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Importance of Potash Fertilizers for Sustainable Production of Plantation and Food Crops in Sri Lanka

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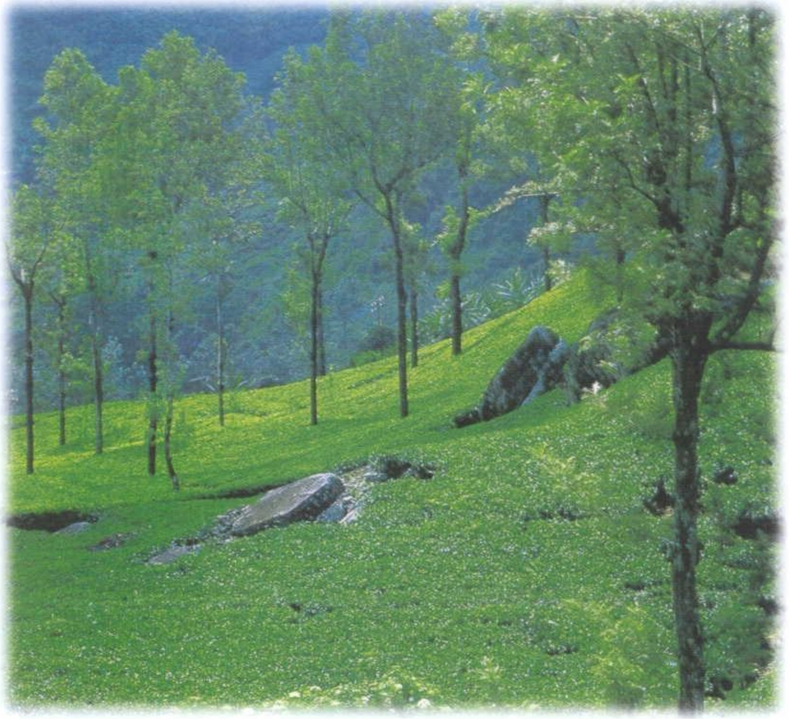
V.V. Nossov & J.D.H. Wijewardena



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Edited by:

V.V. Nossov
IPI Coordinator India, Sri Lanka and Bangladesh
IPC, Post Box 486, Moscow 119034, Russia
Tel.: +7-095-258-61-81
Fax: +7-095-258-61-91
E-mail: nosov@ipcmos.com

J.D.H. Wijewardena
Regional Agricultural Research & Development Centre
Department of Agriculture, Ministry of Agriculture, Livestock, Lands & Irrigation of Sri Lanka
Bombuwela, Sri Lanka
Tel./Fax: +94-34-22-816-73
E-mail: jdhwije@yahoo.com

National Fertilizer Secretariat
Ministry of Agriculture, Livestock, Lands & Irrigation of Sri Lanka
80/5, Govijana Mandiraya, Rajamalwatta Avenue
Battaramulla, Sri Lanka

International Potash Institute
P.O. Box 569
CH-8810 Horgen
Switzerland

International Potash Institute
P.O. Box 569
CH-8810 Horgen
Switzerland
Tel.: +41-43-810-49-22
Fax: +41-43-810-49-25
E-mail: ipi@ipipotash.org
Web: www.ipipotash.org
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Chapter III: POTASSIUM NUTRITION MANAGEMENT OF FOOD CROPS

Foreword

Sri Lanka has favourable climatic conditions suitable for growing of a wide diversity of crops. During the recent yeas the country has experienced considerable changes, resulting in the open economy and the involvement of the private sector into the economic activities.

Concern of a global food production to feed the growing population of the world requires increased efforts to develop new expedients for the future. Free world trade has opened new opportunities for producers in Sri Lanka to enter global markets.

Undoubtedly, to send high quality production to the world market, appropriate attention should be paid to the balanced application of fertilizers. In this respect, potash fertilizers play a vital role in crop production. Healthy agricultural production of high quality could be achieved when potash fertilizers are applied in adequate rates and in balance with other nutrients.

In general, Sri Lankan agriculture shows relatively balanced use of mineral fertilizers (nitrogen to potassium ratio is about 1:0.4). High share of potash in mineral fertilizers is a clear indication that crops, and especially plantation crops, are fed with balanced nutrients. At the same time, there is low total application of fertilizers for some crops, for instance, such plantation crops as coconut and rubber. This is a serious restrain to achieve higher yields and, hence, more earnings from export-oriented agriculture.

The International Potash Institute (IPI) in cooperation with the National Fertilizer Secretariat (NFS), Ministry of Agriculture, Livestock, Lands & Irrigation of Sri Lanka, has conducted the International Workshop on *"The Importance of Potash Fertilizers for Sustainable Production of Plantation and Food Crops in Sri Lanka"* in Colombo on 1-2 December 2003. This workshop is a continuation of IPI activities in Sri Lanka since the year 1994, when the International Seminar on the *"Integrated Crop Management in Tea: Towards Higher Productivity"* has taken place in Colombo.

This book summarizes the results of research activities on the status of soil potassium (Chapter I) and the response of major plantation and food crops to potash fertilizer application (Chapter II and III) in different agro-ecological zones of Sri Lanka. Updated fertilizer recommendations are given for the most important crops. Moreover, major directions of further research activities are indicated to improve the available potash fertilizer recommendation.

In general, the main objective of this publication is to attract more attention to the important role of potash fertilizers in achieving of sustainable high yields and top quality of both plantation and food crops in Sri Lanka.

V.V. Nossov
IPI Coordinator India, Sri Lanka and Bangladesh

Chapter I

POTASSIUM STATUS IN SOILS OF SRI LANKA

Potassium status of tea growing soils in Sri Lanka

A.K.N. Zoysa and G.P. Gunaratne

Tea Research Institute of Sri Lanka, Talawakelle, Sri Lanka

Abstract

Tea (*Camellia sinensis* L.) is grown on highly weathered Oxisols and Ultisols in Sri Lanka. The main features of tea growing soils are low nutrient availability, acidity and low organic carbon content and high erodability. Tea occupies an extent of 180,000 ha in Sri Lanka and spreads from low to high elevations categorized as: Low country (0-600 m), Mid country (600-1200 m) and Up country (>1200 m), which accounts for 42, 30 and 28% respectively. The soils of different agro-ecological regions suitable for tea growing in Sri Lanka fall in to three major soil groups. They are Red Yellow Podzolic soils, Reddish Brown Latasolic soils and Immature Brown Loam soils, of which the greatest extent is represented by Red Yellow Podzolic soils. Tea soils could be divided in to three groups according to mineralogy. Some soils in Mid country have considerable amounts of K-containing minerals, i.e. mica, interstratified mica/vermiculite and vermiculite. The K release patterns in a range of tea soils were studied using an indicator plant with exhaustive cropping to examine the relationship between various K forms. The content of total and exchangeable K in tea soils varies with the location. Both these forms of K are generally high in the Up country compared to the Low country. Potassium that is immediately available for plant nutrition is generally present in the soil solution and application of K fertilizer in tea plantations greatly influences K concentrations in the soil solution. In soils, containing low specifically absorbed or non-exchangeable K, the exchangeable K may play a dominant role in the K availability. The chemical equilibrium between non-exchangeable and exchangeable K forms is very complex and depends on the overall K status of soils. Therefore, differences could be observed in soil K levels in tea growing soils owing to differences in buffering characteristics of soils. It is worthwhile to consider the K dynamics in tea soils while recommending K fertilizer application for tea plantations on a discriminatory basis.

Introduction

Tea is one of major plantation crops grown in Sri Lanka and its contribution to the national economy is highly significant owing to its large share in the annual foreign exchange earnings to the country. Tea generally prefers acidic soil conditions and it is well grown in the wet and intermediate zones of Sri Lanka. The total tea production in the country steadily increased in the last decade and the major contributor to this growth is the tea smallholder sector in the Low country that accounts 61% of the production. Tea production in the country recorded a peak production of 310 million kg in 2002 (CBSL, 2002).

As the country's annual tea production and the productivity are increasing, soil fertility and sustainability issues in tea lands are of serious concern among tea growers in Sri Lanka. Most tea soils are highly acidic and poor in nutrient retention capacity and cation exchange properties owing to highly weathered clay minerals and low organic carbon contents. Therefore, application of mineral fertilizers, especially potassium in tea soils, plays a major role in supplying K requirements to tea plants. Thus, a good understanding of K status in soils and its changes with time is important in effective utilization of K fertilizer in tea cultivation. This paper, therefore, makes an attempt to report the recent findings on K research in tea soils of Sri Lanka.

Tea growing soils

Tea (*Camellia sinensis* L.) in Sri Lanka is grown in a wide range of soil types derived from diverse parent materials (De Alwis and Panabokke, 1972; Eden, 1976). The mineralogy and the type of soils differ greatly within the country. Most tea soils are highly weathered and strongly acidic. Tea soils of different agro-ecological regions in Sri Lanka fall into three major soil groups (De Alwis and Panabokke, 1972). They are Red Yellow Podzolic soils, Reddish Brown Latasolic soils and Immature Brown Loam soils groups. The largest extent of tea cultivation is covered by Red Yellow Podzolic soils.

Most tea soils contain an abundance of variable charged colloidal minerals, such as oxides and hydrous oxides of Fe and Al and 1:1 type clay minerals. Tea soils are generally low in effective CEC (usually <10 $cmol_c\ kg^{-1}$). The soils have low base saturation and high Al saturation (often >40%). The strong weathering of these soils reduces plant-available K contents in the soil solution. The overall effect is that it leads to an infertile plant growth medium. Therefore, tea soils need to be managed properly for the maintenance of high fertility status, which would result in high tea yields. Some important chemical properties of tea soils in Sri Lanka are presented in Table 1.

The most important chemical property for the good growth of tea is pH. Generally, soil pH, where tea is cultivated, varies from 3.3 to 6.0 (1 : 2.5 w/v soil : H_2O). The optimum range of soil pH for tea is 5.0-5.6 (Othieno, 1992). The maintenance of soil pH between 4.5 and 5.5 is recommended for Sri Lanka (Anon, 2000). Tea is considered as a calcifuge, and does not grow well in soils of high base saturation. However, it still needs a certain amount of calcium (Ca) for satisfactory growth and for maintenance of high yields (Eden, 1976; Ranganathan and Natesan, 1985). Tea is also known to take up large quantities of aluminium without suffering from Al toxicity (Chenery, 1955; Foy *et al*., 1978).

Table 1. Some chemical characteristics (0-15 cm depth) of tea growing soils in Sri Lanka (Zoysa, 1997)

Location	Soil pH*	Organic C	Total N	C:N	CEC	Exchangeable K	Exchangeable Mg	Exchangeable Ca	Extract. P, mg kg^{-1}**
		----- % -----			---------- $cmol_c$ kg^{-1} ----------				
St. Coombs	4.5	2.6	0.22	12	10.1-13.3	0.2	0.1	0.6	73
Hantana	4.4	1.4	0.13	11	5.0-7.2	0.1	0.2	1.0	170
Passara	3.9	3.1	0.20	15	1.1-1.9	0.1	0.1	0.3	19
Kottawa	5.2	1.6	0.13	13	3.4-3.9	0.2	0.1	0.2	17
Ratnapura	4.7	1.7	0.13	14	1.3-2.6	0.1	0.1	0.1	25

* Soil : H_2O = 1 : 2.5 w/v

** P is extractable by using Borax method (Beater, 1949)

Clay mineralogy

Major clay minerals presented in tea soils are kaolinite, gibbsite and geothite (Golden *et al*., 1981). These soils are broadly categorised as Ultisols, Oxisols and Inceptisols according to the US soil taxonomy, as these soils are in an advanced stage of weathering. Based on the mineralogy, soils in tea growing regions are divided in to three groups (Golden *et al*., 1981; Wimaladasa, 1989). The first group is comprised of Up country soils (>1200 m above the mean sea level - amsl), which contain predominantly kaolinite, Al-chlorite, gibbsite and geothite with subsidiary amounts of K-feldspars, anatase and plagioclase feldspars. The second group consists of Mid Country Wet Zone (600-1200 m amsl) and Dry Zone (600-1800 m amsl) soils, which contain highest amount of kaolinite and a considerable amount of mica, interstrafied mica/vermiculite and vermiculite. The third group is found in the Low country (<600 m amsl), which is rich in kaolinite and small amounts of gibbsite and geothite. All the tea soils contain considerable amount of gibbsite. Geothite is found in all the soils under tea, except for soils in Galle, where halloysites are found (Hettiarachchi, 1993). Results of detail mineralogical studies on Sri Lankan tea soils are presented in Table 2.

Table 2. XRD analysis on mineralogical composition of clay fraction in tea soils of Sri Lanka (Golden *et al*., 1981)

Location	Depth, cm	Area	XRD analysis	Clay	Gibbsite	Kaolinite
				------------	%	-----------
St. Coombs	0-15	Talawakelle	K, V/C, g, q	38.7	3.87	8.90
	15-30		V/C, K, g, q			
	30-45		V/C, K, g, q	46.9	5.63	9.85
Passara	0-15	Badulla	K, (v/c), v/mi, g (trace)	49.4	<0.50	29.60
	15-30		K, q (trace)			
	30-45		K, q (trace)	44.7	<0.45	19.67
Panwila	0-15	Kandy	K, q, g, mi (trace)	44.7	0.45	27.40
	15-30		K, g, q, mi, v/c (trace)			
	30-45		K, g, q, mi (trace)	50.4	0.50	29.23
St Jaochim	0-15	Ratnapura	K>G, v, q	27.3	1.91	8.39
	15-30		K, v, g, q (trace)			
	30-45		K, v, g, q (trace)	31.8	2.23	18.13
Kottawa	0-15	Galle	K>G, v, q	17.8	1.25	9.43
	15-30		K, g, v, q (trace)			
	30-45		K, g, v, q (trace)	16.2	0.97	8.26

K – kaolinite; V/C – hydoxy-interlayered vermiculite; G – gibbsite, Q – quartz, Mi – mica.
Note: Upper case letters mean major component and lower case for minor components.

Forms of soil potassium

Potassium in soil is generally consisting of three fractions that are in dynamic equilibrium, as shown in the following equation (Mengel and Kirkby, 1987):

Labile K		Labile K		Non-labile K
(soil solution K)	⇆	(K adsorbed to cation exchange complex)	⇆	(K in minerals and organic matter)

The fraction of soil solution K (K^+) is the immediate source of K available for plant uptake. The solid phase of labile K fraction is held on soil colloidal surfaces, and this is in rapid equilibrium with soil solution K. It consists of exchangeable K adsorbed into the cation exchange complex. The non-labile-K is mostly composed of K that is held in organic matter and various K minerals. It is rather resistant form, which may release K very slowly into the labile K pool. These definitions are very broad, and it is very difficult to distinguish clearly between these pools (Schroeder, 1972).

The concentration of K in the soil solution is very low at any given time, hence, replenishment of soil solution K from other exchangeable K sources is very important in determining the continuity of K supply for plants. The ability of soil to replenish the soil solution with K depends on the transformation of K between various labile K forms and the nature of their equilibrium with soil solution (Mengel and Kirkby, 1987).

Plant available potassium

Owing to complexity of the dynamic equilibrium between various soil phases, it is extremely difficult to predict the available soil K. Therefore, plant available K is more a fundamental concept than a measurable quantity, and its determination in soil is not a straightforward task. Only a measure of K related to the pool of K that is plant available can be measured. Such relationships have been developed by regressing measured soil K concentrations against plant yields, or plant K concentration values, for various crops including tea (Sivasubramaniam and Jayman, 1976).

Several investigators have established good relationships between NH_4OAc-extractable K or K that was extracted by other procedures with plant K uptake. These methods can be used for soils high in smectite, kaolinite and organic matter, but low in illite, other K bearing minerals or vermiculite (Bertsch and Thomas, 1985; Chandler *et al*., 1945; Pope and Chenery, 1957; Rasnake and Thomas, 1976; Von Braunschweig, 1980). Potassium concentration measured in water extracts also showed a good relationship with plant uptake (Nemeth, 1975). However, it was found that this method appeared to extract loosely held exchangeable K^+, particularly in tea soils, probably by displacement with H_3O^+ (Wimaladasa, 1989). Lysimeters have been widely used in field trials to extract soil solutions, despite the wide variation in results. Subsequently, the application of centrifugation technique has overcome many problems encountered in the extraction of soil solution (Linehan and Sinclair, 1988). Exchangeable K concentration in the soil is usually used as a guide to assess K status is soils and during the period of 2000-02, a soil survey was conducted to collect data on exchangeable K concentration in tea growing soils. The exchangeable K was determined by NH_4Cl (pH=7) extraction method and data are presented in Table 3.

The soil exchangeable K values in the areas of Up Country Wet Zone are rather high compared to the other areas. This could be attributed to high retention of K in soils with high organic C content in the Up country as compared to the other zones.

Potassium replenishing ability of tea growing soils

The ability to replenish K in soils was studied by Gunaratne *et al*. (2000) using exhaustive cropping of ryegrass (*Lolium perenne*) as an indicator plant. They used soils of six major tea-growing areas for the study. Compared to the initial exchangeable K in the soil (60-116 mg kg^{-1}), the removal of K by the intensive exhaustive cropping reduced it in all the soils to narrow range of 8-21 mg kg^{-1} after 8 repeated cuts. This study revealed that there are some specific locations, which contained either secondary and/or primary K releasing minerals. However, it was found that most tea growing soils do not contain K releasing minerals. This observation was further supported by mineralogical analysis of Golden *et al*. (1981), Wimaladasa (1989) and Hettiarachchi (1993).

Table 3. The exchangeable K concentration in some tea growing areas in Sri Lanka

Agro-ecological region	Areas	Exchangeable K, mg kg^{-1}	
		Average	Range
IM2	Madulsima, Morawakkorale, Haputale, Hantana, Medamahakumbura, Hevaheta lower	156	130-210
IM3	Hewaheta, Matale south	108	65-215
IU1	Kellebokka, Knuckles, Rangala, Matale east	123	60-230
IU2	Udapussellawa, Maturata, Haputale west	123	80-230
IU3	New Galway, Badulla, Haputale west	175	75-200
WL1	Ratnapura, Kalutara, Galle, Kelaniweli	110	70-160
WL4	Galle	100	80-120
WM1	Morawakkorale, Ambagamuwa, Ratnapura	107	75-170
WM3	Balangoda, Rakwana, Hunnasgiriya, Matale south and east	173	155-190
WU1	Kotmale, Maskeliya	180	85-290
WU2	Pussellawa, Dickoya, Dimbula, Ramboda, Pundaluoya	236	90-500
WU3	Nuwara Eliya	290	160-380

Quantity/Intensity (Q/I) isotherms of K in tea soils

The availability of K to plants depends on the K concentration in the soil solution and the ability of the soil to maintain its K concentration at a given time. This capability refers as the K buffer capacity of a soil. It varies between soils and this capability is considered important as far as the K availability is concerned. The quantity factor (Q) represents the amount of the availability of the nutrient, whereas the intensity factor (I) reflects the strength of retention of the nutrient in the soil. In establishing Q/I curves, soils are equilibrated with solutions containing constant amounts of $AlCl_3$ and increasing amounts of KCl (Tinker, 1964). The intensity of K in soil at equilibrium with its soil solution is considered as the activity ratio (AR^K) and these values have been used as a measure of K^+ availability. Tinker (1964) showed that in acid soils, Al^{3+} is dominant compared to Ca^{2+} and Mg^{2+}. Hence, for soils that receive dolomite for a long period, a combination of the activities of Ca^{2+} and Mg^{2+} and Al^{3+} has been found to be more appropriate:

$$AR^K = \frac{a_{K^+}}{(a_{Ca^{2+}} + a_{Mg^{2+}})^{1/2} + (a_{Al^{3+}})^{1/3}}$$

Gunaratne et al. (2002) established Quantity/Intensity (Q/I) curves for six soil series in Sri Lanka where tea is commonly grown and the results are given in Table 4. High initial AR^K values could be observed in the soils of Talawakelle, Hantana, Deniyaya and Passara and they were 23, 17, 22 and 19 × 10^{-4} $M^{2/3}$ respectively compared to the soils of Kottawa and Ratnapura, which had values of 8 and 12 × × 10^{-4} $M^{2/3}$ respectively. This is owing to high initial labile K (ΔK^o) values in the former soils (160, 100, 130 and 80 mg kg^{-1} respectively) compared to low ΔK^o values found in the latter soils (30 and 40 mg kg^{-1} respectively).

Table 4. The parameters derived from Q/I isotherms (Gunaratne *et al.*, 2002)

Location	Soil series	Depth, cm	AR^K, $\times 10^{-4}$ $M^{2/3}$	ΔK^o (-- mg kg^{-1} --)	K_x (-- mg kg^{-1} --)	PBC^K, $\times 10^4$ mg kg^{-1} $M^{-2/3}$
Hantana	Kandy	0-15	17	100	1200	6.15
		15-30	9	40	600	7.61
Ratnapura	Malaboda	0-15	12	40	1200	3.52
		15-30	8	30	530	3.72
Talawakelle	Mattakelle	0-15	23	160	2020	6.66
		15-30	8	40	1040	5.21
Kottawa	Dodangoda	0-15	9	30	630	3.80
		15-30	5	20	380	4.28
Deniyaya	Weddagala	0-15	22	130	530	6.66
		15-30	10	40	580	5.00
Passara	Mahawalatenna	0-15	19	80	340	4.50
		15-30	16	70	530	4.61

Based on the initial potential buffering capacity (PBC^K) of soils, tea soils could be mainly divided into two categories. The soils of Passara, Ratnapura and Kottawa showed low potential buffering capacity (PBC^K) of 4.5, 3.5 and 3.8 × 10^4 mg kg^{-1} × × $M^{-2/3}$ respectively compared to high values found in the soils of Deniyaya, Talawakelle and Hantana, which showed 6.66, 6.66 and 6.15 × 10^4 mg kg^{-1} $M^{-2/3}$ respectively. This could be due to high content of organic carbon and clay in the soils of the latter group compared to the former. The soil group with high values of PBC^K (Deniyaya, Talawakelle and Hantana) showed a continuous availability of K over a long period, while the soil group with low PBC^K (Passara, Ratnapura and Kottawa) required frequent K fertilization to maintain K contents required for tea cultivation.

The studies of Gunaratne *et al*. (2002) also showed the presence of specific sites for K in the cation exchange complex and they attributed that phenomenon to the content and type of clay minerals, organic matter and pH. The soils of Talawakelle, Ratnapura and Hantana showed more K specific sites (2020, 1200 and 1200 mg kg^{-1} respectively) compared to the low values that were found in Kottawa, Deniyaya and Passara (630, 530 and 340 mg kg^{-1} respectively). Using available results on soil K buffering capacity, Gunaratne *et al*. (2002) proposed a scheme to characterized tea soils and this scheme (Table 5) could be used as a guide in the future K fertilizer recommendations for tea growing soils in Sri Lanka on a more site-specific basis.

Table 5. Characterization of tea soils based on K buffering parameters (Gunaratne *et al*., 2002)

Location	PBC^K	K-specific sites	
Talawakelle Hantana Deniyaya	High	High Low	High availability of soil K Low availability of soil K
Ratnapura Passara, Kottawa	Low	High Low	

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Potassium status of coconut growing soils in Sri Lanka

N.A. Tennakoon

Coconut Research Institute, Lunuwila, Sri Lanka

Abstract

The coconut palm is a K-demanding crop and the large quantities of K are removed by nuts. Insufficient K in the soils gives rise to poor growth with thin trunks and spars and to canopy with fewer and smaller fronds and leaflets. The suitable area for cultivation of coconut is around 810,014 ha. Coconut is grown across three main Agro-climatic Zones, viz. wet zone, intermediate zone and dry zone. This figure is inclusive of the famous coconut triangle, i.e. mainly Northwestern Province and part of Western Province of Sri Lanka and other suitable areas in down south. Considering the soil types, coconut are grown in 9 Great Soil Groups which can be further subdivided to 88 and 42 soil series in coconut triangle and in down south, respectively. The annual K removal from various parts of a coconut palm is 880 g, which is equal to 1,760 g of muriate of potash (MOP). The critical level (sufficiency range) of K in adult coconut palm is 1.2-1.4% (DM) under Sri Lankan conditions. The current fertilizer recommendation for adult palm is 1,600 g of MOP and the balance is provided by the soil reserves, i.e. by K release from K-containing minerals. The studies conducted previously on K status of the coconut growing soils have shown that exchangeable K appeared to be a better measure of K availability as this form correlated better with leaf K values (r=0.91). The previous studies further reported that total K was not related to leaf K status because K minerals do not become available for a long-lived crop like coconut. The exchangeable K contents in different soil series (20) in coconut growing areas can be categorized into 3 broad groups based on their exchangeable K contents in coconut manure circle (1.75 m away from the palm) and center of square formed by 4 coconut palms at soil depth as 0-20 cm. Exchangeable K was analyzed using 1.0 M neutral ammonium acetate. In the group 1, exchangeable K in the center of square ranges from 0 to 25 mg kg^{-1}, in the group 2 it ranges 26-50 mg kg^{-1} and in the group 3 it ranges 51-75 mg kg^{-1}. The soil series such as Andigama, Weliketiya, Kalpitiya, Negombo, Sudu, Ambakelle, Katunayaka and Pallama belong to the group 1 while the soil series Gambura, Kuliyapitiya, Rathupasa, Madampe, Thambarawa, Maho and Boralu belong to the group 2 and soil series Wariyapola, Warakapola, Kurunegala and Melsisipura can be categorized as the group 3. When compared to the manure circle soil, the soil series can be categorized as the same groups but the exchangeable K values are different. They are 0-50, 51-100 and 101-150 mg kg^{-1}, respectively. In the

group with exchangeable K content in the manure circles, values of exchangeable K in the same soil series are double the figures obtained from the center of square soil. Compared to the soil threshold value of 179 mg kg^{-1} for exchangeable K for the coconut palm, the content of exchangeable K in most of coconut growing soils is not sufficient for coconut cultivation and, therefore, potash fertilizer application is important. The studies clearly show that the exchangeable K levels are different with the soil types irrespective of the agro-climatic zones and most of soils have exchangeable K levels below the threshold value.

Introduction

The coconut palm is a K-demanding crop as large quantities of K are removed by the nuts of the palm (Fremond *et al.,* 1966). Insufficient K in the soils gives rise to poor growth with thin trunks and spars and to canopy with fewer and smaller fronds and leaflets. The response to K is reflected not only in increased nut production but also in improved setting of flowers and in better copra out-turn. Symptoms of potassium deficiency in coconut are first observed in mature fronds where scattered rust-coloured spots appear on the either side of the midrib (*ekel*) of the entire leaflet. The leaflets would be slightly yellowish and yellowing is more pronounced towards the tip. Gradually, the spots enlarge and coalesce to form large brown patches with leaflet tips showing distinct scorching.

In the case of K deficiency the crown would appear to be yellowish with the lower half showing a slightly orange colour. As the conditions deteriorate the whole crown becomes smaller and yellowish orange. In addition, tapering of the trunk is also a common symptom of K deficiency of coconut trees.

The removal of K from the soil by a coconut plantation having 150 palms per hectare at a production level of 7500 nuts ha^{-1} $year^{-1}$ (50 nuts $palm^{-1}$ $year^{-1}$) is given in Table 1. The critical level of sufficiency range of K for coconut is 1.2-1.4% (DM) in Sri Lankan conditions (Fig. 1).

The suitable area for coconut in Sri Lanka is around 810,014 ha (Somasiri *et al.,* 1996). The figure is inclusive of the famous coconut triangle i.e. mainly Northwestern Province and part of Western Province of Sri Lanka (576,864 ha) and other suitable areas in down south (233,150 ha). Considering the soil types, coconut is grown in 9 Great Soil Groups, which can be further subdivided into 88 and 42 soil series in coconut triangle and in down south respectively (Tables 2 and 3).

Table 1. The removal K from a coconut plantation having 150 palms ha^{-1} (Mahindapala and Pinto, 1991)

Component		Amount of K removed	
		kg ha^{-1}	g $palm^{-1}$
Flower parts		1	7
Frond	a) Petiole	7	47
	b) Leaflets	32	213
Nut	a) Husk	45	300
	b) Shell & kernel	11	73
	c) Nut water	36	240
Total		132	880

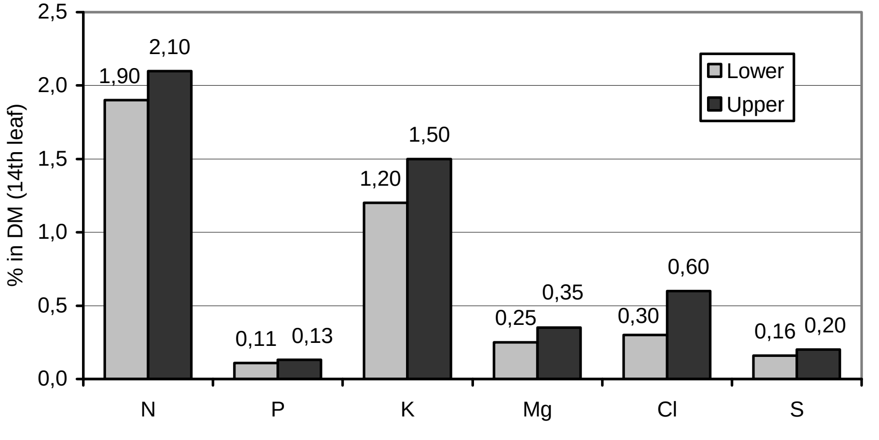

Fig. 1. Sufficiency ranges of major nutrients for coconut (Fremond *et al.*, 1966)

Table 2. Soil series in coconut triangle (Somasiri *et al.*, 1996)

Great Soil Group	Soil series
Sandy Regosols	Madurankuli, Mampuri, Negombo, Weliketiya, Kalpitiya, Halawatha, Tetku, Udappu, Norachcholai
Solodized Solonetz	Puttalam, Kadolkelle
Red Yellow Latosols	Gambura, Wilpattu, Mavillu, Borupan, Eluwankulama
Latosols & Regosols	Ratupasa, Katunayaka, Madampe, Medagama, Sudu
Alluvial	Halpe, Metikotuwa, Rambepitiya, Elwitiya, Thoppuwa, Bombiwila, Association of Rambepitiya & Elivitiya, Dampitiya, Dummalasuriya, Association of Ambakelle & Welipelessa, Association of Rajakadaluwa & Palugaswewa, Association of Kakkapalliya & Kumbukgahawela, Marichchikattiya, Navadankulama, Bangadeniya, Bakmeegolla, Aruvi Katupotha, Siyabalakotuwa & Labugama Complex
Red Yellow Podzolic	Boralu, Kiriwana-Thiruwana, Andigama, Kuliyapitiya, Weligamuwa, Association of Warakapola & Nelundeniya, Association of Waththegama & Raththota
Colluvial Red Yellow Podzolic	Association of Wilaththawa and Thunthotaoya, Pallama, Kurunegala, Meerigama
Reddish Brown Earth	Aluthwewa, Kelegama, Thonigala, Ranorawa, Hambegamuwa, Anamaduwa, Elayapaththuwa, Thabbowa
Non-Calcic Brown	Maho, Wariyapola, Thambarawa
Low Humic Gley	Adippola, Gampaha
Red Yellow Latosols	Gambura, Wilpattu, Mavillu, Borupan, Eluwankulama
Reddish Brown Latosolic	Melsiripura, Association of Melsiripura & Nalanda, Dambakanda, Galketiya
Immature Brown Loams	Association of Akurana & Kundasale, Lenadorakanda, Omarigolla

Table 3. Soil series in the Southern Region (L.L.W. Somasiri, 1998, Unpubl.)

Great Soil Group	Soil series
Regosols	Suduwella, Dickwella, Association of Dickwela & Wadduwa, Beruwala, Association of dickwella and Beruwala
Solodized Solonetz	Lunama
Bog and Half Bog	Thunduwa, Wagura & Madabokke Complex, Thudella
Latersols and Regosols	Association of Payagala & Pothupitiya
Latersols	Ussangoda
Alluvial	Rediyagama, Akuressa, Akuretiya, Maholana, Liyangasthota, Palugaswela, Association of Thebuwana & Anguruwathota, Association of Pugoda & Ovitigama, Weligama, Madurawela, Association of Hanwella & Kaduwela
Alluvial & Colluvial	Kudagoda, Hittatiya
Red Yellow Podzolic	Bandaragama, Athurigiriya, Weeraketiya, Thangalla, Witharandeniya, Association of Bandaragama & Athurugiriya, Association of Athurugiriya & Homagama, Association of Bandaragama & Cabook, Nakulugamuwa, Kamburugamuwa, Association of Pannipitiya & Pallegama, Seenimodara
Reddish Brown Earth	Ranna, Mahawewa
Reddish Brown Laterzolic	Katuwana
Red Yellow Podzolic and Immature Brown Loam	Alughgoda, Association of Agalawatta, Maliboda & Nehinna, Kapirillakanda, Kalatuwana, Gamakanda

Materials and methods

Site description

a) Soils

Twenty different coconut growing soils, where coconut is mostly grown within the coconut triangle, were selected for this study. Selected soil series, their major soil types and the extent of coconut growing areas in Sri Lanka are shown in Table 4.

Table 4. Selected soil series, their major soil types and the extent of coconut growing area

Soil series	Major soil type	Area, ha
Rathupasa	Latosols and Regosols on old red yellow sand	1,638
Madampe	Latosols and Regosols on old red yellow sand	5,131
Sudu	Latosols and Regosols on old red yellow sand	0,566
Wilattawa	Colluvial members of red yellow podzolics with soft or hard laterites	17,822
Andigama	Red yellow podzolics	28,879
Boralu	Red yellow podzolic with soft or hard laterites	24,119
Ambakelle	Alluvial soils	7,398
Wariyapola	Non-calcic brown soils	41,343
Maho	Non-calcic brown soils	15,410
Melsiripura	Reddish brown latosolic soils	35,418
Warakapola	Red yellow podzolic soils	36,875
Kurunegala	Red yellow podzolic soils	63,876
Kuliyapitiya	Red yellow podzolic soils	24,314
Pallama	Colluvial members of red yellow podzolic with soft or hard laterites	19,878
Weliketiya	Sandy regosols	3,302
Thambarawa	Non-calcic brown soils	3,415
Kalpitiya	Sandy regosols	3,335
Negombo	Sandy regosols	2,234
Gambura	Red latosols	3,521
Katunayaka	Latosols and Regosols	2,160

b) Location

Three locations, where fertilizer had not been applied at least for about 3 years in each soil series, were selected for the experiment. The location relevant to each soil series are shown in Table 5.

c) Vegetation

The major crop type of the selected site was belonging to various age groups but most of them were within 20-30 years of age, which were planted as square planting

(7.3 x 7.3 m), whilst a few were equilateral planting (7.4 × 7.4 × 7.4 m) with a density of 190 palms per hectare. Most of these coconut palms were in tall variety.

Table 5. Location of the selected soil series

Soil series	Locations
Rathupasa	Dummaladeniya, Mahawewa, Koswadiya
Madampe	Tummodara, Kirimetiyana, Madampe
Sudu	Suduwella, Karukkuwa, Maradawella
Wilattawa	Wannirasnayakapura, Mahagama, Mudalakkuliya
Andigama	Mudalakkuliya, Weerakodiyana, Wadumunnegedara
Boralu	Divulapitiya, Alabodagama, Bogamuwa
Ambakelle	Sedawatte, Arachchikattuwa, Pottukulama
Wariyapola	Kobeigane, Awulegama, Wariyapola
Maho	Alahena, Wannigama, Wariyapola
Melsiripura	Gaiwarama, Adirillawatta, Panliyadda
Warakapola	Arangalakanda, Wewaldeniya, Neligama
Kurunegala	Metiyagane, Yaggapitiya, Ambanpola
Pallama	Alabodagama, Divulapitiya, Bogamuwa
Weliketiya	Karambe, Kadiyamutte, Marawila
Thambarawa	Koorikulama, Kadigawa, Welipennagahamula
Kalpitiya	Kurunchipitiya, Palakudawa, Nawakkaduwa
Negombo	Kandatoduwawa, Karukapana, Modarawella
Gambura	Vijayapura, Bodhirajapura, Sirambiadiya
Katunayaka	Welihena, Ekala, Kadirana
Kuliyapitiya	Amangalla, Metiyagane, Katupotha

Soil sampling procedure

Soil samples were collected at the manure circle (i.e. 1.75 m away from the base of the palm) and from the centre square (centre position of the four coconut palms). Depth of the sampling was 0-20 cm.

Soil analysis for exchangeable K

Soil samples were mixed with 1 M neutral ammonium acetate solution, shaken for 1/2 hour and then filtered through No. 42 Whatman filter paper. Filtrate was then analyzed for exchangeable K using an Atomic Absorption Spectrophotometer (Tropical Soils and Leaf Analytical Methods, 1982).

Results and discussion

The exchangeable K levels of the soil series are given in Table 6. The exchangeable K levels in different soil series (20) in coconut growing areas can be categorized into 3 broad groups based on their exchangeable K levels in coconut manure circle (1.75 m away from the palm) and centre of square formed by four coconut palms at soil depth 0-20 cm (Tables 7 and 8).

Table 6. Exchangeable K levels in different soil series (mean values of 3 locations)

Soil series	Exchangeable K, mg kg^{-1}	
	Manure circle (MC)*	Centre square (CS)
Wilattawa	66.0	35.1
Andigama	62.4	15.6
Weliketiya	93.6	19.5
Gambura	58.5	31.2
Kalpftiya	39.0	23.4
Negombo	15.6	11.7
Kuliyapitiya	105.3	50.7
Rathnapura	74.1	42.9
Madampe	62.4	27.3
Sudu	23.4	3.9
Wariyapola	113.1	54.6
Ambakelle	39.0	19.5
Tambarawa	82.0	35.1
Maho	58.5	31.2
Warakapola	121.0	66.3
Boralu	78.0	39.0
Katunayaka	27.3	11.7
Pallama	50.7	19.5
Kurunegala	117.0	58.5
Melsiripura	132.6	70.0

* No fertilizer applied last 2-3 years

Table 7. Exchangeable K levels of manure circle soils (MC)

Group	Exchangeable K, mg kg^{-1}	Soil series
Group 1	0-50	Andigama, Weliketiya, Kalpitiya, Negombo, Sudu, Ambakelle, Katunayaka, Pallama
Group 2	51-100	Gambura, Kuliyapitiya, Rathupasa, Madampe, Thambarawa, Maho, Boralu
Group 3	101-150	Wariyapola, Warakapola, Kurunegala, Melsiripura

Table 8. Exchangeable K levels of center square soils (CS)

Group	Exchangeable K, mg kg^{-1}	Soil series
Group 1	0-25	Andigama, Weliketiya, Kalpitiya, Negombo, Sudu, Ambakelle, Katunayaka, Pallama
Group 2	26-50	Gambura, Kuliyapitiya, Rathupasa, Madampe, Thambarawa, Maho, Boralu
Group 3	51-75	Wariyapola, Warakapola, Kurunegala, Melsiripura

Exchangeable K in the center square ranges from 0-25, 26-50 and 51-75 mg kg^{-1} in the group 1, 2 and 3, respectively. The soil series such as Andigama, Weliketiya, Kalpitiya, Negombo, Sudu, Ambakelle, Katunayaka and Pallama belong to the group 1 while the soil series Gambura, Kuliyapitiya, Rathupasa, Madampe, Thambarawa, Maho and Boralu belong to the group 2 and soil series Wariyapola, Warakapola, Kurunegala and Melsiripura can be categorized as the group 3. When compared to the manure circle soils, the soil series can be categorized as the same groups but the exchangeable K values are different. They are 0-50, 51-100 and 101-150 mg kg^{-1} respectively. The group-wise exchangeable K values in the manure circle soil in same soil series are double the values obtained from the center of square soil. Compared to the soil threshold value of 179 mg kg^{-1} for exchangeable K for the coconut palms, the status of exchangeable K of most of coconut growing soils are not sufficient for coconut cultivation and, therefore, potash fertilizer application is necessary. Many researchers (Shanmuganathan and Loganathan, 1976; Somasiri and Liyanage, 1996; Fernando, 1999; Somasiri *et al.*, 1996; Giritharan *et al.*, 2000 and 2002) studied on K status of the coconut growing soils in the past and they concluded that exchangeable K appeared to be a better measure of K availability as this form correlated better with leaf K values (r = 0.91). However, they further reported that total K was not related to leaf K status because K minerals do not become available for a long-lived crop like coconut.

