, it is not possible to build K reserves even by external supply of K due to absence of K fixing minerals; and also the K supply (or release) from soil is not adequate for economic cultivation. Unlike field crops, tea requires a higher K concentration in soil solution *i.e.* the degree of potassium saturation (DKS) (exchangeable K expressed as per cent over CEC) should be around seven per cent for its efficient absorption and high yields where as it is two per cent for most other crops.[36]

The root CEC values of tea plants should be viewed in conjunction with CEC of tea soils. Generally, the CEC of tea soils (4 to 12 meq/100 g soil) is lower than that of tea roots (12-25 meq/100 g dry weight of roots). Hence, large amount of divalent to monovalent cations will be found in the root surfaces compared with that found on the soil clay colloid surfaces. Therefore, a high K activity in soil solution must be maintained to overcome the valence effect of Donnan distribution, if adequate K is to enter the tea roots.[41]

With practically no fixation, the native K released or the applied K is either available to plant or is susceptible to leaching loss, which can be quite substantial depending upon the rainfall and pH. The fluctuations in available K within the soil profile are related to moisture movement due to evapo-transpiration in dry periods and percolation during rainy months. The sharp fall in available K after rainy season and a steep rise following fertiliser application suggest that tea plants depend mainly on added potassium for their K-nutrition in south India.

N:K_2O Ratio

It was reported that up to 40 per cent of variation in crop yield could be accounted by variation in the ratio of nitrogen to bases (K+Ca+Mg+Na) in the leaves, as potassium is present in much higher concentration than other bases, it is the ratio of N to K_2O, which is important. The significance of N:K_2O interaction was recognized in early 1950s in south India [15] and since then, the emphasis has been made on the adequate application of K along with N to maintain the balance and high yield at different years of pruning. The N:K_2O interaction is very important in augmenting the economic yield.

In north east India the need for K manuring was established in the early 1970, [7] which was supported by biochemical investigations [6]; the feeder root theanine level goes to toxic level (above 4.0 per cent) in the absence of K or at the sub optimal level of K. The balanced N:K_2O ratio increases Nitrate reductase activity (NRA) and enhances the nitrogen metabolism leading to the production of amino acids and finally yield. K is involved in earlier steps of nitrogen metabolism. *i.e.* the incorporation of mineral nitrogen especially in the nitrate reduction as well as in the final steps of nitrogen metabolism. Hence, N:K_2O ratio plays a significant role. NRA was found maximum when the ratio of N:K_2O was kept at 1:1 particularly when the nitrogen level was 300 kg/ha and above.[55] All the recommendations of potassium are therefore, based on N:K_2O ratios for young tea, pruned tea as well as other years of the pruning.

Nitrogen Recommendations and Progressive audit of N:K_2O Levels

Potassium (K) manuring is not determined independently, it is always linked with nitrogen in young tea and mature tea in pruned year as well as in other years of pruning and optimum N:K_2O ratios are maintained accordingly as mentioned earlier. In south India, the nitrogen dose is determined based on anticipated yield and organic matter status of tea soils. For the estimation of anticipated yield, in a four year pruning cycle, the yield of second, third and fourth year of the preceding pruning cycle is considered. If the weather pattern in any of these years appears abnormal, previous cycle is considered. If the mean yield of these years is 100 then the yield in different years of next pruning cycle could be predicted (Table 4).

The anticipated yield of the pruned year should be taken as 65 per cent of mean, if the mean Made tea yield is above 3500 kg /ha and 80-85 per cent of mean, if the mean yield is below 3500 kg /ha.

Classification of Organic Matter Status of Tea Soils

The response of nitrogen in mature tea is chiefly dependent on the organic matter status, climatic factors and availability of other nutrients. The sources of organic matter in tea fields are tea litters, tea prunings, weeds, shade tree litters and loppings. The annual average addition of organic matter (OM) by these sources varies with the elevation and length of the pruning cycle. At mid elevation, it is as high as 23 t/ha and at high elevation at 2500 m, it reduces to 14 t/ha.[42] As the elevation increases, the activity of micro organisms are reduced and higher per cent of organic matter is required at the higher elevation in comparison to mid-elevation to release the same amount of nitrogen. Thus, total N released by the decomposition of one per cent of organic matter in mid elevation (500-1500 m) reported in the range of 40-60 kg N/ha and at high elevation (up to 2500 m) it was as low as 15 to 20 kg N /ha.[32] The soil organic matter content depends on the elevation and rainfall of the area and classified as low, medium and high. (Table 5).

Table 4: Anticipated Yield at Different Years of Pruning

Years of pruning	Anticipated yield (per cent of mean)
Pruned year	65-85
Second year	100
Third year	110-120
Fourth year	110-120

Source: Verma and Sharma [61]

Table 5: Classification of Organic Matter Status

Classification	Range of organic matter content in (%)		
	Mid elevation	High elevation	
	500 - 1500 m MSL	1500 - 2000 m MSL	2000 - 2500 m MSL
Low	< 2.6	<5.2	< 7.8
Medium	2.6 - 7.8	5.2-10.4	7.8 – 13.0
High	> 7.8	> 10.4	> 13.0

Source: Hudson *et al.* [10]

Table 6: Rates of N Recommended (Mature tea)

Yield , Made tea kg/ha	Organic matter classification		
	Low	Medium	High
	kg/ha		
Minimum N	160	120	100
	kg N/100 kg Made tea		
Up to 2000	12	10	9
	Additional kg N/100 kg Made tea		
Above 2000	5	5	4

Source: Verma and Palani, [60]

Nitrogen Manuring Based on Yields and Organic Matter Status:

The nitrogen rate in mature tea in different years of pruning is determined based on yield anticipated yield and organic matter status of soil. The recommended nitrogen rates at various yield levels according to organic matter status are given in Table 6.[60] A ready reckoner of nitrogen rates at various yield levels and organic matter status are given in Table 7 [60].

Table 7: Recommendations of N Rate at Different Yield Levels

Made tea kg/ha	N (kg/ha)		
	O.M. status		
	Low	Medium	High
Minimum	160	120	100
2000	240	200	180
2500	265	225	200
3000	290	250	220
3500	315	275	240
4000	340	300	260
4500	365	325	280
5000	390	350	300
5500	415	375	320
6000	440	400	340
6500	465	425	360
7000	490	450	380

Source: Verma and Palani [60]

Progressive Audit of N and K_2O

A scheme has been evolved for auditing of N and K_2O in each split based on the crop harvested in preceding two to three months, which varies as per the prevailing weather conditions during the year. It prevents overdosing and underdosing of N and K_2O fertilisers and assists in maintaining the nutrient status of soil. The scheme allows one or two months time for the procurement of fertilisers and the splits are well distributed throughout the peak growth periods. In order to determine the appropriate crop/N ratio under specific agro-climatic and soil conditions, the mean yield of the field in the previous pruning cycle, excluding the yield of the pruned year has to be assessed. Based on the mean yield, the kg N/100 kg of Made tea required for each split can be determined as per the recommendations (Table 7).[60] A ready reckoner of nitrogen: crop ratio has been given for various yield levels and organic matter status (Table 8).[60] Five splits of $N:K_2O$ applications are suggested in a year in south Indian conditions based on actual yield obtained in two to three months preceding the split (Table 9). The rate of K_2O may be determined depending on the height of pruning in the pruned year. It is suggested to apply $N:K_2O$::1:0.75 or 4:3 in tea under plucking or in other years of pruning below yield level of 3500 kg/ha. For higher yield level above 3500 kg/ha, consequently higher levels of N, $N:K_2O$::1:1 is suggested. One split dose of $N:K_2O$ will be less in the pruned year in comparison to other years of pruning based on crop harvested. The calculated $N:K_2O$ dose may be rounded off for easy adoption. The saving in $N:K_2O$ is expected to be substantial and varies for different years of pruning.

Basis of Recommendations of N: K_2O ratios for young Tea

An experiment was conducted in young clonal tea, two months after planting from July, 1977 till formative pruning in August, 1982 on the clone UPASI-3 (B/5/63). Increasing K_2O levels from $N:K_2O$ ratio of 4:3 to 2:3 had tremendously increased the crop yield (Table 10). Overall for the cycle 26.8 and 36.4 per cent more yield was obtained by the use of 1:1 and 2: 3, N: K_2O ratios

Table 8: Nitrogen: Crop Ratio

Made tea kg/ha	kg N/ Made tea 100 kg /ha		
	O. M. status		
	Low	Medium	High
Up to 2000	12.0	10.0	9.0
2500	10.6	9.0	8.0
3000	9.7	8.3	7.3
3500	9.0	7.9	6.9
4000	8.5	7.5	6.5
4500	8.1	7.2	6.2
5000	7.8	7.0	6.0
5500	7.6	6.8	5.8
6000	7.3	6.7	5.7
6500	7.2	6.5	5.5
7000	7.0	6.4	5.4

Source: Verma and Palani [60]

Table 9: Time table for N: K2O Auditing

Splits	Yield of the Period for calculation of N	Time of application
First	November-December-January	April
Second	February –March	May/June
Third	April – May	September
Fourth	June- July – August	October
Fifth	September – October	November

Source: Verma and Palani [60]

respectively than by the adoption of N: K_2O::4:3 ratio.[40] A strong and significant interaction between N levels and N: K_2O ratio on yield was found in each year of cropping as well as on the overall cycle yield (Table 11). Nitrogen at 1.5 level and N: K_2O ratio 2:3 gave highest yield. Overall for the cycle, the increase in response due to increasing K_2O levels (4:3 to 2:3) was much more than that due to increasing N levels. The plots which received 2:3::N:K_2O ratio fertilisers up to the fourth year produced the highest crop in the fifth year as well as in the overall cycle.[40]

