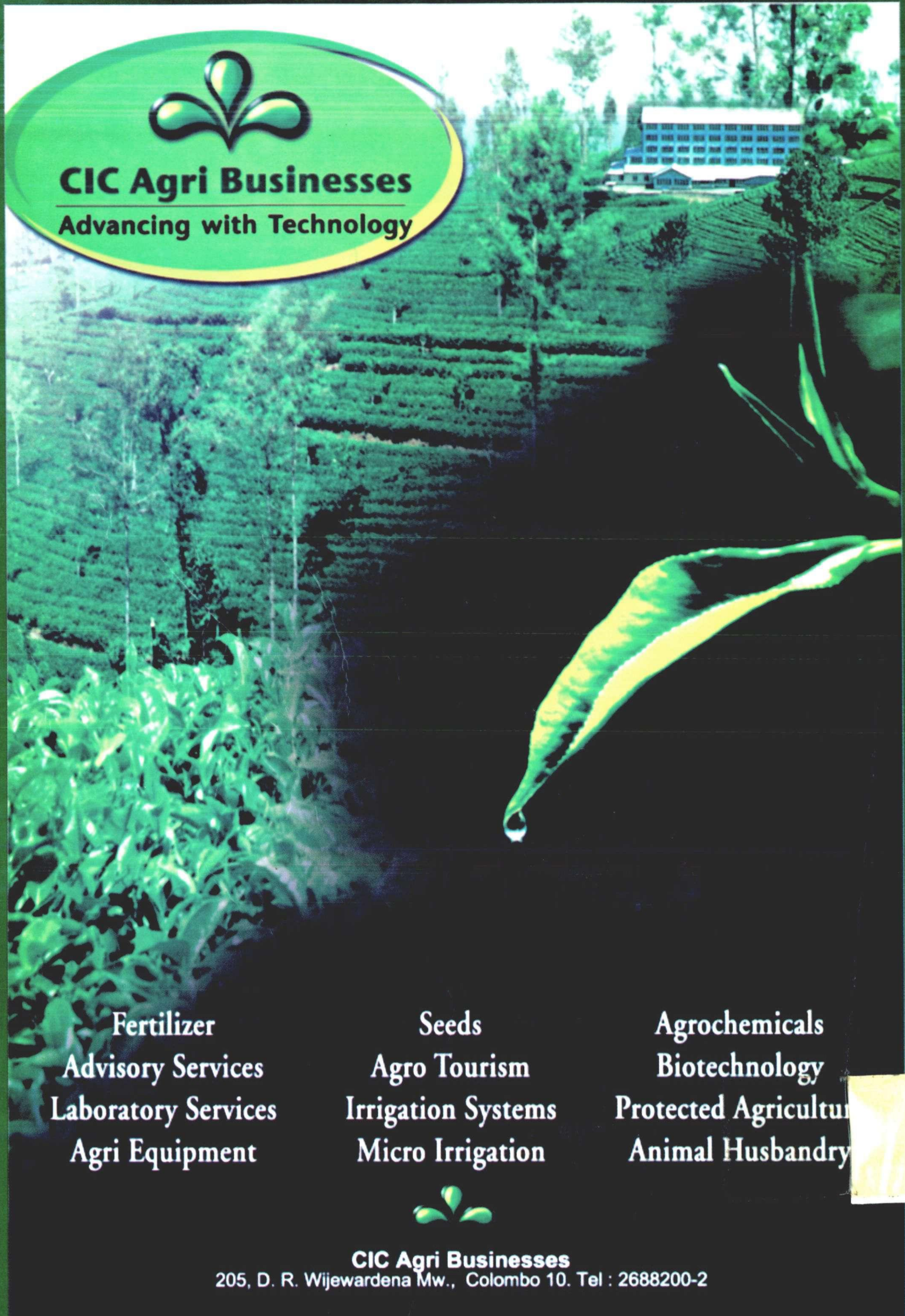


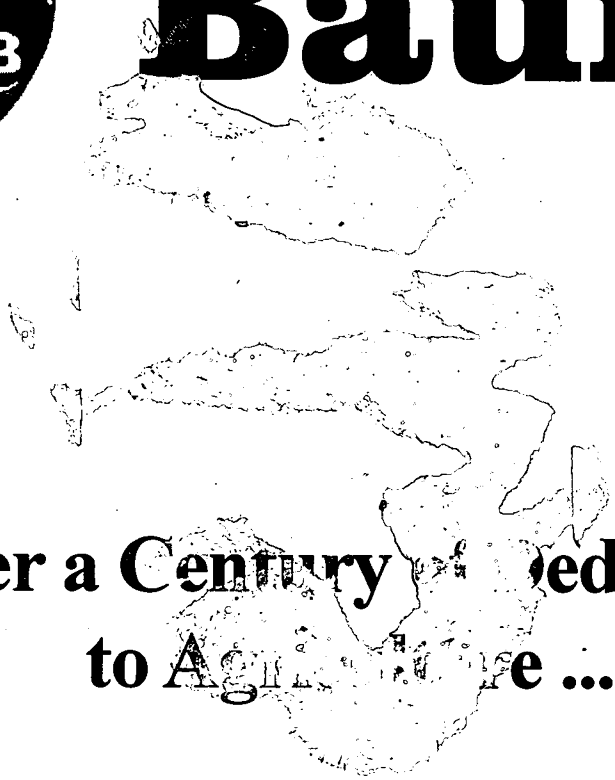
633.072
ZOY

PROCEEDINGS OF THE FIRST SYMPOSIUM ON PLANTATION CROP RESEARCH

TEA RESEARCH INSTITUTE
RUBBER RESEARCH INSTITUTE
COCONUT RESEARCH INSTITUTE

July 8-9, 2004
Bandaranaike Memorial International Conference Hall
Colombo, Sri Lanka

Baurs



Over a Century of Dedication to Agriculture ....

A Baur & Co Ltd.

5, Upper Chatham Street, Colombo 1.
Tel: 2320551-6 Fax: 2448493

PROCEEDINGS OF THE FIRST SYMPOSIUM ON PLANTATION CROP RESEARCH

"Current Trends and Future Challenges"

Jointly Organized by:

The Tea Research Institute of Sri Lanka

Rubber Research Institute of Sri Lanka

Coconut Research Institute

Editors

Dr A K N Zoysa

Dr M T Ziyad Mohamed

July 8-9, 2004

Bandaranaike Memorial International Conference Hall

Colombo 7, Sri Lanka

633.0TR
ZOY

Copyright © 2004, Proceedings of the First Symposium on Plantation Crop Research - Current Trends and Future Challenges.

The Tea Research Institute of Sri Lanka, Talawakelle.

All rights reserved. No part or whole of this publication may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronics, mechanical, photocopying, recording or otherwise, without the prior written permission of the Director, The Tea Research Institute of Sri Lanka, Talawakelle, Sri Lanka.

Published in 2004

ISBN: 955-9023-08-X
Printed in Sri Lanka
at Ceylon Printers Ltd
20, Sir Chittampalam A Gardiner Mawatha
Colombo 2.

The correct citation of these proceedings is

Author(s), 2004. Title of paper. *In* Proceedings of the First Symposium on Plantation Crop Research - Current Trends and Future Challenges. (Eds A K N Zoysa and M T Ziyad Mohamed). The Tea Research Institute of Sri Lanka, Talawakelle, pp.

Organizing Committee

Dr M T Ziyad Mohamed

Dr L M K Tillekeratne

Dr (Ms) C Jayasekara

Dr A K N Zoysa

Dr W M G Seneviratne

Dr C K Jayasinghe

Dr (Ms) C S Ranasinghe

Dr J M D T Everard

Ms K Samaraweera

Secretarial Assistances

Ms R W M W K Illangantilake

Ms A P V Kalyani

Mr N S Ratnapala

Ms A Mannakkara

Mr M Ranatunge

Main Sponsor

CIC Agri Businesses (Pvt) Limited

PREFACE

As the three main plantation crops in Sri Lanka namely Tea, Rubber and Coconut, strive to meet challenges of globalization with the enforcement of world trade organization rules and with free trade agreements between countries, the need for increased productivity, competitiveness and quality management perspectives becomes imperative.

Therefore, it is paramount important that an effective mechanism should be initiated in offering technical expertise and transfer technology by the three research institutes to the stakeholders. It would also be important to expose and train the local scientists in world class production and manufacturing organizations on similar disciplines.

As such, an innovative approach to production from the plantation sector is a prime neccessity for enhancement of productivity. These approaches should address various problems faced by the stakeholders, consultants, policy makers etc. In response to these needs, significant efforts are underway in the Sri Lankan plantation sector towards realization of the economic, social and environmental benefits of plantations. Plantation research institutes are endeavouring towards achieving these goals in a planned manner, through discussions on the management of research and their frequent evaluation.

The first joint symposium organized by the TRI, CRI and RRI is one such effort of this nature, which will undoubtedly help to disseminate research information and share knowledge with the stakeholders on the recent advances in plantation agriculture and processing technology. The objective is to give an opportunity to the scientists and stakeholders of similar interest to interact with each other at a common forum to exchange views, update their knowledge and to identify new research ideas and opportunities for collaboration.

We would earnestly believe that this attempt would undoubtedly help the plantation industries to enhance their contribution to the national economy of the country and wish that these joint efforts by the three institutes would continue in the future too.

Dr A K N Zoysa
Dr W M G Seneviratne
Dr (Ms) C S Ranasinghe

Coordinators/Symposium on Plantation Crop Research

Message of the Hon. Minister of Plantation Industries

It gives me immense pleasure to send this message on the occasion of the first Plantation Crop Symposium in Sri Lanka, jointly organized by the Tea, Rubber, and Coconut Research Institutes. I am happy to note that all three major crop research institutes are pooling their resources and working towards the common goal of eliminating the overlapping of research.

The three major plantation crops namely tea, rubber and coconut are vital to the economy of our country. The total area covered under these plantation crops amount to 777,000 ha, which is 44% of the total agricultural land area in Sri Lanka. These three crops contribute more than Rs. 55 Billion (US$ 730 Million) by way of export earnings annually. The contribution of these three crops to Gross Domestic Product (GDP) is 4.8% and its total contribution to the national economy is much higher than that of the other agricultural exports. In addition to the export earnings, these three crops provide livelihood to more than one million people in this country.

Tea was introduced to our country in 1867 followed by rubber in 1876 as plantation crops. Cultivation of coconut as a plantation crop commenced in 1650's during the Dutch era. Since the introduction of these crops, they have contributed immensely to our economy, one time becoming our biggest foreign exchange earner.

In the intervening years since their introduction, these crops and the related industries have undergone tremendous changes. We have also seen other countries coming in to the market as big producers of these crops. In order to compete we need to keep up with the latest advances in related technology and methods in relation to these industries.

With regard to the production per unit of tea, rubber and coconut, there is much room for improvement in Sri Lanka. We have had to face in the recent past, problems in productivity due to climatic conditions, low fertility, diseases, shortage of suitable land and a low investment rate.

It is obvious that the future of the commercial crops largely depends on value addition. By doing so, we ensure maximum benefits from these crops. Here too, science and technology have an essential role to play.

In the coconut industry, we face the challenge of increasing the productivity of the existing land to meet both the local demand as well as the export market. To do this, we need to develop high yielding plants that are suitable to our conditions. Our research scientists should give the leadership to our efforts to advance and modernise our commercial crops. I therefore urge, the tea, rubber and coconut research institutions to join hands and lead the industry forward.

I wish your symposium success and assure you my fullest support and cooperation.

Mr. Anura Priyadarshana Yapa

Message of the Hon. Deputy Minister of Plantation Industries

It is with great pleasure and pride, I am sending this message to the joint Symposium on Plantation Crop Research, organized by the three main Crop Research Institutions; TRI, RRI and CRI.

We have a great challenge ahead of us to uplift the living conditions of tea, rubber and coconut farmers of this country. I am particularly keen to improve living conditions of coconut growers, as I am representing the Hambantota district which is a major producer of coconut, vegetable and export agricultural products such as cashew in Sri Lanka. The value and attitude system in plantation envisages to look upon coconut estates as coconut based farms, to begin with. Already, I have taken steps in Hambantota district with the participation of private sector export organizations to produce organic cashew plantations and dairy farming in coconut estates. It is expected to expand the export of organic cashew produced and processed in the district in the near future. I am hoping to make Hambantota district, one of the major milk producing district of Sri Lanka, and to convert part of it to curd for which the district is famous in the country.

Tea and rubber are also grown in the Warapitiya and Katuwana areas of the district. Plans are under way to improve the life style of the farmers of tea and rubber generally all over Sri Lanka through the "TEA SHAKTHI' and 'THURUSAVIYA" programmes.

I am sure that our Ministry and the three research institutions, viz TRI, RRI and CRI, and their extension services would support and facilitate the process of improving the living conditions of the farmers in the Hambantota district in particular, and in the whole country.

I wish all the success and strength to the Symposium which is addressed by experts from India on the above three crops. Their experiences exchanged with them would enable Sri Lankan farmers to learn from them the success story of yielding highest productivity for all these crops in India. This joint effort of the three major crop research Institutions in the country would definitely help to enhance the national economy in the future.

Mr. Chamal Rajapaksa

Message of the Secretary
Ministry of Plantation Industries

It is with great pleasure that, I send this message to the first ever Symposium on Plantation Crop Research, jointly organized by the three crop research institutes namely, The Tea Research Institute, Rubber Research Institute and Coconut Research Institute, which are under the perview of this Ministry. I should add that Sugarcane Research Institute is not involved in this Symposium since the subject of sugarcane was assigned to this Ministry quite recently. This event certainly is a milestone, in the history of the plantation sector in Sri Lanka. I am very happy indeed to be involved in this unique event, in the capacity of the Secretary of the Ministry-in-charge and pleased to provide the necessary guidence and assistance needed.

According to year 2002 statistics, agricultural products contributed to 20% of the Gross Domestic Product of Sri Lanka. Out of this 20%, the three plantation crops contributed about 16%, which is very notable. The percentage share of exports too is quite significant, for tea the export share being 14%, as against 1.7 for coconut and 0.6 for rubber in the year 2002. During the last decade, export value of these crops has increased significantly from about US$ 400 Million in 1993, to about US$ 700 Million.

I also note that, although the three institutions have been in existence for nearly 75 years, this is the first time ever, such a symposium had been organized. This was possible due to a concept initiated recently i.e. regular interaction between the three Directors of the institutes.

I must place on record that the three institutions for Tea, Rubber and Coconut did provide the respective sectors with valuable findings and new technologies through research during the past period. I am particularly happy that the organizers have selected the most appropriate theme 'Current trends and future challenges'. I have no doubt that this symposium will provide the much needed opportunity for the scientists of the three Research Institutions to interact and exchange ideas and views, which unfortunately did not take place in an effective manner in the past. Presence of a large number of personnel involved in the plantation sector would further assist the discussions and I am sure that these discussions would facilitate in resolving particular problems faced by them.

I wish to take this opportunity to thank the Directors and their staff for the dedicated services they have rendered to the respective industries, over the last so many decades. I am convinced that the present Directors and the staff are absolutely capable in developing this important sector through valuable research, and in finding solutions to various problems faced by the sector, in order to help the Plantation Industry.

I thank the three institutions for organizing this important event and wish the Symposium all success.

Mr. J Abeywickrema

CONTENTS

Current Trends and Future Challenges in Tea Research in Sri Lanka

Dr M T Ziyad Mohamed
Director
Tea Research Institute of Sri Lanka, Talawakelle, Sri Lanka

ABSTRACT

Sri Lanka is world rewoned for producing quality tea. Over the last decade, Sri Lanka's tea production grew at an average annual rate of about 10%. Out of the total production of 310 million kg in 2002, about 62% of the production came from small holdings and the balance from the corporate sector. Sri Lanka is the leading tea exporter in the world, exporting about 295 million kg yr^{-1}. Through tea exports, the country earns foreign exchange annualy amounting to about Rs. 65 billion, which accounts for 14% of the national foreign exchange earnings. The issues that the tea industry is currently facing could be broadly catergorized into; high cost of production compared to other tea growing countries, low field and factory productivity, shortage of workers and competition from other emerging producer countries. To address the current issues that the industry is facing Research Thrusts are formulated and embodied in the Institute's Corporate Plan under the following major areas viz. crop improvement, productivity improvement, crop management, post harvest technology and resource planning.

TEA INDUSTRY IN SRI LANKA

Sri Lanka is one of the oldest tea producing countries in the world, with commercial production having commenced more than 125 years ago. The tea produced in this country popularly known as "Ceylon Tea" ranks among the best available teas in international trade, and over the years, the word Ceylon has become synonymous with quality tea. The contribution by the tea industry towards the country's economy could be summarized as follows:

(A) Production

The annual production is about 310 million kg, and mostly it is black tea. Sri Lanka's tea production grew at an average annual rate of about 10% over the last decade and following key factors could be identified to have contributed towards this growth:

a. Favourable weather conditions;
b. Better management practices in the corporate sector after privatization of the management of estates;
c. Proliferation of small holders, mainly planting VP varieties;
d. Replacement of poor yielding seedling tea with high yielding vegetatively propagated (VP) varieties.

Out of the total extent of about 181,000 ha cultivated, 58% is managed by the corporate sector, which contributes to a production of about 38% and the balance 42% is managed by the small holder sector with a production of 62% of the total. The average productivity in the small-holder sector is substantially higher (2,216 kg ha^{-1}) than the corporate sector (1,151 kg ha^{-1}), thus giving a national average of 1,618 kg ha^{-1} (Tea Information; Tea Research Institute, 2002).

(B) Export Earnings

Sri Lanka is the leading tea exporter in the world, exporting about 295 million kg yr^{-1}. Through tea exports, country earns foreign exchange amounting to about Rs. 65 billion, which accounts for 14% of the national foreign exchange earnings. The income from the agriculture sector contributes to about 19.7% of the total GNP of which, the contribution from tea is about 70%. Colombo auction prices are the highest, so are the FOB prices. The FOB prices are high, because out of the total quantity of exports, about 40% is in value added form. This is considered to be quite high, when compared with other exporting countries. However, the industry cannot be complacent about this fact and the quantity exported in value added form need to be increased to a level of 60% for the industry to be viable.

(C) Employment

The tea industry employs about 2.2 million people altogether in production trade, export, promotion, research etc. (Central Bank Report, 2002).

The industry had undergone major changes during the last two decades due to privatization of management of large estates and proliferation of small-holdings. However, over the years, contribution from the corporate sector towards total production had been declining in comparison to the small holder sector. The issues that the tea industry is facing could be broadly catergorized into; higher cost of production compared to other tea growing countries, low field and factory productivity, shortage of workers, competition from other emerging producer countries, that are capable of producing similar type of teas at a much lower cost. There is an exodus of experienced managers which threatens the corporate sector tea estates with impending decline. The worker shortage is also could be considered as a very serious threat to the industry. Concerns were also expressed by the sector about a possible decline in the quality of tea, in the recent times.

The stakeholders expect updated, appropriate technologies to suit their local environmental conditions. Hence, to cater the needs of the stakeholders in the industry, research projects were formulated by the Institute, prioritizing using CADMAR (Composite Approach to Decision Making in Agriculture Research) methodology, with specific target dates and budgets. The same information was incorporated to the Corporate Plan of the Institute for the period 1999 - 2003. Subsequently, the same plan was updated (rolled over) in September 2003 for a further period of 5 years.

CURRENT TRENDS IN TEA RESEARCH

The mission of TRI is to raise productivity and quality of teas, by recommending appropriate technologies and practices to facilitate development of the tea industry, sustain resources and enhance the quality of life. The 38 Research Thrusts formulated and embodied in the Corporate Plan highlight current trends in tea research. However, it would be more appropriate to highlight only the major areas. They are as follows:

- i. crop improvement;
- ii. land productivity improvement;

iii. crop management;
iv. post harvest technology and
v. resource planning.

CROP IMPROVEMENT

One of the reasons identified as responsible for low productivity in Sri Lankan tea lands, is the lack of high yielding planting varieties. However, some of the varieties developed by the Institute have been yielding more than 8,000 kg ha^{-1} in South India under commercial conditions. This would simply show that the varieties developed do have the potential to give high yields. If one were to analyze the reasons for poor performance of such varieties under local conditions, poor soil conditions could be identified as the primary factor, mainly due to either negligence or not adopting proper control measures due to financial reasons. This low field productivity results in lower worker productivity, and hence causing higher cost of production.

The objectives of the institute's crop improvement program are to develop high yielding nutrient responsive cultivars having quality, resistance to pest and diseases, tolerance to drought and amenable to mechanical harvesting on commercial basis at high, mid and low elevations. However, a serious limitation, which exists in the crop improvement program, is the narrow genetic base in the country's germplasm collection. It is a well-known fact that out of the VP cultivars introduced to the industry, nearly 85% is derived either directly or indirectly from a single parent. This might mean that the industry is sitting on a time bomb. If and when this genetic base is affected by some serious pest or disease problem, almost 50% of the tea extent could be wiped out. However, one could find solace in the fact that a woody perennial crop such as tea is not expected to be prone to such diseases/attacks. But, if proper cultural practices are not implemented, there will always be a danger of plants undergoing such stress, a phenomenon the scientists have already witnessed.

The institute is also not in a position to use latest technologies, such as molecular biology/ biotechnology/ genetic engineering in our plant breeding programme, as the material produced using such technologies are not acceptable to the consumer. Under the circumstances, such advanced technology is used only to identify potential material for use in our breeding programme.

LAND PRODUCTIVITY IMPROVEMENT

Due to worker shortage, some estates in the corporate sector are facing problems at harvesting the entire quantity of available leaf. One obvious option available is to diversify the marginal lands into fuel-wood, which does not require much labour and employ the available workers effectively, in fields, which have potential to obtain high yields. By adopting this approach, both land productivity as well as worker productivity could be improved.

Replanting and Infilling

The Institute, very recently published a document titled "Agricultural Profile of the Corporate Tea Sector" which is a compilation of valuable data on the agricultural status of 304 tea plantations that are managed by 20 Regional Plantation Companies (RPC's).

The results of the survey in the corporate sector had revealed that 53% of their lands are under old seedling tea and the balance 47% under VP tea. About 90% of the seedling tea is older than 60 years; about 74% of extent yields less than 1300 kg ha^{-1}. Of the VP tea, about 30% is older than 30 years and only 35% yields more than 2200 kg ha^{-1}. These figures emphasize the importance of replanting seedling tea, re-replanting of old VP tea and infilling the rest. It was revealed that, replanting rate in the Corporate Tea Sector, over the past decade (1993-2002), has been only 0.70 percent of the total extent under tea, and it is of much concern to the tea community. There is sufficient documentary proof and commonly accepted, that to sustain the industry, replanting should proceed at a minimum of 2 percent per annum of the total tea extent.

Intercropping

Intercropping too could be practiced to maximize land productivity. TRI had already recommended guidelines on intercropping tea either with rubber, coconut or with some minor export crops.

Soil Fertility Improvement

Tea soils in Sri Lanka, especially in areas of Mid-country and Uva are denuded/eroded. It has been estimated that most of the tea plantations in Sri Lanka have lost 300-450 mm of top soil. This again is due to poor stand of old seedling tea, which occupies a high percentage of the tea lands. Due to poor bush stand the soil is exposed leading to erosion and evaporation of moisture under extreme conditions. The only way to improve soil is by adding more organic matter. Although such resources might not be economically feasible in the short run, however it must be done to sustain the industry. The more the delay, the higher the cost of carrying out improvements.

The Institute has been advocating burying of prunings or addition of decomposed waste tea to improve the organic carbon content in the soil. However, burying of prunings is not practiced, in estates where the workers are not provided with adequate firewood for their domestic use. Addition of decomposed (refuse) tea too does not take place due to difficulties in decomposing and the time taken for the same operation. Recently, the Institute has developed a rapid method to decompose refuse tea into a compost with high content humic substances. The laboratory/glass house studies have amply demonstrated the benefits of using such material on the growth of plants and the method has been already patented. Experiments are already underway, to prove the effect of such compost under field conditions and preliminary results are very encouraging.

There have been queries from the stakeholders about the possibilities of using city solid waste as compost material in tea plantations, to enhance the organic matter content. One of the limiting factors, in using such material is the high content of heavy metals in them. Here again, the Institute has developed a method to detoxify heavy metals using humic substances. This method too has been patented. However, the impact of application of such material on tea cultivation not only with regard to yield and quality, but also on the environment and possible contamination of tea (if any) will be carefully studied, using field trials before making any firm recommendations.

FERTILIZER APPLICATION

The Institute had been advocating 'blanket' recommendation on fertilizer requirements for tea based on yield potential. Ideally it should be on site-specific basis, field by field, if one were to optimize returns and reduce the cost. The research focus had been in this direction since of late, and the fertilizer recommendations have been revised with a view to reducing cost without adversely affecting the yield, quality etc. Very recently the Institute has developed a simple computer model to work out the fertilizer requirements on a field basis and also to assist identification of nutrient deficiency symptoms and employ remedial measures.

CROP MANAGEMENT

Harvesting

Harvesting is the most costly operation in tea cultivation, which requires large amount of labour. Furthermore, due to changing socio-economic situation, and also due to social stigma attached to plucking, there is very poor outturn of workers, in the plantations. The way forward is mechanization, although it might have an impact on the yield as well as on the quality of processed tea. The Institute has developed a plucking shear, a mechanical pruner and a collapsible plucking basket and the use of such innovations would alleviate the problem of worker shortage and improve the quality of the harvested material. These three innovations have been patented. Realizing the importance of this, the Institute has taken a decision to establish a Mechanization Division, to strengthen this area of research.

Pruning

Pruning is another worker intensive operation. Recently, TRI innovated a pruning machine with very higher maneuverability compared to the imported machines. Its performance is comparable to imported machines.

Pest and Disease control

Due to adoption of integrated pest management (IPM) approach in controlling pests, diseases and weeds as recommended by the Institute, Sri Lankan tea had earned an accolade as the "Cleanest Tea in the world, with regard to pesticide residues". The ISO Technical Committee on Tea, pronounced this in 1997, 1999, 2001 and 2003 as well. The tight limits imposed by countries in the European Union on pesticide residues in tea is of our concern. In March 2003, a new European Union (EU) pesticide regulation came into force. Before this regulations were introduced by individual EU member states on own maximum residue levels (MRL) for different crop/pesticide combinations. In new regulations, all MRL's will be established in a harmonized way at EU levels. The basis for agreeing on the harmonized EU levels of MRL's will rest on recommendation from the newly established European Food Safety Authority (EFSA). In this regard, the Institute had come up with biological control methods of Shot-Hole Borer, Horse hair blight etc. The institute has recommended soil solarization as substitute for Methyl Bromide, introduced soil substitutes, soil-less media etc. Taking cognizance of this fact, the research focus is more towards biological control of pests, diseases and weeds. Since of late, the Institute found several biological control methods for pests, diseases and weeds,. Research on organic tea too takes prominence due to the same concern.