Conclusion

Studies on the K status of coconut growing soils clearly show that the exchangeable K levels are different with the soil series irrespective of the agro-climatic zones. Most of soils have K exchangeable levels below the threshold value for coconut palm. It indicates that the application of K fertilizer is necessary to achieve high yield of coconut grown in Sri Lanka.

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Potassium status of rubber growing soils in Sri Lanka

Lalani Samarappuli

Rubber Research Institute, Sri Lanka

Abstract

Planting of rubber *(Hevea brasiliensis)* in Sri Lanka is mostly confined to two great soil groups: Red Yellow Podzol (RYP) and Reddish Brown Latosol (RBL). The Red Yellow Podzolic soils are predominant in the rubber growing areas of Kalutara, Galle, Matara, Ratnapura, Avissawella and Moneragala. The Reddish Brown Latosolic soils occur mainly in the Kegalle, Mawanella, Kurunegala and Matale areas. In these rubber growing areas seven important soils units have been identified, i.e. Parambe, Matale, Homagama, Agalawatta, Ratnapura, Boralu and Deniya, taking into consideration only the parent material from which the soils were derived. The water soluble, exchangeable and total potassium (K) contents can be considered as indicators of K status of rubber growing soils. Water soluble K is very low in all soil series. Total K is highest (1743 mg kg^{-1}) in the Parambe series and Matale, Ratnapura and Agalawatta series soils have medium K contents (718 mg kg^{-1} to 456 mg kg^{-1}). Boralu and Homagama series soils have lowest K contents of 121 and 113 mg kg^{-1}, respectively. The soil series, therefore, fall into three broad categories, i.e. comparatively high, moderate and low. Between different soils, total K and exchangeable K correlates positively, indicating that a soil, which has a high total K content, will generally have a high exchangeable K content. In relating the exchangeable K status of the soils to the sufficiency ranges of K content in rubber growing soils, it is evident that Parambe series soil has medium level of K while all the other soil series fall into low and very low categories. Accordingly, to supplement the K requirement for rubber through fertilizer, low and high K fertilizer mixtures are recommended for medium and low to very low level soils, respectively.

Introduction

Potassium is one of the major nutrient elements required and taken up in large amount by the rubber tree besides nitrogen and phosphorus. Soils normally play a major role in determining the availability of K to rubber trees and the influence on this availability is primarily through the mineral reserves in the soil. The total land area under rubber in the country is 158,000 hectares, which accounts for about 8% of the total cultivated extent in the country. Rubber is mainly confined to the wet and intermediate zone and is grown on a wide range of soils with variable availability of potassium.

Classification of rubber growing soils

Planting of rubber *(Hevea brasiliensis)* in Sri Lanka is mostly confined to two great soil groups: Red Yellow Podzol (RYP) and Reddish Brown Latosol (RBL). The Red Yellow Podzolic soils are predominant in the rubber growing areas of Kalutara, Galle, Matara, Ratnapura, Avissawella and Moneragala. The Reddish Brown Latosolic soils occur mainly in the Kegalle, Mawanella, Kurunegala and Matale areas. In these rubber growing areas seven important soils units have been identified viz. Parambe, Matale, Homagama, Agalawatta, Ratnapura, Boralu and Deniya (Table 1), taking into consideration only the parent material from which the soils were derived (Table 2).

Table 1. Different soil series of rubber growing areas

Soils series	Location	Great Soil Group	Soil taxonomy
Parambe	Kegalle/Kurunegala	Reddish Brown Latosol	Ultisol
Matale	Matale		
Agalawatta	Around Sinharaja forest	Red Yellow Podzol	
Ratnapura	Ratnapura/Meegahatenna		
Boralu	Southern coastal area		
Homagama	Yatiyantota/Deraniyagala		
Deniya		Low Humic Gley	Alfisol

Table 2. Parent materials of different soil series

Soils series	Parent material
Parambe	Micaceous biotite gneiss
Matale	Crystalline limestone
Agalawatta	Granitic rocks
Ratnapura	Garnetiferous rocks
Boralu	Vijayan and Khondalite rocks
Homagama	Quartzitic rocks

K distribution in rubber growing soils

The water soluble, exchangeable and total K contents can be considered as indicators of K status of rubber growing soils. Water soluble K is very low in all soils, due perhaps to the leaching that takes place in soils of the rubber growing areas, confined mainly to the Low Country Wet Zone with high average rainfall. Total K and exchangeable K contents indicated significant differences between different rubber growing soils (Table 3). Total K is highest (1743 mg kg^{-1}) in the Parambe series and these soils are derived from micaceous parent materials, biotite gneiss. These soils are deep, sandy clay loam in texture and brown in colour. There are glistening specks of mica throughout the soil mass. The main areas where Parambe series soils occur are the Kegalle and Kandy districts. Homagama series soil has lowest K content (113 mg kg^{-1}), which may be attributed to the very sandy nature of the soil, derived mainly from highly quartzitic rocks (Table 4). Further, high porosity and low bulk density of Homagama series soil, which contribute towards higher leaching rate, can also reduced the soil K content (Table 5). These soils are moderately deep and sandy loam in texture. Boralu series soil also has very low K content of 121 mg kg^{-1}. These soils are shallow and the presence of laterite at different depths is a diagnostic character of this soil series. Generally other soil series have medium K contents varying from 718 to 456 mg kg^{-1}. The soils, therefore, fall into three broad categories, i.e. comparatively high, medium and low (Table 6). However, it is evident that for Parambe and Matale soil series the range is large, while for the other soil series it is very narrow. This shows to a certain extent the homogeneity with regard to this property in the Ratnapura, Agalawatta, Homagama and Boralu soil series.

Table 3. Soil K content in different soil series

Soils series	Total K	Exchangeable K
	------------------------- mg kg^{-1}	-------------------------
Parambe	1743	105
Matale	718	66
Agalawatta	456	47
Ratnapura	597	51
Boralu	121	16
Homagama	113	27

Table 4. The particle size distribution and textural class of different soil series

Soil series	Texture	Particle distribution, %			
		Coarse sand	Fine sand	Silt	Clay
Parambe	Sandy clay loam	40-52	15-18	10-15	28-34
Matale		42-54	18-20	7-10	20-30
Homagama	Sandy loam	57-65	17-28	4-5	10-20
Agalawatta	Sandy clay loam	42-55	13-18	9-12	20-30
Ratnapura		42-54	16-19	7-12	20-30
Boralu		49-55	19-22	5-8	20-30

Table 5. Bulk density and porosity of different soil series

Soils series	Bulk density, g cm^{-3}	Porosity, %
Parambe	1.49	53.1
Matale	1.33	54.7
Agalawatta	1.51	52.0
Ratnapura	1.36	54.6
Boralu	1.38	53.2
Homagama	1.12	56.2

Table 6. Categorization of different soil series according to soil K status

Soil K status	Soil series
High	Parambe
Moderate	Matale, Ratnapura, Agalawatta
Low	Homagama, Boralu

Moreover, both total K and exchangeable K contents indicate a marked gradient with depth of soil, total K content having an increasing gradient with depth and exchangeable K content having a decreasing gradient (Table 7).

Table 7. Soil K content *vs.* soil depth in different soil series

Soils depth, cm	Total K	Exchangeable K
	---------------------- mg kg^{-1}	----------------------
0-15	1743	105
15-30	718	66
30-60	456	47

K requirement through fertilizer application

Between different soils, total K and exchangeable K correlates positively, indicating that a soil, which has a high total K content, will generally have a high exchangeable K content. In relating the exchangeable K status of the soils to the sufficiency ranges of K content in rubber growing soils (Table 8), it is evident that Parambe series soil has medium level of K while all the other soil series fall into low and very low categories. Accordingly, to supplement the K requirement through fertilizer, low and high K fertilizer mixtures are recommended for medium and low to very low level soils, respectively. The general fertilizer application to rubber with high K mixtures commences with 17 kg of K per hectare during the 1st year of planting and rates increase by 16 kg of K every year until tapping and low K mixtures in the medium K soil, fertilizer application commences with 9 kg of K per hectare during the 1st year of planting and rates increase by 8 kg of K every year until tapping. Application of higher rates of K in the region of 12-25 kg per hectare is recommended for correction of the K deficiency. The K fertilizer recommendation for mature rubber is based basically on its nutrient status (site specific fertilizer recommendation based on soil and foliar analysis). Although general fertilizer recommendations are available for rubber, K fertilizer requirement for newly developed clones under different soil conditions are yet to be studied. The outcome of such studies would facilitate more cost-effective K fertilizer use in rubber cultivation.

Table 8. Sufficiency ranges of K content in rubber growing soils

Forms of K	Very low	Low	Medium	High	Very high
Total K, mg kg^{-1}	<100	101-200	201-780	781-1560	>1560
Exchangeable K, mg kg^{-1}	<59	60-98	99-156	>156	

K nutrient cycle

Potassium is lost from the soil mainly by removal of latex and by removal of timber during replanting operations. Apart from this K may be lost by leaching through the soil and by surface erosion. It is estimated that 216 kg and 990 kg of K is removed from the system through latex and timber, respectively.

K is added to the soil mainly by fertilizer application, contribution from cover crops and addition by the mulching with paddy straw. Annual leaf fall of rubber and rain water can be considered as other additions of K to the soil.

It can be suggested that the introduction of rubber as an agricultural crop has helped to a great extent to improve the soil K status and return to its original status (Table 9).

Table 9. Soil K status of rubber *vs.* virgin soil

Stage	Exchangeable K, mg kg^{-1}
Virgin soil	66
6 months after planting rubber	47
4 years after planting rubber	62

Potassium status of rice growing soils in Sri Lanka

W.M.A.D.B. Wickramasinghe[1], A.R. Dassanayake[2] and D.N. Sirisena[1]

[1] Rice Research & Development Institute, Batalagoda, Ibbagamuwa, Sri Lanka
[2] Land Use Division, Department of Irrigation, Jawatta Rd., Colombo 07, Sri Lanka

Abstract

Rice is adapted to various ecological conditions and therefore, it is globally grown in diverse soil and environmental conditions. This phenomenon is not much deviated under Sri Lankan conditions and rice is grown in almost all the grate soil groups and soil series found in Sri Lanka, although the characteristics of these soils are entirely different. Based on the mean annual rainfall, rice-growing areas in Sri Lanka is divided into three broad climatic zones, i.e. Wet, Intermediate and Dry zones (WZ, IZ and DZ). These climatic zones are further subdivided according to the elevation: <300 m above the mean sea level (Low country - LC), 300-900 m (Mid country - MC) and >1200 m (Up country - UC). The land area under rice cultivation is about 0.73 million ha, of which 0.14 million ha (25%) are in the WZ, 0.13 million ha (20%) are in the IZ and 0.46 million ha (55%) are situated in the DZ. Soils in Sri Lanka are heterogeneous, so that rice growing soils in these zones and their characteristics including K status are also different. The two major rice growing soil series in the Low Country Wet Zone are Gampaha (Typic Endoaquents) and Madabokka (Typic Sulfihemists) and also rice is grown at limited extent in Poogoda (Typic Ustfluents) and Palatuwa (Typic Sulfaquents) soil series as well. The content of exchangeable potassium of Poogoda and Gampaha soil series is low (30-40 mg K kg^{-1}) but it is comparatively higher in Madabokka and Palatuwa series (130-200 mg kg^{-1}). Gampola (Typic Troporthents) and Kiribathkumbura (Aeric Fluvaquents) are major rice growing soil series in the Mid Country Wet Zone and the exchangeable K content of these soil series is as high as 200-400 mg kg^{-1}. The major rice growing soils in the in the IZ are Batalagoda (Typic Endoaquents), Balalla (Typic Endoaqualfs), Kuda Oya (Typic Endoaqualfs), Mutukandiya (Typic Endoaquents) and Ulhitiya (Typic Halpludalfs) soil series. They are mainly located in the Low Country Intermediate Zone. The exchangeable K content is low in all these soil series (23-110 mg kg^{-1}) except in Balalla series where exchangeable K content is around 240 mg kg^{-1}. The minor rice growing soil series in the IZ are Hembarawa (Typic Udorthents), Wariyapola (Pasmmaantic Hapludalfs), Kurunegala (Plinthudults), Bibila (Typic Dystropepts), Badulla (Typic Haplohumults), Bandarawela (Typic Haploudults) and Welimada (Typic Dystropepts). Hembarawa series has a higher level of exchangeable K (>200 mg kg^{-1}) while all other soil

series have lower level of exchangeable K (40-80 mg kg^{-1}). Major rice growing grate soil groups in the DZ of Sri Lanka are Reddish Brown Earth - RBE (Rhodustalfs), Non-Calcic Brown - NCB (Haplustalfs), Low Humic Gley - LHG (Tropaqualfs), Grumusol (Pellusterts) and Alluvial (Aquents, Fluvents and Aquepts) soils. Of these soils, NCB soils have the lowest exchangeable K content (<23 mg kg^{-1}), while LHG and RBE soils have the reasonable level of K (about 90 and 180 mg kg^{-1}, respectively). However, Grumusols have a very high level of exchangeable K (>350 mg kg^{-1}). Except NCB soils, fixation of K by these soils are fairly high, particularly in Grumusols and LHG soils. As such, none-exchangeable K fraction of some of these soils is varied considerably.

Introduction

Sri Lanka is an island having a wide variation of rainfall, elevation, temperature and soil conditions. The annual rainfall ranges from 600 mm in the drier areas to 6000 mm in the wet areas. The elevation ranges from the sea level to 2500 m above the mean sea level (amsl) and the average temperature ranges between 15-30^{0}C at different elevations. Based on the mean annual rainfall, rice-growing areas in Sri Lanka are divided into three broad climatic zones, i.e. Wet, Intermediate and Dry zones (WZ, IZ and DZ). These climatic zones are further subdivided according to the elevation: <300 m amsl (Low country - LC), 300-900 m (Mid country - MC) and >1200 m (Up country - UC). By combining the elevation and the amount of rainfall received, seven major agro-ecological zones (AEZ) have been identified:

LCDZ – Low Country Dry Zone,
LCIZ - Low Country Intermediate Zone,
UCIZ – Up Country Intermediate Zone,
LCWZ – Low Country Wet Zone,
UCWZ – Up Country Wet Zone,
MCIZ – Mid Country Intermediate Zone,
MCWZ – Mid Country Wet Zone.

Considering the rainfall distribution, soil types and the landform, these AEZ are further subdivided into 24 agro-ecological regions. Rice lands are distributed in almost all the above agro-ecological regions except the elevation beyond 1200 m amsl. In Sri Lanka, the hydromorphic associates of almost all grate soil groups are used for rice cultivation if water is not limiting (Panabokke, 1996). In general, compared to many other rice growing countries, Sri Lanka grows rice under a wide range of environments.

Rice is adapted to various ecological conditions and, therefore, it is globally grown in diverse soil and environmental conditions. This phenomenon is not much deviated under Sri Lankan conditions and rice is grown in almost all the grate soil groups and soil series presented in Sri Lanka, although the characteristics of these soils are entirely different. Sri Lanka has 0.734 million ha of rice lands of which 0.46 million ha (55%) are in the LCDZ, 0.13 million ha (20%) in the LCIZ, 0.14 million ha (25%) in the LCWZ and about 4.5 thousand ha are distributed in Up country and Mid country. Rice soils in Sri Lanka can be categorized into three broad categories, i.e. soils of the Dry, Intermediate and Wet zones. The productivity of these soils is differing and their fertility characteristics, risk and limitations are also different.

K status in Sri Lankan rice growing soils

The major rice growing grate soil groups in different agro-ecological zones of Sri Lanka are Reddish Brown Earth (RBE), Red Yellow Podzolic (RYP), Non-Calcic Brown (NCB), Reddish Brown Latosol (RBL), Immature Brown Loam (IBL), Low Humic Gley (LHG), Alluvial and Organic soils. All these soils have different K supplying capacity. In 1964, the first fertility study of Sri Lankan rice growing soils was carried out, in which the status of K in soils of different districts was assessed (Panabokke and Nagarajah, 1964). According to this study, the exchangeable K content in most soils was in a range of 0.01-0.20 meq 100 g^{-1} or 3.9-78.0 mg kg^{-1} (Table 1). Rezania (1992) has shown that the exchangeable K content in soils in the LCDZ and the LCIZ varies between 31-331 mg kg^{-1}, it ranges 51-175 mg kg^{-1} in the MCWZ and 27-94 mg kg^{-1} in the LCWZ. Almost 50% of the soils in the LCWZ have exchangeable K content less than 58 mg kg^{-1}.

Table 1. Exchangeable K (mg kg^{-1}) in major rice growing areas

Area	AEZ	1964*	2000** Number of sites, %	
			<74	74-148
Ampara	LCDZ	39-58	75	20
Anuradapura	LCDZ	58-78	68	24
Polonaruwa	LCDZ	58-78	65	27
Kurunegala	LCIZ	<39	67	22
Hambantota	LCDZ	39-58	31	38
Badulla	UCIZ	39-58	08	33
Wet zone			48	35

* Panabokke and Nagarajah (1964).
** Department of Agriculture (2000, Unpubl.)

K status in rice-rice cropping systems in different agro-ecological zones

Low Country Dry and Intermediate zones

Reddish Brown Earth, NCB, LHG and Alluvial soils are major rice growing grate soil groups in the LCDZ, while RYP, LHG, NCB, RBL and IBL and Alluvial are the rice growing grate soil groups in the LCIZ. If water is not limiting, two rice crops are grown during the year on these soils**.** Yogaratnam (1987) reported that coarse textured NCB/LHG soil complex in the LCDZ contains the lower exchangeable K content (47 mg kg^{-1}), while moderately fine textured Alluvial soils have the higher exchangeable K content (113 mg kg^{-1}). In RBE and LHG soils of LCDZ, the exchangeable soil K content ranges between 31-331 mg kg^{-1} (Rezania, 1992). NCB soils at Aralaganwila in the LCDZ have exchangeable K content as low as 12-24 mg kg^{-1} (Weerasinghe, 1991).

Low and Mid Country Wet zones

Red Yellow Podzolic and RBL are the major rice growing grate soil groups in the MCWZ, especially in Matale, Kandy and Kegalla districts. The exchangeable K content of these soils is in the range of 39-58 mg kg^{-1} (Rezania, 1992). However, in RBL and RYP soils in Mawanella in Kegalla district of MCWZ, the exchangeable soil K content ranges between 47-160 mg kg^{-1}. Almost 50% of the rice growing soils in the LCWZ have exchangeable K content less than 58 mg kg^{-1}, which is considered as the critical soil K level for mineral/alluvial soils (Rezania, 1992). It has been also observed that there is a declining trend in exchangeable K content in these soils when rice is grown continuously. According to Wijewardana *et al.* (1998), 48% of soils in the LCWZ contain exchangeable K below 78 mg $kg^{-1}$of soil, while remaining soils contain more than 78 mg kg^{-1} of exchangeable K.

K status in rice-potato-vegetable and rice-vegetable cropping systems in different agro-ecological zones

In the UCIZ where the intensive rice, potato and vegetable cropping system is practiced, soils have high exchangeable K content due to higher rates of K fertilization for potato and vegetable crops (Wijewardana, 1999). Red Yellow Podzolic soils in rice-potato-vegetable cropping systems contain 97-290 mg kg^{-1} of exchangeable K, which is more than the critical level of K needed for rice cultivation. Similarly, high K contents in rice-vegetable cropping systems were reported for the IBL soil of MCIZ by Joseph *et al.* (1988).

K status in rice growing soil series

Presently, soils in Sri Lanka are being classified into soil series level. Under this classification major rice growing soil series have been identified and characterized.

Low and Mid Country Wet zones

The main rice growing soils series in the LCWZ are Gampaha (Typic Endoaquents), Madabokka (Typic Sulfihemists), Poogoda (Typic Ustfluents) and Paltuwa (Typic Sulfaquents). The exchangeable K content of Poogoda and Gampaha soil series is low (30-40 mg kg^{-1}) but, it is fairly higher in Madabokka and Palatuwa series (130-200 mg kg^{-1}). Gampola (Typic Troporthents) and Kiribathkumbura (Aeric Fluvaquents) soil series are the major rice growing soils in the MCWZ and the exchangeable K content of these soil series is fairly high, 156-195 and 140-195 mg kg^{-1} respectively (Kumaragamage *et al*., 1999). These soils are rich in K because they contain weathering mica.

Low and Mid Country Intermediate zones

Major rice growing soil series in these zones are Batalagoda (Typic Endoaquents), Balalla (Typic Endoaqualfs), Kuda Oya (Typic Endoaqualfs), Mutukandiya (Typic Endoaquents) and Ulhitiya (Typic Halpludalfs). The exchangeable K content is low in all these soil series (23-110 mg kg^{-1}) except in Balalla series where exchangeable K content is as high as 240 mg kg^{-1}. The minor rice growing soil series in the intermediate zone are Hembarawa (Typic Udorthents), Wariyapola (Pasmmaantic Hapludalfs), Kurunegala (Plinthudults), Bibila (Typic Dystropepts), Badulla (Typic Haplohumults), Bandarawela (Typic Haploudults) and Welimada (Typic Dystropepts). Among all these soils, only Hembarawa soil series has a fairly high content of exchangeable K (200 mg kg^{-1}), while other soil series have lower levels (Soil Science Society of Sri Lanka, 2003, Unpubl.) of exchangeable K (40-80 mg kg^{-1}).

Low Country Dry Zone

Rice soils in the dry zone have also been identified in soil series level and accordingly there are 13 major rice growing soil series in the LCDZ. They are Ketagal Ara, Pallegama, Rannas, Nonagama, Timbolketiya, Walawe, Barawakumbuka, Siyambalanduwa, Aluthwewa, Borapola, Akkareipattuwa, Gal Oya and Hingurana series. The exchangeable K content of these soil series varies in a wide range of 39-507 mg kg^{-1}. Pallegama series has the highest exchangeable K content (507 mg kg^{-1}) while Hingurana series has the lowest exchangeable K content (39 mg kg^{-1}). Ranna, Nonagama, Timbolketiya, Walawe, Siyambalanduwa and Aluthwewa series also have high levels of exchangeable K content (234-351 mg kg^{-1}). Ketagal Ara, Barawakumbuka, Borapola, Akkareipattuwa, Gal Oya series are medium in exchangeable K (78-117 mg kg^{-1}) [Soil Science Society of Sri Lanka, 2003, Unpubl.].

Rice response to K application

Recent soil analytical data for NCB, RBE, LHG, IBL and RYP soils from low country dry and intermediate zones have shown that exchangeable soil K in most these soils is low (Table 2). Non-exchangeable K fractions of these soils are in sufficient range and as such there is no response to applied K fertilizers (W.M.A.D.B. Wickramasinghe *et al.,* 2002, Unpubl.). In addition, application of K even up to 150 kg K_2O ha^{-1} has not significantly affected the grain yield of rice in any of these soils. However, grain yield was significantly affected by different soil types indicating that the K supplying capacity of these soils are greatly influenced by their physical and chemical characteristics, rather than by applied K. After crop harvest, the content of exchangeable K in the soils was below the critical levels, showing the depletion of soil exchangeable K due to cropping (W.M.A.D.B. Wickramasinghe *et al.,* 2002, Unpubl.). A negative K balance was recorded in all the soils in spite of high K application (150 kg K_2O ha^{-1}). The highest negative K balance was observed in IBL soils, which have the highest content of both exchangeable and non-exchangeable K, while RBE, RBL and LHG soils exhibited a comparatively low negative K balance, especially with K application. The K uptake by plants was comparatively lower in all the other soils as compared to IBL soils. The lower K uptake may be due to low availability of applied K, possibly due to K fixation.

Table 2. Percentage distribution of exchangeable K in 6 agro-ecological zones

AEZ	Exchangeable K, mg kg^{-1}			
	0-75	75-150	150-400	>400
	No. of samples, %			
LCDZ	68	25	7	0
LCIZ	80	14	5	1
LCWZ	75	18	6	1
MCWZ	75	18	6	1
MCIZ	68	20	10	2
UCIZ	33	30	31	6

Source: Department of Agriculture, Unpubl.

Conclusions

Studies undertaken over the past four decades have shown that the exchangeable K content of the rice growing soils in Sri Lanka is vary from location to location but has not changed drastically over the years, though rice have been grown two seasons per year for over 40 years. Rice absorbs and removes high amount of K, and the K balance as such in all the rice soils is always negative. Therefore, comprehensive study should be undertaken to investigate the K supply from different sources, K content in different soil fractions and also mineralogy of the soils.

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Potassium status of Other Field Crops growing soils in Sri Lanka

P. Weerasinghe

Grain Legume and Oil Crops Research Centre, Department of Agriculture, Angunakolapellessa, Sri Lanka

Abstract

In Sri Lanka, annual crops other than rice, root and tubers, vegetables and fruits are referred to as Other Field Crops (OFC). These crops are mainly cultivated in rainfed conditions. Other Field crops are grown predominantly on Alfisols and Oxisols found in the drier parts of the country. Available data on soil potassium levels suggest that the average content of exchangeable potassium in the majority of soils in the cultivating area is around 150 mg kg^{-1}. However, some of the soils in the area exhibit lower content of exchangeable potassium of 30-60 mg kg^{-1}. Feldspars and mica are commonly found minerals in the majority of soils in the drier part of the country. In spite of the dominance of kaolinite in the clay fraction, the presence of illites, vermiculites and montmorillonites is also observed in some of the soil groups. Irrigation water in this drier part of the country contains comparatively high content of potassium. Though no extensive studies on the behavior of potassium in the OFC growing environment have been undertaken, the evidences suggest that most of OFC grown in this part of the country are adequately supplied with potassium.

Introduction

Sri Lanka is an island having a population of 19 millions with a per capita income of 771 US dollars per year. In the year 2002, the contribution from agriculture to the country's gross domestic production was 19.8% (CBSL, 2002).

Though, Sri Lanka can be broadly divided into 3 major agro-ecological regions (Table 1), cultivation of Other Field Crops (OFC) is mainly confined to the Low Country Dry and Intermediate Zones of the country.

In Sri Lanka, annual crops other than rice, vegetables, root and tuber crops and fruits are referred to as OFC. Hence, OFC group includes coarse grains, condiments, pulses and oil crops. The extent and production of some of the important OFC in Sri Lanka in year 2002 are shown in Table 2.

In Sri Lanka, the majority of OFC is cultivated in rainfed conditions, however, cultivation under irrigation is also popular; chilli and onions are the two most popular OFC cultivated under irrigated conditions. Rainfed crops are mostly grown under low input practice as compares to the irrigated crops.

Table 1. Major agro-climatic regions in Sri Lanka

Agro-ecological region	Elevation, m	Mean temperature, ^0C	Rainfall, mm
Dry zone	0-300	28-32	900-1000
Intermediate zone	0-1500	15-29	1500-2200
Wet zone	0-2000	10-28	2000-3000

Table 2. Extent and production of Other Field Crops in Sri Lanka in 2002

Crop	Area, ha	Production, t
Big onion	2,015	31,966
Red onion	5,124	36,863
Chilli (dry)	17,353	12,260
Maize	25,712	28,755
Green grams	11,065	9,716
Black grams	6,361	5,127
Cowpea	10,792	9,839
Kurakkan	5,636	4,196

Soils in the Other Field Crops growing environment

Soils in OFC grown region are mainly derived from pre Cambrian rocks of Vijayan complex and Highland series. The Vijayan series includes a variety of gneisses, migmatites and granitoid gneisses. The Highland series, on the other hand, comprises of quartzites, acid gneisses, granulites, calc-gneisses, marble and khondalite (sillimanite-garnet-graphite schist). In addition, north and northwestern parts of Sri Lanka are characterized by the presence of the Miocene limestone belonging to the tertiary age (Cooray, 1984).

Three major soil groups are found in the OFC growing regions of the country, namely:

- Reddish Brown Earths (Rhodustalf)
- Non-Calcic Brown soils (Haplustalf)
- Red/Yellow Latosols (Haplustox/Eutrustox)

Immature Brown Loams (Ustropept) and Regosols (Quartzipsamment) are also used for OFC cultivation but in a less extent.

Reddish Brown Earths

Reddish Brown Earths (RBE) are derived from the rocks of Vijayan series and Highland series. RBE is the most dominant soil group found in OFC growing regions of Sri Lanka. Surface soils are dark brown to reddish brown in colour and the texture is from sandy clay loam to sandy clay. The presence of quartz and feldspar gravel is a characteristic feature of these soils, however, the depth to the layer of gravel varies greatly. Surface soil reaction is from slightly acidic to neutral and the cation exchange capacity is around 25 cmol (+) per kg of soil.

Non-Calcic Brown soils

Non-Calcic Brown soils are dominant in the eastern dry zone of Sri Lanka, though such soil types can be found in the North-Central part of the country too. Although this great soil group was also originated from the Vijayan series rocks, its parent material is acidic as compared to the parent material of RBE soils. Surface soil is dark brown to dark grayish brown and the sub soil is from yellowish red to yellowish brown. Soil texture could vary from loamy sand to sandy clay loam. Surface soil reaction of this soil group is slightly acidic and the cation exchange capacity may vary from 3 to 15 cmol (+) kg^{-1} of soil.

Red and Yellow Latosols

Latosols occur in a distinct landscape position in Northern, North-Western and North-Eastern Sri Lanka along the coastal belt. It runs as a stretch in the region. Surface colour of the soil varies from dark reddish brown, brown to yellowish brown depending on the red or yellow the Latosols are. The reaction of the surface soil is from slightly acidic to neutral. The cation exchange capacity varies from 2 to 20 cmol (+) kg^{-1} of soil.

Other soil groups

Immature Brown Loams originated from micaceous gneisses are presented mostly in the Semi Dry Intermediate Zone of the country. The surface horizon is from dark brown to dark grayish brown in colour. Surface soil reaction is from neutral to slightly acidic and soil texture may vary from sandy loam to sandy clay loam. The

cation exchange capacity of the surface soil could vary in a range of 10-20 cmol (+) kg^{-1} of soil.
In general, sandy Regosols with a texture from find sand to moderately coarse sand are found on the raised or elevated beaches (Panabokke, 1996).

Potassium removal by Other Field Crops

Removal of K by some OFC is shown in Table 3. These data indicate that excepting maize and onion other crops in this group remove less than 100 kg K ha^{-1} per season. Hence, except for maize, onion and chilli other crops do not remove much K from the soil at the indicated yield levels.

Table 3. Removal of K by some OFC in Sri Lanka (after Amarasiri and Perera, 1975)

Crop	Yield, t ha^{-1}	K removal, kg ha^{-1}
Maize	4.0	155
Onion	35.0*	133
Chilli	2.0	84
Black gram	1.5	43
Cow pea	1.5	36
Mung bean	1.2	26
Groundnut	1.8	34
Sesame	1.0	36

* Fresh weight (after Kemmler and Hobt, 1986)

Potassium in the soil

Studies on soil potassium status in Sri Lanka are limited mainly due to the unresponsiveness of the crop group to the addition of K. Ponnamperuma (1952) studied the potassium status of high land soils of different districts in Sri Lanka (Table 4). At the majority of locations the author found the content of >130 mg kg^{-1} of exchangeable K. On the average, 215 mg kg^{-1} of exchangeable K was found in the dry zone soils of Sri Lanka. Ponnamperuma (1952) concluded that even the most K-demanding crops would not respond to the application of K in the dry zone of Sri Lanka.
Panabokke and Nagarajah (1964) studied the fertility characteristics of rice soils. They also came to a similar conclusion that dry zone paddy soils are medium to high

in their exchangeable K content. However, the content reported (Table 5) was lower as compared to that reported by Ponnamperuma (1952) for high land soils. Since OFC are also grown in rice-OFC cropping system, the part of paddy soils is therefore considered as OFC growing soils.

Table 4. Exchangeable K content in the high land soils in the dry zone of Sri Lanka (after Ponnamperuma, 1952)

Location	Exchangeable K, mg kg^{-1}	Location	Exchangeable K, mg kg^{-1}
Pelwehera	185	Tabbova	215
Maha Illuppallama	259	Wariyapola	58
Vauniya	176	Weerawila	199
Hingurakgoda	154	Mulliaveli	95
Mankulam	303	Trincomaiie	131
Nikeweratiya	165		

Table 5. Exchangeable K content in some paddy soils in the dry and intermediate zone of Sri Lanka (after Panabokke and Nagarajah, 1964)

District	Exchangeable K, mg kg^{-1}	District	Exchangeable K, mg kg^{-1}
Jaffna	>117	Puttlam	78-98
Vauniya	39-59	Polonnaruwa	39-59
Mannar	>117	Krunegala	39-59
Trincomalle	39-59	Ampara	39-59
Anuradapura	59-78	Hambantota	98-117

Data in Tables 4 and 5, however, show a considerable variation of exchangeable K content even in the same district. Although it is difficult to assess the exact reason for the difference in K content, soil types and sampling locations could be the reason. This fact was further investigated by Amarasiri and Lathiff (1983) and P. Weerasinghe (2000, Unpubl.), and the exchangeable K content in soils reported by them (Table 6) was higher than that reported by Panabokke and Nagarajah (1964).
The data in Tables 5 and 6 show considerable variation in the content of exchangeable K in the dry zone soils when compared with the values reported earlier. However, this variation has no any clear trend of either build up or a decline in the content of exchangeable K over the years. Due to the variability associated

with the each study, it is not possible to draw any conclusion regarding the changes in exchangeable K content in the dry zone soils of Sri Lanka. At the same time, the data show that soils in the areas like Kurunegala and Polonnaruwa contain less exchangeable K as compared to the other areas. Thus, there is clear evidence that the long term monitoring of the K status under different farming situations is necessary.

Table 6. Mean exchangeable K content in soils in the dry and intermediate zones of Sri Lanka in 1983 and 2000

District	Exchangeable K, mg kg^{-1}	
	1983[1]	2000[2]
Anuradapura	92	-
Monaragala	156	186
Polonnaruwa	76	65[3]
Puttlam	117	147
Kurunegala	35	48
Rathnapura[4]	-	211

[1] after Lathiff and Amarasiri (1983)
[2] after P. Weerasinghe (2000, Unpubl.)
[3] only the Elehera-Bakamuna area was considered
[4] only the semi-dry area was considered

Mineralogy of the soils

The available data on the mineralogy of OFC growing soils indicate the presence of K bearing primary minerals in most of the soil groups (Table 7). Except in Ustropepts, quartz is the dominant primary mineral found in the sand fraction. However, in other soil groups K feldspars and mica are present in moderate quantities. In addition, the abundance of both primary and secondary minerals in <5μ soil fraction in some of the dry zone locations was also found (L.A. Lathiff, 2003, Personal communication). K-feldspars were present in moderate quantities in the fine silt fraction in soils from Polonnaruwa, Anuradapura and Kurunagala locations, while they were dominant in Uhana soil.

Clay fraction of the soils is dominant with kaolinite (De Alwis and Panabokke, 1972). However, presence of illites, vermiculite and montmorillonite in appreciable quantities has been reported by various authors for the dry zone soils (Hearth, 1962; De Alwis and Panabokke, 1972; Anon, 1980; Mapa, 1992). Since K bearing primary minerals could contribute to slowly available K source in the soil, the presence of these minerals and also the occurrence of expanding types of clay minerals affect the K status of the soil. No studies have been conducted in this aspect with regard to OFC growing soils. Weerasinghe and Keerthisinghe (1985) indicated the high content of non-exchangeable K in Rhodustalfs and its contribution to rice cultivation.

Table 7. Presence of K bearing primary minerals in soils in the intermediate and dry zones of Sri Lanka (after De Alwis and Panabokke, 1972)

Soil group	K bearing primary minerals in sand fraction
Reddish Brown Earths (Rhodustalf)	Feldspar, mica
Non-Calcic Brown soils (Haplustalf)	Feldspar, mica
Latosols (Eutrustox)	Mica
Immature Brown Loams (Ustropept)	Mica, feldspar

Crops growing environment and response to K

Irrigation water available in the OFC growing regions is quite rich in K (Amarasiri, 1965 and 1973). The quantity of K that could be supplied by the irrigation water to OFC during one season is shown in Table 8. The amount of K supplied via irrigation could vary greatly depending on the source of water. However, the tanks located in the eastern dry zone of Sri Lanka contained water with lower K concentration as compared to the tanks in the other parts of the country. Amarasiri (1973) attributed the high K content in water to the high K content in the soil and acidic nature of parent material. This is in agreement with the exchangeable K content in soils reported earlier.

Table 8. K supplied by the irrigation water to OFC (after Amarasiri, 1973)

Tank	K, kg ha^{-1}	Tank	K, kg ha^{-1}
Iranamadu	38.0	Kalawewa	51.5
Vavunikulan	40.0	Huruluwewa	56.0
Giant's tank	96.5	Minneriya	25.6
Nuwarwewa	63.0	Parakrama Sumudraya	21.6
Nachchaduwa	52.5	Senanayake Sumudraya	17.0

Water requirement for OFC was assumed as 600 mm.

Nagarajah *et al.* (1988) reported that most of the well water in Northern Peninsula where Latosols are dominant could supply 31-54 kg K_2O ha^{-1} for onion and chilli respectively.
The majority of studies conducted on the response of OFC to potash fertilizer application has failed to produce any significant yield increase in most areas of the dry and intermediate zones (Weerasinghe and Lathiff, 2003). However, variable response to K has been also reported by Rezania (1993) and Anon (1983 and 1986). The comparatively high exchangeable K levels in soils and the richness of the growing environment with respect to K could explain these results for OFC. The non-responsiveness was shown for both low K-demanding legumes and high K-demanding maize in this crop group. Due to this unresponsiveness and the risk associated with rainfed cultivation farmers often neglect the application of potash fertilizers to OFC.

Future research

Future research studies in relation to the behaviour of potassium in OFC growing soils of Sri Lanka, could be considered on the following major topics:

- Inherent K supplying capacity of different soil groups under different farming systems.
- K balance sheets in different agro-ecological regions under different farming situations.
- K dynamics in different soil groups under different farming situations.
- Mineralogy of different soil groups.

Conclusion

Other Field Crops are mainly grown in the drier parts of the country and soils in these areas have variable content of exchangeable K. In addition, irrigation water in this region has also variable content of K. However, available data do not exhibit a clear declining or increasing trend in exchangeable K content in all over the OFC growing soil. Soils in this region are derived from K containing primary minerals and have also clay minerals that could play an important role in the dynamics of K in the soil.

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Chapter II

POTASSIUM NUTRITION MANAGEMENT OF PLANTATION AND INDUSTRIAL CROPS

Importance of balanced fertilization to meet the nutrient demand of industrial and plantation crops

A. Krauss

International Potash Institute, P.O. Box 1609, CH-4001, Basel, Switzerland

Abstract

Exports of agricultural goods are of growing importance also for the South Asian region. Unless the farmer can produce top quality, he will not be competitive at the market. Although crop quality such as the content of certain constituencies, processing properties, shape and appearance are genetically controlled, the nutrition of plants can modify the expression of the quality. In this respect, the balance in nutrient supply, especially between nitrogen (N) and potassium (K) is of particular importance. Due to the multifunctionality of K in yield and quality physiology, K can be considered as the element that determines the quality. Examples are given on the impact of balanced fertilization with adequate K on yield, quality and stress tolerance of a range of industrial and plantation crops.