Pronounced increase in collar diameter at the base of the plant was observed due to increase in N:K_2O ratio from 4:3 to 2:3 in all the years and increased the dry

Table 11: Effect of N level x N: K_2O Ratio Interaction on Young Tea Yield (Made tea kg /ha)

	Total Yield (Made tea kg /ha) for the cycle (second, third, fourth and fifth year.)		
	N:K_2O ratio		
	(4:3)	(1:1)	(2:3)
N_1	6010 (100.0)	7585 (126.2)	8515 (141.7)
$N_{1.5}$	6329 (105.3)	8213 (136.7)	8592 (143.0)
N_2	6464 (107.6)	8035 (133.7)	8540 (142.1)
CD at P=0.05		657 (10.9)	

During fifth year, N: K2O:1:1 constant ratio was adopted, however the ratios given in parenthesis refers to the N: K_2O ratios adopted up to the fourth year.
Note: values given under yield in parenthesis denote per cent yield over the yield at N_1 level and 4:3:: N: K_2O ratio
Source: Ranganathan and Natesan [40]

Table 10: Effect of N: K_2O Ratio on Young Tea Yield (Made tea kg /ha)

N:K_2O ratio	Second year	Third year	Fourth year	Fifth year	Total
4:3	187 (100.0)	1091 (100.0)	2330 (100.0)	2659 (100.0)	6267 (100.0)
1:1	287 (153.5)	1413 (129.5)	3050 (130.9)	3194 (120.0)	7944 (126.8)
2:3	300 (160.4)	1433 (131.3)	3331 (143.0)	3486 (131.1)	8550 (136.4)
CD at P=0.05	25 (13.4)	79 (7.2)	113 (4.8)	26 (1.0)	379 (6.0)
CD at P=0.01	33 (17.6)	103 (9.4)	149 (6.4)	33 (1.2)	500 (8.0)

* During fifth year, K level was constant (N: K_2O ratio of 1:1) for all the sub-treatments
Note: Values in parentheses denote per cent yield
Source: Ranganathan and Natesan [40]

weight of branchlets, twigs, wood and total prunings (Table 12). The results clearly showed that $N:K_2O$::2:3 up to fourth year of planting and $N:K_2O$::1:1 in the fifth year appeared to be optimum for young tea for achieving high productivity as well as for better frame and wood development. The young tea manuring is aimed to develop good frames and also to bring the plants to bearing at the earliest possibility with good training practices.[32] $N:K_2O$ ratios of 2:3 for the first 2 to 3 years, depending on thickening of wood and 1:1 there after up to first prune are recommended.[34]

Dry Matter Production, Nitrogen (N) and Potassium Removal and $N:K_2O$ Ratios of Different Plant Parts in the Pruned Year

In the pruned year, tea plant mobilizes large quantities of nutrients including nitrogen (N) and potassium (K) for the formation of new frames and foliage that are essential for the sustained maintenance of bush health and yield in the pruned year and in the subsequent years of pruning cycle. The harvest index varies within a pruning cycle and it is lowest in the pruned year. The total dry matter produced in the pruned year varies from 6 to 10 t/ha depending on the severity of operation and in other years of the cycle it varies between 10 and 20 tonnes/annum depending on the yield potential of the field.[36] In the pruned year, 82 per cent of dry matter formed goes in for the formation of new wood and foliage and only about 18 per cent is removed as crop. The K requirement is 11 kg (13.3 kg K_2O) for every 100 kg Made tea harvested in the pruned year and 3.5 kg (4.2 kg K_2O) in other years with a mean of 4.5 kg (5.4 kg K_2O) for the cycle. Giving allowance for the efficiency of K as affected by leaching losses and the rate factors determining the amount reaching the root surfaces in unit time, the amount of K to be applied to produce 100 kg of Made tea is 17 kg (20.5 kg K_2O) and 6.6 kg K (8.0 kg K_2O) respectively in the pruned year and the other years of the cycle. Overall for the cycle it is 7.7 kg K (9.5 kg K_2O) for every 100 kg of Made tea.[36]

Dry matter production, nitrogen and (N) and potassium (K) removal and $N:K_2O$ ratios were studied in clone B/6/60 at pruning height 35 cm and the data are given in Table 13 [41]. Among different plant parts in the pruned

Table 12: Effect of N: K_2O Ratio on Collar Diameter and Dry Matter of Pruning

Factor	Collar diameter, cm					Pruning, kg dry matter/plant (pruned in August 82)			
$N:K_2O$ Ratio	First year (April 78)	Second year (April 79)	Third year (Oct. 80)	Fourth year (May 81)	Fifth * year (Aug. 82)	Foliage	Branchlet & Twigs	Wood	Total
4:3	0.66	1.77	3.60	4.04	4.98	0.24	0.36	0.22	0.82
1:1	0.70	1.92	3.84	4.32	5.49	0.22	0.30	0.32	0.84
2:3	0.72	1.98	3.97	4.57	5.56	0.27	0.49	0.36	1.12
CD	0.03*	0.10*	0.20*	0.17*	0.31*	NS	0.15**	0.10**	0.26**

* at P = 0.05

** at P = 0.10

Note: During fifth year, N: K_2O adopted was constant (1:1) for all the sub-treatments.

Source: Ranganathan and Natesan [40]

Table 13: Dry Matter Production, Nitrogen (N) and Potassium (K_2O) Removal and N: K_2O Ratios of Different Plant Parts in the Pruned Year (Clone-B/6/60, Pruning Height, 35 cm

Plant parts above the pruning cut	Dry matter (t/ha)	Proportional dry weight	Nutrient removal (kg/ha)			$N:K_2O$
			N	K	K_2O	
Flush shoot	1.20	100	48	24	28.9	1:0.60
Mature foliage	3.30	275	122	60	72.3	1:0.59
Twigs	0.62	52	13	10	12.1	1:0.93
Wood	1.79	149	41	15	18.1	1:0.44
Total	6.91	-	224	109	131.4	-

Source: Ranganathan and Natesan [41]

year, dry matter weight is highest in mature foliage followed by wood and then to flush shoot and twigs, while N and K_2O removal is highest from mature foliage followed by flush shoots, wood and twigs. But the N:K_2O ratio assimilates in twigs is the highest (1:0.93) followed by flush shoot(1:0.60), mature foliage (1:0.59) and then to wood (1:0.44) in the pruned year (Table 13). Hence, the requirement of N:K_2O ratio in the pruned year seems to be more than 1:0.93 as the formation of twigs is in a greater proportion than in other plant parts as well as to assimilate the desired N:K_2O ratio in other plant parts. Thus N:K_2O manuring in pruned year is very vital and must be balanced with the requirement as it is not only influencing the bush health and yield of pruned year but also the bush health and yield of other years of pruning cycle.

Effect of N:K_2O Ratios Applied in the Pruned Year at Different Pruning Heights on Productivity of Different Years of Pruning

The effect of different N:K_2O ratios applied at different pruning heights 35 cm to 40 cm, 50 cm to 60cm, 65 cm to 70 cm in clonal and Assam seedling teas was studied on tea productivity of pruned year and other years of pruning cycle during 1971 to 1985 [45]. Different N:K_2O ratios (1:0.67, 1:1.17 and 1:1.67) were applied in the pruned year at pruning height 35cm to 40 cm in UPASI -10(B/6/61) and tipped at 75 cm and yields were recorded for pruned year as well as for other years of pruning cycle during 1971-75. In second, third and fourth year, equal N:K_2O::1:0.5 was applied. Made tea yields (kg/ha) of pruned year and other years of pruning are given in Table 14.[45] Increasing N:K_2O ratios had significantly increased the yield of pruned year, second year , third year and for the cycle and highest yield was obtained at N:K_2O:: 1: 1.67, which seems to be optimum at 35-40 cm.

In another experiment different N:K_2O ratios (1:1.11, 1:1.48 and 1:1.85) were applied in the pruned year at pruning height 50-60 cm in Assam seedling and tipped at 75 cm and yields were recorded for pruned year as well as for other years of pruning cycle during 1973-78. In other years of pruning N:K_2O::1:0.67 was applied. The higher N:K_2O ratios had significantly increased the yield in fourth and fifth years as well as for pruning cycle (1973-78). The higher yields were obtained at N:K_2O::1:1.48 and 1:1.85 and both were found at par while N:K_2O::1:1.11 had given the lowest yield (Table 15). It indicates that N:K_2O::1:1.11 is sub-optimal while N:K_2O::1:1.48 seems to be optimum at 50-60 cm.