POST HARVEST TECHNOLOGY

Research on process technology is more towards energy conservation and automation of the process towards establishing food factory concepts. Tea produced in Sri Lanka is mainly of orthodox type. As orthodox process is a batch process, worker productivity plays an important role. On account of the worker shortage in the recent times, the current research focus is on automation of tea processing so as to minimize over-dependence on workers.

The introduction of a computer model to select rolling program, followed by rapid microwave oven method for moisture determination are some valuable tools to improve the quality of the processed tea and reduce the cost of tea processing.

Product development and diversification

The Institute research is presently focused on producing value added products such as Instant tea, Ready to drink tea (RTD tea) etc., with increased tea character.

Health benefits of tea

Recent research carried out at the Institute and other laboratories around the world had shown that regular drinking of tea could reduce the risk of degenerative diseases. Recently, the Institute obtained a patent on the discovery of anti-fungal activity of catechins and theaflavins in tea.

Computer Aided Manufacture (CAM)

Tea processing is still considered as an art and it is distinct from science, and several critical judgments are left to subjective decisions of factory staff. For this reason, the Institute's current research focus entails computer-aided tea processing, such as examining the possibility of using electronic sensors at critical control points in the process. However, the difficulty with regard to use of such technology is mainly the non-uniformity of the starting material, presence of dust (light particles), which interferes with electronic sensors, as well as the high costs involved.

Energy conservation measures

Another area of concern is the cost of energy used in tea processing. Accordingly, the Institute's research is focused on developing energy-efficient technologies, with a view to reducd the outlay on electrical and thermal energy.

The Institute has recommended measures to reduce the cost of electrical energy for withering by controlling the hygrometric difference of the air supplied, and by using speed controllers to reduce the speed of the withering fan. A minimum saving of about 40 per cent on electrical energy consumption in withering is possible, by using speed-controllers.

Drying with Solar Energy

The Institute research is presently focused on environmental-friendly, energy-efficient, renewable alternatives, such as solar energy, for drying. Results from experiments carried out with solar-energy, indicate a saving of about 25 per cent on fuel used for drying. However, the capital investment cost of the system is about Rs. 2 million, which makes it less attractive.

RESOURCE PLANNING

Research programmes are formulated under the following categories:

i. human resource planning through socio economic surveys;
ii. natural resource planning. Land use planning system had been recommended using Geographic Information System (GIS) as a tool and taking into account productivity of tea lands and worker

requirement/availability;

iii. capital resource planning, mainly by analyzing the return on capitol investment.

FUTURE CHALLENGES

Finally, the challenges that the Sri Lankan tea industry as well as the institute are facing today, could be summarized as given below:

i. development of high yielding cultivars, with other possible attributes – an average yield of 2000 kg/ha by year 2015 for the country. This was set by policy makers;

ii. mechanization of field practices to overcome worker shortages;

iii. product development/diversification, to increase value addition component in our exports. However, to embark on this, markets for such products should be identified, using market intelligence research;

iv. producing teas with minimum level of pesticide residues, to meet the demand of the Western countries, which virtually expect pesticide free tea!!! In this regard, research on biological control methods take precedence;

v. A shift in fertilizer recommendation from 'blanket' recommendation to, site-specific recommendation, with a view of having higher returns on investments;

vi. Introduction of computer aided manufacture (CAM) with automation to establish food factory concept and also energy efficient environmentally sound technologies in processing to reduce cost of tea processing and preserve the environment.

As in the past, the Institute would come with solutions to these challenges, with the cooperation of our stakeholders.

Overview of the Rubber Industry of Sri Lanka

Dr L M K Tillekeratne
Director
Rubber Research Institute of Sri Lanka, Dartonfield, Agalawatta, Sri Lanka

ABSTRACT

Natural rubber plant has been introduced to Sri Lanka in 1876. Entire Rubber Plantation in the South East Asia has originated from these plants, planted in Sri Lanka. The rubber extent in Sri Lanka has declined vastly since 1975. The total rubber production last year was only 91,000 mt where as the production in 1978 was 165,000 mt; nearly 65% of which is produced by the small holders. The natural rubber consumption in the country has risen to 65% of the total production. Further, raw rubber in both dry and latex forms have been imported to Sri Lanka during the past couple of years to cater to the products industry.

In order to increase the raw rubber production in the country, three strategies planned: the short term strategy is to fix rain guards thereby the production can be increased within the year by over 30%; the long term strategy is to expand the plantation to non traditional areas like Monaragala and into abandoned tea lands in hilly areas; the second long term strategy is to increase national rubber productivity to 1500 kg/ha/yr.

Use of quality planting materials plays a major role in improving the productivity of rubber plantations. Nursery under the management of the Rubber Research Institute of Sri Lanka (RRISL) at present, will provide the entire quality plant needs for year 2004 for the small holders from high yielding clones developed by the RRISL without any shortage. Plant requirement for the privately owned bud wood nurseries, will also be provided by the RRISL from all the recommended clones including recently recommended RRISL clones. If all these goals are achieved, the earnings from the rubber and rubber products industries could be increased to meet 10% of the GDP value by year 2015.

Sri Lanka is the most important country in the world as far as the Natural Rubber (NR) industry is concerned. Rubber tree of botanical name *Hevea brasiliensis* is a native of South America. In 1876 some seeds of this *Hevea brasiliensis* species collected from the forests in Amazon region were brought to Kew Gardens in London and planted there and the plantlets were brought to Sri Lanka and replanted in Henarathgoda Gardens by Mr. Henry Wickham. Hence, this historic Henarathgoda Gardens situated 20 miles from Colombo where these NR plantlets were nursed and grew at the very beginning is known as the cradle of Rubber Industry in the whole world.

Due to the presence of a deadly disease viz. the South American Leaf Blight (SALB), NR production in Brazil, which is the native place of Hevea rubber, is very insignificant today.

Planting material from the plantlets planted in Sri Lanka have later been distributed to other South East Asian countries to establish the rubber plantations in those countries which are now accounting for nearly 95% of the total NR production in the world. The balance 5% comes from African countries. But the amount of rubber produced in its native South America is negligibly small today.

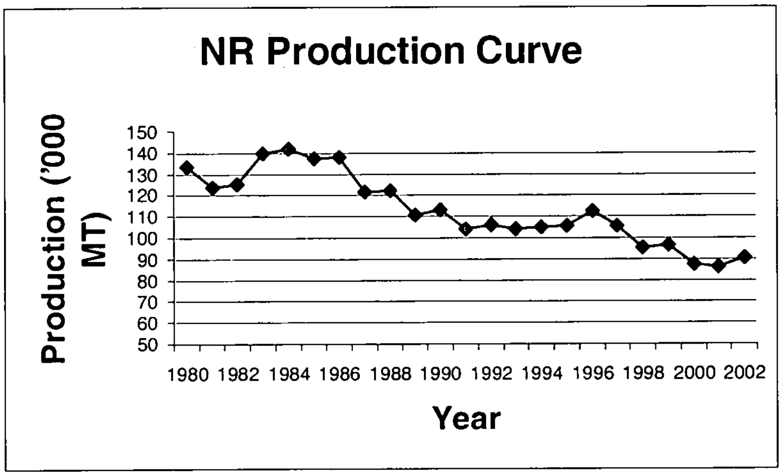


Figure 1. The trend of natural rubber production in Sri Lanka

Even though, Sri Lanka is the first Asian country where the rubber plantation was established, due to limitations in land area available, the contribution from Sri Lanka to the NR requirement of the world market is very small and is about 1.8% at present.

The peak production of NR in Sri Lanka has been recorded in 1978, which was 165,000 mt, when there was 202,000 ha. of rubber plantation in the country. However, due to poor prices that prevailed in the world market for NR for over 30 years prior to the turn of the century, most of the rubber small holders have diversified their crop from rubber to tea because; the price paid for a kg of fresh green leaves in the village was more attractive than the price paid for NR. Further, the labour requirement for rubber is more, compared to tea.

Area under rubber in Sri Lanka has declined very fast, specially during the period after 1997 due to the worst set back experienced in NR prices in the world market caused by the South East Asian (SEA) financial crisis. Actual extent of rubber available in 2003, according to a recent survey is 128,879 ha; of which 83,253 ha (64%) is owned by the small holders.

As a result of this SEA financial crisis, the average world market price of NR that prevailed at US$ 1.05 kg^{-1}. in 1997 fell down to below US$ cts. 60 within 12 months. Hence, most of the rubber plantations owned by small holders and even by estates were abandoned without maintaining or tapping because the owners could not cover the cost of production from the income received from selling rubber. Hence, since 1998, for the first time after World War II; the total annual rubber production of Sri Lanka fell down to below 100,000 mt (Fig. 1). The main reason why the rubber farmers could not survive during this period was because there was no price stabilization operation for rubber implemented during this period; like in Thailand where for every kg of rubber produced by the small holders, the Government paid Bhatts 20; irrespective of the world market price, which was substantial to cover the cost of production, keeping even a small profit.

Rubber Products Industry in the country, however, has developed during this period and at present nearly 65% of the total rubber produced is used locally to manufacture value added end products. In order to encourage foreign investment in the country a Free Trade Zone (FTZ) was established close to the Colombo airport in 1979. With the enormous success shown by this FTZ within a short period of time, and in order to extend the concessions offered to the investors in the FTZ to investments in the other parts of the country, especially in remote villages where the labour is easily available, the Board of Investment (BOI) was formed in 1992. Already there are over 100 rubber based industries operating under BOI in all over Sri Lanka.

Already, in solid tyre manufacture, Sri Lanka is the leading nation contributing to nearly 25% of the world need. Among the other products manufactured in Sri Lanka today:

a. Examination and Surgical gloves;
b. Automotive components;
c. Foot wear;
d. Flooring;
e. Extruded hoses and rubber tubing;
f. Balloons and toys;
g. Foam rubber mattresses and cushions, are the main items.

The Board of Investment (BOI)

Today Sri Lanka is one of the most attractive investment destinations in Asia. The progressive liberalization of economy since 1978 has resulted in a business friendly environment. The Government has pursued a policy of Economic Liberalization with emphasis on private sector investments. The private sector is recognized as the engine of economic growth with the role of the state being to provide an institutional framework supportive of private sector participation in development activities.

The rubber products industry is one of the priority sectors identified for attractive promotion by the BOI and was accorded **"Thrust Industry"** status in 1977. *Under this scheme, investment in the rubber products industry is offered a new package of attractive incentives and concessions.*

Structure of the Rubber Products Industry

The rubber products industry of Sri Lanka can be sub divided into 3 broad categories:

a. Export oriented BOI enterprises;
b. Large scale traditional enterprises;
c. Small and medium scale non-BOI and non-traditional enterprises.

These classifications have been made based on the type of market whether local or foreign, regulatory framework whether BOI or non-BOI and on the scale of the operation.

The total investment under the BOI today is nearly Rs. 800 Million where close to 20,000 people are employed. Nearly Rs. 425 Million of them flow into the category of latex dipped products providing employment to 35% of the work force working there. Significant number of employees are engaged in the category of footwear and solid tyres.

There are 20 countries that have invested in the rubber products industry in Sri Lanka. Nearly half of them are locally owned while the balance is joint ventures with the foreign investment. The participation of foreign investment has directly benefited the country in many ways such as:

a. Transfer of technology;
b. Value addition;
c. Access to international markets and
d. Establishing price.

thereby transferring Sri Lanka into a global player in the rubber industry.

Table 1. NR Consumption by Product Type – BOI vs Non-BOI Sectors

Product Type	NR Consumption (MT)			
	BOI Projects		Non-BOI Projects[1]	
Tyre Treading Pneumatic	1,094	(24%)	3,440	(76%)
Tyres & Tubes	6,575	(80%)	1,600	(20%)
Solid Tyres	15,647	(100%)	–	–
Footwear	3,150	(66%)	1,613	(34%)
Flooring	1,886	(97%)	60	(3%)
Other Dry Rub, Products	1,287	(26%)	3,696	(74%)
Latex Dipped Products	18,300	(84%)	3,600	(16%)
Latex Foam	4,350	(56%)	3,480	(44%)
Total	52,289	(75%)	17,489	(25%)

Note: Figures in parenthesis indicate percentage distribution of NR consumption between BOI and Non-BOI projects by product type.
Source: Board of Investment of Sri Lanka

Australia is the largest foreign investor in rubber products industry followed by Italy, Korea, and Belgium. South Korean projects also account for the highest share of employment (30%) followed by Belgium (19%) and Australia (18%). The major attraction of Sri Lanka for the foreign investors, apart from the investments offered by the BOI are:

a. Availability of high quality raw rubber and latex at a competitive price. The purest grade of raw rubber namely latex crepe, used for making rubber appliances used in food, pharmaceutical and infant products industry is available at reasonable prices;
b. Pool of technical and professional manpower from managerial level down to machine operator level, trained by the Sri lankan universities and the PRI;
c. Competitive wage rate;
d. Good infrastructure.

Table 2. No. of Projects, Investment and Employment by type of Ownership

Type of Ownership	No. of Projects		Investment(Rs.Mn.)		Employment No.	
Foreign Owned (100%)	29	(49%)	3,580	(51%)	5,185	(29%)
Locally Owned (100%)	14	(24%)	675	(10%)	1,841	(11%)
Joint Venture	16	(27%)	2,691	(39%)	10661	(60%)
Total	59	(100%)	6.946	(100%)	17,687	(100%)

Note: figures in parenthesis indicates the percentage value.
Rubber Products Manufacturing Projects in operation under Sec.17 and 16 of the BOI Law.
Source: Board of Investment of Sri Lanka

Latex Protein Allergy

In order to increase the demand for NR based products globally, efforts are taken by the rubber producing countries to combat baseless allegations made against NR products such as the protein allergy. As Sri lanka is already one of the major latex products producing country in the world, all modern test methods available in the world for the analysis of leachable protein levels in dipped products such as:

a. RRIM modified Lowry method (ASTM test D 5712-99);
b. BCA (Bicinchronic Acid) method;
c. Bradford dye method and
d. Chromatographic method.

These methods are now available in RRISl laboratories. Several techniques have also been introduced to minimize the leachable protein levels of the dipped products manufactured.

Still, latex crepe and sole crepe manufacture in the country is also continued while enjoying the reputation as the sole producer of this high quality premium grade of NR made specially for food, pharmaceutical, medical and infant applications. Nearly 30% of the total production of NR in the country is utilized for this purpose.

Among the end products manufactured, mainly in the export promotion zones of Sri Lanka, latex based products such as examination and surgical gloves are in the forefront. Over 20% of the country's rubber production is converted into concentrated latex to cater to these industries.

Since, year 2000, in order to meet sudden short falls of certain grades of NR needed for the products industry, dry rubber and sometimes even latex is being imported to the country. Last year the total importation of raw NR to the country is over 7,000 mt. This process is expected to continue until the raw rubber production in the country is increased substantially in the next couple of years.

Strategies to increase NR production in Sri Lanka

Short Term Strategy: Use of Rain Guards in plantations.

Long Term Strategy:

a) Increasing National Productivity from 950 kg $ha^{-1} yr^{-1}$ to a minimum of 1,500 kg $ha^{-1} yr^{-1}$

b) Extending Rubber Planting to non traditional areas such as to Monaragala in the intermediate Zone and to abandoned Tea lands (over 400 m amsl).

The only rapid way available for a substantial yield improvement in the rubber plantations is by fixing rainguards to prevent rain interruption on harvesting. By means of rainguards, estates have been able to recover over 30% yield increase and thereby earning an additional income of over Rs 25,000 ha^{-1} This yield increase is possible in rubber estates and in small holdings specially in Ratnapura and Kalutara districts, where the rain is more severe than in the other districts. Rain guards eliminate the need to do recovery tapping currently practiced in plantations in a big way thereby minimizing the danger of incidences of tapping panel dryness.

Now the Government of Sri Lanka is considering paying 50% or 25% of the cost of laying rainguards to the small holders in the form of a subsidy. Until then the Advisory services department of the RRI has made arrangements through state banks to give concession loans to the small holders for the purpose of laying rain guards in year 2004. Wide publicity will also be given through media to propagate rainguards in the rubber plantation this year.

Under the long term rubber production increasing plan, the Government of Sri Lanka has launched a scheme of planting rubber in non traditional drier areas such as in the intermediate zone as well as in elevations above 1,000 ft. Most popular foreign clone planted until 1995 viz. PB 86 could not withstand wind and climatic conditions prevailing in elevations over 300 m amsl. But the RRIC 100 series clones of Sri Lankan origin have shown a good response to the conditions in elevations up to 700 m amsl and hence nearly 29,000 ha of abandoned tea lands in these elevations will also be planted with these new clones in the future. Further, this project will help to protect the environment in a big way.

High Yielding Clones Recommended for Planting

For the smallholders:
RRIC 100, 102 and 121
RRISL 203 and 205 up to 10% of the area for holding of extent more than 5 ha.

For Regional Plantation Companies:
Group I: To be planted up to 10% of the extent

- RRIC 100, 102, 121, 130 and Pb 217 *, 28/59 *

* Not recommended for areas having more than 3750 mm of annual rainfall.

Group II: To be planted up to 3% of the extent

- RRIC 117, 131, 133 RRISL 203, 205, 206, 210, 211, 215 and PB 235*, 260*, PBM 24 (* Tapped at 67%).

Group III: Planted up to 2 ha in RRI/Estate collaborative clone trials
RRISL 200,201,204, 208, 217, 218, 219, 221, 222, 225, 226, 227 and RRISL 2000 to 2006 and RRIM 717, GPS 1, PB 255, PR 305, RRII 105.

Only a high quality plant can give its potential yield and hence maintaining the quality of plants issued to the small holders for replanting is also of paramount importance to increase productivity of rubber lands.In future all the government rubber plant nurseries will be managed by the RRI. RRI hopes to cater to the entire need of the smallholders of the country while helping few of the plantation companies too with quality plants. In this process plant production by private nurseries will be discouraged, as the quality control of the plants produced by them is very difficult.

Project of planting rubber in Moneragala district in the intermediate zone of Sri Lanka was commenced this year. Two hundred ha of land will be planted with rubber in the South West monsoon in year 2004 in this district while plants from the seed fall in the month of February in that area will be used for laying a new nursery in Moneragala at the beginning of 2004. These plants will be utilized to plant another nearly 2,000 ha in the district extending up to the eastern province of Sri Lanka, in the future.

On a request made by the private sector rubber products manufacturing companies, the Government is strongly considering giving 2 ha block of lands to small holders on out grower basis to be funded by the multinationals and local companies, who will ultimately buy their latex at a guaranteed price from the farmers.

This is the only way that Sri Lanka can meet the 120,000 mt of rubber requirement for the fast growing local rubber industry by year 2010 and nearly 150,000 mt need by year 2015. In order to encourage rubber plantation in the country, the subsidy payment of approximately Rs.50,000 ha^{-1} at present will soon be increased to Rs.100,000 ha^{-1}. A new export cess on raw rubber exports, rubber products imports and from rubber products exports on the rubber content will be levied to collect funds for building up a price stabilization scheme to help small holders, in case if the world market price again drops drastically.

Scarcity of Rubber Tappers

There is a severe scarcity of labour in rubber plantations in Sri Lanka, particularly skilled tappers. The main reason for this is the social status of a "rubber tapper" at village levels.

The attempts taken by the Sri Lankan government to change the attitude regarding the dignity of the profession by giving them uniforms and issuing them certificates by the RRI after completion of a tapper training program has so far been unsuccessful.

Further, over 75% of the cost of manufacture of raw rubber is the tapping cost which depends mainly on the daily intake of tappers, which in turn depends mainly on their skills. Hence, in order to solve the problem of tapper shortage to some extent thereby eliminating vacant blocks in estates, half spiral tapping once in 3 days (S_2d_3 tapping system) with 25% ethral stimulation was introduced to plantations. The plantation companies are accepting this new technique widely. But, in order to get the maximum benefit from this new tapping system, rain guards is a must in plantations. Even without rain guards, because of this slight stimulation (25% of normal recommended dosage of stimulants) done, there will be an increase in the yield compared to un-stimulated area.

Growing more rubber in the country will fulfill the firewood requirement for domestic cooking and for industries such as the tea industry where 43% of the annual uprooted rubber wood is consumed for drying, and for the bread, tiles, and lime kilns thereby protecting trees in the limited forest reserves in the country. Treated rubber wood based industries which are closed down since the SEA currency crisis are to be revitalized to ensure payment of a realistic price for the old trees uprooted by the small holders for replanting.

Production of more rubber wood from expanded plantations will enable Sri Lanka to permit MDF Board industry to continue production at full capacity who are at present restricted to continue production at 50% capacity due to the shortage of rubber logs.

In order to support NR farmers to improve their income appropriate steps will be taken to show them other avenues of income from their rubber farms such as income from carbon trading. If they gain additional income from such unconventional measures it is most unlikely that they will tend to move away from rubber planting even if the rubber prices drop again by a small percentage in the future.

The ultimate aim of the rubber based industry in Sri Lanka is to be a "World Class Rubber based industrial center in Asia supplying specialty grades of raw rubber and rubber products and rubber wood products to Niche markets thereby earning US$ 550 million per year before the end of this decade;" utilizing only locally grown raw rubber and rubber latex.

8200

Coconut Industry: New Challenges and Vision to Increase Coconut Production

C Jayasekara
Director
Coconut Research Institute, Lunuwila, Sri Lanka

ABSTRACT

Total annual coconut production in Sri Lanka fluctuated in the range of 2,500 – 3,000 million nuts in the last decade, in spite of tremendous advancement made in research on coconut. Availability of improved varieties, planting methods, fertilizer recommendations to substitute nutrient losses, soil water conservation practices, eco-friendly integrated management strategies for pest and diseases, improvement in productivity of coconut lands through mix farming, precision technologies for water and nutrient management, protocols for embryo culture and tissue culture are some of the achievements made in coconut research over the years for sustainable development of the industry.

Coconut industry in Sri Lanka is faced with many challenges today due to shortage of land, high cost of inputs, low productivity due to nutrition depletion, recurrent droughts, newly immerging pests and diseases, shortage of skilled labour.

Our vision, strategies, and recommendations to address these issues for improving coconut production are discussed.

Coconut occupies approximately 430,000 ha of cultivable land area in Sri Lanka and its cultivation is mainly concentrated in the districts of Puttalam, Kurunegala, Gamapaha, Colombo, and Kalutara. It is predominantly a smallholder crop being 75% of the extent consisting units less than 8 ha. According to the recent agricultural survey in the year 1982, approximately 700,000 are smallholdings covering an area of 300,000 ha and the balance represent the estate sector. Coconut provides a livelihood for nearly 500,000 people in the crop production, processing and marketing sectors.

Total annual coconut production in Sri Lanka varies from 2,500-3,000 million nuts. The processing and marketing sector accounts for Rs 11.9 billion export earnings and its contribution to the GNP is 1.3%. Coconut is an important source of edible fats and proteins in the daily diet providing 22% of the caloric intake. Sri Lanka is said to be the highest per capita consumer of coconut in the world, utilizing an average of 110 coconuts per annum. About 70% of the annual total coconut production is used for domestic consumption and the balance 25-30% is for various processing industries.

Coconut industry in Sri Lanka still plays a vital role in sustaining the viability of the economy at village, district and regional level. Commercial industries offer a wide range of kernel products such as desiccated coconut, copra, coconut oil, coconut cream and coconut milk powder and non-kernel products derived from the fibrous mesocarp and the hard shell.

Despite coconut being the largest plantation crop in Sri Lanka, it is faced with many challenges today. Some of these major challenges are given below:

- Rising cost of production due to high prices of inputs;
- Low fertility of coconut lands due to continuous cultivation and lack of implementation of soil conservation measures;
- Thirty percent of the existing coconut plantations are senile plantations;
- Indiscriminate fragmentation of highly productive coconut lands in land suitability classes S_1, S_2 and S_3;
- Recurrent drought experienced in many coconut-growing areas;
- Yield losses due to pest and diseases;
- Difficulties in retaining skilled labour;
- Declining supply of raw material for the processing industries;
- High-energy cost for irrigation and processing industries.

Coconut production is dependent upon the demand for fresh nuts at household level and as raw material at the factories. Regular and reliable supply of raw material depends on the climate as well as the prices at the farm gate, at the factory and in the market. Therefore, to gain profit or to secure better income for all stakeholders in the production chain, maintenance of sustainable high yield is very important.

Impact of Research and Development on the Coconut Industry

Seventy-five years of research on crop improvement, crop management, crop protection and post harvest technology has yielded many promising results and recommendations towards the sustainable development of the industry. The discovery of hybrid vigour by Dr Patel in 1934 and subsequent application of this technology by Dr D V Liyanage in late 1950's paved the way for introducing Tall x Tall (CRIC 60) improved cultivar and dwarf x Tall (CRIC 65) coconut hybrid and Tall x San Ramon (CRISL 98) recently. Two new hybrids produced by crossing Dwarf x San Ramon, and dwarf brown x Tall will be introduced soon. Hybrids of D x Tall and D x San Ramon are not only early bearers; they also give higher yields than their parents. The limited genetic base in Sri Lanka has been a serious constraint and criticisms for breeding of new varieties, whereas Indian coconut breeders have the opportunity to do inter and intra-varietal crosses among 198 indigenous accessions and 132 exotic cultivars for their coconut breeding programmes. Collection, conservation and cataloguing of promising accessions are one of the important areas of plant breeding. The institute undertook this task quite lately in 1980's and to date we have more than 100 accessions collected and conserved in our field gene banks. In the past five years, our breeders have taken new approach to characterise local cultivars and accessions and to determine genetic relatedness using DNA marker technology. Germplasam exchange programme commenced in the year 2002 with India and Papua New Guinea and the institute was able to add 4 Indian and 10 South pacific varieties to the exotic collection to strengthen the future coconut breeding programme. Embryo culture technology perfected in our tissue culture laboratory became very useful for the germplasam collection programme. This is a noteworthy achievement of the tissue culture laboratory.

Crop improvement and Crop management research carried out by Agronomy, Soils and Plant Nutrition and Genetics and Plant Breeding Divisions have lead to several recommendations on application of fertilizer, low cost manuring using locally available resources such as green manure, animal dung, rock phosphate etc, nursery management technology, agronomic practices for the conservation of soil organic matter and moisture, irrigation and crop models to enhance productivity and profitability of coconut lands.

