USE OF POTASSIUM IN KERALA AGRICULTURE

Proceedings

Workshop on Use of Potassium in Kerala Agriculture held on December 16, 2000 at College of Agriculture, Vellayani, Thiruvananthapuram, Kerala

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PREFACE

There is no doubt that the success of India's economy is bound to grow in a sustainable fashion when its agricultural economy is both effective and efficient. Considering that the majority of people are rural inhabitants and that their livelihood is rooted in agriculture, this is the place that we need to first concentrate our efforts. The unfortunate view of too many leaders and decision makers is that farmers inherently understand the needs of crop production and hence, official support is often and inadequate or misdirected. Having the cooperation of industry and the university, as well as involvement of government workers and top farmers is the right way to redress this problem. In note with great pleasure that the committee and those invited are stake holders in agriculture and leaders who will help shape the future of Kerala's agriculture.

The role of nutrients in high yield agriculture is a phenomenon being rediscovered around the world. India and the State of Kerala are part of the global community and must be an integral part of resolving the food security issues the world faces. Understanding the role of potassium as a part of *adequate and balanced fertilization* is fundamental to the world's impending food crisis. That is why I am so pleased to see this initiative, and to be a part of it.

I wish you every success in this and all your keen endeavours to help farmers, as well as those who serve them, understand the science and the meaning of *Potassium Use in Kerala's Agriculture.*

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FOREWORD

Potassium, one of the major elements plays a cardinal role for productivity of crops. It also plays an important role in imparting hardiness and resistance to biotic and abiotic stresses. In a state like Kerala, where plantation crops and spices are important, the role of potassium becomes very relevant. Nut fall in coconut and arecanut are major biotic disorders caused mainly due to deficiency of potassium. Roles of potassium in spices like black pepper, cardamom, ginger, turmeric and tree spices have been adequately studied. The importance is beyond doubt. Being an element wholly imported, cost has become a factor in its full and optimum use. The Potash & Phosphate Institute of Canada found it appropriate to organize a workshop on "Use of Potassium in Kerala Agriculture" during December 2000 at the prestigious College of Agriculture, Vellayani, Thiruvananthapuram. The workshop was well attended and deliberations were very meaningful, useful and timely. Though a little late, the proceedings are now ready for release. There are nine major papers dealing with various facets of productivity in plantation crops like rubber, tea, coffee, coconut and cashew, spices and tuber crops. The workshop has also made valuable recommendations. I have extreme pleasure to foreword the publication to the scientists and farmers of Kerala.

K.V. Peter

Acknowledgements

Kerala is one of the agriculturally important states of India. Many high value crops are grown in the region where production and quality should go hand in hand. Potassium is a key nutrient in Kerala agriculture as it plays crucial and direct role in productivity, quality and protection against environmental stresses. Realizing the importance of potassium use in the intensive, multiple cropping systems the workshop 'Use of Potassium in Kerala Agriculture' was organized on December 16, 2000 by Kerala Agricultural University and Potash & Phosphate Institute of Canada – India Programme at College of Agriculture, Vellayani, Thiruvananthapuram. The purpose of this programme is to provide an ideal platform for scientists, extension specialists, agronomists, horticulturists, progressive farmers and policy makers to exchange views and discuss various issues related to potassium use in an effective manner. This publication is a compilation of valuable information contributed by specialists in those respective areas.

We are indeed grateful to Dr. K. V. Peter, currently the Vice-Chancellor, Kerala Agricultural University, Vellanikkara for full support and inaugurating the workshop. Our special thanks are to Dr. R. Vikaraman Nair, currently the in-charge, Director of Research, KAU for his active support and cooperation for successful completion of the programme. We are also thankful to Dr. Mark Stauffer, President and Dr. Sam Portch, Vice-President, PPIC for their valuable guidance and kind presence. We gratefully appreciate every help received from Dr. A. I. Jose, Director of Extension, Dr. P. A. Wahid, Dean, Dr. V. K. Venugopal, Professor and Head, Department of Soil Science, Dr. B. K. Jayachandran, Dr. M. Meerabai, Dr. S. Lakshmi, Dr. K. Prathapan and Dr. Janardhanan Pillai from the Department of Agronomy and Sudharmai Devi, Dr. Prabhakumari and Dr. Manorama Thampatti from Department of Soil Science, College of Agriculture, Vellayani.

This publication includes all the papers presented at the workshop. We profusely thank all the authors for their valuable contribution and sincere efforts in preparing and presenting the papers. We thank all the delegates from Agricultural University, Department of Agriculture, Department of Horticulture, ICAR institutes, Fertilizer Industry and progressive farmers for their active participation and valuable contributions.

It is our belief that this document would be useful to every one who is dreaming for future sustainable and profitable agriculture in Kerala.

T. Nagendra Rao
K. N. Tiwari

CONTENTS

Potassium: The Building Block for Higher Yields in India

Sam Portch

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Abstract

Potassium (K) is vital for healthy growth of plants and animals including humans. Potassium is needed in vary large quantities for both. Yet, India's application of K is very low, resulting in low yields and low quality crop production. This implies that India will have a difficult time in building a sound foundation for agricultural development. China, a country like India without a major local source of K, but with a greater agricultural population and less arable land; has recognized the importance of high levels of balanced fertilizer use, especially K, for its development. China is importing about four times K than India. China is providing a better diet for its citizens, both in quantity and quality.

This paper discusses some of the possible reasons why India finds itself in this situation. The paper clearly states the unmistakable importance indicating that there is no other way than to markedly increase the use of K in crop production. Healthy high yielding and high quality crops means healthy animals and profitable farms. These are building blocks for lasting agricultural development.

In general, nitrogen (N), phosphorus (P) and potassium (K) are considered the three major plant nutrients. Some insist sulphur (S) should be considered as a fourth major plant nutrient, because it is needed by plants in amounts about equal to P.

It has been about a century and a half since K was found to be beneficial to plant growth. It has been equally long since Justus von Liebig stated his now famous *Law of the Minimum*. Yet, today we see countries who have not learned these simple lessons. India is one such country. The history of India's fertilizer consumption is a testimony to this statement (**Table 1**).

Table 1. Fertilizer consumption in India 1965-1997 in million tonnes (M.t.)

Year	N (M.t.)	P_2O_5 (M.t.)	K_2O (M.t.)	Ratio N : P_2O_5 : K_2O
1965	0.575	0.133	0.077	1 : 0.23 : 0.13
1975	2.149	0.467	0.278	1 : 0.22 : 0.13
1985	5.661	2.005	0.808	1 : 0.35 : 0.14
1990	7.997	3.221	1.328	1 : 0.40 : 0.16
1992	8.427	2.844	0.884	1 : 0.31 : 0.12
1994	9.507	2.932	1.125	1 : 0.31 : 0.12
1996	10.302	2.977	1.030	1 : 0.28 : 0.10
1998	11.353	4.112	1.332	1 : 0.36 : 0.12
2000	10.920	4.215	1.568	1 : 0.39 : 0.14

Source: Potash and Phosphate Institute of Canada, India Program.

Whereas the N : P_2O_5 : K_2O ratio should be close to 1:0.5:0.25, the best ratio achieved (1990) was 1:0.4:0.16 showing complete neglect in use of K, but a better understanding of the need for P.

Here is a good place to interject the fact that in all of the discussions about K herein, it has to be clearly understood than while K is an important building block for higher yields in India, it is not the only one. Understanding the *Law of the Minimum* tells us that. All essential plant nutrients are of equal importance if they are equally deficient. Extending Liebig's law further to encompass all the factor involved in producing a yield (crop, climate, soil and management) one complicates the picture, but also clearly recognizes that no one plant nutrient - in this case K - is the only thing that will affect crop yield.

Conversely, when the quantity of K taken up by a plant to produce a reasonably high yield **(Table 2)** is studied, K must be considered one of the most important high yield building blocks..

Table 2. Plant nutrient uptake to produce the indicated yields (t/ha) of selected crops.

	Yield	**N**	**P_2O_5**	**K_2O**	**MgO**	**S**
Crop	**t/ha**	**kg/ha**				
Rice (paddy)	6	100	50	160	20	10
Wheat	6	170	75	175	30	30
Soybean	3	220	40	170	40	20
Corn	6	120	50	120	40	25
Cotton (lint)	1	120	45	90	40	20
Sugar cane	100	130	90	340	80	60
Rapeseed	3	165	70	220	30	65

Source: Potash and Phosphate Institute of Canada

In many cases crops need for K are greater than that for N. But, in India from data **(Table 1)** it is noted that at its maximum only 16% as much K was used as N. Obviously, some K comes from soil reserves whereas very little N comes from this source. Still, K in reserves in soils is being depleted when this type of management is used. K in the soil is somewhat like K in a mine. If we keep taking it out until the mine is empty, then we will have to close the mine. But, with soil, we are lucky because fertilizers can replace that which has been mined out by growing plants.

Present situation

Scientists know the many important functions K plays in plant growth and human nutrition.

- Potassium is vital for photosynthesis, the process by which most animals obtain their food. Without K, photosynthesis is impaired and lowers the plant's ability to accumulate carbohydrates.

- Potassium is essential for protein synthesis
- Potassium is needed for breakdown of plant carbohydrates to provide energy for plant growth
- Potassium controls ionic balance in plants
- Potassium has an important role in the translocation of heavy metals such as iron in plants
- Potassium is important in fruit formation.
- Potassium helps plants overcome stresses of diseases, drought and cold weather
- Potassium is involved in more than 60 plant enzyme systems that regulate plant growth and,
- Balanced use of potassium increases N and P use efficiency thereby, improving the environment.

Potassium is also known as the counter stress and quality plant nutrient. Low available potassium levels for plant growth fosters disease because plants low in K have thin cell walls which breakdown readily and have an accumulation of unused nitrates, phosphates and sugars.

Everyone is familiar with crop lodging when "too much" nitrogen is applied to grain crops. Often, the problem is not too much N, but rather too little K. This has been clearly demonstrated in several locations in India.

Potassium is known as the quality plant nutrient because it makes plant products look better on the market shelf whether it is grain, fruit or vegetables and gives these products a longer shelf life which means more profit for those that market them. Besides, many blind and analytical tests have shown that fruits and vegetables supplied with adequate K, are better tasting, and more nutritious for the consumer.

All of the above statements refer to functions related to plants. Potassium is of equal importance to humans.

It is physiologically important in many functions of the human body including the cardiovascular, respiratory, digestive, endocrine, renal and neurological systems.

One scientist recommended the daily human consumption of K be 50-140 meq K/day while another scientist suggested up to 2000 mg/day/person over 18 years old.

The average adult's total K weight is about 140g. These are very large amounts.

Ranges of K concentration of some common beverages in mg/kg are milk 1440-1780, fruit juices 1060-2270, beer 320-440 and white wine 660-920. Mean values for tea and coffee are 170 and 880 mg/kg. But, the main sources of K for humans (about 87%) are solid foods. Some foods with high K content are banana, citrus, potato, apple, beans, tomatoes, *etc.*

As stated earlier, scientists know all these facts and their importance to present and future daily life. Yet, in much of the developing world, like India, K is supplied to plants in very inadequate amounts. And, one might conclude, these same plants are providing less than optimal amounts of K to animals, including humans.

The question now arises as to what measures can be taken to change this negative situation with respect to K. We must for India's development. Use of more K will benefit today's farmers, their communities, the environment as well as future generations. In other words, having high yield sustainable agriculture.

Reasons

There is no real evidence or statistical data to base the reasons why this imbalance - that leaves K out of the fertilizer system - occurs in India. There are many possibilities on which to speculate. A few commonly heard reasons are given below:

1. Farmers can see the effects of N in the field, but not K, therefore, they tend to use N before either P or K. This is probably true, but some very spectacular differences in yield and crop quality can be seen when K is added to a K deficient soil that received only N and P applications. Possibly extension efforts need to be better focused and be more extensive.

2. Farmers cannot afford K fertilizers. There are two things wrong with this statement. One is that if there is an economic response to K, farmers cannot afford <u>not</u> to use K since without it, they are losing efficiency and profit from the N and P they apply. Thus, governments or companies must provide the needed credit for K to be used when needed.

   Secondly, farmers often waste large quantities of natural sources of K such as manure, straw and other organic sources rather than collecting them for field application. While organic sources cannot usually supply enough K for a good crop yield, a little is better than none.

3. Potassium fertilizer is too expensive. From studies of the range of world market prices for N, P and K fertilizers averaged over the past 10 years, it is obvious this statement is incorrect since K is the cheapest of the 3 major nutrients and will most likely remain so because of good supplies in world markets.

4. Farmers are not educated in the real functions and needs of K. This relates to point 1 above and reflects in part, on the scientific community as poor communicators. If scientists were, or wanted to be as good at communicating to the general public as companies trying to sell products, then they would use the mass media TV, radio and newspapers. Or, they could use a different strategy and involve the fertilizer industry in this aspect by giving them technical support for promotional programs that would teach farmers about balanced fertilizer use. This is done extensively in China and other countries.

5. Scientists just prepare elaborately scientific reports that only other scientists understand. This is often true, but is writing scientific reports in a more popular, understandable manner a requirement for job advancement for a scientist? In most cases it is not, so the job seldom gets done. Scientists job evaluations are most likely based on the number of scientific papers produced, not popular articles.

6. The government extension service is either slow or too involved in government paperwork to get out to the field to communicate information to farmers. Exceptions to this statement have been seen – China is a good example where extension personnel are found in the field – but the Indian situation is not well enough understood. But, this point certainly needs to be considered.

7. Policy makers and government administrators do not know the importance of K to the well being of the country's soil and citizens; thus, they do not form the correct policies and do not fund K research or demonstration/extension activities enough. This is most likely correct, but whose fault is it that these non-scientists do not know the present and future importance of K as a building block for a healthy soil and people? Is it the scientists who need to communicate their results in a clearer manner not only to farmers, but also to policy makers? This point needs further thought and discussion as well as ideas on how this can be done.

8. There is not enough potassium supply in the country, or distributed to where it is needed most. This is correct. But does this problem not relate directly to point 7 above?

Surely there are many more reasons that can be heard. This paper does not intend to be comprehensive in this area, rather it intended to stimulate thought and discussion on what can be done to improve the utilization of K in India to help farmers and their communities grow in wealth and health.

Conclusions

Increased use of K, along with adequate amounts of other needed plant nutrients, is extremely important for India. K alone cannot do the task, but soils deficient in K produce low quality, low yielding crops. These soils also lose profits for farmers and the nation as well. K deficient soils can also contribute to environmental problems.

If we continue to harvest crops directly or through animals without replacing plant nutrients being removed, we are heading for eventual disaster.

Potassium is a fundamental building block for plant and animal nutrition. A nation cannot be strong that lacks K, or any other essential plant nutrient, in any large quantity. Indian must realize this quickly in order to feed its rapidly growing population.

We must use mass media of all kinds to get our message across to policy makers, farmers and the general public. We should encourage the fertilizer industry to help us with this task. After all, the most direct benefit will go to them.

Good plant nutrition provides good human nutrition that is essential for India's development. Unhealthy people are not productive for their families or the nation. A nation cannot be strong when its soils are deficient in plant nutrients. The challenge lies before us to make farmers, extensionists, other scientists and policy makers aware of the urgent K needs of India.

This task will only be complete when we hear Indian policy makers paraphrasing what the late USA President (1933-1945) Franklin Roosevelt said "The history of every nation is eventually written in the way in which it cares for its soil".

The task will be finished when the common man as well as farmers of this great agricultural state understand the importance of K to them and their children's well being. The challenge lays with the scientific community, to communicate this to farmers, extension personnel, policy makers and others and the community must reward the scientists accordingly. All possible means of communication including, radio, television, movie houses, newspaper, roving vans, meetings, courses and personal communications must be used to achieve this end.

No one would live in a house build with a weak foundation of soft bricks. No nation wants to have development pass them by because their agricultural and human resource base has a faulty foundation, especially when it is one as simple to improve as increasing K use, as in India's case.

Potassium Status of Kerala Soils - Build Up or Depletion?

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Extended Summary

Early works on potassium nutrition in the state relate to the period of 1950-1960 and studies during this period indicated that 88% of the wetland and 93% of the dryland of the state are low in available potassium (< 115 kg/ha). Later studies confirmed the early findings that Kerala soils are highly depleted of potassium due to the characteristic clay mineralogy, climatic and topographic factors, soil acidity and low organic matter content.

On comparing the potassium status of the major rice soils of Kerala *viz.*, kole, kari, kayal, karappadam and low level laterite, it was seen that relatively higher amount of K was present in the coarser fractions of laterite and karappadam soils. However, the content of K in the coarser fraction of the soil cannot supplement the crop requirements since this K forms a part of the primary minerals of these soils. Kari, kayal and kole soils retained relatively higher content of K in the finer fractions probably due to the contribution of high level of exchangeable K in these soils. The latter soils are characterized by the deposition of alluvial materials rich in exchangeable cations. Many studies indicated that potash reserves could not be built up in soils with kaolinitic minerals, as these minerals are characterized by low cation retention and lack of site for interlayer binding of K. Obviously, these soils are highly responsive to potassium applications. However, in certain studies it has been reported that heavy application of K can gradually build up the K reserve of the soil and can thus reduce the necessity of K fertilization in succeeding years.

One of the techniques for improving the efficacy of applied potassium in soil is liming. Liming of acid soils improves the potassium fixation and thus prevents the loss of potassium by leaching. In the lateritic soils of Kerala, there is severe depletion of K, due to the relatively high content of sequioxides, low clay activity, undulating topography, soil acidity and continuous cropping. Recent studies conducted at the College of Horticulture, Vellanikkara, Trichur indicated that significant yield increase in paddy is possible by K application at higher rates (120 kg/ha). Frequent light application of K, incorporation of crop residues and organic manures, balanced application of fertilizers and liming are suggested for the maintenance of K status of these soils.

The studies so far conducted are indicative of the fact that due to the inherent mineralogy, climatic factors, topography and relatively high K requirement of the crops grown in the state, Kerala soils are, in general, deficient in potassium. Positive response to application of potassium is therefore anticipated in contrast to the K response of the soils dominant in high activity clays. At the present level of optimum K application, a build up of K in Kerala soils cannot be expected. At the same time, results reveal that in general, the soils of the state are still deficient in potassium.

Potassium Requirement and Response to K Application in Cereal Crops

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Abstract

Potassium is a major plant nutrient and is required by plants in amounts equal to or greater than nitrogen. Cereal crops generally absorb potassium faster than other nutrients but the actual rates of K uptake vary considerably depending upon soil, crops and environmental factors. The uptake studies show that i) potash responses are generally higher in rice than in wheat ii) responses are generally higher in rabi rice than in kharif rice but this pattern does not hold good in each and every geographic region iii) potash responses are higher with the high yielding varieties as compared to traditional or local varieties iv) crop responses to potassium are generally higher in soil testing low to medium in available K than in high-K soils, both low and medium K areas need potash application for high yields. Yield response to potassium may appear anytime between 1 and 15 years of continuous cropping depending upon the rate of release of K from the soil and the rate of K removal by crops. Intensive cropping without potassium application depletes the soil K which in some cases may not even be reflected in the changes in available soil test values. With the present approach to soil fertility evaluation, crop responses in the field will perhaps provide better clues than changes in the soil test values. The number of soil crop situations for which split application of potassium along with N, as a superior practice, are increasing. The N x K interaction studies reveal that additional gains are possible from integrated NK applications. Potassium application may improve water use efficiency, crop quality, tolerance to salinity, frost, drought, pest and diseases and helps to maintain crop yields. Thus potassium is an important component of optimum use of nutrients in balanced ratios. Current potassium recommendations are aimed at generating an economic yield response and are not meant to sustain or improve soil fertility. The negative balances of potash and the declining trends in yield of the LTFEs conducted at different centers indicate the need for critical examination and modification of the existing K fertilizer recommendation to compensate for gradual loss of native soil potassium.