Industrial and plantation crops are of economic importance for South Asia

Industrial and plantation crops, also called cash crops, became a substantial economic factor in the agriculture of South Asia. As shown in Fig. 1, the area of industrial and plantation crops increased the last 4 decades by almost 50% to currently some 75 million ha, whereas the area with subsistence crops (cereals, pulses and root and tuber crops) stagnated at a level of 230 million ha. Correspondingly, the share of the area with industrial and plantation crops on the total area increased the last 40 years from 27 to 33%.

The increase in production of both crop types is substantial; production of subsistence crops almost doubled the last four decades from about 135 to 250 million t, and that of the cash crops even trebled from 180 to 500 million t.

Industrial and plantation crops are equally important for the domestic market and as export earner. Concerning the domestic market, there is a pronounced shift in food consumption as affected by the demographic development in South Asia. Rajendra Prasad (2003) quoted a report by Kumar showing that urban people in India consumed on average (1987) about 50% more oil, 33% more fruits and vegetables but 23% less cereals than their rural counterpart. Even more remarkable is the fact that with increasing income the consumption of cash crops, i.e. fruits and vegetables, oil, and sugar increased substantially in contrast to cereals, which showed only a moderate increase with raising income (Fig. 2). It is as important to notice that income also has a great impact on the consumption of animal protein. In this context, it should be kept in mind that to produce one kg meat it requires 4 to 8 kg cereals.

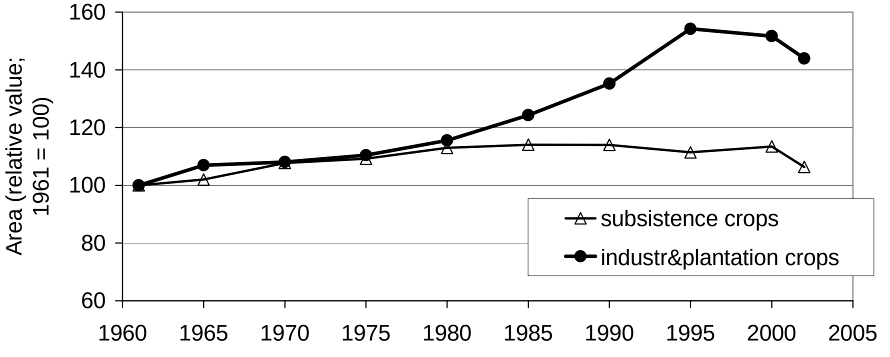

Fig. 1. Change of the crop spectrum over time in South Asia (FAO, 2003)

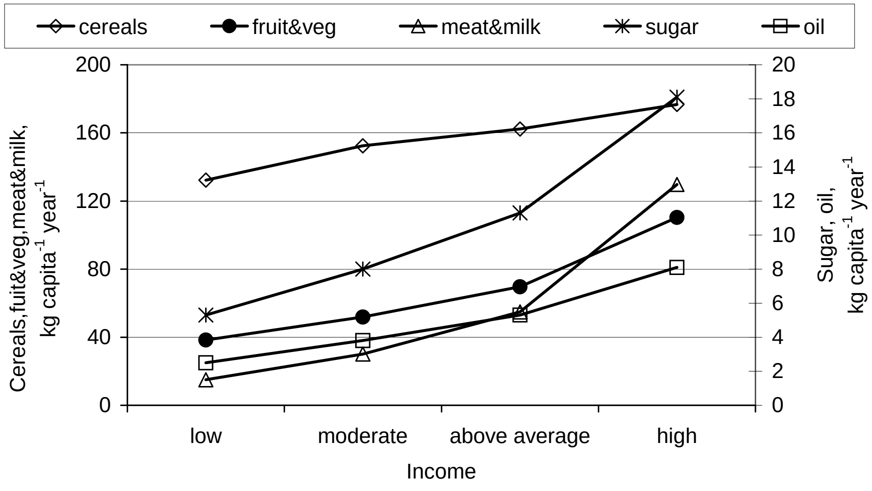

Fig. 2. Consumption of food items in India as affected by income (after Rajendra Prasad, 2003)

A major share of the produced goods is for export. As shown in Fig. 3, South Asia exported agricultural goods worth $7.2b (mean of 1999-2001). More than half of the value came from export of cash crops such as fruits and vegetables, tea, spices etc. In Sri Lanka, about 70% of the export earning of agricultural products derives from tea (FAO, 2003).
However, irrespective, whether industrial and plantation crops are produced for export or for the domestic market, the quality determines the commercial success of the grower. Although quality of crop products such as oil, protein and sucrose content, fibre quality, taste and appearance is genetically controlled, the nutrition of plants can have a considerable impact on the expression of quality. It is therefore essential to judiciously take care on the nutrient supply of the plants.

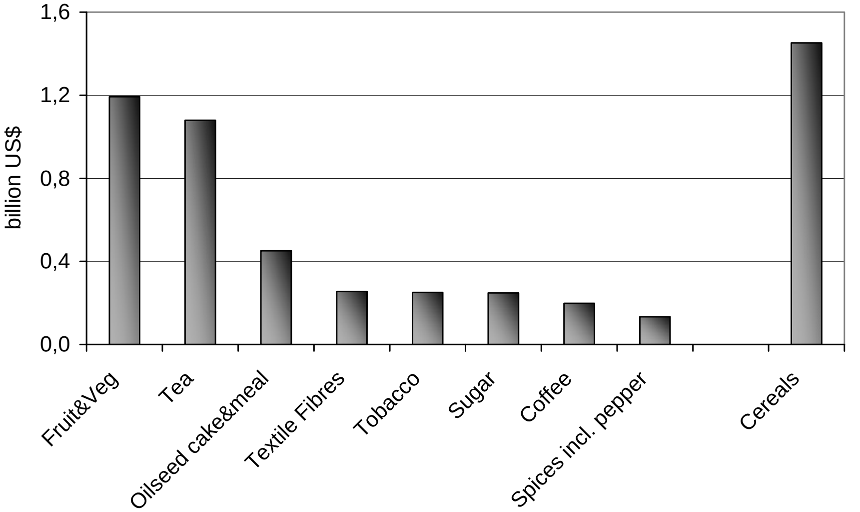

Fig. 3. Export earning (gross export) of South Asia with selected crops - mean of 1999-2001 [total value of agricultural export $7.2b] (FAO, 2003)

Nutrient uptake and removal of major cash crops

Table 1 informs on nutrient uptake and removal by selected cash crops. However, the nutrient removal with the harvested part of plantation crops reflexes only partially the amount of nutrient involved in plant growth and yield development. In tea for instance, the nutrients removed with the plucked leaves represent only 23%

of N, 41% of P and 22% K, which is assimilated by the whole plant. Tandon (1993) also showed that for an overall production of 10.8 t made tea cycle of four year, the plant parts above the pruning cut need 1028 kg N, 357 kg P_2O_5 and 482 kg K_2O.

Table 1. Nutrient uptake and removal by selected cash crops (from Tandon, 1993; IFA, 1992)

Crop	Yield	N	P_2O_5	K_2O
		-------------------	kg ha^{-1}	-------------------
Cane	132 t ha^{-1}	161	104	205
Cotton	2.5 t ha^{-1} seed cotton	100-200	35-70	110-200
Jute	3.15 t ha^{-1} fibre	110	64	198
Soybean	2.34 t ha^{-1} seeds	196	45	135
Tobacco	2-2.5 t ha^{-1} cured leaves	66-150	22-50	108-200
Coconut	6920 nuts	96	47	144
Coffee	1 t green beans	40	5	52
Rubber	in latex	6-36	2.4-17.6	6-39.1
Tea	1 t marketable tea	41.5	7.5	26
Banana	40-70 t ha^{-1} $cycle^{-1}$	225-450	50-100	1000-1500

Banana bunches remove at harvest about 49% of N, 56% of P, 54% of K and 39% of Mg, which is absorbed by the whole plant. The net removal with the harvested bunches represents the equivalent of 189, 29, 778 and 49 kg ha^{-1} N, P, K, and Mg, respectively (Lahav and Turner, 1989).

In rubber trees the total amount of nutrients, which is immobilized in the tree, sums up over a 30 years period to 1500-1800 kg ha^{-1} N, 458-573 kg ha^{-1} P_2O_5, 1440-1680 kg ha^{-1} K_2O and 300-365 kg ha^{-1} MgO (IFA, 1992).

Nutrient removal with the green berries in coffee represents merely 20% of N, 32% of P, 39% of K and 8% of Mg taken up by the whole coffee bush (Tandon, 1993).

Mature oil palms take up annually some 190 kg ha^{-1} N, 60 kg ha^{-1} P_2O_5, 320 kg ha^{-1} K_2O and 100 kg ha^{-1} MgO. However, the amount of nutrients, which is effectively removed with the harvested fruits is only 38% of N, 46% of P and 35% of K taken up by the trees. The total nutrient demand of a nine years old plantage is about 1266-1722 kg ha^{-1} N, 470-600 kg ha^{-1} P_2O_5, 2260-3000 kg ha^{-1} K_2O and 510-700 kg ha^{-1} MgO (Goh and Haerdter, 2003).

This disparity between nutrient removal and nutrient absorption/immobilization has to be taken into consideration when fertilizer recommendations are developed for the different perennial crops and trees.

Nutrient management of cash crops

Cultivation of cash crops aims to have high yields at best quality because quality based procurement becomes increasingly more common, also in South Asia. Looking at the three macronutrients, nitrogen is known as a constituent of amids and amino acids, the basic precursors of protein, enzyme systems and vitamins. Inadequate N supply is immediately and easily recognized by pale yellowish discoloration of the plant, retarded growth and low yield. Leaf color cards, chlorophyllometers, quick leaf sap tests are easy to handle tools for precise and economic N management.

Phosphorus is mostly involved in energy transfer as well as in storage and transfer of genetic information in plants. P deficiency symptoms are fairly characteristic, i.e. stunted growth, dark green, purplish discoloration of the leaves and retarded root growth. The soil conditions often indicate the probability whether P deficiency can be expected. Acidic soils fix P in form of Al- and Fe-phosphates, and calcareous soils in form of Ca-phosphates. Soil amendments and use of P fertilizers show a rather rapid response of the crop.

Potassium is a very versatile nutrient and contained in plants, as shown earlier, in quantities similar or even higher than N. It activates a large number of enzyme systems involved for instance in assimilation, sucrose transport, starch and fat/oil synthesis, N metabolism and thus protein synthesis. Potassium plays also a major role in the osmoregulation of plants. Plants adequately supplied with potassium in concert with the other macro- and micronutrients are more tolerant to pests and diseases (Perrenoud, 1990) and more resistant to climatic and soil borne stress such as drought, heat, frost or salinity. The involvement in numerous metabolic processes renders K as the key element in quality production. Inadequate K supply is noticeable mostly through indirect indicators such as early wilting, variable yields, early senescence, poor quality and appearance of fruits and vegetables, lodging of cereals and cane, more insect and disease damages, i.e. indicators, which are usually not been associated with K deficiency. Typical K deficiency symptoms, e.g. chlorosis and necroses on leaf margins or orange spotting in oil palms are seen only at very severe K deficiency. Omission of potash use seldom provokes an immediate response of the plant unlike the omission of N or P because the soil functions as a buffer in K supply. No wonder that potash use lags seriously behind the requirement of plants and fails to compensate the K removal by crops (Fig. 4).

However, as soon as quality based procurement is introduced like in the plantation sector, the nutrient ratio in fertilizer use improves. The North of India with its food grain oriented cropping systems has an N:K ratio of 1:0.03 whilst the South of India with its high share of plantation crops uses N and K in a ratio of 1:0.33. Quality of food grain still has no importance at the local grain market in India.

The secondary nutrients Mg, S and Ca gaining importance, especially in view of increasing yields and thus, increasing nutrient removal, and in view of using high grade mineral fertilizers such as urea, diammonium phosphate (DAP) and muriate of potash (MOP), which do not contain secondary nutrients as a 'by-pack'. Also use of organic manure as a potential source of S is minute. But Mg and S are taken up by plants in quantities similar to P. The Sulphur Institute (TSI) projects that the S deficit in fertilizer use will grow in India to 1.8 m tonnes and in whole Asia to 5.7 m tonnes S by 2010. In India, TSI conducted research showed that out of 19,000 soil samples, 42% showed S deficiency and 31% were potentially deficient. On the other hand, yield increases of up to 60%, especially in oil crops were achieved in India with application of S together with NPK (Messick, 2002).

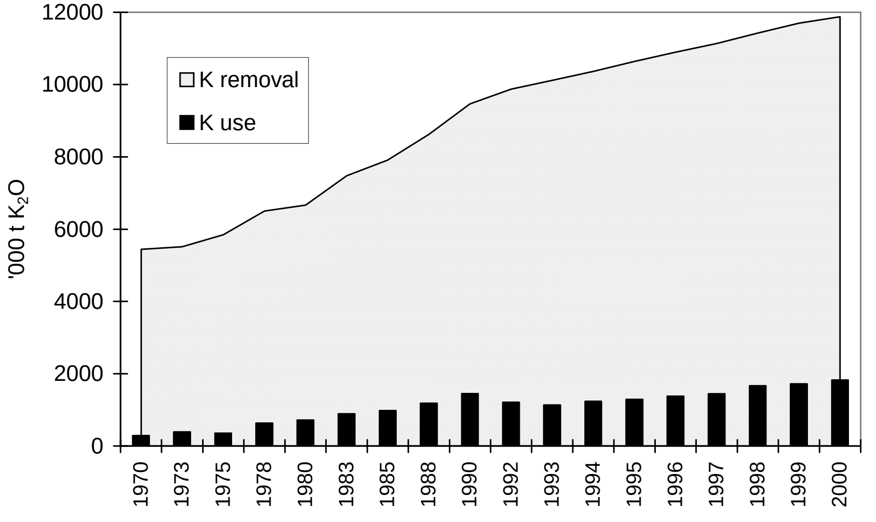

Fig. 4. K removal by crops in relation to potash use in South Asia

Availability of micronutrients is often a problem in high pH calcareous soils. In those regions, Zn and Fe deficiency in fruit trees is quite commonly observed. Foliar application of chelates gives a quick relief.

A special case is chloride. It is contained in coconut and oil palm in quantities similar to P and Mg although the physiological requirement is much lower. Chloride ion has its function in photosynthesis and is a strong osmoticum. In this function Cl^- is involved in stomata regulation. In other crops, Cl^- is a true micro nutrient required in rather small quantity. However, taken up in excess Cl^- can deteriorate the quality of Cl-sensitive crops such as tobacco, pome fruits and berries.

Integrating legume cover crops and recycling of plant residues are additional sources of nutrients. Tandon (1993) quotes results from India showing that a good Mucuna cover crop contributes 220 kg N, 11 kg P, 68 kg K, 18 kg Ca and 9 kg Mg. One tonne of EFB, empty fruit bunches in oil palm contain nutrients equivalent to 2.7-6.1 kg urea, 0.3-2.6 kg rock phosphate (RP), 10.3-16.9 kg MOP and 1.9-3.9 kg Kieserite (Redshaw, 2003).

How to apply the nutrients

Surface application is still the common practice. To incorporate the fertilizer into the soil as quick as possible is essential to minimize volatilization and run-off losses. In areas where micro irrigation is introduced, it is mandatory to inject fertilizers into the irrigation system, called fertigation, because in the restricted root zone the soil nutrient reserves are rapidly exhausted.
The area under micro-irrigation expanded substantially during the last 20 years (Fig. 5). It increased from about 0.4 million hectares in the early 80ies to more than 3 million hectares today.

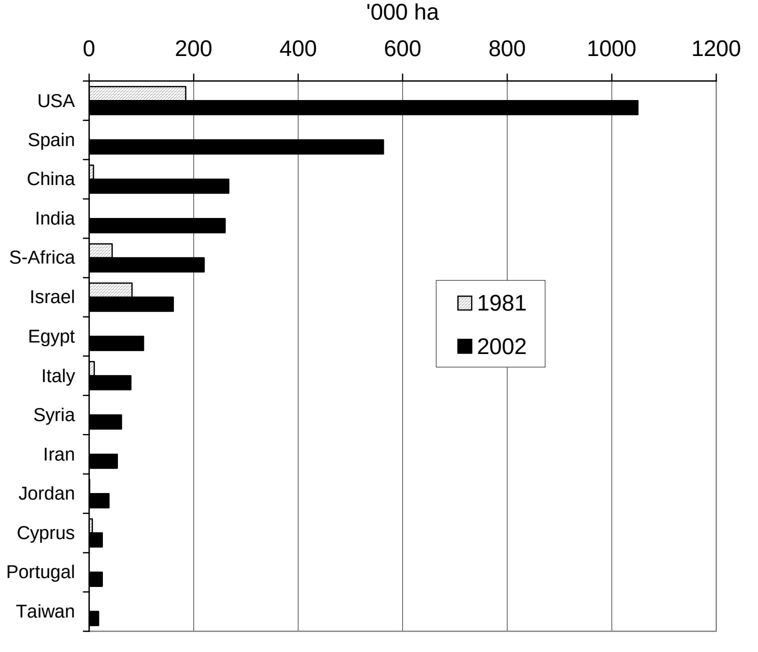

Fig. 5. Development of micro irrigation (New Ag International, 2002)

The advantage of fertigation in combination with micro-irrigation has been summarized by Imas and Magen (2002) as follows:

- Accurate and uniform application of fertilizers
- The amount and concentration of nutrients are adapted to the plant needs and climatic conditions
- Improves fertilizer efficiency, saving water and fertilizers
- Increases the availability and the uptake of nutrients
- Increases yield and quality of crops
- Reduces nutrients leaching below the root zone, and
- Large savings on time, traffic, labor and fuel costs.

Comparing the yield achieved with traditional fertilization and with fertigation, it confirms the advantages of the latter (Fig. 6). Also citrus in Iran significantly increased the fruit yield from 171.6 kg tree^{-1} for surface irrigation to 186.7 kg tree^{-1} for drip irrigation in combination with fertigation. At the same time, the water use efficiency increased from 5.5 kg m^{-3} in surface irrigation to 8.5 kg m^{-3} for drip irrigation (Malakouti, 2003).

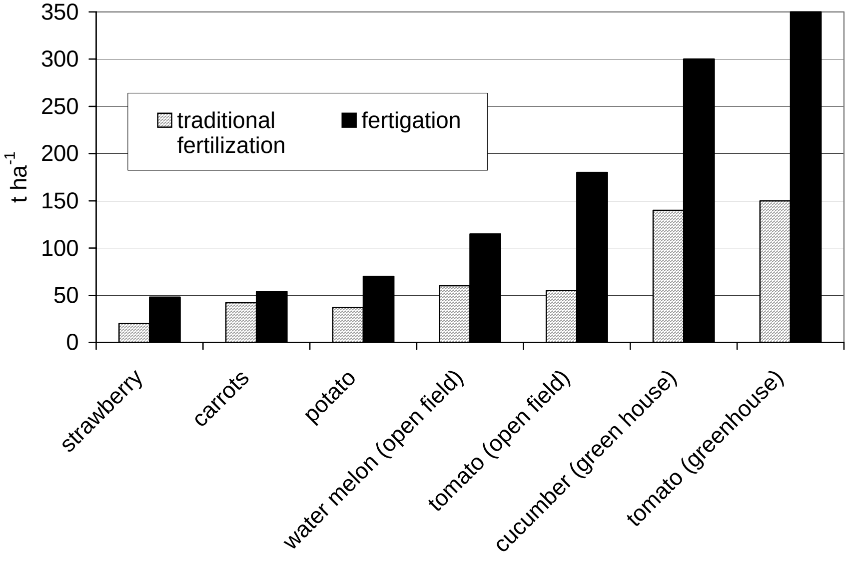

Fig. 6. Effect of fertigation on crop yield (New Ag International, 2002)

As mentioned, with fertigation the nutrient supply, in particular the ratio between the nutrients can be adjusted according to the need at a particular stage of development. Hagin *et al*. (2002) gave for tomatoes the following recipe:

- From planting to flowering 1.6 kg N ha^{-1} day^{-1} and 1.3 kg K ha^{-1} day^{-1}
- Flowering to fruit set 2.1 kg N ha^{-1} day^{-1} and 2.6 kg K ha^{-1} day^{-1}
- Fruit set to ripening 2.8 kg N ha^{-1} day^{-1} and 4.6 kg K ha^{-1} day^{-1}
- Fruit ripening to harvest 3.6 kg N ha^{-1} day^{-1} and 6.0 kg K ha^{-1} day^{-1}

There is a clear shift from an N oriented nutrient ratio during the vegetative growth phase to a K oriented ratio during the generative phase.

The impact of balanced fertilization on yield and quality – few examples from activities of International Potash Institute (IPI)

- Soybean in India: Large-scale soybean production started in India rather late. From 11,000 ha in 1961 the area increased to 125,000 ha in 1976, to 1.2 million ha in 1984 to a record size of 6.49 million ha in 1998 (FAO, 2003). The production increased accordingly, from a minute 5,000 t in 1961 to 7.1 million t in 1998. International Potash Institute (IPI) trials with a wheat-soybean rotation started during the mid 80ies in Madhya Pradesh, the soybean State of India. More recent results show economically viable yield increases of up to 26% over control and B:C ratios between 2.7 and 7.7. Split application of K was superior to basal dressing (Fig. 7). The content of crude protein increased from 37.3% at the control to 39.9% at the best treatment. There was also a significant increase in the number of nodules (+48%) and the nodule dry weight (+22%). The gain in biologically fixed nitrogen due to application of potash is accordingly.
- Jute in West Bengal: IPI on-farm trials during the early 90ies in West Bengal showed an increase of fibre yield from 25.8 q ha^{-1} at the control to 29.7 q ha^{-1} with 60 kg ha^{-1} K_2O in split application and an additional source of S (gypsum).
- Vegetables in China: Vegetable production in China skyrocketed from 58 million t in 1961 to currently 368 million t on 20 million ha, and in India from 18 to 78 million t on currently almost 6 million ha. Preliminary results from IPI trials in China show that use of balanced fertilization with potash increased yield of cauliflower by 24%, of lettuce by 13% and of potatoes by 35%. At the same time, the quality improved as well, cauliflower increased the dry matter content from 6.6% at the control to 7% with potash. The nitrate content of lettuce decreased in the leaves from 480 to 360 µg g^{-1}, and in the stem from 2000 to 800 µg g^{-1} with potash. And in potato, the share of large sized tubers (>6 cm in diameter) increased from

11.8% at the control to 19% with potash whilst the share of small tubers (<3 cm in diameter) decreased from 54.5% at K_0 to 48.1% with potash.

- Citrus in China: Citrus production in China started slowly with 100,000 ha and 350,000 t production in 1964. Twenty five years later, 1989, citrus was grown on 1.1 million ha and produced 5.11 million t fruits. Currently, 2002, China grows citrus on almost 1.5 million ha and production has increased to 12.3 million ha. The increase in production was due to a considerable increase in yield, namely from 3.5 t ha^{-1} in 1964 to 5 t ha^{-1} in 1989 to currently 8 t ha^{-1}. In India, citrus production increased less spectacular as in China, it evolved from 93,000 ha and 1.2 million t in 1961 to currently 264,000 ha and 4.5 million t of fruits.
- International Potash Institute established field trials in China with citrus with conventional fertilizer application as well as with fertigation. Mandarins responded significantly to potash applications with higher yields (Fig. 8), higher juice content and an increase in the total soluble solids (TSS). Representative measures showed that the share of large sized mandarins, >6 cm diameter, increased from 18.5% at the control to an average share of 19.2% with MOP and 19.9% with sulphate of potash (SOP) as the K source.
- The fertigation experiment started in 1999. After two years, the tree height increased in the control (no K) by 48%, but with 100 mg l^{-1} K in the irrigation water by 68% and 58%, respectively in the treatment with 200 mg l^{-1} K. Correspondingly, the tree trunk circumference increased by 62% in the control, 70% at 100 mg l^{-1} K and by 80% at 200 mg l^{-1} K.
- Tea in China: China and South Asia share about 2/3rd of the global area and production of tea. Yield-wise, the South Asian region appears to be more advanced (1.7 t ha^{-1}) than China with 0.83 t ha^{-1}. International Potash Institute conducted, together with the Tea Research Institute of the Chinese Academy of Agricultural Science, in Hangzhou, China during the 90ies a range of fertilizer experiments with tea. Application of K improved the biomass production up to 15%, however, in dry years even up to 30%. Potassium also improved the survival of seedlings at drought stress; at soil moisture of 55% of field capacity, only 67% of the control plants survived. With K application the survival rate increased to 89%, these plants had also a higher biomass (+65%) and higher K uptake (+82%). Potassium is known for its beneficial role in regulating the water household of plants.
- The accompanying anion can modify the effect of K on yield and quality of tea. As shown in Fig. 9, K application increased the biomass production of green tea by 26% with MOP and 49%, respectively with SOP as the K source. The presence of Cl led even to a declining quality in form of lower contents of amino acids and reduced activity of nitrate reductase.

- Potassium in combination with $MgSO_4$ could increase the content of aromatic components in oolong tea. Use of potash also reduced the incidence of Anthracnose, *Colletotrichum gloeosporides*. More details on the TRI-IPI research are published in IPI website www.ipipotash.org.

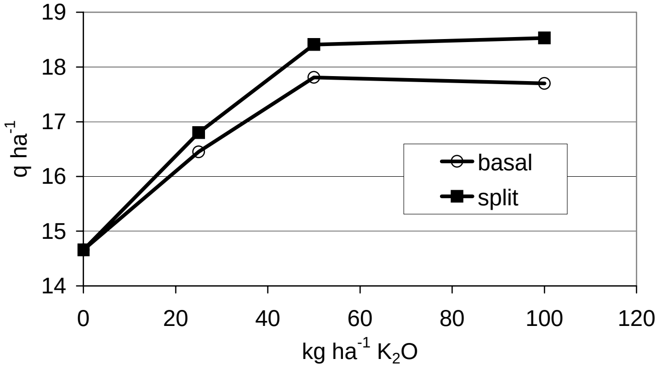

Fig. 7. Effect of potash on soybean yield in India (IPI trials, 2001)

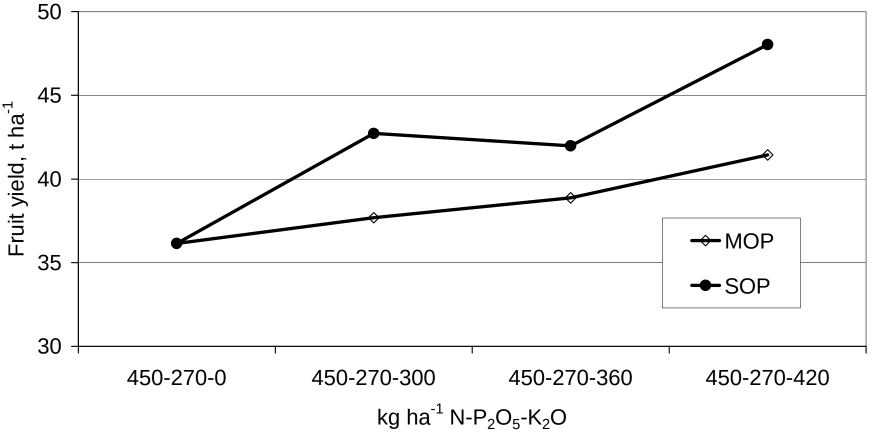

Fig. 8. Effect of the K source on fruit yield of Puncan mandarins (IPI trials China, mean 2000-2002)

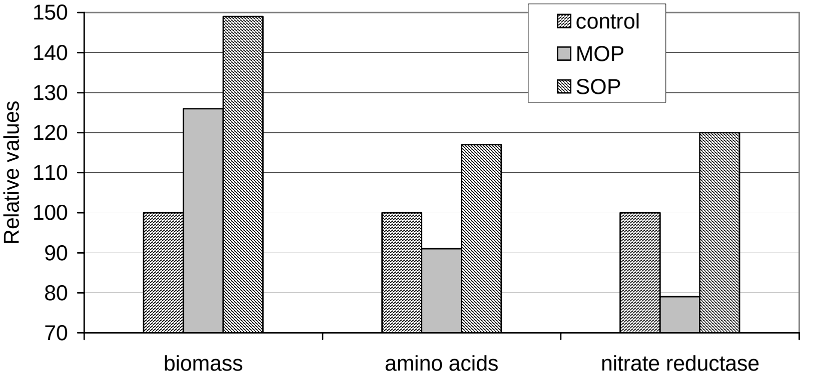

Fig. 9. Effect of K source on yield and quality of green tea (Wu Xun *et al.*, 1997)

Conclusion

Globalization and World Trade Organization (WTO) open the international markets although there are still complain about non-trade barriers, export subsidies etc, which affect the free flow of goods. Irrespectively, success in trade, also with cash crops highly depends on the quality. This refers both to the home trade and the export trade. Failing to meet the quality norms set by the customer renders the goods as not competitive to the detriment of the producer, the farmer. Achieving no surplus in income by selling his crops the farmer lacks of funds for expenditures of non-agricultural products, which ultimately prevents rural development.

Because of the potential the nutrition of the plant has on the quality of the product we have to investigate and to demonstrate how best to feed the plant to achieve the goal, namely competitive quality. Of course, fertilizer trials, especially with plantation crops are costly and it takes a long time until a significant response is seen. We need more public funds for agricultural research and development. Unfortunately, the agricultural research expenditures for instance in India is stagnating. By 1997, public spending in Agricultural research as a percentage of agricultural Gross Domestic Product (GDP) was only 0.4%. This compares with 2-3% in many developed countries. On the other hand, agricultural research plays an important role in reducing rural poverty. Shenggen Fan (2002) estimates that each additional one million Rs spent in agricultural research and development raises 157 people above the poverty line.

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Current status of fertilizer use to plantation crops in Sri Lanka

D.R. Wijayatilleke

National Fertilizer Secretariat, Ministry of Agriculture, Livestock, Lands & Irrigation, 80/5, Govijana Mandiraya, Rajamalwatta Avenue, Battaramulla, Sri Lanka

Introduction

Plantation crop sector had been a fairly well managed commercial crop sector even before the time of the independence in Sri Lanka. Therefore, use of chemical fertilizer to plantation crops had commenced much before its adoption for domestic food crops. Soils in traditional growing areas of major plantation crops, i.e. tea, rubber and coconut, in the wet and the intermediate agro-climatic zones of the country are degraded in varying degree. Use of chemical fertilizer is necessary for commercial production of these crops. However, the product price and the price of fertilizers (fertilizer subsidies) are both important factors determining the level of fertilizer use to plantation crops. Basic statistics related to plantation crops sector is shown in Table 1.

Table 1. Basic statistics related to plantation crops in 2002 (NFS, 2003)

	Tea	Rubber	Coconut
Area cultivated, '000 ha	181	157	439
Production, million kg	310	91	2,392*
Use of mineral fertilizers, '000 t	185	7	38
Average fertilizer use, kg ha^{-1} $year^{-1}$	1,020	40	90
Cost of production, Rs kg^{-1}	125.00	48.50	3.85

* Million nuts

Mineral fertilizers used in plantation crops sector

Nitrogen fertilizers

Urea and sulphate of ammonia are the major nitrogen fertilizer used to plantation crops. A gradual shift from sulphate of ammonia to urea could be observed due to the subsidized price of urea and the advantage of low soil acidity with urea application as compared to that of sulphate of ammonia. However, sulphate of ammonia is still used in substantial quantities to tea and coconut. Supplies of sulphate of ammonia under the Japanese Food Production Grant have been terminated and, therefore, all supplies are made as imports under free exchange.

Phosphate fertilizers

Tropical climate with adequate rainfall facilitates the use of ground rock phosphate as the source of phosphorus for plantation crops in Sri Lanka. Availability of local rock phosphate or Eppawela rock phosphate (ERP) as a cheaper source of rock phosphate is a further advantage. Eppawela rock phosphate has become the major source of rock phosphate by substituting the imported rock phosphate (IRP), which has been the major source of rock phosphate hitherto since early 1980's. In the year 2002, the rate of substitution was around 80% with tea crop achieved a substitution rate above this percentage.

In the year 2002-03, an improved grade of local rock phosphate has been introduced as High Grade Eppawela Rock Phosphate (HERP). The citric acid solubility of this product range between 6% and 7% and, therefore, this product may act as a close substitute for IRP. Imported rock phosphate is still applied for nurseries, young stage of coconut and for young rubber plants. However, use of IRP is diminishing over the years.

Both triple super phosphate and diammonium phosphate are used in smaller quantities for nurseries.

Potash fertilizers

Muriate of potash (MOP) is the major potash fertilizer used in the country. Supplies of MOP come mainly from Russia. About half of the total MOP imported into the country is used to plantation crops. Tea crop is the largest consumer of MOP in the plantation sector.

Sulphate of potash (SOP) is used on a much smaller scale. However, the Tea Research Institute of Sri Lanka recommends its use, particularly under drought conditions.

Compound fertilizers

There is no significant use of NPK compound fertilizer in the plantation crop sector. Sul-Po-Mag (S, K, Mg) has been used mainly to tea crop, but its use is diminishing.

Magnesium fertilizers

Being a locally produced fertilizer from calcium magnesium limestone deposits in the central province of the country, dolomite is the cheapest and abundantly available magnesium fertilizer. It is often used as a soil ameliorant to control soil acidity. Dolomite is widely applied for both tea and coconut plantations, it is estimated that about 20,000 tonnes of dolomite is used annually. However, due to very low water solubility of dolomite, rapidly magnesium releasing fertilizers are used depending on crop needs. Kieserite with water solubility of about 40% is applied mainly to tea, but also to coconut and rubber. Commercial Epsom salt is used under magnesium deficient situations as a foliar spray.

Micronutrient fertilizers

Zinc sulphate is used to correct zinc deficiencies and also to promote sprouting of tea buds. Micronutrient fertilizer mixtures are now distributed by private sector companies, particularly for tea crop.

Fertilizer use in plantation crops sector

Fertilizer use in the plantation sector for the period 2000-03 is shown in Table 2. On the average, 90,474 tonnes of NPK were applied annually to plantation crops, including 49,265 tonnes of N, 10,245 tonnes of P_2O_5 and 30,964 tonnes of K_2O.

Tea

Tea crop is the second largest consumer of mineral fertilizers in the country (after rice). With favourable prices for tea, fertilizer use to this crop has almost doubled during last three decades and about 40% of growth in fertilizer use has been achieved during the last decade alone (Fig. 1).
Current fertilizer recommendations of the Tea Research Institute of Sri Lanka (TRI) correspond to yield levels anticipated by growers. However, there are many growers/estates using site specific fertilizer recommendations based on soil/foliar analysis.
Available statistics indicates that the average tea grower more or less follows the common fertilizer recommendations; fertilizer rates above the normal level are used in anticipation of higher yields. Related figures calculated in consultation with TRI are given in Table 3. Private small holders, growing clonal tea, use higher rates of fertilizers as compared with the large estates. It appears that owing to high overhead costs, large estates are not in a position to allocate sufficient funds to increase

fertilizer application. Tea growers continue to use fertilizer nutrients (NPK) in balanced manner (Table 3).

Table 2. Average annual fertilizer use (tonnes) in the plantation crop sector during the period 2000 to 2003 (NFS, 2000, 2001, 2002 and 2003)

Fertilizer		Tea	Rubber	Coconut	Total
N	Urea	72,343	2,872	6,730	81,945
	Sulphate of ammonia	45,617	412	3,770	49,799
P	Eppawela rock phosphate	16,087	2,821	4,774	23,682
	Imported rock Phosphate	6,258	1,930	3,711	11,899
	Triple super phosphate	758	55	533	1,346
	Diammonium phosphate	235	0	7	242
K	Muriate of potash	38,118	2,069	11,229	51,416
	Sulphate of potash	135	4	6	145
Compound	NPK	0	6	25	31
	Sul-Po-Mag	503	2	42	547
Mg	Kieserite	4,745	452	612	5,809
	Dolomite	1,513	610	2,729	4,852
	Commercial Epsom salt	433	12	3	448
Micronutrient	Zinc sulphate	403	4	2	409
Others		88	1	435	524
N		43,972	1,403	3,890	49,265
P_2O_5		6,613	998	2,634	10,245
K_2O		22,934	1,244	6,786	30,964
MgO		1,141	377	546	2,064
Total		74,780	4,022	13,856	92,658

Rubber

In fact, the economic factors have more influence in determining the level of fertilizer use in plantation crops sector. Natural rubber as an industrial raw material is subjected to competition with the synthetic product. Drop in international market prices for natural rubber has negatively affected the fertilizer use to rubber tree in the recent past. Fertilizer use to rubber has declined since early 1990's (Table 4) due to both unfavourable rubber prices and reduction in cultivation area.

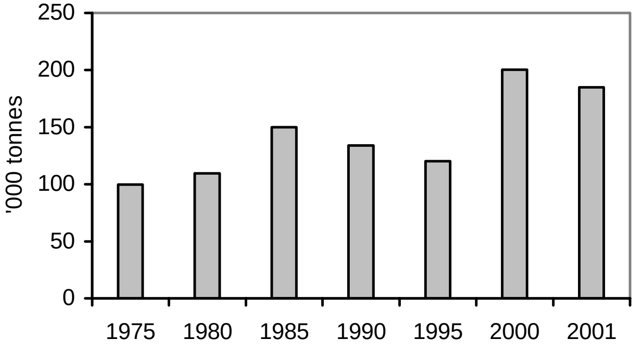

Fig. 1. Mineral fertilizer use to tea crop in Sri Lanka

Table 3. Specificity of fertilizer use to tea in Sri Lanka

Year	Fertilizer use, t		Rates, % to recommended	$N: P_2O_5:K_2O$
	Estates	Others/small holders		
2000	38,769	161,485	149	1 : 0.14 : 0.54
2001	38,765	145,268	136	1 : 0.15 : 0.52
2002	45,846	141,175	106	1 : 0.15 : 0.51

Table 4. Specificity of fertilizer use to rubber in Sri Lanka (CBSL, 2002)

Year	Average price of RSS1 rubber, Rs kg^{-1}	Fertilizer use, thousand t			Rates, % to recommended	$N:P_2O_5:K_2O$
		Total	Estates	Small holders/ others		
1990		22.2				
1995	72.45	14.9				
2000	54.91	13.8	2.2	11.6	31	1 : 0.67 : 0.81
2001	54.77	9.1	4.8	4.3	19	1 : 0.79 : 1.02
2002	67.99	6.9	5.8	1.1	15	1 : 1.17 : 0.91

Fertilizer use to rubber is inconsistent, although there is no imbalance in the nutrient formulations used. Present level of fertilizer use by growers is much below the recommended level. Fertilizers are mostly used during immature stage of the crop. The decline in fertilizer use has been observed mostly due to the small holders, who have neglected the crop in results of poor economic returns. Improvement in fertilizer use to rubber could be expected from 2003 in response to better product prices.

Coconut

Coconut is a crop requiring application of comparatively high level of potash fertilizer. Small holders dominate coconut cultivation in Sri Lanka and therefore, strong programmes have been in force to increase fertilizer use. The highest level of fertilizer use to coconut has been recorded in the year 1980 and, thereafter, it has dropped to more or less static level (Fig. 2). Vagaries in weather conditions coupled with fluctuations in product price are the major causes of this situation. However, as observed in Table 5, there was an improvement in product price since 2001. Response of growers to increased product prices could be observed in the years 2001 and 2002. Coconut is a perennial crop, therefore, production responses show a lagged effect. Recovery in fertilizer application to coconut could be observed in the year 2003.