The interaction between N:K_2O::1:1.25 and 1:1.88 applied in pruned year with N:K_2O::2:1, 4:3 and 1:1 applied in other years of pruning were studied in Assam seedlings at pruning height 65-70 cm during 1978-82 and yields of pruned year and other years of pruning were recorded. The interactions of different N:K_2O ratios had influenced the yield significantly of second, third and fourth year as well as for pruning cycle except pruned year (Table 16). The effect of higher N:K_2O::1:1.88 applied in pruned year had not given significantly higher yield in pruned year as well as for other years of pruning and thus, it seems that N:K_2O::1:1.25 might be adequate at 65-70 cm. Among different N:K_2O ratios applied in other years of pruning , the higher N:K_2O::1:1 had given higher yield and more marked as the cycle advanced in

Table 14: Effect of N: K_2O Ratios Applied in the Pruned Year at the Pruning Height 35-40 cm on Productivity of Different Years of Pruning as well as for Cycle (1971-75) (Clone –UPASI 10 (B/6/61), Tipping ht. 75 cm

K_2O (kg/ha) pruned Year	N: K2O pruned Year	Yield , Made tea (kg/ha)				
		Pruned Year	Second Year	Third Year	Fourth Year	Total for the cycle
80	1: 0.67	904 (100)	2597(100)	3169(100)	2634(100)	9304(100)
140	1:1.17	1056 (117)	2800(108)	3349(106)	2687(102)	9892(106)
200	1:1.67	1184 (131)	3020(116)	3535(112)	2718(103)	10457(112)
CD at P = 0.05	-	94 (10.4)	201(7.7)	333(10.5)	NS	391(4.2)
N applied kg/ha	-	120	240	240	240	840

N: K_2O Ratio in other years except pruned year: 1:0.5
P_2O_5 -80 kg/ha in pruned year and 30 kg/ha in subsequent years.
Figures in parentheses denote percentage
Source: Ranganathan *et al.* [45]

Table 15: Effect of N: K_2O Ratios Applied in the Prune Year at Pruning Height 50-60 Cm on Productivity of Different Years of Pruning as well as for Cycle (1973-78) (Assam seedling, Tipping height. 75 cm)

K_2O (kg ha^{-1}) pruned Year	N:K_2O pruned Year	Yield, Made tea kg/ha					
		Pruned Year	Second Year	Third Year	Fourth Year	Fifth Year	Total for cycle
150	1:1.11	682(100)	2698(100)	2767(100)	3364(100)	3810(100)	13321(100)
200	1:1.48	692(102)	2839(105)	2771(100)	3457(103)	3917(103)	13676(103)
250	1:1.85	719(105)	2809(104)	2822(102)	3493(104)	3924(103)	13767(103)
CD at P = 0.05	-	NS	NS	NS	92(2.7)	41(1.1)	236(1.8)
N applied kg ha^{-1}		135	240	260	320	300	1255

N: K_2O Ratio in other years except pruned year: 1:0.67
P_2O_5 -90 kg/ha in pruned year and 45 kg/ha in subsequent years.
Figures in parentheses denote percentage.
Source: Ranganathan *et al.*[45]

Table 16: Effect of N: K2O Ratios applied in the pruned year at pruning height 65-70 cm x N:K_2O Ratios in other years on productivity of different years of pruning as well as for cycle (1978-82) (Assam seedling, Tipping height + 2 leaves)

K_2O (kg/ha) in other years	N:K_2O other years	Pruned year		Second year		Third year		Fourth year		Total for the cycle	
		A N:K_2O 1:1.25	B N:K_2O 1:1.88	A	B	A	B	A	B	A	B
180	2:1	1409	1409	2841	2866	3794	3598	3252	3059	11296	10932
270	4:3	1413	1399	2912	2800	3753	3673	3153	3014	11231	10886
360	1:1	1401	1445	2897	2970	3803	3921	3308	3352	11409	11688
Average		1403	1418	2883	2879	3783	3731	3238	3142	11312	11169
CD at P=0.05 A, B x level		NS		98		182		152		246	

A and B correspond to 200 K_2O kg/ha (N: K2O:: 1:1.25) and 300 K_2O kg /ha (N:K_2O::1:1.88) in the pruned year respectively.
160 N kg /ha applied in the pruned year and 360 N kg /ha in the subsequent years.
Source: Ranganathan *et al.*[45]

comparison to N:K_2O ratios 2:1 an 4:3 and seems to be not adequate (Table 16).

The effect of N:K_2O ratios 1:0.80 and 1:1.30 applied in the pruned year was studied in clone C-194 at pruning height 70 cm and productivity was recorded for pruned year as well as for other years of pruning cycle during 1981-85. In the pruned year and second year as well as for the pruning cycle, significantly higher yields were recorded at N:K_2O::1:1.30 in comparison to 1:0.80 (Table 17). It seems that N:K_2O::1:1.30 is more appropriate than 1:0.80 at pruning height 70 cm. Thus, based on the results of above experiments, the N:K_2O ratios were suggested as mentioned in Table 18 for application irrespective of sources of nitrogen (N) based on the pruning heights in the pruned year for clonal as well as Assam seedling teas under south Indian condition:

N:K_2O Ratios of Tea Under Plucking or in Other Years of Pruning Except Pruned Year

In other years of pruning except pruned year, an average of 73 per cent goes for thickening of wood and formation of new plucking points and the new maintenance foliage left on the surface for sustaining photosynthetic efficiency; 27 per cent of the dry matter is converted in to flush shoots.[36] To produce 100 kg of Made tea, the supporting growth required is 120 kg of foliage to be left on the bushes, 280 kg wood including branchlets and twigs and 180 kg of roots (all expressed as dry matter). Though 100 kg of Made tea contains only 2 kg of K, the total

Table 17: Effect of N: K_2O Ratios Applied in the Pruned Year at Pruning Height 70 cm on Productivity of Different Years of Pruning as well as for Cycle (1981-85) (clone: C/194, Tipping ht. 80 cm

K_2O (kg/ha) pruned Year	N:K_2O pruned Year	Yield, Made tea (kg/ha)				
		Pruned Year (Dec.-Nov.)	Second Year (Dec.-Nov.)	Third Year (Dec.-Nov.)	Fourth Year (Dec.-Aug.)	Total for the cycle
240	1:0.80	2503 (100.0)	3581 (100.0)	3746 (100.0)	2422 (100.0)	12252 (100.0)
390	1:1.30	2737 (109.4)	3854 (107.6)	3811 (101.7)	2472 (102.1)	12874 (105.1)
CD at P = 0.05	-	189 (7.6)	81 (2.2)	206 (5.5)	119 (4.9)	306 (2.5)
N applied kg ha^{-1}	-	300	300	300	150	1050

N: K_2O Ratio in other years except pruned year: 1:0.75
P_2O_5 -80 kg/ha in pruned year and third year
Figures in parentheses denote percentage;
Source: Ranganathan *et al.*[45]

Table 18: N: K_2O Ratios at Different Pruning Height in the Pruned Year

Sr. No	Height of pruning	N:K_2O ratio
1.	Rejuvenation and hard pruning below 35 cm	1:2.0
2.	Pruning between 35 cm up to 45 cm	1:1.75
3.	Pruning above 45 cm and up to 60 cm	1:1.50 or 2:3
4.	Cut across or Pruning above 60 cm	1:1.25

Source: Verma and Palani [60]

amount of K required to produce that quantity of tea is around 4.5 kg of K (5.4 K_2O) taking into account that is needed for the supporting growth.[36]

The proportional dry weight, nitrogen (N), potassium (K) and N:K_2O ratios of different plant parts are given in Table 19. To assimilate N:K_2O::1:0.62 in flush shoots , at the higher N:K_2O ratios are required to be formed in different plant parts such as wood and root except foliage (N:K_2O::1:0.47)(Table 17).Thus the requirement N:K_2O ratios of tea under plucking seems to be higher than flush shoots N:K_2O::1:0.62 to balance the N:K_2O ratios in different plant parts. The adequate values of nitrogen (N) of third leaf in certain experiments of south India are found between 3.5 to 5.0 per cent and low values are found between 2.0 to 3.0 per cent and below 2.0 per cent are likely to be deficient on dry matter basis. The adequate values of potassium (K) of third leaf are found between 2.1 to 3.0 per cent and low values are found between 1.0 to 1.5 per cent and below 1.0 per cent are likely to be deficient on dry matter basis.

A long term (1974 -2003) field experiment was conducted at UPASI experimental farm in UPASI -9 in tea under plucking. The highest cumulative yield of 9 years was found at N: K_2O::1:0.83, when N levels were 300 kg/ha (31,587 kg/ha) and 450 kg/ha (34,000 kg/ha). At N level (N150 kg/ha), the highest yield was obtained at N:K_2O::1:1.67 (28687 kg/ha), which was at par with N:K_2O::1:0.83 (26,732 kg/ha)[57] (Table 20). Thus, the N:K_2O::1:0.83 was found superior among all N:K_2O ratios of experimentation, when N levels varied from 150 kg/ha to 450 kg/ha. In south India, N level also varies from 150 kg/ha to 450 kg/ha according to yield levels and organic matter status of soils.