Potassium (K), an essential element and one of the three major nutrients, is needed by plants in amount similar to or greater than nitrogen. After the introduction of high yielding varieties and increasing use of nitrogen and phosphorus, crop response to potassium has become more widespread. The volume of available research amply shows that high yields and intensive cropping can only be sustained through optimum use of nutrients in balanced ratios. Potassium is an important component of balanced fertilizer use strategies.

Effect of K on cereals

Removal of K in proportion to N is very high in cropping systems particularly those involving cereal crops. In the Long Term Fertilizer Experiments (LTFE) at various locations over the 1971-83 period indicated that cropping without fertilizer application resulted in an average removal of 78.5 kg K_2O/ha/ year, the application of N alone led to a 50 percent increase in the crop uptake of potassium which increased even more to 145 percent with the continuous use of N + P (**Figure 1**).

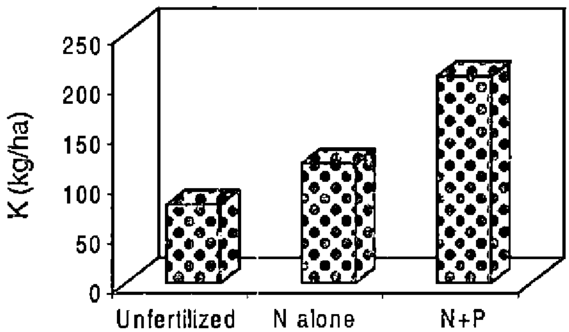

Figure 1. K removal by crops from unfertilized and fertilized plots in LTFEs

Most data show that even at optimum levels of potash application, crop uptake of potash exceeded the potassium added so that some amount of K-depletion was always going on. The negative balance of potash imply that crop responses to potassium will be more frequent and larger. Unfortunately, application of K did not receive due attention.

Response of cereals to K

Cereal crops required more K_2O than N and P_2O_5 to produce one ton of grains (**Figure 2**).

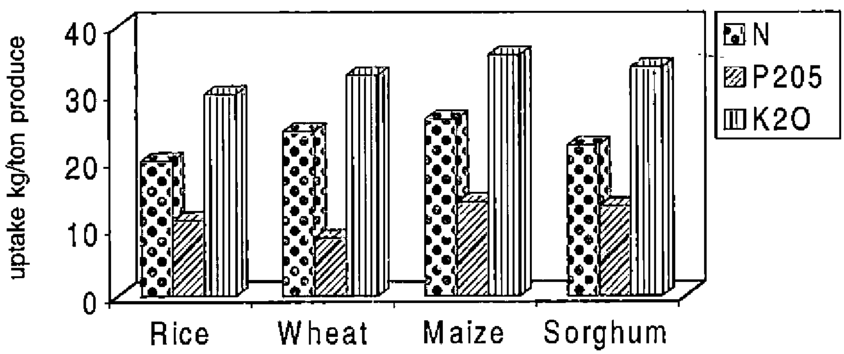

Figure 2. Total uptake by crops to produce one tonne of produce
Data Source: Velayutham and Reddy (1987)

The response of cereals to K depends on the type of soil, climate, crop, varieties and management practices.

In light textured soils with low exchangeable K under high rainfall condition there is a significant response to K. Alluvium and red-soils are rich in K as they contain illite; while coastal alluvium and lateritic soils are poor in K content. Low-land rice soils are frequently high in K content while the high-land rice soils have less K due to leaching. Light-textured and excessively drained sandy soils are inherently low in K content. Because of contribution of non-exchangeable K pool towards K uptake by the crops, the deleterious effect of neglecting K application is often not reflected on exchangeable K status of the soil in short-term experiments but with continuous intensive rice-wheat cropping over years in Inceptisols of Kanpur with illite as dominant clay mineral, it has been difficult to maintain even initial K status despite K application at recommended rates (Tiwari *et al.,* 1992). In LTFEs, uptake dose was far in excess of fertilizer K applied in almost all soils and cropping systems indicating inadequate K application and much greater exploitation of native K reserves of the soil (Nambiar, 1994).

A common observation is that fertilizer responses are generally higher in dry season than in wet season. Based on the results of Experiments on Cultivators' Fields (ECF), Goswami *et al.,* (1976a) concluded that the extent of response in *rabi* rice was higher than *kharif* rice. It was observed a higher uptake of K by rice in the dry season than in the wet season. But, reports indicate that the response to K is usually observed in acidic and sandy soils during *kharif* season in the high rainfall areas where it is liable to leaching loss.

Crops differ in their response to K application. The rate of K absorption during the crops growth varies with the crop. In rice, K uptake occurs fast and 75 per cent of the plant's K requirement may be absorbed up to boot leaf stage (Patnaik and Nanda, 1969). In sorghum 50-60 per cent of the total uptake of K was completed before heading (Roy and Wright, 1974). In the cereals most of N and P removed by crop goes to grain, most K is retained in straw. In wheat, oats and maize the ratio of the amount of K in straw or stover compared to that in grain is about 18:1, 3:1 and 4:1 respectively. The wheat or sorghum contain about 0.5 per cent K, whereas the straw contain about 1.5 per cent K.

Varieties differ in their response to K application. Dwarf varieties responded more than tall indica varieties at adequate K level in conjunction with N + P. The amount and percentage of K content of the hybrid rice was significantly higher than the local one at different growing stages. K application increases the K content in the rice tissue and the increasing rate of K/N content of local variety was lower than with the hybrid at different growth stages.

Response of cereals to K fertilizers vary with method of application. K fertilizers are usually broadcasted but in soils with low available K or with a high K fixation, band application is advisable. In soils with a high K fixation capacity, K fertilizer has to be applied just before sowing the crop and also as a top-dressing in order to reduce the time of contact between fertilizer K and K- fixing minerals. On fine-textured soils, the vertical movement of K in the soil profile is restricted, while in sandy and organic soils, high K losses occur due to leaching. In those high leached soils also, K should be applied just before sowing, in order to avoid excessive K-losses during rainy season. In the soil having high water permeability and low retaining capacity for K, top-dressing is highly effective. Bordoli (1998) reported that potassium increased yields in several soils that tested optimum or higher in soil test K, and yields were higher when K was deep banded and high rate of broadcast or planter banded K did not offset the advantage of deep banded K.

K in physiological process

Potassium has an important role to play directly or indirectly in physiologiclal process such as root-growth, water uptake and utilization efficiency, translocation, transpiration, stomatal behaviour, osmoregulation, respiration, starch and protein synthesis, enzyme activation and economic yield determining process. It is also involved in imparting resistance to drought, frost, pests, diseases and physiological disorders. Under drought, added K enhance water uptake and impart resistance to water stress. Potassium may improve water use efficiency and help to maintain crop yield under moisture stress or to reduce the extent of crop losses under such conditions. There are indications of an association between a crop or crop variety's tolerance to salinity and its potassium status. Sekhon (1982) cites results which show that potassium application reduced the damage due to bacterial leaf blight, sheath blight and bronzing of rice; black rust of wheat and surgary diseases of sorghum. Prakasa Rao (1985) indicates that the incidence of leaf roller, thrips, brown plant hopper and green leaf hopper decreased with potassium application while potash had no effect on the stem borer and gall midge, and an inconsistent effect on the whorl maggot.

Effect of K on quality

Potassium is quite often associated with improved crop quality. K increase the proportion of large grain and has favourable effect on 1000 grain weight, it increases crude protein content and relative proportion of protein fraction viz., albumin, globulin, glutamin and also individual aminoacids. Adequate supply of K can increase the proportion of lysine in the grains.

Potassium plays an important role in ensuring efficient utilisation of nitrogen. K and N are found to be complementary to each other in their mutual beneficial action, each enabling the plants to make use of the other. K has a counter balancing effect of excess nitrogen. K reduces the harmful effect of high levels of N. K application increased rice yield at applied N and the most appropriate ratio of K: N was 1:2 (Singh and Singh, 1979). Application of K tended to increase grain N content and total N uptake while P content was little affected.

Reichenbach (1972) reported a differential rate in fall of productivity in respect of *kharif* and *rabi* rice in the absence of K application appeared to be due to the adsorption and desorption of K^+ resulting from the reduction and oxidation of Fe abundantly available in this soil. Oxidation of

Fe^{2+} to Fe^{3+} during Rabi season leads to desorption requirement to a great extent. However, adsorption of K takes place during reduction of Fe^{3+} to Fe^{2+} in *kharif*, leading to lowering of K concentration in the soil solution. Therefore, there is decrease in K uptake and greater decline in productivity of *kharif* rice.

Potassium for rice

Potassium is indispensable to the growth and grain production of rice. Tanaka *et al.*, (1977) indicated that the rice plant was characterized by its high capacity of absorbing as well as exhausting K and thereby they tended to maintain the K concentration in a plant at a constant level. When the K concentration in the rice plant was forced to be low, its relative growth increment decreased drastically. The cropping pattern in rice has become very intensive in recent years, due to extensive use of high yielding, photo-insensitive, short to medium duration varieties and thus K has become increasingly a critical factor after the harvest of several crops from the same piece of land. The higher the intensity of cropping, the higher the yield and more K has to be applied in relation to N.

Response of rice to K fertilizers

Goswami *et al.*, (1976b) reported that India has K deficient rice-growing soils in high rainfall areas like Kerala. Pillai (1985) reports high response of rice to K in Kerala.

Effect of K on physiological parameters of rice

Application of K at higher rates advanced the crop maturity by three days. It is a known fact that excess N delays the crop maturity. Similarly, deletion of K caused delay in flowering. The phenomena of grain-filling was distinctly influenced by K fertilization. The crop without applied K recorded increased sterile and partially filled spikelets/panicle. Addition of 60 kg K_2O/ha enhanced the filled spikelets by decreasing the sterility.

Effect of K on yield and yield attributes

Verma *et al.*, (1979) observed longer panicles with increased K rates while Vijayan and Sreedharan (1972) reported greater number of spikelets per panicle. In a nutritional balance analysis for productivity improvement of rice in laterite alluvium, Bridgit (1999) reported that 85 percent of the locations sampled for the study were low in potassium content and there exist a real and relative deficiency of K. Significant yield increment were obtained by application of 120 kg K/ha and the main effects worked out to 528 kg grain/ha and the result showed that effect of increasing K content of the culm, leaf and grain was significantly related to the total biomass production. Potassium content in root, shoot and culm were significantly related to straw yield. Rice yield and its attributing characters responded favourably to higher dose (60 kg K_2O/ha) of

K but not at lower dose (40 kg/ha) except when the entire dose was applied at panicle-initiation stage.

Split application of potassium for rice

Studies on potash nutrioperiodism in Kerala revealed that half the recommended dose of potash applied at periods of active utilization in split doses gave as much yield as that of full dose of potash in the case of both medium and short duration varieties of rice (KAU, 1980) (**Table 1**). Results of split application of potash in rice showed that three application of K synchronizing with application of N is relatively better than the existing recommendation of two split applications (KAU, 1987). However, response to split application of K is closely related to an optimum N: P ratio.

Table 1. Potash application schedule for rice in Kerala State - an example of split application of K

Region	Situation	Recommendation
Kuttanad and Onattukara	Transplanted, short-medium-long duration	50% K before planting plus 50% 5-7 days before panicle initiation
Onattukara (rainy season)	Transplanted, short-medium-long duration	50% K basal plus 25% K at tillering and 25% at panicle initiation
Upland and wet land	Direct seeded	50% K basal plus 50% at panicle initiation
Wynad and hilly region	Transplanted , long duration	50% K one month after planting plus 50% before flowering
Wynad and hilly region	Direct seeded	50% K one and a half month after planting plus 50% at panicle initiation

Data Source: Kerala Agricultural University, Package of Practices (1996)

Future research needs

There is an urgent need for determining the N: K ratio and NPK balance formula for each crop and cropping system in different agro-climatic regions of the state and country based on nutrient uptake, nutrient use efficiency, indigenous soil nutrient supplying capacity and availability of other inputs of agriculture which control the ultimate the yield of a crop.

Development and testing of some NK complex fertilizers should be undertaken for situation requiring split application of K in addition to the established practice of applying N in splits.

The soil graded as high in available K are gradually changing to medium and low in available K and are showing response to K. Careful monitoring of soils for available K is hence essential.

The role of K in alleviating the iron toxicity and acidity of different agro climatic zone of the state need to be studied.
Further work is needed to better characterize and predict responses to deep-banded K.

Long term fertilizer experiments should be laid out on well characterized sites and should be carefully monitored for changes in K status, for accurate estimate of potassium balance and crop productivity.

Research on the development and standardisation of plant analysis norms for K content and adequacy/deficiency levels to serve as diagnostic tools should be undertaken.

In some cases, potassium uptake by crops in excess of their physiological requirement leading to luxury consumption and put an extra strain on the potassium balance. The potassium requirement of crops should therefore be studied to determine the optimum amount of potassium required for crop production.

Preparation of potassium fertility maps of different regions and states may be undertaken.

Development and standardization of critical / sufficiency levels of potassium in soils and plants needs to be worked out.

Research on priority basis is needed on the effect of potassium on water economy and water use efficiency by crops.

An all out effort has to be made to create farmers awareness on the loss of K as crop residue, cow dung ashes, which should be returned back to the soil to maintain a good K reserve in soil.

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Potassium Dynamics in Coconut and Coconut Based Cropping Systems

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Abstract

Potassium is a vital major nutrient for coconut as it's requirement is high. Coconut growing soils of Kerala are generally low in available potassium. Estimates indicate potassium use in the state is less than half compared to fertilizer removal in coconut growing areas there by causing depletion of soils' nutrient reserves. Systematic studies on soil K – crop relationships in coconut and coconut based cropping systems are lacking in Kerala.

Potassium plays an important role in nutrition of coconut. It 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. Potassium is also known to favour early bearing in coconut. K-deficiency leads to chlorosis, leaf scorch and the development of poor crown with short fronds (Manciot *et al.,* 1979). Coconut has unique feature among the plantation crops as 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.

Coconut growing soils and their potassium status

In general, coconut like any other plantation crops is grown on variety of soils namely laterite, littoral coastal sand, red sandy loams, alluviums, coral, peaty and black soils. The ideal coconut growing soils are well drained and aerated with a minimum depth of 80 to 100 cm, pH range between 5 to near neutral, adequate nutrient availability and water holding capacity (Fremond, 1964). The major coconut growing soils are lateritic, coastal sand and alluvial. Except for alluvials, all the other soils have low native fertility and poor physical properties. Some of the characteristics of coconut growing soils are shown in **Table 1.**

Table 1. General physico-chemical properties of the soils

Soil group	Mechanical composition (%)			pH (1:2.5 soil-water)	Organic Carbon (%)	CEC (m.e./100g)
	Clay	Silt	Sand			
Laterite	16.8 (9.2-39.2)	10.5 (2.2-20.0)	64.4 (49.2-86.8)	5.72 (4.0-6.8)	0.55 (0.06 -1.8)	5.1 (1.0-14.4)
Alluvial	17.9 (9.2-31.6)	6.9 (1.0-18.0)	75.1 (50.4-89.2)	5.79 (4.2-7.1)	0.69 (0.03-1.8)	4.4 (0.7-11.3)
Reclaimed marshy	15.0 (9.0-26.4)	3.9 (0.0-13.6)	78.7 (64.0-91.0)	4.76 (3.7-6.5)	0.68 (0.23-2.9)	4.1 (0.6-24.3)
Coastal sandy	6.8 (3.6-10.8)	0.8 (0.07-7.8)	92.4 (87.2-95.4)	6.67 (5.2-8.3)	0.13 (0.00-0.46)	0.5 (0.4-5.4)
Sandy loam	17.0 (8.8-30.2)	3.8 (10.6-14.0)	79.4 (69.4-90.2)	5.81 (4.8-8.6)	0.31 (0.06-1.44)	3.7 (1.0-11.7)

Source: Pillai, 1975. (*Figures in parentheses denote ranges*)

The major area of the coconut being in South India suffers from prolonged spell of high temperature and high rainfall leading mainly to leaching losses of silica and bases from parent material with concurrent accumulation of oxides of Fe and Al. This leads to the formation of laterites, a dominant soil group under plantation crops. Various studies have long established that these soils are acidic in reaction with poor native fertility, low CEC, a characteristic of Kaolinite as dominant clay minerals and have high presence of sesquioxides. Based on the ratings of Muhr *et al.* (1963), Pillai (1975) 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. The mean values for coastal sandy soil in the 0-50 cm and 50-100 cm layers were 12.2 and 10.9 ppm K and corresponding values for sandy loam soils were 28.4 and 28 ppm K, respectively. Robert Cecil (1981) reported similar values for the sandy loam soil of Kayamkulam. Surveying the soils of Badagara taluk, a premier coconut-growing tract, Ramanandam (1977) reported that the soils were poor in K. Krishnakumar and Koshy (1985) held similar opinion for 'Poonthalpadam' area in Kerala where the exchangeable K varied from 0.07 to 0.24 m.e./100 g. Bastin and Venugopal (1986) indicated that the Alfisols, which are intensively cultivated for coconut, are generally low to medium in potash status (**Table 2**).

Table 2. Available K status in different red soil series (Alfisols) 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

Potassium dynamics in soil

Critical studies on soil potassium in relation to coconut nutrition are lacking except for some manurial experiments with potassium as one of the factorial component (Biddappa *et al.,* 1993). 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. The influence of clay minerals in K supply to the nutrient pool was also indicated by Ramanathan and Krishnamoorthy (1976).

Hameed Khan *et al.* (1982) further observed that desorption of applied K showed a constant release after third and fourth extraction, irrespective of soil groups. Even after the 8^{th} extraction, a constant release of 1.5 to 2.5 ppm K was observed in two extractions. The soils under the 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). As K is likely to get depleted more easily from the feeding zone and 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.

The selective distribution of potassium in representative soils (Hameed Khan *et al.,* 1982) revealed that the major part of applied K was extracted with boiling HNO_3 followed by 1 N NH_4OAc and more or less uniform extraction of K in 0.01 M $CaCl_2$. Variation in water soluble K among soil groups was attributed to initial available K in soils, prior to saturation with K for the study. There was evidence to show that applied K was converted into difficult exchangeable forms and the equilibrium between exchangeable and labile-K is maintained relatively faster in these soils. Further, in the incubation experiments with different coconut growing soils, highest watersoluble 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. 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.