In the area of crop protection, the institute has pioneered in developing successful biological control methods and integrated pest management strategies for Coconut leaf miner (*Promecotheca cumingi*), Coconut caterpillar (*Opisina arenosella*), Red weevil (*Rhynchophorous ferrugineus*) and Black beetle (*Oryctes rhinoceros*). However poor adoption of these technologies has lead to sporadic occurrences of epidemic situations in some areas. In the case of root and bole rot disease caused by *Ganoderma bonenens* that emerged in epidemic level in the Southern province was controlled successfully by trunk injection of fungicide Calexin. Now CRI has taken a leading role in developing IPM strategies for coconut areophid mite Aceria guerreronis. Our scientists have identified a predatory mite and mass breeding of the predator and releasing to the field on experimental scale are being carried out to develop control strategy.

In the field of technology development for product diversification, the institute has made a significant stride in early era by developing technologies for the manufacture of desiccated coconut, copra, and coconut vinegar from nut water, arrack, jaggery and treacle. Due to various policy decisions taken from time-to-time, coconut processing research was handled by other research organizations like Industrial Technology Institute (Former CISIR) and Coconut Development authority. CRI took over this responsibility again in 1997 and during the past 7 years, CRI was able to develop new technologies to prepare coconut paste with long shelf life to reduce domestic wastage, virgin coconut oil, value added virgin coconut oil based products, coco cheese and coco yoghurt with no substitution of animal proteins and fat, and coco powder.

In early eighties, the institute took step forward by giving emphasis to conduct basic research. Pioneering research conducted in the area of Plant Physiology and Biochemistry lead to the identification of criteria for screening for drought tolerance and identification of photosynthetic and water relations characteristics of different cultivars of coconut to compliment the crop improvement and management programmes.

Tissue culture division of the institute marked its pride by putting into the field nearly hundred tissue cultured coconut plants raised by somatic embryogenesis. Some of the coconut plants are flowering and bearing fruits and their performance is comparable to plants raised from seeds. Molecular biology related studies in the area of genetic characterization of different cultivars and accessions lead to identification of genetic distances of cultivars using RFLP/AFLP and microsatallite protocols. Further PCR technology being used successfully to identify causative agent/s for rapid decline syndrome of coconut.

Statistical studies and crop modelling have been successfully used for crop forecasting and developing crop behaviour scenarios under different climatic conditions.

Research strategies/directives of the institute to address current issues and future benefit of the industry

One of the major constraints faced by the coconut industry today is the limited availability of land for coconut cultivation and gradual decline in coconut lands from the coconut triangle. The most formidable challenge faced by the coconut industry in the new millennium is to achieve substantial increase in coconut production from existing coconut plantations to meet the domestic demand and to cater the needs of the processing industries.

Strengthening of breeding programme is one of the priority areas of research in the institute. More attention of the scientists is necessary for alleviating the abiotic stresses and developing varieties, to give high yields with tolerance to drought and high temperature. Water is a scarce resource. It is very important to make the crop water use efficient and capable of combating drought. This aspect demand considerable research input. Use of exotic varieties in developing new cultivars with a potential for sustainable high yields and wider adaptability for environment stress will be another important area of coconut breeding that need wider impetus of breeders. The aid of biotechnology will complement such a programme.

Coconut palm has a large photosynthetic area of about 100 m^2. However daily photosynthetic productivity of this palm is low compared to oil palm. One way of increasing the production will be by resorting to genetic engineering to make a C_4 plant by introducing new gene/s to coconut. Also 20-25 years long breeding programmes could be shortened considerably by using DNA marker technology to identify desirable traits in parental palms and their progenies. Molecular biology techniques are advancing very rapidly. CRI has the critical mass of scientists to take up molecular biology related R & D studies. The sustainable productivity of the coconut palm should be augmented through exhaustive application of breeding technologies for which infusion of new genetic material into the breeding programme is critically necessary. It is worth to have one advance molecular biology laboratory for the whole plantation sector to conduct more cutting edge research.

Tissue culture programme of the institute has reached considerable progress in the past couple of years. Further refinements to the currently used protocols will help to enhance multiplication rate of callus tissues to achieve more somatic embryos. If one callus tissue could be multiplied to get over 200 somatic embryos, it would be a tremendous achievement. Strengthening of research on new hormones and more basic studies towards understanding the process of somatic embryogenesis will help to achieve this goal.

Coconut palm is threatened by newly emerging pests like ereophid mites causing 10-30 % crop losses. Development of eco-friendly pest management strategies is important to control pest damage and economic losses. Similarly diseases of unknown aetiology are also spreading at a low pace. As a long term strategy, emphasis should be placed on screening of resistant cultivars and development of new varieties and cultivars, and strengthen quarantine measures to prevent entry of new pests and diseases.

Development of precision technologies to manage nutrition and water requirement of palms under different agro ecological zones is another important area of research to utilize scarce resources more precisely and efficiently.

Despite the fact that the coconut palm potentially provides over 300 products that are useful to man, only handful of kernel and non-kernel products are produced and marketed. Therefore it is of paramount importance to diversify the product base, particularly with regard to coconut kernel and fibres. Intensification of R & D activities on value addition and product diversification to reduce domestic wastage and to introduce more value added products from husks, shell, sap and wood for niche markets will definitely help to increase income from the processing sector.

Transfer of Technologies to the coconut growers and evaluation of these technologies at farmers fields are important to achieve maximum benefit of the research and technological advancements made. Strengthening of linkages among other coconut related organizations, strong extension programme to take technology to the grass root level are need of the hour.

Technical Session 1

Cultural Practices and Plant Productivity

Shade In Tea: Is It Beneficial?

A J Mohotti
Physiology Division, Tea Research Institute, Talawakele, Sri Lanka

ABSTRACT

Shade is considered as a necessary management practice in tea. However, there is still much debate on the necessity of shade in tea plantations. This paper deals with some physiological responses of tea due to shade in several experiments, two long term experiments carried out in St Coombs Estate, Talawakele (1,372 m amsl) and one experiment with pot grown young tea plants in a growth chamber.

In field grown tea, the maximum photosynthesis (A_{max}) of unshaded leaves was found to be nearly 40% less than shaded, indicating the increased capacity of shaded leaves for higher productivity. Under increased N input, the gap of A_{max} between shaded and unshaded leaves narrowed down. The total linear electron transport rate was found to be similar in both shaded and unshaded leaves. The allocation of electron transport products to CO_2 fixation was higher in shaded leaves, which was about 50% less in unshaded leaves than in shaded leaves. Conversely, allocation of electron transport products to photorespiration was significantly larger in unshaded leaves. The photosynthesis of field grown tea in several seasons with different climatic conditions showed that when there was high incident radiation intensity, the rates of photosynthesis were significantly low. Fv/Fm, which is a measure of photoinhibition was significantly lower in unshaded tea leaves. None of the other parameters, i.e. leaf temperature were significantly different between shaded and unshaded leaves, indicating the decrease in photosynthesis is due to photoinhibition. Interestingly in terms of the physiological responses, the best microclimate to the tea was provided under the shade of *Grevillea robusta* L.

In summary, shade can be considered as essential and beneficial for tea, in addition to the other known advantages such as nitrogen fixation, harbouring natural enemies of tea pests, moisture conservation and biodiversity aspects. Identification of alternate species of shade trees with favorable microclimate and low competition with tea for tea plantations will have to be carried out in order to sustain the long term stability.

Key words: Tea (*Camellia sinensis* L.), photosynthesis, fluorescence, shade

INTRODUCTION

Shade is considered as an important management practice in tea, but also subjected to much controversy. In its native habitats tea has been growing under the shade of forest trees (Eden, 1976). The history of the establishment of Shade in Tea Plantations dates back to 1800 (Dutta, 1961; Murthy, 1996). Masters (1863) claimed that the Assam tea does not appear to thrive well in the inferior soils when exposed to the full sunlight, hence recommended partial shade for tea. Following this, planting tea under the shade of trees, mainly *Albizzia chinensis* became the practice in India (Barua, 1989). The practice of using shade trees spread from North East India to South India, Sri Lanka, Indonesia and Africa. Since then, shade has been a subject of much debate: Some authors claim that the yield increase under shade (Barua and Gogoi, 1979; Hadfield, 1962), some claim that there are decreasing yields under shade (Mc Culloch et al., 1965; Obaga and Othieno, 1987; Othieno, 1983) while others claim there are no yield responses.

In the mid 60's shade was removed from tea plantations in Sri Lanka, owing to the increase of the leaf disease 'blister blight' caused by the fungus *Exobasidium vexans*. However, by about 1970 it was realized that several problems occur as a result of shade removal, causing a yield drop as much as 25%. As a result, the shade trees were re-introduced (Sivapalan, 1993).

However, there is still much debate on the necessity of shade in tea plantations. This paper deals with some physiological responses of tea due to shade, in several experiments. Main focus was on tea photosynthesis and some of its partial processes as photosynthesis is regarded as the driving force of plant productivity.

MATERIALS AND METHODS

Two long term experiments were carried out in field number 8 at St Coombs Estate, Tea Research Institute, Talawakele, Sri Lanka (latitude 6^0 55' N, longitude 80^0 40'E and altitude 1,382 m amsl) and one experiment with pot grown young tea plants in a growth chamber.

Experiment 1

This experiment was carried out during July 1996 to June 1999. In this experiment, mature tea planted in 1964 of the cultivar TRI 2025 was used. This field experiment comprised of 3 shade levels, i.e. 70%, 35% and 0% shade and 3 N levels, i.e. 0, 360 and 700 kg ha^{-1} yr^{-1}. The shade was provided with black nylon netting. These treatments (3 factor factorial) with 3 replicates were arranged in a completely randomized block design. On a clear day, the leaves on top of the canopy received about 1,750 µmol m^{-2} s^{-1} PAR during mid-day. The plots were approximately 16 m^2 area containing approximately 26 plants. In this paper only the results of the extreme treatments, i.e. High shade (70% shade), unshaded, high N (700 kg N ha^{-1} yr^{-1}) and no N (0 kg N ha^{-1} yr^{-1}) treatments will be discussed.

Experiment 2

This experiment was carried out from April 2001 onwards. In this experiment, mature tea planted in 1964 of the cultivar TRI 2025 was used. The experiment had 35% shade (provided by black nylon netting), 0% shade and the shade provided by *Grevillea robusta* L. as treatments with 3 replicates, arranged in a randomized block design. All other management practices were carried out as per TRI recommendations. On a clear day the leaves on top of the canopy received about 1,750 µmol m^{-2} s^{-1} PAR during mid-day. In the shade tree plot the tree was in the middle of the plot. The plots were approximately 16 m^2 area containing approximately 26 plants.

The measurements were made in 2002-2003 on days with different climatic conditions. Four categories were selected to represent most common climatic conditions experienced in the region, based on the cloud cover and the light intensity. They were named as; A (bright, clear days with no clouds, receiving an average PAR about 1,750 µmol m^{-2} s^{-1}), B (morning bright and clear, but afternoon overcast sky with intermittent cloud cover), C (morning and evening overcast sky with a cloud cover, but mid-day bright) and D (overcast throughout the day, with no bright sunshine, with PAR ranging between 100-500 µmol m^{-2} s^{-1} over the day). For day category A, measurements were taken on two seasons (season one in April 2001 and season two in March 2002): PAR and rate of photosynthesis (A) are presented for both seasons while other parameters of both seasons were merged for easiness of the discussion. Under each category, measurements were repeated at least on four similar, consecutive days, which were taken as replicates for statistical analysis.

Experiment 3

This experiment was carried out at IACR-Rothamsted, Harpenden, UK, in 1998. In this experiment, 1 year old tea plants of the cultivar TRI 2025 grown in peat based compost (pH=4.5) filled plastic pots (4 L volume), supplied with T65 nursery mixture as per recommendations, were used. The plants were grown in a growth chamber, acclimatized at different light intensities for 2 months (shaded, i.e. approximately 150-250 μmol m^{-2} s^{-1} PAR and unshaded, i.e. 650-750 μmol m^{-2} s^{-1} PAR) before measurements were taken.

Measurements

Photosynthesis and chlorophyll fluorescence Measurements

In all the experiments mature leaves with a swollen, active axillary bud was used for the measurements. Rate of photosynthesis and chlorophyll a fluorescence were measured on intact, healthy leaves.

In experiments 1 and 2, water vapour and CO_2 exchange of the leaves were measured at ambient CO_2 concentration (approximately 360 μmol mol^{-1}) and natural light intensities using a portable photosynthesis meter (model: LI-6200, Li-Cor inc., USA). Measurements were made from 5.30 a.m. to 7.30 p.m. at two hourly intervals. Two similar leaves on top of the canopy were used in each treatment. All the measurements were made when the leaves were enclosed in the chamber. Chlorophyll a fluorescence of photosystem II was measured using a portable modulated fluorescence meter (model OS-100, OSLOG-PP Systems, Hitchin, Herts, UK), soon after the photosynthesis measurements. F'_o was estimated using F_o, F_m, F_s, and F'_m (Oxborough and Baker, 1997). The F_o and F_m measurements were taken after completely darkening a set of similar leaves for a period of at least 45 minutes using dark adapted cuvettes provided by the manufacturer. When fluorescence reached a steady-state (F_s) in leaves exposed to actinic light, a saturating light pulse was applied to obtain the maximal fluorescence under actinic light (F'_m). Immediately after the photosynthesis and fluorescence measurements leaf disks of 10 cm^3 were taken using a cork borer, dipped in cold MCW (60% methanol, 25% chloroform and 15% distilled water) and frozen in –20 °C and analyzed for the content of total sugars and starch.

In experiment 3, a six-chamber open-circuit gas exchange system with automatic data handling (ADC, model 225 MK3 IRGA, Hoddesden, Herts, UK) was used. Photon flux was provided with metal halide photo-flood lamps. The light was passed through a cold water filter to remove IR and UV radiations, to maintain temperature. The rates of total linear electron transport, the allocation of electron transport products to CO_2 fixation and photorespiration were calculated according to Ghashghaie and Cornic (1994) using the gas exchange and fluorescence measurements.

Total soluble sugar and hot water soluble starch

The samples mentioned in experiment 2, were homogenized using a homogenizer (model T8) and soluble and insoluble fractions were separated by centrifugation at 4 °C for 3 minutes. The pellet was kept for starch analysis. An equal volume of distilled water and chloroform (10 cm^3) was added to the supernatant, shaken and separated into chloroform and aqueous methanol phases by centrifugation. The chloroform fraction was discarded and methanol -water fraction was removed and used for the total sugar content determination: to 50 μl of the sample, 0.9 cm^3 of anthrone reagent containing 0.15% w/v anthrone in 75% sulphuric acid was added, mixed and incubated in 40 °C for 20 minutes in a water bath. Each sample was replicated twice. Optical density was read at 630 nm in a spectrophotometer (model GBC UV/VIS 911A, GBC Scientific Equipment Pvt Ltd., Victoria, Australia) in disposable plastic cuvettes, against a blank. A standard curve was prepared using sugars of known concentrations and absorbance, and the sugar concentration per unit leaf area was calculated per unit leaf area.

Starch content of leaves was estimated in the pellet as follows: First it was extracted with 10 cm³ 80% methanol to remove traces of sugar. The extract was then centrifuged at 5000 rpm for 30 minutes, and supernatant was discarded. To the residue, 10 cm³ distilled water was added, well mixed and heated in a water bath at 100 °C for 30 minutes. It was then centrifuged at 5000 rpm for 30 min, supernatant was collected in 10 cm³ volumetric flasks and made up to the volume. Two drops of a mixture of iodine (I_2) and potassium iodide (KI) was added to the solution and the absorbance measured at 660 nm wavelength against a blank. A standard curve was prepared using known concentrations of starch and absorbances, and starch concentration per unit leaf area was calculated.

Data were analyzed using SAS and Genstat statistical packages.

RESULTS

Fig. 1 represents the light response curves of field grown tea in experiment 1. Tea leaves attained light saturation around 800 µmol m^{-2} s^{-1}. The maximum photosynthesis (A_{max}) of unshaded leaves was found to be nearly 40% less than the shaded, indicating the increased photosynthetic capacity of shaded tea leaves. They also had relatively low apparent quantum yields and larger dark respiration values (Table 1). Under increased N input, the gap of A_{max} between shaded and unshaded leaves narrowed down.

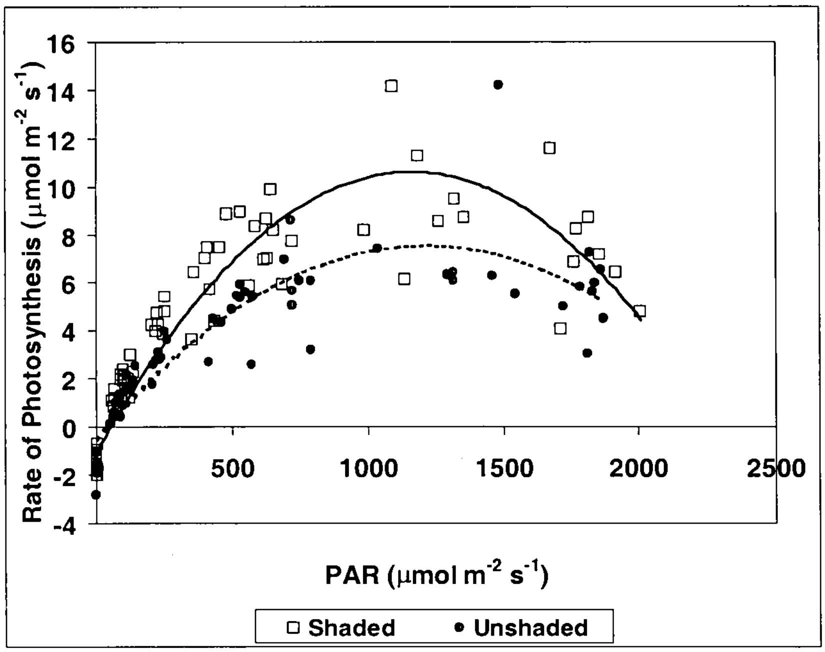


Figure 1. Light response curves of shaded and unshaded field grown tea leaves

Table 1. Mean photosynthetic parameters of the light response curves of field grown tea

	Apparent Quantum Yield (mol CO_2 mol^{-1} photons)	A_{max} (µmol m^{-2} s^{-1})	Dark respiration (µmol m^{-2} s^{-1})
Unshaded, High N	0.026	9.70	-1.56
Unshaded, Low N	0.025	7.09	-1.38
High Shade, High N	0.028	10.19	-1.17
High Shade, Low N	0.029	9.88	-1.15

As measured in the Experiment 2, the total linear electron transport rate was found to be similar in both shaded and unshaded leaves (Fig. 2). However, the differences lay in the allocation of the electron transport products: the allocation of electron transport products to CO_2 fixation was higher in shaded leaves than in unshaded leaves (Fig. 3). This was about 50% less in unshaded leaves than in shaded leaves. Conversely, allocation of electron transport products to photorespiration was significantly larger in unshaded leaves (Fig. 4).

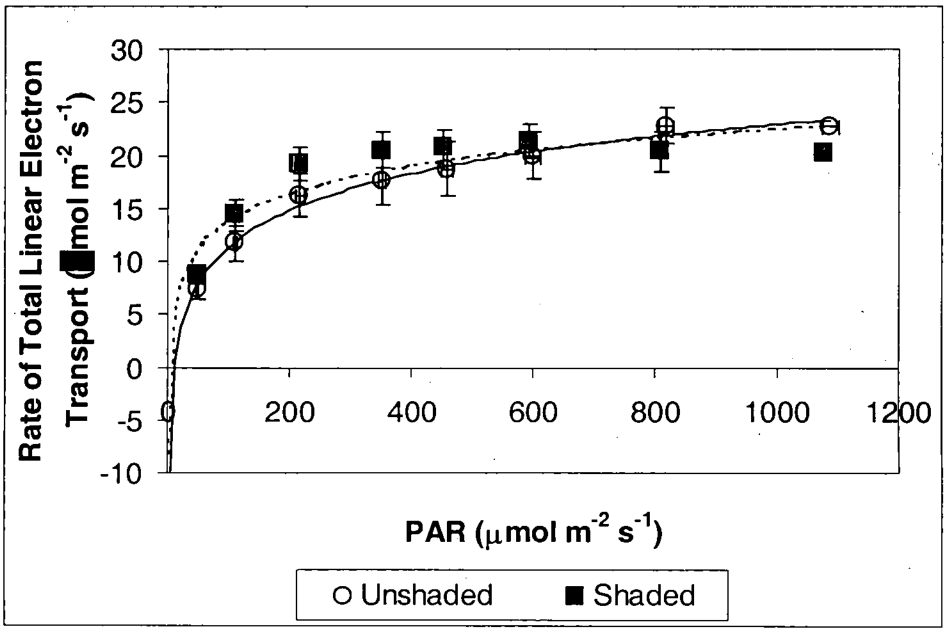


Figure 2. Rates of total linear electron transport of shaded and unshaded tea leaves

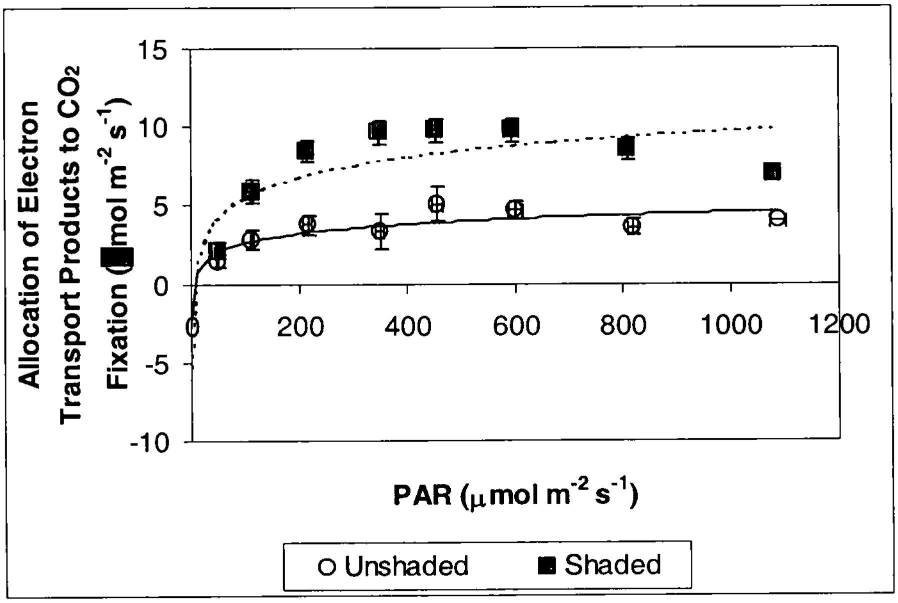


Figure 3. Allocation of electron transport products to CO_2 fixation in shaded and unshaded tea leaves

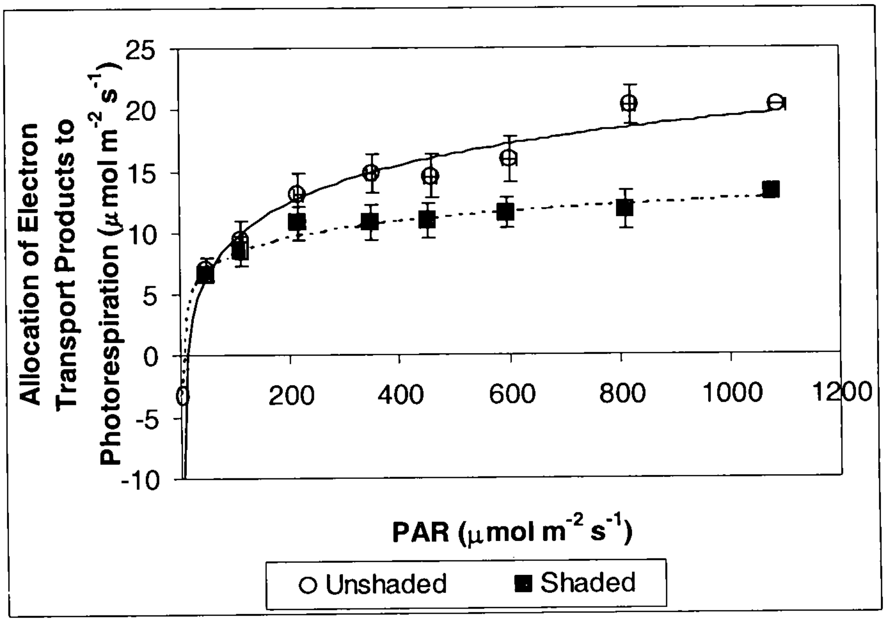


Figure 4. Allocation of electron transport products to photorespiration in shaded and unshaded tea leaves

The photosynthetically active radiation (PAR) was significantly low under the artificial shade than the other two treatments (Fig. 5). This was most prominent in the day categories A (bright, clear weather throughout the day) and B (morning and afternoon cloudy but bright mid-days). During cloudy weather throughout the day (category D), these differences between the treatments were not very prominent.

Interesting results could be observed with the photosynthesis measurements taken under different conditions: During bright, clear weather (category A), when there was high incident radiation intensity around mid-day, the rates of photosynthesis of unshaded leaves were significantly lower than in the other two treatments, which behaved in a similar manner (Fig. 6). In day categories B and C the rates of photosynthesis were not significantly different between the treatments.In general, the rates of photosynthesis were largest under the shade tree in all the day categories. When cloudy weather prevailed throughout the day (day category D), the photosynthetic rates under the artificial shade was the lowest amongst the treatments as the PAR did not reach saturating light intensities.

The changes in the leaf temperature did not show any significant differences between the treatments, during all the seasons (data not shown). In the day category A, when the rates of photosynthesis of unshaded leaves were significantly lower, the leaf water potential did not show any significant difference between the treatments (data not shown), indicating these differences were not due to any deficit of water in those plants. The total soluble sugar contents showed significantly lower contents in unshaded leaves than in the other two treatments (data not shown), indicating no end-product inhibition of photosynthesis in unshaded leaves.