The third leaf of tea under plucking of 9 different tea estates of Valparai, Coonoor, Kotagiri and Gudalur of clonal as well as Assam seedling tea were analysed for all the essential nutrients from 2004 to 2008. The typical representative data of nitrogen (N) and potassium (K_2O) and N:K_2O ratios of third /fourth year of experimentation of different estates are presented in Table 21. It was found that N:K_2O ratio varied markedly based on yield levels, the levels of nitrogen and potassium fertilisers applied , cultivars and climatic conditions. The highest N:K_2O ratio was found at 1:0.73 and the lowest was N:K_2O::1:0.48 while the mean N:K_2O::1:0.58 was found of third leaf of tea under plucking (Table 21). It is expected that N:K_2O ratio of bud , first leaf , second leaf are likely to be higher than third leaf. It is suggested to apply at 25-35 per cent higher N:K_2O ratio than the mean N:K_2O::1:0.58, that means N:K_2O::1:0.73-1:0.78 may be

Table 19: Proportional Dry weight, Nitrogen (N), Potassium (K) and N:K_2O Ratio(s) of Different Plant Parts of Tea

Plant parts	Proportional dry weight	Dry matter basis			N:K_2O
		N (%)	K (%)	K_2O (%)	
Flush shoots	100	4.15 ± 0.15	2.15 ± 0.09	2.59 ± 0.11	1:0.62
Mature foliage	120	3.20 ± 0.18	1.24 ± 0.18	1.49 ± 0.22	1:0.47
Twigs	80	1.37 ± 0.09	1.00 ± 0.08	1.21 ± 0.10	1:0.88
Wood	200	1.04 ± 0.09	0.55 ± 0.12	0.66 ± 0.15	1:0.64
Root	-	1.06 ± 0.08	0.83 ± 0.25	1.00 ± 0.31	1:0.94

Source: Ranganathan and Natesan [41] and Natesan and Ranganathan [23]

Table 20: Long Term Impact of N: K_2O Ratio on Made Tea Yield of Tea under Plucking

Rate of application kg/ha/ year	Made tea yield in kg/ha (April, 1994-March,2003)				
	K_0	K_{125}	K_{250}	K_{375}	Mean
N:K_2O	1:0	1:0.83	1:1.67	1:2.5	-
N_{150}	23701	26732	28687	28229	26837
N:K_2O	1:0	1:0.42	1:0.83	1:1.25	-
N_{300}	27873	28784	31587	31025	29817
N:K_2O	1:0	1:0.28	1:0.56	1:0.83	-
N_{450}	31026	32718	33305	34000	32762
Mean	25955	27079	28459	28684	-
		N	K_2O	N x K_2O	
CD at P= 0.05		2686	1399	2798	

Source: Venkatesan *et al.*[57]

applied to maintain the desired N:K_2O ratio in third leaf, in buds, first leaf, second leaf as well as in internodes in tea under plucking. Thus, it is suggested to apply minimum N:K_2O::1:0.75 or 4:3 in tea under plucking or in other years of pruning except pruned year, below yield level of 3500 kg/ha Made tea.

The efficiency of K decreases with increasing yields; probably the transport processes within the soil are becoming a limiting factor. The utilization of applied K was 80 per cent at yield level of 2000 kg/ha Made tea and declined to 75 per cent at yield level of 3000 kg/ha and further to 65 per cent at yield level of 4000 kg/ha.[34] The demand for K (g/ha/day) increased to 520 g at 4000 kg/ ha yield level from 130 g at 1000 kg/ha yield level during the rush periods.[34] Ranganathan recommended for yield levels above 3500 kg/ha, a high N:K_2O ratio of 1:1 irrespective of N sources.[34] Therefore tea fields where yield levels are 3500 kg/ha or more,N:K_2O ::1:1 is suggested in other years of pruning. The higher K_2O with respect to N ratio will also helps and provide drought tolerance during the dry period.

Effect of N:K_2O Ratios on Quality Parameters of Made tea

The effect of N:K_2O ratios was reported on the contents of amino acids and polyphenols. Precursors of quality parameters as also other quality parameters in flush shoot (Table 22).[55] Amino acids contents were found highest at N:K_2O::1:1 at 300 and 450 kg/ha and both were found at par. This may be due to higher nitrate reductase activity required for nitrogen metabolism to form free amino acids. [46, 47] Polyphenols were found maximum at N:K_2O::1:1 at 450 N kg/ha indicating proper balance of N:K_2O fertilisers. The percentage of water soluble solids of Made tea at N:K_2O::1:1 at 300 and 450 kg N/ha were found higher than PFA standard (minimum 32 per cent) and both were found at par. The caffeine content was found highest at N:K_2O::1:1 at N450 kg/ha (3.67 per cent) followed by N300 kg/ha (3.56 per cent) and both were found at par. The maximum theaflavins was found at N:K_2O::1:1 at 300 kg N/ha (1.12 per cent) followed by 450 kg N/ha (1.08 per cent) and both were found at par.

Table 21: N: K_2O Ratios of Third Leaf of Tea Under Plucking of Different Tea Estates of South India

Sr. No	Names of Estates/ Location	Cultivar	Sample Ref.	Date of sampling	Yield Made tea (kg ha	On Dry matter basis (%)			N:K_2O Ratio
						N	K	K_2O	
1.	Korangumudi estate, Valparai, TamilNadu	UPASI-9(B/6/61)	F.No.2,IMT-1	5.6.2008	5158	4.17	1.65	1.99	1: 0.48
2.	,,	,,	F.No.2A-KGM-3	5.6.2008	4516	3.79	1.68	2.02	1: 0.53
3.	Gajammudi estate, Valparai, TamilNadu	Assam seedling	F.No.45-IMT-3	11.01.2008	2680	3.96	2.14	2.58	1: 0.65
4.	,,	,,	F.No.45-GMD-1	11.01.2008	2459	4.29	2.20	2.65	1: 0.62
5.	Velonie estate , Valparai, TamilNadu	Assam seedling	F.No.16,IMT-3	15.12.2007	2409	3.81	1.58	1.90	1: 0.50
6.	,,	,,	F.No.16,VLE-2	15.12.2007	1741	3.33	1.50	1.81	1: 0.54
7.	Karamalai estate, Valparai, TamilNadu	Assam seedling	F.No.16,IMT-3	05.06.2008	2008	4.31	2.35	2.83	1: 0.66
8.	,,	,,	F.No.16,KME-3	05.06.2008	1576	4.13	2.18	2.63	1: 0.64
9.	Glendale estate, Coonoor, TamilNadu	CR-6017	F.No.7,IMT-2	29.01.2008	4315	3.34	2.02	2.43	1: 0.73
10.	,,	CR-6017	F.No.7,GLE-3	29.01.2008	3448	3.43	1.87	2.25	1: 0.66
11.	Kil-Kotagiri estate, Kotagiri, TamilNadu	Assam seedling	F.No. Poomanu-A, IMT-2	18.01.2008	1699	3.43	1.53	1.84	1: 0.54
12.	,,	,,	F.No. Poomanu-A, KKE-1	18.01.2008	1339	3.38	1.53	1.84	1: 0.55
13.	Sussex estate , Gudalur, TamilNadu	UPASI-9(B/6/61)	F.No.7, IMT-2	27.09.2006	6978	3.94	1.64	1.98	1: 0.50
14.	,,	,,	F.No.7,SUX-3	27.09.2006	6224	3.68	1.57	1.89	1: 0.51
15.	Silver Cloud estate, Gudalur, TamilNadu	Assam seedling	F.No.3,IMT-2	03.02.2007	2737	3.42	1.70	2.05	1: 0.60
16.	,,	,,	F.No.3,SCD-2	03.02.2007	2329	3.40	1.57	1.89	1: 0.56
17.	New Hope estate, Gudalur, TamilNadu	Assam seedling	F.No. 16 A, IMT- 1	18.11.2006	2367	3.37	1.62	1.95	1: 0.58
18.	,,	,,	F. No. 16 A, HMP-1	18.11.2006	1838	3.32	1.62	1.95	1:0.59
							Mean		1:0.58

The maximum theaflavins (TF) could be due to increase in catechin synthesis at optimum N:K_2O::1:1 ratio. The highest thearubigins (TR) was found at N:K_2O::1:1 at N450 kg/ha (10.6 per cent) and significantly superior to other N:K_2O ratios. The flavour index was found maximum at N:K_2O::1:1 at N300 kg/ha (3.01) followed by N450 kg/ha (2.44) (Table 20). The increase in flavour index could be due to synthesis of higher concentration of Group II compounds, linalool, methyl salicylate and benzaldehyde imparting sweet aroma to tea at optimum balance ratio of N:K_2O::1:1. Thus, positive influence on overall quality of CTC Made tea was found at N:K_2O::1:1, when the nitrogen level was 300 and 450 kg/ha.

The impact of N:K_2O ratios on quality parameters was studied in a long term field experiment at UPASI-TRF experimental farm in clone UPASI-9 in tea under plucking. [57] The highest polyphenols content was found at N:K_2O::1:0.83 at N300 kg/ha (333 mg/g) and N450 kg/ha (335 mg/g), which were significantly superior to other N:K_2O ratios, while at N150 kg/ha, the highest polyphenols contents was found at N:K_2O::1:2.5 (306 mg/g) which was at par with N:K_2O::1:0.83 (305

Table 22: Effect of $N:K_2O$ Ratios on Quality Parameters of Clone SA-6 of Tea

Sr. No.	$N:K_2O$ (kg/ha)	$N:K_20$	Amino acids (%)	Poly-phenols (%)	Water soluble solids (%)	Caffeine (%)	Theaflavins (%)	Thearubigins (%)	Flavour Index
1.	$N_{150}K_{300}$	1: 2	1.47	24.3	37.82	3.38	0.94	9.3	1.80
2.	$N_{300}K_{150}$	1: 0.5	1.80	25.6	38.25	3.31	0.89	8.8	1.61
3.	$N_{300}K_{300}$	1: 1	2.34	26.4	37.80	3.56	1.12	9.4	3.01
4.	$N_{300}K_{450}$	1: 1.5	1.82	30.1	36.39	3.31	0.96	8.7	2.00
5.	$N_{450}K_{150}$	1: 0.33	1.57	27.2	38.43	2.98	0.87	9.1	1.05
6.	$N_{450}K_{300}$	1: 0.67	1.60	29.6	38.30	3.30	0.92	9.9	1.72
7.	$N_{450}K_{450}$	1: 1	1.97	31.4	38.33	3.67	1.08	10.6	2.44
		SE ±	0.18	0.52	0.41	0.09	0.03	0.26	0.05
	CD at P= 0.05		0.53	2.10	0.59	0.19	0.07	0.56	0.11