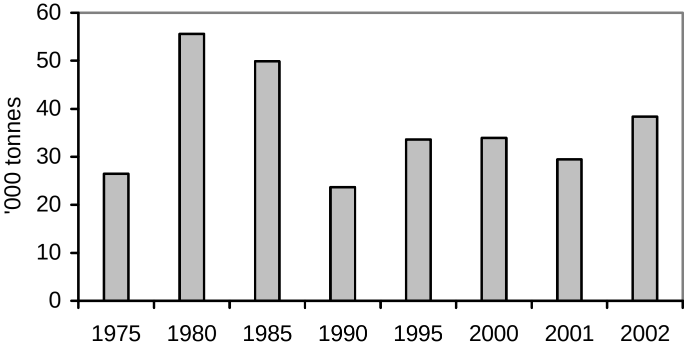

Fig. 2. Mineral fertilizer use to coconut in Sri Lanka

Even though there was an improvement in fertilizer application to coconut in 2002, the present level of fertilizer use is still inadequate. It is much below the recommended level as most small holders use less or no fertilizers. The Coconut Cultivation Board has initiated the intensive campaign to promote fertilizer use to coconut. With improved product prices there has been room for enhancing of fertilizer use to this crop. Table 5 illustrates that the present level of fertilizer use to coconut is far below the required level.

Coconut is a high potassium demanding crop. High proportions of P and K are maintained in fertilizer application practice.

Table 5. Specificity of fertilizer use to coconut in Sri Lanka (CBSL, 2001 and 2002)

Year	Price, Rs 1000 nuts^{-1}	Rates, % to recommended	$N:P_2O_5:K_2O$
2000	4,735	14	1 : 0.58 : 1.49
2001	8,233	12	1 : 0.74 : 1.93
2002	10,811	16	1 : 0.72 : 0.86

Conclusions

For all the plantation crops, i.e. tea, coconut and rubber, there was a change in types and quantities of fertilizers used over the last years:

- Utilization of urea as the main source of N has increased, substituting sulphate of ammonia for all the three major plantation crops. Heavy fertilizer subsidies given to urea have made it the cheapest source of N.
- Eppawela rock phosphate has emerged as the major source of P and meets more than 2/3 of the phosphate fertilizer requirement for plantation crops.
- Muriate of potash is the major single source of K for the all plantation crops. The use of MOP has almost doubled during the last three decades.
- Sulphate of potash has been recommended by TRI for the tea crop to be used under drought conditions.
- Since mid 1980's, kieserite, dolomite and commercial Epsom salt are used as sources of magnesium. However, dolomite is now widely used as a soil conditioner for adjustment of the pH level.
- Many tea growers have started the application of zinc sulphate and micronutrient fertilizer mixtures to improve yields.

Site-specific fertilizer recommendations based on soil and foliar analysis are gaining popularity, particularly among planters. Use of organic sources of plant nutrients is also promoted in Sri Lanka.

One of the major problems in the plantation crop sector is high cost of production. Whilst labour is the largest cost component in the plantation crop sector, higher efficiency in fertilizer use is also desirable to improve productivity and to cut down the cost of production.

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Potassium fertilization of tea

A.K.N. Zoysa and G.P. Gunaratne

Tea Research Institute of Sri Lanka, Talawakelle, Sri Lanka

Abstract

Conventional tea is a natural beverage made of tea plants (*Camellia sinensis* L.). Sri Lanka is world renowned for production of quality Ceylon black tea. Sri Lanka exports 95% of its total production and it contributes 14% of the total foreign exchange earnings. Pluckable shoots consist of two tender leaves and a bud and internodes. The concentration of potassium (K) in the flush and internodes is 2% and 2.4% respectively. A field yielding an average yield of 2000 kg ha^{-1} yr^{-1} of processed tea would remove 40 kg K ha^{-1} yr^{-1}. With increasing rates of K application in tea soils, the K concentration in the foliage increased but there was no response for higher rates of application, but causes an antagonism on Mg uptake. The tea plant's response to K application depends mainly on the soil K status and the plant availability of soil K and plant characteristics viz. age, growth and potential yield. A large number of laboratory and glasshouse investigations and field trials on K fertilizer related studies conducted in tea growing areas of Sri Lanka for more than six decades have showed that the optimum rate of K_2O for tea varied from 50 to 120 kg ha^{-1} yr^{-1}. This is due to tea types (clonal or seedling) and spatial variability of soils and climatic conditions of the soils. Therefore, six basal fertilizer mixtures were recommended for tea to match regional differences and type of tea. A clear distinction between new and old recommendations is that K application was subjected to a maximum of 140 kg K_2O ha^{-1} yr^{-1}, which prohibits excessive application of K. This saves large amounts of foreign exchange to the country. The K and Mg interaction was also considered in recommending fertilizers to tea. The current fertilizer recommendation can be further extended to a more discriminatory level by application of site specific fertilizer using the knowledge of K dynamics that gives a clear idea of the natural potential of soils in supplying K.

Introduction

The importance of potassium in tea nutrition received much attention among planters and researchers since the beginning of fertilizer use in tea (Petch, 1928). The research studies that were conducted on the response of applied K may be perhaps the area that was most researched in tea nutrition. The earliest recorded research on K in tea in Sri Lanka dates back to 1931 (Eden, 1934). Since then, the Tea Research Institute of Sri Lanka continued working on the line of K use in tea plants.

Potassium is the second largest nutrient required for tea and young leaves contain more K than the old leaves (Ranganathan and Natesan, 1985). Potassium is important to maintain optimum turgor needed for cell elongation and cell division (Mengel, 1978). It is very mobile and circulates freely in plants. If K is deficient, K from older leaves redistributes to younger tissues. K is indispensable for biochemical and biophysical reactions in tissues. Hence, optimum rates of K should be supplied to maintain highest economic yields.

Annually, tea removes a considerable amount of K per ha with yields compared to other macro- and micronutrients. The yield component of tea consists primarily of tea leaves and a bud and the internodes. The concentration of K in the internodes could be as high as 2.4%. The K concentration in the tender shoots varies from 1.8-2.0%. A field yielding 200 kg of marketable tea of 2000 kg ha^{-1} would remove about 40 kg K ha^{-1} yr^{-1}.

Petch (1928) stated that although K deficiency symptoms in tea were described as 'marginal scorch', such symptoms are unlikely to appear in tea under existing local conditions. However, he commented that K was essential for wood growth. Portsmouth (1953) based on the data of leaf chemical analysis of Eden (1934) NPK trial reported that tissue K concentration was completely dependent on the quantity of applied K fertilizer, and consequently Ca and Mg concentration declines with increasing levels of K fertilizer. Sivasubraniam and Jayman (1976) also reported that an increase in application of K fertilizer increased the K concentration in the soil and the leaf tissues and this increase was significant from zero to lower rates, but was not evident at higher rates. Tea yields also showed similar trends. Water-soluble K was better correlated with K requirements of the plant than either exchangeable or total K (Sivasubraniam and Jayman, 1976). However, Tolhurst (1971) found that the leaf K concentration was strongly associated with the changes in climate. Sivasubraniam and Jayman (1976) found that water-soluble K was better correlated with plant K requirements than with exchangeable or total K.

The fertilizer recommendations on K for tea plantations in Sri Lanka were made based on the available research information and this paper attempts to collate the available research information on K nutrition in tea plants and presents the current fertilizer recommendation on K in Sri Lanka.

Tea industry in Sri Lanka

Agriculture plays a vital role in Sri Lanka's economy and it constitutes 20% of the gross domestic product in 1999. Around 1.9 million ha of the total land area of the country is cultivated with plantation crops and nearly 40% of the cultivated area is occupied by the three main plantation crops namely tea, rubber and coconut. Tea occupies an extent of 181,172 ha in Sri Lanka and spreads from low to high grown elevations. Of the total extent, Low country (0-600 m), Mid country (600-1200 m) and Up country (>1200 m) account 42, 30 and 28% respectively (Anon, 2002). Tea production in the country recorded a peak in 2002 reaching 310 million kg due to favourable weather conditions. Some important statistics on tea growing is presented in Table 1 and the differences in tea production of Up, Mid and Low country regions are shown in Fig. 1.

Table 1. Some important statistics of Sri Lankan tea (Anon, 2002)

Year	Production, million kg	Productivity, kg ha^{-1}	COP	NSA	Export, million kg	Export earnings, billion Rs
			------- Rs kg^{-1} -----			
1990	233	1051	50.00	70.97	216	19.8
1991	241	1086	58.00	58.27	211	17.7
1992	179	806	72.00	61.75	178	14.5
1993	232	1045	76.00	68.88	211	19.2
1994	242	1092	75.67	65.12	225	20.5
1995	246	1331	76.14	72.21	236	24.0
1996	258	1380	87.04	103.88	234	32.5
1997	277	1465	93.47	119.40	258	40.4
1998	280	1495	106.72	134.35	265	48.2
1999	284	1514	101.29	115.31	264	42.0
2000	306	1618	110.64	135.53	281	51.0
2001	295	1562	121.57	143.96	290	59.3
2002	310	1649	125.05	150.28	287	61.2

In 2001, Sri Lanka spent Rs. million 5,862 for the import of all fertilizers and the amount of money spent on imported K fertilizers only during that year was Rs. million 1,116 (NFS, 2001). Potassium fertilizer imports are mainly from Russia and Belarus. The import of muriate of potash (MOP) for tea in Sri Lanka has increased with time and now it is about 36,500 million tonnes per annum. Periodic changes in the import of MOP for tea in Sri Lanka are presented in Fig. 2. An increase in the trend of MOP imports for tea after 1995 should be due to increase in the use of MOP in the plantations.

Response to K fertilizers in tea

The response of tea plant plants to K fertilizer depends mainly on the prevailing soil K status and the ability of the soil to meet K requirements of the plant according to its age, growth and yield. However, other factors also could influence the response for applied K in tea. The long-term field trials were conducted since 1931 in the Up, Mid and Low country since to investigate the application of increasing levels of K on tea plant's growth and yield at various stages of its growth.

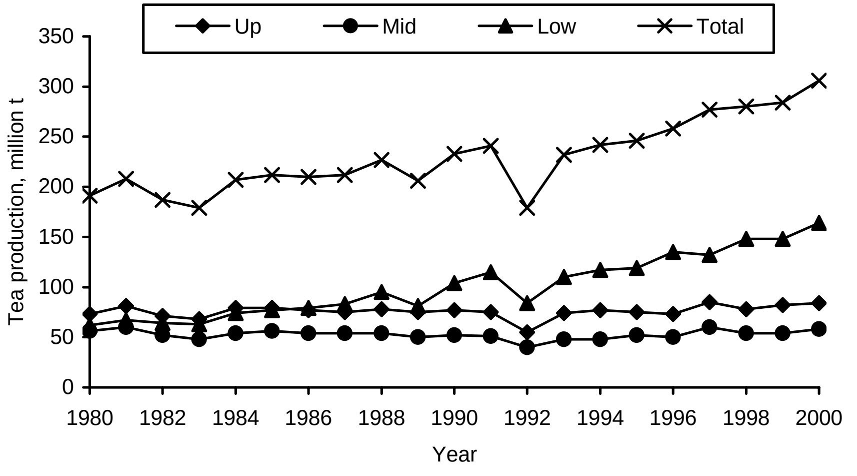

Fig. 1. Total and regional tea production in the Low, Mid and Up country regions of Sri Lanka

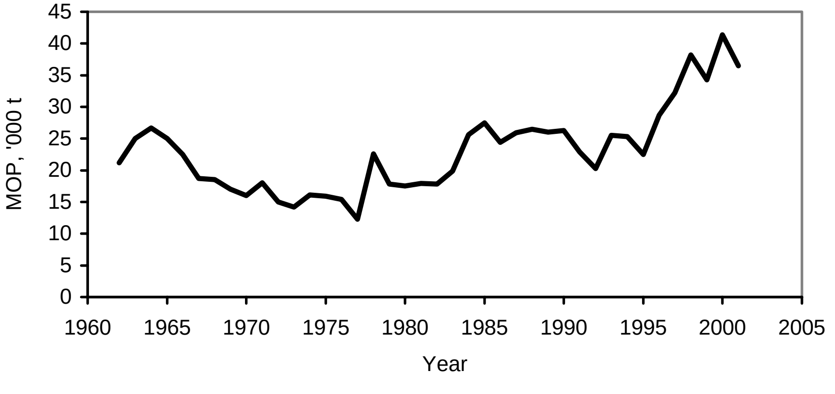

Fig. 2. Periodic changes in the imports of MOP for tea cultivation in Sri Lanka

Studies on nursery and immature tea

In 1986, a study (LA 99) on the application of increasing levels of K using T65 fertilizer mixture (0, 35, 70 and 105 g) for nursery plants (TRI 2023 – drought susceptible and TRI 2025 – drought tolerant) was conducted. It showed that there was a decrease in transpiration rate and an increase in the diffusive resistance and turgidity pressure in plants with increasing rates of K up to the 3rd level.

A field trial (LA 102) that was conducted in Palmgarden estate with CIDA (Canadian International Development Agency) assistance during 1984 on 15 month old immature tea plants with K application at 0, 90, 180 and 270 kg K_2O ha^{-1} yr^{-1} at 2 levels of Mg (36 and 72 kg MgO ha^{-1} yr^{-1}). The trial continued until 1988 and found that the increase in application of K and Mg increased leaf K and Mg. However, it was shown that the increase of K beyond 90 kg did not improve the tipping weights and flush yield. This trial also showed an indication of drought resistance build-up in plants only up to 90 kg of K_2O.

Another trial (LA 109) was started at Palmgarden estate in 1984 using the remaining plants of LA 99. The K treatments were based on T200 formulation and K was supplied at 90 (recommended rate), 180 and 270 kg ha^{-1} yr^{-1}. In 1987, the effect of K levels on drought tolerance was estimated and found that the increase of K from 0 to 180 kg K_2O ha^{-1} yr^{-1} reduced the drought affected plants by 13 to 14% in both clones. Also it was found by leaf analysis that the leaf K concentration increased from 1.05 to 1.45% and reduced Mg concentration by 0.29 to 0.25% owing to increase of K_2O rate from 0 to 180 kg. There was no benefit in flush yield in plots due to increase in K beyond 90 kg K_2O and significant increase in pruning and tipping weights was seen only at 90 kg K_2O compared to the control treatment.

A field trial was done at Hantana during 1986-1987 using three levels of K at the first year (90, 135 and 180 kg K_2O ha^{-1} yr^{-1}) and at the second year (113, 169 and 225 kg K_2O ha^{-1} yr^{-1}). Young tea plants (10 months old) of three clones (TRI 2023 – drought susceptible, TRI 2025 – moderately drought tolerant and DG 7 – drought resistant) were used in the trial. The K levels were based on T200 fertilizer. The increasing levels of K showed no effect on plant height, stem girth and dry matter in any of the clones. However, stem girth measured after 12 months for 90 kg K_2O application was significantly greater than the control.

Studies on mature tea

The trials started in 1931 by Eden did not show any significant yield increase compared to the control, until the 12th year of the experiment (Child, 1964). However, responses were evident with applications of 22 and 45 kg K_2O ha^{-1} yr^{-1}. The maximum response was observed by at about 120 kg K_2O ha^{-1} yr^{-1} (Bavanandan and Manipura, 1969; Sandanam *et al.*, 1980; Sivasubramaniam, 1972; Watson and Wettasinghe, 1972).

The long-term field trial (A8) initiated in 1961 at St. Coombs, Talawakelle, on mature VP (vegetative propagated) tea (TRI 2024) fertilization with NPK (112, 224 and 336 kg N; 0, 70 and 140 kg K_2O; 0, 56 and 112 kg P_2O_5 ha^{-1} yr^{-1}) showed a significant increase in yield only up to 70 kg K_2O ha^{-1} compared to the control. Similarly, tipping and pruning weights also showed significant improvement only up to 70 kg K_2O ha^{-1}. Some parameters, notably, stomatal and cuticular transpiration, evapotranspiration and photosynthesis rate, were studied in the trial during the dry periods of 1983-1986 to find possible relationships between K levels and water economy of the plants. The increase of K_2O from 70 to 140 kg ha^{-1} improved the efficient water use in plants but there was no corresponding yield increase when annual mean yield was considered for the entire experimentation period of 21 years (Krishnapillai *et al.*, 1988; Krishnapillai and Anandacoomaraswamy, 1994).

Another long-term field trial (A12) was started in 1969 at St. Coombs, Talawakelle, on mature seedling tea to study the efficiency of NPK use (N: 0, 100, 200, 300, 400 and 500 kg ha^{-1} yr^{-1}; K_2O: 0, 84 and 168 kg ha^{-1} yr^{-1}; P_2O_5: 0 and 34 kg ha^{-1} yr^{-1}). The significant improvement in yields was observed only up to 84 kg of K_2O ha^{-1} yr^{-1} compared to the control. Similar observations were seen on tipping and pruning weights.

The field trial (LA 81) conducted at Hapugastenne estate during 1981-1984 with N (0, 300 and 600 kg N ha^{-1} yr^{-1}) and K fertilizers (0, 70 and 140 kg K_2O ha^{-1} yr^{-1}) revealed no significant relationship between the K levels and active buds and shoot yield.

During 1984-1990, the field trial (LA 107) was undertaken at Noragolla estate with TRI 2023 plants on the effect of different N:K_2O ratios, i.e. 3:1, 2:1 and 1:1 (300 kg N : 100 kg K_2O; 300 kg N : 150 kg K_2O and 300 kg N : 300 kg K_2O ha^{-1} yr^{-1} respectively) on wood growth and yield. No significant differences in yield and pruning weights were observed between any of the N:K_2O ratios during the trial period of two pruning cycles.

Since mid-1970s, a large number of K related field trials were carried out to refine the optimum application of K in the form of muriate of potash under nursery, immature and mature tea under field conditions.

During 1987-1992, a field trial was laid down on mature tea at St. Coombs estate, Talawakelle, testing increasing rates of K (0, 60, 120, 180 and 240 kg K_2O ha^{-1} yr^{-1}. N was supplied from two sources (sulphate of ammonia and urea) at 240 kg N ha^{-1} yr^{-1}. No significant differences were observed between any of the rates of K fertilizer applied in addition to N sources during the trial period.

In the end of 1984, five long-term field trials were started on mature tea in different parts of the country [Giragama (Kandy), Craighead (Nawalapitiya), Kotiyagala (Bogawantalawa), Deniyaya (Deniyaya) and Walahanduwa (Galle)] to study the effect of increasing K rates on yield, wood growth and recover after pruning. The level of K_2O was ranged from 60 to 360 kg ha^{-1} yr^{-1} at 60 kg intervals. These trials were continued during 6 years but no significant improvements were observed in any of the parameters tested.

Four trials were initiated on mature tea in 1984 and with the same levels of K. Those trials were located at Halgolla (Yatiyantota), Beaumont (Pussellawa), Glenannore (Haputale) and Maha Uva (Udapussellawa) estates. The trials were continued until 1990 but no significant yield increase due to K was reported.
There were four other field trials on mature tea commenced in the mid 1987 and continued until March 1992 at El-tab, Kotiyagala, New Peacock and Waltrim estates to study the effect of increasing levels of K (90, 180 and 270 kg K_2O ha^{-1} yr^{-1}) and Mg (45, 90 and 135 kg MgO ha^{-1} yr^{-1}) on growth and yield of tea. These trials also showed that the increase of K and Mg did not result in significant yield increase at any of the experimental sites.
In the recent past, in 1998, a field trial on VP teas was established at Brunswick estate (Norwood) with increasing rates of N (240-600 kg N ha^{-1} yr^{-1} at 180 kg N increments) and K (120-480 kg K_2O ha^{-1} yr^{-1} at 180 kg K_2O increments) to study the soil and plant nutrient status and the yield response of tea. So far, no significant improvement in yield was observed with respect to any of the K rates compared to the control treatment in any of the years after trial commencement. The concentration of leaf N and K increased with increasing rates of N and K.

Current K fertilizer recommendations for tea in Sri Lanka

The fertilizer mixture T65, which is water soluble, is used for tea nurseries. Potassium sulphate is applied to provide K for nursery plants. Fertilizer mixtures T200 (1st and 2nd year) and T750 (3rd and 4th year) are recommended for immature tea. Both mixtures contain N, P, K and Mg.
In mature tea fertilization, there are several factors, i.e. the variation in soil and climatic conditions, affecting tea yield response to applied K fertilizers. These factors vary widely between tea growing regions in the country and the current fertilizer recommendations attempt to address such issues using the available research information. There are six basal fertilizer mixtures recommended for mature tea in Sri Lanka. A summary of K requirements in all growth stages of tea plants is presented in Table 2.

Table 2. K fertilizer recommendation for nursery, immature and mature tea plants

Growth stage		Age / region	K_2O, kg ha^{-1} yr^{-1}	Source of K
Nursery (100,000 plants)			89-100 kg	SOP
Immature		1st year	83	MOP
		2nd year	120	
		3rd year	140	
Mature	Seedling	Up and Mid	70	MOP
		Low	50	
		Uva	70-100	
	Vegetatively propagated	Up and Mid	100-140	
		Low	100	
		Uva	140	

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Potassium fertilization of rubber

Lalani Samarappuli

Rubber Research Institute of Sri Lanka, Dartonfield, Agalawatta, Sri Lanka

Abstract

Sufficiency range of leaf potassium content for physiological function of the rubber (*Hevea brasiliensis)* tree is from 1.3% to 1.6%. Application of K fertilizers increases the leaf K content by nearly 47%. Application of K at recommended level throughout its immature period increases growth by 15% reducing the unproductive period by 12 months. Moreover, the tappability of rubber trees increases by 34%. Significant yield increases ranging from 17-33% are also obtained with application of K at the recommended level during the mature stage of rubber tree. Experimental evidence suggests that K fertilizer enhances the annual girth increment of mature rubber by 17% and bark renewal by 0.3 mm. Moreover it is clearly shown that the K fertilizer application is essential for latex flow and stability. Experimental results obtained on the role of K in plant water status of rubber revealed that K sufficient rubber plants always have a better plant water status, and influence of higher levels of added K fertilizer in overcoming of moisture stress effects is also evident. The general potash fertilizer application to rubber on soils with low and very low K level commences with 17 kg K ha^{-1} during the 1st year of planting and rates are increased up to 66 kg K ha^{-1} until tapping. On soils with medium K level potash fertilizer application starts with 9 kg K ha^{-1} during the 1st year of planting and rates are increased up to 33 kg K ha^{-1} until tapping. The K fertilizer recommendation for mature rubber is based on soil and foliar analysis (site specific fertilizer recommendation).

Introduction

Rubber is one of the main plantation crops in Sri Lanka, which produces natural rubber, and its contribution to the national economy is significant due to large foreign exchange earnings and employment generation. The current position of Sri Lanka in production and exports in the world are 11th and 8th, respectively. The total land area under rubber is 158 thousand ha, which accounts for about 8% of the total cultivated extent in the country. Rubber is mainly confined to the wet and intermediate zone and is grown on a wide range of soils with variable availability of

K. Potassium management in rubber cultivation has gained greater importance in recent years mainly for three reasons:

- rubber plantations are no longer raised in fertile virgin forest soils,
- most of the plantations are either in the third or fourth cycle of re-planting,
- the high cost of K fertilizers.

Potassium is one of the major nutrient elements required and taken up in large amount by the rubber tree besides nitrogen and phosphorus. Potassium is required by the rubber tree for early maturity, (reduction of unproductive immature period), higher yield of latex, maintenance of stability and flow of latex and for drought and disease resistance.

K nutrient cycle

Potassium is being continuously transferred between the soil, the tree and the ground vegetation. The uptake and accumulation by the tree is the major process in this cycle, although in the early years after planting uptake of K by vigorous leguminous cover plants, growing in the almost open conditions can exceed that by the tree. Samarappuli and Yogaratnam (1995) reported the K content of 80-120 kg K ha^{-1} in creeping leguminous covers at two years after planting; as the covers die back under the developing tree shade, K is returned to the soil and is thus again in active cycle early in the life of a rubber planting. After first two years, the rubber trees assume a dominant position in the K nutrient cycle. Potassium is taken up in considerable quantities and a large proportion is immobilized within the roots, trunk and main branches of the trees (Table 1).

Table 1. Amount of K immobilized in rubber

Age, years	K, kg ha^{-1}
1	8
2	46
3	65
4	230
6 (end immature period)	450
10	775
33 (end of mature period)	1875

The amount of K contained in the timber is considerable and reaches 1500 kg ha^{-1}, which is equivalent to about 3 tonnes of fertilizer MOP. The removal of the timber

during replanting markedly affects the K content of the soil; even after one replanting cycle such depletion is likely to be serious on soils with low K content.
Potassium is also lost from the cycle by removal of latex and it is estimated that K removal with latex amounts to 216 kg K ha^{-1} during the economic life cycle of rubber. Apart from this, K may be lost by leaching through the soil and by surface erosion.
Potassium is added to the soil mainly by fertilizer application. It is estimated that 280 kg of K are added to 1 hectare of immature rubber throughout its 6-years immature period and during 27 years of mature period 500-700 kg of K are added to 1 hectare of rubber land. Annual leaf fall of rubber, rainwater and addition of paddy straw as a mulching material can be considered as other contributions of K to the soil. It is reported that during the immature period (6 years) 10-20, 20-30 and 300-350 kg of K are added to the soil by annual leaf fall, rainwater and paddy straw, respectively.

Importance of K nutrition

Potassium is an important nutrient, which is necessary for the rubber plant to complete its life cycle. Potassium is involved in various process of plant metabolism and it seems to be needed for almost all the physiological processes in the rubber plant. Moreover, this element is essential in increasing of both growth and yield, for better water relations and in balancing of excess magnesium levels in the tree; thus influencing latex stability and pre-coagulation situations. Sufficient K nutrient status in the tree, therefore, plays a major role in latex yield of a rubber tree.

K nutrient status of the tree

Leaf nutrient content provides an apparently consistent guide to the K nutrient status of the rubber tree according to deficiency/sufficiency ranges of leaf K content (Table 2). Sufficiency range of K content for physiological function of the tree is from 1.3% to 1.6%, which drops to 0.75% when deficiency symptoms appear. Potassium deficiency in rubber can be clearly identified by visual symptoms of marginal and tip parts of leaves turning yellow or chlorotic. Defoliation (wintering) is usually late and incomplete in K-deficient trees. Application of K fertilizers as muriate of potash (MOP) is effective in increasing of the leaf K content by 40-50% over the deficient status [Table 3] (Yogaratnam *et al.,* 1984; Samarappuli, 1992). Moreover, efficiency of K uptake appears to have been influenced by the level of Mg content in the soil. Significant antagonistic effect between K and Mg has been recorded [Table 4] (Weerasuriya and Yogaratnam, 1989).

Table 2. Categorization of leaf K content (%) in rubber

Very low	Low	Medium	High	Very high
<1.2	1.2-1.4	1.4-1.7	1.7-1.9	>1.9

Table 3. Effect of K fertilizer application on leaf K content in rubber

Treatment	Leaf K content, %
Without K	0.82
With K	1.21

Table 4. K and Mg interaction in rubber

Level of K	Leaf Mg content, %
No K	0.212
Recommended level	0.108
Double recommended level	0.101

Growth

Fertilization with K has also been shown to be an efficient method in increasing the vigour of immature rubber. Potassium fertilization has been proved to be helpful in encouraging the desired early growth and girth at 6th year after planting. The average 15% increase in growth has been revealed by application of K at recommended level of 280 kg K ha^{-1} for the six years of immature period (Fig 1). Increasing the application of K beyond this level is not likely to give any additional benefit (Yogaratnam *et al.,* 1984).
Moreover, repeated fertilization with K throughout immature period has been proved to be effective in shortening the unproductive period by 12 months (Fig. 1) and in increasing the tappability of rubber trees by 34% (Table 5).

Yield

Significant yield increases ranging from 17% to 33% have been obtained with application of K at the rate of 100 g of K per plant per year during the mature stage of rubber tree (Table 6). However, there is a lag period of about 4 years between fertilizer application and yield response. Table 7 signifies the average net benefit of fertilizer application under different rubber prices. The increase in yield due to fertilizer application could be a direct effect or mediated through the effect on other factors such as girthing, growth of bark, bark renewal, canopy maintenance, etc. Thus, no single factor can stand at its own; an integrated picture of all these factors is essential to sustain an economic yield. To attain economic yields, the general health and girthing of the tree must be maintained at a satisfactory level even during the mature period. Experimental evidence suggests that K fertilizer enhances the annual girth increment of mature rubber by 17% and bark renewal by 0.3 mm (Table 8). Larger trees may have thicker bark and greater lengths of the tapping cut or higher yield per unit length of the tapping cut than the smaller trees. Moreover, the number of latex vessels, their size and starch reserves in the bark are all related to tree girth. Furthermore, it has been clearly shown that the K fertilizer application is essential for latex flow and stability (Table 9) thus, balancing the excessive Mg levels in the latex (Table 10).

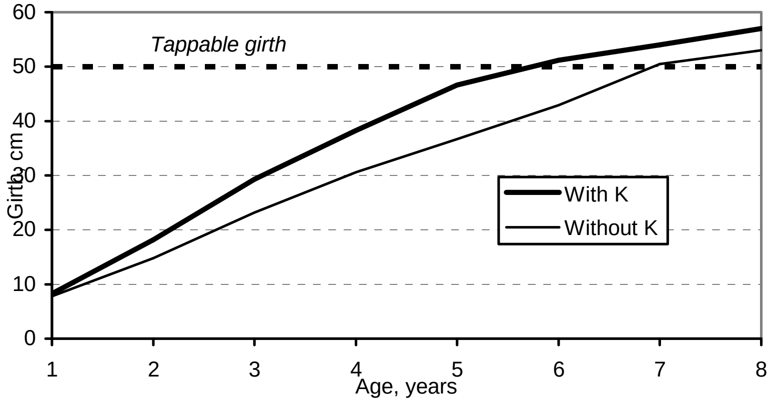

Fig. 1. Effect of K on girthing during immature period

Table 5. Effect of K fertilizer application on tappability of rubber

Treatment	Tappability, % (6 years after planting)
Without K	50
With K	84

Table 6. Effect of K fertilizer application on rubber yield

Treatment	Yield, kg ha^{-1} year^{-1} (average of 8 years)	Relative yield increase, %
Without K	900	100
With K	1116	124

Table 7. Average net benefit from K fertilizer application under different rubber prices

Rubber price, Rs kg^{-1}	Yield increase due to K use, kg ha^{-1} year^{-1}	Income	Cost of K fertilizer	Net benefit
		----------------	Rs ha^{-1} year^{-1}	----------------
50	200	10,000	1,980	8,020
75	200	15,000	1,980	13,020
100	200	20,000	1,980	20,020

Average yield – 1000 kg ha^{-1}, yield increase due to K – 20%, cost of MOP – 22 Rs kg^{-1}.

Table 8. Effect of K fertilizer use on girth of mature rubber trees (at the end of Panel B) and bark renewal

Treatment	Girth (at 5 ft above the bud union)		Thickness of renewed bark (3 years after tapping), mm
	cm	%	
Without K	53.5	100	5.1
With K	62.8	117	5.4

Table 9. Influence of K on latex flow and K content

Treatment	Volume, ml	Time of flow, min	Rate of flow, ml min^{-1}	K content, %
Without K	165	220	0.75	0.58
With K	191	235	0.88	0.80

Table 10. Effect of K on Mg:P in latex

Level of K	Mg:P in latex
No K	0.30
Recommended level	0.22
Double recommended level	0.19

Plant water status

Data obtained on the role of K in plant water status of rubber revealed that with the increase in soil moisture stress transpiration rate (TR) of K sufficient rubber plants is decreased. However, in the absence of K, TR is greater under soil moisture stress condition, losing more water from the tree. It seems to suggest that K sufficient rubber trees appear to reduce TR more readily than the K deficient trees (Samarappuli *et al.,* 1993). It is possible that water stress in plants low in K is developed due to the sluggish opening and closing of stomates and their low capacity to respond to rapidly changing transpirational conditions (Table 11). Measurement of relative water content of leaves under the influence of decreasing water availability in the soil reveals a better water status of the leaf tissues for K sufficient plants. It has been also noted that the plant diameter at adequate soil water status with recommended level of K is almost similar to the diameter of rubber plants under soil moisture stress condition in combination with double the recommended level of K. Moreover, this has been further confirmed by the higher girth and tappability recorded with the increase in the level of K under field condition in dry areas [Table 12] (Samarappuli, 1992; Samarappuli and Yogaratnam, 1998).

Disease management

Informations on K and disease control seem to suggest that rubber trees are more resistant to diseases under sufficient plant K status.

Integrated management of K in rubber

To supplement the K requirement through fertilizer, high and low K fertilizer mixtures are recommended for low – very low and for medium soil K levels, respectively. On soils with low and very low K content, the general potash fertilizer application to rubber in a form of high K mixtures commences with 17 kg K ha^{-1} during the 1st year of planting and rates are increased up to 66 kg K ha^{-1} until tapping

(Table 13). On soils with medium K content, potash fertilizer application in a form of low K mixtures starts with 9 kg K ha^{-1} during the 1st year of planting and rates are increased up to 33 kg K ha^{-1} until tapping. Application of higher starting rates of K (12-25 kg K ha^{-1}) is recommended for correction of the K deficiency.

Table 11. Effect of K on transpiration, relative water content and plant diameter at different conditions

Parameter	Treatment	Situation		
		Dry	Medium	Wet
Transpiration, mmol m^{-2} sec^{-1}	No K	6	5	5
	Recommended level	3	4	6
	Double recommended level	2	4	6
Relative water content, %	No K	79.2	81.4	88.9
	Recommended level	88.3	90.3	98.2
	Double recommended level	91.2	97.4	98.1
Plant diameter at 1 year after planting, cm	No K	11.7	11.9	12.3
	Recommended level	13.0	13.6	17.1
	Double recommended level	16.6	15.9	15.6

Table 12. Effect of K on growth and tappability (under dry conditions)

Level of K	Girth, cm	Tappability, %
No K	38.1	17.9
Recommended level	45.0	51.0
Double recommended level	49.0	71.2

Table 13. Potash fertilizer recommendation for immature period

Age	Low to very low soil K		Medium soil K	
	g $tree^{-1}$ $year^{-1}$	kg ha^{-1} $year^{-1}$	g $tree^{-1}$ $year^{-1}$	kg ha^{-1} $year^{-1}$
1	33	17	17	9
2	66	32	33	17
3	99	50	50	25
4	99	50	50	25
5	132	66	66	33
6	132	66	66	33

The K fertilizer recommendation for mature rubber is based basically on its K status (site specific fertilizer recommendation based on soil and foliar analysis). Although general fertilizer recommendations are available for rubber, K fertilizer requirement for newly developed clones under different soil conditions are yet to be studied thoroughly. The outcome of such studies would facilitate more cost-effective K fertilizer use for rubber.

The removal of K is much higher when yield stimulants are applied (Table 14). This is due to the greater volume of latex being removed from the trees. Under such conditions additional 25% of K fertilizers are necessary to maintain a satisfactory K nutrient status within the tree and thereby to sustain the impact of stimulation. Moreover, it is recommended to apply an extra 100 g of K fertilizer to the fields badly affected with *Oidium* secondary leaf fall. It is also stated that soil K tends to increase the water use efficiency of rubber under stress conditions (Samarappuli, 1992a; 1992b; Samarappuli and Yogaratnam, 1998). Application of more K in the form of MOP at rates between 50-200 g per tree depending on the age, therefore, would be beneficial under soil moisture stress conditions.

Table 14. Removal of nutrients with use of yield stimulants

Situation	Nutrients removed, kg ha^{-1}			
	N	P	K	Mg
Without stimulation	9	2	8	2
With stimulation	24	7	22	4

Paddy straw contains about 1.4-1.9% of K. Incorporation of 23 t ha^{-1} of paddy straw during the 6-years immature period (2-5 kg per plant per application, once in 6 months) would contribute 300-350 kg of K. This quantity represents more than 100% of K presently recommended as chemical fertilizer for rubber during the immature period and mulching with paddy straw has been found to increase soil and leaf K contents (Tables 15 and 16). Moreover, the requirement of K as fertilizer during the first 8 years mature period can be reduced by 300 kg ha^{-1} if paddy straw is applied during the immature period. Further, incorporation of 5 kg of paddy straw per tree per annum would contribute about 2/3 of K recommended as chemical fertilizer for rubber during the mature period (Samarappuli *et al.*, 1998).

Management of leguminous ground covers is an important aspect in rubber cultivation for the preservation of soil fertility and it is reported that cover crops immobilize 80-120 kg of K in their green matter during the first two years after planting. This green matter with low C:N ratio is rapidly mineralized, recycling K to the soil, and this K becomes quickly available to rubber plants.

Moreover, 10-20 kg and 20-30 kg of K are also added to the soil through annual leaf fall of rubber and rain water, respectively.

Table 15. Effect of different soil management practices on soil and leaf K content

Treatment	Exchangeable K, cmol kg^{-1} soil	Leaf K, %
Naturals	0.090 a	0.67 a
Legumes	0.094 a	0.75 a
Dead mulch	0.113 b	0.91 b

Different letters indicate significant differences at P = 0.05

Table 16. Effect of different covers incorporation on soil and leaf K content

Covers	Exchangeable K, mg kg^{-1} soil		Leaf K, %	
	K_0	K_1	K_0	K_1
Weeds	34	46	0.67	0.85
Legumes	35	46	0.61	0.94
Legumes + straw	66	69	1.10	1.15

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Potassium fertilization of sugarcane in Sri Lanka

M.W.N. Dharmawardene, S.A. Ranjith and W.L. Bodhinayake

Sugarcane Research Institute, Uda Walawe 70190, Sri Lanka

Introduction

Sugarcane is cultivated as a commercial crop mainly in the dry and intermediate agro-climatic zones of Sri Lanka. Its current distribution and the potential areas, for which feasibility studies exist, are shown in Fig. 1. Those areas come under the five major Great Soil Groups found predominantly in the dry zone of Sri Lanka, namely the Reddish Brown Earth (RBE), Non-Calcic Brown (NCB), Immature Brown Loam (IBL), Alluvial and Low Humic Gley (LHG) soils (Panabokke, 1967; Mettananda, 1990; Dharmawardene and Krishnamurthi, 1992; Survey Department of Sri Lanka, 1996).

Due to the decline of the sugar industry in the late nineties, factories in the northeast in the country at Kantale and Hingurana were closed down. Thus, current cropping area is largely confined to two districts, namely Moneragala and a small part of Ampara district, totaling approximately 15 thousand ha. Due to the decline of the area, one of the great soil groups, namely RBE (Alfisols) now completely predominates over the rest, occupying nearly 90% of the cropping area although its share in the early to mid nineties was not more than 60% of the cropping area then under sugar. This paper reviews the methods used at present in existing fertilizer recommendations with respect to potash fertilization of sugarcane in the country.

Chemical properties of sugarcane soils

The chemical properties of sugarcane soils that affect the growth and development of sugarcane are the pH, cation exchange properties, organic matter content, total nitrogen content, available phosphorous, available potassium, other major elements, trace elements, salinity and sodicity.