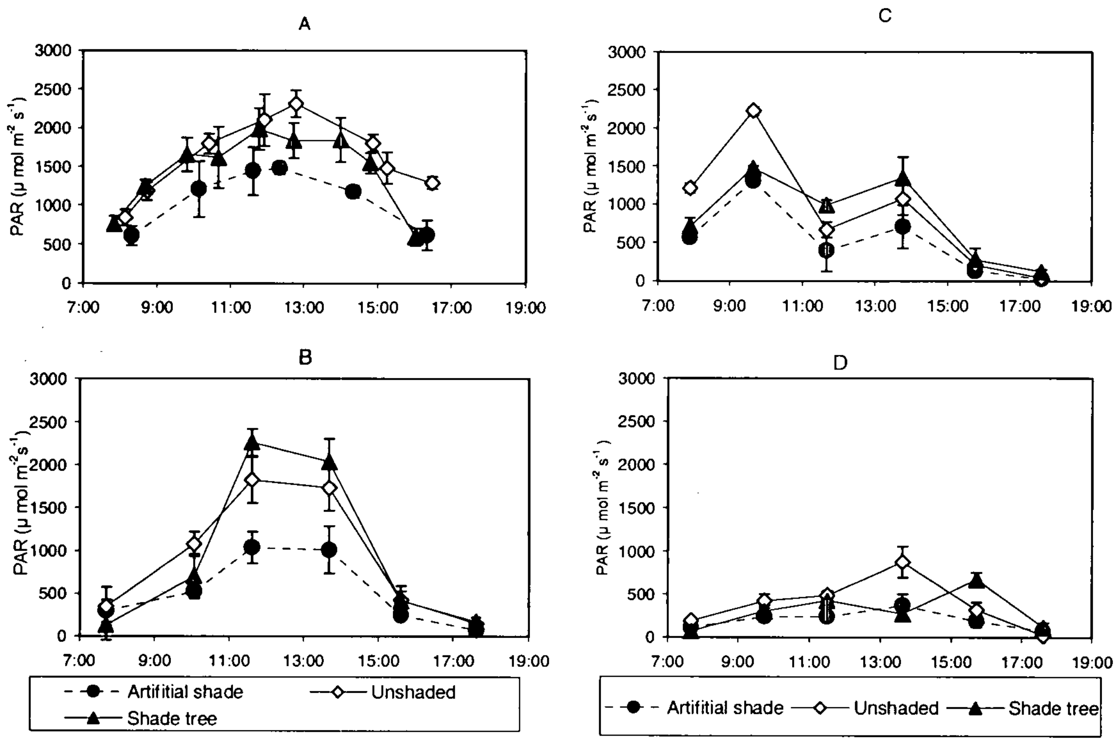


Figure 5. The PAR during the day in different seasons when the measurements were taken with field grown mature tea (Experiment 3): A: bright, clear weather throughout the day, B: Morning and afternoon cloudy but bright mid-days, C: Clear and bright mornings and cloudy afternoons, D: whole day cloudy.

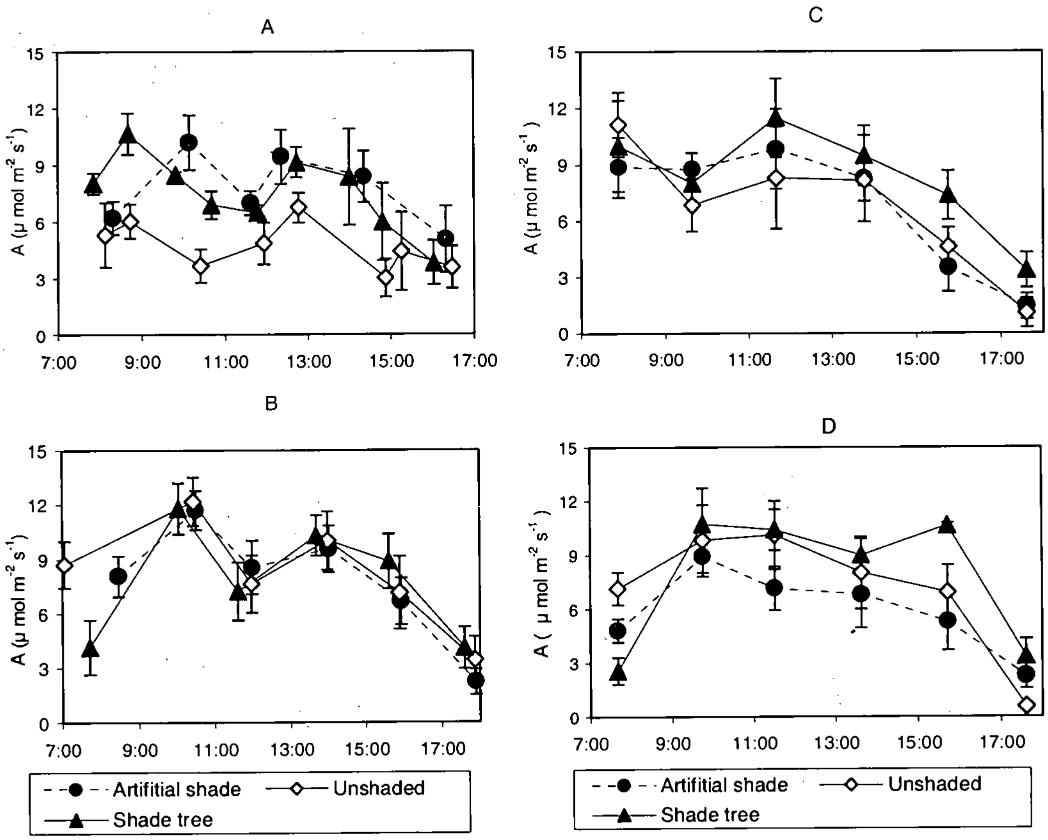


Figure 6. The diurnal variation of photosynthesis of tea leaves during different seasons when the measurements were taken with field grown mature tea (Experiment 3): A: bright, clear weather throughout the day, B: Morning and afternoon cloudy but bright mid-days, C: Clear and bright mornings and cloudy afternoons, D: whole day cloudy.

DISCUSSION

As shown with the light response curves, photosynthesis of tea is light saturated around PAR 800 μmol $m^{-2} s^{-1}$. At light intensities above this value, photosynthesis drops as a result of photoinhibition (Fig. 1). Shade increased the capacity for increased photosynthetic efficiency in tea, and at the same time decreased the dark respiration (Table 1). This was also evident with the photosynthetic measurements taken in the field, where unshaded tea leaves showed significantly low values than the values of shaded leaves. This increase could be observed both in day category A and mornings of day category C. The decreased rates of photosynthesis were also shown not to be due to any shortages of water or due to end-product inhibition. During consistently cloudy weather, only the plants in unshaded plots and under shade tree received light intensities adequate to drive light saturated photosynthesis. Increased rates of photosynthesis of tea under shade has been reported by several authors (Barman et al., 1993; Mohotti and Lawlor, 2002; Rajkumar et al., 2002). Many authors attribute these increases in photosynthesis to decreased leaf temperatures under shade (Barman et al., 1993; Hadfield, 1975). Shade is also reported to improve the bush health as measured by increased root starch content and increased chrorophyll content and increase soil water holding capacity and organic matter content than the unshaded tea (Rajkumar et al., 2002).

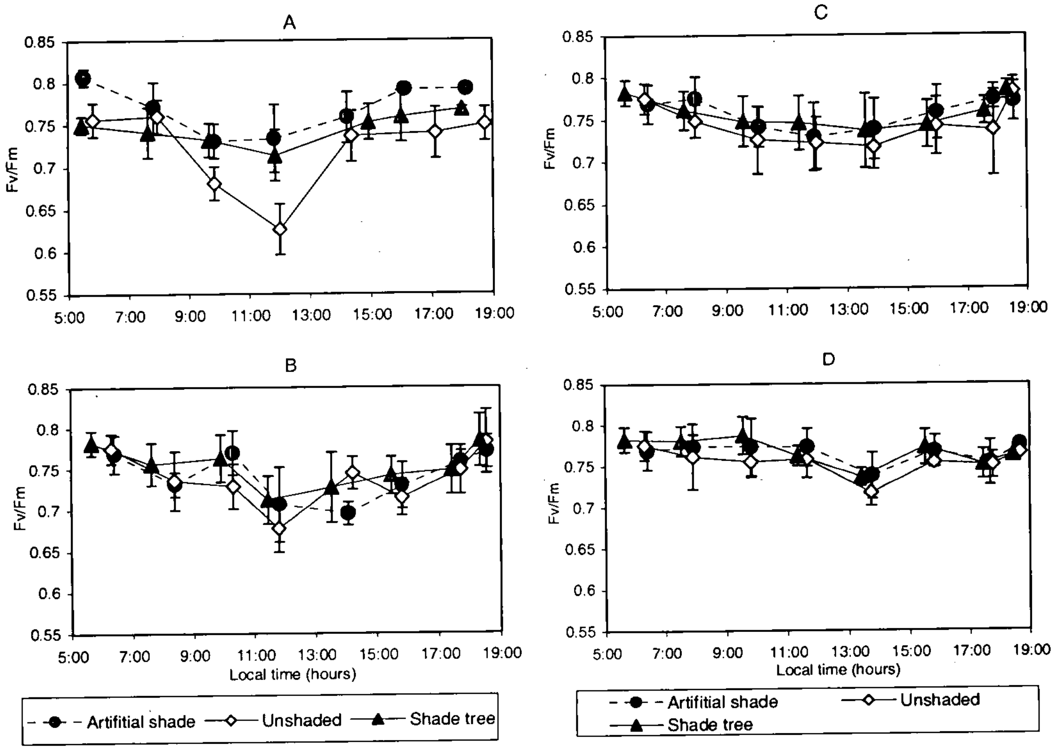


Figure 7. The diurnal variation in Fv/Fm of tea leaves during different seasons when the measurements were taken: A: bright, clear, weather throughout the day, B: Morning and afternoon cloudy but bright mid-days, C: Clear and bright mornings and cloudy afternoons, D: whole day cloudy.

Photosynthetic CO_2 assimilation is the culmination of the sub-processes of photosynthesis and their interactions. As shown by the subsequent figures, some processes related to light reactions of photosynthesis showed differences in relation to shade, therefore the increased CO_2 assimilation in relation to shade is expected.

The F_v/F_m is a measure of the intrinsic efficiency of the photosynthetic system in capturing excitation energy when the photosystem II reaction centers are fully oxidized (Genty et al., 1989). In general, F_v/F_m in tea was lower than the classical value of 0.8 in healthy, unstressed leaves and was reached to a near figure only during the night period. The fact that tea has relatively lower value of F_v/F_m could mean that tea has less efficient primary photochemistry of photosystem II which could be due to the nature of the light harvesting complex-reaction center interactions with less efficient mechanisms for energy transfer. Shading increased the F_v/F_m and hence increased the efficiency of the primary photochemistry of photosystem II. This complies with some earlier work (Mohotti, 1998), where F_v/F_m of close to 0.75 has been reported in field grown tea, which was increased with shading.

Analysis of electron transport provided clear evidences of the beneficial effects of shade in tea. The rates of total linear electron transport were not significantly different between unshaded and shaded tea leaves. The differences lay in the allocation of electron transport products: Its allocation in CO_2 fixation was significantly greater in shaded tea leaves. The allocation of electron transport products to photorespiration was substantially greater in unshaded tea leaves. The greater rates of photosynthesis in shaded tea leaves could be a result of this allocation of electron transport products to CO_2 fixation.

At higher light intensities, photons are in excess of those that can be utilized in CO_2 assimilation (Pearcy, 1998). Also, if conditions restrict CO_2 assimilation and yet the leaves absorb the same number of photons the rate of photosynthetically generated energy equivalents is in excess of what is required by the dark reactions of photosynthesis. In such instances there may be an imbalance between photosynthetic processes, which can lead to an over-reduction of the photosynthetic electron transport chain, causing effects such as photoinhibition (Biehler and Fock, 1996). There has also been previous records of photoinhibition of field grown tea in Sri Lanka (Mohotti and Lawlor, 2002) and Tanzania (Smith et al., 1993). Mohotti and Lawlor (2002) have claimed that the recovery from photoinhibition was independent of shade or N nutrition of the tea bush, contrary to this experiment.

It was also evident that photoinhibition occurrs in unshaded leaves, as measured by F_v/F_m (Figure 7): it is also considered as a measure of photoinhibition. The F_v/F_m was significantly lower in unshaded tea leaves than the other two treatments, between 9:00 –15:00 hours. The decrease in F_v/F_m could also be due to adjustment of the mechanisms to cope with intrinsically greater radiation loads experienced during bright sunny days. Except in the day category A, there was no difference in F_v/F_m between the treatments during other seasons indicating the decrease in photosynthesis of tea due to photoinhibition occurs only under bright and clear weather. During this type of days, differences in the morning values of photosynthesis and F_v/F_m between different treatments were not statistically significant, indicating the photoinhibition was removed during the night. However, the morning values of photosynthesis were smallest in unshaded leaves indicating that this recovery is slower when tea leaves were unshaded. In conclusion, shade was found to be having beneficial effects on the physiological measurements that were taken, which could have an impact on the productivity. Interestingly in terms of the physiological responses, the best microclimate to the tea was provided under the shade of *Grevillea robusta* L.

ACKNOWLEDGEMENTS

Dr D W Lawlor, IACR-Rothamsted, UK who has given valuable advice and guidance, post graduate and under graduate students of the University of Peradeniya, and staff of Physiology Division of the Tea Research Institute who contributed in collecting data are gratefully acknowledged.

REFERENCES

Barman T S, Baruah U and Sarma A K 1993 Effect of light and shade on diurnal variation of photosynthesis, stomatal conductance and transpiration rate in tea. *In* Tea Science and Human Health. pp 208-218. Proceedings of the International Symposium Tea Tech, 1993, India.

Barua D N 1989 Science and practice in tea culture. Tea Research Association, Culcutta, 509p.

Barua D N and Gogoi B N 1979 Effects of shade removal. Two and a Bud 26 (1) 40-42.

Biehler K and Fock H 1996 Evidence for the contribution of the Mehler-Peroxidase reaction in dissipating excess electrons in drought stressed wheat. Plant Physiol. 112 265-272.

Dutta S K 1961 Efficient use of shade trees. Two and a Bud 8 (4), 16-24.

Eden T 1976 Tea, 3rd Ed., Longman Group Ltd., London, 54-73.

Genty B, Brianthais J and Baker NR 1989 The relationship between the quantum yield of photosynthetic electron transport and quenching of chlorophyll fluorescence Bichim. Et Biophysic. Acta 990 87-92.

Ghashghaie J and Cornic G 1994 Effect of temperature on partitioning of photosynthetic electron flow between CO_2 assimilation and O_2 reduction and on the CO_2/O_2 specificity of Rubisco. J. of Pl. Physiol. 143, 643-650.

Hadfield W 1962 New thoughts on shade. Two and a Bud 9 (4), 16-24.

Hadfield W 1975 The effects of high temperatures on some aspects of the physiology and cultivation of the tea bush, *Camellia sinensis*, in North East India. *In* Light as an ecological factor II, The 16th Symposium of the British Ecological Society. Eds. G C Evans, R Bainbridge and O Rackham, pp 477-495. Blackwell Scientific Publications, Oxford.

Masters J W 1863 J. Agric. and Hort. Soc., 13(1), 31-47.

McCulloch J S G, Pereira H C, Kerfoot M A and Goodchild N A 1965 Effect of shade trees on yields. Agr. Meterol., 2, 385-399.

Mohotti A J 1998 Effect of irradiance and N nutrition on photosynthesis of tea (*Camellia sinensis* (L.) O. Kuntze) in comparison with sunflower (*Helianthus annus* L.) PhD Thesis, University of Reading, UK. 195p.

Mohotti A J and Lawlor D W 2002 Diurnal variation of photosynthesis and photoinhibition in tea: effects of irradiance and nitrogen supply during growth in the field. J. of Expl. Bot. 53(367), 313-322.

Murthy S B K 1996 Shade in tea plantations. The Plant. Chron. 591-595.

Obaga S M O and Othieno C O 1987 Effect of different types of shades and nitrogen rates on tea yields; Preliminary results. Tea 8 (2), 57-62.

Othieno C O 1983 Studies on the use of shade in tea plantations in Kenya. 1. Effects on nutrient uptake and yield of tea-preliminary results. Tea 4 (2), 13-20.

Oxborough K and Baker N R 1997 Resolving chlorophyll a fluorescence images of photosynthetic efficiency into photochemical and non-photochemical components-calculation of q_P and F_v2 /F_m2 without measuring F_o2 . Photosyn. Res. 54, 135-142.

Pearcy R W 1998 Acclimation to sun and shade. *In* Photosynthesis, A comprehensive treatise. Ed. A S Raghavendra pp 251-263, Cambridge University Press, UK.

Rajkumar R, Marimuthu S and Muraleedharan N 2002 Photosynthetic efficiency of sun and shade grown tea plants, S. L. J. Tea Sci. 67 (1/2), 67-75.

Sivapalan P 1993 Shade and green manure trees in tea – A holistic appraisal. S. L. J. Tea Sci. 62 (2), 41-46.

Smith G, Stephens W, Burgess P J and Carr M K V 1993 Effects of light, temperature, irrigation and fertilizer on photosynthetic rate in tea (*Camellia sinensis*). Expl. Agric. 29, 291-306.

Productivity and Tapper Shortage in Rubber Plantations; How Low Frequency Tapping Can Address the Shortage of Tappers in Rubber Plantations of Sri Lanka

V H L Rodrigo, N A A D Wickramarathna and R D Vidanapathirana
Rubber Research Institute of Sri Lanka, Dartonfield, Agalawatta, Sri Lanka

ABSTRACT

Tapper shortage is a serious problem in rubber plantations and low frequency tapping (LFT) systems are considered to be a solution to this issue by reducing the tapper requirement. The present study was aimed to assess the severity of tapper shortage and its effects on the productivity in the plantation sector of Sri Lanka together with the level of adoption of LFT. Attempts were made to identify any constraints for the adoption of LFT. Information was initially gathered using a questionnaire based survey and then observations were verified through a central workshop. The study revealed that the poor productivity in the plantation sector was highly associated with the tapper shortage with that as an average 12% of mature rubber area has been left untapped and 38% of the tappers have been unskilled. An extensive programme is proposed to overcome tapper shortage whist uplifting the productivity and profitability of rubber estates. In that, the application of LFT together with improved ground conditions and proper incentive schemes that would transmit some benefits of LFT to tapper, could be considered as an immediate need. Tapper training programmes and large scale demonstrations were identified as primary needs for the effective introduction of LFT to the plantation sector.

Key words: labour, low frequency tapping, plantation, rubber

INTRODUCTION

Rubber industry plays an important role in Sri Lankan economy making an export earning of US$ 196 million per annum (Central Bank, 2001) and the livelihood of over 500 thousand people (CARP, 1992). It has also supplemented to the forest cover with 157 thousand hectares (Central Bank, 2001). Moreover with quality timber produced, it is a long-term sink for atmospheric carbon, hence important in carbon trading. Despite some short-term fluctuations of rubber price, the demand for natural rubber has shown steady increase throughout the past. In Sri Lanka, industries based on rubber are rapidly developing with that the local value addition of rubber has increased by over twofold during last decade (Plantation Sector Statistical Pocket Book, 2003). In order to support these growing industries, production of natural rubber in the country has to be increased in a cost effective manner. In commercial plantations, exploitation of latex (tapping) is the most costly operation contributing to ca. 1/3 of the cost of production (Nugawela et al., 2000). In addition, it requires high level of skill and this contributes partly to the problem of tapper shortage. The problem is aggravated if any increase in tappers' wages cannot be afforded. Ultimate effect of tapper shortage is such that large extents of productive rubber clearings have been left without being properly tapped. A previous study in the plantation sector of Sri Lanka has shown that on average ca. 20% of vacant tapping blocks exist in an estate due to the shortage of tappers (Nugawela et al., 2000), whilst over 3500 hectares were recorded to be untapped in 2001 in the smallholder sector due to the same or its combined effect with poor market prices prevailed (unpublished data of Advisory Services Department of RRISL). Further, to overcome the tapper shortage, unskilled tappers are employed at the cost of the long-term yield potential of rubber trees. Removal of skill factor has not been successful and also, not cost effective in instances where it has been tried (eg. Mechanized tapping). Therefore, local and international focus has been made to introduce low frequency tapping systems (LFT) with the objective of reducing the requirement of tappers to a minimum. In Sri Lanka, instead of the traditional system of tapping a rubber tree in alternate days (1/2S D/2), a LFT system, i.e. tapping once in three days with ethephon stimulation (1/2S D/3 + ET), has been introduced by the RRISL in order to address the shortage of tappers. It is expected that any potential yield loss due to reduced tapping frequency is compensated by increase in yield from ethephon stimulation. First recommendation was issued in 1994 (RRISL 1994) and if adopted, this would have brought down the tapper requirement by 1/3 and cost of tapping by ca. 20% (Nugawela et al., 2000). Nevertheless, the level to which this system has been adopted is not clearly known, but appears to be very low according to the general consensus. This indicates that there may be some hindering factors for the adoption process and, those have also not been identified to date. Based on these facts, the present study was aimed to assess the severity of tapper shortage with respect to the productivity and to identify the level of adoption of LFT systems together with the possible constraints, if any, for the adoption of LFT in the plantation sector of Sri Lanka.

MATERIALS AND METHODS

The study was done during the latter half of the year 2003 and comprised with two steps, a questionnaire based rapid appraisal and a workshop to verify the findings of the rapid appraisal.

Rapid appraisal

The questionnaire of the rapid appraisal was formulated using the checklist given in table 1 and aimed to investigate the issues related to tapper shortage in the plantation sector of the rubber industry. The questionnaire was pre-tested in two commercial plantations and then, sent by post to 160 estates in 17 Plantation Companies that govern all rubber plantations in Sri Lanka. Information was provided by 69 estates representing all 17 companies. However, data analyses were confined to 55 estates in 11 companies due to discrepancies in the information provided.

Table 1. Checklist used in the questionnaire based rapid appraisal

- Availability and the requirement of tappers in different plantations
- Availability of skill tappers
- Financial loss due to tapper shortage
- Extent to which a low frequency tapping system is practised
- Potential area for the d/3 system and how it will solve the tapper shortage
- Distribution of tappers in different age categories
- Availability and the requirement of casual labours in different plantations
- Casual labours falling into different age categories

Yield performance of each estate with respect to land area and tapper productivity was assessed. Tapper availability was evaluated in terms of average daily outturn of both permanent and substitute tappers and vacant tapping blocks. Adoption of the LFT and its potential effectiveness to solve the negative effects of tapper shortage were assessed. The age distribution of tappers was also examined in order to assess the future trends in tapper availability. Also, availability casual labour was examined to consider the possibilities of training them for tapping.

Data analyses were conducted mainly on rather descriptive manner. In order to derive the parameters at national level, data were initially summarised on estate basis and then overall figures derived. However where necessary, data were analysed on company basis, i.e. only for the companies of which more than three estates provided information requested by the questionnaire.

Workshop for planters

After the data analyses, a central workshop (one day) was organised at the RRISL for the planters. Managers of rubber plantations who responded to the questionnaire-based survey were the invitees of the workshop and in total 42 planters participated. Work programmes of some plantation companies did not permit all invitees to participate in the workshop, hence allowed reasonable representation. In addition to the planters, scientists and technicians working on rubber exploitation joined the workshop.

Primary aim of the workshop was to review the outcome of the rapid appraisal and then to build up an action plan to over come the problems associated with tapper shortage. Based on the findings of the rapid appraisal, an overall review on the productivity and tapper related issues in the plantation sector was presented by the researchers together with an analysis on the effectiveness of LFT to address the tapper shortage. Then the planters were requested to divide into four groups for the working session in which each group discussed on the importance and the reliability of the review presented, the practicality of LFT and any other measures to be taken up to address the tapper shortage and an action plan to overcome the problem of tapper shortage.

Each group comprised planters from different companies and areas and scientists acted purely as facilitators in the discussion process. At the end of the discussion, each group appointed someone to present their conclusions. On issues where groups were in different opinions, there was an extended discussion to finalise conclusions.

RESULTS

Outcome of the rapid appraisal

The productivity of latex production at the estate level varied between 530 to1314 kg ha^{-1} on area basis and from 3 to 9.8 kg day^{-1} on tapper basis with mean values of 893 and 6.4 kg, respectively (Table 2). Number of trees allocated to each tapper was 600 and in general, in a two tapping blocks. All estates practised d/2 tapping system (i.e. tapping a tree on every other day) and in 87% of their mature rubber. Low frequency tapping with ethephon stimulation was practised by few estates (10%) and in an area representing less than 2% of total mature extent of the plantation sector. However, the LFT was generally practised without stimulation in a larger extent (ca.10%) during the first year of tapping (i.e. 48% estates) and to the clones recommended for tapping at d/3 without stimulation (i.e. 25% estates) (Table 2).

Table 2: Productivity levels and the adoption of tapping systems in the plantation sector of the rubber industry of Sri Lanka. Technical terms 1/2S d/2 and 1/2S d/3 refer to half spiral tapping at every two and three days frequencies, respectively whilst ET is for ethephon stimulation.

Average yield (kg/ha/yr)	893.4
Average daily intake per tapper (kg)	6.4
Proportion of estates practising 1/2S d/2 tapping	100%
Proportion of estates practising 1/2S d/3 +ET	10%
Proportion of estates practising 1/2S d/3 during the 1st year of tapping	47.8%
Proportion of estates practising 1/2S d/3 for d /3 clones	24.6%
Proportional extent under 1/2S d/2 tapping; total	87.6%
in virgin bark	*54.8%*
in renewed bark	*31.8%*
Proportional extent under intensified tapping	13.5
Proportional extent under 1/2S d/3 + ET tapping	1.3
Proportional extent under 1/2S d/3 during the 1st year of tapping	5.4
Proportional extent rubber under 1/2S d/3 for d /3 clones	5.6

On average for the plantation sector, trees with intensified tapping occupied in the 13.5% of mature extent whilst the composition of the area under the d/2 tapping in virgin and renewed barks were 55% and 32%, respectively (Table 2). The daily total requirement of tappers in an estate depended on the area under mature rubber, however on average, tapper requirement of an estate was 135 (Table 3). More importantly, hardly any company or estate had permanent tappers up to the requirements. On average for an estate, availability of permanent tappers has been limited to 71% whilst usage of substitute tappers was 17% of the total tapper requirement. Therefore, untapped area represented by the vacant tapping blocks, occupies 12% of the mature extent.

Table 3: Summary on the tapper requirement and availability in plantation companies of Sri Lanka. Only the companies of which more than three estates responded to the questionnaire are shown. Values represent the mean for the estates in different plantation companies with standard error.

Company	Tapper requirement per day		Usage of tappers and vacant tapping blocks		Yield loss due to vacant tapping blocks (kg ha^{-1} yr^{-1})
		Permanent tappers %	Substitute Tappers %	Vacant blocks %	
A	154 (±18)	77.2 (±8.1)	10.9 (±6.6)	11.9 (±6.1)	112.7 (±15.1)
B	228 (±44)	93.1 (±3.8)	5.9 (±5.0)	1.0 (±0.6)	97.1 (±6.3)
C	62 (±18)	69.6 (±4.1)	5.1 (±4.6)	25.3 (±4.7)	223.5 (±40.2)
D	106 (±40)	74.5 (±4.6)	13.9 (±5.3)	11.9 (±5.3)	101.1 (±24.1)
E	99 (±41)	48.0 (±8.1)	21.4 (±3.6)	30.6 (±4.5)	278.1 (±5.5)
F	225 (±42)	21.5 (±4.6)	76.8 (±4.3)	1.7 (±1.8)	12.6 (±3.1)
G	153 (±29)	90.8 (±5.2)	3.2 (±3.4)	6.0 (±2.3)	55.7 (±44.6)
H	89 (±32)	70.3 (±4.0)	7.9 (±3.3)	14.5 (±3.9)	149.5 (±13.2)
I	103 (±23)	92.8 (±2.5)	3.8 (±3.1)	3.7 (±0.7)	31.7 (±15.4)

On an average, potential yield loss due to vacant blocks was as high as 118 kg ha^{-1} per year (Table 3). However in some plantation companies, this value was extremely high with the highest value recorded as 278 kg ha^{-1} $year^{-1}$. If LFT, i.e. d/3 frequency with ethephon stimulation, were practised on either fully or partly, the tapper shortage of almost all estates would have been overcome. Out of 55 estates, the tapper shortage of 42 estates (76%) could be fully addressed by the LFT only with the permanent tappers leaving only 13 estates which may require some substitute tappers (Fig. 1).