Source: Venkatesan [55]

mg/g)[57] (Table 23). Polyphenols are important quality precursors of Made tea and responsible for the formation of (TF) and (TR). TF imparts briskness and brightness of tea decoction. The increase of polyphenols content in response to applied K fertilisers had been reported in tea gardens of China.[47]

Similarly, the highest amino acids was found at $N:K_2O$:: 1:0.83 at N450 kg/ha (11.6 mg/g) and N150 (8.1 mg/g), while at N300 kg/ha, the highest amino acid was found at $N:K_2O$::1:0.42 (8.8 mg/g), which was at par with $N:K_2O$::1:0.83 (8.7 mg/g), they were significantly superior to other $N:K_2O$ ratios[57] (Table 24). It was reported that the increase in amino acid content could be due to improved nitrogen metabolism regulated by nitrate reductase at the optimal $N:K_2O$ ratio of 1:1.[46,47] The amino acids are most important precursors for the development of aroma in black tea. The similar trend was found also in Catechins. The highest catechins content was found at $N:K_2O$::1:0.83 at N300 kg /ha (249.0 mg/g) and N450 kg/ha (245.2 mg/g), which were significantly superior to other $N:K_2O$ ratios, while, at N150 kg /ha the highest Catechins was found at $N:K_2O$::1:2.5 (226 mg/g), which was at par with $N:K_2O$::1:0.83(221.4 mg/g)[57] (Table 25). The major catechins are Epigallocatechin (EGC), Epicatechin gallate (ECG), Epicatechin (EC) and Catechins (C) and regarded as quality precursors and involved in the development of aroma of tea.

Thus, $N:K_2O$::1:0.83 seems to be ideal ratio, when N levels varies from 150 to 450 kg/ha in tea under plucking for obtaining higher polyphenols, amino acids and catechins, important quality precursors of Made tea.

P and K Interaction in Tea

An experiment was conducted in clonal tea (C-194) last pruned in April, 1977 from April, 1979 to

Table 23: Long Term Impact of N: K2O Ratio on Polyphenols of Tea Leaves of Tea Under Plucking

Rate of application kg/ha/year	Polyphenols (mg/g)				
	K_0	K_{125}	K_{250}	K_{375}	Mean
$N:K_2O$	1:0	1:0.83	1:1.67	1:2.5	-
N_{150}	298	305	290	306	300
$N:K_2O$	1:0	1:0.42	1:0.83	1:1.25	-
N_{300}	307	318	333	295	313
$N:K_2O$	1:0	1:0.28	1:0.56	1:0.83	-
N_{450}	293	307	325	335	315
Mean	297	306	312	307	
		N	K_2O	N x K_2O	
CD at P = 0.05		5.0	3.3	7.0	

Source: Venkatesan [57]

Table 24: Long term impact of N: K2O Ratio on Amino acids of tea leaves of tea under plucking

Rate of application kg/ha/year	Amino acids (mg/g)				
	K_0	K_{125}	K_{250}	K_{375}	Mean
$N:K_2O$	1:0	1:0.83	1:1.67	1:2.5	-
N_{150}	5.3	8.1	7.8	7.8	7.2
$N:K_2O$	1:0	1:0.42	1:0.83	1:1.25	-
N_{300}	8.2	8.8	8.7	7.7	8.3
$N:K_2O$	1:0	1:0.28	1:0.56	1:0.83	-
N_{450}	8.7	9.1	9.2	11.6	9.6
Mean	6.8	8.1	8.2	8.2	
		N	K_2O	N x K_2O	
CD at P = 0.05		0.3	0.4	0.7	

Source: Venkatesan [57]

November 1981. There were two main treatments of levels of $N:K_2O$::360:180 (2:1) and $N:K_2O$::360:360(1:1) kg/ha with six sub-treatments control (No phosphorus) and five different sources of phosphorus where 90 kg P_2O_5 /ha applied as placement in pruned year and third year The effect of P and K interactions on tea yield was significant in all the three years and the data are given in Table 26.

There was no response to increased $N:K_2O$ ratio from 2:1 to 1:1 in control (no phosphorus) plots in all the three years. However, in phosphorus applied plots the response to increased $N:K_2O$ ratio was significant. The highest yield was obtained at $N:K_2O$::360:360 (1:1), when 90 kg P_2O_5/ha was applied in pruned year and third year in all the three years indicating pronounced P x K interactions.[43] Both P and K are essential to maintain the linear response to nitrogen.[62]

Mg x K_2O Interaction:

The interaction between magnesium and potassium was studied in south India (Table 27) in Assam seedling at UPASI Tea Research Institute in Anamallais for two pruning cycles (1980 to 1988). In the pruned year, $N:K_2O$::2:3 was adopted in both the cycles while in other years $N:K_2O$::1:1 was applied.

In the first cycle, in all the years there was yield depression due to the application of Mg at lower $N:K_2O$ levels, while there was increase in yield at higher $N:K_2O$ levels, The response due to Mg application at higher $N:K_2O$ levels was 13.8, 11.5, 4.4 and 3.3 per cent in the four successive years from pruning and 7.3 per cent for the first pruning cycle (Table 28). In the second pruning cycle, there was crop depression in the pruned year and second year after pruning, while there was marginal increase in third year as well as in fourth year at lower $N:K_2O$ levels. At higher $N:K_2O$ levels , there was significant increase in yield , which was 15.0,18.2,14.3 and 12.4 per cent in the four successive years from pruning and 14.9 per cent higher crop in second pruning cycle (Table 28).

Thus, Mg and $N:K_2O$ interaction was found significant at higher $N:K_2O$ levels in the pruned year as well as in other years of pruning in both the pruning cycles. The higher per centage of crop increase in the second cycle may be due to adoption of higher $N:K_2O$ levels in second, third and fourth year of pruning in comparison to first pruning cycle. The crop depression by the application of Mg at lower levels of $N:K_2O$ may be due to antagonism between Mg and $N:K_2O$. The antagonism between K and Mg had been well documented.[1,21,41] Work done in Sri Lanka also indicated that the response of magnesium increases with increasing levels of potassium.[16] The data obtained from this study showed that there was a definite response to the soil application of magnesium sulphate at higher $N:K_2O$ levels in tea soils of south India.[26]

Table 25: Long Term Impact of N: K_2O Ratio on Catechins of Tea Leaves of Tea Under Plucking

Rate of application kg/ha/year	Catechins (mg/g)				
	K_0	K_{125}	K_{250}	K_{375}	Mean
$N:K_2O$	1:0	1:0.83	1:1.67	1:2.5	-
N_{150}	212.1	221.4	225.7	226.0	231.3
$N:K_2O$	1:0	1:0.42	1:0.83	1:1.25	-
N_{300}	234.8	241.5	249.0	208.2	233.4
$N:K_2O$	1:0	1:0.28	1:0.56	1:0.83	-
N_{450}	221.5	221.9	232.2	245.2	230.2
Mean	220.3	227.2	236.3	223.5	
		N	K_2O	N x K_2O	
CD at P = 0.05		5.9	3.8	7.5	

Source: Venkatesan [57]

Ca x K Interaction

Calcium x Potassium antagonism is well documented in tea as well as in other crops. Excess of available cal-

Table 26: P x K Interaction on Tea Yield (kg /ha)

	1979/80		1980/81		1981		1979/81	
	K levels		K levels		K levels		K levels	
	A	B	A	B	A	B	A	B
No 'P' Plots	4662 (101.2)	4529 (98.6)	4896 (100)	4894 (99.9)	2498 (100)	2499 (100)	12056 (100.6)	11918 (99.4)
'P' plots	4971 (108.2)	5153 (112.1)	5028 (102.7)	5377 (109.9)	2501 (100.1)	2668 (106.8)	12500 (104.3)	13198 (110.1)
S.E. (%)	3.6	3.6	3.8	3.8	4.7	4.7	2.3	2.3

$N:K_2O$::360:180(2:1) kg/ha
$N:K_2O$::360:360(1:1) kg/ha
Source: Ranganathan *et al.* [43]

Table 27: Levels of MgO and N:K_2O in Assam Seedling (1980-88)

	I[st] Pruning cycle (1980-84)				
	Pruned Year kg/ha	**Second Year kg/ha**	**Third Year kg/ha**	**Fourth Year kg/ha**	**Total kg/ha**
MgO	50	63	63	88	264
A(N:K_2O)	160:240	233:233	233:233	327:327	953:1033
	(2:3)	(1:1)	(1:1)	(1:1)	
B(N:K_2O)	240:360	266:266	266:266	373:373	1145:1265
	(2:3)	(1:1)	(1:1)	(1:1)	
	2[nd] Pruning cycle (1984-88)				
MgO	50	75	75	75	275
A(N:K_2O)	160:240	240:240	240:240	240:240	880:960
	(2:3)	(1:1)	(1:1)	(1:1)	
B(N:K_2O)	240:360	360:360	360:360	360:360	1320:1440
	(2:3)	(1:1)	(1:1)	(1:1)	

Source: Palani and Verma [26]

Table 28: Response to Soil Applied Magnesium

N:K_2O kg/ha/cycle	**First cycle (Made tea kg/ ha)**		**% Deviation**
	No MgO	MgO (264 kg MgO)	
953:1033 (1:1.1)	15877	15518	- 2.3
1145:1265 (1:1.1)	15547	16682	+ 7.3
	Second cycle (Made tea kg/ha)		
	No MgO	MgO (275 kg MgO)	
880:960 (1:1.1)	16745	16798	+ 0.3
1320:1440 (1:1.1)	15331	17610	+ 14.9

Source: Palani and Verma [26]

cium in the soil depresses the uptake of potassium [3]. In strongly acidic soils, below a pH of 4.0 the H^+ or Al^{+++} ions interfere with K uptake and above a pH of 6.0 the excess Ca^{++} inhibits K uptake. Tea planted in soils with too high a pH will not thrive as tea in this situation will be very deficient in K. The overall efficiency of applied N:K_2O fertilisers is high when pH is around 4.8 at which Ca^{++} concentrations seems to be optimum.