Generally, RBE and the other sugarcane growing soils in the country mentioned already have pH values within the acceptable range of growth for cultivation of sugarcane. Reddish Brown Earth soils are fairly rich in total nitrogen. However, for continuous cropping, addition of nitrogen fertilizer is necessary. In contrast, NCB soils are generally poor in nitrogen and they require a higher dosage of nitrogen than RBE soils. Reddish Brown Earth and NCB soils are low in their phosphorous levels and very often they fall below the critical level for sugarcane, which is 0.16

mmol kg^{-1} (Meyer, 1991). The RBE soils are fairly rich in potassium. However, under continuous cropping it is known that soil reserves could be deplete below the critical levels. Thus, sugarcane grown in the nucleus area in the Pelwatte sugar project located in the intermediate climatic zone of the country showed the symptoms of K deficiency caused by soil depletion due to continuous cropping without added K fertilizers. The critical level of soil exchangeable K for sugarcane is 3 mmol kg^{-1}. Non-Calcic Brown soils also need K fertilizers, as these soils do not have rich K reserves. Apart from NPK, both RBE and NCB soils have adequate supplying capacities of other major and minor elements. Generally, there have been no changes in the content of other major and trace elements even under continuous cropping in these soils. In general, both RBE and NCB soils are low in their organic carbon content and enrichment of these soils with organic matter would improve crop yields.

Fig 1. Current and potential sugarcane areas (only the potential areas where feasibility reports are available)

Methods and criteria used for K recommendations

The main aim of all the fertilizer programmes is to provide the amount of nutrients that are in short supply over and above that is available to the plant from soil to meet the crop demand in the most economically feasible manner. Guoqing (1988) has quantified the same as follows:

$$K_f = \frac{K_y - K_s}{E_f},$$

where K_f is the deficit requirement of fertilizer K, K_y is the total uptake of K by the crop to achieve a yield goal for a given locality, K_s is the contribution of K from the soil and E_f is the efficiency of K fertilizer utilization. Thus, it is evident from the above, that the K fertilizer requirement of a given crop could be estimated as the amount of K required by a crop to achieve a certain yield goal in a given locality under a given set of management practices if amounts available from the soil and the efficiency of K fertilizer utilization (recovery of fertilizer K) are known (Harmesen, 1984; Saint-Fort *et al.*, 1990; Meyer, 1991; Muchow and Robertson, 1994; Vallis and Keating, 1994).
Following methods are used generally to estimate the above-indicated parameters:

1. Determination of K removal by the crop in a given locality.
2. Determination of yield goals for the crop for a given locality.
3. Determination of the amounts of a given nutrient available through mineralization in a given locality.
4. Analysis of soil to ascertain the available, labile and fixed pools of nutrient in question in the soil.
5. Foliar analysis of crop plants to ascertain sufficient and deficient levels.
6. Fertilizer rate trials to obtain response curve with respect to Mitscherlich equation.
7. Diagnosis and Recommendation Integrated System (DRIS) for balanced fertilization.

Nutrient requirement of sugarcane including that of K was assessed for the sugarcane crop grown in Reddish Brown Earth Soils of Sri Lanka using the above methods as per the standard procedures (Knudsen *et al.*, 1982; Houba *et al.*, 1989; MSIRI, 1990).

Nutrient removal by sugarcane

During sugarcane cultivation, mature stalks are removed to the factory at the end of growing season and only about 10% of the total biomass produced by the crop is returned to the soil, part of which may be burnt down during field preparation for the next season. Thus, there is a constant removal of nutrients from sugarcane fields with the harvested stalks. It has been shown by various workers that mature sugarcane stalks remove from the soil about 2.13 kg of K per tonne of cane (Singh, 1978; Sorensen, 1982).

The one of the earliest approaches in the nutrient management was to recognize what was removed from the soil by way of adding fertilizers. Thus, South Africa has used a factor of 1.25 to multiply the targeted cane yield (in t ha^{-1}) to obtain the required amount of N fertilizer for cane throughout the industry (Meyer, 1991). In Taiwan, about 2 kg of N are required to produce 1 tonne of cane, thus the factor of 2 is used. In Taiwan, cane production areas have set yield goals of less than 50, 80 and 125 t ha^{-1} and more than 175 t ha^{-1} of cane (Li, 1993); and the fertilizer recommendations are made for each of the areas, to meet those yield goals. Under present management conditions in Sri Lanka (Fig. 2), about 2.4 kg of K are required to produce one tonne of millable stalks (SRI, 1995).

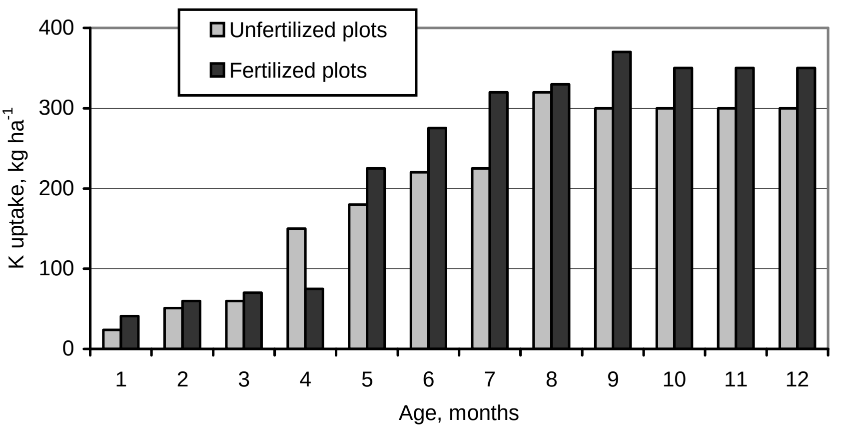

Fig. 2. Potassium uptake into aerial biomass by sugarcane variety CO 775 grown in RBE soils

Investigations on the NPK removal by sugarcane into aerial parts from planting to full maturity of crop under irrigation in RBE soils show that total K accumulation in both unfertilized and fertilized plots have a similar pattern. However, nutrient accumulation was always higher in the fertilized plots than in the unfertilized plots. It is evident from the results shown in Table 1 that the average total accumulation of N is almost five times that of P and the average total K removal is 11 times that of P. Based on those results it can be concluded that the mean nutrient removal figures for the three key elements by the sugarcane variety CO 775 is 0.991 kg of N, 0.222 kg of P and 2.443 kg of K per tonne of millable cane.

Table 1. Total NPK removals by sugarcane into its aerial biomass (Dharmawardene and Bodhinayake, 1995)

Treatment	Nutrient removal, kg ha^{-1}		
	N	P	K
Unfertilized	114	26.2	299
Fertilized	152	33.4	358
$LSD_{0.05}$	18	5	37
CV, %	16	14	10

Thus, it is evident that the continuous sugarcane cropping without fertilizer replenishments could rapidly deplete soils reserves of P and K derived from soil mineral sources. NPK removal into cane tops, leaves, stalks with and without the addition of NPK fertilizers are given in Table 2.

Table 2. Partitioning of NPK into various plant parts of sugarcane grown on RBE soils at Udawalawe (Dharmawardene and Bodhinayake, 1995)

Treatment	Plant part	Nutrient removal, kg ha^{-1}		
		N	P	K
Unfertilized	Tops	28.16	5.74	98.91
	Leaves	46.18	5.56	85.23
	Stalks	37.05	14.98	96.91
	Total	111.39	26.28	281.05
Fertilized	Tops	33.23	6.08	87.56
	Leaves	55.85	10.47	108.01
	Stalks	64.13	15.44	120.96
	Total	153.21	31.99	316.53

Foliar analysis of sugarcane

A variety of methods have been used in the foliar diagnostics of nutrient status of sugarcane plants. These methods have been developed in different sugarcane growing regions of the world to meet the local conditions. The techniques vary in scope and complexity from the crop logging system introduced by Clements (1980) for Hawaiian sugarcane crops, to the simple procedure used in Mauritius (Burr, 1955; Halais, 1959; Evans, 1965; Clements, 1980). Samuels (1959) has classified these methods under two groups, namely (a) the multiple plant analysis methods such as crop logging and (b) the selective plant analysis methods such as analysis of indicator leaf at a given time. The former method is used exclusively in Hawaii, while the latter one is widely practiced throughout the world. Sugarcane Research Institute, Sri Lanka has used the latter method in its studies.

The foliar diagnostics is a measure of both soil and plant availability of nutrients for crop growth at a given time. Once critical levels are calibrated against target yields for a given region, such an approach can be used to estimate fertilizer nutrient requirements without any further tests. The foliar diagnostic technique can be used not only to estimate the NPK (or any other) fertilizer requirement, but also to predict the potential deficiencies and toxicities in crops, to assess the effectiveness of current practices and to evaluate the extent to which the nutrients are removed from the soils (Anderson and Bowen, 1990).

Experiments carried out using the 3rd leaf of sugarcane as the indicator leaf have shown a good correlation between available soil NPK and nutrient levels of the indicator leaf. Indicator leaf NPK levels that can be used to monitor crops and soil availability of essential nutrients are given in Table 3.

Table 3. Nutrient adequacy/inadequacy levels in indicator leaf* for sugarcane in Sri Lanka (M.W.N. Dharmawardene, 2000, Unpubl.)

Level	N	P	K
	------------------------ % (on dry weight basis) ------------------------		
Critical	1.78	0.15	0.62
Optimal	2.01	0.20	1.05

* 3rd leaf, mid portion, less mid rib; age from 4 to 5 months.

Soil analysis and field experiments and as a tool for fertilizer recommendations

Fertilizer requirements of sugarcane were first investigated by a series of fertilizer rate trials carried out for RBE soils at Udawalawe, Sevenagala and Pelwatte and NCB soils at Hingurana.

Soil analyses show that RBE soils at Pelwatte area were deficient in soil exchangeable K, while RBE soils at Sevenagala have sufficient amounts (Table 4). It must be noted that levels of K at Pelwatte was below the critical levels for K, which is generally fixed at 3 mmol kg^{-1} in clay and silt soils. Soil analysis also shows that the available P content in RBE soils at Pelwatte and Sevenagala are lower than the accepted critical levels (0.16-0.48 mmol kg^{-1}) for this element. Thus, it is evident that both these elements are in short supply at Pelwatte RBE soils, while P is in short supply at Sevenagala RBE soils.

Table 4. Initial soil analysis at Pelwatte & Sevenagala (Ranjith, 1998)

Soil property		Pelwatte RBE		Sevenagala RBE
		CO 775	SL 8306	SLI 121
pH		6.35	6.47	6.69
Total N	mmol kg^{-1}	77.92	73.42	75.14
Available P	mmol kg^{-1}	0.10	0.11	0.14
Exchangeable K	mmol kg^{-1}	2.52	2.87	4.85
Exchangeable Ca	mmol kg^{-1}	33.94	34.30	44.31
Exchangeable Mg	mmol kg^{-1}	8.35	8.19	13.89
Organic matter, %		1.70	1.34	1.68

The results of fertilizer rate experiments of plant and ratoon crops showed that the significant response of cane and sugar yields to added NP (data not shown) and K fertilizers at Pelwatte and Hingurana. On the other hand, at Sevenagala, crop showed response to N and P but not to K as the exchangeable K content in Sevenagala RBE soils was sufficient. Some typical results of fertilizer experiments at Pelwatte and Sevenagala are given in Tables 5, 6 and Fig. 3.

Table 5. Average cane and sugar yields of plant crop at different K fertilizer rates (Ranjith, 1998)

K, kg ha^{-1}	CO 775 (Pelwatte)		SL 8306 (Pelwatte)		SLI 121 (Sevenagala)	
	Cane	Sugar	Cane	Sugar	Cane	Sugar
	t ha^{-1}					
0	165.7	17.44	116.8	14.74	154.1	20.95
50	185.6	19.93	133.5	15.80	153.0	19.93
100	193.6	22.40	139.3	17.01	153.3	19.49
150	178.5	19.83	129.7	15.60	146.6	19.76
$LSD_{0.05}$	4.9	2.37	1.8	1.45	14.5	1.95

Table 6. Average cane and sugar yields of 1st ratoon at different K fertilizer rates (Ranjith, 1998)

K, kg ha^{-1}	CO 775 (Pelwatte)		SL 8306 (Pelwatte)		SLI 121 (Sevenagala)	
	Cane	Sugar	Cane	Sugar	Cane	Sugar
	t ha^{-1}					
0	147.2	21.14	100.7	14.65	119.7	15.05
50	162.0	23.94	128.6	18.83	117.2	15.84
100	167.1	23.90	133.0	19.51	122.2	16.28
150	157.9	22.59	121.4	17.43	120.8	15.95
$LSD_{0.05}$	8.8	1.60	7.4	7.43	14.9	2.85

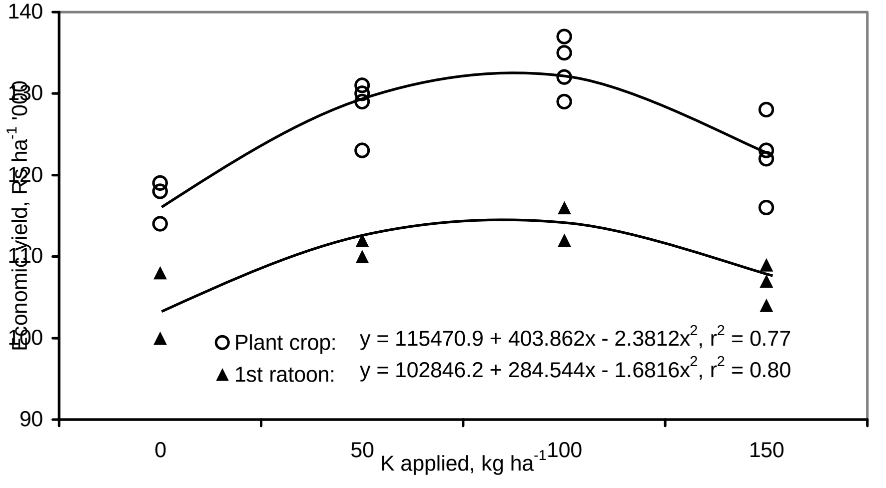

Fig 3. Economics of K fertilizer use to sugarcane at Pelwatte

It can be suggested from the results shown in Fig. 4 and 5 that the addition of 50 kg K ha^{-1} to RBE soils at Pelwatte is unable to replenish the K removed from the soil, while the addition of 100 kg K ha^{-1} is little in excess of the requirement; while the Sevenagala soils, having adequate exchangeable K, are able to supply the K requirement of the crop without any added K fertilizers.

It is clear from the above-indicated results that although RBE soils initially have adequate supplying of exchangeable K to raise sugarcane crops without potash fertilizers, continuous cropping over a period of time (more than ten years at Pelwatte RBE soils) would deplete K reserves as seen for Pelwatte area, while at Sevenagala (where continuous application of K has been practiced) K release from soil reserves is capable to sustain exchangeable K levels without K fertilizer use (Fig. 5).

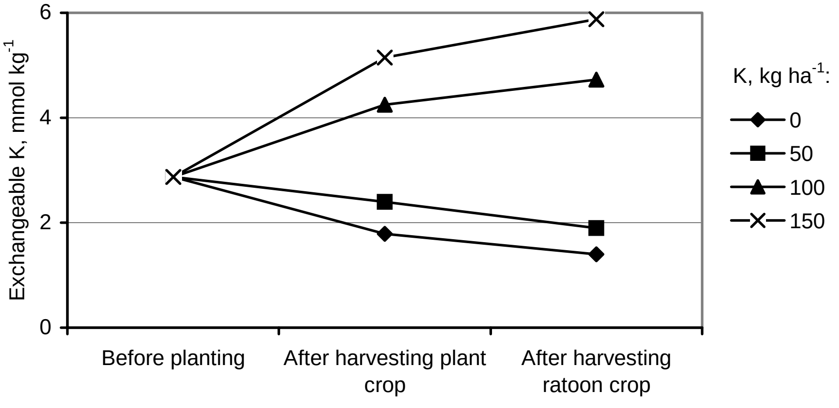

Fig. 4. Effect of K fertilizer application on K exchangeable content in RBE soil grown with sugarcane SL 8306 at Pelwatte (Ranjith, 1988)

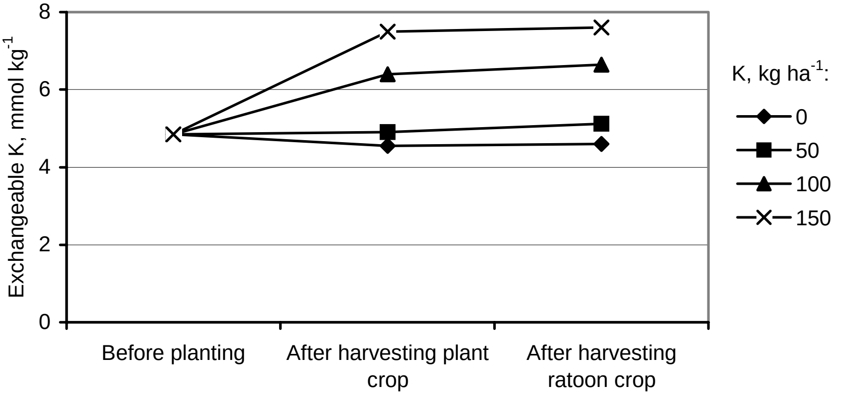

Fig. 5. Effect of K fertilizer application on K exchangeable content in RBE soil grown with sugarcane SLI 121 at Sevenagala (Ranjith, 1988)

The yield goals in each of the sugar production area are determined by examining the past yield records at least for the last ten years. Climatic data and other factors that contribute to yield should be carefully analyzed together. It is also necessary to ascertain whether differences observed are due to edaphic factors. Thus, routine soil analyses would be necessary. The range and average yields for the three cane productivity levels based on the past yield records of Sevenagala sugar project are shown in Table 7 (Dharmawardene and Ranjith, 2000).

Table 7. Three sugarcane productivity classes at Sevenagala (t ha^{-1})

Productivity class	Rainfed sector		Irrigated sector	
	Range	Average	Range	Average
Low	9-57	42.05	17-90	75.75
Medium	57-75	66.65	90-108	98.85
High	75-279	90.83	108-287	124.02
Total	9-279	66.53	17-287	99.52

The three productivity classes are randomly scattered in each sector in the project area and show no clear boundaries or demarcations between the allotments. Soil analysis showed that there were no significant differences in soil chemical properties between the productivity classes. This indicates that the differences in average yield were rather due to differences in management of cane than due to soil fertility differences.

The analysis of cane samples obtained from the project area showed that one tonne of sugarcane grown in the project area removes approximately 1.17 kg of N, 0.45 kg of P and 2.13 kg of K at harvest (Dharmawardene and Ranjith, 2000). Thus, continuous cultivation of cane without addition of K could deplete K reserves in the soil to a very large extent and may result in the transformation of clay mineral structure due to displacement of interlayer K.

However, analysis of 100 soil samples obtained randomly from top 30 cm layer from the irrigated and rainfed sectors show that soils contain from 85 to 450 mg kg^{-1} of exchangeable K, averaging 232.9 mg kg^{-1} (Dharmawardene and Ranjith, 2000). Thus, current K status of Sevenagala soil is adequate. In places where soil K falls below 80 mg kg^{-1}, K fertilizer K should be added as this soil K levels become inadequate to support good crop of sugarcane.

The average total N content of 0-30 cm soil layer was about 960 mg kg^{-1} or about 3,750 kg of N per hectare. So, soils have a good supply of N possibly due to mulching practices adopted by the farmers. The high mineralization and high nitrogen content could explain the non-responsiveness of cane to added fertilizer N. Soil analysis reveals that Sevenagala soils contain very low levels of available P averaging 7.2 mg kg^{-1}. Less than 10 mg kg^{-1} of available P is considered to be very critical for sugarcane cultivation. In order to calculate the P availability from soil, P fixation capacities are required. With the available data, soil available P was estimated at 29.7 and 36 kg ha^{-1} under rainfed and irrigated conditions respectively (Dharmawardene and Ranjith, 2000).

Using the above data, NPK requirement of sugarcane growing in the high productivity class of Sevenagala can be estimated from nutrient removal per tonne of cane, nutrient availability in the soil and the fertilizer use efficiencies for N, P and K under rainfed and irrigated conditions to be assumed as 25, 35 and 60% and 35, 45 and 80% respectively (Table 8).

Table 8. Estimated optimum NPK fertilizer requirements for sugarcane at Sevenagala

Sector	N	P	K
	----------	kg ha^{-1}	----------
Irrigated	147	44	124
Rainfed	116	32	91

Fertilizer rate experiments carried out at Sevenagala and discussed earlier are in close agreement with the above findings. Similar recommendations are available for other areas. Some typical results of soil analyses at Sevenagala, Kantale and a nearby tea estate (Opatha estate, Kahawatte) are given in Table 9. It is evident that Kantale soils are depleted of major nutrients compared to Sevenagala and the fallow soils examined. Tea estate soils were also low in major nutrients.

Table 9. Chemical properties of soils from Sevenagala, Kantale & Opatha estate (M.W.N. Dharmawardene, 2000, Unpubl.)

Location	Sample	pH 1:2.5 w/v	Total N, %	Available P*	Exchangeable K	Exchangeable Ca	Exchangeable Mg	Exchangeable Na
				----------	----------	mg kg^{-1}	----------	----------
Sevenagala	Exp. site	6.47	0.18	15.4	149.3	267.6	31.6	13.7
	Fallow	6.47	0.16	16.1	354.4	254.6	22.8	8.4
	Cultivation	6.74	0.11	21.5	292.4	272.2	35.9	16.0
	Irrig. ratoon	6.53	0.19	1.2	164.3	403.8	64.0	27.4
Kantale	Irrigated cane	6.28	0.08	3.2	57.4	306.3	45.8	20.1
Opatha	Field No. 15	4.50	0.09	0.6	7.3	4.0	1.2	128.1

* Houba *et al.* (1989)

Evolution of fertilizer recommendations for sugarcane in Sri Lanka

Sugarcane can remove very substantial amounts of nutrients from soils under continuous cropping, especially when there is no rotation or fallow. In order to achieve sustainable crop production, soil fertility should be maintained by adding of suitable amounts of nutrients through fertilizers as well as organic manure. With the expansion of sugarcane areas from Kantale and Hingurana (irrigated crops) to Moneragala district (both rainfed and irrigated crops), fertilizer recommendations have undergone various changes over the time. These are as follows:

(a) In 1986, the following fertilizer recommendations were made for Hingurana and Kantale crops based on nutrient removal and past yield records. A single recommendation was formulated for plant crop and the ratoon crops.

Method of application	Time of application	Urea	TSP	MOP
		---------------- kg ha^{-1}	----------------	
Basal	At planting/stubble shaving	67	166	108
1st top dressing	45 days	134	-	108
2nd top dressing	90 days	202	-	108
Total		403	166	324

(b) In 1987, the recommendation was to apply 120 and 80 kg N ha^{-1} for a plant crop of CO 775 under irrigation at Kantale and rainfed conditions at Sevenagala respectively. It was also recommended to apply the total N requirement within the 3 months in split application.

(c) In 1988, N fertilizer recommendations were made on the basis of the 3rd leaf N content of CO 775 at the 4-month age grown under irrigation on RBE soils.

3rd leaf N content at 4th month, %	Additional N requirement, kg ha^{-1}
<1.8	100
1.8-2.0	50
>2.0	-

(d) In 1993, the following new fertilizer recommendations were done for RBE and NCB soils at Hingurana on a basis of fertilizer rate trials, soil and leaf analysis.

Crop	Method of application	Time of application	Urea	TSP	MOP
			---------------- kg ha^{-1}	----------------	
Plant	Basal	At planting	169	159	74
	1st top dressing	45 days	112	-	155
	2nd top dressing	90 days	56	-	-
	Total		337	159	229
Ratoon	Basal	Stubbling	119	204	95
	1st top dressing	45 days	245	-	204
	2nd top dressing	90 days	84	-	-
	Total		448	204	299

(e) In 1997, the following fertilizer recommendations were made for Hingurana on a basis of yield goals, nutrient removal and soil nutrient availability.

Soil	Crop	Method of application	Time of Application	Urea	TSP	MOP
				----------- kg ha^{-1}	----------	
RBE	Plant	Basal	At planting	100	140	70
		Top dressing	After 2.5 months	235	-	155
		Total		335	140	225
	Ratoon	Basal	Stubble shave	70	85	35
		Top dressing	After 2.5 months	165	-	85
		Total		235	85	120
NCB	Plant	Basal	Planting	120	180	100
		Top dressing	2.5 months	285	-	235
		Total		405	180	335
	Ratoon	Basal	Stubble	90	125	65
		Top dressing	2.5 months	215	-	150
		Total		305	125	215
Alluvial	Plant	Basal	Planting	100	100	55
		Top dressing	2.5 months	225	-	125
		Total		325	100	180
	Ratoon	Basal	Stubble	70	45	20
		Top dressing	2.5 months	155	-	50
		Total		225	45	70

(f) In 1998, the following recommendations were made for RBE soils at Pelwatte and Sevenagala after fertilizer rate trials, soil and plant analysis.

Sector	Crop	Method of application	Time of application	Urea	TSP	MOP
				----------- kg ha^{-1} ---------		
Irrigated	Plant	Basal	Planting	110	235	85
		Top dressing	2.5 months	220	-	-
		Total		330	235	85
	Ratoon	Basal	Stubble	100	235	85
		Top dressing	2.5 months	200	-	-
		Total		300	235	85
Rainfed	Plant	Basal	Planting	95	200	85
		Top dressing	Onset of rains	190	-	85
		Total		285	200	170
	Ratoon	Basal	Stubble & rain	85	200	85
		Top dressing	Onset of rains	170	-	85
		Total		285	200	170

(g) In 1999, the following fertilizer recommendations were done for Sevenagala on the basis of yield goals, nutrient removal by crop, estimated soil nutrients supply after categorizing farmers into high, medium and low yield classes.

For medium and high yield classes:

Cane yield, t ha^{-1}	Sector	Crop	Method of application	Time of Application	Urea	TSP
					----- kg ha^{-1} -----	
>90	Irrigated	Plant	Basal	Planting	106	220
			Top dressing	2.5 months	213	-
			Total		319	220
		Ratoon	Basal	Planting	160	220
			Top dressing	2.5 months	160	-
			Total		320	220
>60	Rainfed	Plant	Basal	Planting	84	160
			Top dressing	Rain & 2.5 months	168	-
			Total		252	160
		Ratoon	Basal	Rain & stubble	126	160
			Top dressing	Rain & 2.5 months	126	-
			Total		252	160

For low yield class:

Cane yield, t ha^{-1}	Sector	Crop	Method of application	Time of Application	Urea	TSP
					----- kg ha^{-1} -----	
<90	Irrigated	Plant	Basal	Planting	65	102
			Top dressing	2.5 months	130	-
			Total		195	102
		Ratoon	Basal	Planting	98	102
			Top dressing	2.5 months	98	-
			Total		196	102
<60	Rainfed	Plant	Basal	Planting	62	96
			Top dressing	Rain & 2.5 months	123	-
			Total		185	96
		Ratoon	Basal	Rain & stubble	93	96
			Top dressing	Rain & 2.5 months	93	-
			Total		196	96

Potash fertilizer has been made optional as Sevenagala soils have been found to contain adequate K supplying capacity at present. Applications are made on the results of soil and leaf tissue analysis. In the above recommendations, the data on critical nutrient concentration, critical nutrient range and nutrient removals have been related to those obtained by rate experiments. However, the recommendations have to be further examined to ascertain the balance of the nutrients through the diagnosis and recommendation integrated system (DRIS) as this will help in the diagnosis of nutrient imbalance in the crop (Sumner, 1982; Walworth and Summner 1987; Khan *et al*., 1988; Ramesh and Varghese, 1999), which is crucial to prevent any nutrient limitations to the yield.

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Chapter III

POTASSIUM NUTRITION MANAGEMENT OF FOOD CROPS

Importance of balanced fertilization to meet world food challenges

A. Krauss

International Potash Institute, P.O. Box 1609, CH-4001, Basel, Switzerland

Abstract

The demographic development and the depleting natural resources in South Asia make it mandatory to increase the productivity of the remaining land. Balanced use of chemical fertilizers is one of the options to increase yields and to improve quality and stress tolerance of food crops. However, use of chemical fertilizers in South Asia is highly unbalanced to the detriment of potassium. Although plants absorb K in equal quantity as N, the use of N in South Asia exceeds that of K by about 10 times. Soil K mining due to negative K balances is prevalent in the region. One of the problems is seen in the dynamic exchange processes, to which soil K is subjected and which makes precise estimations of soil K reserves and corresponding K recommendations rather difficult. On the other hand, numerous on-farm trials of IPI in South Asia prove repeatedly the beneficial effect of balanced fertilization with adequate K on yield, quality and tolerance to pests and diseases. With higher yields and better quality, the farmer can generate more income that, on the other hand, contributes to the rural development. However, further research on soil K and more education on the benefits of balanced fertilization are still necessary.

The steadily increasing global population demands more and better food

There are four main challenges, which confront the global agriculture:

- to produce more food (and fiber) for a steadily growing global population
- to produce the food from shrinking land and water resources
- to produce safe and healthy food with better quality to meet changing food habits in context with urbanization as well as globalization of trade
- and to produce food (and fiber) in context with the environmental needs

Taking South Asia as an example, it shows in Fig. 1, that the population of South Asia is still rapidly growing. From less than 500 million inhabitants 50 years ago, the population increased to currently 1.3 billion and will reach the 2 billion mark in some twenty five years from now. At the same time, the acreage of arable land has hardly increased; it stagnated in the last 25 years at around 192 million ha, which in turn reduces the per capita land availability from 0.33 ha in 1960 to currently 0.15 ha.

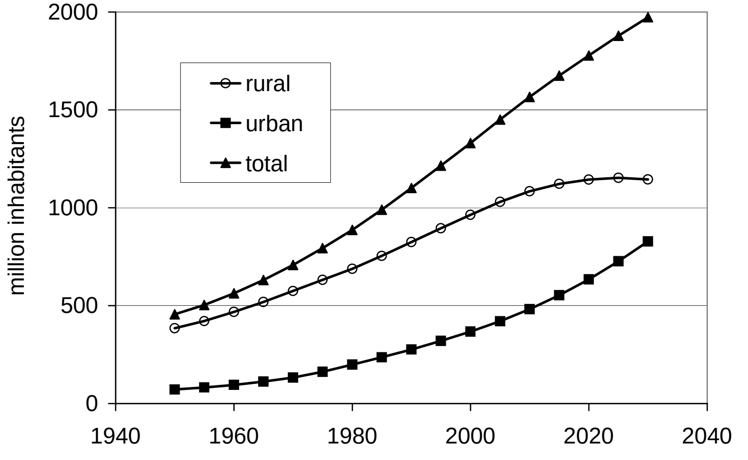

Fig. 1. Evolution of the population of South Asia (FAO, 2003)

Fig. 1 also reveals that the share of urban on the total population is steadily increasing. This means that increasingly more food and thus nutrients will be transferred to the urban centres, from where the nutrients will hardly be returned to the arable land where they came from. An increasing urban population also changes the food habits from subsistence food to packed and processed food. And finally, with higher incomes, the urban inhabitants also look for better quality as well as safe food, and whether the food has been produced in context with the environment.

As far as the supply of more food to a growing population is concerned, the FAO statistics show that cereal production in South Asia almost trebled within the last 40 years. This was mainly caused by an increase in yield from about 1 t ha^{-1} in the early 60ies to currently 2.4 t ha^{-1}. With the higher cereal output, the per capita production remained fairly stable at about 210-230 kg.

The impact that the urbanization has on the food habit and the corresponding demand can be seen in Fig. 2. The area of subsistence food such as cereals and pulses has hardly changed the last four decades. In contrast, the area with fruits and vegetables, root and tuber crops and cane has increased substantially. As shown earlier the demand for those high value crops increases with the income.

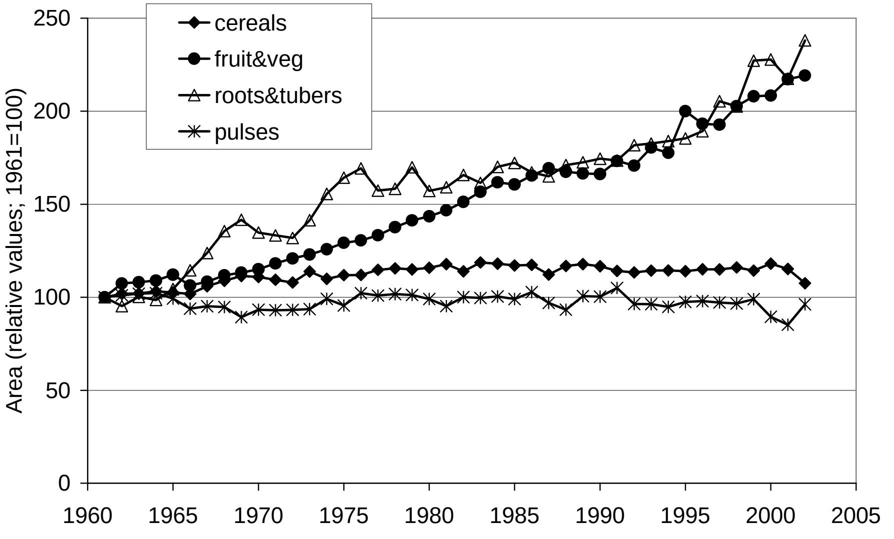

Fig. 2. Change of crop spectrum over time in South Asia

Balanced fertilization is one of the essentials to increase food production

The use of fertilizers is, next to the genetic potential of the crops, the crop management and irrigation, one of the major inputs to increase food production. As shown in Fig. 3, fertilizer use, nitrogen in particular, has increased substantially during the last decades. Potash use lags seriously behind N and P, the decreasing NK ratio indicates that the imbalance in fertilizer use worsens in South Asia.

Concerning the nutrient ratio in fertilizer use, the FAO statistics also show that Sri Lanka still has a better NK ratio in fertilizer use as compared to the other countries of South Asia. However, the NK ratio in Sri Lanka deteriorated rapidly from a balanced ratio of N:K = 1:0.65 during the 70ies to currently N:K = 1:0.28. This compares with a current NK ratio in Southern India of N:K = 1:0.33. The NK ratio in All-India and Bangladesh varies between N:K = 1:0.10 to 1:0.15, whereas Pakistan has a depressing imbalance in fertilizer use of N:K = 1:0.01, meaning that, for each kg N, a Pakistani farmer uses only 10 g K_2O.

The obvious preference for N fertilizers and the sparse use of potash contradict the ratio at which crop plants absorb and remove the nutrients from the field. As shown in Fig. 4, K is removed by the crop at about the same quantity as nitrogen. Therefore, if fertilizer is applied with a NK ratio of 1:0.10 as currently in South Asia but crops remove both nutrients at almost equal quantities, substantial soil K mining has to be assumed.

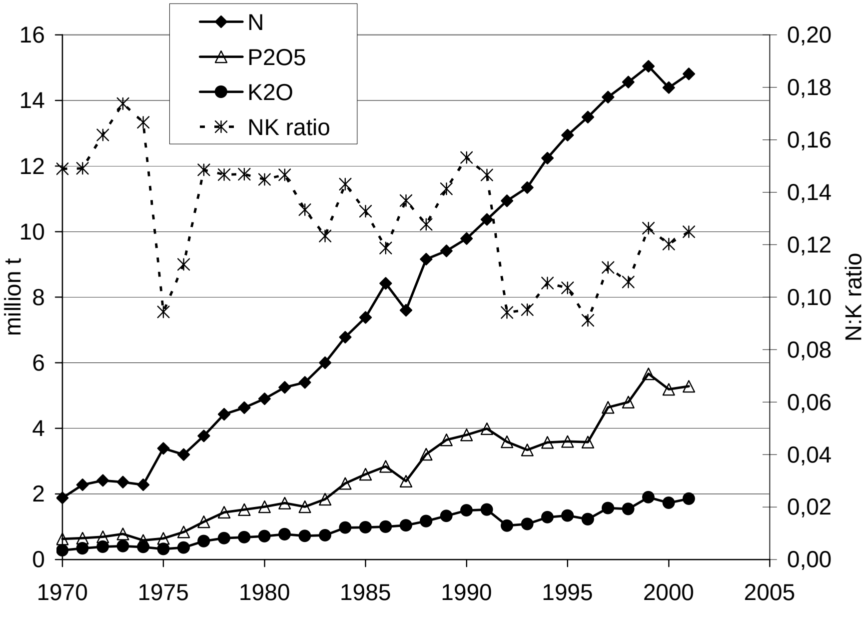

Fig. 3. Fertilizer use in South Asia

Comparing the nutrients removed by the crops with the use of chemical fertilizers in South Asia, it shows that the resulting balance for nitrogen is becoming increasingly more positive (Fig. 5). Also the P balance improves with time. The K balance in contrast shows the reverse order, namely an increasingly negative balance. This means that the farmers in South Asia remove annually some 50 kg K_2O ha^{-1} more from the field than they return with potash fertilizers. It is also obvious that with the widespread use of farmyard manure as fuel, the increasing deficit in the K balance cannot be closed with more use of organic manure, because of its restricted availability as soil amendment.

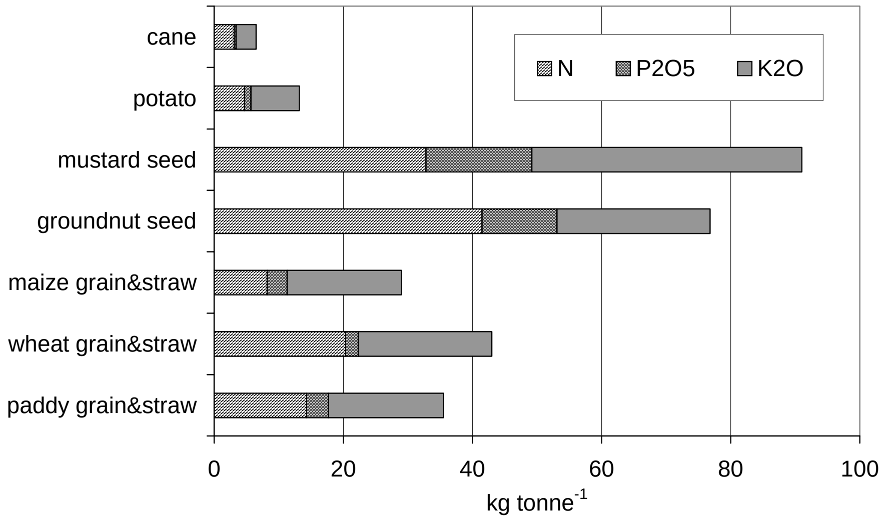

Fig. 4. Nutrient removal by crops (Indian conditions: FAI, 2002)

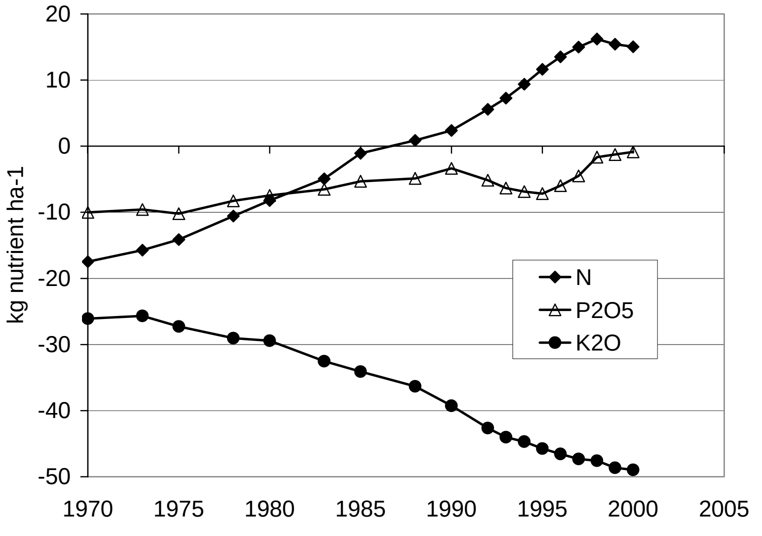

Fig. 5. Apparent nutrient balance in South Asia

More detailed calculations of the nutrient balance made for several States in India confirm the simplified calculation of IPI. For instance, Vinod Kumar *et al*. (2001) estimated for Haryana a K deficit that nose-dived from -35 kg/ha during the 60ies to currently -90 kg K_2O ha^{-1}. The N balance of 4 kg N ha^{-1} is almost in equilibrium. Yadav *et al*. (2001) calculated for Uttar Pradesh (UP) a current deficit of annually 1 million t K_2O that contrasts sharply a surplus of 1.2 million t of N and 0.5 million t of P_2O_5 in UP. Yadav and co-workers (2001) also concluded by saying *"…over-mining of K… as evident through apparent K balance sheets, is not reflected in available K status in most cases, and the soil-testing laboratories go on reporting medium to high K fertility rating. … In view of the established contributions on non-exchangeable K in meeting plant K demands, this form of K should also be used as an index of K availability in the soil. Threshold levels of non-exchangeable K for different soils and crops have to be worked out, and used for the purpose of fertilizer K recommendations…"*.