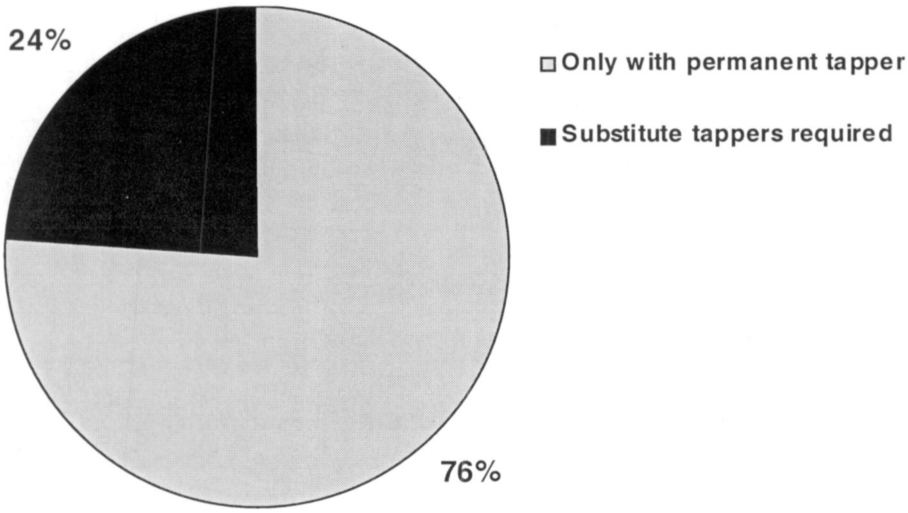


Figure 1. Proportion of estates where the tapper shortage could be addressed with Low frequency tapping.

Majority of tappers (ca. 60%) were in the age group of 31 to 50 (Fig.2). Tappers falling into the age groups of 21-30 and 51-60 were more or less same and only few were in the age above 60 and below 20. Similar to the age distribution of tappers, number of casual labourers falling into the age group 31 to 50 was greatest and then in 21-30 yr and 51-60 yr age categories (Fig. 3).

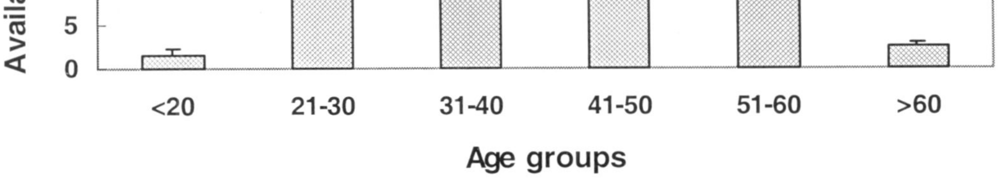


Figure 2. Age distribution of tappers in plantations. Values represent the mean for 55 estates with standard error as error bars.

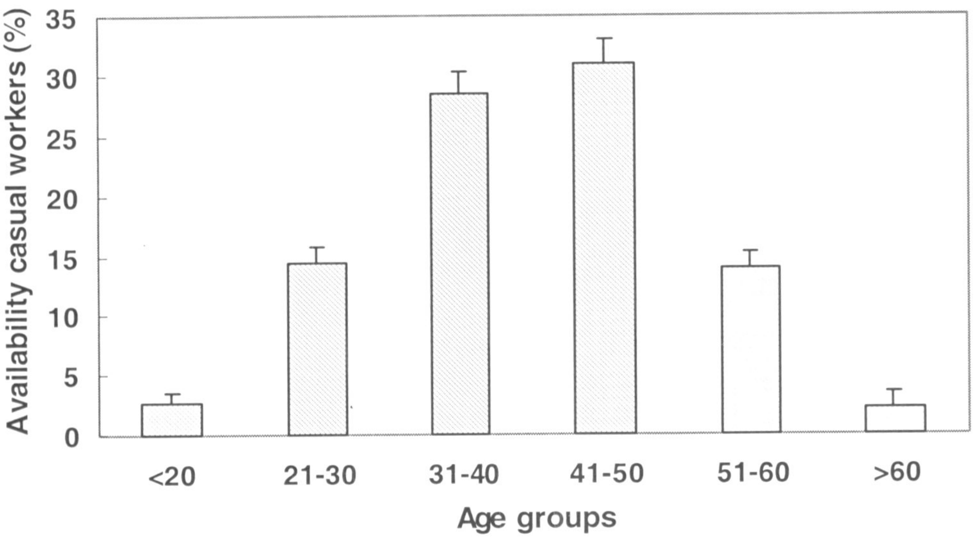


Figure 3. Age distribution of casual workers in plantations. Values represent the mean for 55 estates with standard error as error bars.

The composition of skill tappers was only 62% leaving 38% as unskilled (Table 4). In some estates, percentage of unskill tappers was as high as 89%. Gender ratio of tappers was biased towards female representing over 60%. However in the case casual workers, females were only 53% showing ca. 10% difference from tappers. In general, the majority of tappers were residing within the estate whilst the ratio of residents to non residents was approximately 1:1 for casual workers.

Outcome of the workshop

All participants agreed with the outcome of the rapid appraisal and emphasised that the problem of tapper shortage in the rubber industry should be addressed without any delay. The general opinion were that the tapper shortage is governed by poor social dignity for tappers, unfavourable weather conditions offering interrupted working days, poor wage structure for tappers with lack of incentives, poor ground conditions (eg. weeds) and infrastructure facilities (eg. long distance head carrying of latex) and lack of tapper training programmes.

Most of participants were not aware of the full protocol of the LFT. However the workshop was an opportunity for them to discuss all aspects of the LFT. Participants preferred to practise LFT with stimulation (1/2S d/3 + ET) instead of the most widely adopted alternate day tapping, i.e.1/ 2S d/2 due to the reduced requirement of tapper. This will reduce the present level of untapped vacant tapping blocks and the use of unskilled tappers maintaining the potential yield levels of mature clearings and the tapping quality. More importantly, with increase in tree yield per tapping, LFT can enhance the daily income of tappers if an effective incentive system is implemented. However, LFT alone cannot solve the problem of tapper shortage in long run. Therefore, participants were of the opinion that LFT should be implemented as a package considering all associated factors of tapper shortage. Further, the need of a dissemination process which will demonstrate the effectiveness of the LFT and other measures to tackle the tapper shortage, was emphasised. Accordingly, the action plan given in table 5 was formulated by the participants.

Table 4: Status of tappers (a) and casual labourers (b) on basis of gender, residing within the estate and skill for tapping in plantation companies of Sri Lanka. Only the companies of which more than three estates responded to the questionnaire are shown. However, the mean value represents all estates (55) responded to the questionnaire.

(a)	TAPPERS					
COMPANY	% Male	% Female	% Resident	% Non resident	% Skilled	% Unskilled
A	29.77	70.23	46.9	53.1	63.9	36.1
B	56.05	43.95	49.31	50.69	74.1	25.9
C	42.87	57.13	68.3	31.7	73.35	26.65
D	18.1	81.9	45.99	54.01	33.24	66.76
E	25.96	74.04	70.17	29.83	61.19	38.81
F	69.86	30.14	31.28	68.72	69.47	30.53
G	35.13	64.87	47.29	52.71	75.53	24.47
H	29.84	70.16	64.67	35.33	40.8	59.2
I	26.28	73.72	34.39	65.61	97.54	2.46
Mean	37.17	62.83	57.94	42.06	62.18	37.82

(b)	LABOURS			
COMPANY	% Male	% Female	% Resident	% Non resident
A	51.3	48.7	47.02	52.98
B	49.2	50.8	44.6	55.4
C	41.97	58.03	59.15	40.85
D	54.88	45.12	56	44
E	54.1	45.9	65.89	34.11
F	31.32	68.68	30.72	69.28
G	42.33	57.67	51.25	48.75
H	41.08	58.92	68.26	31.74
I	43.23	56.77	30.91	69.09
Mean	46.61	53.39	49.04	50.96

Participants proposed to launch a national programme addressing the points mentioned in table 5 in 40-50 estates. In each estate, an extent of ca. 50 ha is initially allocated to this programme and these sites will be used as both adaptive research sites and models for the demonstration purpose in the national programme to overcome tapper shortage. Plantation companies are prepared to provide partial funding for the programme, if the financial assistance to cover the cost on materials and monitoring is met by another party.

DISCUSSION

Tapper productivity of rubber plantations in the estate sector of Sri Lanka appeared to be rather poor when compared to that in neighbouring countries. It could be attributed to the existing levels of land productivity (IRSG, 2004) suggesting that agro-management conditions have to be improved. In perennial crops like rubber, the yield potential of mature trees basically depends on the quality of planting materials used at the beginning and how plants are looked after during the immature phase. Raising the productivity through these factors is a long-term strategy, however, it has been evident that a remarkable yield improvement could be achieved within a short period by correct application of tapping techniques. Unskill tappers have largely been employed in Sri Lankan plantations and that would have been the single most important factor which affects the quality of tapping. According to Nugawela et al. (2000), yields obtained by unskilled tapperes are generally 25% less than those of skilled tappers. In the absence of regular tappers (i.e. permanent tappers) in required numbers, substitute tappers who are undoubtedly unskilled, are generally used to minimise the yield loss in untapped (vacant) tapping blocks. Nevertheless, poor quality tapping of those substitutes reduces not only the instantaneous latex yield but also long-term latex and timber yield potential of rubber trees with irreversible damages to the bark and wood.

Table 5. Action plan to overcome the tapper shortage along with Low frequency tapping.

To upgrade the social status of tappers and their social security; • Provision of uniforms to tappers • Provision of adequate recognition using a proper designation to tappers. • Awareness programmes on the importance of the tapping profession even at school level.
To improve the knowledge and skill of tappers; • Awareness programmes on LFT. • Tapper training programmes.
To upgrade financial status of tappers; • Introduction of attractive incentive payment schemes for additional latex brought by tappers. • Maintain transparency in latex weighing and payments to tappers. • Provision of fringe benefits to tappers (eg. uniforms, pension scheme, meals and health care facilities). • Introduction of banking systems and cooperative societies to encourage tappers to adopt proper finance handling systems. • Adoption of rainguard technology to increase the number working days of tappers.
To reduce the tediousness in tapping operation; • Improvement in ground conditions eg. making foot paths and weeding, providing latex transport facilities and additional collecting centres to avoid head carrying of latex. • Provision of good quality tapping utensils. • Adoption of the techniques on division of labour, e.g. skill tappers are employed only for tapping and sundry workers for other activities in tapping operation such as cup cleaning and latex collection.

More importantly, poor attendance of tappers resulted in large extent of untapped area on each day and explained another factor for low level of land productivity. Even with substitute tappers, it was clearly evident that existence of untapped area had not been totally wiped out with that ca. 12% of mature rubber extent were untapped. In a situation where number of tappers is inadequate, obviously the low yielding areas are left out without tapping, however, it is still a significant share of the total yield of an estate. Had there been no such level of untapped area, the present level of average yield per hectare per year (YPH) would have approached the value 1000 kg. Further increase in YPH could be expected, if skilled tappers replace unskilled tappers.

Only ca. 80% of tappers were employed on permanent basis. The rest, i.e. substitute tappers, are considered to be almost unskilled; and even among permanent tappers, a significant share was unskilled explaining why % unskilled- exceeded the % substitute-tappers. On this basis, the portion of the permanent tapper falling into unskilled category could be estimated as ca. 18%. In order to overcome the yield losses in the traditional d/2 tapping system resulting from the existence of vacant tapping blocks and unskilled tappers, the tapper availability should be increased by over 12% together with a proper programme to convert unskilled- to skilled-tappers. Tapper training programmes would be one solution especially for the latter, however there should be a proper incentive scheme to motivate tappers to continue with their quality tapping. Improved remunerations would play a big role in this regard. Most estates in Sri Lanka adopt special payment schemes for tappers to encourage them to harvest for high yields. However, the biggest weakness of these schemes is that there is no any assessment on the quality of tapping. Tappers would therefore try to bring maximum possible yields with no intention to protect the long-term yield potential of rubber trees.

When compared with casual labourers of the estate, tappers could earn little more through the incentive schemes available in the estate sector, however those incentive schemes may not be attractive or competitive enough to retain good tappers or recruit new ones. Also, the estate managers are concerned with the existing level of expenditure on tapping which is supposed to be ca. 30% of the cost of production of rubber (Nugawela et al., 2000). Therefore, any further increase in the wages of tappers should depend on the amount of latex harvested by them. Low frequency tapping systems facilitate to increase the number of trees allocated to each tapper thereby reducing the tapper requirement. In Sri Lanka, the low frequency tapping system (LFT), i.e. tapping once in three days with 2.5% ethephon stimulation four times per year (i.e. 1/2S d/3 ET2.5% 4/y), has been proven to produce similar yields given by the traditional alternate day (d/2) frequency tapping. Obviously, with given three tapping blocks to each tapper, it reduces the requirement of tappers by one third over the traditional d/2 system with that the tapper shortage of most of estates can be solved only with skilled tappers. More importantly, the tapping cost is reduced by ca. 20% due to increase in tapper productivity resulted by the increase in latex yield per tree per tapping in LFT (Nugawela et al., 2000). Increased tapper productivity in the d/3 system facilitates to raise the daily income of tappers thereby motivating them to be in tapping profession as skilled tappers.

Annual bark consumption rate of the d/3 is less than that in traditional d/2 due to less number of tapping days per year with that the economic lifespan, i.e. tapping cycle, could be increased by ca. 6 years (Nugawela et al., 2000). This will increase the extent of mature rubber clearings (i.e. revenue area) of an estate increasing the overall profitability. Managing companies of rubber estates had no interest in replanting uprooted rubber during the recent past when rubber prices were very low and now plan to implement huge replanting programmes. In this context, the LFT will help to keep on tapping in existing mature clearing delaying uprooting thereby maintaining the mature/immature ratio at an economical level.

When compared with casual labouers, more women engage in tapping than men. Tapping requires a skill and perhaps it would be easier for women to achieve this skill. Also, more resident workers engage in tapping when compared with casual labourers. These factors could be taken into consideration in tapper training programmes. If it is required to retain females in tapping, sufficient support should be given to reduce the tediousness in the tapping process, e.g. facilities to collect latex in order to prevent head carrying. This is particularly important in LFT systems of which daily latex intake of tappers is greater than that of the traditional d/2 tapping.

A similar pattern of age distribution was shown in both tappers and casual workers. Although total labour force in the country between 20-30 and 30-40 is more or less same (Department of Census & Statistics, 2002), few tappers/casual workers were in the young age categories, i.e. below 30 yrs, confirming the unwillingness of the young generation for this type of jobs as proven in the workshop. Tapping is also considered to be a labour job for the people with no proper educational background. Particularly in Sri Lankan social context, tapping has lower level of social recognition compared to the most of other jobs for the same category of people. Therefore, young people with no proper educational background may prefer to join other jobs falling into the little higher level of the social ladder in the first instance, e.g. factory workers. However, they may have little options when they become older, so take up positions in the plantation sector. Therefore, it may also be necessary to take steps to upgrade the social status of tapping profession as mentioned in the action plan to overcome tapper shoratge. For instance, changing the designation, mindset at school level and proper uniforms could be considered in this regard. Also, necessary steps should be taken to establish the income stability of tappers.

LFT systems which require further reduction in tapping frequency, have been recommended in other rubber growing countries (Karunaichamy et al., 2001; Vijayakumar et al., 2000). In Sri Lanka, 1/2S d/3 tapping with ethephon stimulation was first introduced in 1994 (RRISL, 1994), however the adoption rate is rather poor although this system can undoubtedly solve the present level of tapper shortage in Sri Lankan estates. This suggests that publicity given so far on LFT has not been sufficient and extension programmes have to be strengthened. In support of weakness in technology transfer, the present study revealed that d/3 tapping without stimulation is still being adopted during the first year in tapping of rubber trees though at present it is not required according to the tapping recommendation in Sri Lanka (Nugawela, 2001). Also, clones recommended for d/3 tapping without stimulation have not been planted to a greater extent. Therefore, an extensive programme as suggested in the workshop should be launched to overcome tapper shortage whist uplifting the productivity and profitability of rubber estates. In that, application of LFT together with improved ground conditions and proper incentive schemes which would transmit some benefits of LFT to tapper, could be considered as an immediate remedy. Then as medium-term strategy, the tapper training programmes and application of rainguards play an important role whilst measures to upgrade the social status of tappers and their financial stability are long-term strategies. As shown in the workshop, short and medium term strategies could initially be implemented in 40-50 estates setting up adaptive research plots and models for demonstration purpose.

ACKNOWLEDGEMENTS

We thank the Rubber Research Institute of Sri Lanka (RRISL) for providing facilities to conduct this study. The support given by the staff of the Plant Science Department and Training centre of RRISL for the workshop is highly appreciated. This paper is an output from a project funded by the Council for Agricultural Research Policy (CARP) of Sri Lanka.

REFERENCES

CARP 1992 Status review report of the Rubber Reserch Institute of Sri Lanka; Operational area. Sri Lanka Council for Agricultural Research Policy, Colombo.

Central Bank 2001 Annual report of the Central Bank of Sri Lanka. 67-68.

Department of Census and Statistics 2002 Quarterly report of the Sri Lanka labour force survey. Department of Census and Statistics of Sri Lanka.

IRSG 2004 Rubber Statistical Bulletin. Vol. 58 (6). International Rubber Study Group, Wembley, UK.

Karunaichamy, K, Vijayakumar, K R, Thomas, K U, Rajagopal, R and Kumar, D A 2001 Response of rubber trees (*Hevea brasiliensis* Muell. Arg., clone RRII 105) to Low Frequency Tapping (LFT) systems. Indian Journal of Natural Rubber Research, 14 (2), 79-87.

Nugawela, A 2001 Exploitation for economic yields. *In* 'Handbook of rubber. Volume 1, Agronomy'. Eds. L.M.K. Tillekeratne and A. Nugawela, Rubber Research Institute of Sri Lanka. pp. 176-190.

Nugawela, A., Peries, M R C, Wijesekera, S and Samarasekera, R K 2000 Evaluation of d/3 tapping with stimulation to alleviate problems related to d/2 tapping of Hevea. Journal of the Rubber Research Institute of Sri Lanka, 83, 49-61.

Plantation Sector Statistical Pocket Book 2003 Ministry of Plantation Industries, Colombo.

RRISL 1994 Advisory circular – Tapping 1994/05. Rubber Research Institute of Sri Lanka.

Vijayakumar, K R, Thomas, K U and Rajagopal R 2000 Tapping. *In* Natural Rubber – Agromanagement and Crop processing, pp. 239-249 (Eds. P.J. George and C.K. Jacob) Rubber Research Institute of India.

List of abbreviation

LFT - Low frequency tapping
1/2S - Half spiral cut in rubber tapping
d/2 - Tapping a rubber tree once in two days
d/3 - Tapping a rubber tree once in three days
ET - Stimulated with ethephon

8201

Gliricidia - for Production of Green Manure and Green Energy in Coconut Plantations

H A J Gunathilake and H G Wasanthe
Agronomy Division, Coconut Research Institute, Lunuwila, Sri Lanka

ABSTRACT

An unreplicated research and development project on interplanting of *Gliricidia sepium* was established at the Pallama Coconut Genetic Resource Centre in the Low Country Intermediate Zone of Sri Lanka having objectives of generating data base on productivity of gliricidia for green manuring of coconut and for fuel wood production. Agronomic and economic data were collected and several of those are on microclimate, soil and palm nutrition, productivity on foliage and fuel production and finally on cost/benefit analysis. Study of long term impact of intercultivation of gliricidia on soil health and soil water in coconut plantations was also carried out.

Results showed that, intercultivation of gliricidia in coconut lands improved microclimate by increase utilisation of sunlight, reduce soil temperature and as a result, soil moisture was increased in soils of coconut with gliricidia over coconut with no gliricidia situation. Nutrition of coconut palms was increased in gliricidia plots and this was prominent in nitrogen probably due to fixation of atmospheric N by gliricidia. Except K, other plant nutrition such as P, Ca and Mg levels were also elevated in soils of gliricidia plus coconut that assumed gliricidia is mining nutrition from deeper layers to surface of soils through the process of pruning and decomposing of foliage.

Productivity of gliricidia was high and at the fifth year of planting, foliage and wood yields were 24.3 and 24.3 mt per ha respectively. From third year of planting, gliricidia was able to establish positive cash flow and fifth year old gliricidia inter cultivation generated Rs. 35,388 ha^{-1} yr^{-1} as net profit. This encourage coconut growers to intercultivate gliricidia in their coconut lands as a source of income while indirectly increasing fertility of their coconut soils to maintain sustainability of coconut plus gliricidia farming system. Finally, this could be considered as an environmental friendly CDM Project.

Key words: Coconut gliricidia, green manure, fuel wood, inter-cultivation

INTRODUCTION

Gliricidia sepium Jac. Welp is a versatile multipurpose tree species introduced to Sri Lanka in 1700's from the West Indies for boundary planting. It has been used in the perennial agricultural systems such as tea and spice crops and by small farmers in Sri Lanka over 100 years. It has now become naturalised in almost all parts of the country, including coconut-growing areas. It has been clearly demonstrated that Gliricidia could be grown successfully in coconut plantations without any detrimental effect on coconut yield (Anon., 2000). Nitrogen fixing tree legumes such as gliricidia offer opportunities to increase soil N levels. Gliricidia has been identified as a good source for green manuring, feeding ruminants, or to reclaim degraded soils and reduced soil erosion (Liyanage et al., 1998; Peoples and Herridge, 1990).

Gliricidia exhibits its unique advantage as a source of fuel wood particularly with the development of gasification technology. Coconut growers are now able to fertilise their coconut lands with lopping of gliricidia and gliricidia wood could be sold as a source of energy.

The objectives of this study were to demonstrate planting of gliricidia under coconut on a large scale as a research/development project and collect agronomic and economic data which are valuable for large scale dedicated green manure/green energy gliricidia intercultivation in coconut plantations, while assessing its impact on soil health and soil water in the long run.

MATERIALS AND METHODS

This unreplicated study was conducted in a 50 years old coconut plantation (planted in an 8 m x 8 m square pattern-156 palms ha^{-1}) at the Pallama Coconut Genetic Resources Centre (Low country intermediate Dry Zone) of the Coconut Research Institute from October 1998 to December 2003. Mean annual rainfall is around 1,400 mm, distributed in two crops cultivation seasons. Mean annual temperature is 30 C^0. The soil is clay loamy underlined (60–70 cm) with gravels. Transmission of photosynthetically active radiation at the site under coconut palms averaged 90% near mid day on a sunny day.

Gliricidia was planted vegetatively with mature sticks (diameter – 3-4 cm; height – 90 cm) in October, 1998. Three rows of gliricidia 1.0 m apart were planted in the avenue of coconut keeping 1.0-m distance within a row. Density of gliricidia was 3,750 trees ha^{-1}. Total extent of the study was 20 ha including 80,000 gliricidia trees.

Gliricidia and coconut trees were not fertilised with any inorganic fertilisers. This bio energy plantation was weeded twice a year. The soil temperature (C^0) was measured with "Casella" soil thermo meters at 5-cm depth around 14,00 hr on several days. Soil moisture was measured at 0 – 15 cm and 16 - 30cm depths using the gravimetric method.

Harvesting of foliage and wood was commenced from the second year onwards. Harvesting frequency was 8 months and yield was calculated on annual basis. Each sample consisted of 10 trees of gliricidia in six different locations distributed in 20 coconut ha. Weight of fresh foliage and weight of wood yield at 20% moisture level were measured.

Soil samples were within the distance of 0.5 m, from the base of gliricidia trees at two depths; 0 - 15 cm and 16 - 30 cm. The same in coconut monoculture was taken in centre of the coconut square.

Costing and income was reported on values that prevailed in the year, 2003.

RESULTS

Establishment of Gliricidia

All gliricidia sticks were planted by cuttings (height 1.0 m and diameter – 2.5-3.0 cm) during October-November rainy seasons. At the initial planting, sprouting percentage was 58 percent and subsequently two attempts were made to obtain 94 percent establishment rate at the end.

Effect of gliricidia on microclimate

(a) Sunlight penetration to the ground

Underneath coconut, 94 percent of sunlight reached to the ground using only 6% by coconut palms (Table 1). On average, after two months of pruning, 75% of sunlight was used by coconut plus gliricidia tree system as indicated by measurements taken in the middle and ground level of gliricidia rows. The same measured at 6 months after pruning was 94 percent. The sunlight reaching the ground was gradually developed and it was 15 percent at 8 months after pruning.

Table 1. Effect of gliricidia intercultivation on sunlight usage

Situation	% of sunlight received at the ground level	Usage by crops
Open field	100	0
Coconut alone	94	6
Coconut + Gliricidia (immature - 4 month after pruning)	25	75
Coconut + Gliricidia (6 months after pruning)	6	94
Coconut + Gliricidia (at the maturity 8 months after pruning)	15	85

(b) Soil temperature

During dry months (July-September), soil temperature was 41.4 ^{0}C at 14.00 hrs underneath coconut and the same in coconut plus gliricidia system was 31.5 C°. This reduction in gliricidia plot was 10 C° over coconut monoculture planting.

(c) Soil moisture

After prevailing 30 days dry spell, up to the depth of 15 cm, soil moisture was slightly higher in coconut stand than the same in coconut+gliricidia system (Table 2). However, the difference was not observed at the depth of 30 cm. At the 45 days of dry spell, soil moisture levels were always high in coconut + gliricidia system in comparison to soil moisture levels in coconut monoculture up to soil depth of 60 cm.

Table 2. Effect of gliricidia plus coconut cultivation on soil moisture

A) at 30 days dry spell

Situation	Soil depth (cm)		
	0-15 cm	16-30 cm	31-60 cm
Coconut only	4.7	4.8	5.2
Coconut + Gliricidia	4.0	4.9	5.6
A) 45 days dry spell			
Coconut only	2.2	3.4	3.6
Coconut + Gliricidia	4.1	4.6	5.2

Effect of gliricidia on soil fertility and coconut nutrition

(a) Nutrient levels of 14th leaf of coconut

Nitrogen level of 14th leaf of coconut was considerably increased where coconut intercropped with gliricidia. Such coconut palms with gliricidia showed high N level over leaf sufficiency range too (Table 3). Levels of Ca also followed the same trend. P and Mg levels were not different in the 14th leaf of coconut with and without gliricidia. However, coconut palms with gliricidia intercultivation showed reduced K levels in comparison to coconut without gliricidia.