Soil profiles from three soil series of Kannur district were analysed for different K fractions. In Dharmadham series, the water soluble K ranged from 4 to 39 ppm, Exch. K from 1 to 69 ppm and non-exch. K from 11 to 98 ppm whereas the water soluble K ranged from 4 to 18 ppm, Exch. K from 2 to 53 ppm and non-exch. K from 37 to 71 ppm in Kunhimangalam series. In Pilathara series, the water soluble K ranged from 4 to 8 ppm, Exch. K from 10 to 36 ppm and non-exch. K from 44 to 125 ppm. In general, the soils are poor in K status, and will need investment in the form of K currency for high yields.

Nutrient exhaust

According to Von Uexkull (1985) potassium is usually the least needed major nutrient in low yield agriculture but climbs into dominant position when yields are maximized. Kanwar (1993) stated that low yield level of 40 nuts/palm/year 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.

Nevertheless, potash requirement of coconut is very high as indicated by the amount of nutrients removed annually by the palm (**Table 3**). The nutrient ratio of N: K of 1: 1.2 – 1.4 themselves is indicative of its influence being exerted on the crop. The nutrient exhaust studies conducted in India show that the proportionate requirement of NPK of the palms in terms of N: P_2O_5: K_2O is 2:1:3 and the quantitative order of requirement of major nutrients for adult bearing palm is K>N> Ca> Mg> P which suggests that K is the dominant nutrient required by palm while P requirement is the least. It has been estimated that in India, total potassium removal by the coconut crop is 336 thousand tonnes and the estimated fertilizer K consumption is 150 thousand tonnes (Nair *et al.*, 1996). This shows a huge gap in K nutrient supply to the crop.

Table 3. Annual nutrient removal by coconut palm

Location	**Basis**	**Nutrient Removal**						**References**
		kg			**Ratio**			
		N	**P**	**K**	**N**	**P**	**K**	
India	70 palms/acre yielding 40 nuts/palm	22.5	5.2	28.4	1	0.23	1.26	Pillai and Davis (1963)
India	175 palms/ha	97.3	21.0	121.1	1	0.22	1.24	Ramadasan and Lal (1966)
Ivory Coast (IRHO)	Hybrid palms (PB 121) 6-7 tons copra/ha	174.0	20.0	249.0	1	0.12	1.43	Ouvrier and Ochs (1978)

Response to K application

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 seed nuts collected from palms manured with K displayed better vigour and growth than those obtained from unmanured plots (Nelliat, 1973).

Influence of potassium on 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 4**). The later practice was decidedly inferior for all palms. 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 4. 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	9	8
1958	Length of frond (cm)	256	233
1959	Girth (cm)	124	105
1960	No. of fronds (one yr)	12	11
1962	Copra (kg/ha)	2560	272
1966	Copra (kg/ha)	2480	2272
1970	Copra (kg/ha)	-	2096
1961-1970	Cumulative yield (kg/ha)	17344	12704

Influence of potassium on adult palms: Coconut continuously mines nutrients from the soil nutrient bank to produce higher yields. The potassium levels influence the yield and yield attributing characters in coconut. Menon and Pandalai (1958) on reviewing the work 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.

Application of 340 g N, 340 g P_2O_5 and 680 g K_2O/palm/ year improved the nut yield by 35 percent and copra out turn by 44 percent in the cultivators 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). Muliyar and Nelliat (1971) 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. 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/year in the 21st year after planting under no fertilizer, 450 g K_2O and 900 g K_2O/ palm/year respectively.

Long-term impact of fertilization on nutrient status

Hameed Khan *et al.* (1986) reported that after 18 years of coconut growth, the control (M_0) plot analyzed 19 ppm available K where as it was 55 and 70 ppm in M_1 and M_2 treatments, respectively. K levels in the control and treated plots decreased with depth. Further, Reddy *et al.* (2000) 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 212 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 5**). Application of potassic fertilizers also raised the leaf K levels to 1.14 percent (M_1) and 1.25 percent (M_2) compared to 1.07 percent in M_0 under rainfed condition. Under irrigation, leaf K content was 1.07 percent under M_1 and 1.20 percent under M_2 compared to 0.90 percent 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 percent). 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 K (1N NH_4Oac) content of 50-60 ppm (0.128 to 0.153 m.e./100g) is adequate for maintaining sufficiency levels in coconut. Manicot *et al.* (1979) reported that 0.015 to 0.20 m.e./100g (59-78 ppm) and Loganathan and Balakrishnamoorthy (1980) suggested that 0.13 m.e./100g (51 ppm) of exchangeable K is sufficient for satisfactory growth of coconut palm.

Table 5. Long term effect of fertilization on available potassium status of red sandy loam soils (Arenic Paleustult) at different soil depths (cm)

Fertilizer level	Available K (ppm)			
	Irrigated condition		Rainfed condition	
	0-25 cm	25-50 cm	0-25 cm	25-50 cm
M_0 (No fertilizer)	79	38	66	66
M_1 (500g N: 218g P: 833g K /palm/year)	110	69	202	153
M_2 (1000g N: 437g P: 1667g K/palm/year)	212	129	318	235

Source: Reddy *et al.* (2000)

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 ppm at K_1 level (750g K_2O/palm/year) to 96 ppm at K_2 level (1250g K_2O/palm/year) to 106 ppm 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, the statement of Biddappa *et al.* (1993) - soil available K content of 50–60 ppm is adequate for maintaining the sufficiency levels in coconut appears to be true.

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 lead 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. Further, Joseph and Wahid (1997) has observed that the application of muriate of potash resulted in a large increase in K reserves in soil to 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/palm 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 (1 N 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 6). 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.

Table 6. Dosages of K required for laterite and red sandy loam soils to raise the soil test value of K to any predetermined level (g K_2O/palm/year)

Soil test value (kg/ha)	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							

Nutrient interaction

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.

Manciot *et al.* (1979) reported that there exist strong antagonisms between K-Ca, K-Mg and K-Na. Often, Mg level in the tissue decreased consequent upon high fertilization. Application of potassium lead to a significant drop in the content of Ca, Mg and Na in the leaf (**Table 7**). Wahid *et al.* (1988) also indicated the antagonistic effect of combined level of Na, Ca and Mg on K in the palms judged through foliar analysis.

Table 7. Effect of KCl application on the nutrient concentrations in the leaf

KCl application (kg/palm/year)	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

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.

Coconut based cropping system

Nutrient management in the cropping system is the interplay of various factors *viz.*, crop's nutrient requirement, differential responses in different soils, crop residue additions, climatic variations *etc.* 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. 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).

In case of coconut-cocoa system, cocoa, as a component of multiple cropping system adds substantial quantity of organic matter to the soil, thus leading to annual internal recycling of nutrients in the system. It has been observed that 8.2 and 19.8 t/ha/year (oven dry basis) of cocoa litterfall was obtained from single and double hedge systems of planting respectively (Varghese *et al.,* 1978). Taking nutrient concentration of cocoa leaves to be 2.84 percent N, 0.26 percent P and 1.73 percent K on dry weight basis (Eernstman, 1968), it could be assumed that about 50 kg N, 11 kg P_2O_5 and 35 kg K_2O could be returned to the soil every year through leaf fall of cocoa under double hedge system of mixed cropping.

Conclusions

The reserves of potassium in soils growing coconut are lower on account of low CEC and high amounts of 1:1 clay type, mainly Kaolinite. Since, K is required in many physiological functions but does not form part of plant structure, K supply through external sources could be necessary so as to meet the crop's K requirement. Secondly, it can be considered a mobile capital investment highly capable of being recycled but also highly 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.

Coconut 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 crop.

Further, crop residues contain the remnants of nutrients after the plant has transferred its absorbed nutrients to its economic produce (about 75 percent of absorbed N and P, 50 percent of S and 25 percent of absorbed K) (Tandon, 1991). Thus, crop residues are more important sources of potash as compared to nitrogen and phosphorus.

Climatic factors 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 many interactions between K nutrition, soil management, and climate are poorly understood and needs further studies on this.

Another field of research needed is the possible effect of K and Cl on leaf temperatures.

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Potassium requirement and response to Potassium Application in Plantation Crops (Rubber, Tea and Coffee)

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Abstract

Potassium nutrition of three plantation crops viz., rubber, tea and coffee and the responses of these crops to K application at the various growth phases are reviewed. These crops with entirely different economic produce show variation in their K requirement. The economic product of rubber is latex, which is a hydrocarbon. The removal of K through the crop produce is negligible compared to the nutrients locked up in the tree. The K requirement is comparatively low similar to the other major nutrients however positive responses to K application are recorded under low K availability situations. The importance of proper K and Mg balance in the fertilizer schedule is needed.

In tea, the new flushes (vegetative growth) are the economic produce and the requirement for K is quite high. The fertilizer K recommendations depend on the stages of growth, pruning cycle and the rate of N application. The importance of proper N:K balance in the fertilizer programmes is evident from the response trials. In case of coffee also, the removal of K through berries is high and the K requirement varies with the physiological stages of the crop and was found to be high immediately after harvest of the crop. Inspite of high K removal through berries, the response to added K fertilizer was found to be poor. Importance of K in improving the quality of latex (flow and stability), quality of made tea and coffee was reported in addition to the positive influence of K in inducing pest and disease resistance, drought tolerance etc.

Although, large quantities of nutrients are recycled through litter fall and pruning of these perennial crops, continuous cultivation with no K application results in reduced growth, poor stand per hectare and eventually low yields. Site-specific nutrient management based on soil and foliar analyses, age of the crop etc., for different yield levels would be the most ideal for these crops. These plantation crops are generally grown in the lateritic, red ferruginous soils with poor nutrient status, low cation exchange capacity and clay mineralogy dominated by variable charged clays. However, the situation is improved by the medium to high organic matter status. To understand the crop response pattern in a better way, studies on the dynamics of K in soil in specific management situations will be useful.

Rubber

Potassium plays a vital role in the growth and development of the plant and deficiency of potassium produces characteristic symptoms in rubber. Yellowing or chlorosis of the margin and tip of the leaves followed by necrosis is the characteristic symptoms of potassium deficiency.

On young unbranched trees, the symptoms appear first on the older flushes of leaves and extend to the mid-storeys in advanced stages of deficiency. In old branched trees, the symptom appears on leaves exposed to sunlight. In mature plantations, potassium deficiency is revealed by the appearance of butter yellow colour all over the canopy. Leaf size gets reduced considerably. The symptoms appear seldom before August.

Potassium requirement

In rubber the harvested produce, latex is a hydrocarbon and the nutrient removal through dry rubber is minimal compared to other crops. It is estimated that an average 5 kg K alone is removed through a dry rubber yield of 1500 kg/ha/year. Pushparajah (1977) estimated the total K removal by rubber over a thirty year period (25th year of tapping) as 451 kg/ha in Malaysian soils. The amount of K immobilised in the trees has been estimated at 1400 kg K/ha.

Lack of K limits the active leaf area and reduces the photosynthetic activity of the foliage, resulting in a slow girth increase and a prolonged immature growth phase (Sivanadyan *et al.*, 1976). Samsidar *et al.* (1976) observed that K influences the anatomy of the bark. Further research indicated that by increasing the number and size of latex vessels, K increases the total volume of latex-producing tissue and thereby the yield is increased.

Potassium has a direct or indirect role in reducing precoagulation of latex. It prevents early plugging and thus increases the duration and rate of latex flow after tapping. Latex with high concentrations of either P or K had a high mechanical stability whereas high Mg^{2+} concentration depressed stability. Some clones with an inherently high Mg content in latex respond favourably to K application.

Fertilizer K recommendation for rubber

The Rubber Research Institute of India recommends potash application at the rate of 4,16,20 and 16 kg K_2O per hectare during immature phase, for first, second, third and fourth year respectively. The dose is increased to 24 kg/ha at the fifth year up to tapping when no legumes cover has been maintained in the field and 30 kg/ha where legume cover has been maintained in the immature phase. In the mature rubber the general K recommendation is 30 kg K_2O /ha in combination with 30 kg each of N and P_2O_5/ha.

Based on soil and leaf analyses, site and situation specific K recommendations are being offered by the Rubber Research Institute of India through their central and regional laboratories. This is popular among rubber growers and is being widely accepted by both large estates and small holders because of its advantages of improved yield and quality of latex achieved through balanced use of nutrients. Fertilizer recommendation based on leaf analysis was introduced during 1955 and has since been refined many times (Beaufils, 1955; Pushparajah and Tan, !972; Joseph *et al.*, 1998). For soil analysis the sufficiency range value followed in India for the available K is

5-12.5 mg/100g soil. Similarly the sufficiency range value used for diagnosis of K in rubber leaf is from 1.0-1.5 percent (Karthikakutty Amma *et al.*, 2000). Joseph *et al.* (1998) reported the critical concentration of leaf K as 1.35 per cent derived from response functions. In an earlier work Joseph and Ranganathan (1996) reported a critical value of 1.31 per cent derived through DRIS approach.

Response of rubber to Potassium fertilization

The need for fertilizer application for rubber was felt in 1920s and yield increases were reported by the application of Nitrogen. Based on the results of a few initial experiments only minor importance was attached to K nutrition. But afterwards based on the experimental results, number of reports from Malaysia and Sri Lanka are available presenting the variable nature to rubber in the response to applied K fertilizer during immature and mature phases (Lau Chee Heng, 1979; Yogaratnam and Weerasurya, 1984; Dissanayake and Mithrasena, 1986 and Ann. Rep. RRIM, 1981; 1983 and 1987). A detailed review on potassium in soils of rubber plantations was provided by Krishnakumar *et al.* (1993). Similarly, the response of rubber to added K fertilizer was reviewed by Punnoose and Mathew (1993). The experiments conducted by Rubber Research Institute of India from 1955 onwards on K nutrition were reviewed and the response pattern at the various growth phases were discussed. In seedling nurseries and in immature rubber during the initial four years response to K application was observed in low K soils. Similarly during the latter part of the immature phase and also during the mature phase the response depended on the early management practices adopted and again on the available K status of the soil. Some of the experimental results are presented and discussed in this paper.

Growth - immature rubber

Potty *et al.* (1978) compared the response pattern under two different management situations, and it was observed that the mean girth increment during the latter half of the immaturity showed response to higher levels of K application in the legume cover maintained area and no response was observed in the natural cover maintained area (**Table 1**). The decay of the legume cover might have added large quantities of N to the soil and to maintain an optimum balance between higher levels of N higher quantities of K was needed. Here again it is observed that the dose of K at which response obtained is only 32 kg/ha compared to the very high levels tried in the previous experiments indicating the low K requirement of the crop.

Table 1. Effect of K on girth increment

Levels of K_2O (kg/ha)	Girth increment (cm)
16	9.18
32	9.93
CD (5%)	0.70

Source: Potty *et al.*, 1978

Sherin *et al.* (1997) studied the response of two high yielding clones (RRII 105 and PB 235) to applied fertilizers during immature phase and reported that 20 kg K_2O/ha caused significant increase in girth and girth increment in both the clones (**Tables 2&3**).

Table 2. Effect of potassium on mean girth and girth increment in clone PB 235

K_2O (kg/ha)	Girth (cm)			Girth increment (cm)		
	1990	1991	1992	1987-90	1987-91	1987-92
0	38.82	45.76	50.83	26.78	33.72	38.79
20	40.86	48.55	53.01	28.45	35.78	40.60
40	39.00	46.03	51.86	26.85	33.84	39.67
CD (5%)	0.82	1.05	0.76	0.35	0.44	0.32

Source: Sherin *et al.*, 1997

Significant positive response to the application of K at the rate of 20 kg/ha was noticed for girth and cumulative girth increment and this effect was consistent throughout the experimental period for PB 235. But at 40 kg/ha there was a reduction in girth and cumulative girth increment. Yogaratnam *et al.* (1984) and Weerasuriya and Yogaratnam (1988) observed that K requirement of vigorous clones was comparatively high.

Table 3. Effect of Potassium on mean girth and girth increment in clone RRII 105

K_2O (kg/ha)	Girth (cm)				Girth increment (cm)			
	1990	1991	1992	1993	1988-90	1988-91	1988-92	1988-93
0	28.72	38.29	45.26	50.54	17.39	26.96	33.15	37.64
20	30.61	39.02	47.01	52.07	19.32	27.73	35.07	41.48
40	29.81	37.94	46.02	51.54	18.83	26.96	35.08	41.14
CD (5%)	0.97	NS	NS	NS	0.38	0.50	0.29	1.37

Source: Sherin *et al.*, 1997

Potassium application at the rate of 20 kg/ha significantly increased the girth at 42 months from planting and thereafter the response ceased and the same effect was observed with nitrogen also. But the cumulative girth increment throughout the experiment period showed a significant positive response to the application of 20 kg of K_2O /ha. However, at the higher level of application, girth and cumulative girth increment were less. The response obtained to K application could be attributed to the low available K status of the soil (3.07 g/100g soil). In the study conducted by Rubber Research Institute of India in the traditional region the treatment combination of 30:30:20

kg/ha recorded statistically significant girth and girth increment during the 7th year of planting. The results of this study also indicate the low K requirement of rubber.

Yield - Mature rubber

In the experiment on mature rubber, where in the K treatments were imposed during the initial four years and the residual effect of applied K was studied for another four years. There was only numerical increase in yield with increasing levels of K during the first four years. Statistically significant response to K application was observed during 4th year and continued up to eighth year (Table 4). The available K status was depleted in the soil from 4th year onwards but at the same time leaf K status was maintained at the optimum level (Punnoose *et al.,* 1978). Similar results were reported by Yogaratnam and Weerasuriya (1984).

Table 4. Residual effect of K on yield (g/tree/tapping)

Year	Levels of K_2O (kg/ha)				
	0	50	100	SE	CD (5%)
1967-68	14.70	15.80	16.30	0.44	—
1968-69	20.10	20.20	21.40	0.59	—
1969-70	25.80	25.90	27.40	0.75	—
1970-71	38.80	39.70	42.90	0.99	2.83
1971-72	24.60	24.30	27.80	0.73	2.09
1972-73	32.70	34.36	38.50	1.15	3.29
1973-74	32.90	32.70	35.00	0.70	2.00
1974-75	35.70	35.70	38.70	1.03	—

Source: Punnoose *et al.,* 1978

Response of Hevea to fertilizer application was compared under two management situations during the immature phase *viz.,* maintenance of legume ground cover and natural cover. Response to K application was observed during the first year of tapping when K level was increased from 16 to 32 kg/ha in legume cover maintained plots and afterwards no response was observed. In the natural cover maintained area, no response was observed with higher levels of K application. Similar trend was observed in the immature phase of this experiment where response to K application was recorded in the legume cover maintained situations only.