With decrease in soil pH, Ca content of mature leaves decreases, while K content of flush and mature leaves increases.[33] At pH levels of 5.0 and above, Ca content in the foliage increases and K content decreases having a depressing effect on yield.[33] At higher pH levels above 5.0, excess quantities of Ca^{++} reduce the uptake of K and induce K deficiency with a consequent reduction in the yield.[63] In Sri Lanka, liming the soils to a pH more than ≥5.0 reduced the yield.[48]

Foliar Application of Potassium (K) to Provide Drought Resistance and Frost Tolerance and Maximize Productivity of Tea During the Dry Period

In south India, drought period ranges between three and five months in different districts during which potassium will not be available from soil to tea bush due to lack of moisture or moisture stress. Hence, foliar application of potassium (K) during the dry period will be helpful to maintain high level of K in flush shoots and foliage and result in reduction of evapo-transpirational (ET) loss, increase in water use efficiency and turgidity of leaf. The mechanism responsible for reducing ET losses could be regulatory influences of potassium on either the osmotic pressure of cell sap or stomatal opening and closing or both the processes together. When exposed to desiccating winds, plants well supplied with potassium are able to close the stomata much more quickly than potassium deficient ones. Potassium plays a significant role in stomatal opening and closing. [9,11] Plants well supplied with K require relatively lower amounts of water in relation to the synthesis of organic material.[4] Potassium is also known to regulate membrane permeability and increases turgidity of leaf. Higher levels of potassium ensure adequate crop uptake of K under conditions of low soil moisture and reduce frost damage. Potassium has been found valuable in reducing frost injury to a certain extent. Thus, potassium improves the water use efficiency and helps in maintaining yield under moisture stress or reduces the extent of crop losses under such conditions.

Foliar application of one per cent muriate of potash (KCl) in mature tea during dry months (January to March) in south India gave significantly higher yield than control.[27] When potassium was mixed with nitrogen and applied as foliar application had been found effective to impart drought tolerance to young and mature tea. The suitable source of nitrogen is urea, which improves the permeability of cuticle and favours the diffusion of foliar applied nutrients. Urea is readily absorbed and metabolized to amino acids and serves as carrier for potassium. The foliar application of one per cent muriate of potash (MOP) combined with urea (one kg each of urea and MOP in 100 liters of water) given from November/December to April at monthly interval in Assam seedling tea during 1990 to 1992 and yields were recorded. During dry months, the yield was increased by 11 per cent while the annual yield was increased six to eight per cent [18] (Table 29).

In another experiment in clone UPASI-3, during 1992-94, the foliar application of one per cent each of urea and MOP were applied at monthly interval during December to March/April had significantly increased shoot water potential, declined the proline content, enhanced the photosynthetic rate and higher carbohydrate reserves in tea roots (Table 30). This perhaps might had resulted in higher crop productivity, 11 per cent during drought period and eight per cent for the whole year (Table 31), which were found significantly higher than control.[19]

A field experiment was carried out in clone UPASI-2 during 1997 to 2002, to explore the possibility of substituting soil and foliar applications of urea and MOP with potassium nitrate (KNO_3). It was found that four to five rounds of 2 per cent KNO_3 foliar application during December and May had given equivalent yield than 0.62 urea + 1.33 per cent KNO_3 and had given five per cent higher yield than each one per cent urea and MOP.[56] The foliar application of KNO_3 had also shown improvement in polyphenols and Chlorophyll content of tea shoots.[56] Potassium nitrate contains 13 per cent N in the form of nitrate and 45 per cent K_2O and found better source for foliar application than urea and MOP.

Potassium sulphate contains 50 per cent K2O and 17.5 per cent sulphur (as S) and better source of potassium than muriate of potash (MOP). Four to six foliar applications of one per cent each of urea and sulphate of potash (SOP) applied as foliar during the dry period

Table 30: Foliar Application of NK on Physiological Parameters (UPASI-3, 1992-95)

Parameters	Control	MOP + Urea 1% each	CD P = 0.05
Photosynthesis (mg $CO_2/dm^2/hr$)	7.7	9.2*	0.91
Shoot water potential (-bars)	12.8	9.9**	0.70
Carbohydrates (%)	10.6	13.4**	1.00
Proline (μmol/g.fw)	1.5	0.9**	0.30

*Significant (5%) **Significant (1%)
Source: Manivel *et al.*[20]

Table 31: Foliar Application of NK on Productivity (UPASI-3, 1992-94)

Treatments	Mean yield Made tea (kg/ha)			
	Drought period	Yield in percent	Whole year	Yield in percent
Control	995	100.0	4412	100.0
MOP + Urea (1% each)	1102*	110.8	4760*	107.9
CD P= 0.05	100	-	298	

*Significant at 5% level
Source: Manivel *et al.*[19]

Table 29: Effect of NK Foliar Application on Seedling (Assam) Tea

Treatments	Yield Made Tea kg/ha					
	Drought Nov.90-Apr.91	Whole year Nov.90-Oct.91	Drought Nov.91-Apr.92	Whole year Nov.91-Oct. 92	Mean	
					Drought	Whole year
Control	1779.75	4441.59	1603.44	4936.31	1691.60	4688.95
Urea + MOP 1% each	1955.89	4683.79	1786.49	5447.49	1871.19	5065.64
% increase over control	9.9	5.5	11.4	10.4	10.6	8.0

Source: Manivel [18]

November/ December to April are likely to be give higher yield because of sulphur content than urea and MOP. The sulphur content of third leaf varies between 0.20 to 0.50 per cent on dry matter basis and helps in nitrogen metabolism and finally yield.

Potassium schoenite ($K_2SO_4MgSO_4.6H_2O$) has been included in The Fertiliser Control Order 1985 (FCO) (as amended up to November 2012), which is a double salt of potassium and magnesium sulphate. It contains 23 per cent K_2O, 10 per cent MgO (Magnesium oxide) and 15 per cent sulphur (S). It supplies three vital elements potassium (K), magnesium (Mg) and sulphur (S) required for tea nutrition. The magnesium content of third leaf varies between 0.20 to 0.50 per cent on dry matter basis. Magnesium (Mg) is the only mineral constituent in the chlorophyll molecule that regulates photosynthesis. The foliar application of potassium schoenite was applied at minimum concentration of one per cent and maximum concentration of two per cent (3 and 6 kg/300 liters of water/ha) and had been found effective in improving bush health, reducing Banji shoot percentage and increasing yield. Potassium schoenite was found the better source of potassium for foliar application than other sources of potassium, applied during the dry period at the interval of three weeks to one month for maximization of productivity in tea plantations of south India.

Disease Resistance due to Balanced Potassium (K) Nutrition and Nitrogen and Potassium Ratios ($N:K_2O$)

Potassium helps in controlling diseases and pests by enabling the plant to develop leaves with strong epidermal walls and thick cuticles, a physical barrier to infection or penetration by sucking insects and preventing the entry of germinating spores from the leaf surface. It reduces moisture on leaf surface, which is necessary for spore germination, by checking transpiration and restricting the presence of soluble nutritional substance such as free amino acids and reducing sugars in the tissues.[51] As a mobile regulator of enzyme activity, K is involved in essentially all cellular functions that influence disease severity. Some plant diseases may be favoured by changes in metabolism associated with low plant K contents. When a plant becomes infected by a fungus, its natural defences are triggered. The infection causes increased production of fungus inhibiting phenolic compounds and flavonoids, both at the site of infection and other parts of the plant. The production and transport of these compounds is controlled in large part by the general nutrition of the plant. However, K is especially critical and shortage of K reduces the amount natural antifungal compound at the site of infection in the plants.

Potassium is a major factor in reducing leaf diseases. With a shortage of K the plant exudates certain higher amount of compounds such as sugars and amino acids that promote the establishment of most fungal and parasitic infections. An accumulation of excess mineral N or sugar is often an indication that the plant is not efficiently converting the N to proteins or the sugars to energy. Potassium plays a critical role in these processes. Nitrogen balanced with potassium is significant to provide resistance to fungal and bacterial diseases. Many disease infections occur through open wounds and rapid healing of wounds tends to reduce infections. Higher potassium fertilization helps in rapid healing of wounds and the accumulation of compounds toxic to the fungus around the wounds.

Deficiency of K is one of the factors that weakens the plant, thus predisposing it to the attack by red rust caused by the Alga *Cephaleuros parasiticus karst.*[53,49] It is a serious disease, particularly in young tea, causing branch dieback and hindering frame formation. The Alga infects stem, leaf and fruit coat (pericarp) of tea. It was found that in the plot which was not fertilized with K for ten years, infection was as high as 65 per cent and where K was applied regularly at the rate of 45 kg K_2O per ha per year, the infection was as low as 1.3 per cent.[54] The omission or inadequate application of K is one of the reasons for the unhealthiness of bush frames.