The K dynamics in soils, a decisive factor in balanced nutrition of annual crops

The timely pattern of nutrient uptake by annual crops like maize differs substantially between the nutrients as shown in Fig. 6; about 70 days after planting (day 197) when little less than one third of the total dry matter has been accumulated, the crop had taken up about half of its P requirement, three quarters of its N requirement and virtually all of its total K needs. The uptake of the other nutrients proceeded at a steadier rate (Corazzina *et al*., 1991).
The rapid increase in K accumulation implies that the K uptake rate at the early stage of plant development is also considerable, reaching levels of 5 to 20 kg ha^{-1} day^{-1}, or, as in the reported case with maize, more than 19 kg K_2O ha^{-1} per day. This in turn requires that the soil contains adequate amounts of K to be in the position to release within a short period of time enough K into the soil solution to meet the needs of the plant.
Correspondingly, Johnston *et al*. (2001) found that barley, cultivated on soils with 300 mg kg^{-1} exchangeable K, had a maximum daily K uptake of almost 6 kg K ha^{-1}, whereas the same crop but grown on a soil poor in K, namely 50 mg kg^{-1} exchangeable K, took up only 0.5 kg K ha^{-1} a day. The total K uptake and ultimately the final yield differed correspondingly. Barley on the soil poor in K took up around 30 kg K ha^{-1} and produced 4.2 t ha^{-1} biomass, the crop on the soil with adequate K took up 160 kg K ha^{-1} and yielded 7.5 t ha^{-1} biomass.
Soil K is subject to dynamic exchange processes between different fractions. A widely accepted concept divides soil K into four pools or compartments (Fig. 7):

- the soil solution K (K_{sl})
- the exchangeable K (K_{ex})
- the fixed or non-exchangeable K (K_f)
- and the K in the lattice of certain primary minerals (K_l).

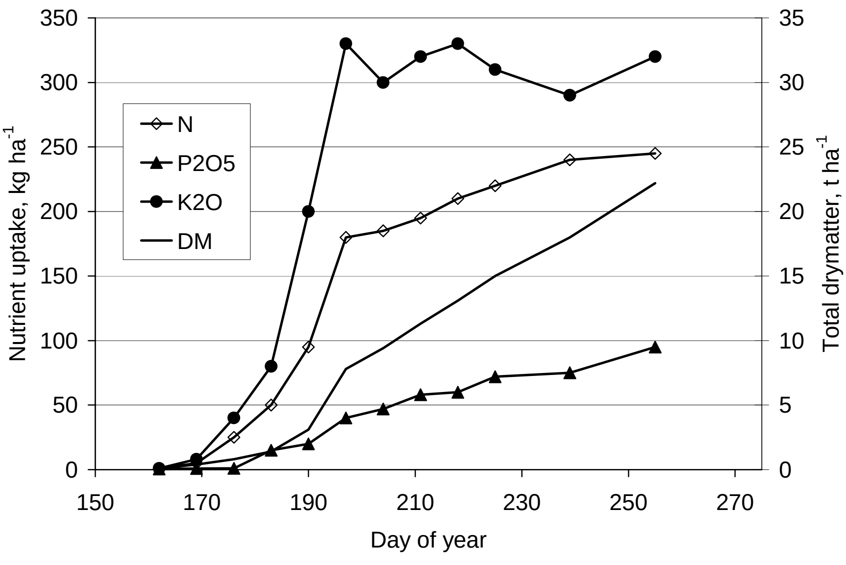

Fig. 6. Nutrient and dry matter accumulation of maize (redrawn after Corazzina *et al*., 1991)

The amount of K in each fraction varies and depends on the past cropping history, past fertilizer and manure use, i.e. the K balance, soil pH and soil water content. Golakiya *et al*. (2001) for instance reported that the content of soluble K in the calcareous soils of Gujarat, India ranges from 0.003 to 0.21 $cmol_c$ kg^{-1} soil, the exchangeable K varies from 0.03 to 2.00, non-exchangeable or fixed K from 0.32 to 21.7 and total K from 1.10 to 20.30 $cmol_c$ kg^{-1} soil.

As indicated in Fig. 7, the fractions K_{sl}, K_{ex} and K_f are related to each other through reversible exchange processes. K removed by uptake of plants and/or leached into the subsoil is replenished by K released from both the K_{ex} and K_f pools. There can be simultaneous release of K from both pools to the soil solution or a linear exchange process, from the non-exchangeable to the exchangeable pool, and from the exchangeable pool to the soil solution. Whether one or other of these two possible mechanisms predominates is of little practical importance provided that the K in the soil solution is replenished quickly enough to meet the maximum demands of a rapidly growing crop. When there is surplus K in the soil solution, after the addition of fertilizer or manures, K is transferred to both fractions through exchange and fixation processes.

The exchange processes and the possible involvement of two fractions in the replenishment of solution K, namely the fraction of K_{ex} and the fraction of K_f can also be a source of misinterpretation. Johnston and co-workers (2001) reported that in the Garden Clover Experiment in Rothamsted, a total balance of 1667 kg K over a period of 10 years increased the content of exchangeable K by 690 kg ha^{-1}, which is only 41% of the K balance (Fig. 8). Almost 60% of the K balance had gone into a pool of K that did not belong to the K_{ex} fraction always assuming that no large amount of K was lost through leaching. On the other hand, in the same experiment the subsequent long-term omission of K, and thus, a negative K balance of 1494 kg K ha^{-1} due to crop removal, resulted in a reduction in the content of K_{ex} by only 563 kg K ha^{-1}, i.e. a reduction by 38%. The other 62% of the K removed had to be supplied by K in other soil K pools.

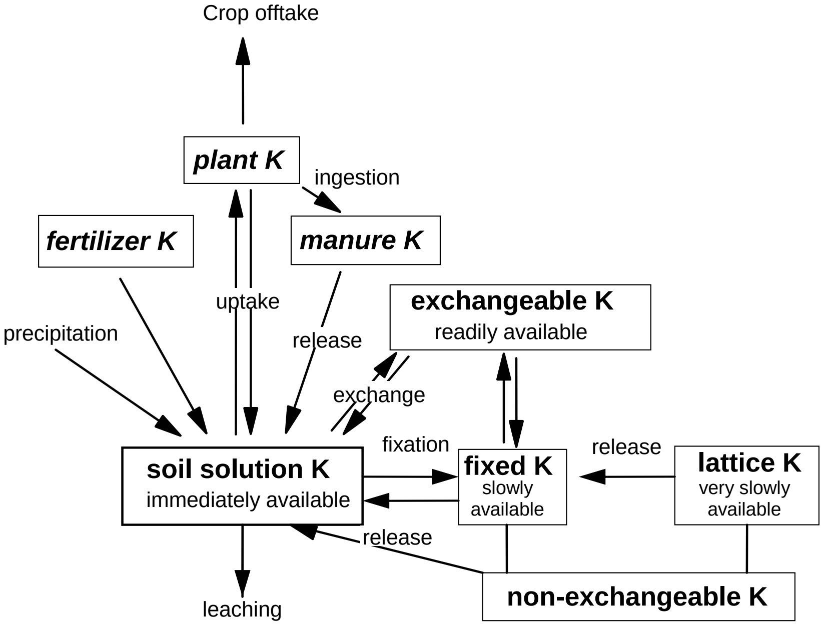

Fig. 7. The potassium cycle in the soil-plant-animal system (from Syers, 1998)

Therefore, finding a smaller increase in K_{ex} than the K balance, and removing more K from the soil than was indicated by the decline in K_{ex} at cropping without application of K, questions the validity of relying only on one parameter when assessing the soil K status as it is also stated above by Yadav and co-workers (2001). The concept of a 'tripartite' relationship is supported by the findings of Johnston and Mitchell (1974). They showed that the release of K from the non-exchangeable pool was linearly related to the content of initial exchangeable K (Fig. 9). There was also a close linear relationship between the decrease in exchangeable K and the release of K from the non-exchangeable pool. The higher the initial content of exchangeable K, the more K was released from the non-exchangeable pool, and with the decline in the uptake of K from the K_{ex} pool, the release of K from the K_f pool also declined. In the soil used by Johnston and Mitchell (1974), the uptake of K from the non-exchangeable pool was twice the amount taken from the exchangeable fraction, suggesting there was an equilibrium between the K in the K_{ex} and K_f pools. It can be assumed, however, that the ratio of K released from these two fractions will differ with the type of clay minerals, degree of weathering, etc. Nevertheless, it is probable that the K in the K_f pool is of importance especially for crops with a restricted root system such as potato. As shown by Johnston and co-workers (1998), the poorer the root density, the higher should be the concentration of K in the soil solution to sustain a particular K uptake rate. The same authors also showed that with increasing clay content and/or decreasing soil moisture the solute K concentration has to be increased proportionally to support the required K uptake rate.

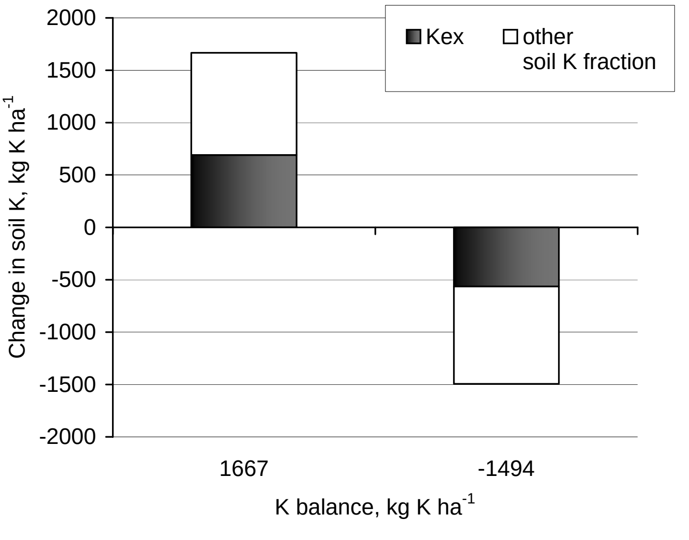

Fig. 8. K balance and changes in K_{ex} (after Johnston *et al.*, 2001)

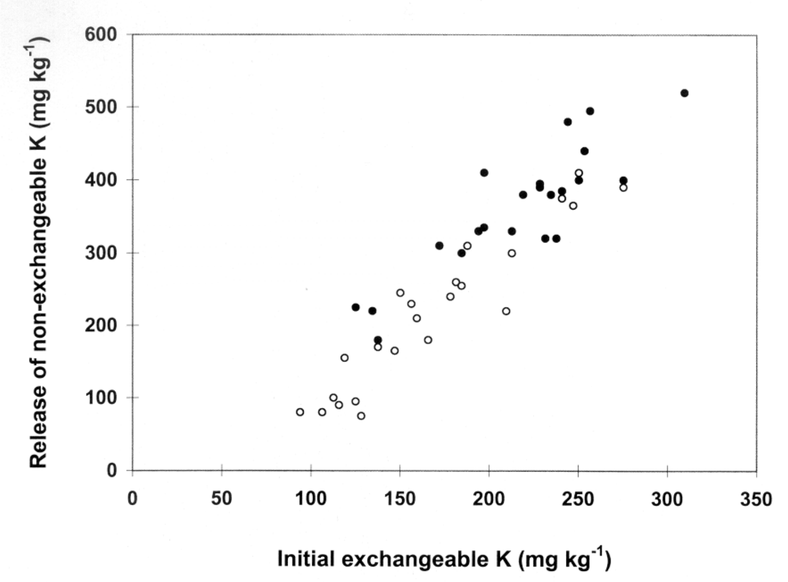

Fig. 9. Release of fixed (non-exchangeable) K related to initial exchangeable K (adapted from Johnston and Mitchell, 1974)

Consumer not only wants more but also high quality and healthy food

Potassium, after being absorbed by the plant roots from the soil solution affects yield and quality of the crop in a multiple way:

- Potassium supports the plant's metabolism by stimulating some 50 different enzyme systems, some of which are directly or indirectly involved in quality development.
- One major aspect of the functions of K is to stimulate assimilation, which is the conversion of CO_2 from air with the help of sun energy into sugar that can be translocated through the plant to storage organs and converted to starch, etc. The latter is an important parameter in food processing like chips production from potato tubers and in fibre quality.
- Potassium also assists to transfer the assimilates from the leaves to the storage organs like tubers, roots, fruits or the stalk, a process called phloem loading. The higher sugar content of fruits and sugarbeets or cane at adequate K supply refers to the nutritive value and the processing properties in the quality management. An example is given in Fig. 10 that

shows the impact of K application on the sucrose content and the corresponding sugar yield in cane.

- Another important aspect is the role of K in the nitrogen metabolism. With adequate K, the absorbed nitrate-N is rapidly incorporated into amino acids, the basic constituents of protein. At inadequate K, less nitrate-N is metabolized, nitrate accumulates in the plants and the protein contents remain low (Fig. 11). This has also an impact on the food safety (nitrate) and on the nutritive value (protein content).
- Plenty of carbohydrates in plants adequately supplied with K allow ample conversion to fatty acids and oils apart from the demand for the N-metabolism (Fig. 12). This improves the nutritive value as well as the processing quality of plant products.
- Also K acting as the counter-ion stimulates the translocation of nitrate from the roots to the shoot. At inadequate K, less nitrate is transferred from the roots to the shoot, the building-up of higher nitrate concentrations in the root signals to reduce N uptake which consequently lowers the N fertilizer use efficiency (Fig. 13). More residual N in soils at low uptake increases the risk of environmental pollution of the groundwater and the atmosphere, and the farmer cannot claim to produce his crops in an environmentally friendly manner.
- Potassium is the main component in regulating the water household of plants. Potassium deficient plants desiccate rapidly. Early wilting is indeed a good indicator of inadequate K supply to plants. Desiccating green vegetables will not sell at the market, the poor appearance and attractiveness of the produce from K deficient plants repel potential purchasers.
- Wilting plants at inadequate K supply also cease assimilation rapidly. This lowers the yield and reduces the content of quality components like sugar, starch or protein.
- On the other hand, efficient assimilation at adequate K supply leaves plenty of carbohydrates available in the plant to produce the so-called secondary plant constituents such as vitamins, lycopene, isoflavones, phenolic compounds. The first group is associated with health care of the consumer, the phenolic compounds are also important repellents in disease and pest control.
- Last but not least, plants supplied with adequate K within the concept of balanced fertilization proved to be more tolerant to soil borne and climatic stress such as drought, frost, salinity, and resist better to pests and diseases (Fig. 14). Less variable yields of stress tolerant plants contribute to food security, and freedom from pests and diseases is essential for instance in food export and marketing. Less need of agrochemicals in plant protection at balanced fertilization with adequate K reduces the production costs and complies with the demand for safe food.

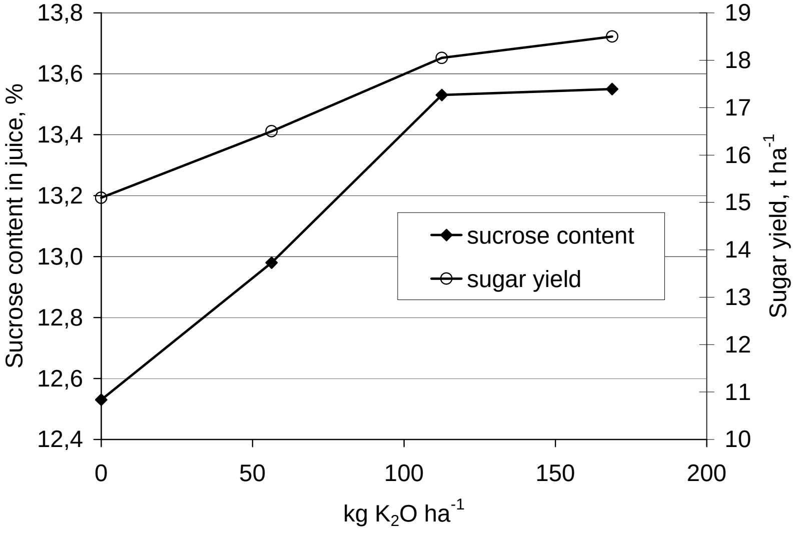

Fig. 10. Effect of K on sucrose content and sugar yield of cane in India (IPI on-farm trials, 2001)

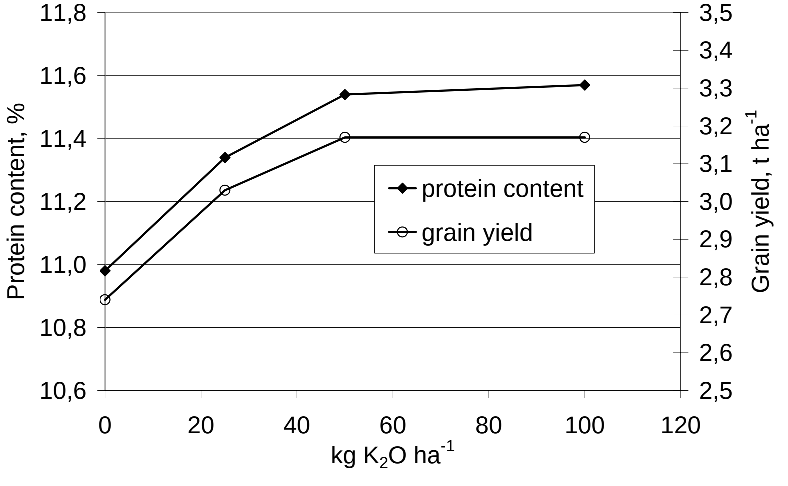

Fig. 11. Effect of K on yield and quality of wheat in India (IPI on-farm trials, 2001)

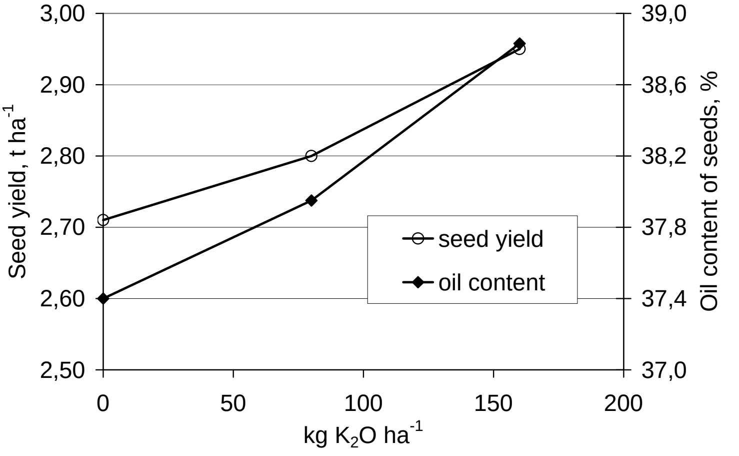

Fig. 12. Effect of K on yield and quality of oilseed rape in China (IPI on-farm trials, 2001)

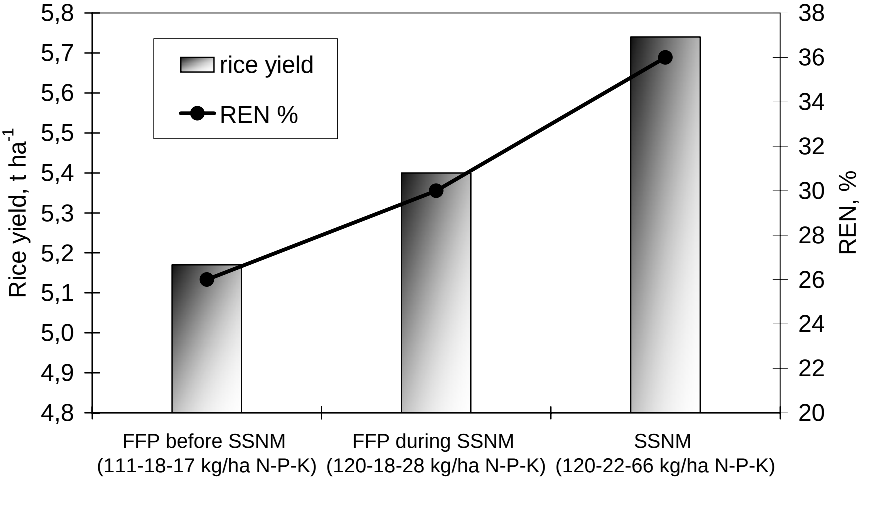

Fig. 13. Impact of site-specific nutrient management (SSNM) as compared to farmer's fertilizing practice (FFP) on rice yield and recovery efficiency of N (REN) [Dobermann, 1999]

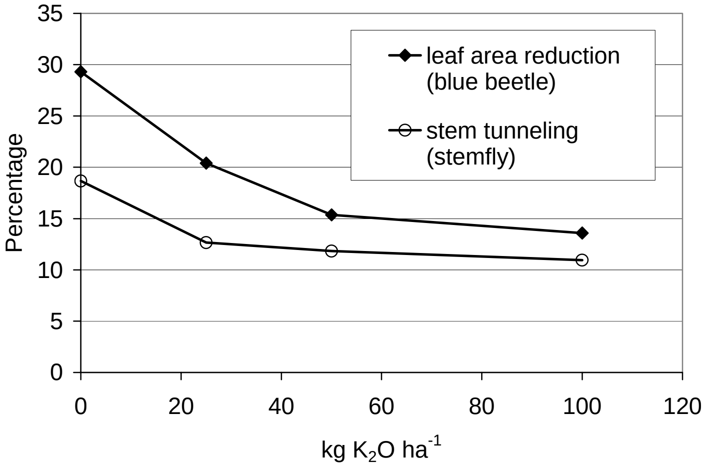

Fig. 14. Effect of K appliication on pest incidences in soybean (IPI on-farm trials 2001 in India)

Conclusions

The benefits of balanced fertilization of annual crops are obvious: with higher yields the farmer increases his profits, with better crop quality he remains competitive at the market, and the better resistance to pests and diseases reduces the production costs. His higher income will also attract other business, it creates jobs and thus, contributes to the rural development. At the same time, the nation benefits from higher food security, less dependency from food imports and even from export opportunities.

However, the short duration of annual crops and consequently, the quick turnover of nutrients require a judicious nutrient management to optimize the efficiency of the costly inputs and to minimize the environmental impact of fertilizers. Potassium plays a particular role in these aspects.

Unfortunately, the use of potash fertilizers lags seriously behind the requirement of the plant. One of the factors responsible for this is certainly lack of knowledge, especially as far as the assessment of soil K is concerned.

There is also need to convince farmers to re-invest in soil fertility not only with N and P but also with K. With increasing K deficits due to unbalanced fertilizer use, which is common in South Asia, soil fertility degrades and the farmer looses the basis for a sustained production and income. It is indeed often fairly difficult to visualize the effect of potash use but this should not prevent us to demonstrate the effect of balanced fertilization on yield, quality and stress tolerance in the farmer's field, to train the extension staff and the fertilizer dealers on the effectiveness of potash in concert with other fertilizers, and to inform the government on the consequences if soil K mining continues.

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Current status of fertilizer use to food crops in Sri Lanka

D.R. Wijayatilleke

National Fertilizer Secretariat, Ministry of Agriculture, Livestock, Lands & Irrigation, 80/5, Govijana Mandiraya, Rajamalwatta Avenue, Battaramulla, Sri Lanka

Introduction

The domestic food crop sector in Sri Lanka is comprised of the staple food crop rice, subsidiary food crops covering other coarse grains, pulses, oil seeds, fruits and vegetables. Significant use of chemical fertilizer for food crops in Sri Lanka commenced after independence in the country. However, emphasis on wide spread use of high analysis chemical fertilizer for this group of crops was made from the decade commencing from the year 1960. In order to promote balanced use of plant nutrients, fertilizer mixtures containing N, P and K nutrients had been recommended during early stages. The Department of Agriculture until 1990 promoted fertilizer recommendations in mixtures.

It was conclusive from elaborate studies conducted on the soil nutrient status of lands that blanket fertilizer recommendations were not the best economical solution for soils in farmlands with varying conditions. Since 1990, the Department of Agriculture has recommended the use of straight fertilizers, in order to provide an opportunity to farmers for making necessary adjustments in fertilizer application for optimum results. Fertilizer statistics related to the year 2002 indicate that about 49% of the total chemical fertilizers used were in the form of straight fertilizers (NFS, 2002). However, fertilizer mixtures are still popular with some farmers due to convenience in fertilizer application and also due to limitations in the availability of straight fertilizers in the market.

Most food crops are annual or semi-annual crops; therefore, more soluble forms or quick nutrient releasing types of chemical fertilizer are used in this crop sector. Over the years there had been a transition from use of low analysis fertilizers such as bone meal to high analysis fertilizers such as urea, muriate of potash and triple superphosphate. However, until recent times emphasis had been on use of NPK fertilizer and much of the research efforts also had been in this direction. After using NPK fertilizers for maximizing crop yields for few decades, deficiencies in certain trace elements had been apparent in the field.

Mineral fertilizers used in food crops sector

Nitrogen fertilizers

Urea is the most dominant form of nitrogen fertilizer used in the country, it accounts for approximately 50% of the total fertilizer used (NFS, 2002). Annually, around 300,000 tonnes of urea are imported and used either as a straight fertilizer or in mixed form. Since October 1997, the fertilizer subsidy scheme of the government was confined to Urea and with the heavy subsidy granted, the demand for urea has increased.

Past experience indicate that particularly the crops grown in coarse textured soils in Sri Lanka are highly sensitive to biuret content in urea. Therefore, biuret level in imported urea is monitored continuously.

Sulphate of ammonia is the second major nitrogen fertilizer used. With the removal of restrictions on transport of urea to the Northern and Eastern areas of the country, use of sulphate of ammonia for paddy has diminished. However, occasional application of sulphate of ammonia may be beneficial to the paddy crop as it involves addition of sulphur nutrient through this fertilizer. At present sulphate of ammonia is used in some of the vegetable fertilizer mixtures found in the market.

Potash fertilizers

Next to urea, muriate of potash (MOP) is the major fertilizer used in the country in terms of the quantity. Annually, about 100,000 tonnes of muriate of potash is imported and used in Sri Lanka. Bulk of the MOP requirement is supplied from Russia either directly or via China. Muriate of potash is a common fertilizer used for all types of crops. Paddy crop uses approximately 36% of MOP imported, other field crops use about 8% and vegetable and other crops use about 3.7% of MOP available annually (NFS, 2002).

Sulphate of potash (SOP) is used in a limited scale. Normally, it is used for chloride sensitive crops such as tobacco, grapes, etc.

Phosphate fertilizers

In Sri Lanka, triple super phosphate (TSP) is used as the traditional high analysis phosphate fertilizer for short duration crops. However, triple superphosphate allows more flexibility in formulation of fertilizer mixtures. Annually, from 40,000 to 50,000 tonnes of TSP are imported into the country (NFS, 2000; 2001 and 2002). Of the total quantity imported about 80% is utilized for the paddy crop. The balance is used mainly for other food crops. Therefore, if the Government wishes to confine fertilizer subsidy to the food crop sector, TSP probably would be one of the better choices available.

Short duration crops cannot exploit the available phosphorous in Eppawela rock phosphate (ERP) due to low solubility of this fertilizer. However, potential is there to convert this fertilizer to a more soluble form, thus saving valuable foreign exchange involved in importing high analysis phosphate fertilizer. Some companies use this fertilizer as filler for basal mixtures or as a basal fertilizer in combination with TSP. High grade ERP has been introduced as HERP. This fertilizer could substitute imported rock phosphate in usage.

Diammonium phosphate (DAP) is a suitable fertilizer for annual crops grown in Sri Lanka, but its use is very limited. Very few farmers use it to paddy, vegetables and other field crops.

Compound fertilizers

The major type of compound fertilizer used in the country is the NPK compound fertilizer. Few years back NPK of the formulation 05:15:15 was available for paddy cultivated in the wet zone of the country and this fertilizer was supplied under the Japanese Food Production Grant. With the termination of this program the current usage is limited to about 4000 tonnes and is mainly used for both paddy and tobacco.

Magnesium fertilizers

Dolomite available locally as calcium magnesium limestone extracted from the Central Province of the country. Also the cheaper source of magnesium and often used as a soil ameliorant or soil conditioner for acidic soils. It is used for many crops including potato, vegetables and other horticultural crops. Since there are variations in the magnesium content from one deposit to another, maintenance of the quality is important.

Kieserite is an imported natural fertilizer with higher water solubility. It is used as a quick magnesium releasing fertilizer for other field crops, fruits and vegetables.

Commercial Epsom salt is a readily available source of magnesium, used particularly to correct magnesium deficiencies in other field crops, fruits and vegetables.

Special fertilizers

Special fertilizers are relatively expensive fertilizers often used for special purposes or to more remunerative crops. These include special formulations of NPK

fertilizers with or with out trace elements, micronutrient mixtures, fertigation mixtures, mixtures for hydroponic systems and fertilizer with growth promoting substances.
These fertilizers are used for floricultural crops, vegetables, and other horticultural. But micronutrient fertilizers are used for many commercial crops where micronutrient deficiencies have been reported. Imports of these special types of fertilizer for the year 2002 are furnished in Table 1 to indicate the level of their usage.

Table 1. Imports of special fertilizers to Sri Lanka in 2002

Category	Liquids, litres	Granules	Powder
		------------------- tonnes	-----------------
NPK	2296	179.5	21.0
NPK+ micronutrients	8910	636.5	7.9
Micronutrient fertilizers	6001	47.1	18.9*
Fertigation mixture	-	-	115.0
Hydroponic mixture	-	-	12.0

* Crystals

Fertilizer use by major groups of food crops

The annual fertilizer use to food crops in Sri Lanka is indicated in Table 2. On the average in 2000-02, 162,852 tonnes of NPK were applied annually to food crops, including 115,466 tonnes of N, 21,132 tonnes of P_2O_5 and 26,254 tonnes of K_2O.

Paddy

Paddy consumes the largest part of chemical fertilizers, it accounts for approximately 50% of the overall use of chemical fertilizers in Sri Lanka. Since 1990, the Department of Agriculture has terminated recommending fertilizer mixtures for all food crops, including paddy. Instead, wet zone farmers use chemical fertilizers less than the recommended level. The relative average use of fertilizers to paddy in the country against the recommendations during three consecutive Maha (north-east monsoon) seasons (major season, which commences in October and ends in March) is indicated in Table 3. These data indicate that overall fertilizer use is little below the recommended level. The deficit is a result of using less or no basal fertilizer for paddy cultivation by particularly the farmers growing paddy in marginal lands and in cultivation under rain fed conditions.

Table 2. Average annual fertilizer use for food crops in 2000-02, tones (NFS, 2000; 2001 and 2002)

Fertilizer		Paddy	OFC*	Others	Total
N	Urea	225,921	6,365	12,246	244,532
	Sulphate of Ammonia	4,536	14,166	5,543	24,245
P	Triple Super Phosphate	32,415	5,939	2,417	40,771
	Imported Rock Phosphate	37	1,445	1,468	2,950
	Eppawela Rock Phosphate	1,914	1,543	1,077	4,534
	Diammonium Phosphate	89	139	16	244
K	Muriate of Potash	32,249	6,135	3,851	42,235
	Sulphate of Potash	11	17	5	33
Compound	NPK Compound	1,133	0	147	1,280
	Sulpo-mag	6	110	10	126
Mg	Kieserite	5	190	174	369
	Dolomite	317	1,102	1,112	2,531
Others		2,302	250	2,339	4,891
N		104,949	5,325	5,192	115,466
P_2O_5		15,716	3,569	1,847	21,132
K_2O		19,524	4,395	2,335	26,254
MgO		65	332	164	561
Total		140,256	14,225	11,113	165,594

* OFC - Other Field Crops group, which includes coarse grains, oil seeds, pulses, onions and chilli.

Table 3. Actual fertilizer use to paddy against the recommendations

Maha season	Relative use of NPK, %
1999/00	78
2000/01	80
2001/02	85

The cost of cultivation of paddy in Sri Lanka is increasing from season to season. The average size of a paddy holding is less than one acre. Therefore, productivity of this small unit needs to be enhanced to improve the incomes of the cultivators. Past experience indicates that application of chemical fertilizer alone cannot improve the productivity in paddy cultivation. For sustainable increase in paddy yields, both improvements of the soil conditions and also balanced nutrient application are necessary. These conditions would be satisfied under the Integrated Plant Nutrition Systems (IPNS) approach. Results from a field trial on IPNS conducted by the Department of Agriculture in late 1990's are summarized in Table 4.

Table 4. Economics of integrated plant nutrition systems [field trial was conducted on 1 acre of paddy in the Badulla district] (FADINAP, 2000)

Treatment	Yield, t $acre^{-1}$	Net return, Rs $acre^{-1}$	Cost of grain production, Rs kg^{-1}
No fertilizer	1.0	1000	10.00
NPK (recommended)	1.4	3968	8.13
NPK + RS	1.8	8068	6.52
NPK + RS + CD	2.6	15368	4.97
NPK + RS + CD + GM + RHC	4.0	28760	3.81

RS – rice straw, CD – cow dung, GM – green manure, RHC – rice husk ash.

Therefore, it would be possible to improve the incomes of farmers through the IPNS approach. These yield improvement programmes need to be supplemented with soil testing for better fertilizer recommendations. It is also necessary to emphasize here the need for application of deficient nutrients, which become apparent at high yield levels.

Other Field Crops

Other Field Crops include few groups of crops such as coarse grains, oil seeds, pulses, onions and chilli. Area under these crops may vary depending on several factors such as market prices for production and weather conditions. In the year 2002, the area under Other Field Crops covered 76,000 ha in Maha (north-east monsoon) season followed by 29,000 ha in Yala (south-west monsoon) season (begins in April and ends in September). Annually, 40,000-45,000 tonnes of chemical fertilizer are used to these crops (NFS, 2002). The fertilizer use may vary depending on the variety of crops grown, cropping system, etc. For pulses, little or no fertilizers are used and the indicated crops are more dependent on residual nutrients from the previous crops in the crop rotation.

For coarse grains, fertilizer application in general is at a low level, and yield improvement is possible through application of recommended rates of fertilizers. To comparatively more remunerative crops such as onions, high rates of fertilizer are used and these rates are sometimes above the recommended levels. Over-application of fertilizers in some areas such as Kalpitiya area has been reported.

To other field crops, fertilizers are applied as onion mixtures, urea and paddy mixtures. Special fertilizers, including micronutrient mixtures, are also used.

Chilli is another important subsidiary food crop grown in Sri Lanka. All commercial growers use moderate to high rates of fertilizers to chilli. Fertilizers are applied in the form of chilli mixture, paddy mixtures, urea and special fertilizers.

Vegetables

Vegetable crops represent the important group of crops grown seasonally depending on weather conditions or throughout the year with supplementary irrigation. The annual area under vegetables is little over 100,000 ha. In Maha season 2001-02, about 61,000 ha have been cultivated under vegetables (NFS, 2001 and 2002).
In general, vegetables are high remunerative crops, although both gluts and shortages are reported depending on the seasonal availability. Moderate to high rates of fertilizers are applied to vegetables. Unlike the general pattern of fertilizer used in Sri Lanka, vegetable crop growers in the upcountry areas use high rates of both organic and chemical fertilizer.

Conclusions

As regards the cultivation of food crops in Sri Lanka, imbalance in fertilizer use, application of fertilizers below the recommended levels and sometimes even over-use of mineral fertilizers to more remunerative crops are some problems requiring corrective measures in future.
The malpractice in fertilizer trade, particularly availability of adulterated fertilizer, is a hindrance to achieve higher productivity levels in a shortest way. More importantly, both correct agronomic fertilizer recommendations and reasonable farmer fertilizer practice are necessary to achieve higher efficiency in fertilizer use. The indicated measures are some of the measures required to reduce the cost of production of food crops in Sri Lanka.

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Potassium fertilization of paddy in Sri Lanka

W.M.J. Bandara, W.M.A.D.B. Wickramasinghe and D.N. Sirisena

Rice Research & Development Institute, Batalagoda, Ibbagamuwa, Sri Lanka

Abstract

Rice is the staple food of Sri Lankans and has been cultivated for well over 2000 years. Presently, annual cultivated area is 0.83 million hectares produced 3.2 million tonnes of rough rice through 113% cropping intensity and national average of 3.9 t ha^{-1}. To keep the rice production at self sufficient level in the future, increase in rice production must come from increasing rice yield per unit area and increasing cropping intensity through better soil fertility management in rice growing environments. In this context, K fertilization to paddy soils is an important soil fertility management practice as rice crop removes more potassium than nitrogen and phosphorous agro-ecological zones in Sri Lanka. In the most of the dry and intermediate zones soils, there was no response to applied K. Except in a few occasions, response of rice to applied K in soils of mid country wet zone was similar to above. On the other hand, 50% of the tested sites in the low country wet zone showed a response to applied K and split application of K gave the best results. In addition, under soil stress condition such as Fe toxicity, there was a clear response to applied K and the requirement is more than that of normal soil. Experiments conducted very recently in Low Humic Gley (LHG) soils in the low country intermediate zone showed that yield could be further increased with the addition of K up to 75 kg K_2O ha^{-1}, if other soil fertility limiting factors and nutrient imbalances are corrected. A tentative K fertilizer recommendation for rice was first given in 1950 and there were separate fertilizer mixtures for the low country dry zone (no K_2O), the low country wet zone (10.3-12.4 kg K_2O ha^{-1}) and for the sandy soils of northern and eastern provinces (7.0-8.4 kg K_2O ha^{-1}) only in single application, as basal. During the period of 1962-1964, a new set of K fertilizer recommendation was introduced separately for each district. Potassium fertilizer was recommended as a basal application, but for fertilizer responsive varieties in certain cases additional potassium dose was recommended at two weeks before heading. In 1971, fertilizer recommendations were revised again and there were 31 different K formulations on the basis of different agro-climatic zones, rice varieties, age classes and yield levels. Since there were no new research findings to substantiate any changes to K recommendations in 1990, no major changes has been introduced to the rates of K. However, rates of K fertilizer were reduced when rice straw is added and for the iron toxic areas of the low country wet zone, an additional dose of K was recommended

as a top dressing at primordial initiation. In 1996, the number of fertilizer formulations was reduced to 9 and they were based on the agro-ecological region, soil textural classes and rice varieties; and K was also added as a straight fertilizer in the form of muriate of potash. In the year 2001, K fertilizer recommendations were revised on the basis of targeted yields for each agro-ecological zone and nutrients removal by the crop. As an example in the dry zone, when expected yields are 5 and 7 t ha^{-1}, recommended K rates are 37.5 and 67.5 kg K_2O ha^{-1}, respectively. Likewise, minimum and maximum K rates are respectively 37.5 and 67.5 kg K_2O ha^{-1} for rice cultivation in all the agro-ecological zones in the country. During the last 3 decades K fertilizer consumption has been increased by 11,000 tonnes of K_2O, from 7,000 tonnes in 1972, with the annual growth rate of 5%. During the last decade, annual consumption of K fertilizer was fluctuated in the range between 17,500-25,100 tonnes, of which 25,100 tonnes of K_2O was the highest level recorded in 1994. However, considering the amounts of K removal and amount of K applied for rice cultivation in Sri Lanka, the balance of K is negative. Under the present system of cultivation, the efficiency of K use to rice is around 40%. Thus, investigations are needed to study the contribution of K from various sources, e.g. weathering of K minerals, recycling of crop residues, transfers from upland and supply from irrigation waters, and K losses from paddy fields. In addition, other soil factors that limit the response of rice to added K even under low exchangeable K content should also be studied. However, to maintain soil fertility levels for sustainable crop production, it seems prudent to apply a maintenance dose of K in certain environments.