The experiment on nutrient response under two different ground cover managements was continued and the yield data were monitored during the 7th, 8th and 9th year of tapping. The results reported by Punnoose *et al.* (1994) show that during the 7th year of tapping increasing the level of K from 16 to 32 kg/ha significantly reduced the yield in the legume cover maintained area. Pushparajah *et al.* (1983) reported that in areas where legume cover was maintained during immature phase the magnitude of increase in yield to applied K during early years of tapping was small. But in the natural cover maintained area, application of K at 32 kg/ha level recorded significantly higher yield over the 16 kg level during the 6th, 7th and 8th years after tapping (**Table 5**). In the natural cover maintained area higher levels of N (40 and 80 kg/ha) were applied compared to the legume cover area of (20 and 40 kg N/ha), higher level of K was needed to balance higher dose of N.

Table 5. Influence of K on yield under two management situations

Levels of K (kg/ha)	Years after commencement of tapping			
	6	7	8	9
Legume cover				
16	54.73	54.54	50.57	61.56
32	55.63	51.79	50.01	61.56
F ratio	NS	S*	NS	NS
CD	—	2.00	—	—
Natural cover				
16	51.63	50.24	53.54	63.67
32	55.05	52.53	56.93	67.22
F ratio	S**	S**	S**	S**
CD	1.13	1.83	2.00	2.08

S*-Significant at 5% level, S** - Significant at 1% level

Source: Punnoose *et al.*, 1994

The effect of K x Mg interaction on yield was also reported (Punnoose *et al.*, 1994). During the 7th, 8th and 9th year of tapping, the K x Mg interaction was significant (**Table 6**). With the lower level of K, application of Mg significantly depressed the yield. But with the higher level of K, application of Mg significantly increased the yield. Similar effect was reported during the ninth year of tapping in a parallel experiment where natural cover was maintained in the field during the immature phase.

Table 6. Effect of K x Mg interaction on yield (g/tree/tapping)

Levels of K_2O (kg/ha)	Levels of MgO (kg/ha)		SE	CD (5%)
	0	6		
7th year				
16	55.97	53.11		
32	47.65	55.92	0.98	2.83
8th year				
16	53.41	47.73		
32	46.31	53.71	0.99	2.85
9th year				
16	64.34	58.79		
32	57.44	65.69	1.05	3.02

Source: Punnoose *et al.*, 1994

Influence of K application on dry rubber yield was studied by Joseph *et al.* (1998). During the initial four years no significant difference between treatments was recorded. Response to K in respect of dry rubber yield was observed during the 4th and 5th years, but the effect was statistically significant only during the fifth year (1995). Increase in yield was recorded with K application up to 75 kg K_2O/ha and a marked depression in yield was observed with the application of 90 kg K_2O/ha. It is possible that a relative deficiency of a complementary ion, such as Mg causes an imbalance and consequently yield depression. Even in a low K soil, the response to K application appeared only in the fourth year of experimentation. This might be due to an adequate nutritional status relative to the supply of other growth factors and internal translocation and reallocation of the nutrient in the tree system.

Joseph *et al.* (1998) while analysing the effect of K application on monthly volume of latex and dry rubber yield observed that the positive effect of K application was recorded during the summer months when there is shortage of moisture. The beneficial effect of K in imparting drought tolerance to plants is reported in many crops. Earlier study revealed that a higher soil potassium during dry period helped in maintaining a better plant water status in rubber.

Available K status and leaf K concentration

Significant treatment difference was observed from the second year of application onwards (during 1992 and 1993) and with 45 kgK_2O /ha, the soil available K rose to medium status. A similar effect was obtained with 30 kg/ha levels onwards during 1994 and 1995. In the control plot the available K status was low but the level was maintained for five years indicating that there is continuous buffering from the non-exchangeable pools (Joseph *et al.*, 1996; 1998) (**Table 7**).

Table 7. Influence of potassium on available K status of the surface soil (mg/100g soil)

Treatment (kgK_2O/ha)	1991	1992	1993	1994	1995
0	2.13	3.71	3.71	3.50	2.34
15	4.13	3.17	4.08	4.98	3.21
30	3.67	3.16	3.25	6.38	5.83
45	4.54	5.80	7.13	6.42	4.33
60	3.83	8.29	5.83	7.13	9.96
75	2.83	9.79	8.33	6.42	4.37
90	3.54	8.20	6.16	6.38	6.92
CD (5%)	NS	NS	2.54	2.93	3.08

Source: Joseph *et al.*, 1996 & 1998

The effect of K application on leaf K concentration is presented in **Table 8.** Positive influence of K fertilizer application on leaf K concentration is evident through the gradation in absolute values between control and K levels. However, the effect was statistically significant only during 1995. Even with continuous withdrawal of K for five years, the K concentration in the control treatment was maintained at the medium level. The control plot recorded a low leaf K status only during 1993.

Table 8. Influence of potassium on leaf K concentration (%)

Treatment (kgK_2O/ha)	1991	1992	1993	1994	1995
0	1.07	1.08	0.86	1.18	1.18
15	1.09	1.13	1.13	1.36	1.37
30	1.11	1.14	1.12	1.29	1.46
45	1.16	1.13	1.40	1.42	1.54
60	1.15	1.16	1.33	1.34	1.58
75	1.25	1.20	1.26	1.28	1.64
90	1.25	1.22	1.36	1.50	1.21
CD (5%)	NS	NS	NS	NS	0.31

Source: Joseph *et al.*, 1996 &1998

Conclusions

The response of rubber to potassium fertilization has been reported to vary considerably. Earlier studies reported no response or even negative response to applied K fertilizer. These trials were taken up in newly cleared forestlands with adequate supply of native K. Experiments with very high levels of K also recorded negative response to applied K. Positive response to applied K was recorded at lower levels of K application and under low available K status of the soil.

The laterite (red ferruginous) soil in the tracts where rubber is generally grown are highly weathered, clay mineralogy dominated with variable charged clays, low in cation exchange capacity, low in base status and acidic in reaction. These soils are inherently low in available K status. Most of the plantations in the traditional rubber growing regions are now in the third planting cycle. Karthikakutty Amma (1997) reported a net negative balance of K in rubber plantation agro ecosystem at the end of one plantation cycle and stressed the need for K fertilizer application to rubber plantations. Results of the field experiments conducted in the recent years indicated response to K application at the lower levels indicating a low K requirement of rubber compared to other crops.

Tea

Potassium is most important nutrient for tea similar to nitrogen. It is extremely mobile in the plant and is important in promoting the translocation of carbohydrates to young flushes that are harvested periodically. It plays important role in the maintenance of turgor pressure, uptake of other nutrients and many other physiological processes. Potassium is also important for the development of healthy frames, which is essential to sustain productivity of tea.

Ranganathan and Natesan (1985) published an exhaustive review on the various aspects of tea nutrition, which has been often quoted in this review.

Requirement and uptake of K

The concentration of K and other nutrients in the different parts of a young clonal tea presented in **Table 9** show highest concentration in leaves.

Table 9. Nutrient content of various plant parts of young clonal (6/8) tea

Plant part	**Nutrient content (g/kg)**					
	N	**P**	**K**	**Ca**	**Mg**	**Mn**
Leaf	28.8	2.1	17.0	7.5	1.9	3.1
Stem	7.9	0.8	8.3	2.3	0.8	0.7
Root	11.0	0.8	14.1	1.3	1.5	0.7

Source: Magambo, 1979

The nutrients assimilated by above ground parts of tea to produce 100 kg of made tea are given in **Table 10.** Among the different nutrients, assimilation of N is the highest and K follows it. Of the total quantity of K assimilated, about 54 per cent is in the flush, which is removed from the plant by harvesting. Flushes accumulate the highest quantity of K followed by mature leaves, branches and wood.

Table 10. Nutrients assimilated and removed by tea to produce 100 kg of made tea

Part	**Proportional dry weight**	**N**	**P**	**K**	**Ca**	**Mg**
Flush	100	4.0	0.50	2.0	0.6	0.25
Mature foliage	120	3.9	0.43	0.9	1.5	0.36
Branchlets and twigs	80	1.1	0.24	0.4	0.5	0.16
Wood	200	2.0	0.48	0.4	0.5	0.30
Total assimilated	—	11.0	1.65	3.7	3.1	1.07
Amount removed *	—	6.0	0.98	2.4	1.1	0.55

Source: Ranganathan, 1976b

* Removed as crop (1) and for fuel at pruning (4); 2 and 3 are retained in the field at pruning

The nutrient removal from tea is estimated to be 40, 5 and 20 kg NPK per tonne of made tea and the requirement of nutrients is estimated to be 62.5, 10.3 and 34 kg N: P_2O_5 and K_2O for 1350 kg dried leaves (FAI, 1998-99).

The dry matter production and nutrient uptake after pruning during 4 year period before next pruning was reported by Ranganathan (**Table 11**). For a crop production of 10.8 t/ha, the plant parts above the pruning cut assimilated 412 kg of K. Of this quantity, about 50 percent is utilised for the production of shoots harvested for marketable tea. Based on the removal through harvesting, the total K requirement of the bushes was estimated at around 4.5 to 5.0 kg for every 100 kg of marketable tea (Ranganathan and Natesan, 1985).

Table 11. Dry matter production and nutrient removal of plant parts formed above pruning cuts of bushes (clone B/6/60) under regular plucking*

Plant part above pruning cut	Dry matter (tonnes/ha)	Nutrient removal (kg/ha)		
		N	P	K
Upto first year:				
Crop	1.20	48	6	24
Foliage	3.30	122	15	60
Twigs	0.62	13	2	10
Wood	1.79	41	8	15
Total	**6.91**	**224**	**31**	**109**
Up to second year:				
Crop	4.80	192	18	96
Foliage	4.74	164	12	46
Twigs	3.50	64	7	24
Wood	7.02	68	10	25
Leaf litter	0.60	13	2	11
Total	**20.66**	**501**	**49**	**202**
Up to third year:				
Crop	8.00	317	33	152
Foliage	5.23	183	22	52
Twigs	5.76	123	21	49
Wood	12.95	126	35	54
Leaf litter	0.08	30	4	3
Total	**32.74**	**779**	**115**	**310**
Up to fourth year:				
Crop	10.80	414	46	201
Foliage	7.33	249	30	81
Twigs	6.74	142	25	54
Wood	17.27	162	45	69
Leaf litter	1.80	61	10	7
Total for the cycle	**43.94**	**1028**	**156**	412

Sources: Ranganathan, 1973b, 1974, 1975, 1976b

*The experiment was carried out in 1965 clonal clearing after pruning at 35 cm in 1972.

Potassium deficiency

With the increase in productivity and depletion of soil K, deficiency of K began to manifest in tea growing areas in the mid sixties. Depletion of starch reserve in roots, degeneration of feeder roots and build up of nitrates leading to decline in health of the bushes and die back was reported when K application was not matched with N (Deb Choudhury and Bajaj, 1988).

Jayaraman and Jong (1955) have reported that the tea bush population in 3 pruning cycles was reduced by 46.1 percent in the no K plots.

Plants do not express any visual symptoms until K become extremely deficient. Ranganathan and Natesan (1985) have reported the deficiency symptoms of K. There will be a gradual decline in growth rate and yield followed by tip and margin scorch of mature leaves. This is followed by premature leaf drop leaving a crown of young foliage at the top and development of thin wood. Decline in new flush growth and poor recovery after pruning and ultimate death of the plants are also reported. (Ranganathan, 1970, 1982).

Fertilizer K recommendation for Tea

The ratio and source of nutrients vary according to soil reaction. The quantity of fertilizer varies with the age of the crop also. The fertilizer K varies from 180kg/ha to 450kg/ha depending upon the situation (**Table 12**).

Table 12. Fertilizer recommendation for tea (kg/ha/year)

Age of the clearing	**pH of the soil**		
	<4.5	**4.5 - 5.5**	**>5.5**
	NPKMg	**NPK**	**NPK**
First year	180 : 90 : **270** : 30	180 : 90 : **270**	180 : 60 : 180
Second year	240 : 90 : **360** : 40	240 : 90 : **360**	240 : 80 : **240**
Third year onwards upto first pruning	300 : 90 : **450** : 50	300 : 90 : **450**	300 : 100 : **300**

Source: KAU, 1996

Response to K fertilizers

Response of tea to potassium fertilizers will depend on the K status of the soil, age of plants and the productivity of the bushes.

Nursery

In nurseries, Visser and Kehl (1961) recommended the use of an NPK Mg mixture containing 10.9 percent N, 4.7 percent P_2O_5 and 9.2 percent K_2O and 2.4 percent Mg prepared by using ammonium sulphate, ammonium phosphate, potassium sulphate and magnesium sulphate. Potassium sulphate is recommended in the nursery since chlorine toxicity in young plants may cause leaf scorch if potassium chloride is applied in the nursery. Further increase in K level in this mixture did not result in any response either on the growth characteristics or the dry matter content of the nursery plants (Ranganathan, 1980).

Young tea

Tea before first pruning is referred to as young tea. During this period, nutrients through fertilizers should be supplied for the development of healthy bushes with good frames and to reduce the immaturity period. NPK mixtures of $N:P_2O_5:K_2O$ in the ratio of 1:2:2 or 1:2:3 (De Jong, 1957) or 4:3:3 (Ranganathan, 1973b; 1976b) with N levels varying between 96 and 192 kg/ha/year was recommended for young tea, for the development of good frame. Later on thrust was also given to increasing productivity. In South India, young tea has been found to respond well to K fertilizers. Natesan *et al.* (1984a) have reported response to potassium from the first year of planting. Different levels of K were applied up to the fourth year of planting. In the fifth year, same dose of K was supplied to all the treatments (**Table 13**).

Plants, which received the highest level of K, gave the highest yield in all the years. The beneficial effect of high dose of K applied till 4th year was noticed in the fifth year also, when the same dose was given to all the treatments. Based on the results $N:K_2O$ ratios of 2:3 up to the fourth year from planting, and 1:1 from the fifth year onwards were recommended for high productivity and better frame development.

Table 13. Effect of K level ($N:K_2O$ ratio) on productivity (kg made tea/ha) of young tea

K level ($N:K_2O$ ratio)	1st yr.	2nd yr.	3rd yr.	4th yr.	5th yr.*	Total for the cycle**
K_2O applied (kg/ha)						
K1 (4:3)	90	169	197	225	188	869
K2 (4:4)	120	225	263	300	188	1095
K3 (4:6)	180	338	394	450	188	1550
Made tea (kg/ha)						
K1 (4:3)	-	187	1091	2330	2659	6257 (100)
K2 (4:4)	-	287	1413	3050	3194	7944 (127)
K3 (4:6)	-	300	1433	3331	3486	8550 (136)
SE	-	13	40	58	13	194 (3)
CD (5%)	-	25	79	113	26	379 (6)
CD (1%)	-	33	103	149	33	500 (8)

* K level was constant ($N:K_2O$ ratio of 1:1 or 4:4) for all the sub-treatments.
** Values in parentheses denotes percent yield.
Source: (Natesan *et al.*, 1984a)

Mature tea

A tea plant after its first formative pruning is called mature tea. In the review on K nutrition of tea, Ranganathan and Natesan (1985) have reviewed the major studies in South India on the response of mature tea to K and have reported crop responses up to 250 kg/ha/year. It was concluded that there is a definite response to K applied in the pruned year on the subsequent year's crop and a significant interaction of K level applied in the pruned year and that applied in the subsequent years. It was recommended that the quantity of K applied should be related to the age of the plant from pruning and the quantity of N applied annually.

Pruned tea

Following pruning, tea plants mobilises large quantities of nutrients within a short period for the formation of healthy frames and sufficient foliage. Since K is very important for the formation of sound and healthy frames, deficiency of K during this period will adversely affect the yield of the crop, even if sufficient quantity is applied during the later stages. Natesan *et al.* (1984b) in South India found significant response to K fertilizers in the pruned year on the crop harvested both in the pruned year and in the subsequent years. Higher levels of K application was found to increase the efficiency of N utilisation also.

Verma (1995) recommended the following ratios of $N:K_2O$ in the pruned year depending on the height of pruning (**Table 14**)

Table 14. Ratio of N: K in the pruned year.

Height of pruning	$N: K_2O$ ratio
Rejuvenation and pruning below 45 cm	1:2
Pruning between 45 to 60 cm	2:3
Cut across above 60 cm	1:1

Source: Verma, 1995

In the remaining years of the pruning cycle, $N: K_2O$ of 4:3 was suggested when urea is used as the source of N.

Effect of potassium on disease resistance and pest control

Deficiency of K is reported as one of the factors that weaken the plant and thus making it susceptible to red rust. (Venkataramani, 1953; Satyanarayana and Barua, 1978). Ranganathan and Natesan (1985) have reported that a high rate of applied K and shot hole

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Ranganathan and Natesan (1985) have reported that a high rate of applied K and shot hole control measures in the pruned year will help to build up the health of tea bushes by increasing the mechanical strength of stem tissues and protecting them from new attack in early stages. Verma (1995) recommended high rate of potassium (N: K_2O at 1:2) in the pruned year to protect tea bushes from new attack of shot hole borer.

Application K has been reported to increase the water use efficiency of plants. Saikia and Dey (1978) reported the effect of K application at different moisture levels on the K content in the leaf and evapotranspiration loss in young plants. Increased K concentration in the leaves resulting from an increased K application reduced the evapotranspiration losses and evapotranspiration and total K uptake were inversely related.

Manivel *et al.* (1995) reported that foliar spray of muriate of potash (KCl) combined with urea, each at 1 percent imparted drought tolerance to mature tea bushes when applied four times at monthly intervals from November/December onwards. Treated bushes were less affected by moisture stress and radiation than untreated control. Verma (1995) reported three to four applications of urea and muriate of potash each at one percent at monthly intervals, during dry period to maintain turgidity of cells, to improve water use efficiency and to reduce shoot formation.

Effect of potassium on quality

Potassium has shown favourable influence on the quality of marketable tea (Jayaratnam, 1980). Increasing level of K partially counter balanced the quality deterioration caused by very high rates of N (De Beaucorps, 1978; Deyin, 1983).

Leaf analysis

Ranganathan and Natesan (1985) suggested foliar analysis as a diagnostic tool for K deficiency. They opined that the existing methods are too imprecise to allow quantitative predictions of response to increased nutrient supply.

Conclusions

The requirement and uptake of K in relation to other major nutrients were discussed and K is regarded as the second important nutrient after N and the fertilizer K recommendations range from 180 to 450 kg/ha/year for a bush population of 13,000/ha. Response of tea to applied K depends upon the K status of the soil, age of the plants and productivity of the bushes. Results of the field experiments indicated response to K application at all the growth stages of the crop *viz.,* nursery, young, mature and pruned tea. In young tea, N: K_2O ratio of 2:3 up to the fourth year of planting and 1:1 from the fifth year onwards were recommended for high productivity and better frame development. In mature tea, the quantity of K applied is related to the age of the plant from pruning and the quantity of N applied. As under K deficiency situations growth of the plants and size of the bushes is reduced and considerable reduction on the total stand of plants was recorded, adequate supply of K should be ensured for high yield, quality and profits.

Coffee

Nitrogen and potassium are the most important nutrients required by coffee. Coffee berries contain high concentration of potassium, which will be removed from the field through harvesting. Hence maintaining adequate potassium reserve in the soil is essential to sustain the productivity of coffee.