Table 3. Effect of gliricidia intercultivation on coconut nutrition (14th leaf)

	N%	P%	K%	Mg%	Ca%
Coconut alone	1.68	0.11	0.91	0.35	0.39
Coconut + Gliricidia	2.18	0.12	0.84	0.33	0.54
Sufficiency range/level	1.9-2.1	0.11-0.13	1.2-1.5	0.25-0.35	0.35-0.5

(b) Soil organic carbon and nutrients

Soil organic carbon:

Coconut interplanted with gliricidia showed increase level of soil carbon over coconut soils without gliricidia. This was prominent at surface soil layer of 0 – 15-cm depth (Table 4).

Table 4. Effect of gliricidia intercultivation on soil organic matter (%) levels

Situation	Soil depth (cm)	
	0-15	16-30
Coconut only	0.46	0.5
Coconut + Gliricidia	0.76	0.55

The level of soil nitrogen was elevated nearly 1.5 fold in gliricidia plots over no gliricidia intercultivation. This increase was even high at the depth of 16-30 cm (Table 5).

Table 5. Effect of gliricidia intercultivation on soil N, P, K, Ca and Mg levels

Situation	N (ppm)		P (ppm)		K %	Mg %
	0-15	16-30	0-15	16-30	0-15 16-30	0-15 16-30
Coconut only	490	327	3.4	trace	0.15-0.17	0.8-0.7
Coconut + Gliricidia	644	471	8.1	5.6	0.23-0.26	1.1-1.1

The P level was more than doubled where coconut with gliricidia at the soil depth of 0-15 cm and continued to be high at 16-30 cm depth.

The soil K level was also high in plots of coconut with gliricidia over coconut with no gliricidia at both soil depths of 0-15 cm and 16-30 cm.

The soil Mg levels also showed as in K levels (Table 5).

Yield of Gliricidia

(a) Leaf yield (fresh weight)
Fig 1.a shows that leaf yield at the first year was 2 kg.tree/year and then increased to 5.0-6.0 kg $tree^{-1}$ yr^{-1} at fourth year and seems to continue at that level up to sixth year of planting.

(b) Wood yield (at 20% moisture)
At the second year, wood yield was 3 kg $tree^{-1}$ yr^{-1} and then increased to a maximum of 6 kg $tree^{-1}$ yr^{-1} at the fourth year after planting (Fig. 1a). Then wood and foliage yields were maintained equally up to sixth year of planting.

(a)

(b)

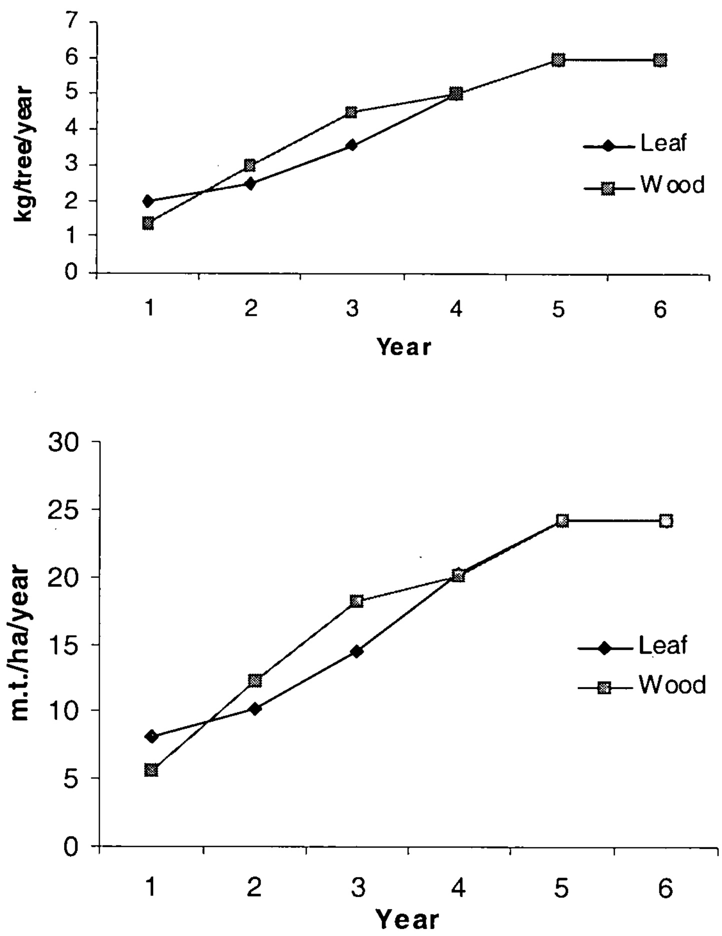


Figure 1. Gliricidia wood and leaf yield

With this productivity levels, gliricidia produced total biomass yield (foliage plus wood) of 48.6 mt coconut ha^{-1} yr^{-1} (Fig. 1b) at the 4th year.

Cost/benefits

During the first year, establishment of 1 ha of gliricidia cost Rs. 20,700/- and of the total establishment cost, 50% was for labour. From the second year onward, maintenance cost did not exceed Rs. 4,000 ha^{-1} yr^{-1}. At the fifth year, harvesting cost raised to Rs. 18,000 ha^{-1} yr^{-1} in addition to transport cost of gliricidia woods.

Income of gliricidia is calculated mainly from selling of wood and use of leaf biomass for fertilisation of coconut. Value of wood at 20% moisture level was Rs. 2.60 kg^{-1} and this market price generated Rs. 63,000/- ha^{-1} yr^{-1} in addition to value of leaf biomass. At the fifth year, leaf of gliricidia as a supplementary green manure was calculated as Rs. 6,200/- ha^{-1} yr^{-1} and total value of leaf and wood was Rs. 69,388 ha^{-1} yr^{-1}.

One hectare of intercultivated, gliricidia was able to generate approximately Rs. 35,000/- as a net profit in the 5th year.

Table 6. Expenditure and Income of interplanting gliricidia in 1 ha of coconut during the initial 5 year period (Rs.)

Activity	Year 1	Year 2	Year 3	Year 4	Year 5
A) Materials					
Planting materials	4,500	-	-	-	-
Weedicides	6,000	-	-	-	-
B) Labour					
Land clearing	2,500	-	-	-	-
Planting	2,800	-	-	-	-
Vacancy filling	900	-	-	-	-
Maintenance (Weeding etc.)	4,000	4,000	4,000	4,000	4,000
Harvesting	-	9,000	13,500	15,000	18,000
Transport (Rs/Mt.)	-	6,000	9,000	10,000	12,000
Total cost	20,700	19,000	26,500	29,000	34,000
C) Income					
Wood	-	31,720	47,320	52,520	63,180
Leaf	2,064	2,576	3,278	5,200	6,208
(equivalent to subsidised price of Urea)	-	-	-	-	-
Total	2,064	34,296	50,598	57,720	69,388
D) Net Profit (Rs/ha)	(- 18,636)	15,296	24,098	28,720	35,388

- Value of leaf was calculated on the basis of urea equivalent – 1.0 kg of urea = Rs 16.00
- Wood price – Rs 2.50 per kg (as 20% moisture level)

DISCUSSION AND CONCLUSION

Establishment

Planting of gliricidia could be done with sticks, and seeds. However, vegetative propagation by sticks is the most popular among growers; hence total planting of this research project was done with sticks. At the initial planting, 60% success rate was seen and personal observation revealed that at the time of planting, rainfall and reduced air temperature by cloud cover reduced mortality rate.

Effect on microclimate

It is evident from these results that intercultivation of gliricidia in coconut plantations caused a significant improvement in the soil and microclimate. Coconut seems to be a poor sunlight user; hence 94 percent of sunlight reached the ground, and field observations revealed that this encouraged excess growth of weeds. After pruning of gliricidia for wood and leaf, increase use of sunlight was gradually developed due to profuse regrowth. Light usage of 94 percent was reached by coconut plus gliricidia at six months after pruning. Undoubtedly, this would reduce weed growth. Reduced sunlight reaching the ground would reduce soil temperature considerably and this reduction was approximately 10 °C over coconut monoculture system. Reduce soil temperature particularly in tropical climate may have several benefits.

Among them, increase of root activity, reduction of soil moisture losses, reduction of soil carbon oxidation are important. Leaf litter developed by sheded gliricidia leaves would also cover the soil and thereby further reduce soil temperature. Reduction of dry wind blow due to gliricidia canopy cover may have added advantage on soil temperature reduction. In Nigeria gliricidia prunings are being used to prevent marked fluctuations in soil temperature during the dry period (Kans and Wilson, 1987).

After 30 and 45 days of dry spell, soil moisture levels were improved in gliricidia interplanted plots compared to control (monoculture coconut). This was more prominent at the 45 days of spell over the same at 30 days dry spell. This may be due to soil surface cover and mulch formed by litter of gliricidia leaves. Remison and Mgbeze (1987) also reported that mulching the soil surface would conserve soil moisture and reduce soil temperature. Vidhana Arachchi and Liyanage (1988) also found that available water fraction through the soil profiles of gliricidia was higher than in a coconut monoculture situation. In other perennial crop combinations interplanting coffee, pepper and cocoa with coconut improved the available water due to their root activity and decomposing litter. Increase efficiency of rainwater harvesting may cause increase soil moisture in coconut plus gliricidia system over coconut alone.

Soil fertility improvement

Increased supply and retention of plant nutrients in soil will be important to realise the full potential of coconut production in degraded soils. Chemical fertilisers, one of the most important inputs in coconut production will continue to play a significant role in increasing productivity. These fertilisers, however, are chemical products that are not helpful for sustainability in soil and as well as in agricultural productivity. Green manuring of coconut lands, or in other words the practice of incorporating undecomposed plant materials into the soil with the object of increasing soil fertility, is an age-old manuring method known to coconut growers in most coconut growing countries. Gliricidia a well known atmospheric nitrogen fixing tree can produce large quantities of leaf biomass (Jayasundera et al., 1997). As shown in Fig. 1a and 1b one ha of gliricidia with coconut produced approximately 24.0 mt of leaf biomass annually which is very usable for fertilising of coconut soils. Organic materials are considered as important resources for building soil fertility. On coconut soils of the low organic matter content (e.g. sandy or boralu soils) and considering the rapidity with which it is biodegraded in arable soils continued addition of organic matter to these soils seasonally is necessary, if fertility is to be maintained. In this study organic matter level on surface of soil has been increased considerably (Table 4) and expected several benefits on coconut are plant nutrients retention, high soil microbial activity and good root growth. This was indicated by high nutrient contents in coconut foliage with gliricidia compared with coconut alone. Besides improved nutrition in coconut palm, soils also showed elevated levels of organic carbon, nitrogen, phosphorus in gliricidia + coconut situation over no gliricidia plots. These changes in soil nutrients profile are general because gliricidia could mine plant nutrients such as P, Ca, Mg, from deeper soil layers. With the continuous lopping of gliricidia such plant nutrients are expected to become high in surface layers of soil. However, removable nutrients could be become lower with time. This was evident with K and hence maintenance of soil K level need close attention with gliricidia intercultivation. K is also a highly required nutrient for coconut. Thus it is suggested to recycle ash and carbon materials after gasification of fuel wood of gliricidia.

Gliricidia yield

Biomass yield of gliricidia consisted mainly of two components; leaf (foliage) and wood. In this study, gliricidia produced total of 48.0 mt $ha^{-1} yr^{-1}$ as leaf (wet weight) and wood (at 20% moisture) yields at 5th year of production. These yields achieved a maximum at the fourth year and the trend appears to continue (Fig.1b).

It has been reported that the foliage of gliricidia contains about 4% nitrogen and is therefore an excellent source of green manure for coconut palms. On decomposition, this can restore the physical condition of the soil. The CRI has recommended to incorporate 35-50 kg of fresh pruning from Gliricidia into the soil, to a depth of 15-20 cm aiming to meet the entire nitrogen requirement of a palm (Liyanage, 1993). The use of this technique can result in a substantial saving when compared with the cost of using chemical fertilisers. Intercultivation of gliricidia is beneficial to rehabilitate degraded soils (Liyanage, 1993). As an example, Liyanage and Jayasundera (1987) reported that decomposed gliricidia foliage improve the water holding capacity of degraded Ultisols from 45-99 mm m^{-1}, the organic carbon content from 0.83 to 1.73% and reduced bulk density from 1.49 to 1.39 g cm^{-3} compared with a control that received no gliricidia treatment. The present study also revealed that soil organic carbon levels elevated in gliricidia plots over no gliricidia situation due to addition of foliage. It has shown that the incorporation of 30 kg of *G. sepium* lopping into quarter circle trenches dug around each palm results in a 12% increase in nut yield two years later (Gunasekera, 1989). So, gliricidia plays a significant role in restoring the fertility of degraded marginal coconut lands.

Interestingly, gliricidia has been identified as a good source of fuel wood (Anon., 1994). Wood of Gliricidia is now widely used in thermal and electricity generation through gasification of biomass. Hence in the near future there will be a ready market for gliricidia as a fuel wood. In this study, gliricidia produced wood yield of 24 mt $ha^{-1} yr^{-1}$ (with 20% moisture) at the fourth year. (note: 20% moisture with gliricidia is the acceptable level for gasification technology). Liyanage et al. (1990) also reported that gliricidia wood has a high density and calorific value with a low ash content as a promising fuel wood species. At present, daily fuel wood production of this project is 1.3 mt from 20 ha of extent.

Cost/ benefits of gliricidia

Based on overall results of this study Gliricidia could be identified as promising tree for production of green manure and fuel wood. Intercultivation of gliricidia in coconut lands improves microclimate and fertility of soils and therefore benefits the coconut palm. As a result of gliricidia intercultivation, nutrition of coconut palms is also improved. So, possible negative impacts such as competition for soil water and nutrition by gliricidia could be ruled out with properly managed gliricidia intercultivation in coconut. Direct income generated by selling of gliricidia wood for gasification seems to be attractive and this increases productivity of coconut lands too.

It appeared that general maintenance cost of a gliricidia intercultivation was low. The major part of cost was for harvesting and transport of fuel wood. Our present experience shows that transport of gliricidia fuel wood within the radius of 15 km from power generating plant is economical.

Income of wood is considerable and ratio between wood and leaf is 10:1. Considering a low cost of maintenance, net profit of gliricidia intercultivation seems to be attractive for coconut growers. Demand of gliricidia fuel wood is growing and price is also now in a increasing trend due to continuous energy crisis in the country. Green energy will be the most appropriate source for Sri Lanka because fossil fuels are not possible in current context (Anon., 2003).

It is not easy to encourage farmers to grow gliricidia for green manuring coconut. However, selling of gliricidia generate direct income. While getting direct income from fuel wood, foliage of gliricidia increases fertility in coconut soils. So this exercise could be considered as a CDM project.

ACKNOWLEDGEMENTS

The author wishes to thank the Director, Coconut Research Institute, Lunuwila for granting permission to present the date and gratefully appreciate the initial works by Dr K B Dassanayake and K de Silva. Dr A Tennekoon, Head of Soils and Plant Nutrition Division of the CRI is also acknowledged for helping soils and leaf analysis. The assistance given by the Agronomy Division staff is gratefully acknowledged. Finally I thank Mr. A A D N Athauda for typing the manuscript.

REFERENCES

Anon 1994 Annual Report of the Coconut Research Institute of Sri Lanka.

Anon 2000 Annual report of the Coconut Research Institute of Sri Lanka.

Anon 2003 Regaining Sri Lanka with Bio Energy- The Dendro Option. A Publication of Bio Energy Association of Sri Lanka. Colombo.

Gunasekara, T G L G 1989 Rehabilitation of low yielding coconut palms. Coconut Bulletin 6 (1): 14-15.

Jayasundera, H P S, Dennett, M D and Sangakkara, U R 1997. Biological nitrogen fixation in Gliricidia sepium and *Leucaena leucocephala* and transfer of fixed nitrogen to an associated grass. Tropical Grass Lands Vol. 32, 14-22.

Kang, BT and Wilson, G F 1987 Agroforestry: A decade of development (ed.) H. A. Steppler and P.K.R. Nair ICRAF, Nairobi, Kenya 227 -243.

Liyanage, L V K, Jayasundera, H P S and Gunasekera T G L G 1988 Potential for use of Nitrogen Fixing Tree legumes in small coconut holding in Sri Lanka. *In* Multipurpose Tree Species for Small Farm Use. Withington, D. et al. (eds.), Pattaya, Thailand p.p. 251-253. Proceedings of an International Workshop.

Liyanage, M de S, Jayasundera, H P S and Perera, K P C 1990 Studies on growth performance and biomass productivity of selected multipurpose and biomass productivity of selected multipurpose trees in the low country intermediate zone. *In* Proceeding of 1st Regional Workshop on Multipurpose Trees, Ed. H. P. M. Gunasena, Kandy, Sri Lanka.

Liyanage, M de S 1993 Forestry Farming Trends Vol. 5 (3).

Liyanage, L V K and Jayasundera, H P S 1987 Potential of use of MPTS in coconut plantations. *In* Proceedings of the Workshop on Nitrogen Fixation and Soil Facility. Ed. Gunasena, H. P. M. Kandy, Sri Lanka. P. 78-87.

Peoples, M B and Herridge, D F C 1990 Nitrogen fixation by legumes in tropical and subtropical agriculture. Advances in Agronomy. 44, 155-221.

Remison, S U and Mgbeze, G 1987 Competitive effect of weed and beneficial effects of mulching on coconut seedlings COCOS 5, 19 – 28.

Vidhana Arachchi, L P and Liyanage, M de S 1988 Soil physical conditions and root growth in coconut plantations interplanted with nitrogen fixing trees in Sri Lanka. Agro Forestry Systems 39: 305-318.

Effect of Soil Moisture Deficit and Temperature on Dry Matter Accumulation in Tea Shoots

M A Wijeratne
Tea Research Institute of Sri Lanka, Low Country Station, Ratnapura, Sri Lanka

ABSTRACT

The effect of soil-moisture deficit and temperature on dry-matter accumulation in tea shoots of mature tea bushes, in the low-country wet zone of Sri Lanka, was studied at St Joachim Estate, Tea Research Institute, Low Country Station, Ratnapura.

The annual dry-matter accumulation in young tea shoots was estimated to be about 10-13 mt ha^{-1} of which about 48-58% was harvested, with the balance being added to the canopy. The harvested proportion was comparable to the proportion of dry mass removed (or harvested) from a single shoot, which was affected by clonal characteristics such as inter-nodal length. Soil-moisture deficits reduced dry-matter accumulation in tea shoots, and the critical moisture deficits were around 30 mm for the drought-susceptible tea clone, TRI 2023, and 42 mm for the drought-tolerant clone, TRI 2025. The highest dry-matter accumulation in shoots of these two clones were found to be at ambient temperatures of 26.9 °C and 27.7 °C, respectively.

These results show that drought-tolerant clones can withstand greater soil-moisture stress, and higher temperature regimes in relation to dry-matter accumulation in shoots, than drought-susceptible clones.

Key words: soil-moisture deficit, shoot yield

INTRODUCTION

A part of the assimilates, produced by mature leaves in the canopy of the tea bush, is partitioned between the components of the bush, such as the growing buds and shoots, the stems and the roots which are presumably the storage organs. The rest of the assimilates is used in respiration. The respiratory losses are greater than the dry matter accumulated in the bush, and account for about 60-67% of total dry matter production (Barbora and Barua, 1988; Rahman, 1988; Tanton, 1979).

In commercial tea plantations, frequent harvesting of shoots removes a significant amount of dry matter accumulated in the shoots. The harvest index of tea is reported to be about 14-26% depending on clones and plant densities (Burgess, 1992; Magambo et al., 1988; Tanton, 1979).

Growing shoots are the major sinks for carbohydrates assimilated by the leaves of the canopy. The sink capacity is greatest in the elongating buds even in comparison to the larger shoots. Manivel and Hussain (1986) found that the sink capacity of an unopened, growing bud declines to about 30% when it unfolds its first leaf. Barua (1987) reported that the sink capacity of the first, second and third leaves, from the apex of a shoot with three leaves, was 70, 40 and 30% that of the apical bud. It is, therefore, clear that the elongating buds and younger shoots on the plucking table are strong sinks for assimilates.

The yield of tea is greatly dependent on dry-matter accumulation in the tea shoots, and is affected by climatic factors and management policies, mainly the harvesting practices. Therefore, studies on dry-matter accumulation in tea shoots, in relation to environmental factors, are of great importance. Further, the findings of such studies are also helpful in choosing suitable plucking policies, based on weather conditions and clonal characteristics. Many studies have been conducted in other tea-growing countries (India and in African countries) on dry-matter production, partitioning and accumulation in tea shoots (Burgess, 1992; Marimuthu et al., 1994; Mathews and Stephens, 1998). However, similar information on dry-matter accumulation in tea shoots, in relation to environmental factors, in the tea-growing regions of Sri Lanka is lacking. Hence this study was conducted with the objective of estimating dry-matter accumulation in tea shoots based on yield components, and the effects of soil-moisture deficit and ambient temperature on dry-matter accumulation in tea shoots in the low-country wet zone of Sri Lanka.

MATERIALS AND METHODS

Two tea clones, the drought-tolerant TRI 2025 and the drought-susceptible TRI 2023, were selected from Field No. 2 at St Joachim Estate, Tea Research Institute, Ratnapura. The bushes were planted at 1.2 x 0.6 m (approximately 12,500 bushes ha^{-1}). They were seven years old, and were in the second year of their pruning cycle.

Ten plots (five plots per clone), each having 15 bushes, were demarcated for recording data on yield, shoot population density, weight of shoots and soil moisture, over a period of one year. Shoots were harvested at weekly intervals, leaving the most mature normal leaf unplucked ('mother-leaf plucking'). A few shoots were occasionally harvested below the mother leaf, in order to maintain the level of the plucking table. Shoot counts (total and harvested) were made at weekly intervals, on five randomly selected tea bushes from each clone (one bush $plot^{-1}$), over a period of one year. The total shoot population density was ascertained by counting all the growing shoots (elongating buds, shoots with fish or scale leaves only, and shoots with one to four normal leaves) on half of the tea bush before harvesting them and doubling the count. The number of shoots left after plucking was also counted separately for each category, in the same way.

The weight of full, growing shoots of all categories was measured at weekly intervals by removing the shoots from tea bushes not used for recording shoot density. Harvested shoots were separated into different groups, based on the number of leaves and their stage of growth (active or dormant), and weighed. The dry-matter content of shoots was also recorded at each harvesting, by oven-drying a sample of shoots to constant weight at 90 °C.

The weekly increase in shoot dry weight W (g $bush^{-1}$ $week^{-1}$), or the amount of weekly dry-matter accumulation in shoots, is given by the following relationship:

$$W = W_T - W_L$$

where W_T is the total dry weight of shoots (g $bush^{-1}$) immediately prior to harvesting, and W_L is the total dry weight of shoots (g $bush^{-1}$) remaining after the previous harvesting. Dry-matter accumulation in the shoot butt, and in the mature leaves left after plucking, was not considered in this exercise as dry-matter partitioning to such tissues was reported to be negligible (Barua, 1987; Manivel and Hussain, 1986).

Weather data were taken from the meteorological station at the Tea Research Institute, Ratnapura. The soil-moisture content was determined gravimetrically, by taking core-samples at 30, 60 and 75 cm depths, using a sampling corer (diameter=6.5 cm). The depth of the root system was measured by excavating roots (3 bushes clone^{-1}), and was found to be 75 cm.

In order to minimize soil disturbance and root damage, sampling was done at fortnightly intervals at the centre of the inter-row. However, sampling was done at weekly intervals during dry months. A soil sample of 200 g (fresh weight) was oven-dried to constant weight at 105 °C, in order to determine moisture content on a dry weight basis. The total moisture content at field capacity was 214 mm. The mean weekly temperature, and the soil-moisture deficit, were also calculated. The height of the plucking table (5 bushes plot^{-1}) was also measured, and mean values were calculated separately for each clone.

Data were analyzed using the Minitab statistical package. The results are given with standard errors in parenthesis (±SE). Clonal and seasonal comparisons were made by the sample t test, and the relationships between the dry-matter accumulation in shoots, and the soil-moisture deficit and temperature, were evaluated by regression analysis.

Of these two environmental factors, the more influential one affecting shoot growth in the low country was the soil-moisture deficit. Hence, the critical soil-moisture deficits affecting dry-matter accumulation in shoots were first established by regression analysis. In order to establish the relationship between temperature and weekly dry-matter accumulation in shoots, the data corresponding to soil-moisture deficits higher than the critical limit were excluded.

RESULTS

Weekly dry-matter accumulation in shoots of TRI 2025 bushes ranged from 5.6 to 28.4 g bush^{-1} week^{-1}, while in TRI 2023 it ranged from 6.6 to 37.0 g bush^{-1} week^{-1}. The statistically analyzed results are given in Table 1.

Table 1. Mean dry-matter accumulation in tea shoots over different periods (g/bush/week). Wet and dry periods were defined based on the critical soil-moisture deficits of each clone.

	TRI 2025	TRI 2023
Annual (±SE)	15.9 (0.81)	19.9 (1.26)
Wet (±SE)	17.7 (0.97)	23.1 (1.35)
Dry (±SE)	12.9 (1.07)	14.8 (1.63)

Weekly dry-matter accumulation in shoots was significantly higher in TRI 2023 bushes than in TRI 2025 bushes ($p<0.01$). For both clones, dry-matter accumulation in shoots during dry periods (that is, periods during which soil-moisture deficits were above the critical limits shown below) was significantly lower than that during wet months ($p<0.01$), the reduction being about 27-36%. The total, annual dry-matter accumulation in shoots (summation of the weekly dry matter accumulation) was about 825 g $bush^{-1}$ (10 mt ha^{-1}) for TRI 2025, and 1064 g $bush^{-1}$ (13 mt ha^{-1}) for TRI 2023. Of these amounts, 482 g was harvested from a TRI 2025 bush, and 514 g from a TRI 2023 bush.

The proportion of shoot dry mass harvested from the total shoot dry mass of the bush at plucking, and also from the weekly increase in shoot dry mass, was tabulated for wet and dry periods separately (Table 2). The harvested percentage of shoot dry mass (both from the total and the weekly increment) for TRI 2023 is significantly lower than that for TRI 2025 ($p<0.001$). The annual means were 28.7% and 33.9% for total shoot dry mass, and 48.3% and 58.4% for the weekly increment for the same clones, respectively.