Pests Resistance due to Balanced Potassium (K) Nutrition and Nitrogen and Potassium Ratios ($N:K_2O$)

Feeding intensity and reproduction by sucking insects tend to be higher on plants with higher amino acid content. This condition is typical of plants with a K deficiency, or a relative excess of N compared to these nutrients. While the direct damage from these insects is important, they may also be vectors for viruses. Adequately K nutrition can reduce the severity of nematode infection. Application of K markedly reduces damage from root knot nematodes.

Effect of $N:K_2O$ Ratio on Shot-Hole Borer Infestation and Productivity of Made tea in Rejuvenated Tea

Generally, the shot hole borer (*Xyleborus fornicatus Eichhoff*) attack in young tea stems causes branch breakage at the point of internal girdling, resulting in crop decline to the extent of loss of bearing branches, whereas in old tea stems, the attack causes *chlorosis*, defoliation and finally dieback of branches partly arising from numerous discontinuity points in the nutrient transport vessels. An experiment was conducted in Assam jat in Central Travancore in rejuvenated late thirties planted tea and shot hole borer (SHB) infested tea during 1978 till 1982. The initial shot hole borer infestation was 12.5 per cent and average gallery count was 1.89 per cent. The main treatments were T_1 control (no spraying for SHB), T_2-spraying the pruning with heptachlor and T_3- T_2 + mid-cycle spraying with Endosulphon + Nuvan and all above three treatments each at two levels of K_2O (150 and 300 kg/ha) (N:K_2O::1:1.25 and 1:2.5) while, 120 kg N/ha was common to all the treatments in the pruned year. From the second year onwards the sub-treatments were three levels of N (N_1= 200, N_2= 250 and N_3= 300 kg N/ha) each at two N:K_2O ratios (2:1 and 1:1) were imposed.

The data of total cycle yield (1978-82) are given in Table 32. The highest yields were obtained at higher rate of K_2O applications (300 Kg/ha) i.e. N:K_2O::1:2.5 over 150 kg/ha i.e. N:K_2O::1:1.25 in the pruned year at all three levels of nitrogen. The maximum infestation at the end of the cycle in treatment plots was 4.1 per cent with mean gallery count 0.5 per cent in new wood, while in control plots it was 11.1 with a gallery count 1.5 per cent in new wood.[44] The results showed the usefulness of higher rate of K_2O application, 300 kg/ha (N:K_2O::1:2.5) in the pruned year and spraying the pruning with Heptachlor in increasing the responses to fertiliser by 5.6 and 6.2 per cent, respectively in shot hole borer infested fields. The higher N: K_2O::1:2.5 application in the pruned year increases the mechanical strength of tissues and protects it from new attack at early stage and thus substantially controls the shot hole borer pest and increases the yield.[44]

Thus based on the results of above experiments, it is recommended to apply in shot hole borer infested fields N:K_2O::1:2 in the pruned year and N:K_2O::1:1 in other years of pruning to minimize the infestation of shot hole borer as well as increase the productivity of tea.

Method of K Application

The broadcasting method of K application was compared with placement method in cultivar, C-194 (January to December, 1972). It was found that the broadcast method had given 2.6 per cent higher yield than placement method.[24] In tea soils of south India which are predominantly Kaolinite and lack in fixation, the potassium fertilisers move down freely to the root zone with the percolating rain water. Therefore, it is adequate to broadcast potassium (K) fertilisers and that is the reason, it was found marginally superior to placement method. In placement method, a major portion of the potassium fertilisers moves down to a zone, where the active feeder roots are sparsely seen.[38] The sub-soil placed potassium fertilisers moves down below the root zone, there by, not being readily available during the rush months. Hence, it is recommended to apply potassium fertilisers by broadcast method in tea soils of south India.

Frequency of K applications

The trials were conducted during 1974 -1977 in clone C-194. Ten per cent more Made tea yield was obtained with four splits applications compared to single application in second year as well as with six applications compared to two splits in fourth year, while six per cent

Table 32: Effect of Shot-Hole Borer (SHB) Control Measures and Pruned Year K Levels on the Yield of Tea over the Cycle

Cycle yield(1978-82) Made tea t/ha					
Sub-treatment (from second year onwards)		**SHB control pruned year spraying**		**No spraying for SHB control (control treatment)**	
N:K_2O ratio	N levels	Pruned year K_2O (kg/ha)		Pruned year K_2O (kg/ha)	
		150 (N:K_2O::1:1.25)	300 (N:K_2O::1:2.5)	150 (N:K_2O::1:1.25)	300 (N:K_2O::1:2.5)
2:1	N_1	14.8	13.7	12.8	14.0
	N_2	14.7	16.7	14.1	15.0
	N_3	15.2	16.2	14.7	15.7
1:1	N_1	15.1	16.1	14.9	15.2
	N_2	15.5	16.1	15.2	15.1
	N_3	15.6	17.2	13.8	15.6

Source: Ranganathan *et al.* [44]

more Made tea yield was obtained with four splits applications compared to two splits in third year (Table 33). The response of K was further increased with the number of splits applications in young tea at Mount Stuart estate (1976-77). On an average 12.4 and 18.5 per cent more crop obtained with six and eight applications respectively than that with four split applications during Sept. 1976 to May 1977 and 6.4 and 10.9 per cent during June to December 1977 [24]. Trials conducted in south India showed that there was an increase of 13 per cent higher yield in clone B/6/62 by application of K along with N in four splits compared to one application.[37] The beneficial effect of split application of K may be due to the better utilisation of applied K, due to reduction of leaching losses and maintenance of higher K concentration in the soil solution during rush cropping seasons. Due to split application, the optimum N:K_2O ratio will be maintained thought out the year for efficient utilisation of nitrogen. Thus, there is a need for application of potassium along with nitrogen in four to six splits depending on N:K_2O levels during two high cropping seasons to get the most economic return in south Indian condition.

Future Strategies:

More research is needed to rationalize magnesium levels of soil and foliar applications with respect to N:K_2O levels and also to examine the efficacy of different magnesium sources for identifying the most suitable source for nutrition of magnesium in tea. There is a need to rationalize sulphur levels of soil and foliar application with respect to N:K_2O levels as well as to examine the efficacy of different sulphur sources, for identifying the most suitable source for nutrition of sulphur in tea. Research is needed to evaluate the efficacy of combined foliar application of potassium and boron by different sources at different concentration to determine the suitable source and optimum concentration, to minimize the adverse impact of continuous shearing on bush health for enhancing productivity of tea.

Acknowledgements

We are indeed grateful to Prof. V. Ranganathan for sending his valuable publications on our request promptly and allowing us to use his data on various aspects for the article. We are also thankful to Mr. N. Palani for sending relevant important UPASI publications on short notice. We extend our sincere thanks to Dr. S. Venkatesan for readily allowing us to use the data of his Ph.D thesis for the article. We express special gratitude to Dr. S. S. Ranade for providing the kind support and assistance.

References

1. Barua DN. 1989. *Science and Practice in Tea Culture.* Tea Research Association, Calcutta. 509p.
2. Barua DN. 2008a. Tea soils. In *Science and Practice in Tea Culture.* Tea Research Association, Calcutta, 5: 139-179.
3. Barua DN. 2008b. Mineral Nutrition and Water Management. In *Science and Practice in Tea Culture.* Tea Research Association, Calcutta, 13: 489-542.
4. Blanchet R, Studer R & Chaumont C. 1962. Some aspects of interactions in the water supply of plants. *Ann. Agron.*13, 93-110.
5. De Jong P. 1950. Defoliation, a disorder of tea in southern India, *Planters' Chronicle*, 45(6).

Table 33: Effect of Split Application of K on Tea Yield (Clone: C-194, 1974-77)

Second Year Field (April to March)		Third Year Field (April to March)		Fourth Year Field (April to March)	
Split No.	Made tea kg/ha	Split No.	Made Tea kg/ha	Split No.	Made Tea kg/ha
1	3664 (100)	2	2831 (100)	2	3609 (100)
4	4034 (110)	4	3009 (106)	6	3975 (110)
CD at P = 0.05	225 (6)	CD at P = 0.05	85 (3)	CD at P = 0.05	85 (2)

N: P2O5: K_2O kg/ha applied are 220:45:120, 240:45:130 and 320:50:160 in second, third and fourth year respectively.
Figures in parentheses denotes percentage
Source: Natesan *et al.*[24]

6. Devchaudhary MN & Goswami MR. 1983. A rapid method for determination of total polyphenolic matter in tea (*Camellia sinensis* (L) O.Kuntze). *Two and A Bud.*30: 59-61.

7. Dey SK. 1971. Potash as a limiting factor. *Two and A Bud.*18: 34-47.

8. Elzam OE & Hodges TK. 1967. Calcium inhibition of potassium absorption in corn roots. *Plants Physiol.*42: 1483-1488.

9. Fischer RA & Hsiao TC. 1968. Stomatal opening in isolated epidermal strips of *Vicia faba* 11, Response to KCl concentration and the role of potassium absorption. *Plant Physiol.* 43: 1953-1958.

10. Hudson JB, Durairaj J & Muraleedharan, N. 2002. Organic matter soil classification. *Guidelines on Tea culture in South India*: 96p.

11. Humble GD & Hsiao TC .1969. Light dependent influx and efflux of guard cell potassium during stomatal opening and closing. *Plant Physiol.* Suppl. 44, Nr.97, P.21.