Requirement and uptake of potassium

Reviews on potassium nutrition of coffee were earlier published by Carvajal (1985) and Rao *et al.* (1993). The nutrient uptake of the plant will depend on the nutritional status of the soil, growth rate and physiological stage of the plant and the variety. The nutrient uptake rate of single stem coffee, 3-4 years old was studied by Carvajal *et al.* (1969) in Costa Rica. The approximate amount of major nutrients taken up were 115 g of N, 8 g of P, 66 g of K, 25 g of Ca and 8 g of Mg. K uptake accounted for 30 percent of the total macronutrients excluding S (**Figure 1**). The highest rate of K uptake was observed immediately after harvesting followed by two secondary increases prior to fruit ripening and after flowering, indicating that K absorption increases immediately after main flowering and during the last stage of fruit development and later as the plant recovers from bearing fruit, when water is not limiting. It was concluded that, the uptake of nutrients by coffee would depend upon its physiological stage.

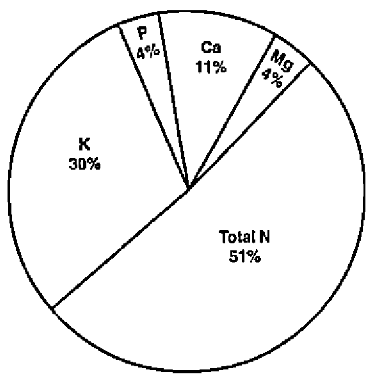

Figure 1. Yearly nutrient uptake pattern by a 3 to 4 year old coffee tree growing in nutrient solution

Cannell and Kimeu (1971) investigated the nutrient uptake and distribution in a single deblossomed stem and in fruit bearing coffee trees growing in a fertile soil. The annual uptake of macronutrients was 100g of N, 6g of P, 100g of K, 35g of Ca and 10g of Mg. Of these quantities, 8 to 29 percent would be removed in an average crop of coffee berries, and 50 to 81 percent would be returned to the soil by pruning and litter. Nutrient uptake was relatively rapid by deblossomed trees during active flush growth followed by a steady rate of uptake except for P. Uptake of P was found to be rapid during the cool dry season.

Rao (1989) reported that the nutrient removal through harvest is in the order K>N>P in India. For a yield of 6000 kg of fruit, *Coffea arabica* removed 43 kg of K, whereas for a yield of 5000 kg of fruit, *Coffea canephora* removed 48 kg of K. The distribution of K in the different plant parts of coffee was studied (Table 15). The potassium requirement of arabica coffee to produce 1000 kg coffee was estimated as 138 kg. For robusta coffee the potassium requirement was around 258 kg for production of 5000 kg of fruits equivalent to 1000 kg of clean coffee.

Table 15. Distribution of K in different plant parts of coffee

	Percent of K distribution	
Plant parts	***C. arabica***	***C. canephora***
Leaf	15.5	29.9
Stem	14.4	7.5
P/S/T	6.4	16.6
Root	1.8	9.3
Fruit	1.9	36.7
% K retained in biomass	38.1	63.3

Source: Rao, 1993

Potassium deficiency

Continuous cultivation of coffee in the same site will lead to a depletion of soil K. Mathew *et al.* (1970) reported depletion of potassium to an extent of 93 percent from a soil cultivated with coffee for over 22 years. Carvajal (1985) has described the deficiency symptoms of coffee. Mature oldest leaves show a yellowish ribbon like chlorosis near the leaf margins. A narrow yellow zone often limits the necrotic area that develops at the leaf margin. Necroses of mature leaves, followed by leaf abscision are also exhibited by K deficient plants. Dieback of the fruit bearing branches is also noticed when there is K deficiency.

Fertilizer K recommendations for coffee

The general K recommendation for the first year coffee plants is 45 kg K_2O/ha in combination with 45 and 30 kg/ha of N and P respectively. For the 2nd and third year the recommendation is 60 kg K_2O/ha in combination with 60 and 45 kg/ha of N and P_2O_5/ha respectively. The dosage is increased to 80 kg K_2O/ha during the fourth year in combination with 80 and 60 kg/ha of N and

P_2O_5. From 5th year and above the fertilizer recommendation is based on the yield (**Table 16**).

Table 16. Fertilizer recommendation for mature coffee

Yield	NPK (kg/ha)	
	Arabica	**Robusta**
Less than 1 tonne/ha	140 : 90 : 120	80 : 60 : 80
1 tonne/ha and above	160 : 120 : 160	120 : 90 : 120

Source: (KAU, 1996)

Response to potassium fertilizers

In India, coffee is usually grown under partial shade provided by regulating the canopy of shade trees. The shade trees will absorb nutrients and recycle large quantity of organic matter to the soil through pruning and litter fall which will supplement part of the nutrient requirement of the coffee plants. Hence the response of coffee to fertilizers will depend upon the nutrient status of the soil, extent of shade, nutrient uptake by the shade trees and the recycling of nutrients through pruning and litter fall.

In majority of the fertiliser experiments on coffee, response to potassium was meagre or absent. However balanced fertiliser application with N, P and K was found to be beneficial for the growth and yield of coffee.

In the review on K nutrition of coffee Rao *et al.* (1993) has reported the results of major fertilizer experiments on coffee (**Tables 17 and 18**). Data from a permanent manurial experiment with control, N, NP, NK and NPK as treatments conducted over 30 years revealed that NPK application was superior to control (no manure). Application of N at 90 kg/ha increased yield by 250 kg over control. P_2O_5 at 50 kg/ha increased the yield further by 170 kg over control. Addition of K at 90 kg/ha did not at increase the yield much. But application of NPK at 90:50:90 kg/ha resulted in an overall increase of 375 kg over no manure.

Table 17. Effect of NPK on yield of arabica coffee (kg ripe cherry/ha)

Treatment	Control	N	NP	NK	NPK
Yield	3019	3218	3211	3436	3536

Source: Rao *et al.*, 1993

Table 18. Effect of varying K levels on yield of arabica coffee (kg ripe cherry/ha)

	K levels (kg/ha)											
Treatment	0	45	90	135	180	225	270	315	360	405	450	495
Yield	3792	5032	5165	5043	5336	5681	5607	5594	5565	5743	5413	5927

Source: Rao *et al.,* 1993

Based on the results of forty six bulk trials in different agroclimatic zones with N, NP, NK, NPK and control at the rate of 75:35:45 kg/ha, a favourable trend in the response to application of balanced fertilizers of N, P and K rather than N alone or in combination with P or K was reported. Differences in yield due to K additions were marginal.

Fertilizer experiments conducted with 5 levels of NPK revealed yield increase upto a level of 160 kg N: 120 kg P_2O_5 and 160 kg K_2O/hectare.

In the experiment to determine optimum and economic dose of N, P_2O_5 and K_2O, linear response was noticed upto a dose of 225:175:225. Out of the 27 seasons studied, the data was statistically significant only in two seasons.

In another fertilizer experiment in South India with a control and NPK combinations at 60:30:60, 120:60:120 and 240:120:240 kg/ha, no significant response in yield was noticed to different levels of fertilizers. However, fertilizers applied at the rate of 120:60:120 kg/ha/yr was superior to other doses (Coffee Board, 1997-98).

K- Mg interactions

Rao *et al.* (1968) reported K induced Mg deficiency in arabica coffee at a leaf K level of 2.48% and Mg levels of 0.21 percent. The antagonistic effect is particularly relevant at total cation content of 3.5 percent and around a soil reaction of less than 6 under high rates of K applications overlooking Mg. However, K and **Mg** interaction on yield was not noticed (Rao *et al.,* 1993).

(i) Robusta coffee

Based on the results of forty-six bulk manurial experiments, application of NPK @ 60: 30: 40 kg/ha was recommended. Varying doses of NPK from 0:0:0 kg/ha to 120:90:120 kg/ha indicated linear yield increase up to 120:90:120 kg/ha and K was recommended at the rate of 120 kg/ha as the optimum dose for a crop yield of 1000 kg/ha.

NPK ratio

The NPK ratio recommended for coffee is 1:0.75:1 (Iyengar and Awatramani, 1975 and Mathew and Rao, 1980).

Effect of potassium on quality

Very few studies have been conducted on the effect of K on the quality of produce, disease and pest incidence and drought and frost resistance. Blore (1965) in Kenya and Malavolta (1970) in Brazil reported that excess potassium depressed quality. But no such adverse effect was noticed in India, even after application of K at 500 kg/ha. Adequate K fertilizers were reported to reduce the percentage of floats and black bean (Rao *et al.,* 1993).

Disease and pest incidence

It has been reported that K deficiency in the plant tissues decreases the resistance to certain parasitic fungi (Carvajal, 1985). Pathogenic fungi such as *Colletotrichum coffeanum Corticum koleroga and Cercospora coffeicola* attack the trees suffering from K deficiency causing severe damage (Anon, 1957). The die back associated with K deficiency provides a port of entry for bacteria and saprophytic fungi.

Drought resistance

Carvajal (1984) reported that potassium application enhanced drought resistance of coffee.

Resistance to frost

Potassium sulphate sprays at 0.5 to 1.0 percent in water to arabica coffee two weeks earlier to frost prone dates protected coffee to some extent from the damage due to frost resulting at temperature of around -2°C in South India (Rao *et al.,* 1985).

Leaf analysis

The fourth pair of leaves from coffee bearing lateral branches of the lower part of the tree is selected for analysis to find out the nutrient status of the plant. It was recommended to collect leaf samples twice in a year, 60 days after fertilizer application and prior to harvesting. Carvajal (1985) reported the critical level of K in the leaf as 1.5 percent and the sufficiency level as 1.5 to 2.5 percent. Visible deficiency symptoms of K was observed at a leaf K concentration below 1 percent in the fourth pair of leaves for arabica coffee. A concentration above 2.5 percent induced Mg deficiency. In robusta coffee, a leaf concentration between 1.8 and 2.5 percent in the third pair of leaves was reported to indicate normal nutrition.

Conclusions

Potassium requirement is equivalent to that of nitrogen in coffee and the optimum NPK ratio recommended for coffee is 1:0.75:1. Coffee berries contain large quantities of potassium and is removed from the system through harvesting. The uptake of K by coffee depends upon its physiological stages. The highest rate of K uptake was observed immediately after harvesting followed by two secondary increases prior to fruit ripening and after flowering. Varietal variations in the K requirement was indicated. The response to applied K was reported to be often meagre or absent. However, the need for balanced use of NPK for optimum yield was indicated through the fertilizer experiments. Large quantities of K are recycled to the system through prunings and litter of both coffee and shade trees, which may be the reason for the poor response to applied nutrient. However, continuous cultivation without K addition was reported to deplete the soil K reserve and deficiency symptoms were produced by the plants indicating the need for K additions.

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Potassium Requirement and Response to K Application in Spices

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Abstract

Spices viz., black pepper, cardamom, turmeric and ginger play important role in the economy of Kerala State. Black pepper is predominantly cultivated in the backyard as a homestead crop. It is also grown as a mixed crop and trailed on shade trees in coffee and tea plantations in the upland hills as well as in the valleys in arecanut gardens in northern parts of Calicut, Kannur and Kasaragaod districts. Much of the pepper cultivation is on lateritic soils of hill slopes or sandy clay loam soils adjacent to coastal tracts. Black pepper responds well to application of K fertilizers, as pepper growing soils are low to medium in potassium status. Removal of K by pepper was second after N. Potassium fixing capacity of cardamom growing soils of Kerala varied from 16.9 to 32.1 percent. Cardamom yields were closely related to the K buffer power of the soils and not NH_4OAc extractable K suggesting refinement of K fertilizer schedules based on K buffer power of soils.

Turmeric is mainly cultivated in Calicut, Wynadu, Kottayam, Idukki and Ernakulam districts. This crop is also a heavy feeder of potassium. When turmeric was intercropped in coconut plantations, the shade was found to influence K uptake. The uptake ranged from 158 to 314 kg/ha depending upon shade level. As ginger is mostly cultivated under homestead conditions, its growth and yields are affected by low light intensities especially when cultivated as an intercrop. Hence K nutrition plays a key role in ginger production. It was reported that only under high rates of K application the crop could be successfully grown under shade.

Spices play an important role in the economy of Kerala state. Considerable area is put under cultivation of spices in Kerala and a perusal of the figures indicates that the state stands first in area and production of these two important spices. As per the 1998-99 statistics, black pepper is being cultivated in an area of 2.31 lakh hectares (96.9 percent of Indian area) and the production is 64,340 tonnes (97.5 percent of total production). Small cardamom accounts for an area of 41,449 hectares (57.5 percent of Indian area) with a production of 4990 tonnes (69.6 percent of total production) in the same period. Ginger and turmeric are the other two important spices of Kerala. Ginger is cultivated in 14,570 hectares (18.8 percent of Indian area) and the production is 49,950 tonnes (19 percent of total production). Cochin ginger and Calicut ginger are specific grades traded in the international market for their unique quality attributes. Turmeric is cultivated in an area of 3800 hectares only (2.4 percent of Indian area) and the production is 9100 tonnes

(1.5 percent of total production). Alleppey Finger Turmeric cultivated in Ernakulam, Kottayam and parts of Duck district is another class by its own containing higher curcumin content. A review is made in this paper on the requirement of potassium and response to its application of these important spices.

Black Pepper

In Kerala black pepper is predominantly cultivated in the backyards as a homestead crop. It is also seen grown as a mixed crop and trailed on shade trees in coffee and tea plantations in the upland hills as well as in the valleys in arecanut gardens in northern parts of Calicut, Kannur and Kasaragaod districts. In Kerala much of the pepper cultivation is on lateritic soils of hill slopes or sandy clay loam soils adjacent to coastal tracts. The other soil types are alluvial and forest loam soils. Sadanandan (1993) indicated that pepper growing soils broadly come under the order mollisols, alfisols and ultisols. These soils are low to medium in potassium status. He found that exchangeable soil potassium status of major pepper growing tracts from 196 locations to range from 40 ppm to 550 ppm of soil with a mean of 180 ppm of soil. Sadanandan *et al.* (2000) while working out DRIS norms classified black pepper soils based on exchangeable K as deficient (<35 ppm), low (36-90 ppm), optimum (91-286 ppm), high (290-930 ppm) and excessive (>930 ppm).

Potassium deficiency symptoms

Nybe and Nair (1986) studied the deficiency symptoms of K in six month old rooted cuttings of black pepper (Panniyur-1) through sand culture experiment. Initial deficiency symptom appeared when leaf K was reduced to 2.1 percent. Characteristic symptoms of K deficiency include necrosis of the older tips and margins. The necrotic areas are black in colour. The necrosis appears first at the tip of older laminae gradually progressing toward the proximal end and cover about one-tenth of the leaf. The symptom spreads to upper leaves also. In severely deficient vines, the necrosis may cover as much as one-third to two-thirds of the leaf lamina. The unaffected portion of the lamina remains green. The affected leaves even with severe symptoms may not show any tendency for abscission.

Potassium content and uptake

Of all the three major nutrients, potassium is required in the largest quantity. It has been found that the potassium requirement of pepper is associated with the content of the other nutrients in the plant notably nitrogen. The nutrition of pepper cannot be taken in isolation from other aspects of its agro management, because pepper yield vary greatly as the vines are trailed on a variety of standards under a wide range of soil and climatic conditions as well as agronomic practices. The K fertilization is normally done as muriate of potash, being the only source available in the market. Even though the exact requirement of potassium for proper growth and development of different varieties of black pepper has not been worked out, only limited information is available. According to the schedule advocated by Pillai and Sasikumaran (1976) for Panniyur-1, when K was applied at 140 kg K_2O/ha, the uptake of K was 32 kg K_2O/ha. However, there was no change in the uptake of K when the dose applied to the same variety was enhanced to 200 kg/ha/year (Pillai *et al.,* 1987). According to Sadanandan (1993), when K was applied at 270 kg /ha/ year in laterite soil deficient in K, the uptake was 330 K_2O kg/ha mainly due to increase in yield obtained.

Wahid *et al.* (1982) analysed leaf samples from 'slow decline' affected plants and found that K levels of the leaves of affected vines were considerably lower than those of healthy ones. Necrosis of the distal ends of laminae was attributed to K deficiency. The pot culture studies conducted by them indicated K deficiency as a cause for the slow decline of pepper vines.

Wahid (1987) while studying the seasonal variation in foliar nutrient concentration reported that the concentration of N and K increased up to June and then decreased. With the application of NPK fertilizers in August-September, the leaf concentration again increased and dropped thereafter in October. It was found that for one kg dry berry of pepper the uptake of K was 21 grams.

Geetha and Nair (1989) noticed that a low K level in shoots is one of the factors responsible for spike shedding in Panniyur-1. Sadanandan (1993) reported the effect of soil application of K on the K status of soil, black pepper leaf and berry (**Table 1**).

Table 1. Effect of K application on K content of soil, leaf and berry

K levels (g/vine)	Soil K (ppm)	Leaf K (%)	Berry K (%)
70	81	2.26	0.72
140	102	2.40	0.81
280	125	2.64	1.00
Control	67	1.83	0.48
CD (5%)	5.6	0.08	0.04

The data presented above indicates that as the dose of applied K is increased, the K content of soil, pepper leaf and berry goes up.

Sadanandan (1994) worked out the uptake of various nutrients by rooted cuttings of about three months with four to five leaves weighing approximately two grams. The uptake of K by different cultivars used for the study is given in **Table2.**

Table 2. Uptake of K by some important cultivars of pepper

Cultivar/ Variety	Dry matter (g)	Root length (cm)	Shoot length (cm)	Uptake of K (mg/plant)
Aimpiriyan	2.8	7.0	23.0	68.1
Kottanadan	2.5	12.0	26.0	59.3
Panniyur-1	1.7	25.0	23.8	51.3
Karimunda	1.7	90.8	29.8	40.5

The K uptake was highest in the case of Aimpiriyan followed by Kottanadan. The lowest uptake was seen in the case of Karimunda indicating that nutrient removal varied between cultivars necessitating judicious application of nutrients for proper growth of nursery plants.

Mathew *et al.* (1995) noticed that the magnitude of K removal was second (6.53 g/kg fresh yield), after N which was 6.87g /kg fresh yield. They observed that the nutrient removal followed the order N > K > Ca > Mg > P > S > Fe > Mn >Zn. They also observed that the exchangeable K of the pepper root zone (0-25 cm deep and 15 cm away from the vine) ranged from 105 to 610 ppm with a mean of 271 ppm. Foliage K content (percent) ranged from 1.80 to 3.20 percent with a mean of 2.61 and spike K content from 1.65 to 2.60 with a mean of 2.70 percent.