Introduction

Rice is the staple food of Sri Lankans and has been cultivated for well over 2000 years. Presently, annual cultivated area is 0.83 million hectares produced 3.2 million tonnes of rough rice through 113% cropping intensity and national average yield of 3.9 t ha^{-1}. Domestic annual rice requirement in the year 2000 was 3.11 million tonnes and it is estimated to be 3.46 millions tonnes in the year 2010 (Abeysiriwardena and Sandanayake, 2000). Increase in rice production through further increase in cultivated area is very limited. Therefore, the major portion of rice production in future must come from increasing rice yield per unit area and increased cropping intensity. Hence, soil fertility management in rice soils would play a major role in this context.

Soil fertility management and fertilizer use are the most important criteria that account for increasing crop output. In order to achieve the goal of meeting the domestic food requirement, fertilizer use will have to be increased substantially. If the maximum benefits from fertilizer application are to be obtained, these fertilizers should be applied judiciously. In this respect, forms, quantities, methods and time of fertilizer application are important. However, these factors depend on soil, climatic condition and varieties used. Realizing that fertilization is essential to get good yield from improved varieties, the Government of Sri Lanka imported N, P and K fertilizers and provided subsidized fertilizer prices for farmers (Nagarajah, 1980). Therefore, yield per unit area from modern varieties and total rice production in Sri Lanka was gradually increased.

Potassium is one of the major nutrient elements required for rice crop growth. Potassium has essential functions in osmoregulation, enzyme activation, regulation of cellular cation-anion balance, regulation of transpiration by stomata and the transport of assimilate. As rice is concerned, in addition to the normal functions of K, optimum K nutrition increases the number of spikelets per panicle, percentage of filled grains and 1000 grain weight. K deficient plants are susceptible to the most of plant diseases such as bacterial leaf blight, sheath blight, brown spots and seeds spots (Doberman and Fairhurst, 2000). In general, potassium deficiency symptoms in rice plant are often not detected, because these symptoms are not easy to recognize as those of P and N deficiencies and symptoms tends to appear during later growth stages. Stunted plants with early senescence leaves are recognized as some of the K deficiency symptoms. Potassium deficient plants, which were susceptible to lodging, produce large number of sterile and unfilled grains. Moreover, K deficient plants have unhealthy root system with many black roots, low root length and density, causing a reduction in the uptake of other nutrients. Poor root oxidation power, causing decreased resistance to toxic substances, can be also a result of inadequate K supply (Doberman and Fairhurst, 2000). Therefore, more attention should be given to the K nutrition in rice in order to increase the rice production and productivity of soil.

In Sri Lanka, there are different cropping patterns in different agro-ecological zones, considering seasonal variation of soil moisture regimes during the cropping period. Cropping patterns of rice-rice, rice-fallow, rice-other field crops can be seen in low country dry and intermediate zones while rice-rice and rice-fallow cropping pattern are observed in low country wet zones. Rice-vegetable is the main cropping system in mid country intermediate zone and rice-vegetable, rice-tobacco and rice-potato cropping systems are practiced in up country intermediate zones.

Rice growing soils in different agro-ecological zones of Sri Lanka, namely Reddish Brown Earth (RBE), Red Yellow Podsolic (RYP), Non-Calcic Brown (NCB), Reddish Brown Latosols (RBL), Immature Brown Loams (IBL), Low Humic Gley (LHG), Alluvial and Organic soils have different capabilities of K supplying capacity.

Since 1971, the extent of rice land under new improved varieties has been steadily increased in Sri Lanka and reached to a plateau of 95% of the total rice area in 1982. Since these varieties are better fertilizer responsive and have a much higher nutrient requirement than traditional varieties, fertilization was essential to increase the rice yields.

During the last 3 decades, annual K fertilizer consumption for rice in production terms was increased by 11,000 tonnes of K_2O, from 7,000 tons in 1972, which is an

annual growth rate of 5.2%. But, during the last decade, annual consumption of K fertilizer was fluctuated in the range between 17,500-25,100 tonnes of K_2O, of which 25,100 tonnes was the highest level recorded in 1994 (NFS, 2000). This figures show that K fertilizer use in the country reaches to a plateau, but the consumption depends on some other parameters than the requirement.
In this paper, salient finding of research carried out since 1972 by the Department of Agriculture with respect to forms, quantities, methods and time of K fertilizer application for rice grown under different soil and climatic conditions are reviewed.

Potassium requirement of rice

During vegetative growth up to flowering, the K supply is usually sufficient and a response to additional K supply is unlikely when the leaf concentration is between 1.8-2.6%. To produce the maximum number of spikelets per panicle, the K content in mature leaves should be more than 2% at the booting stage of the crop (Table 1). The critical level for K in the straw at harvest is between 1.0% and 1.5%, but yields more than 7.0 t ha^{-1} require more than 1.2% K in the straw at harvest and more than 1.2% K in the flag leaf at flowering (Doberman and Fairhurst, 2000). For optimum growth, the N:K ratio in straw should be between 1:1 and 1:1.4.

Table 1. Optimal ranges and critical levels of K in plant tissue

Growth stage	Plant part	Optimum range	Critical level for deficiency
		------------------------ %	------------------------
Tillering to PI	Y leaf	1.8-2.6	<1.5
Flowering	Flag leaf	1.4-2.0	<1.2
Maturity	Straw	1.5-2.0	<1.2

PI - Primodial initiation

Rice crop removes more K than N and P. Usually, 5 tonnes of rice crop remove about 150 kg K_2O ha^{-1} compared to 100 kg N ha^{-1} in rice cultivation in Sri Lanka (Amarasiri and Perera, 1975). Therefore, chemical fertilizers must be used to give each nutrient at optimum level in order to increase the yield.
The internal K use efficiency of rice depends on the K supply and the overall plant nutritional status. Under balanced nutrition and optimum growth conditions, the internal efficiency of 69 kg grain per kg plant K uptake can be expected that is equivalent to a removal of 14.5 kg K per tonne at economic yield levels (Table 2).
In farmer's fields, however, the measured average internal K use efficiency is only 60 kg grain per kg K taken up. The observed average K removal in irrigated rice systems in Asia is 17 kg K per tonne grain yield (Table 2). Therefore, rice crop yielding 6 t ha^{-1} takes up 100 kg K per ha (compared with only 87 kg K per ha under

optimum growth conditions) of which >80% remain in the straw at maturity. If only the grain is removed and straw is returned to the field, K removal is 2.5 kg K t^{-1} of grain yield.

Table 2. K content in modern rice varieties and K uptake (Doberman *et al.,* 1998)

Plant part	K content, %		K uptake, kg t^{-1} grain	
	Range	Average	Range	Average
Grain	0.22-0.31	0.27	2-3	2.5
Straw	1.17-1.68	1.39	12-17	14.5
Unfilled spikelets	0.61-1.20	1.07	-	-
Straw + grain	-	-	14-20	17.0

Soil K

Generally, the 1 M NH_4OAc-extractable K in lowland rice soils ranges 0.05-2.00 cmol (+) kg^{-1}. A critical concentration of 0.2 cmol (+) kg^{-1} is often used. Depending on the texture, clay mineralogy and K inputs from the natural sources, critical levels of exchangeable K can vary from 0.1 to 0.4 cmol (+) kg^{-1} (Dobermann and Fairhurst, 2000). The amount of tightly bound or fixed K increases with clay content so that critical levels are larger in soils containing large amounts of 2:1 clay minerals. For the general applicability, critical soil classes have been determined. Soils, containing less than 0.15 cmol (+) kg^{-1} exchangeable K, are classified as low K soils with the response to K fertilizer application (Dobermann and Fairhurst, 2000). Soils of medium K class (exchangeable K between 0.15-0.45 cmol (+) kg^{-1}) show the probable response to K fertilization. Soils of high K class (>0.45 cmol (+) kg^{-1}) show response to K application only at very high yield levels [>8 t ha^{-1}] (Dobermann and Fairhurst, 2000).

Potassium saturation (% of total CEC) is often a better indicator of K supply than the absolute amount of K extracted with 1 M NH_4OAc, because it takes into account the relationship between K and other exchangeable cations (Ca, Mg, Fe). The proposed ranges are as follows:

- K saturation < 1.5% in soil which is low K status shows the response to K fertilization;
- K saturation between 1.5-2.5% which is medium K, response to K fertilizer probable;
- K saturation > 2.5% in soil, which is high K status, response to K, is unlike.

Rice response to K

Low Country Dry and Intermediate zones

Reddish Brown Earth, NCB, LHG and Alluvial are the rice growing soils in the low country dry zone, while RYP, LHG, NCB, RBL and IBL and Alluvial are the rice growing soils of the low country intermediate zone. In the early seventies, field experiments have been started to observe the response of rice crop to K application in these soils. Experiments, testing split application of potash fertilizer with K rates from 0 to 134.4 kg K_2O ha^{-1}, have been carried out on RBE and Alluvial soils at Polonnaruwa and Paranthan respectively. On RBE soil in Polonnaruwa, response to K was up to 22.4 kg K_2O ha^{-1} in Maha (north-east monsoon) season (October-March) and it was up to 44.8 kg K_2O ha^{-1} in Yala (south–west monsoon) season (April-September), while there was no response to application of K in Yala on Alluvial soils in Paranthan (Table 3).

Table 3. Grain yield (t ha^{-1}) of rice at different rates and times of K application on RBE and Alluvial soils in the low country dry zone (Nagarajah, 1980)

K_2O, kg ha^{-1}		Polonnaruwa (RBE)		Paranthan (Alluvial)	
Basal	PI	Maha 71/72	Yala 72	Maha 71/72	Yala 72
8.0	0	7.29	4.00	4.17	6.50
22.4	0	7.82	4.25	4.29	6.63
44.8	0	7.85	5.06	4.30	6.54
67.2	0	8.01	5.28	4.39	6.67
67.2	22.4	8.19	5.09	4.39	6.65
67.2	44.8	8.34	5.20	4.52	6.68
67.2	67.2	8.46	5.40	4.52	6.59
$LSD_{0.05}$		0.51	0.38	ns	ns
Rice variety		Bg 11-11	Bg 34-8	Bg 11-11	Bg 34-8

All treatment received 100 kg N ha^{-1} as urea and 52.7 kg P_2O_5 ha^{-1} as TSP.
PI- Primodial initiation

Experiments carried in Ampara district have shown that response to K varies with soil types (Balasuriya *et al.*, 1977). In coarse textured NCB/LHG soil complex which has low exchangeable K content (47 mg kg^{-1}), a significant yield response was observed up to 67.2 kg K_2O ha^{-1} provided K applied half at planting and the other half at primordial initiation stage (Table 4). On the other hand, on moderately fine textured alluvial soils with high exchangeable K content (113 mg kg^{-1}) significant yield response was observed only up to 33.6 kg K_2O ha^{-1} (Table 4).

Table 4. Grain yield (t ha^{-1}) of rice at different levels and time of K application on NCB/LHG and Alluvial soils in Ampara in Maha season 1972/73 (Nagarajah, 1980)

K_2O, kg ha^{-1}		NCB/LHG	Alluvial
Basal	PI		
0	0	3.85 c	4.62 b
33.6	0	4.26 b	5.70 a
67.2	0	4.33 b	5.95 a
33.6	33.6	4.63 a	6.05 a
67.2	33.6	4.69 a	6.12 a

All plot received 112 kg P_2O_5 ha^{-1} as TSP and 112 kg N ha^{-1} as urea. Variety: Bg 11-11.
PI- Primodial initiation

In general, studies conducted on dry zone soils during 1980's showed that response to K application was insignificant. Experiments carried out with irrigated rice on Grumosol soils showed response to K application up to 30 kg K_2O ha^{-1} only, and there was no response to splits application of K at planting, maximum tillering and primordial initiation stages (Yogarathnam, 1987). On RBE and LHG soils in the low country dry zone, there was no response to K even to the level of 80 kg K_2O ha^{-1} with either medium or short age rice, although soil exchangeable K content at the sites ranged from 31 to 331 mg kg^{-1}. Sixteen trials conducted in the well drained and imperfectly drained RBE and LHG soils in the same zone showed no significant response to K at any of these sites (Table 5). Data from few trials established on RBE soils in the low country dry zone during 1987 and 1988 showed a positive relationship between soil exchangeable K content and grain yield, and this was completely different from that on LHG soils (Rezania, 1992). Rezania (1992) further stated that the available evidence is sufficient to affect K fertilizer recommendations, but it does not provide further background information on the dynamics of K in relation to soil physical characteristics.

Weerasinghe (1991) reported that there was no response to applied K on NCB soils at Aralaganwila in the low country dry zone although soil exchangeable K content was as low as 12-24 mg kg^{-1}. This may be due to addition of K through irrigation water (23.5 kg K ha^{-1} per season) and from dying roots (17 kg K ha^{-1} per season) as described by Kendaragama (1988).

Non Calcic Brown soils in the eastern dry zone provided significant yield increase only in the 1st season out of 5 seasons, for the application of 20-80 kg K_2O ha^{-1} in 3 splits (Regional Agricultural Research and Development Centre, Aralaganwila, 1988, Unpubl.).

A long-term study conducted on coarse textured soils in the low country intermediate zone showed no significant yield increase with K application up to 60 kg K_2O ha^{-1} throughout the experiment (Regional Agricultural Research and

Development Centre, Makandura, 1988 Unpubl.; Wijesundara *et al*., 1990). Experiments conduct in farmers field in the same zone under similar conditions also failed to show any response to applied K.

Table 5. Response of rice to different levels and split application of K in LCDZ (Wijesundara *et al*., 1990)

K level, kg K_2O ha^{-1}	Grain yield, t ha^{-1}								
	Maha 1987/88							Yala 1988	
	RBE (WD)			RBE (ID)		LHG		LHG	
0	6.5	6.7	8.0	5.5	6.5	8.5	6.6	4.1	4.4
20 (b)	7.3	6.4	8.7	6.1	6.7	9.2	6.4	3.4	4.1
40 (b)	6.7	7.3	8.4	5.8	6.4	8.4	6.7	4.3	4.3
60 (b)	6.7	7.3	8.7	6.0	6.2	9.1	6.3	4.0	3.7
80 (b)	6.6	7.3	7.8	6.1	6.8	8.2	6.7	3.5	4.4
20 (½b, ½ PI)	6.6	7.0	8.6	5.7	6.9	8.4	6.6	3.6	3.9
40 (½b, ½ PI)	7.4	7.2	8.4	5.9	6.5	8.4	5.9	3.8	3.5
60 (½b, ½ PI)	7.1	7.6	8.7	6.1	7.0	9.2	6.4	3.6	3.9
80 (½b, ½ PI)	6.8	6.9	8.2	5.7	6.3	8.1	5.8	4.4	4.1
44 (DOA rec.)	-	7.5	8.3	-	6.5	9.0	6.3	4.2	2.7
$LSD_{0.05}$	ns	ns	ns	ns	ns	ns	ns	ns	ns
CV, %	11	7	6	10	8	8	7	14	22
$K_{exch.}$, meq 100 g^{-1}	0.08	0.40	0.80	0.18	0.26	0.31	0.49	0.24	0.25

All treatment received 100 kg N ha^{-1} and 75 kg P_2O_5 ha^{-1}.
WD – well drained, ID – imperfectly drained.

Potash fertilizer response studies carried out on RBL soils in Matale in the mid country intermediate zone also showed no response to K application (exchangeable K content in soils was 78 mg kg^{-1}). However, there was increasing trend in yield with K application over zero K treatment.

Mid Country Wet Zone

Potassium response studies in the mid country wet zone have been carried out on two great soil groups (RYP and RBL). A long-term study over 6 seasons with 30, 60 and 90 kg K_2O ha^{-1} showed response only up to the first level and no response to higher levels or 3 methods of split application. It has been reported that K content in rice leaves in zero K treatment was low and showed K deficiency symptoms in some seasons (Wijesundara *et al*., 1990; Rezania, 1992). Studies conducted on IBL, RYP and RBL soils indicated that K response was up to about 60 kg K_2O ha^{-1} only on

RBL soil. The exchangeable K content in these soils was in the range 39-58 mg kg^{-1} soil. There was no response to K in other soils, although the exchangeable K content of these soils was reported as extremely low (Former Central Agricultural Research Institute, Gannoruwa, 1988, Unpubl.).
In the field trials conducted on farmers' fields on RBL and RYP soils, significant yield increase to added K was observed only in one location out of six locations during two seasons (Table 6). Small consistent increases in grain yield were recorded for applications of 20-40 kg K_2O ha^{-1}. Addition of Mg, S, and Zn with 80 and 120 kg K_2O ha^{-1} failed to increase the grain yields (Wijesundara *et al*., 1990). At all the experimental sites, the exchangeable K content in soils ranged 47-160 mg kg^{-1} and declined after harvest in most locations irrespective of the K rate applied. These results suggest that the exchangeable K content does not appear to have a relationship with the K nutrient status of the soil (Wijesundera *et al.,* 1990). Amarasiri and Wickramasinghe (1988) reported that addition of 360 kg K_2O ha^{-1} in the form of muriate of potash or even higher quantity of K from straw over 8 seasons failed to increase the exchangeable K content in soil. Plant uptake, percolation losses and retention by soil in a form not extracted by ammonium acetate were considered as possible causes for this behavior (Wijesundara *et al*., 1990). The apparent lack of response to K application could be due to K transformation from non-exchangeable complex into available forms and supply of K with irrigation waters (Wijesundera *et al.,* 1990).

Low Country Wet Zone

Experiments carried out in Kalutara district showed that response of rice to added K was only up to 33.6 kg K_2O ha^{-1} (Table 7). Similar results have been obtained in Bombuwela (Regional Agricultural Research and Development Centre, Bombuwela, 1983, Unpubl.). The heavily leached soils of this zone have a much lower exchangeable K content than soils of other zones. Almost 50% of the tested sites in the low country wet zone had exchangeable K content less than 58 mg kg^{-1}, which is considered as the critical soil K level for mineral/alluvial soils (Rezania, 1992). Experiments conducted after 1980 showed that the estimated optimum rates of K for the K responsive sites were in the range of 80-120 kg K_2O ha^{-1}, much higher than the DOA 1980 recommendation of 30 kg K_2O ha^{-1} (Rezania, 1992).
The long-term experiments conducted on a coarse textured soil over 3 consecutive seasons with 3 levels of K and 2-4 split applications did not indicate any response to K or to time of K application (Regional Agricultural Research and Development Centre, Bombuwela, 1983, Unpubl). However, in K experiments conducted on farmers' fields, a significant response to K application was obtained up to 30 kg K_2O ha^{-1} in both mineral and organic rice soils, but there was no response to split application of K (Table 8).

Table 6. Response of rice to different levels and split application of K in RYP and RBL soils of mid country wet zone: Kandy, Kegalle and Matale districts (Wijesundara *et al*., 1990)

K level, kg K_2O ha^{-1}	Grain yield, t ha^{-1}							
	RYP				RBL			
	Maha 87/88		Yala 88		Maha 87/88		Yala 88	
	Site1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
0 (b)	5.5	4.8	4.1	5.6	4.4	5.9	4.6	4.0
20 (b)	5.7	5.0	-	-	4.7	5.6	-	-
40 (b)	5.6	5.4	4.3	5.8	4.4	5.5	4.5	4.7
60 (b)	5.8	5.4	4.6	5.7	4.3	5.6	4.9	4.8
80 (b)	6.0	5.3	4.5	5.5	4.4	5.9	4.7	4.7
120 (b)	-	-	4.2	5.9	-	-	4.9	4.8
20 (½b, ½ PI)	6.1	5.4	-	-	4.2	5.7	-	-
40 (½b, ½ PI)	5.4	5.0	4.2	5.6	4.3	6.3	4.9	4.2
60 (½b, ½ PI)	5.6	5.7	4.2	5.9	4.5	5.8	4.5	4.4
80 (½b, ½ PI)	5.9	5.5	4.2	5.4	3.9	5.8	4.9	4.5
120 (½b, ½ PI)	-	-	4.4	5.6	-	-	4.7	4.8
$LSD_{0.05}$	ns	ns	ns	ns	ns	ns	ns	0.7
CV, %	13	5	5	6	8	7	8	15
$K_{exch.}$, meq 100 g^{-1}	0.14	0.41	0.12	0.25	0.15	0.25	0.13	0.26

All treatment received 100 kg N ha^{-1} as urea and 75 kg P_2O_5 ha^{-1} as TSP.

Table 7. Grain yield (t ha^{-1}) of rice at different levels and time of K application in soils of low country wet zone (Nagarajah, 1980; Wijesundara *et al*., 1990)

K_2O, kg ha^{-1}		Kalutara*	Bombuwela**	
Basal	PI*** stage	Maha 1972/73	Maha 1975/76	Yala 76
0	0	2.89	2.59	3.52
33.6	0	3.39	3.06	3.89
16.8	16.8	-	3.08	3.66
67.2	0	3.50	3.31	3.89
33.6	33.6	3.55	3.45	3.85
	33.6	3.72	-	-
$LSD_{0.05}$		0.53	0.33	0.25
Variety		Bg 11-11	Bw 78	Bw 78

* All plots received 89.6 kg N ha^{-1} as urea and 112 kg P_2O_5 ha^{-1} as TSP.

** All plots received 56 kg N ha^{-1} as urea and 44.8 kg P_2O_5 ha^{-1} as TSP.

*** PI - Primodial initiation

Table 8. Response of rice to different levels and split applications of K in low country wet zone (Wijesundara *et al*., 1990)

K level, $kg\ K_2O\ ha^{-1}$	Grain yield, $t\ ha^{-1}$								
	Maha 87/88						Yala 88		
	Colombo		Galle		Kalutara		Colombo		Kalutara
	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2	Site 1
0	4.7	4.4	5.4	5.5	3.0	3.7	3.3	3.4	2.1
30 (b)	5.2	4.3	8.5	6.0	3.1	4.4	3.5	3.6	2.9
60 (b)	4.8	4.9	6.7	5.5	3.1	4.3	3.7	3.6	2.7
90 (b)	5.2	4.3	6.5	5.4	3.2	3.9	3.8	3.4	2.5
120 (b)	4.9	4.2	7.5	5.7	3.3	3.7	4.2	3.1	2.4
30 (½b, ½ PI)	5.4	4.1	6.7	5.8	3.1	4.6	3.9	3.4	2.5
60 (½b, ½ PI)	4.6	4.4	6.5	5.6	3.4	4.7	4.1	3.7	2.6
90 (½b, ½ PI)	5.0	4.3	6.3	6.7	3.2	4.1	4.0	2.8	2.2
120 (½b, ½ PI)	5.4	4.1	6.0	5.5	3.2	4.0	4.8	2.8	2.4
$LSD_{0.05}$	0.5	ns	1.7	ns	ns	0.9	ns	ns	ns
CV, %	9	13	16	10	15	14	17	10	14
$K_{exch.}$, $mg\ kg^{-1}$	31	27	94	55	43	62	82	70	58

All treatment received 75.15 kg N ha^{-1} as urea and 75 kg P_2O_5 ha^{-1} as TSP.

Response to K application under stress conditions such as Fe-toxicity in mineral soils have been extensively studied in the low country wet zone. Potassium use to rice crop is presumed to be useful under conditions of stress similar to those prevalent in the region. Improved plant growth parameters and increased grain yield were observed in the iron toxic mineral and organic soils with the addition of higher K levels. In series of experiments on mineral soils with application of different K rates (34.5, 69.0, 103.5 and 138.0 kg K_2O ha^{-1}) to two rice varieties, one tolerant and other susceptible to iron toxicity; it was shown that bronzing symptoms were reduced to a mild level in the tolerant variety at 69.0 kg K_2O ha^{-1} and in the susceptible variety at 103.5 kg K_2O ha^{-1} (Bandara and Gunatilaka, 1984; 1994a; 1994b; 1997). Thus, the variety susceptible to iron toxicity benefited more by application of the higher K rates. On iron toxic organic soil, grain yield increases were greater with K application (Bandara and Gunatilaka, 1994).

In the experiments conducted at 4 locations in Rathnapura district under extreme condition of iron toxicity, application of extra K at PI stage was found to increase the yield of both susceptible and tolerant rice varieties (Regional Agricultural Research and Development Centre, Bombuwela, 1983, Unpubl.). Wanniarachchi *et al.* (2002) reported that the contribution of K in seepage and interflow waters from the adjacent highland involved to depress the iron toxicity problem in rice.

Effect of K on disease incidences of rice

Incidence of narrow brown leaf spot (NBLS) disease in rice and its resistance level to NBLS under different levels of K application averaged over 2 seasons are presented in Table 9 (Dissanayaka and Wickramasinghe, 1999). These results do not indicate any effect of K levels on NBLS incidence. It appears that the soil had an adequate level of K available for the plants. It is generally believed that K helps to reduce plant disease incidence, hence, it has been recommended to apply higher rates of K as a control measure against blast disease (Ou, 1985). With brown spot disease, even at higher rates of K, the disease severity was reduced only when Mn and Zn were available in adequate amounts. Therefore, it may be concluded that NBLS disease cannot be managed by manipulating of soil K levels, as is done with respect to most other plant diseases (Dissanayaka and Wickramasinghe, 1999).

Table 9. Disease reaction and incidence of narrow brown leaf spot disease in rice (Bg 379-2) at different levels of K (the average over 2 seasons at Rice Research and Development Institute, Batalagoda)

K level, kg K_2O ha^{-1}	Disease reaction*	Disease severity (No. of lesions per flag leaf)
0	S	43.42 a
20 (basal)	S	43.82 a
20 (at 8 weeks after transplanting)	S	47.19 a
40 (basal)	S	50.55 a
20 (basal) + 20 (at 8 WAT)	S	52.27 a

* Standard Evaluation System for rice introduced by IRRI.
Values followed by the same letter in a column are not significantly different at 0.05 level.

Potassium status in soils of different agro-ecological zones

In the up country intermediate zone, where intensive rice and vegetable cropping system is prevailed, high exchangeable soil K has been reported due to higher rates of K fertilizer use to vegetable crops (Wijewardana, 1999). Red Yellow Podzolic soils in these cropping systems contain 97-390 mg kg^{-1} of exchangeable K that is more than the critical level needed for rice plant growth. Similar results have been reported for IBL soil of mid country intermediate zone (Joseph *et al.,* 1992). Wijewardana *et al*., (1998) also reported that 48% of soils of low country wet zone contain exchangeable K below 78 mg kg^{-1}, while remaining soils have more than 78 mg kg^{-1} exchangeable soil K and do not respond to K application.

Recent soil analytical data for NCB, RBE, LHG, IBL and RYP soils from low country dry and intermediate zones have shown that the exchangeable K content in most of these soils is low and is depleted, while the non-exchangeable K content is in sufficient range (D.B. Wickramasinghe *et al.,* 2002, Unpubl.) However, IBL soil that has high exchangeable K content gave higher rice yield compared to other soils. It has been also reported that application of K up to 150 kg K_2O ha^{-1} has not significantly affected on the grain yield of rice in any of these soils. However, grain yield was significantly affected by different soil types indicating that the K controlling ability of these soils are greatly influenced by their own physical and chemical characteristics, rather than applied K. They further reported that K content in tissue and K uptake by plants at all levels of applied K were highest in IBL soil which had highest initial exchangeable and extractable K. Reddish Brown Earth soil, which is the largest rice growing soil in Sri Lanka, had the rice plants with highest tissue K content, but had low K uptake. Addition of K increased the tissue K and the K uptake by plants in all the soils. After crop harvest, exchangeable K content, remaining in the soils, was below the critical levels, showing depletion of soil exchangeable K after cropping. A negative K balance was recorded in all the soils in spite of high rate of K application (150 kg K_2O ha^{-1}). The highest negative K balance was observed in IBL soil, which has the highest content of exchangeable and non- exchangeable K, while RBE, RBL and LHG soils exhibited a comparatively low negative K balance, especially with K application. The K uptake by plants was relatively low in these soils as compared to IBL soil. The lower K uptake may be due to non-availability of applied K, possibly due to K fixation.

Low Humic Gley soil of low country intermediate zone with 55 mg kg^{-1} of exchangeable K showed a significant yield increase (14%) by application of 75 kg K_2O ha^{-1} when all the other nutrient deficiencies and nutrient balances were corrected (W.M.J. Bandara *et al.*, 2001, Unpubl.). In these conditions, even application of 150 kg K_2O ha^{-1} increased the yield indicating that the present requirement in K fertilizer on this soil is in between 75 and 150 kg K_2O ha^{-1} (W.M.J. Bandara *et al.*, 2001, Unpubl.).

Changes in K fertilizer recommendations for rice in Sri Lanka

In order to assist rice farmers in achieving higher yields, the Department of Agriculture from time to time provides fertilizer recommendations, depending on the available research information on the response of rice to fertilizers. The first fertilizer recommendations for rice were formulated in 1950. Since then, the recommendations were altered in 1956, 1959, 1964, 1967, 1971, 1980, 1990, 1996, 1998 and 2000 (Table 10).

A tentative K fertilizer recommendation was first given in 1950. There were separate fertilizer mixtures for the dry zone (no K), the low country wet zone (10.3-12.4 kg K_2O ha^{-1}) and the sandy soils of Northern and Eastern provinces (7.0-8.4

kg K_2O ha^{-1}) only in single application as basal. Although there were changes in N and P rates in fertilizer recommendations in 1956 and 1959, K rates remained the same as in 1950.

Table 10. Levels of major nutrients recommended from 1950 to 2000 (Nagarajah, 1986)

Year	Number of formulations	N	P_2O_5	K_2O
		-------------------------	kg ha^{-1}	-------------------------
1950	3	10-20	16-23	8-10
1956	3	34-48	30-40	28-56
1959	10	12-51	17-53	15-31
1964	28	21-57	17-51	18-56
1967	13	43-57	34-84	18-56
1971	31	35-108	19-74	12-56
1980	19	30-108	36-55	30-68
1990	13	30-120	30-50	28-50
1996	9	45-120	10-30	10-30
2000	8	57-140	28-50	37-67

During the period 1962-1964, the all-island fertility survey of the rice soils was conducted (Panabokke and Nagarajah, 1964). Based on the results of this survey, trials in cultivator's field and experiments in research stations and farms, a new set of fertilizer recommendation was developed separately for each district on the basis of Divisional Revenue Office. Potassium fertilizer was recommended as a basal application, but for fertilizer responsive varieties in certain cases, additional K dose was suggested at two weeks before heading. Up to 1971, this recommendation remained the same.

In 1971, 31 different fertilizer formulations were introduced for different agro-climatic zones, rice varieties, age classes and yield expectations. There were 3 basal mixtures called V1, V2 and V3, containing respectively 13%, 13% and 10% K_2O. V1 was recommended for dry zone, V2 for wet zone and V3 for P deficient soils in Kurunegala and Ratnapura districts. A pelleted compound fertilizer containing 15% K_2O was recommended for ill-drained soils of low country wet zone. Three top dressing mixtures TDM_1 (15% K_2O), TDM_2 (20% K_2O) and TDM_3 (30% K_2O) were recommended for application at the primordial initiation stage. TDM_2 and TDM_3 were used in ill-drained soils of low country wet zone.

There were 9 fertilizer formulations for rice in 1996. The revised fertilizer recommendations of 1996 were based on the straight fertilizers and the source of K was muriate of potash. The agro-ecological region, soil textural classes and rice varieties were taken into consideration.

Since then, there have been no new research findings to substantiate any changes to K rates recommended in 1990 and no principal changes have been done. Potassium fertilizer recommendations have been reduced when rice straw is incorporated. For the iron toxic areas of low country wet zone, an additional dose of K has been recommended as a top dressing at primordial initiation of the crop. In 2000, targeted yields in each agro-ecological zone and nutrient removal by crop have been taken into consideration. In the dry zone, for the yield target of 5 t ha^{-1} grain 37.5 kg K_2O ha^{-1} is recommended and for 7 t ha^{-1} grain 52.5 kg K_2O ha^{-1} is suggested. Likewise, minimum and maximum K doses are respectively 37.5 and 52.5 kg K_2O ha^{-1} for rice cultivation in all the agro-ecological zones in the country.
The recent experiment conducted on LHG soils in the low country intermediate zone has indicated that the further addition up to 75 kg K_2O ha^{-1} increases the yield if other nutrients are in optimum and balanced levels in the soil (W.M.J. Bandara *et al*, 2001, Unpubl.).

Estimated K fertilizer requirement of rice in Sri Lanka

The estimated requirement in potash fertilizers for the rice cultivation in Sri Lanka is 54.7 thousand tonnes of K or 65.9 thousand tonnes of K_2O or 109.9 thousand tonnes of muriate of potash (MOP) when considering the average yield levels in all the agro-ecological zones and crop removal at the rate of 17 kg K t^{-1} of grain yield (Table 11). If the efficiency of K utilization from fertilizers is 70%, 157.0 thousand tonnes of MOP should be applied to rice in Sri Lanka. However, the total requirement in MOP per year for the whole area of rice cultivation will be 51.7 thousand tonnes when the minimum recommended level of 62.5 kg MOP ha^{-1} is considered. But the maximum level of MOP application per year has been achieved as 25.1 thousand tonnes. So, there is a deficit in K application for the rice culture in Sri Lanka. When crop removal is concerned, there is a very big deficit in MOP application to the rice crop.

Conclusions

Generally, rice soils in Sri Lanka do not respond to K fertilizer application and a significant response to K use has been observed only in less than 5% of the experiments conducted over a period of 30 years. This suggests that potassium is sufficiently available in the majority of low land rice soils. Sites that showed significant K response are located in the area of acidic mineral/alluvial and organic soils of low country wet zone of Sri Lanka. In addition to the indicated soils, a response may be expected on light textured sandy soils of other zones.
Though there appeared to be a positive relationship between the content of exchangeable K and the initial productivity of well-drained RBE soil, addition of K

to these soils with low exchangeable K content did not improve their productivity. In poorly drained LHG soils the above-mentioned relationship has been proved to be negative.

Table 11. Estimated annual K requirement for the rice cultivation in Sri Lanka

Agro-ecological zone	Area, '000 ha	Production		K requirement, '000 t
		Per unit area, t ha^{-1}	Total, '000 t	
LCDZ	466.7	4.19	1,956	33.2
LCIZ	187.5	3.78	709	12.0
UCIZ	3.0	3.73	11	0.2
LCWZ	146.5	3.20	469	8.0
UCWZ	2.2	3.61	8	0.1
MCIZ	3.2	3.65	12	0.2
MCWZ	18.0	3.19	57	1.0
Total	827.1		3,222	54.7

LCDZ – Low Country Dry Zone,
LCIZ - Low Country Intermediate Zone,
UCIZ – Up Country Intermediate Zone,
LCWZ – Low Country Wet Zone,
UCWZ – Up Country Wet Zone,
MCIZ – Mid Country Intermediate Zone,
MCWZ – Mid Country Wet Zone.

The response to K rarely observed in rice despite the location of trial sites in widely different soils, agro-ecological regions and climatic conditions, highlights the need to investigate the dynamics of K availability in relation to characteristics of micro-environments. Also, a comprehensive study on K transformation from uplands to lowlands through water streams and irrigation systems would be of considerable interest.

Nevertheless, to maintain soil fertility levels for sustainable crop production, it seems prudent to apply a maintenance dose of K in certain environments. Further investigations are needed to study the contribution of various sources of K, e.g. weathering of K-containing minerals, recycling of crop residues, transfers from upland and supply from irrigation water to K availability in soils. In addition, other soil fertility limiting factors in relation to K response in soils with low available K must be thoroughly studied.

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Potassium fertilization of Other Field Crops

D.M. Jinadasa and K.J. Perera

Field Crops Research and Development Institute, Maha Illuppallama, Sri Lanka

Introduction

The Other Field Crops (OFC), which include annuals of condiments, coarse grains, grain legumes and oil crops, play an important role in Sri Lankan economy contributing about Rs. 4 billion to the country gross domestic product every year. However, in recent past this sector showed a marked decline mainly due to the liberalization of imports. Cost of production of these crops is very low in other countries in the region compared to Sri Lanka, and Sri Lankan farmer cannot compete with the price of imported products. This has resulted in declining the cultivated extents and production (Table 1).

Table 1. Extent and production of OFC in 1996 and 2001

Crop	1996		2001	
	Area, ha	Production, t	Area, ha	Production, t
Chilli	26,098	18,400	17,410	12,300
Onions	12,809	86,454	10,333	84,594
Maize	30,895	32,963	25,888	29,100
Finger millet	6,129	3,906	5,655	4,212
Cow pea	18,884	16,997	12,121	10,072
Green gram	18,261	16,585	11,208	9,874
Ground nut	8,793	5,120	9,983	6,765
Sesame	7,567	3,817	6,911	4,073

One of the alternatives, which could be helpful to overcome this problem, is to bring down the cost of production by increasing yields with introduction of new technology. In this regard balance fertilizer application has to play a major role. However, in a par with the extent of cultivation fertilizer use to OFC has also gone down in the recent past as indicated in Table 2.

Table 2. Fertilizer consumption by OFC in the period from 1996 to 2001

Year	Total amount used in the country, tonnes	Amount used by OFC	
		tonnes	%
1996	524,040	54,974	10
1997	508,449	48,592	10
1998	561,352	44,182	8
1999	616,335	42,617	7
2000	597,507	34,320	6

Nutrient removal by Other Field Crops

Table 3 shows nitrogen and potassium removal by OFC. Maize, which is a major crop, based on the cultivated area, removes up to 155 kg K ha^{-1}. Potassium uptake by chilli, the second major crop, reaches 64 kg K ha^{-1}. Thus, potash fertilizer use to OFC should be considered as highly importance.

Table 3. Removal of nitrogen and potassium by Other Field Crops (Amarasiri and Perera, 1975)

Crop	Yield, t ha^{-1}	N	K
		---------------------- kg ha^{-1}	----------------------
Chilli	2.0	64	64
Maize	4.0	118	155
Sorghum	4.0	101	108
Cowpea	1.5	60	36
Green-gram	1.2	54	26
Groundnut	1.8	101	34
Sesame	1.0	51	36

Response of chilli and onions to K

Chilli

Chilli is a cash crop grown in Sri Lanka and is used as a condiment in the daily diet. K.A. Renuka *et al.* (2000, Unpubl.) and P. Weerasinghe (2000, Unpubl.) did not observe the significant response of chilli to potash fertilizer application both at Maha

Illupallama and Angunakolapelessa (Table 4). High content of exchangeable K in soils of experimental areas explains these observations.

Table 4. Effect of K on chilli yield at Maha Illuppallama and Angunakolapelessa

K_2O, kg ha^{-1}	Yield, t ha^{-1}		
	Maha Illupallama	Angunakolapelessa	
	Yala 2000	Maha 2000/01	Yala 2000
0	2.65	2.89	0.85
40	2.50	3.21	0.92
60	2.32	3.44	0.93
75	2.34	3.23	1.08
90	2.81	2.75	0.91
$LSD_{0.05}$	ns	ns	ns
CV, %	17	13	27
Exchangeable K, cmol kg^{-1}	0.67	0.61	0.61

However, Anonn (1986) reported positive response of chilli to added potassium in Reddish Brawn Earth (RBE) soils in farmer's fields at Kalawewa (Table 5).