12. Idem. 1954. Some aspects of tea manuring. *UPASI Sci. Dept.(Tea Sect.)Bull.No.*12: 4-9.

13. Jayaraman V. 1954. Some aspects of tea manuring, *UPASI Tea Sci. Dep. Bull*, 12: 4-10.

14. Jayaraman V. 1959. Report of the soil chemist. *Annual Report. UPASI Tea Sci. Dep.* 1958/1959: 9-12

15. Jayaram V & De Jong P. 1955. Some aspects of nutrition of tea in southern India. *Trop. Agric. (Trin.)* 32: 58-65.

16. Krishnapillai S. 1991. Response to magnesium fertilisers in young and mature tea. *Better Crops International* 7(2): 12-13.

17. Lauchli A & Pfluger. R. 1978. Potassium transport through plant cell membranes and metabolic role potassium in plants. In Potassium research-review and trends. *Proc. Congr. Int . Potash Inst.*11: 111-163.

18. Manivel L. 1993. NK foliar spray to induce Drought tolerance in Mature Tea, In *Handbook of Tea Culture*, 24: 1-2.

19. Manivel L. Marimuthu S. Venkatesulu V & Rajkumar R. 1994.Effect of potassium nutrition and growth regulators on photosynthesis and assimilate translocation in tea *Proc. International Seminar on "Integrated Crop Management in Tea: Towards higher tea productivity"*, Tea Research Institute SriLanka and International Potash Institute, Switzerland. Pp. 217-223.

20. Manivel L, Rajkumar R, Marimuthu S & Venkatesulu V. 1995. Foliar application of potassium for increasing drought tolerance in tea. *J. Potassium Res.* 11(1): 81-87.

21. Mengel K. 1978. Consideration of factors which affect the potassium requirements of various crops. In *Potassium Research Review and Trends. Proc. Congr. Int. Potash Inst.* 11: 225-237.

22. Mengel K & Kirkby EA. 1978. Potassium In *Principles of Plant Nutrition*, Ed. International Potash Institute, Berne, Switzerland. 10: 367-390.

23. Natesan S & Ranganthan V. 1990. Content of various elements in different parts of the Tea plant and in Infusions of Black tea from southern India. *J. Sci. Food Agric.* 51: 125-139.

24. Natesan B, Bhat S & Ranganathan V. 1982. Agronomic and cultural factors interacting with potassium manuring in tea, *proceedings of PLACROSYM V*: 358-374.

25. Natesan S, Ranganathan V, Nemeth K & Krishnan V. 1985. EUF analysis of tea soils of southern India and tea productivity. *Plant and Soil.* 83: 191-198.

26. Palani N & Verma DP. 1993. Magnesium fertilisers for sustainable tea productivity in south India , *Journal of Plantation Crops* 21 (supplement): 81-85.

27. Raman K. 1964. Manuring of tea – Principles and Practice, *Bull. United Plant. Assoc. South India* Tea Sci. Dep. 23: 2-20.

28. Ranganathan V. 1970. Potassium, a master nutrient for tea. UPASI Tea Sci. Dep. Bull. 28: 13-19.

29. Ranganathan V. 1971. Phosphorus nutrition in tea. *UPASI Tea Sci. Dep. Bull.*29: 31-34.

30. Ranganathan V. 1974. Effect of cessation of manuring and of reduction in the rate of fertiliser application on tea yields in south India. *Planters' Chronicle.* 69(13): 259-261.

31. Ranganathan V. 1975. Report of the Chemistry Div. *Annual Report UPASI Tea Sci. Dep.* 31-62.

32. Ranganathan V. 1976. Retention losses and utilization efficiencies of major nutrients in tea culture under south Indian conditions. *Planters' Chronicle.* 71: 13-14.

33. Ranganathan V. 1978. Certain aspects of calcium nutrition in tea culture, *Proc. of the 1st Ann. Symp. on plantation crops, March 20-23(1978) held at Kottayam*: 121-131.

34. Ranganathan V. 1981.Recent Advances in Agronomic Practices –Technology for increasing efficiency of fertilizer use. *UPASI Tea Sci. Dep.Bull.* 37: 92-103.

35. Ranganathan V. 1982. Potassium in tea culture in south India – a review. *Indian Potash Journal* Vol. VII(3): 2-9.

36. Ranganathan V. 1986. Potassium in tea- a Review, *Planters' Chronicle* 81(6): 219-223.

37. Ranganathan V & Ganesan. 1975. Frequency of potassium application. *UPASI Tea Sci. Dep. Bull.* 32: 72-76.

38. Ranganathan V & Ganesan M. 1976. New Recommendations in manuring of tea . *UPASI Tea Sci. Dep. Bull.* 33: 140-152.

39. Ranganathan V & Narayanan B. 1974. Potassium behavior in tea soils and its practical utility. *Bull. Upasi Tea Sci.* Dept. 31: 43-71.

40. Ranganathan V & Natesan S. 1985a. Levels and ratios of N and K for young tea. *Planters' Chronicle April/ May*: 153-155.

41. Ranganathan V & Natesan S. 1985b. Potassium Nutrition of Tea In: Potassium in Agriculture, ASA-CSSA-SSSA, 677 South Segoe Road Madison, WI,53711, USA 42: 981-1022.

42. Ranganathan V, Ganesan M & Natesan S, 1980. Organic matter flux in south Indian tea soils: a Need for conservation. *Planters' Chronicle*, 75 (7&8): 309-312.

43. Ranganathan V, Natesan S & Subrahmanya Bhat S. 1982. P and K interaction in tea, a pointer to balanced nutrition for high yields. *Indian Potash Journal.* Vol. VII (3): 10-16.

44. Ranganathan V, Natesan S & Govindarajulu V.1985. Response to fertilisers in relation to control measures to contain shot hole borer infestation in tea. *Planters' Chronicle November*: 387-389.

45. Ranganathan V, Natesan S & Palani N. 1988. Response of tea to potassium application in the pruned year and effect of manuring on yield trend. *Planters' Chronicle*, 83(11): 373-378.

46. Ruan J, Wu X, Ye Y & Hardter R. 1998. Effect of potassium, magnesium and Sulphur applied in different forms of fertilisers on free amino acid content in leaves of tea.(*Camellia sinensis* L.). *J. of Sci. Food Agric.* 76: 389-396.

47. Ruan J, Wu X, & Hardter R. 1999. Effect of potassium and magnesium nutrition on the quality components of different types of tea. *J. of Sci. Food Agric.* 79: 47-52.

48. Sadanam S, Sivasubramanian S & Rajasingham CC. 1980. Response of seedling tea to forms and levels of nitrogenous fertilisers, levels of potassium and liming in the up country tea growing districts of SriLanka. *Tea Quart.* 49: 20-29.

49. Satyanarayana G & Barua CS. 1978. Red rust of tea. *Two and A Bud* 25: 11-14.

50. Sanyal SK. 2002. Soil colloids in Fundamentals of soil science, Indian Society of soil Science, Division of Soil Science and Agricultural Chemistry, Indian Agricultural Research Institute, New Delhi 110012, 14: 229-259.

51. Sekhon GS & Ghosh AB. 1982. Potassium. Review of soil research in India, Part-I. *Proceedings of 12 th International Congress of Soil Science*. New Delhi, 6-8 February: 331-341.

52. Subba Rao A & Brar MS. 2002. Potassium, In *Fundamentals of Soil Science,* Indian Society of Soil Science, Division of Soil Science and Agril. chem. IARI New Delhi-110012, 21: 369-380.

53. Venkataramani KS . 1953a. some aspects on the work of botanical section of the tea experimental station. *Bull. United plant. Assoc. South India Tea Sci.. Dep.* 11: 4-11.

54. Venkataramani KS . 1953b. Report of the Botanist. In: *Annual Report of UPASI* scientific department Tea Section, Coonoor, TamilNadu:27-32.

55. Venkatesan, S. 2001. "Influence of N:K_2O Ratio on quality", in Rationalisation of Nitrogen and potassium in tea in relation to Soil Test Crop Response Study, PhD Thesis , Bharathiar University, India: 8-72.

56. Venkatesan S. 2006. Notes and amendments to the recommendations on manuring of tea in south India. *Planters' Chronicle*, 102 (4 & 5): 4-16.

57. Venkatesan Selvaraj, Murugesan Subramanian, Ganapathy Muthukumar NK & Verma Dinesh P. 2004. Long term impact of nitrogen and potassium fertilisers on yield , soil nutrients and biochemical parameters of tea. *J. Sci. Food Agric* 84: 1939-1944.

58. Verma DP. 1994. Managing Red and Lateritic Soils for Sustainable Agriculture. *Planters' Chronicle*, 89(1): 25-27.

59. Verma D & Palani N. 1997a. Manuring of Tea in South India (Revised Recommendations) *Hand book of tea culture*. UPASI Tea Research Institute, Valparai 11: 22.

60. Verma DP & Palani, N. 1997b. Nitrogen in Mature tea, in manuring of tea in south India (Revised Recommendations), *A Hand Book of Tea culture* , UPASI Tea Research Institute, 11: 8 -12.

61. Verma DP & Sharma V S .1994. in south India ...... Nutrient Management Research on Tea, *Indian Horticulture*, 39 (3): 24-30.

62. Wilson KC.1975a. Studies on the mineral nutrition of tea (iv) potassium. *Plant and Soil.* 43. 279-293.

63. Wilson KC. 1975b. Studies on the mineral nutrition of tea, (v) Calcium. *Plant and Soil*, 43(2): 295-307.