Response to K

Sadanandan (1992) opined that pepper will respond to K application, if the ammonium acetate extractable soil K is less than 70 ppm. Black pepper responds to K application as most of the pepper growing soils in Kerala are deficient in K (Sadanandan, 1993). He also noticed significant yield increase in Panniyur-1 variety of pepper when potassium application was done at 270 kg K_2O /ha/year as muriate of potash. Sivaraman *et al.* (1987) studied the response of black pepper to application of different nutrients and fitted response functions for each one of them. The response function, optimum dose and optimum yield obtained with potash are given in **Table 3.**

Table 3. Black pepper yield response function with potassium

Response function	Optimum K dose (kg/ha)	Optimum yield (kg/ha)
$895.06+17.8095-0.033585K^2$	265	3256

Potassium requirement

Investigations on nutritional requirement of hybrid Panniyur-1 pepper in ultisol, poor in major nutrients showed that application of 270 g K_2O vine/year along with 140g N and 55 g P_2O_5 as optimum (Sivaraman *et al.*, 1987). For bush pepper grown in pots, bimonthly application of K_2O at 2.0 g/bush together with 1.0 and 0.5 g each of N and P_2O_5 was found to be optimum (Anon, 1992).

Fertilizer K recommendation

General recommendation: 150 g/vine/year.
For Panniyur-1, northern most part of Kerala and similar agro climatic regions: 200g/vine/year.
Calicut region and similar agro climatic areas: 275 g/vine/year

Small Cardamom

Cardamom is commonly grown in fairly deep laterite soils with good drainage. The texture varies from sandy loam to sandy clay loam with kaolinite as the dominant clay mineral. Srinivasan (1990) studied the K fixing capacity of cardamom growing soils of Kerala and found that it varied from 16.9 to 32.1 percent. He also found that this was positively and significantly correlated with total K. In majority of cardamom growing soils the available K status is rated to be medium to high and the main factor responsible for this is the high organic matter content of soil contributed through addition of leaf litter. The exchangeable K content of 36 soil samples from cardamom growing areas of Kottayam and Idukki districts ranged from 35 to 697 ppm with a mean of 195 ppm (Sadanandan *et al.*, 1993). Nair *et al.* (1978) noticed that there was a gradual decrease in K content with depth of soil and attributed biocycling as the reason for the high content of K in the upper layer of soil.

Potassium deficiency symptoms

Studies by Deshpande and Sulikeri (1973) revealed that K deficiency in cardamom seedlings appear first on older leaves. There was reduction in growth of shoots as well as roots and plants showed browning of leaf tips, which extended downward. Later the whole leaf turned dark brown in colour. Further sucker production was completely absent and plants died within two weeks after deficiency symptoms were first appeared.

K content and uptake

Though detailed studies on uptake of nutrients by different plant parts have not been done for cardamom in Kerala, indications of K uptake by different plant parts are available from studies conducted by Sulikeri (1986). The highest uptake was seen in shoots (42.73 percent) followed by leaves (22.69 percent), rhizome (21.20 percent) and roots (13.33 percent). However, at harvest stage, shoots accounted for the highest uptake (50.31 percent) followed by rhizome (23.67 percent), leaves (15.86%), capsules (5.31 percent), roots (3.66 percent) and panicles (1.17 percent).

Vasanthakumar (1986) reported an uptake of 540g K by one kg of dry capsules of Malabar type of cardamom. The uptake of K by Mysore and Vazhukka types were 899 and 394 g respectively.

The young leaves, tender panicles and capsules of cardamom contain more K than the older parts suggesting higher demand for proper growth, development and productivity. The leaf content of K varied between 0.89 and 2.37 percent with a mean of 1.6 percent (Sadanandan *et al*, 1993). They also reported significant correlation (r=0.550**) between exchangeable K status of soil and crop yield.

Nutrient requirement

Srinivasan and Biddappa (1990) developed a model to work out K requirement of cardamom by desorption isotherms. Based on this the total potassium requirement was worked out as TPR=(300-x) X 2.64 where 300 is the desired soil fertility level for K (kg K_2O/ ha), x is the soil test value for K (kg K_2O /ha) and 2.64 is a constant derived from the desorption isotherm model. Nair *et al.* (1997) studied the importance of K buffer of cardamom soils in the growth and yield of the crop. They observed that cardamom yield was closely related to the K buffer power of the soils and not NH_4OAc extractable K and suggested refinement of K fertilizer schedule based on K buffering capacity of soils.

Potassium refinement of recommendation

Potassium recommendations for cardamom in Kerala given in **Table 4** indicate increasing K demand with age of the plant. Potash recommendation for irrigated condition is higher than rainfed condition.

Table 4. Potassium recommendations for Kerala (kg/ha)

Year after planting	Rainfed	Irrigated
First year	50	80
Second year	75	125
Third year	150	250

Turmeric

In Kerala, turmeric is mainly cultivated in Calicut, Wynadu, Kottayam, Idukki and Ernakulam districts. Though it is cultivated in various types of soils, a well-drained loamy or alluvial soil with good organic matter status having p^H in the range of 5.0 to 7.5 is suitable for the crop. The crop cannot withstand water logging. Gravelly, stony and heavy clay soils are unsuitable for the cultivation because of their interference with the development of rhizomes.

K content and uptake

Uptake of any nutrient is influenced by various factors such as variety, type of planting materials used, soil fertility status, the amount of fertilizers applied, shade management and cropping systems. Saifuddin (1981) noticed that uptake of K was higher up to third month, which is a phase of moderate vegetative growth. He also suggested that the third leaf from top as the diagnostic leaf for K status and the period between 90 and 120 days after planting as the ideal time for sampling. When turmeric was intercropped in coconut plantations, the shade was found to influence K uptake. The uptake ranged from 158 to 314 kg/ha depending up on shade level (Anon, 1991).

Effect of K on quality

Studies by Ahmed Shah *et al.* (1988) showed that curcumin content increased with increasing quantity of applied K. Saifuddin (1981) could not notice any change in oleoresin content with graded dose of K.

Potassium recommendations

Turmeric is also a heavy feeder of potassium. The quantities of K found optimum by different workers are given in **Table 5**.

Table 5. Optimum doses of potassium for turmeric in Kerala

Location/type	Quantity of K_2O (kg /ha)	References
Kasaragod-Laterite	236	Nagarajan and Pillai (1979)
Vellanikkara-Laterite	141-233	Anon (1991)
Wynadu-Laterite	80	Muralidharan and Balakrishnan (1972)
Calicut-Laterite	120	Anon (1992)
Kerala (general)	60	Anon (1996)

(50% basal and 50% at 60 days after planting)

Ginger

Ginger is grown in a variety of soils under well drained conditions but its performance is not good in extremely acid soils. Being a rhizome crop, deep and well-drained soil is prerequisite for successful growth and production. As ginger is mostly cultivated under homestead conditions, its growth and yield are affected by low light intensities especially when cultivated as an intercrop.

Potassium nutrition plays a key role in ginger production. Jayaraj (1990) reported that only under high rates of K application, the crop could be successfully grown under shade.

Potassium content and uptake

The amount of nutrients taken up by a crop varies considerably with the soil type, climatic condition, quantity of nutrients present in soil, variety of the crop, yield realized *etc.* According to Johnson (1978), total uptake of K by ginger progressively increased with advancing period of growth. Uptake of K in leaf and pseudostem progressively increased up to 180 days and then decreased while uptake by rhizome steadily increased till harvest. He also suggested selection of 5 to 12 leaves from top for foliar diagnosis for K content and the period between 90 to 120 days after planting (active vegetative phase) as the ideal time for sampling.

Response to applied potassium

Johnson (1978) did not get any significant response to application of K for morphological characters. Low response to K application has also been reported by Muralidharan and Kamalam (1973).

Potassium recommendations

Table 6. Recommendations of K for ginger in Kerala

Reference	Quantity (kg/ha)
Nair (1969)	150
Nair and Varma (1970)	200
Paulose(1970)	150
Muralidharan and Kamalam (1973)	60
Muralidharan and Ramankutty (1977)	120
Johnson (1978)	40
Anon(1986)	40
Anon (1996)	50 (50% basal and 50% 120 days after planting)

Future lines of R& D on K

1. Spices are valued for their intrinsic quality. The role of potash nutrition in quality of spices need in depth study. Similarly K is considered to impart disease tolerance to crop plants. One disease or other attacks all the spice crops and studies are required to understand the effect of

K nutrition in imparting tolerance to spices.

2. Studies on organic matter decomposition resulting from forest litter in cardamom and mulching in other spices and the K availability in the soil have not been carried out to any great extent. It is quite possible that decomposition of organic matter by certain bacteria present in soil may make K in a more available form to the plants.

3. The release of K in soil, factors affecting its availability, influence of different cations and anions on absorption of K as well as translocation is to be understood in much more deeply. Recommendation for K based on the buffer power of soil needs further analysis.

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Potassium Requirement and Response to K Application in Banana

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Abstract

Banana with its versatile utilities and capacity to thrive both as an irrigated upland crop and as rainfed low land crop equally is a favourite choice of the farmers, whether marginal, medium or large. Kerala, is the second largest banana producing state and is cultivated in an area of 80,640 hectares with a production of 793,330 tonnes.

Potassium has been recognised as the key element in banana nutrition as the effect of this nutrient being manifested equally on the quantitative and qualitative aspects of the crop. The potassium requirement by banana exceeds that of by any other crop and over any other element. The different cultivars of banana commercially popular in Kerala have shown response upto the level of 400 grams of K per plant, depending upon the soil type. Potassium fertilization favourably influences all the important growth characters of the crop namely height and girth of pseudostem, total leaf area index and dry matter production at all growth stages of the crop. Uptakes of major nutrients and some micronutrients show increasing trend with potassium supply. Significant positive correlations exist for potassium application with bunch yield and also yield contributing factors viz., number of bands, fruits per bunch and size of the fruit. Potassium is found to enhance individual fruit characters like length, girth, weight and volume of the fruit. Potassium also plays a pivotal role in improving the quality of the produce like shelf life, flesh peel ratio, total and non-reducing sugars.

Potassium Requirement and Response to Potassium Application in Cashew

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Abstract

Cashew responds very well to K application in K deficient soils. Potassium application enhances growth, flowering, nut yield and nut quality. There is a linear relationship between nut yield and K requirement in cashew. Potassium stands second, next to nitrogen in the order of importance, in cashew nutrition. Yield increases in the order of 50 to 100 percent, are reported from many places. Right doses of potassium are to be applied at the right time following appropriate methods for getting optimum yields. A thirty-year-old cashew tree removes 1265g of K_2O through vegetative parts including root system, apples and nuts. A kilogram of raw nut and its apple removes 24.7g of potassium. The K recommendation for cashew varies from 125g K_2O per tree (Andhra Pradesh) to 750g per tree (Kerala). Spray application of 1 percent KNO_3 along with Cultar (1000 ppm) and carbaryl (0.1%) during late September enhances flowering, fruiting and nut yield. Soil fertility based and productivity linked K recommendations are necessary for each and every agro climatic conditions.

Cashew *(Anacardium occidentale L.)* is one of the most important and widely relished nuts in the world. The global cashew area is around 2 M. ha with a raw nut production of around 1.2 M. t. India ranks first in the world with respect to area (0.72 M. ha) and production (0.44 M. t) with foreign exchange earnings equivalent to Rs. 24500 millions during 1999-2000 by export of cashew kernels and cashew nut shell liquid. In India cashew is mainly grown in the states of Kerala, Andhra Pradesh, Orissa, Maharastra, Karnataka, Tamil Nadu and Goa. Kerala has second highest area under cashew (**Figure 1**). The production and productivity of cashew remained low mainly because of low adoption of scientific nutritional and management practices.

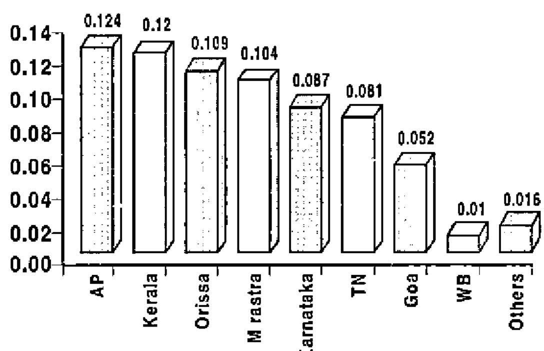

Figure 1 Cashew area (M.ha) in major states

Cashew is a tree crop that follows an indeterminate type of growth pattern. Since the tree thrives well even in adverse soil environments, there is a belief that cashew does not require any fertilizers. This is not at all true. A large number of experiments conducted in India and abroad conclusively proved that cashew generally responds very well to applied fertilizers. In this paper potassium requirement and responses to potassium application in cashew have been reviewed.

Cashew soils

Cashew is being grown all over the tropics and part of subtropics. It is well adapted to a wide variety of soils from coastal sands to degraded, poor soils, which are not suited to grow other crops, are normally allotted for cashew. Cashew grows well in soils, which are very poor in nutrients. It is grown abundantly in loose sandy soils particularly in South India. In Kerala, it grows well in poor laterite soils. Cashew prefers well-drained aerated sandy loam with adequate moisture. Coastal plains and plateau regions are very good for cashew.

Potassium uptake by cashew

Potassium is the second major nutrient that is required by cashew in the largest quantity, next to nitrogen. A 30 year old cashew tree removes 1.265 kg of K_2O through vegetative parts including root system, apples and nuts (Mohapatra *et al.,* 1973). Beena *et al.* (1995a) quantified nutrient offtake of cashew. According to them, through a kg of nut and its apple, 24.7 g potassium, is removed. Mohapatra *et al.,* 1973 studied the nutrient composition of one-year vegetative and reproductive growth of a 30-year-old cashew tree and determined the NPK ratio as 8.6:1:3.2. Richards (1993) determined the N: P: K ratio of a 6-year-old tree as 4:5:1.3.

Effect of potassium on flowering

Spray application of 1 percent KNO_3 along with cultar (1000 ppm) and carbaryl (0.1%) during late September enhances flowering, fruiting and nut yield in cashew (Pushpalatha, 2000).

Response to potassium

Plant height increased with increase in K application upto 150 g of K_2O per tree per year (Kumar, 1985). According to Latha (1992), the plant height increased with increasing K application upto 1000 g of K_2O per tree per year.

Leaf nutrient content: According to Haag *et al.* (1975), leaf K content ranging from 1.11 to 1.29 per cent indicates sufficiency where as K content ranging from 0.2 to 0.26 per cent K deficiency in cashew. The leaf K concentration for highest growth was determined as 0.342 per cent in cashew seedlings (Falade, 1978). Increase in K application from 50 to 150 g per tree per year increased leaf K content from 0.85 to 0.98 percent in cashew (Kumar, 1985). The leaf K content of cashew seedlings raised in Hoglands nutrient solution completely devoid of K was

1.06 percent where as it was 3.17 per cent in seedlings grown in nutrient solution containing K (Gopikumar and Aravindakshan, 1988). The leaf K content increased from 1.14 to 1.23 per cent when K level was increased from 0 to 1000 g K_2O per tree per year (Latha 1992). The leaf K content decreased from 0.96 to 0.73 percent with increase in age of the plant from 6 to 70 months (Richard, 1992).

The leaf K content varied with leaf position. It was highest (2.74 %) in seventh and eighth leaf and lowest (0.54 %) in first leaf from inflorescence (Mathew, 1990). Beena (1992) reported the highest leaf K content at early flowering phase and lowest at fruiting phase. The concentration of N, P and K in leaf was high at flushing and early flowering phase. (Richards 1993).

Nut yield: Nambiar (1983) observed positive effects of potassium on cashew. Application of potassium increased the cashew nut production particularly in the presence of nitrogen (Lefebvre, 1973). Significant positive effects of potassium on growth and yield of cashew were reported by Ghosh (1988). Kumar (1985) obtained linear response for potassium upto 150 g K_2O per tree. Increase in potassium levels from 50 g per tree to 150 g per tree increases nut yield (**Figure 2**), apple yield (**Figure 3**), shelling percentage (**Figure 4**) and kernel protein (**Figure 5**) in cashew. A linear relationship between potassium uptake and nut yield in cashew (**Figure 6**) was also observed. Research indicates that, next to nitrogen, the response of cashew is more to potassium application. The response of cashew to the major nutrients is in the order of N, K and P. Cashew is a nitrogen lover and N and K nutrition is of greatest significance in enhancing the production and productivity of cashew (Abdul Salam, 1997).

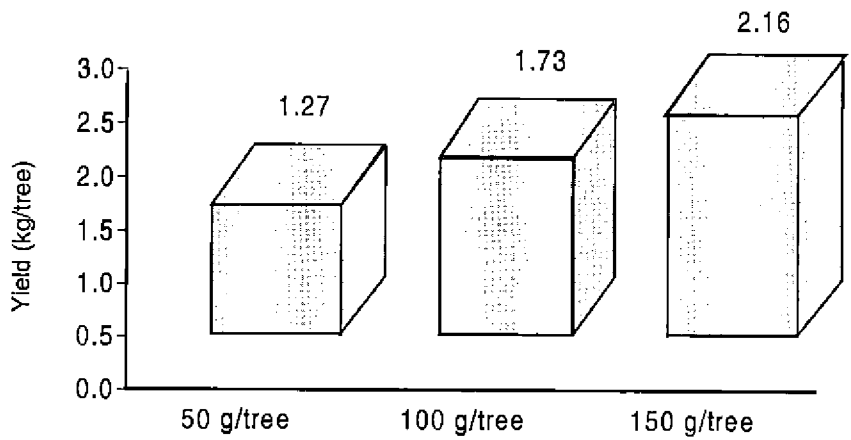

Figure 2. Effect of potassium on nut yield (kg/tree)
(Kumar, 1985)

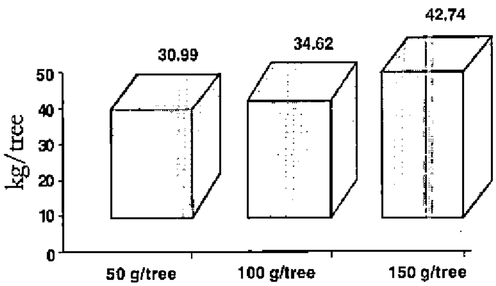

Figure 3.
Effect of Potasium on Cashew Apple Yield
(kg/tree)
(Kumar, 1985)

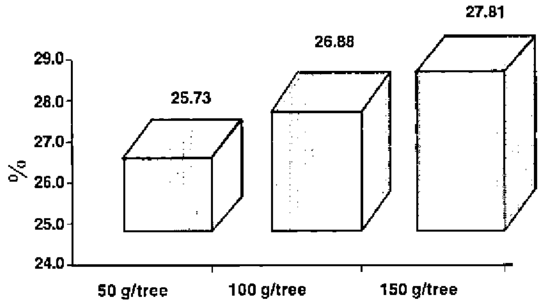

Figure 4.
Effect of Potasium on Shelling Percentage
(Kumar, 1985)

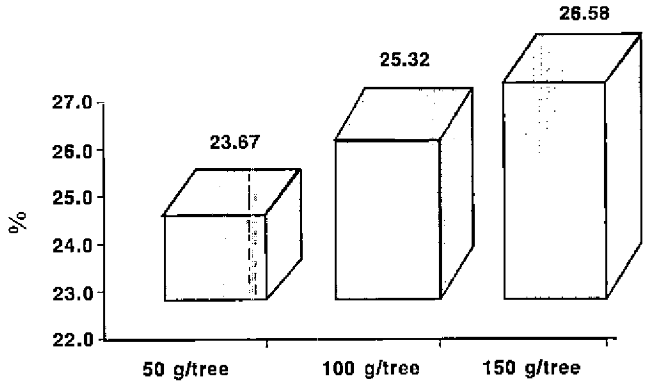

Figure 5. Effect of Potasium on Kernel Protein Percentage

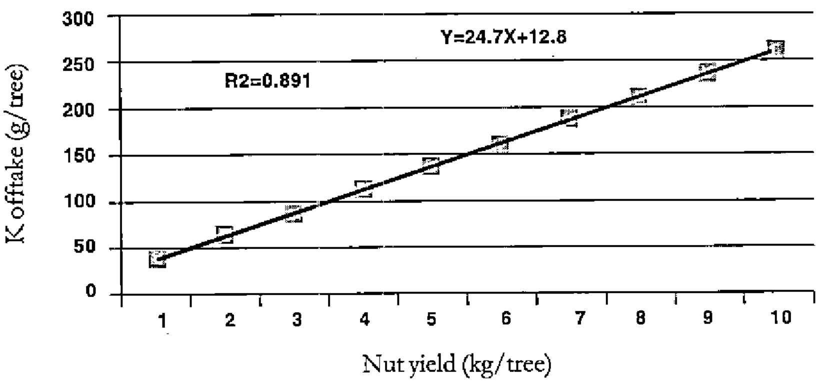

Figure 6. K offtake in relation to Nut Yield in Cashew

Factors influencing fertiliser requirements

The nutritional dose of a crop depends on several crops and climate related factors in which the crop is grown. The level of crop productivity also influences the nutritional requirement. The important soil, climate and crop related factors that dictate the nutrient requirement of cashew is briefly indicated below.