Table 5. Effect of K on chilli yield at Kalawewa

K_2O, kg ha^{-1}	Yield	
	t ha^{-1}	%
0	2.34	100
40	3.17	135
80	3.68	157
$LSD_{0.05}$	1.08	
CV, %	23	

Onions

Compared to chilli, few studies have been reported with potassium response of onions. In a study conducted by Thenabadu *et al.* (1975) in the wet zone with shallot onion there have been observed no response to added potassium. The data reported by Rezania (1993) for a study conducted at the dry zone also show no response to added potassium (Table 6).

Table 6. Effect of K on onion yield in the dry zone

K_2O, kg ha^{-1}	Yield, t ha^{-1}			
	Maha Illuppallama		Bulnewa	Dambulla
	Maha 89/90	Yala 90	Yala 90	Yala 90
0	11.5	22.8	16.6	17.4
50	10.1	21.2	15.7	18.4
100	10.4	22.1	15.8	18.7
$LSD_{0.05}$	ns	ns	ns	ns
CV, %	21	8	11	9
Exchangeable K, cmol kg^{-1}	0.62	0.63	0.40	-

However, Anonn (1983) observed a response of onion to added potassium at a number of locations (Table 7).

Table 7. Effect of K on onion yield at different locations

K_2O, kg ha^{-1}	Yield, t ha^{-1}		
	Mulative	Vavunia	Kalawewa
0	13.31	15.81	2.45
40	12.70	17.91	3.17
80	16.22	18.97	3.68
$LSD_{0.05}$	1.81	1.96	1.08
CV, %	14	12	23

The study conducted in the Field Crop Research and Development Institute of Sri Lanka (1991) on the effect of nitrogen and potassium on yield and storability of onion revealed that potassium or potassium-nitrogen interaction was not significant, even though nitrogen gave a significant yield increase. In this experiment the author further observed that there was no significant effect of potassium levels applied on the storability of onion (Table 8).

In another study conducted at Maha Illuppallama (D.M. Jinadasa *et al.*, 2002, Unpubl.) showed that there was no response of onion to added potassium (Table 9).

Table 8. Effect of K on yield and storability of big onion

K_2O, kg ha^{-1}	Yield, t ha^{-1}	Storage losses for a 6 month period, %			
		Rotting	Sprouting	Driage	Total
0	17.7	5	29	28	62
50	17.6	3	32	31	66
100	17.9	6	32	29	67

Table 9. Effect of different K rates on yield of big onion at Maha Illuppallama

K_2O, kg ha^{-1}	Yield, t ha^{-1}	
	Yala 2001	Yala 2002
0	31.4	44.5
27.5	29.6	41.3
45.0	30.1	43.8
67.5	28.1	39.8
90.0	34.3	43.6
112.5	32.6	40.0
45.0 + OM	29.0	40.1
$LSD_{0.05}$	ns	ns
CV, %	12	12

Response of coarse grains to K

Crops come under this commodity group are maize, sorghum and millet. Cultivation of these crops is confined to the dry zone and certain parts of the intermediate zone. These crops are also grown under supplementary irrigated and rainfed conditions. Recently, these crops have been introduced into rice-OFC cropping systems.

Earlier, farmers did not use chemical fertilizers for these crops probably due to low income. However, with the introduction of hybrids farmers now started to use fertilizers.

Hindagala *et al.* (1971) have conducted fertilizer experiments with maize at Maha Illuppallama and Bibile with fertilizer K rates up to 60 kg K_2O ha^{-1}. According to their results, there was no significant response to added potassium at either location (Table 10).

Table 10. Effect of K on maize yield in the dry zone

K_2O, kg ha^{-1}	Yield, t ha^{-1}	
	Maha Illuppalma	Bibile
0	2.26	2.03
30	2.26	1.99
60	2.24	1.97
$LSD_{0.05}$	ns	ns
Exchangeable K, cmol kg^{-1}	0.25	0.36

P. Weerasinghe (1987, Unpubl.) also reported no response to potassium on the same soil group at Aralagnwila. The exchangeable potassium content in these soils was in a range from 0.13 to 0.41 cmol kg^{-1}.

However, Anonn (1986) conducted 144 trials and reported yield increase of 11.7 kg per 1 kg of potassium fertilizer on RBE soil.

D.M. Jinadasa *et al.* (2002, Unpubl.) conducted a study to investigate the response of hybrid maize to potassium. Even though they observed high yields in the experiment they failed to observe the significant response to added potassium (Table 11).

Table 11. Response of hybrid and open pollinated maize (OPV) to K at Maha Illuppallama

K_2O, kg ha^{-1}	Yield, t ha^{-1}			
	Maha 2000/01		Maha 2001/02	
	Hybrid	OPV	Hybrid	OPV
0	5.40	4.10	7.07	5.13
12.5	5.36	4.47	6.88	4.93
25	5.42	3.97	7.12	5.19
37.5	5.24	4.37	6.83	5.45
50	5.14	4.22	7.21	5.27
62.5	5.51	4.10	7.18	5.38
$LSD_{0.05}$	ns	ns	ns	ns
CV, %	10	11	6	6

Fertilizer studies with other coarse grains are limited when compared to maize. An experiment conducted by Ranaweera Banda (2003, Unpubl.) found that the significant response of finger millet to added potassium upto 30 kg K_2O ha^{-1} (Table 12).

Table 12. Effect of K on finger millet yield in a rice finger millet cropping system

K_2O, kg ha^{-1}	Yield, t ha^{-1}
0	1.88
30	2.38
60	2.07
90	2.12
$LSD_{0.05}$	0.17
CV, %	6

Response of gram legumes to K

Mungbean, black gram, cowpea, soybean and pigeon pea are the important grain legumes grown in the dry zone and in the drier parts of the intermediate zone as rainfed or supplementary irrigated crops on Reddish Brown Earth, Non-Calcic Brown, Latosol and Regosol soils. Compared to chilli, onion and maize, few studies have been reported on potassium response of grain legumes.

Sabesen and Sathananda (1986) conducted a study on sandy Regosol soil with soybean at a site with high soil exchangeable potassium of 0.76 cmol kg^{-1}. They reported no response to added potassium. However, Anonn (1986) reported a response to added potassium with cowpea and mungbean in adaptability testing trials (Table 13).

Dissanayake *et al.*, (1993) also observed response of these crops to added potassium in technology verification trials.

Response of oil crops to K

Groundnut, sesame, sunflower and mustard come under this commodity group. Similar to legumes, potassium response studies with these crops are also limited. P. Weerasinghe (1987, Unpubl.) reported a positive response of groundnut to potassium on NCB soils (Table 14).

Table 13. Effect of potassium on the yield of mungbean and cowpea

K_2O, kg ha^{-1}	Yield, t ha^{-1}		
	Mungbean		Cowpea
	Anuradapura	Kurunegala	Kurunegala
0	0.80	-	0.92
40	1.01	0.43	0.99
80	1.06	0.35	1.17
$LSD_{0.05}$	0.23	0.39	0.20
CV, %	21	38	22
No. of locations	6	6	10

Table 14. Effect of K on the yield of groundnut

K_2O, kg ha^{-1}	Yield, t ha^{-1}		
	Maha 1997/98	Yala 1998	Maha 1998/99
0	3.66	2.25	1.96
20	3.68	2.47	2.27
40	3.79	1.86	2.17
60	3.67	2.25	2.10
80	3.87	2.35	2.18
$LSD_{0.05}$	ns	ns	ns
CV, %	11	15	11
Exchangeable K, cmol kg^{-1}	0.50	0.52	0.26

Reasons for poor response of Other Field Crops to K

The main reason for the poor response of OFC to added potassium is, perhaps, the high content of exchangeable potassium in the soil. This has been highlighted even in very early studies conducted on soil potassium status of the areas where OFC are grown. According to Ponnamperuma (1952), the average content of exchangeable potassium in soils of the dry zone is 0.55 cmol kg^{-1}. In this research the author has stated that these soils are not likely to show any response to potash fertilizer even under the most K-demanding crops.

Most of OFC growing soils were formed from parent materials rich in feldspars and micas. In addition, these soils contain smectite type clay minerals, which easily release non-exchangeable K (Herath, 1962; P. Weerasinghe and G. Keerthisinghe, 1985, Unpubl.). Therefore, the release of non-exchangeable potassium is very rapidin these soils. According to P. Weerasinghe and G. Keerthisinghe (1985, Unpubl.) the release of potassium from the non-exchangeable pool in rice grown RBE soils is about 500 mg kg^{-1} per crop. These soils are found in the upper catena of the rice tracts where farmers practice rice-OFC cropping systems. The other reason for the low response of OFC to added potassium is the contribution of K from the irrigation water. According to Amerasiri (1973), one acre feet of irrigation water may supply about 20 kg of K.

Potash fertilizer recommendations and farmer practices

Though it has been shown that OFC were poorly responded to added potassium, the Department of Agriculture recommends potash fertilizers for all OFC to avoid any deficiency or soil depletion with continuous cropping (Table 15).

Table 15. Present NPK recommendation for Other Field Crops

Crop		N	P_2O_5	K_2O
		------------------------- kg ha^{-1}	-------------------------	
Chilli	Rainfed	120	45	60
	Irrigated	150	45	60
Onions		90	45	45
Maize	Rainfed	100	45	30
	Irrigated	150	45	30
Sorghum		70	45	30
Millet		60	20	30
Grain legumes		30	45	45
Sesame		50	55	30
Sunflower		70	20	30

Potash fertilizer is added mainly as a basal application for OFC. Top dressings are practiced only with chilli and onions. However, most of the farmers very rarely apply potash fertilizer as they cultivate these crops under highly risk rainfed conditions. Farmers who cultivate them under irrigated conditions generally practice the Department of Agriculture recommendation.

Conclusion

According to the reported results, response of Other Field Crops to added potassium is very rare. This is mainly due to high availability of potassium in soils and its contribution from the irrigation water. In addition, crop residue incorporation also plays an important role as high amount of potassium is returned to the soil compared to other nutrients. Therefore, taking into consideration all the above-mentioned reasons, it is very important to know the balance of potassium on the long-term basis for cropping systems with OFC. Rice-OFC cropping system is more important in this regard as this system undergoes flooded conditions with the rice crop and considerable amounts of potassium are added with the stubble and the irrigation water. Additionally, the information on mineralogical aspects of soils is very important to understand the behaviour of potassium in the soil.

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Potash fertilization of fruit crops in Sri Lanka

J.M.P.B. Jayasundara

Horticulture Research & Development Institute, Gannoruwa, Peradeniya, Sri Lanka

Abstract

In Sri Lanka, most fruit crops are grown in home gardens under rainfed conditions. Few commercial growers have their fruit orchards as a mono-crop system under irrigated conditions. Some growers have established fruit crops under mixed cropping systems with rubber and coconut plantations. In the recent past, the local and the export market potential for fruits has increased considerably, particularly for banana, mango, pineapple, mangoosteen, rambutan and papaya. The extent of cultivation, national production and foreign exchange generated from fruit crops have increased accordingly during the last decade. However, the declining trend in average yields of some fruit crops is observed. This is often attributed to poor nutrient management practices due to higher fertilizer cost currently prevailing in the country. Chemical fertilizer application to fruit crops in home garden cultivations is scarce and nutrition of fruit crops entirely depends on soil nutrient supply, kitchen wastes, organic manure etc. Market oriented growers use chemical fertilizer mixtures, but unsystematically. However, the use of potash fertilizer is almost comparable with the total use of N and P fertilizers and a drastic improvement is necessary. Research studies on nutrient management in fruit crops are limited in the country. Nevertheless, the recent studies have revealed that most of the fruit crops well respond to added K fertilizers on long-term basis with the improvement of their yield and quality parameters. Major fruit crops such as pineapple, rambutan, papaya and banana respond well to added K fertilizers on soils with low exchangeable K content. Early maturity, higher yields and improved quality of fruits have been observed due to potash application along with better returns. The integrated use of cattle or poultry manure with K fertilizers exhibited significant effect on quantity and quality parameters of fruit crops with increasing K fertilizer efficiency. Fertilizer recommendations currently available for fruit crops are mainly based on foreign information. Higher rates of K compared to N and P are recommended for most fruit crops at vegetative and bearing stages. These recommendations are to be applied for highly variable soil and climatic conditions prevailing in Sri Lanka. However, most fruit growers do not follow the recommendations due to many reasons. In order to improve current nutrient management practice for fruit crops, fertilizer recommendations based on local research information should be developed. The regionalized recommendations may be more effective. In addition,

the introduction of leaf nutrient guides will enhance the reliability, quickness and efficiency of such recommendations.

Introduction

In Sri Lanka, the market demand for fruit crops has increased in the recent past due to increased income, urbanization, export demand and health and nutritional awareness. Major fruit crops such as banana, papaya, pineapple, mangoosteen, passion fruit, citrus, rambutan and mango, which were grown in home garden level, are gradually moved towards commercial scale cultivation. The most important impediment for the expansion of commercial fruit cultivation in Sri Lanka is shortage of quality planting materials and proper nutrient management packages.

Growing of fruit crops in Sri Lanka

Extent of fruit cultivation

In Sri Lanka, fruit crops are being currently cultivated on about 160,000 hectares, which are mainly restricted to home garden scale. The total extent under fruit crops has increased significantly and has almost doubled during the last decade (Fig. 1). The extent of cultivation of different fruit crops is illustrated in Fig. 2. The extents under banana, cashew and mango have increased considerably during the last decade. Extents under other fruit crops have also increased gradually. Banana is the major fruit crop grown in all parts of the island and it accounts for about 33% of the total extent under fruit crops.

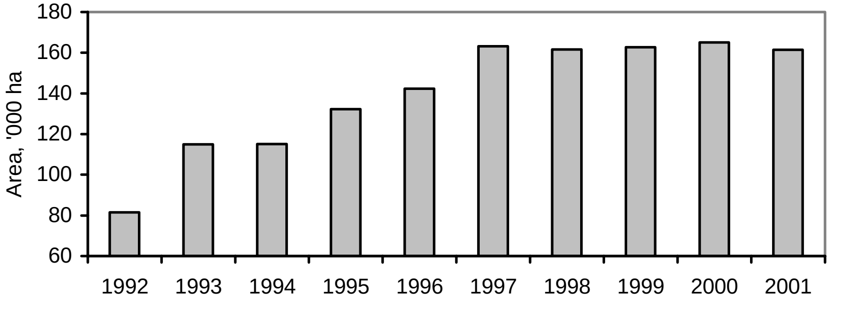

Fig. 1. Changes in total extent under fruit crops during the last decade (Department of Census and Statistics, 2002)

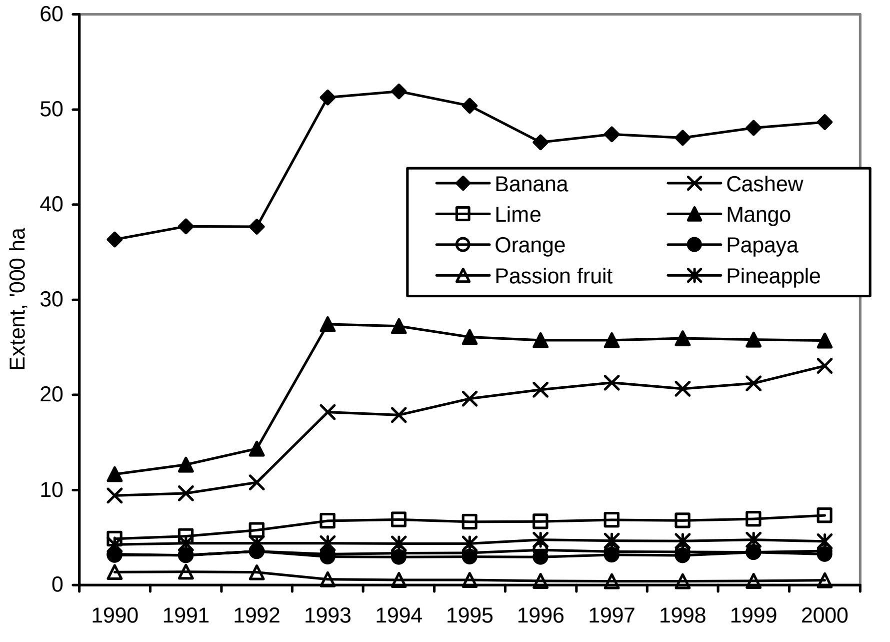

Fig. 2. Changes in extent under major fruit crops during the last decade (Department of Census and Statistics, 2002)

National fruit yields

Average yields of most fruit crops have decreased considerably during the last decade (Fig. 3) and several reasons have been attributed for this trend. Lack of quality planting materials, unawareness of nutrient management systems, increasing trend in fertilizer prices, high labour costs, planting of cultivars in unsuitable agro-ecological regions, unavailability of proper irrigation systems and incidence of pests and diseases at flowering and bearing stages are major constrains for obtaining higher crop yield. The potential and the average fruit yields of selected fruit crops in Sri Lanka are illustrated in Table 1. The yield gap between the potential and the average yields of the most fruit crops reflects the facts, which should be considered for the future research.

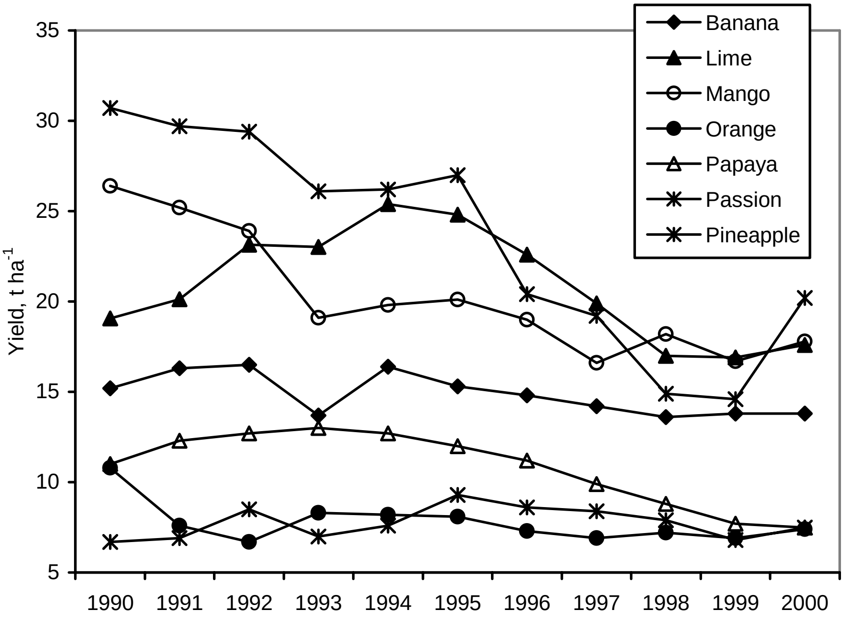

Fig 3. Average yield of some selected fruit crops during the last decade (Department of Agriculture, 2002, Unpubl.)

Table 1. Average and potential yield of selected fruit crops (Food Task Force, 1992)

Crop	Yield, t ha^{-1} year^{-1}	
	Potential	Average
Banana	45	30
Butter fruit	35	25
Grapes	10	6
Mango	30	20
Orange	20	15
Pineapple	14	10
Papaya	30	22
Passion fruit	12	9
Rambutan	20	12

Major growing areas of fruit crops

The distribution of fruit crops in major ecological zones of the country is illustrated in Table 2. Most fruit crops are grown in Dry and Wet zones of the country. Crops such as pineapple, banana, mango, rambutan and papaya are grown mainly in the Gampaha and Kurunegala districts. On the other hand, banana and passion fruit are grown in throughout the country.

Table 2. Distribution of fruit crops in different Agro-ecological zones of Sri Lanka (Food Task Force, 1992)

Zone	Rainfall, mm	Fruit crop
Dry	600-1000	Banana, passion fruit, papaya, mango, wood apple, pomegranate, melon, citrus, guava, grapes
Low Country Intermediate	1000-1200	Banana, passion fruit, citrus, pineapple, papaya, wood apple
Upcountry Intermediate	1200-2300	Banana, passion fruit, pineapple, papaya, strawberry, pears, apple
Wet	1500-3300	Banana, passion fruit, citrus, pineapple, mangoosteen, papaya, mango, rambutan, durian, avocado

There is a very high potential for fruit crops in the dry zone than in the other zones of Sri Lanka. Availability of arable lands with fertile-deep soil, prevailing of optimum air temperature, appropriate long spells of solar radiation and the availability of comparatively cheap labour are advantageous for the cultivation of tropical fruit crops in the dry zone of Sri Lanka. However, rainfall pattern prevailing in this region is a major constrain for satisfactorily growing some of the moisture sensitive fruit crops unless efficient irrigation techniques are adopted.

Cropping systems

Less than 5% of the existing extent of fruit cultivation is on orchard scale under proper management (Department of Census and Statistics, 2002). The rest is on home garden scale where not much attention is paid. The high input fruit orchards that have been recently established with crops such as banana, papaya and rambutan are less than 5 ha in extent under drip, supplementary irrigation or fertigation techniques (H.M.S. Heenkenda, Personal communication). Most of these orchards are established as monocrop systems and few have been established under rubber and coconut plantations as intercropping systems. Most fruit crops grown under coconut are mixed crops with pineapple, banana and citrus, whereas under rubber the major fruit crop is banana.

Nutrient management in major fruit crops

The physiology and nutrition of fruit crops are different from annual crops in many aspects. Some of them are:

- Long vegetative phase with alternative bearing
- High biomass production
- Low proportion of economical yield to the total biomass, e.g.

Banana:	5-10%
Papaya:	4-6%
Passion fruit:	5-10%
Pineapple:	50-60%

- Large canopy with its annual new flush
- Yield is sensitive to weather, climate and nutrients
- Flowering, fruit yield and fruit quality are governed by quantity, type and time of application of macro- and micronutrients (NFS and MOAL, 2000)

Therefore, selection of proper fertilizer materials, appropriate time of application, suitable method of application and correct rates are extremely important to obtain a profitable yield. Efficient nutrient management is essential for obtaining of optimum productivity of any crop. Unfortunately, nutrient management can be considered as one of the most neglected aspects for the majority of fruit crops grown in Sri Lanka. As a result, fruit crop yields are not at optimal levels and are also not consistent. The quality of fruits does not satisfy the export standards. Even the improved varieties provide low quality fruits under neglected nutrient management practices currently adopted by local producers. On the other hand, current nutrient management techniques for the majority of fruit crops are based on foreign research information. Hence, in order to increase the national fruit production, in addition to other factors, due attention should be given to local nutrient management practices of fruit crops.
Except few commercial growers, most small-scale farmers rarely use any fertilizers or organic manure for most fruit crops. Even for market oriented fruit crops, fertilizer usage is not satisfactory due to insufficient knowledge in nutrient management. On the-other hand, fertilizer prices, currently prevailing in the country, are not affordable to the marginal fruit growers. Even application of organic manure for fruit crops is very rare in either commercial or home garden cultivations. Some commercial growers use different types of fertilizer mixtures available in the open market, and apply them in two split applications per year irrespective of the type of crop, soil type and climatic conditions under which they are grown. Some even use coconut and paddy fertilizer mixtures, which are available in the market. Time and

frequency of fertilizer application depend mainly on the rain and on the economic situation of the farmer. However, commercial growers with irrigation facilities, apply chemical fertilizer three times a year. Thus, nutrient management is not systematic, and there is an urgent need to develop efficient fertilizer recommendations based on soil and climatic factors, prevailing in Sri Lanka, for different fruit crops.

Crop response to potassium

Potassium plays many important roles in the nutrition of fruit crops and, being a mobile element, it moves readily towards meristematic tissues. Potassium:

- Is important for many physiological processes such as protein synthesis, cytokinin supply, enzyme activation, etc., therefore, directly influences plant growth rate.
- Regulates the water balance inside the plant through regulatory effect on stomatal movement and, hence, affects growth and yield.
- Is important for photosynthesis and translocation of photosynthetic assimilates and, hence, affects fruit filling, yield and quality of fruits (Bose *et al.,* 1988)

In general, K removal in fruit crops is higher than N and P removal (Table 3). Therefore, potash fertilization is extremely important in order to achieve better growth, yield and quality of fruit crops.

Table 3. Nutrient removal in different fruit crops (Bose *et al.,* 1988)

Crop	Yield, t ha^{-1} $year^{-1}$	Nutrient removal, kg ha^{-1} $year^{-1}$		
		N	P	K
Banana	60	70.0	9.0	242.0
Pineapple	40	43.0	19.5	131.0
Grapes	25	57.6	23.9	135.0
Citrus	38	230.0	54.0	206.0

Since there was limited attention paid to growing and to consuming of fruits until recent past, initiation of systematic research studies on nutrient management for fruit crops have been delayed accordingly. As local and export market demand for fruit crops have increased rapidly during the last decade, research activities in this direction also gradually progressed. As a result, a very few research studies have been conducted on potash fertilization of fruit crops.

Research on potash fertilization of fruit crops

Banana

An investigation of the influence of K fertilizer on growth and yield of banana (cv. Embul) was conducted on Reddish Brown Earth (RBE) soil under irrigated conditions for three crop cycles. The application of K_2O was ranged from 0 to 240 g per clump per application (recommended rate is 150 g per clump per application), N and P_2O_5 were applied according to recommended rates of 110 and 60 g per clump per application, respectively. Results of this experiment showed that:

- Plant height and number of leaves at flowering stage did not respond to added K in all three-crop cycles.
- Addition of K increased the stem girth significantly up to 240 g K_2O rate in ratoon crops.
- Bunch weight increased with K application up to 240 g in ratoon crops (Fig. 4).

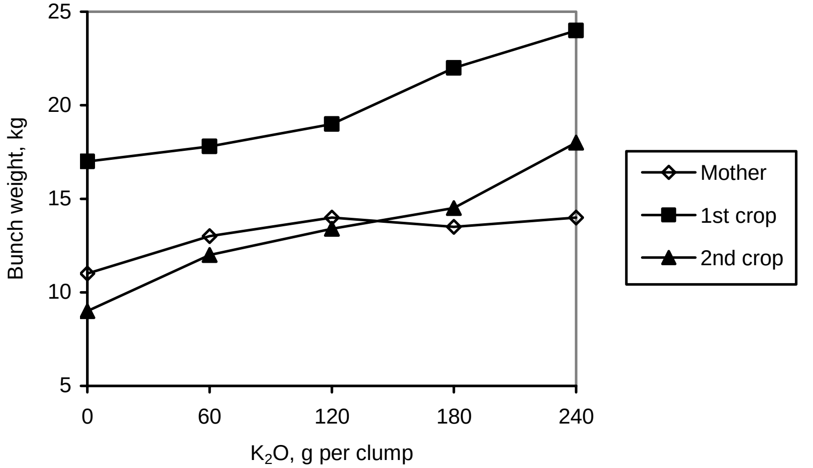

Fig. 4. Effect of K level on bunch weight of 3 crop cycles of banana (Weerasinghe and Premalal, 2002)

The increase in banana yield due to K application was 20% in the mother crop, 36% in the 1st ratoon crop and 85% in the 2nd ratoon crop. This shows the importance of potash fertilizer for banana grown in RBE soils. It has been also apparent that further response to added K fertilizer might be possible. Yield increments correlated with the increase in number of hands per bunch and the number of fingers per bunch (Table 4).

Table 4. Effect of K rates on the number of hands and the number of fingers per bunch (Weerasinghe and Premalal, 2002)

K_2O,	No. of hands per bunch			No. of fingers per bunch		
g clump^{-1}	Mother	Ratoon 1	Ratoon 2	Mother	Ratoon 1	Ratoon 2
0	8.8 a	10.8 b	8.3 c	132.9 b	180.7 b	131.3 c
60	8.8 a	10.8 b	11.0 a	137.3 b	172.5 b	167.7 b
120	8.8 a	10.8 b	10.0 b	160.7 a	183.6 b	148.9 bc
180	9.3 a	11.3 a	10.3 b	151.1 a	204.3 a	174.9 b
240	9.3 a	11.8 a	11.3 a	150.1 a	212.5 a	201.0 a
CV, %	13	18	13	29	32	22

Numbers followed by the same letter are not significantly different at 5% level by DMRT (in this table and hereafter).

Another research was conducted by J.M.P Jayasundera (1998, Unpubl.) to find out the effect of different combinations of P and K fertilizers on growth, yield and fruit quality of banana (cv. Embul) on Reddish Brown Latosolic (RBL) soils under rainfed conditions in Mid Country Wet Zone (MCWZ). Potassium rates were 0, 75, 150 and 300 kg K_2O ha^{-1} per application and P rates were 0, 60 and 120 kg P_2O_5 ha^{-1} per application (recommended rates are 115 kg K_2O ha^{-1} and 45 kg P_2O_5 ha^{-1} per application). Results of this experiment indicated that (Tables 5, 6 and Fig.5):

- Vegetative or yield parameters of the mother crop showed no response to increasing application of either P or K fertilizers.
- However, first ratoon crop responded well to added K fertilizer but not to P fertilizer.
- The highest yield was obtained when P_2O_5 and K_2O were applied at the rates of 60 and 300 kg ha^{-1} per application, respectively.
- The main effect of K on growth and yield parameters was highly significant
- The highest stem girth was observed when K_2O ranged from 150 to 300 kg ha^{-1}.
- No significant yield response to increasing application of K was observed when P was limiting.
- The highest yield was recorded with K_2O applied at 300 kg ha^{-1} per application and further response may be possible.

- Application of K_2O at 300 kg ha^{-1} significantly increased bunch weight (71%) and the number of fingers per bunch (42%) when compared to the zero K treatment.
- Fruit yield was found to be the highest when the ratio between K_2O and P_2O_5 ranged from 5 to 10.

Table 5. Effect of K rates on stem girth and yield parameters of banana

K_2O, kg ha^{-1}	Stem girth, cm	No. of hands per bunch	No. of fingers per bunch	Fruit yield, t ha^{-1}
0	62.2 b	13 a	165 c	11.72 c
75	68.5 b	13 a	182 bc	19.32 b
150	72.3 ab	15 a	205 b	21.64 b
300	85.2 a	14 a	266 a	27.34 a
CV, %	19	13	25	28

Table 6. Effect of different ratios of P and K in fertilizers on yield of banana (J.M.P.B. Jayasundera, 1998, Unpubl.)

$K_2O : P_2O_5$	Fruit yield, t ha^{-1}
0	11.72 c
0.625	19.32 b
1.250	21.64 b
2.500	21.62 b
5.000	27.34 a
10.000	27.32 a
CV, %	32

An experiment was carried out to study the effect of integrated use of organic manure and NPK fertilizer on growth and yield of banana (cv. Kolikuttu) under rainfed conditions in a Red Yellow Podzolic (RYP) soil in the Low Country Intermediate Zone LCIZ) of Sri Lanka. In this study, the recommended dose of NPK fertilizers (N - 55, P_2O_5 - 40, K_2O -150 kg ha^{-1} per application), half and twice the recommended doses were tested with and without organic manure application. The organic manures used were poultry and cattle manure. Results of three crop cycles revealed that:

- Fruit yield declined continuously when NPK fertilizers were cut down by 50% without application of organic manure.
- The highest yield of the mother crop was recorded at the recommended level of NPK and further increase of NPK fertilizers did not show yield increment. However, in the first and the second ratoon crops, yield increased with twice the recommended dose of NPK fertilizers.

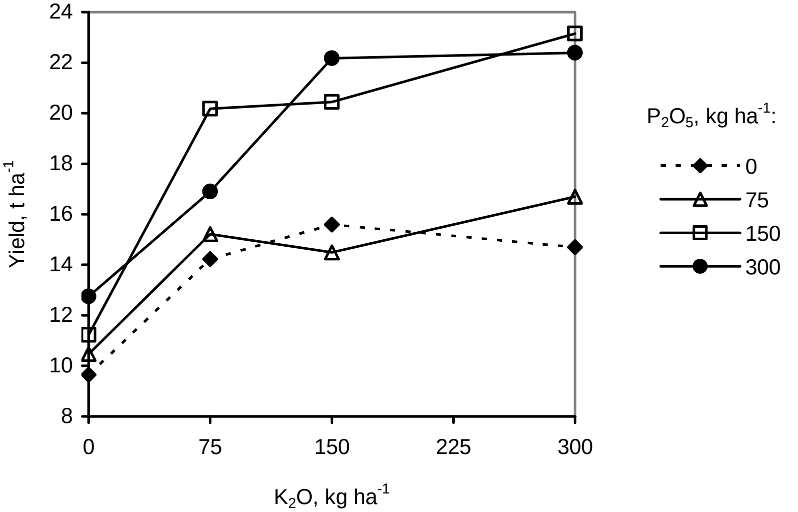

Fig. 5. Effect of K rates on fruit yield of banana at different levels of P

Pineapple

A study was conducted to find out the effect of different ratios of K and Mg fertilizer application on growth and yield of pineapple on RYP soil with soft and hard lateritic soils in Low Country Intermediate Zone of Sri Lanka. Potassium and Mg rates used were 0, 150, 300 and 450 kg K_2O ha^{-1} per application (recommended: 200 kg ha^{-1} per application) and 0, 25 and 50 kg Mg ha^{-1}, respectively. Results of this experiment indicated that (Tables 7 and 8):

- Fruit yield responded up to 300 kg K_2O ha^{-1} even at the mother crop stage.
- Further significant yield increase was observed over 300 kg K_2O ha^{-1} at later stages of the crop. This was found to be prominent at the 3rd and the 4th crop cycles, indicating the importance of K fertilizer application on the long-term basis.

- Most suitable K:Mg ratio in applied fertilizers was recorded as 12 for better performance of pineapple grown under this soil conditions.

Table 7. Effect of potash fertilizer application on pineapple yield

K_2O, kg ha^{-1}	Fruit yield, t ha^{-1}					
	Mother crop	1st crop	2nd crop	3rd crop	4th crop	Total
0	15.3 b	12.5 b	13.5 b	10.8 c	11.6 b	63.7 b
150	18.6 ab	14.6 ab	13.5 b	12.2 bc	10.9 b	69.8 b
300	23.2 a	16.2 a	17.2 a	15.4 b	14.5 ab	86.5 a
450	22.6 a	17.5 a	16.5 a	18.2 a	17.5 a	92.3 a
CV, %	16	23	20	35	29	26

Table 8. Effect of K:Mg ratio on fruit yield of pineapple

K_2O : MgO	Fruit yield, t ha^{-1}					
	Mother crop	1st crop	2nd crop	3rd crop	4th crop	Total
3	24.6 a	23.2 b	28.3 ab	21.6 bc	20.5 c	118.2 bc
6	22.2 a	24.3 ab	26.7 ab	22.5 b	19.4 c	115.1 c
9	21.3 a	26.2 a	28.7 ab	25.4 b	26.4 b	128.0 b
12	22.6 a	28.5 a	31.6 a	38.2 a	37.0 a	157.9 a
18	19.2 a	25.9 a	25.8 b	25.9 b	27.8 b	124.6 b
CV, %	19	21	20	23	19	22

Rambutan

A field experiment was conducted to find out the effect of different rates and split application of K fertilizer on growth and yield of rambutan (six years plantation) on RYP soil in Low Country Intermediate Zone of Sri Lanka. Potassium rates used were 0, 75, 150, 300 and 450 kg K_2O ha^{-1} $year^{-1}$ (recommended rate: 300 kg K_2O ha^{-1} $year^{-1}$). Results of this experiment revealed that:

- Fruit yield responded to K application up to 300 kg K_2O ha^{-1} $year^{-1}$. Yield increase was obtained due to both increase in fruit weight and the number of fruits (Table 9).
- Three split applications of potash fertilizer per year were found to be superior to 1 and 2 split applications per year. Similarly, the highest number of fruits was obtained when K was applied 3 times per year.

However, 100 fruit weight was not influenced by split patterns of K (Jayasundera, 2004).

Table 9. Effect of different rates of K on yield parameters of rambutan

K_2O, kg ha^{-1} $year^{-1}$	No. of fruits per tree per year	100 fruit weight, kg	Fruit yield, kg $tree^{-1}$ $year^{-1}$
0	872 b	2.92 c	34.26 bc
75	786 b	2.98 bc	30.82 c
150	890 b	3.18 b	35.18 bc
300	1193 a	3.86 a	50.02 a
450	936 ab	3.22 ab	41.00 b
CV, %	19	13	23

Fertilizer recommendations for fruit crops

The current fertilizer recommendations for fruit crops in Sri Lanka given by the Department of Agriculture (DOA) are formulated on the basis of research information generated in some Asian countries. The applicability and the efficiency of such recommendations have not been sufficiently tested for some crops under local climatic and soil conditions. Therefore, there is need to develop fertilizer recommendations at least for major fruit crops grown in different agro-climatic regions based on local research information.
Department of Agriculture fertilizer recommendations for some of major fruit crops are given in Table 10. The recommendations indicate dose and time of fertilizer application in three major ecological zones. Except few commercial fruit growers, most small-scale farmers rarely use any fertilizers for fruit crops grown as few isolated fruit trees in their home gardens due to poor economic returns and other factors. Even for market oriented fruit crops, fertilizer use is not systematic due to insufficient knowledge in nutrient management, economic reasons, use of unsuitable fertilizer mixtures available in the local market and application of fertilizers at improper time.

Conclusions

Though DOA has introduced different fertilizer recommendations for various fruit crops on the basis of research data generated in other countries, the validity of these recommendations under local conditions is limited. Therefore, it is necessary to study the nutrient requirements for important fruit crops grown under different soil and environmental conditions in Sri Lanka. Based on these findings, appropriate fertilizer recommendations could be given. The most suitable fertilizer material, appropriate time of application and the method of application should be included in these recommendations. Since, the quality of fruits largely depends on the supply of micronutrient studies should be focused on this direction.

Table 10. Department of Agriculture fertilizer recommendations for important fruit crops

Crop	Time	Amount of fertilizer, g $plant^{-1}$ $application^{-1}$					
		Wet zone			Dry & Intermediate zones		
		N	P_2O_5 (as RP)	K_2O	N	P_2O_5 (as TSP)	K_2O
Citrus	Basal	35	34	15	37	46	27
	Until bearing (2 splits per year)	205	205	96	218	271	124
	Bearing stage	163	190	192	124	285	273
Mango	Basal	53	65	63	74	90	54
	1 year after	53	65	63	74	90	54
	Annual increment until bearing	28	32	33	37	46	27
	Bearing stage	100	91	228	108	74	309
Papaya	Basal	25	22	57	28	18	78
	2 months after planting	25	22	57	28	18	78
	3 month intervals	25	22	57	28	18	78
Banana	2 months after planting	50	45	114	55	37	135
	4 month intervals	50	45	114	55	37	135
Pineapple	1 month after planting	5	3	9			
	3-4 month intervals	5	3	9			
Guava	Basal	53	65	63			
	6 month intervals	27	33	32			
	Bearing stage	324	380	380			

RP – rock phosphate.

Some of the other aspects that need attention include use of locally available fertilizer materials such as Eppawela rock phosphate as a source of P, particularly for fruit crops grown in the wet zone soils. In addition, effect of different sources of organic manure on the efficiency of applied chemical fertilizers for fruit crops is also an important area to be considered. Since micronutrients play an important role to improve the quality of fruits, investigations should be carried out to find out the effect of micronutrients on quality of major fruit crops grown in Sri Lanka. In addition, fertigation techniques and effect of foliar fertilizers on fruit crops should be done, as most of rainfed fruit crops are entirely depend on rainfall for soil moisture requirement. Research activities must determine the effective concentrations of nutrients and the most suitable time of feeding with nutrient solutions through the leaf as flower development depends on the leaf nutrient status at the time of flowering. Based on these findings, nutrient management packages could be introduced.

In addition, well-managed fruit orchards should be set up in each area of the country with the assistance of the extention staff in order to promote fruit cultivation on a larger scale.

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