When analyzed separately for wet and dry periods, it was observed that the dry weather had significantly reduced the proportion of shoot dry mass harvested from the bushes ($p<0.05$). The positive linear relationship between weekly dry matter accumulation in the shoots, and weekly harvested shoot dry mass (that is, the yield), is shown in Fig. 1, where the regression coefficients are close to the estimated mean percentages given in Table 2. The intercepts were not significantly different from zero ($p>0.05$), and hence the regression lines were drawn through the origin.

Table 2. Mean harvested proportion of shoot dry mass over different periods. Wet and dry periods were defined based on the critical soil-moisture deficits of each clone.

	Harvested proportion of total shoot dry mass (%)		Harvested proportion of weekly increment (%)	
	TRI 2025	TRI 2023	TRI 2025	TRI 2023
Annual (±SE)	33.9 (0.90)	28.7 (0.89)	58.4 (1.5)	48.3 (1.2)
Wet (±SE)	35.9 (1.2)	31.2 (0.7)	61.5 (2.0)	49.7 (1.4)
Dry (±SE)	30.8 (1.0)	24.9 (1.6)	53.0 (2.3)	44.0 (1.8)

During the experimentation, it was also estimated that about 59.5% of the dry mass of a single growing shoot was harvested from TRI 2025, compared to about 48.5% for TRI 2023. Bush height at the end of the experiment was 97.2 (±1.1) cm for TRI 2025 bushes, and 106.8 (±2.5) cm for TRI 2023 bushes.

With regard to the effect of temperature and the soil-moisture deficit on dry-matter accumulation in shoots, it was assumed that the main limiting factor for growth of tea during dry weather was the soil-moisture deficit, and that during wet weather it was temperature. Accordingly, the effect of soil-moisture deficit on dry-matter accumulation in shoots, and their critical limits, were first established, and then the effect of temperature on dry-matter accumulation in tea shoots was studied, excluding the effect of soil-moisture deficit. The variation of the soil-moisture content in the root zone of the two clones is shown in Fig. 2, and the effects of soil-moisture deficit and temperature on dry matter accumulation in shoots are shown in Figs. 3-6. The critical soil-moisture deficit was first established by the polynomial curve, and then the effect of the soil-moisture deficit was estimated by the gradient of the linear trend line.

Increases in the soil-moisture deficit caused decreases in dry-matter accumulation in shoots of both clones, irrespective of their ability to tolerate drought. However, the critical moisture deficits, above which the dry-matter accumulation in the shoots was affected, were around 30 mm for the drought-susceptible TRI 2023, and around 42 mm for the drought-tolerant TRI 2025. When considering the effect of temperature, the highest dry-matter accumulation in the shoots was found at 26.9 °C in TRI 2023, and 27.7 °C in TRI 2025.

DISCUSSION

Total, and weekly, accumulation of dry matter in tea shoots, and the harvested proportion of shoot dry mass in relation to varying soil-moisture deficits and ambient temperatures, were estimated based on yield components.

The results showed that the dry-matter accumulation in shoots of the drought-tolerant clone, TRI 2025, was significantly less than in the drought-susceptible clone, TRI 2023. The annual, total shoot dry mass produced by a TRI 2025 bush was estimated to be about 77% of that produced by a TRI 2023 bush. However, the yield records during the experimentation showed no significant difference between these two clones.

The annual yield of TRI 2023 was only about 6% higher than that of TRI 2025, that is 6,425 kg ha^{-1} yr^{-1} and 6,025 kg ha^{-1} yr^{-1}, respectively. This was due to differences in the harvested proportions of shoot dry-mass between the two clones. A higher proportion of shoot dry-mass, accumulated over a period of one year, had been harvested from the TRI 2025 bushes compared to the TRI 2023 bushes, that is 58% and 48%, respectively ($p<0.05$). This conclusion was further supported by the harvested proportion of a single growing shoot, which was 59.5% and 48.5% for TRI 2025 and TRI 2023, respectively. These results show that TRI 2023 bushes retain more dry matter than TRI 2025.

Although not recorded in this experiment, a separate analysis of root-starch reserves of these two clones have shown that the root-starch reserves of TRI 2023 was higher than that of TRI 2025 (Anon., 1996).

The results of the present study show that the harvested proportion of total dry matter accumulated in shoots (the annual total of weekly increments in shoot dry mass) was the same as the harvested proportion of a single growing shoot. Therefore, total dry-matter accumulation in the shoots (TDM) could be estimated approximately by yield (Y), and the harvested proportion of a single growing shoot (HP), as given below. Y and HP vary with the plucking policies such as severity (point at which the shoot is removed), and the standard of harvesting (size of the harvested shoot). Hence, if a mixture of different systems of harvesting is adopted, a mean value of the harvested proportion needs to be considered.

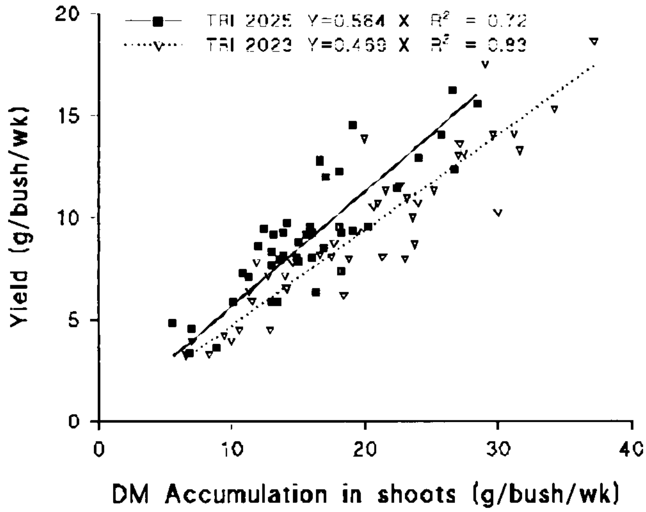


Figure 1. Relationship between weekly dry matter accumulation in tea shoots and harvested shoot dry mass (yield).

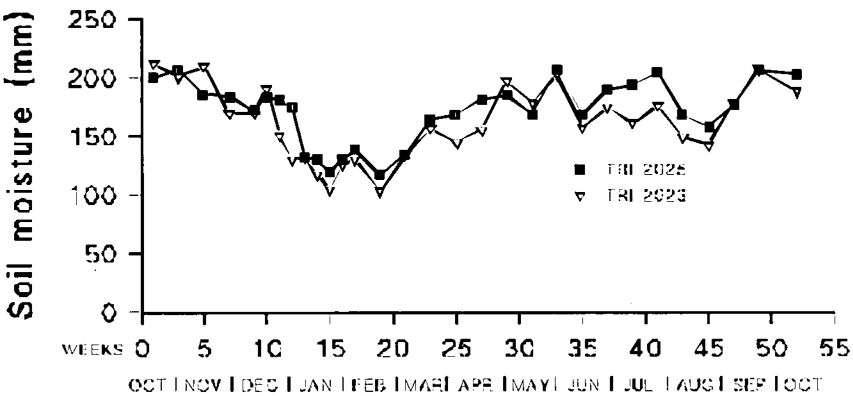


Figure 2. Soil moisture content in the root zone over the experimental period.

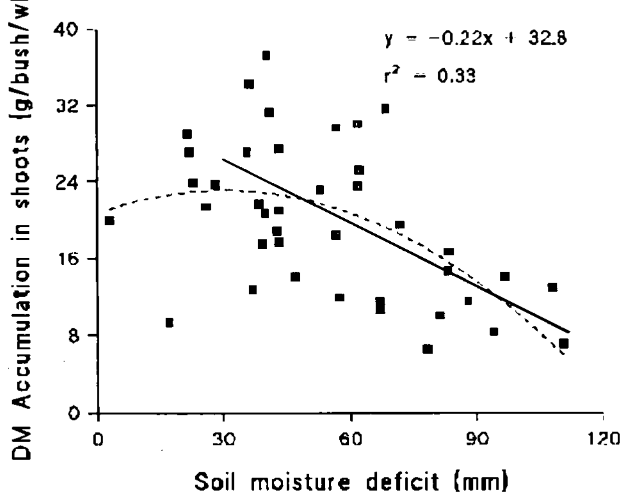


Figure 3. Effect of soil moisture deficit on dry matter accumulation in tea shoots (TRI 2023).

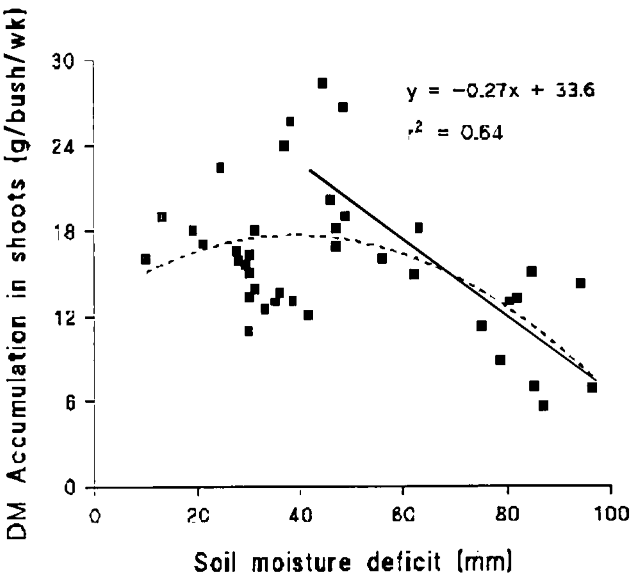


Figure 4. Effect of soil moisture deficit on dry matter accumulation in tea shoots (TRI 2025).

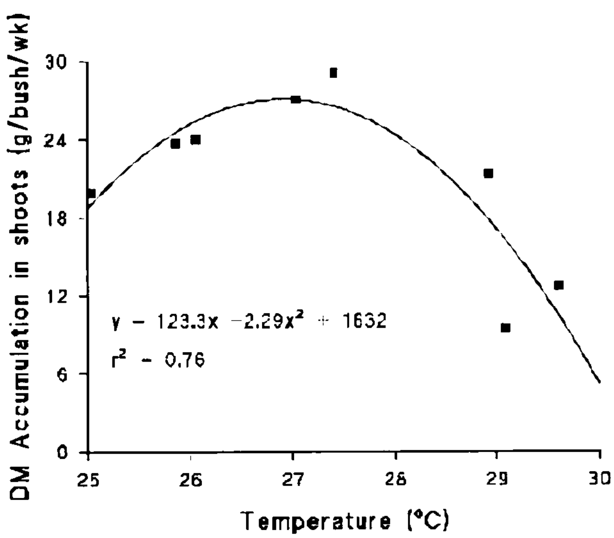


Figure 5. Effect of temperature on dry matter accumulation in tea shoots (TRI 2023).

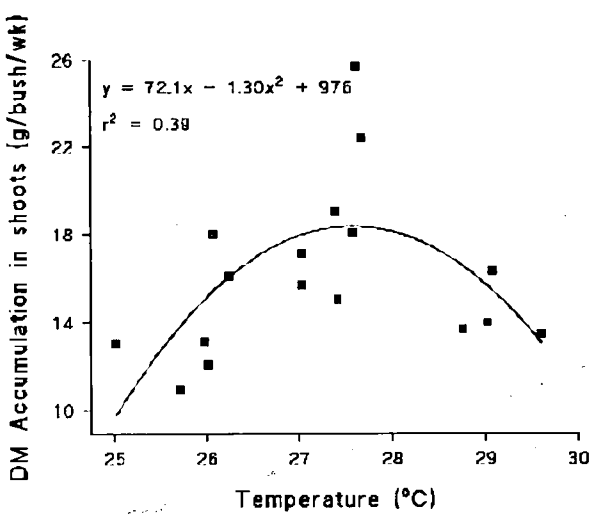


Figure 6. Effect of temperature on dry matter accumulation in tea shoots (TRI 2025).

TDM (kg ha^{-1} yr^{-1}) = Y (kg ha^{-1} yr^{-1}) / HP (%)

The harvested proportion of a single shoot recorded in this study was comparatively lower than that reported by Tanton (1979, 1992) for the SFS 204 clone in Malawi, namely 62-87%, which could be due to differences in shoot characteristics and harvesting policies.

The differences in the harvested proportions of a single growing shoot of the two clones, TRI 2023 and 2025, were attributable to their shoot characteristics. The internodes of TRI 2023 shoots are longer than the internodes of TRI 2025 shoots (Wickramaratne, 1981). Therefore, the proportion of the dry mass of a shoot left after plucking would be greater in TRI 2023 than in TRI 2025. This result was also confirmed by differences in the height of the plucking table. The height of the plucking table of TRI 2023 was greater than that of TRI 2025: 106.8 (±2.5) cm and 97.2 (±1.1) cm, respectively. These results suggest that the shoot characteristics, and the plucking policies, can have a marked influence on the canopy structure and the yield of harvested tea bushes.

Dry weather limits dry matter production and accumulation in shoots. Despite the differences in drought-tolerant capabilities of the two clones, the soil-moisture deficit reduces dry-matter accumulation in the shoots of both clones. However, the critical soil-moisture deficits affecting dry-matter accumulation in shoots were estimated to be about 30 mm for TRI 2023, and about 42 mm for TRI 2025. These values were close to the critical soil-moisture deficits affecting shoot-water potential of the two clones, at the same location, that is 35 mm and 45 mm, respectively (Wijeratne, 1996). However, the soil-moisture deficits of the most effective root zone (the top layers of soil) would have been much higher than the critical limit estimated for the entire root zone (75 cm).

The results show that shoot growth of the drought-susceptible clone, TRI 2023, was affected by moisture stress earlier than in the drought-tolerant clone, TRI 2025. Wijeratne (1996, 2001) reported that the shoot population density and the shoot extension rate of these two clones decline at temperatures above 26-27 °C, which were close to the temperatures estimated for maximum dry-matter accumulation in the shoots. These results show that the performance of drought-tolerant clones, under dry weather conditions and at high ambient temperatures, is superior to drought-susceptible clones.

CONCLUSIONS

1). The amount of dry matter accumulated in tea shoots could be estimated by yield, and by the harvested proportion of a single shoot.

2). About 48-58% of the total dry matter accumulated in tea shoots is harvested, and the rest added to the canopy of the tea bush.

3). Dry-matter accumulation in tea shoots is significantly reduced at soil-moisture deficits above 30-42 mm, and the optimum temperature for dry-matter accumulation in tea shoots was found to be around 26.9- 27.7 °C.

4). The performance of drought-tolerant clones under dry weather conditions, and at higher ambient temperatures, was superior to that of drought-susceptible clones.

REFERENCES

Anon. 1996 Report of the Plant Physiology Division. Annual Report of the Tea Research Institute of Sri Lanka, p. 79-86.

Barbora, A C and Barua, D N 1988. Respiratory losses and partition of assimilates in tea bushes (*Camellia sinensis* L.) under plucking. Two and a Bud 35, 75-82.

Barua, D N 1987 Tea. In: *Tree Crop Physiology* (eds. M R Sethuraj, A S Raghavendra.), p. 225-246. Elsevier, Amsterdam.

Burgess, P J 1992 Dry matter production and partitioning by clone 6/8. Ngwazi Tea Research Unit, Quarterly Report No.9, 11-16.

Magambo, M J S, Omolo J G and Othieno C O 1988. The effect of plant density on yield, harvest index and dry matter production. Bulletin, United Planters Association of South India, No.40, 7-14.

Manivel, L and Hussain, S 1986 Relative sink capacity of developing tea shoots. Two and a Bud 33, 30-38.

Marimuthu, S, Raj Kumar, R and Manivel, L 1994 Factors affecting partitioning of assimilates in tea. J. Nuclear Agric. Biol. 23, 219-223.

Matthews, R B and Stephens, W 1998 CUPPA-TEA: A simulation model describing seasonal yield variation and potential production of tea. 2. Biomass production and water use. Exp. Agric. 34, 369-389.

Rahman, F 1988 Physiology of the tea bush. Two and a Bud 35, 1-14.

Tanton, T W 1979 Some factors limiting yield of tea (*Camellia sinensis*). Exp. Agric. 15, 187-191.

Tanton, T W 1992 Tea crop physiology. *In*: Tea: Cultivation to Consumption. (eds. K C Willson, M N Clifford), p. 173-199. Chapman and Hall, London.

Wijeratne, M A 1996 Effect of environmental factors on growth and yield of tea (*Camellia sinensis* L.) in the low country wet zone of Sri Lanka. S.L.J.Tea Sci. 64, 21-34.

Wijeratne, M A 2001 *Shoot Growth and Harvesting of Tea*. Tea Research Institute of Sri Lanka, Talawakelle, Sri Lanka.

Wickramaratne, M R T 1981 Variation in some leaf characteristics in tea (*Camellia sinensis* L.) and their use in the identification of clones. Tea Q. 50, 183-189.

Quality of Planting Material on the Growth Phase of Hevea

P Seneviratne, A M W K Senevirathna and N M C Nayanakantha
Rubber Research Institute of Sri Lanka, Dartonfield, Agalawatta, Sri Lanka

ABSTRACT

The growth of seedlings and buddings of rubber is periodic and the growth during the first 3-5 years is purely vegetative. Also, rubber tree undergoes a phase change during its development process. Trees attain the mature phase in 5-6 years of age which is generally characteristic by flowering and wintering. As far as the rubber planting is concerned, the physiological and biochemical characteristics related to the mature phase, such as slow growth rate, loosing of root regeneration capacity, high content of phenolic compounds etc. are all undesirables. All improved or known clonal materials belong in this phase. Being a long term perennial tree, with 30 years life span, use of quality guaranteed plants in every planting programme cannot be over emphasized. Though the potential yields of new clones recommended are in the range of 1,500-2,500 kg ha^{-1} yr^{-1}, the national average productivity of rubber in Sri Lanka is in the range of 700-900 kg ha^{-1} yr^{-1}. One of the main reasons for not been able to reach the potential yield in Sri Lankan plantations is the use of poor quality plants. The annual planting hectarage in Sri Lanka is about 5,000 which requires 2.75 million budded plants. This quantity should be produced in government owned nurseries located in different regions under the management and the strict supervision of the Rubber Research Institute for the quality. Furthermore, the government spends about 500 million rupees annually on new and replanting of rubber. Therefore, it is the responsibility of all national organizations involved in rubber sector to take necessary steps to guarantee the production and supply of high quality plants in order to achieve the potential yields of the clones recommended.

Key words: budwood nurseries, juvenility, maturity, stock nurseries

INTRODUCTION

Plant improvement through breeding is a story of success as far as rubber is concerned. The yield improvement that has been achieved so far is five fold of wild rubber. Rubber is a highly heterozygous, open pollinated, perennial tree belongs to the family euphorbiaceae. The free growing rubber trees found in its native amazon area are about 250 cm in girth and about 40 m tall. However, rubber is grown for latex and the average yield per tree of the improved material planted in the far east region is far too high with compared to that of the seedlings grown in south american forests.

The growth of a rubber tree is episodic. That is, each shoot passes through alternate phases of growth and dormancy. The length of the shoot in the growth flush decreases with the increase number of flushes. Through the elongation of stem is intermittent, the girth increase seems continuous. Generally, the trees with this type of growth are deciduous. In both seedlings and buddings the growth during the first 3-5 years is purely vegetative and the trees grow upward without branching. The increase in the girth during this period is relatively small but as soon as the terminal growth retards and the branches begin to develop, girthing of the main stem is greatly accelerated. The rate of girthing differs from one clone to another and also from one individual to another. In any case, girth development gradually becomes slow after 6-8 years. This is similar for seedlings and buddings but, in seedlings the stem at the base of the tree soon becomes conical and the shape of the trunk gets tapering in contrast to the stem of buddings.

In the development of all woody plants from the seed, there is a juvenile phase during which the seedlings cannot be induced to flower (Hackett, 1980). The length of the juvenile period or the phase is influenced by environmental factors as well as genetic factors (Hackett, 1985). It is inversely related to the breeding efficiency in woody perennials and to the selection of improved cultivars. In many plant species, juvenile plants often differ both morphologically and physiologically from adult plants of the same species. Attainment of the ability to flower indicates the end of the juvenile phase. Actual production of the flowers is the first sign of the adult phase but, the end of the juvenile phase and the first appearance of the flowers may not coincide. When they do not, the intervening period may be referred to as a transitional phase (Zimurman, 1992). Although the juvenile period cannot be eliminated, it can be shortened or lengthen, to advantage, considerably by various techniques (Zimnurman, 1972).

This concept of juvenile and the phase change is of particular interest in *Hevea* and it was known since as early as 1939 (Baptist, 1939). As reported by Songquan et al. (1990) in *Hevea*, juvenile and mature development stages exist in both seedlings and buddings. In the case of*Hevea*, up to age four is considered as juvenile phase, age six as the beginning of the mature phase and age five as transitional phase. Once established, a given growth phase tends to be lasting under continuous vegetative propagation. Also, the sequence of ontogeny from extreme juvenile to full mature type exist in a gradual change of a mature tree from the base to the top. Accordingly, the bare of a plant retain juvenile type stage and those at the top also exhibit juvenile type when young. When the plant is well grown up, the top meristems will be considerably aged. Further, it is believed that the mature phase is more stable than the juvenile phase. However, it does not seem to be a permanent change in the genome, since it is the adult phase which produces the seeds which in turn give rise to seedlings with juvenile characteristics (Pierik, 1990).

In *Hevea*, the shape of the leaves of the juvenile and mature phases are not different but the colour of the young shoots and the branch angle differs. The shape of the trunk is conical in seed originated plants and its more cylindrical in bud grafted plants. However, this cylindrical shape of the trunk, seems to be more related to the growth phase of the material used for bud grafting, as if juvenile materials are used, then the shape of the trunk is conical at the base. This has been reported for micropropagated plants of *Hevea* by another culture. Flowering and wintering of *Hevea* is normally observed after about five years of growth, perhaps at the beginning of the entering in to the mature phase. Wintering is a mature characteristic but there are differences between clones in wintering behavior. A few tend to shed and replace part of their foliage simultaneously over a large period while some become leafless for a short time. The majority of intermediate clones vary considerably in the extent to which they suffer yield depression during defoliation. Further, the age they start wintering seems to be a clonal characteristic. Characteristics of each growth phase seems to be preserved from one generation to the other through asexual reproduction techniques such as rooted cuttings. However, this stability in characteristics associated with the juvenile phase contrasts with the changes that occur in some traits such as reduced growth rate and type of branching which also occur as the plant grow older. One difference that has been observed between the juvenile and the adult state of plants is the capacity to produce roots. The ease of rooting of cuttings of woody perennials is strongly affected by ontogenetic age . Apart from the differences between the cuttings from juvenile and mature trees, the position of the parent plant from which the cuttings are taken has been found to be an important factor, sometimes, even if rooting occurs, the propagates may show plagiotrophic growth, reduced growth rate etc.

EXPERIMENTAL AND FIELD OBSERVATIONS

Root regeneration and growth

Cotyledonary and adventitious shoots, originated from the stem of the first internode of young seedlings produced roots on all of the cuttings after about 6 weeks of planting them under a mist spray. But rooting was only 15% when the cuttings were taken from axillary shoots originated at a higher level of the same stem or the batch of plants indicating the cuttings taken from a lower position of the stem, i.e. more close to the roots, root easier than those removed from higher levels.

As far as growth is concerned, a faster growth rate and better growth vigour is always seen with juvenile type buddings with compared to those of mature type buddings. Mature type buddings are those done with buds removed from branches of the trees which consist of a crown or in other words from trees which are in mature phase of growth. It appears that these resulting trees, do not pass through the juvenile stage while buddings done with normal buds taken from proper budwood plants reproduce the growth phases of their mother tree and pass through the juvenile stage to the mature stage.

Growth stage of source bush plants of *Hevea*

Though rubber plants to enter the mature phase after about 5-6 years of continuous growth, in budwood nurseries, the recommendation is to pollard the trees annually whether the pollarded material is needed or not. Severe pruning is one of the techniques to reinstate juvenile characteristic or to revert the growth phase. Therefore, in properly maintained budwood nurseries, wintering or flowering is not observed even after 10-15 years. But there is no guarantee that the budwood plants in every age is equal as far as the degree of juvenility is concerned. Though the degree of juvenility of the plants in a budwood nursery is different, they do not show external characteristics of the mature phase. Therefore, source bush nurseries should be maintained in order to retain the juvenile characteristics in them by adopting proper cultural practices.

Effect of juvenility of budwood plants on productivity

As far as the productivity or the production is concerned, the vegetative growth of the tree is the key indicator within any clone. Number of nuts or fruits per tree, or the time taken to fruit bearing etc. are immaterial for rubber. Similarly, rubber planting material production is a very complicated process with compared to that of coconut or tea. It is a two part plant and each part has a selection process unique to it, in order to guarantee the quality. Though nothing can be said about the quality by the external appearance of the plant, the most important factor with regard to rubber cultivation is the quality of the planting material. Clone is important to achieve high yield. *But, unlike any other crop, (in any high yielding clone) rubber requires a certain vegetative growth (50 cm girth at 120 cm height) within a shortest possible period (4-5 years) in order to become economically viable. Only when the required vegetative growth is achieved, the tree can show its true performance, i.e. the potential yield.*

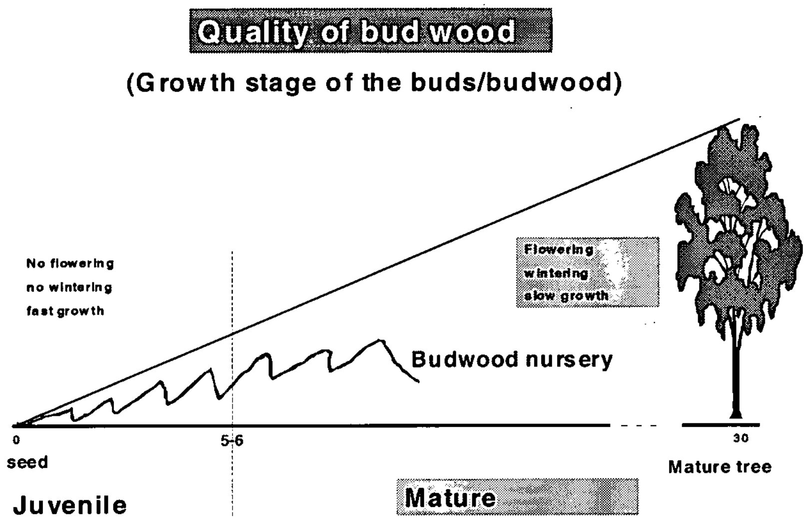


Figure 1. Growth and the growth phases of trees in plantations and in budwood nurseries.