Soil factors : The major soil related factors that influence the K requirement of cashew are the available potassium status of the soil, soil pH, soil organic carbon, the base saturation, and cation exchange capacity of the soil. In addition, the soil physics involving the structure, texture and water holding capacity also influence the nutritional dose. It is obvious that the fertiliser requirement will be low in a rich soil and high in a poor soil.

Varietal factors : The productivity of the variety is another important factor that influences the quantity of fertilisers. Varieties possessing higher yield potential should receive higher doses of fertilisers in tune with their higher physiological demand.

Climatic factors : The most important climatic factor that influences the nutritional requirement of a crop is the quantum of rainfall and its distribution. The potential evapo-transpiration of the area is a major environmental parameter, which decides the soil moisture availability of the region. Cashew performs well under low altitudes (less than 450 m) with a well-distributed annual rainfall of 1500 - 2000 mm. The performance is good in humid tropical environments where maximum temperature does not exceed 35 - 40 ^{0} C and minimum temperature do not fall below 18^{0}C. The humidity regime of 70-80 per cent without frost is good for better performance. The fertiliser requirement will be more in an environment with well distributed rainfall as it encourages production.

Type of farming : The K requirement of a crop depends on the type of farming (rainfed or irrigated). Under rainfed conditions, the nutritional demand may be less compared to irrigated farming. Under irrigated farming, the crop productivity will be larger and cashew may demand higher nutritional dose.

Nutrient recommendations for cashew

The nutritional doses recommended for cashew in the seven major cashew growing states of India are indicated in **Table 1.** Kerala recommends higher K dose mainly because of poor soil fertility status of soils where cashew is grown.

Table 1. Fertilizer doses recommended for cashew in Karala compared with recommendations for other states

State	**Fertilizer dose for adult tree (g)**		
	N	**P_2O_5**	**K_2O**
Kerala	750	325	750
Maharastra	1000	250	250
Tamil Nadu	500	250	250
Andhra Pradesh	500	125	125
Karnataka	500	250	250
West Bengal	500	160	160
Orissa	500	250	250

Nutrition in relation to age: Cashew is a tree crop that requires at least seven years to attain the status of a full-grown tree, with stabilized yield. During this period, the growth parameters in terms of height, girth and canopy spread increase gradually. Therefore, it is necessary to evolve fertiliser doses in relation to age. The fertiliser recommendation in relation to age of trees for different states, are given in **Table 2.**

Table 2. Fertiliser recommendation in relation to tree age

State	**Percentage of fertilizer dose recommended for adult trees**				
	1 year old	**2 year old**	**3 year old**	**4 year old**	**5 year old**
Kerala	10%	25%	50%	75%	100%
Maharastra	25%	50%	75%	100%	100%
Tamil Nadu	15%	30%	40%	60%	100%
Andhra Pradesh	-	25%	50%	75%	100%
Karnataka	12%	25%	50%	N-100% P&K-50%	100%
West Bengal	33%	66%	100%	100%	100%

Time of fertilizer application: Agronomically, for getting maximum efficiency of applied nutrients it is necessary to apply the fertilizers at the physiological phase of the tree at which the internal nutrient demand is the highest. Beena *et al.* (1995b) studied root activity of cashew in relation to phenological phases employing ^{32}P soil injection technique, in the laterite soils of Kerala. Highest root activity and peak absorption of ^{32}P were noticed in flushing and early flowering stage, which extended from September to December. It is suggested that the onset of this phase is the most appropriate time for fertilizer application in a cashew orchard. Root activity was lowest in maturity and harvest phase (March - June). However, irrigation during this period enhanced ^{32}P uptake by the roots.

The seasons of fertiliser application for cashew, for various states of the country are shown in **Table 3**.

Table 3. Seasons of fertilizer application in Kerala and other states

State	Month of application
Kerala	June-July and September-October
Maharastra	August-September
Tamil Nadu	October-November
Andhra Pradesh	June-July and October- November
Karnataka	September
West Bengal	September-October

Root distribution pattern of cashew and method of fertiliser application:

Cashew being a perennial tree, it has to remain continuously in a soil over a long period of time. It has a deep and spreading root system. Root distribution pattern of cashew depends on the age of the tree, the type of planting material, the soil environment in which it is grown, level of nutrition, irrigation *etc.* Majority of feeding roots normally reside in the surface layer of the soil. Taproot of three and half-year-old cashew extends upto 3.2 m and lateral spread of root varies with age of trees. Khader (1986) reported that 85 percent thick roots and 45 percent fine roots occur within 15-cm surface soil layer. Shallow soil depth restricts vertical spread of cashew roots (Vidhyadharan and Peethambaran, 1979). According to Wahid *et al.* (1989), the lateral root activity of adult cashew tree was traced upto 4 m and to a depth of 60 cm. Using ^{32}P soil injection technique, they found that absorption was mostly from 0 to 15 cm soil layer than from deeper zone, suggesting that cashew is a surface feeder. They explained that an area of 2 m radially around the tree account for above 72 percent of total active roots. In shallow laterite soils, cashew tree develops an extensive root system and majority of roots (89.3%) occur 300 cm laterally around the tree and 100 cm vertically. The pattern of decrease in root density in relation to lateral distance suggests that fertiliser application is to be done within 300 cm laterally around the cashew tree (Abdul Salam *et al.,* 1995).

Fertilizers are to be applied in the tree basin where the feeding roots are concentrated. The feeding root zone depends on the age of the tree. It is generally believed that majority of the feeding roots reside under the canopy area, and as such fertiliser application can be restricted to this zone. For adult trees, fertilizers can be broadcast and incorporated over the entire tree basin (15 cm deep) within a radial distance of 2 to 3 meters within the drip line, leaving half a meter from the tree trunk. Instead, fertilizers can be placed in narrow trenches of 15-cm depth (taken

2-3 m radially around the tree), and covered with soil. For young trees, fertilizers can be broadcast and incorporated over the entire tree basin (10 cm deep) within the canopy area.

Future K needs

Potassium is one of the most important elements in cashew crop nutrition. Its role in increasing growth, flowering, fruiting, nuts yield and nut quality of.cashew is well established. The K recommendation for cashew varies from 125g K_2O per tree (Andhra Pradesh) to 750 g per tree (Kerala). For the present cashew area of Kerala state (0.12 M. ha) (at a plant population of 200 trees per hectare) and K_2O dose of 750 g per tree) the annual K requirement is estimated to be around 18,000 tons. The area under cashew is expanding fast and as such, this estimate may cross the figure of 50000 tons within a time span of another five years.

Suggested future lines of research and development

Productivity linked and soil fertility based nutritional recommendations are to be evolved for every agroclimatic environment.

The effect of KNO_3 on flowering is well indicated. However this aspect needs elaborate studies.

The NK interaction appears to be more significant in cashew and therefore the effect of combined application of N and K needs to be explored further.

The effect of K to induce tolerance against tea mosquito bug also needs investigation.

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Potassium Requirement and Response to Potassium Application in Tuber Crops

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Abstract

*Tuber crops viz., cassava (**Manihot esculenta**), sweet potato (**Ipomoea batatas**), yams (**Dioscorea alata and Dioscorea esculenta**) and edible aroids (**Colocasia esculenta, Xanthosoma sagittifolium** and **Amorphophallus paeoniifolius**) play an important role in the maintenance of food security, since they serve as starchy secondary staple, especially for the weaker sections of the population. They also serve as animal feed and industrial raw material. Potassium deserves special attention in the production of tuber crops, due to very high K removal in the harvested produce and the relatively low K supplying capacity of the soils in which they are generally cultivated. Potassium nutrition of cassava is fairly well investigated. Positive responses of cassava to K application, in plant growth, dry matter partitioning, production of higher number of storage roots, tuber yield and improvement in tuber quality have been reported. Cassava under rainfed farming responded up to 100 kg K_2O/ha. High yielding hybrid varieties of cassava responded to still higher levels of K nutrition under irrigated conditions. Potassium fertilization at higher levels was instrumental in realizing higher yields from cassava intercropped in coconut gardens. In other tuber crops detailed investigations on K nutrition are limited. The available information shows that the K demands of these crops are very high and they respond positively to K fertilization. For sweet potatoes, 50 kg K_2O per hectare was found to be sufficient. Yams responded up to 120 kg K_2O/ha. Yield attributes and tuber yield in taro significantly increased up to 100 kg K_2O/ha. To realize satisfactory yield from elephant foot yam 150 kg K_2O/ha is recommended.*

The important tuber crops cultivated in Kerala are cassava (*Manihot esculenta*), sweet potato (*Ipomoea batatas*), greater yam (*Dioscorea alata*), lesser yam (*Dioscorea esculenta*), elephant foot yam (*Amorphophallus paeoniifolius*), tannia (*Xanthosoma sagittifolium*) and taro (*Colocasia esculenta*). Minor tuber crops like Chinese potato (*Solenostemon rotundifolius*) and arrow root (*Maranta arundinacea*) are grown in certain areas. The recently introduced African white yam (*Dioscorea rotundata*) is also gaining popularity among farmers of Kerala. Among these, cassava ranks first in area (0.15 M ha) and production (2.58 M. t) and thus it is found in the cropping patterns of all the districts, covering 7 percent of the net cultivated area. Sweet potato is grown in 2000 hectares with an average yield of 10 t/ha. Other tuber crops mainly yams and edible aroids are grown in 30,000 hectares. Since most of them are under polyculture in homestead gardens, crop-wise statistics on area and production is not available. In general, resource poor farmers cultivate tuber crops with very little attention on soil fertility management. This is one of the reasons for the low productivity of tuber crops, when compared to their potential yield (**Table 1**).

Table 1. Potential and average yield of major tropical tuber crops

Crops	Reported high yield		Duration	Average yield (t/ha)* 1996-97		
	Source	t/ha	(days)	World	India	Kerala
Cassava	CIAT, 1969	100	305	10.1	22.5	18.2
Sweet potato	Enyi, 1977	51	150	15.0	8.2	10.5
Taro	Plucknut and Pena, 1971	129	365	6.6	NA	NA
Yams	Rehm and Espig, 1976	60	275	9.1	NA	NA

* *Source:* FAO Production Year Book
NA- not available

The high demand for nutrients especially for K, by tuber crops is well known. Hence for the realization of the full potential of these crops and to sustain the productivity, greater attention needs to be given to soil fertility management.

Potassium requirement of tuber crops

Potassium through its role in synthesis and translocation of carbohydrates has considerable importance in the nutrition of tuber crops. Inadequate supply of K in the nutrition of tuber crops may lead to excessive vegetative growth at the expense of tuber production. Potassium deficiency leads to reduced tuber growth and production of poor quality tubers. The amount of nutrients required for different tuber crops per ton of harvested produce are provided in **Table 2.** As a general rule, for every kg of N removed by tuber crops, 1 to 1.25 kg of K is removed. Most of the soils growing tuber crops being lateritic (Oxisols), red (Alfisols) and sandy loams (Entisols), are poor in native fertility with poor nutrient retention capacity and low K supplying capacity. Hence K is often considered as the limiting factor in maximizing the yield.

Table 2. Nutrient requirement (kg) for one ton of harvested produce

Crop	N	P	K
Cassava	6.58	2.37	6.28
Sweet potato	6.15	0.75	8.75
Greater yam	6.52	0.92	7.77
White yam	6.11	1.11	5.40
Lesser yam	6.10	1.36	5.68
Elephant foot yam	3.38	0.83	7.27
Taro	7.00	1.00	9.23
Chinese potato	4.11	0.50	4.11

Uptake of potassium by tuber crops

Considerable variation is noticed in the uptake pattern, of potassium among tuber crops. The varieties, soil type, level of nutrient supply, cropping system and management practices usually dictate K uptake.

Potassium uptake by cassava

Experiments conducted at Central Tuber Crops Research Institute, Trivandrum (CTCRI) indicated considerable variations among cultivars in the K removal pattern. The high yielding hybrids extracted more nutrients in comparison to local cultivars. Most of the varieties producing 30 tons fresh tubers per hectare removed about 140-160 kg K (CTCRI, 1983). Nayar *et al.* (1986) found that the high yielding varieties, Sree Sahya and Sree Visakham absorbed higher amounts of K both under rainfed and irrigated conditions as compared to other cultivars under test (**Table 3**) and increased with increased rate of K application. As regards the effect of crop component in the cropping system, K uptake by cassava in association with banana was found to be higher (**Table 4**) that in association with eucalyptus being the lowest (Ghosh *et al*, 1987). This variation suggests that cassava is more efficient in absorption of K than banana, but less efficient when compared to eucalyptus. Nayar and Sadanandan (1992) evaluated the nutrient uptake pattern of cassava intercropped with coconut and found that the peak demand for K was from 120-240 days, which coincides with the tuber enlargement phase. According to Mohankumar and Nair (1996) in rice-cassava sequential cropping system, which is becoming popular in the upland paddy lands of Kerala, the K uptake by the system is as high as 340 kg/ha (54 kg K by rice and 286 kg K by cassava).

Table 3. Potassium uptake by cassava (kg/ha)

Cassava varieties	**1981-82**			**1982-83**		
	Rainfed	**Irrigated**	**Mean**	**Rainfed**	**Irrigated**	**Mean**
M-4	92	90	91	90	127	109
Sree Sahya	105	116	111	112	153	132
Sree Visakham	109	134	122	112	161	136
Levels of N:K(kg/ha)						
50 : 50	71	88	80	70	95	83
100 : 100	97	106	102	99	133	111
150 : 150	119	125	122	114	172	143
200 : 200	122	134	128	135	198	166
Mean	102	113	-	105	147	-

Source: Nayar *et al.* (1986)

Table 4. Uptake of potassium by cassava under different crop combinations

Crop/crop combinations	K uptake (kg/ha) by Cassava
Cassava (Sole crop)	129.8
Banana + cassava	204.0
Leucaena + cassava	106.5
Eucalyptus + cassava	60.6
Coconut + cassava	98.7

Source: Ghosh *et al.* (1987)

Potassium uptake by other tuber crops

Information on nutrient uptake pattern by other tuber crops is very limited. In sweet potato, maximum K uptake was recorded up to 60 days of planting (CTCRI, 1983). A crop yielding 15 t/ha extracted about 160 kg K/ha. Nair and Mohankumar (1984) found that increase in levels of lime application was instrumental in enhancing K uptake by sweet potato. To produce one ton of sweet potato tuber, about 11 kg K_2O is required (Sree Latha *et al.*, 1999).

Kabeerthumma *et al.* (1987) investigated the nutrient uptake and utilization by yams, edible aroids and Chinese potato. The uptake of K in relation to N by these crops are provided in **Table 5.**

Table 5. Nutrient uptake by yams, aroids and Chinese potato

Crop	Yield (t/ha)	Dry matter (t/ha)	Nutrient uptake		
			N	P	K
Lesser yam	17.87	9.97	111.56	14.88	92.16
Greater yam	18.60	8.55	114.41	14.87	140.54
White yam	28.99	11.67	116.52	17.30	122.68
Elephant foot yam	33.00	8.70	128.82	23.64	239.55
Taro	17.00	6.20	124.80	19.20	134.97
Chinese potato	25.54	10.52	106.70	13.23	107.42

Source: Kabeerathumma *et al.* (1987)

In yams (*D. alata* and *D. esculenta*), the uptake of K increased progressively with age of the plant and the maximum utilization was noticed between 3rd and 5th month. In elephant foot yam also maximum K utilization coincided with the tuber-bulking phase between 3rd to 5th months. In the case of taro (*Colocasia esculenta*) the peak uptake of K was recorded during 2nd and 3rd month. Mohankumar and Sadanandan (1990) also reported similar results. According to Kabeerathumma *et al.*, (1987) in Chinese potato the peak period of K utilization spreads over a long period *i.e.* between 60-120 days after planting. The K uptake pattern as influenced by different levels of shade in yams and aroids was investigated by Pushpakumari and Sasidhar (1996). In general, high shade depressed K uptake (**Table 6**).

Table 6. Effect of shade on potassium uptake of yams and edible aroids

Shade levels	Greater yam	Lesser yam	Tannia	Elephant foot yam
Open	329.00	118.33	93.92	145.35
25% shade	253.43	176.80	143.80	131.38
50% shade	481.73	85.30	121.25	32.22
75% shade	78.40	27.00	81.92	42.25
Mean	285.64	101.80	110.22	88.05

Source: Pushpakumari and Sasidhar (1996).

Response to applied potassium by tuber crops in Kerala

Cassava

Effect on growth and yield

The influence of potassium on growth and yield of cassava was studied, by many research workers. Ashokan and Sreedharan (1980) found increase in plant height and top yield at higher levels of potassium applied to cassava. Nair (1982) recorded enhancement in plant height during the later stages of growth at higher rates of K fertilization. In a micro plot experiment in red loam soil, Nair and Aiyer (1985) observed improvement in plant height, stem girth and leaf retention due to higher rates of potassium. The influence of six levels of K_2O, *viz.* 0, 50, 100, 150, 200 and 250 kg/ha applied to the high yielding hybrid cassava, Sree Sahya was studied by Ramanujam and Indira (1987). They observed that plants that received no potassium were stunted. Further, increase in plant height, number of leaves produced per plant, accumulation of biomass per plant and crop growth rate was recorded with increase in levels of K_2O up to 200 kg/ha. In leaf area index (LAI), there was no significant effect beyond 50 kg K_2O per ha (**Table 7**). Nayar *et al.* (1985) evaluated the effects of four levels of potassium *viz.*, 50,100,150 and 200 kg/ha in combination with corresponding levels of nitrogen on three varieties of cassava under irrigated and rainfed conditions. From this study it was found that incremental dosages of potassium in combination with nitrogen were instrumental in enhancing the crop growth rate, total dry matter production and root to shoot ratio up to 150 kg K_2O/ha (**Table 8**)

Table 7. Effect of potassium on growth characters of cassava

Levels of K_2O (kg/ha)	Plant height (cm)	Number of leaves/plant	LAI	Biomass (g/plant)	CGR (g m^2/day)
0	176.9	277.2	1.88	1681.4	6.91
50	191.3	290.0	2.20	1859.1	7.64
100	195.0	296.7	2.29	1878.9	7.72
150	200.0	305.0	2.24	1872.2	7.71
200	210.0	306.2	2.34	2023.2	8.31
250	201.3	301.9	2.26	1928.3	7.29
CD (5%)	6.4	12.5	0.13	96.6	0.41

Source: Ramanujam and Indira (1987)

Table 8. Effect of N and K on dry matter production, crop growth rate (CGR) and root: shoot ratio of cassava under rainfed and irrigated conditions

Levels of N & K_2O (kg/ha)	Dry matter (t/ha)		CGR (gm^{-2}/day)		Root : Shoot ratio	
	Rainfed	Irrigated	Rainfed	Irrigated	Rainfed	Irrigated
50:50	8.47	10.68	2.84	3.64	1.41	1.74
100:100	10.33	14.96	3.49	4.97	1.45	2.10
150:150	11.96	16.72	4.01	5.56	1.53	2.08
200:200	12.88	17.95	4.33	5.96	1.54	2.02

Source: Nayar and Mohankumar (1985)

In cassava, number of storage roots per plant and the mean tuber weight were reported to be affected by levels of K nutrition. Mohankumar *et al.* (1971) recorded significantly higher number of tubers per plant at 100 kg K_2O/ha. Better tuber size also was reported at the above level (CTCRI, 1973). According to Nair and Aiyer (1985) though maximum number of tubers per plant was recorded at 100 kg K_2O/ha greater tuber size was obtained at 150 kg K_2O/ha. However, Nair and Sadanandan (1987) got significant increase in tuber number per plant up to 200 kg K_2O/ha (**Table 9**). In cassava, intercropped in coconut gardens, effect of potassium in enhancing number of tubers per plant was significant only up to 100 kg K_2O/ha (Nayar, 1986). But the mean tuber weight increased up to 150 kg K_2O/ha (**Table 10**).

Table 9. Response of cassava (Sree Sahya) to K fertilization

Levels of K_2O (kg/ha)	Mean no.of		Mean tuber tuber/plant		Tuber yield weight (g)	Starch (%) pooled		HCN (µg/g)	
	1978	1979	1978	1979	mean	1978	1979	1978	1979
50	10.03	9.93	152	148	17.25	27.59	28.02	52.33	51.67
125	11.58	11.12	161	178	22.75	28.19	28.94	40.28	42.46
200	12.03	13.47	150	193	24.20	29.47	29.17	43.61	36.39
CD (5%)	0.69	0.77	NS	9.6	2.12	0.44	0.74	6.85	5.48

Source: Nair and Sadanandan (1987)

Table 10. Fresh tuber yield (t/ha) of cassava as influenced by N:K fertilization under rainfed and irrigated farming

N:K levels	1981-82			1982-83		
	Rainfed	Irrigated	Mean	Rainfed	Irrigated	Mean
50 : 50	23.56	34.46	28.91	14.55	17.84	16.20
100 : 100	22.53	36.94	30.76	18.06	28.19	23.13
150 : 150	24.18	40.23	32.20	23.03	31.97	27.49
200 : 200	22.74	41.05	31.89	24.73	35.20	29.97
Mean	23.25	38.17	-	20.09	28.30	-
CD (I mean)	5.55			5.71		
CD(M mean)	N.S			2.02		

Source: Nayar *et al.* (1985)

Potassium fertilization resulted in significant yield increase in cassava. The response to potassium levels ranging from 0 to 200 kg K_2O/ha by hybrid cassava variety, H-97 was evaluated by Mohankumar *et al.* (1971). It was observed that maximum yield of 29 t/ha was obtained at the level of 100 kg K_2O/ha. Application of K beyond 100 kg/ha depressed tuber yield, though the concentration of K in plant parts increased. Rajendran *et al.* (1976) also reported that 100 kg K_2O/ha was optimum for cassava and higher rates resulted in luxury consumption. However, Pushpadas and Aiyer (1976) obtained yield response up to 125 kg K_2O/ha for the variety H-165. Similarly Ashokan and Sreedharan (1977) recorded, response up to 135 kg K_2O/ha for the variety H-97. For the red loam soils having an available status of 65.2 kg K/ha, Nair and Aiyer (1985) recommended 128 kg K_20/ha as the optimum dose. Nair and Sadanandan (1987) studied the response to 3 levels of potassium, *viz.* 50, 125 and 200 kg K_2O/ha and recorded yield increase up to the highest level of potash application (Table 9). Nayar *et al.* (1985) observed increase in tuber yield with increase in rates of N and K especially under irrigated conditions (Table 10). In cassava intercropped in coconut gardens, significant increase in tuber yield was recorded with higher rates of K application. But the difference in yields at 100 kg K_2O and 150 kg K_2O/ha was marginal (Nayar and Sadanandan, 1992) (**Table 11**).

Table 11. Effect of levels of potassium on cassava intercropped in coconut gardens

Levels of K_2O (kg/ha)	Number of tubers/plant		Mean tuber weight (g)		Tuber yield (t/ha)		Pooled mean
	1983-84	1984-85	1983-84	1984-85	1983-84	1984-85	
50	3.75	3.46	170.12	173.19	6.19	5.74	5.96
100	4.40	4.43	220.94	204.87	9.55	8.70	9.12
150	4.63	4.46	226.40	213.44	10.17	9.05	9.61
CD (5%)	0.11	0.09	5.83	9.33	-	-	0.10

Source: Nayar and Sadanandan (1992)

Effect on tuber quality

Several investigators observed the beneficial effect of potash nutrition in enhancing the starch content of cassava tubers. Improvement in starch content and quality parameters of starch, *viz.,* amylase content, granule size, pasting temperature, viscosity and swelling volume with increase in rates of K application was reported by Nair and Aiyer (1986). The effect of potassium at higher levels in reducing HCN content was documented by Nair and Aiyer (1986), Nair and Sadanandan (1987), and Ramanujam and Indira (1987).

N: K Interaction

The effect of N: K interaction in cassava nutrition varies according to soil type and variety. Mohankumar *et al.* (1971) at CTCRI, Trivandrum found that in laterite soil the optimum N: K ratio was 1:1 i.e., 100 kg each of N and K_2O. Rajendran *et al.* (1976) also confirmed the ratio 1:1 of N:K_2O for cassava in laterite soil. Pillai and George (1978) reported that for cassava cultivar, M-4 in red loam soil an N: K ratio of 1:1.5 gave higher yield. However, Ashokan and Sreedharan (1978) observed that an N: K ratio of 1: 1.3 was ideal for cassava grown in red loam soil. Nair (1982) working out the N: K requirements of high yielding cassava varieties reported N: K ratio of 1:1.25 for cassava in red soil of Trivandrum and ratio of 1:2 in sandy loam soils of Kayamkulam (Alleppy district).

Sweet potato

Differential response to applied potassium by sweet potato has been reported. Ashokan *et al.* (1984) found 60 kg K_2O/ha as the economic dose for the rainfed sweet potato grown in Trichur tract. Oommen (1989) observed that higher levels of potassium had positive effect on leaf area index, net assimilation rate and crop growth rate recorded at different stages of growth. Similar results were reported by Nair and Nair (1995). Bhuvanendran Nair and Muralidharan Nair (1992) investigated the effect of 3 levels of K (50,75 and 100 kg K_2O/ha) on sweet potato and reported that the variations in levels of K had no significant influence on yield components and yield of sweet potato . In reclaimed soils of Kuttanad also there was no response to increased levels of K by sweet potato (Elizabeth and Mohamed, 1989). In field experiments conducted at CTCRI (**Table 12**) also there was no response to K application beyond 50 kg potassium per hectare (Ravindran and Bala Nambisan, 1987). Nayar and Vimala (1991) also reported similar results.

Table 12. Effect of K fertilization on sweet potato tuber yield (t/ha)

Levels of K (kg/ha)	Low land	Upland
25	14.74	16.00
50	19.21	18.23
75	18.23	18.80
100	20.36	18.60

Source: Ravindran and Bala Nambisan (1987)

Yams

Studies on potassium nutrition of yams in Kerala are very limited. From experiments conducted at CTCRI, Trivandrum, Singh *et al.* (1973) reported that lesser yam (*D. esculenta*) responded up to 120 kg K_2O/ha (**Table 13**). However the quality parameters of lesser yam were not influenced by lower levels of K application (**Table 14**). Greater yam (*D. alata*) also responded up to 120 kg K_2O/ha (CTCRI, 1983). However the quality parameters of lesser yam were not influenced by higher levels of K application.

Table 13. Effect of K fertilization on yield (t/ha) of lesser yam

Potash levels (K_2O kg/ha)	1967-68	1968-69	1969-70	Average
0	15.88	16.00	16.07	16.28
40	19.22	22.20	18.53	19.98
80	20.81	22.02	19.50	20.78
120	26.35	23.90	21.19	23.81
160	22.43	22.00	18.02	20.82
C.D. (5%)	1.97	0.78	1.41	

Source: Singh *et al.* (1973)

Table 14. Quality constituents of lesser yam as affected by different levels of K

Potash levels (K_2O kg/ha)	1968-69			1969-70			
	Dry Matter (%)	Carbo-hydrate (%)	Crude protein (%)	Dry Matter (%)	Starch (%)	Sugar (%)	Crude protein (%)
0	26.89	22.84	2.85	25.40	18.99	1.23	3.02
40	27.34	23.04	2.71	26.70	19.62	1.57	3.16
80	27.02	23.96	3.04	25.70	20.90	1.56	2.71
120	28.34	24.31	3.20	26.20	21.90	1.09	2.78
160	27.14	23.68	2.90	26.10	20.74	1.19	3.13

Source: Singh *et al.* (1973)

Edible aroids (Taro, Tannia and Elephant Foot Yam)

Earlier studies in taro showed that increased levels of K nutrition had no significant effect on plant height; number of suckers and leaf area index (Pillai, 1967) but the later studies clearly indicated that K application at 100 kg K_2O/ha had significant positive effect on plant height and LAI (Mohankumar and Sadanandan, 1989). Pillai (1967) from field experiments conducted at Vellayani, Trivandrum, reported that tuber yield of taro increased linearly with K application up to 120 kg K_2O/ha. Ashokan and Nair (1984) recorded positive response on yield components and yield up to 80 kg K_2O per ha, at Vellanikkara, Trichur. Mohankumar and Sadanandan (1989) suggested 100 kg K_2O/ha as the optimum dose (**Table 15**). Detailed investigation on K nutrition of tannia is lacking. According to Nair *et al.* (1990), elephant foot yam needed 150 kg K_2O/ha to produce good yields in Ultisols, under rainfed upland conditions (**Table 16**).

Table 15. Effect of levels of K on yield and yield components of taro

K levels (kg K_2O/ha)	Cormel yield (t/ha)	No.of cormels	Mean weight of cormel (g)
50	8.36	7.30	30.94
100	8.82	7.36	32.76
150	9.10	7.41	33.72

Source: Mohankumar and Sadanandan (1990)

Table 16. Effect of K nutrition on elephant foot yam

Levels of K Kg/ha	Yield (t/ha)
75	14.00
150	15.50
225	18.50

Source: Nair *et al.* (1990)

Future K needs

Crop-wise statistics on potassium fertilizer consumption in Kerala are not available. Limited information on adoption of fertilizer recommendation by tuber crops farmers indicated that, in general, adoption level is poor mainly due to financial constraints. Since tuber crops remove large amounts of K from the soil, to sustain the production K fertilization at the recommended rates (**Table 17**) will be imperative. If it happens, the need for K fertilizers will increase and for the increased K demand, assured K supply would be essential and inevitable.

Table 17. Fertilizer recommendation for tuber crops

Fertilizers (kg/ha) Crop	FYM (t/ha)	N	P_2O_5	K_2O
Cassava	12.5	100	50	100
Sweet potato	5.0	50	25	50
Taro	12.5	80	50	100
Tannia	12.5	80	50	100
Lesser yam	10.0	80	60	80
Greateryam	10.0	80	60	80
Elephant foot yam	25.0	100	50	150
Chinese potato	10.0	60	60	100

Future research needs

Review of research on K nutrition of tuber crops has shown significant and consistent yield increases in all the crops like cassava, taro and elephant foot yam. But inconsistent response in sweet potato, which removes very large quantities of potash needs systematic research. K nutrition on yams and minor tuber crops is also limited. Hence, more studies are required. Further, the following aspects need detailed investigation.

Nutrient management for targeted yield

Targeted yield site-specific nutrient management involving varying doses of K assume greater importance now than before. More detailed studies are required.

K management for the cropping system

It is well known that in Kerala most of tuber crops are cultivated in association with tree/ plantation crops Hence studies on K requirement of the cropping systems involving tuber crops is important.

Maximization of K use efficiency

The entire quantity of K fertilizers to India is imported, hence any effort to improve the efficiency of K fertilizers will go a long way not only to improve the economy of the country, but also to enhance the returns to the resource poor farmers who are the main producers of tuber crops. In long duration crops like cassava, yams and edible aroids that too grown under high rainfall areas the use of slow nutrients release products are beneficial. Since slow release N and P fertilizers are available, development of slow release K is felt necessary.

Effect of K on quality

In each and every experiment, quality parameters as influenced by K fertilization need to be thoroughly studied.

Potassium budgets

Monitoring K balance in soil under varying treatments would help arresting K mining.

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Conclusions and Recommendations

Session I

Potash - global supply and need

Over the years, there was an increased use of nitrogen but not a proportionate increase in the use potassium. This over-reliance on N causes unbalanced fertilizer use which is the major factor in low production in India. The demand of potassic fertilizers should be increased to fulfill the need. Importance of popularizing the use of K especially under Indian scenario was emphasized.

Potassium - The building block for high yields in India

The unbalanced NPK ratio limits nutrient use efficiency thus, reducing farmer's profit. The law of minimum and the requirement of K for different plant functions are discussed. The removed K from soil by plants can be replaced only through fertilizers. Steps to overcome K problems and urged for refocusing of extension need for K application, use of mass media for popularization of research results, involvement of scientists in fertilizer industry, extension service of the scientists to the field, involvement of policy makers in scientific meetings giving more importance to the popular articles of scientists are stressed. It is concluded saying that awareness among farmers on the use of K is very much essential for India's development.

Potassium requirement and response to K application in cereals

Continuous cropping without K application will cause depletion of nutrients leading to more response of cereals to K in the Kerala soils. The requirement of K in cereal crops is high. There is seasonal variation in the response of K in cereal crops and differential response to K between traditional and high yielding varieties. Response to K varies in various soil textures also. The role of K in disease and pest incidence of rice, quality of rice, physiological parameters and yield attributes are significant. Nutrient interaction *viz.*, K/Mg, K/Mn, K/Fe were found to affect the yield potential even when the nutrient concentrations are above critical level. The reasons for this are to be explored. Application of 120 kg K_2O/ha in K deficient zone gave good response.

Potassium requirement and response to K application in plantation crops

Requirement of K depends on the nature of produce, nutrient recycling, deficiency symptoms of K in plantation crops such as rubber, tea and coffee, nutrient removal and immobilization of K in plants, soil sufficiency range, leaf sufficiency range and critical ion concentration of K in soil. Review of the research work indicated that K nutrition greatly helped in crops. Effect of K on quality of tea and coffee was highlighted.

Session II

Potassium requirement and response to K application in coconut gardens and coconut based cropping systems

Potassium dynamics in coconut based cropping system and the role of K in plant nutrition was discussed. Studies conducted by CPCRI reveal that all soil groups in Kerala are deficient in potassium. Without K application, a yield of 40 nuts per palm can be obtained. To increase the yield, application of K fertilizer is essential. Studies on crop removal indicate that 70 kg of potash is removed by a tree in Kerala. Effect of K in precocity in flowering was discussed. The necessity of K fertilizer right from the date of planting was stressed.

Adult palms responded positively to K fertilizer application and there was 35-45 percent increase in nut and copra yield. Nut characters were also influenced favourably by K addition. The K requirement of coconut-cocoa intercropping system and coconut-clove-pineapple intercropping systems were discussed. It was concluded that K retentive capacity of tropical soil could be enhanced through organic recycling.

Status of potassium reserves in soils of Kerala - Build up or depletion

It was pointed out that clay mineral type, soil reaction, heavy crop removal and low organic matter content were the factors governing K depletion in Kerala tropical soils. Early work done on the extent of K deficiency, forms and types of K in rice soils of Kerala, K in particle size fraction, total and available K in Kerala soils were discussed. It was concluded that Kerala soils are inherently deficient in K. Build up of K as in the case of P cannot be expected and judicious application of K has to be continued.

Requirement and response to application of potassium in cashew

Requirement of K is next to N in cashew followed by Ca and P. A 30 year old cashew tree removes 1265 g K_2O. Application of K showed increase in nut yield by 50 -100 percent. Potash recommendation for cashew should be based on nut yield. The high K requirement of high yielding varieties of KAU was projected. Potassium fertility rating and K fertility status of cashew plantation were reviewed as low or medium and K recommendation for cashew ranges from 125 - 750 g/tree. Development of location specific varieties, standardization of optimum NK combinations, studies on the effect of KNO_3 on flowering, effect of K on kernel quality and effect of K in combating tea mosquitoes were suggested as future lines of work..

Potassium requirement and response to K application in banana

Banana is a heavy feeder of K. Pseudostem girth, photosynthetic efficiency, and duration of photosynthesis were higher with K applied plants. Yield components, quality parameters, pulp peel ratio, were also improved by K application. Firmness of pulp was improved due to K application which also extended shelf life. It was emphasized that Judicious application of K to mother plants creates a healthy future generation and quality planting material.

Potassium requirement and response to K application in tuber crops

Average yield of tuber crops is very low in Kerala compared to the potential. The role of K in important tuber crops cultivated in Kerala as human food, animal feed and industrial raw material are considerable. Tuber crops generally show high K uptake. Under shaded conditions K uptake was high. Potassium application improved plant height and number of leaves of cassava. Effect of N and K on dry matter and crop growth rate was high under irrigated condition. Intercropping cassava in coconut gardens showed that number of tubers increased upto 100 kg K/ha. N:K ratio of 1:2 was found better for cassava. Sweet potato responded well upto 50 kg/ha of K_2O. The studies on lesser yam are very limited. Responses have been recorded upto 120 kg K_2O/ha. On the quality parameters of *Diascorea esculenta* and taro, response upto 150 kg/ha was obtained. In elephant foot yam response were significant upto 225 kg/ha. Nutrient management for targeted yield, development of slow release K fertilizers, K management for cropping system and maximization of K use efficiency were suggested.