Effect of cultural practices on the productivity

Seed propagated crop species will not face this problem of poor vegetative growth as seedlings normally selected for growth are fully juvenile, and hence will show natural vigorous growth. Unfortunately, rubber seedlings show a large variation for growth and for the yield and bud grafting has become a must. However, unlike for species like mango and "Amberella" (Hog-plum) where early maturation followed by early flowering and fruiting is very desirable (Figure 2), *rubber prefers the lengthened juvenile or immature phase. Vegetative growth of the trees in juvenile phase is faster than those in the mature phase. Once the tree enters the mature phase of growth (starts flowering and fruit set) that tree will be in the mature phase till it dies. This means, the growth rate of the tree (girthing) will be very poor and therefore, the tree will take 10-12 years to reach tappable girth if at all it grows to that growth level (Figure 3). Some times such trees will remain very thin and giving very poor yields throughout its life time.*

A rubber tree has about 5 years of juvenile period (fast growing period). If the rootstock plant is weak (not selected for vigorous growth) and had to spent 1-2 years in the ground rootstock nursery to become buddable and another 10-12 months in the polybag nursery the resulting budded plant will have only another 2-3 years remaining in its juvenile period of 5 years (Figure 3). As it is a 2-3 years old and also a weak plant, it will grow up to about 20-30 cm and then will enter the mature phase when the girthing is minimum and start to show wintering and flowering as mature trees.

Further, the budwood which are used for grafting, had been propagated by grafting ever since they were developed. For instance, RRIC 100 has been bread in 1950's and its true age (chronological age) is nearly 50 years. That too affects the growth rate of the budded plants. More-over, trees in budwood nurseries, do not show flowering and wintering up to 10-12 years only become they get pollarded every year. Therefore, maturation process get reversed annually enabling the tree to be in juvenile phase for a longer period than normal 5 years. However, budwood nurseries more than 10 years of age are not suitable even if the trees had been pollarded annually. Similarly, trees in a nursery below 10 years may

Figure 2. Three years old hog plum tree with fruits

Figure 3. Three years old rubber clearing showing wintering

contain poor quality budwood, if annual pollarding manuaring and maintaining the frame had not been done properly. If the budwood is harvested from any of these nurseries, the resulting plants will enter the mature phase sooner than 5 years. The first visible results will be poor growth which is characteristic to mature growth phase, which is shown from the first whorl of leaves (Figure 4)

Note: This is the technique used by the Agricultural Dept., to make their mango and Hog-plum plants to mature and give a crop in 1-2 years. As we all know these budded trees show a minimum vegetative growth with shorter lifespan.

How should a rubber plant be produced?

The time of the seed collection, the area from where the seeds are collected, transportation conditions, storage methods, conditions in the germination bed etc. are all important for a successful nursery.

Figure 5 shows how the seedling selection should be for the rootstock. The bad effects due to use of poor quality planting material are always very long term as far as rubber is concerned. Though the production capacity of new clones produced by RRISL is about 5 times the yield of the original rubber trees, Sri Lanka's national average remains below 3 times. This is evident by the condition of immature

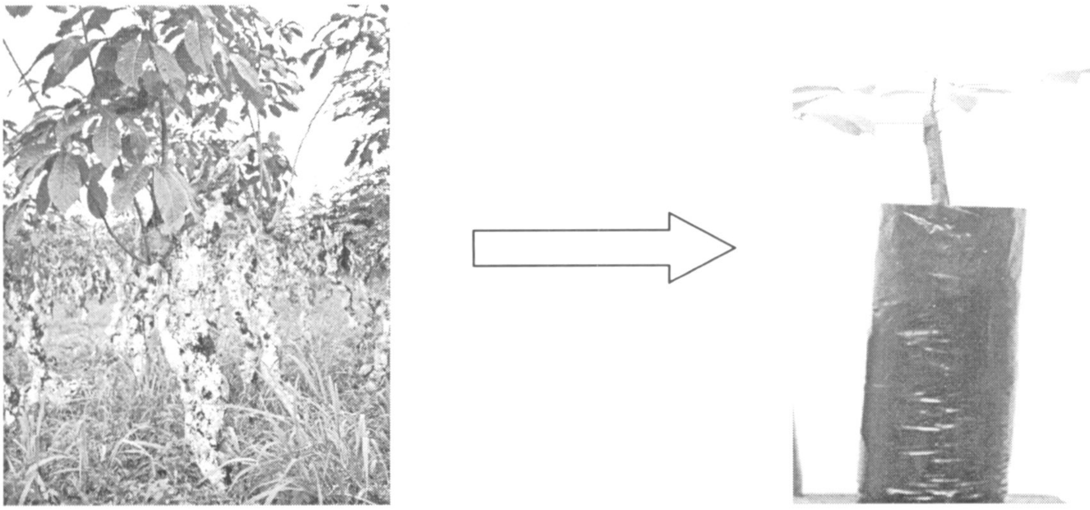


Figure 4. Inferior quality plant produced using an overage budwood nursery.

and mature clearings today. Also, as the COP is on the increase, rubber industry cannot survive unless the production/ha or the price/kilo is high. The price/kilo is normally beyond our control and hence productivity should be increased by using high quality plants. If the productivity is fairly close to the potential, rubber industry will make profits even at much lower prices and with low number of tapping days.

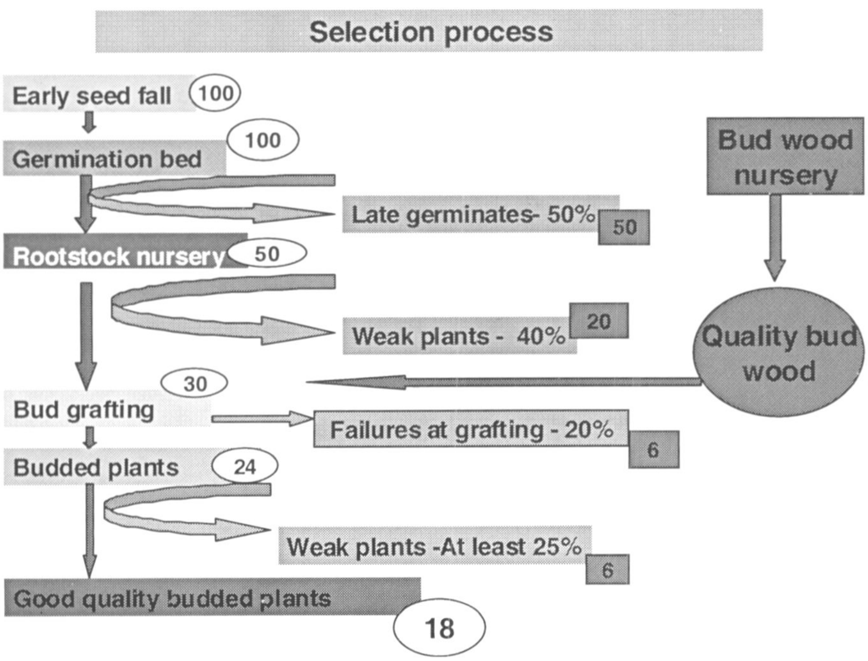


Figure 5. Culling process for a budded rubber plant

Planned Annual Planting programme in Sri Lanka

Traditional areas		
New planting	-	500 ha
Replanting	-	2,500 ha
Non traditional areas	-	2,000 ha
Total	-	**5,000 ha**

Annual planting material requirement in Sri Lanka
Replanting

Area under rubber in Sri Lanka	=	114,679 ha
Annual replanting (3%)	=	3,440 ha
(Recommended annual replanting area)		
Small holder sector requirement 64% of 3440 ha*	=	2,201 ha
∴ the planting material requirement	=	1,211,010 plants

(*Balance 36% is under Regional Plantation Companies and their planting material requirement i.e. about 681,120 plants are produced in their nurseries).

New planting

Traditional areas	=	500 ha
Non traditional areas	=	2,000 ha
Total	=	2,500 ha
∴ the planting material requirement	=	1,375,000 plants

Rubber cultivation in traditional areas are continuously being threatened by housing schemes and other development programmes. Whenever the prices are low, crop diversification too takes place. New planting programmes in traditional rubber growing areas remains very low due to non availability of land. Fortunately, rubber has been successful in areas, marginal with elevation and climate. Moreover, the farmers in marginally drier areas are depressed with their traditional annual crops and show a great interest on perennial crops such as rubber. Price increase has further encouraged them to move on to rubber farming. However, it should be mentioned that establishment and the upkeep during immature period may demand better cultural practices as well as devoted hard work as the climatic conditions are rather adverse with limited rainy periods.

The possibility in increasing the rubber production, without increasing the area under rubber, is evident by the gap between the potential yield and what is achieved in existing clearings. If the plantations today are to achieve the potential yields of the clones planted, the production should double the existing yield. There is always a possibility for the immature period to get longer due to poor growth rate of the plants. But once the clearing has passed its juvenile phase (5 years in the case of rubber) there is hardly anything left for the farmer to change the performance of a tree. Therefore, if rubber is planted, they should be planted properly with good quality plants, so that the potential yields of the clones planted can be obtained. As reported in the First Annual Report (1.2.2002 – 31.1.2003) of INCO: International Scientific Corporation Project 1998 2002, Contract No.ICA4-CT-2001-10046 "Interactions between

Environment, Society and Technology" (INTEREST), from a sample of 233 holdings in Kegalle, Kalutara and Ratnapura areas, 57% of the immature clearings are from 6 to more than 9 years of age. In other words, 57% of the holdings are with extended unproductive periods and thereby no return for the farmer or for the country for the money and the land invested.

DISCUSSION AND CONCLUSIONS

With this concept of the phase change, the term rejuvenation is also discussed. Rejuvenation occurs or juvenility is gained totally during sexual reproduction and can sometimes be induced by other means such as application of sprays, pastes or injections of synthetic plant growth regulators i.e. BAP, GA etc. (Franclet et al., 1987; Pierik, 1990; Robbings, 1957). Application of GA_3 to mature pear, *Citrus*, *Acasia* and some *Prunus* species has inhibited flowering and induced juvenile morphological characteristics (Hackett, 1985; Robbins, 1957). Severe pruning has been used successfully to obtain shoots with higher rooting potential of apple, *Pinus radiata* and several *Eucalyptus* species (Hackett, 1985; Libby and Hood, 1976). Pruning the stock plants of plum severely in winter has enhanced rooting of both the conventional and *in vitro* derived cuttings (Howard et al., 1989). Alteration of the balance of vegetative and tree productive growth through girdling, light treatments, root pruning and addition of nitrogenous fertilizers or growth retardants, preconditioning of explants etc. has also been found to rejuvenate mature plant materials. However, it is evident that the rejuvenation is a prerequisite for possible cloning of adult trees and that the success in practice will mainly depend on the ability to rejuvenate them (Pierik, 1990).

The changes in phase related characteristics as a result of *in vitro* culture has also been reported (Jones and Hadlow, 1989; Mullins et al., 1979). The length of the culture period and the number of subculture involved seem to be related to such changes. Shoot production and rooting ability of apple cultivar M 9 has been increased with *in vitro* sub culture (Webster and Jones, 1989). Increasing of percentage rooting from 10% in the primary cultures up to 60% in the second and subsequent subcultures of 199 years old *Tectona grandis* tree has been reported by Gupta et al., 1981.

The reduced growth rate of older plants can often be reversed if an aged shoot is grafted on to a young seedling plant or some times if a cutting of an aged shoot is rooted. In some cases flowering may be delayed by such propagation, but not to the same extent as by sexual reproduction. However, the two terms 'aging' and 'maturation' should in this case mean two phenomenas, the former to indicate the loss of growth vigor associated with increased complexity of the plant while the latter for the transition from the juvenile to the mature phase. Therefore, it may be that aging as well as maturation must take place before flowering can occur.

Multiple grafting of scions from the selected mature trees on to seedlings rootstocks has been used effectively for some conifers in order to induce juvenile characteristics (Cresswell et al., 1982; Zimmerman, 1985). Grafting of adult stems on to seedlings as induced juvenile type growth in *Hevea* also (Muzik and Cruzado, 1958). Buds have been taken from branches of 8-10 year old trees of Tjir 1 to initiate the grafting procedure. When the grafted bud is grown about 3-5 feet long, cuttings had been made and planted under a mist spray. At the same time, buds removed, from the scions had been grafted to new seedlings. This sequence of grafting and planting cuttings had been repeated four times. Thirty percent of the cutting from scion of the forth and fifth grafting had formed roots in about 8 weeks after planting them under the mist spray, but cuttings from the original tree and from the first, second and third graftings had failed to root under similar conditions.

The concept of juvenility and the phase change is of particular interest in the *Hevea* for many reasons. Except for the production of seeds which is characteristic of mature phase, most of the physiological characteristic related to mature phase of *Hevea* are undesirable for the farmer. Losing of or the great reduction of the capacity to propagate vegetatively is the most indescribable. If rooting of cuttings of clonal materials had been easy, it would be very much advantages as a true-to-type propagation method. The conventional method, *i.e.*, grafting buds from selected clones on to unselected rootstocks is only a partial vegetative propagation method. For this reason, intraclonal variation in girth and yield exist in any population planted with the particular clone.

Slow growth rate which is characteristic of mature phase has a large influence on the productivity of a clearing. All improved clonal materials belong in the mature phase. If the buds use for grafting are very old, this effect may be more pronounced. The recommendation for budwood nurseries is to pollard the trees regularly every year whether budwood is used or not. Further, the nurseries should be uprooted and replanted after 10 years or after 7-8 harvests. Agromanagement practices such as fertilizing and weeding has an impact on the quality of budwood and thereby on the budgrafting success and the quality of the resulting plants. When the growth rate of the plants are low, the immature period of the plantation gets extended. A clearing becomes tappable when more than 60% of the trees becomes tappable, *i.e.*, 50 cm measured at 120 cm from the graft union. Under good conditions, a clearing should become productive in about five years. The number of latex vessels or the yield of trees become tappable at different ages is not known. Anyhow, it is very unlikely for such a phenomenon to exist. Contrary to this, trees with high rate of growth can be expected to cope with tapping for their existence and growth than the trees with low rate of growth.

Wintering shows some direct influence on the growth and the yield. Normally, a yield drop is expected during the refoliation period. However, the pattern of wintering seems to be related to the clone also. Some clones such as RRIC 130, a very high yielder during the initial years of tapping, start wintering a few years later than most of the other clones. Also there are clones which show partial wintering. The occurrence and the length of the wintering period has indirect influence of the growth and the yield by making the plants vulnerable for diseases at refoliating stage.

Use of *Hevea* explants for micropropagation is similarly being affected with the phase change. As stated earlier also all elite trees are in the mature phase. Culture establishment is the primary requirement and it is very difficult with mature origin materials, mostly due to high content of phenolic compounds and difficulties in surface sterilization. The most undesirable characteristic seems to be the very slow growth and poor respond to culture medium. In *Hevea* axillary bud growth of explants taken from 4-5 year old plants was similar to those of embryo cultured plants. Explants of clonal origin were not as responsive as juvenile materials at any age of growth.

Long term strategy for supplying plants for the small holder sector
Possible sources:

1. RRISL nurseries in traditional areas;

2. RPC Nurseries;
3. Private nurseries in traditional areas;
4. RRISL nursery at Moneragala;
5. Private nurseries in Moneragala.

Traditional areas

The total planting material requirement of traditional rubber growing areas can be easily supplied from the 5 government nurseries namely Egaloya, Gurugoda, Karapincha, Walikadamulla and Meerigama located in these areas (Item 1 above).

Involvement of RPC nurseries for the plant production for the smallholder sector for year 2004 was due to on one hand, the unexpected very high demand for plants and on the other hand, very low production levels in government nurseries in the year 2003. However, with the handing over of the management of government nurseries to the RRISL in July 2003, it was well realized that the whole requirement of plants in Sri Lanka in traditional areas could easily be produced in 5 government nurseries in traditional areas. Therefore, it is very clear that there is no need of RPC nurseries getting involved in the planting material production for the smallholder sector. There were instances in the past that some estates sold their excess plants (left over plants) to the smallholder farmers.

The private nurseries scattered in the country played a little role in the planting material production for the smallholder sector. But, as it was emphasized in this report there were more disadvantages than advantages in this. Among the main disadvantages, non adoption of recommended practices, non availability of plants when required by the farmers, difficulty in monitoring, lack of major resources such as budwood, skilled labour and funds and production of very poor quality plants etc. affect the whole rubber industry in Sri Lanka. Therefore it is strongly recommended that all these substandard private nurseries should be discouraged for the betterment of rubber industry.

Non Traditional areas
RRISL Nursery at Moneragala

Plant production in this nursery will be expected to increase until the total demand is produced. However, the budwood plants will come to the full production after 4 years and will be unusable only for 6 more years (life span of a budwood nursery is only 10 years).

Private Nurseries at Moneragala

Requests were made by people in non traditional areas, for authentic material to establish budwood nurseries. The first lot of plants (about 2500 budded stumps) was issued by the RRISL in NE 2003 among 7 prospective nursery owners. Budwood from these nurseries, will be available from year 2006, Initially for about 25,000 plants (the maximum possible) which will then increase annually till 2010 which will continue till 2016 (the maximum number of budded plants that can be produced will be below 100,000).

RPC nurseries

36% of the total rubber extent in Sri Lanka is under the management of RPCs. Though the number of estates is about 125, they are managed by about 15 plantation companies. Earlier, most of the estates had their own budwood and rootstock nurseries for the supply of plants for their own replanting programmes. These nurseries, in general, are better than private nurseries under smallholder sector, but not all nurseries produce quality plants. There are one or two plantation companies where they have central nursery system to supply plants for all the estates (7-8 estates) under the company.

Though each estate has the replanting programme for at least 10 years, they do not have a plan for the supply of planting material for those programmes. Clonal composition is also not satisfactory at all. A survey done by the RRISL in 1999, on the condition of budwood nurseries under plantation companies revealed that the condition was very poor with regard to most of the aspects. The authentic material for the establishment of bud wood nurseries are supplied by the RRISL. But, the condition of most of the budwood nurseries are not satisfactory and RRISL recommendation are not practiced to guarantee the quality. This is true for the rootstock nurseries too in many estates.

In fact, most of the plantation companies are willing to buy plants from government nurseries mainly due to their higher cost of production. Lack of trained staff and skilled labour too are common problems in many estates.

Though one of the intentions of the RRISL was to increase the production in government nurseries to meet the demand of RPCs also, the government nurseries had to supply a large quantity for the farmers in the Moneragala in 2004. However, as the production in RRISL nursery at Moneragala will be increased annually, it will be considered by the RRISL to cater to the entire rubber industry.

REFERENCES

Baptist, E J C 1939 Plant hormones. Journal of Rubber Research Institute of Malaysia 9: 17-39.

Hackett, W P 1980 Control of phase change in woody plants. In: Control of shoot growth in trees. Proceedings of joint workshop IUFRO working parties on xylem and shoot growth physiology. Frederiction , NB, Canada. pp 257-272.

Hackett, W P 1985 Juvenility, maturation and rejuvenation in woody plants. Horticultural Review 7: 109-155.

Pierik, R L M 1990 Rejuvenation and micropropagation. In: Current plant science and biotechnology in agriculture. Progress in plant Culture and molecular biology, Kluwer Academic Publishes, pp 91-101.

Zimmrman, R H 1972 Juvenile and flowering in woody plant. A review Hort. Science 7: 447-455.

List of Abbreviation

BAP - Benzyl aminopurine
COP - Cost of production
GA - Gibberellic acid
RPC - Rubber planting companies
RRISL - Rubber Research Institute of Sri Lanka

Technical Session 2

Soil Fertility and Environmental Conservation

Boundary-Line Approach in Specifying Nutrient Diagnosis Ranges for Vegetatively Propagated Tea in Sri Lanka

[1]G P Gunaratne, [1]L S K Hettiarachchi and [2]A N Jayakody
[1]Soils and Plant Nutrition Division, Tea Research Institute of Sri Lanka, Talawakelle, Sri Lanka
[2]Department of Soil Science, Faculty of Agriculture, University of Peradeniya, Peradeniya, Sri Lanka

ABSTRACT

A relatively new approach, the 'boundary line' approach, for objectively assessing cause-and-effect relationships in biology, was made to a systematically-collected set of data, representing climates, soils, ownerships and management practices, from the present distribution of vegetatively-propagated tea plantations in the corporate sector of Sri Lanka. This was primarily to investigate whether this technique could be used to study tea nutrition and determine nutrient sufficiency or deficiency, and to investigate whether diagnosis ranges for vegetatively-propagated tea could be upgraded with a view to using leaf analysis as an effective diagnostic tool.

Accordingly, nutrient diagnosis ranges were arrived at for nitrogen (N), phosphorus (P), potassium (K), sulphur (S) and magnesium (Mg), and rated as 'optimum', 'deficient', 'low' and 'excess'. The optimum nutrient ranges are 2.78 - 3.39, 0.12 - 0.15, 0.91 - 1.24, 0.23 - 0.37, and 0.13 - 0.22, respectively. An attempt was also made to compare the diagnosis ranges with those ranges currently in use in Sri Lanka, and other tea-growing countries. It is apparent that the 'optimum' leaf-nutrient ranges for tea in Sri Lanka had been fixed using a limited set of information, representing a limited number of areas. Hence, the nutrient diagnosis ranges established using the boundary line approach, can be used to improve the utility of plant testing in tea when more precise interpretation and/or more narrow ranges of critical values are warranted.

Key words: boundry line approach, nutrients critical values

INTRODUCTION

Tea in Sri Lanka is planted from almost mean sea level to around 2200 metres above mean sea level, in the wet and intermediate zones of the country. Of the tea extent, approximately 46% are under old seedling while the rest is vegetatively propagated (VP) tea with high yield potential. The tea lands are classified as high- (above 1200 m), medium- (between 600-1200 m) and low- grown (below 600 m), depending on the elevation of the green leaf-processing factories. This classification originated in the early days of tea production, and is primarily to help consumers to recognize the characteristics of made tea available for sale.

The soils present in the tea-growing areas fall into three large groups, namely Red Yellow Podzolic (RYP), Reddish Brown Latasolic (RBL) and Immature Brown Loam (IBL) (Moorman and Panabokke, 1961). According to the USDA soil taxonomic classification (Anon., 1975), the RYP and RBL groups are regarded as an order Ultisol while IBL is regarded as Inceptisol.

Besides these large groups, the soils of the wet zone have been provisionally characterized and classified into series levels, using both the USDA and FAO/UNESCO systems (Mapa et al., 1999). Accordingly, 13 main series have been recognized from the following tea-growing areas: Mattakelle, Maskeliya, Nuwara Eliya, Kandy, Ukuwella, Akurana, Malaboda, Pallegoda, Weddagala, and Dodangoda, Ragala, Badulla and Mahawalatenne.

Annual rainfall, mean temperature and the duration of mean annual sunshine vary widely within the tea-growing areas in Sri Lanka. The climatic conditions, together with the soil properties at a given location, determine the land use and management requirements. Following this criterion, the areas with similar climatic and soil conditions were identified and demarcated as agro-ecological regions (AER) (Panabokke and Kannangara, 1975). Accordingly, 12 AERs have been identified within the tea-growing areas (see Fig. 1). However, the rate of growth, and in turn the production of harvestable shoots from a given site, primarily depend on the interactive rôle of climate, soil and plant factors, together with a host of management practices.

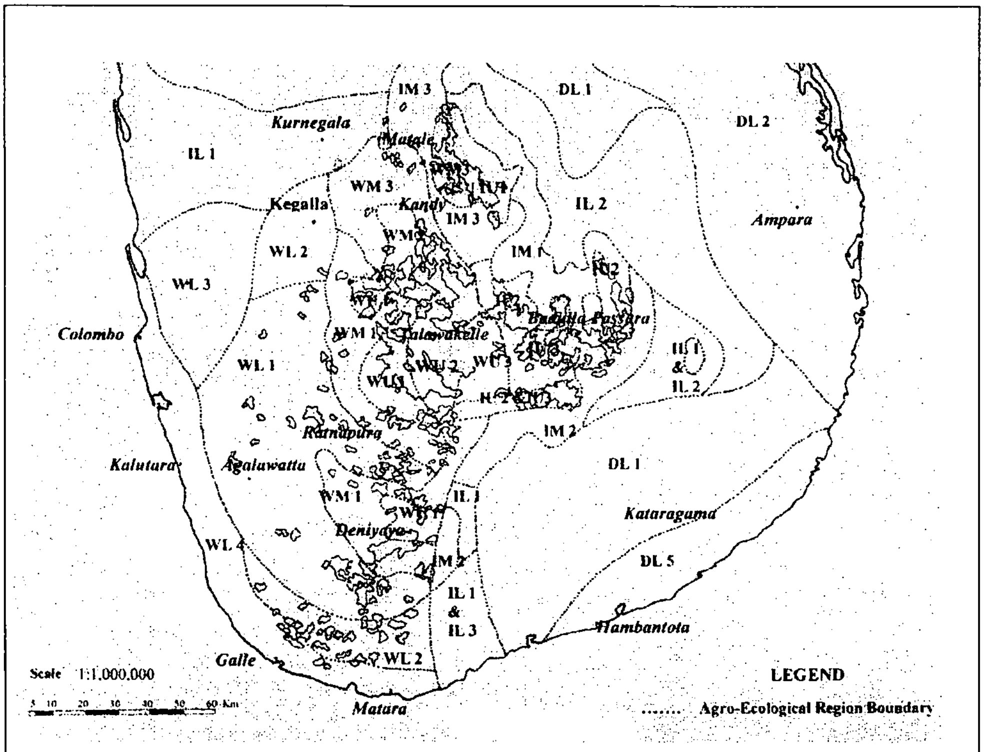


Fig 1. The distribution of tea growing areas in agro-ecological regions in Sri Lanka

Generally, there is a basic relationship between the concentration of a plant nutrient and the growth rate, or yield, of the plant (Dow and Roberts, 1982; Mengel and Kirkby, 1987). Over the range of this relationship, the critical nutrient range of concentration (CNR) or sufficiency range is a narrow range, above which, with a reasonable confidence, the plant is amply supplied, and below which the plant is deficient (Dow and Roberts, 1982). Plant-tissue analyses provide a satisfactory basis for determination of the relative proportion of nutrients present in plants and/or available in soils. In Sri Lanka, the mother leaf, in whose axil a pluckable shoot has developed, has been shown to be the most suitable for most plant nutrient analyses, and also for the diagnosis of most nutrient deficiencies and excesses (Hasselo, 1965; Wickremasinghe and Krishnapillai, 1986). However, for foliar analysis the first and/or third leaf of the pluckable shoot from the bud is sampled in East Africa (Tolhurst, 1972; Willson, 1974), while the uppermost mature leaf is sampled in Kenya (Othieno, 1988).

Leaf analysis is being increasingly used as a diagnostic tool for perennial crops. The concentration of nutrients in the plant tissue reflects what the plant has obtained from the soil, in relation to its growth up to the time of sampling. It is based on the principle that the nutrient levels reflect fertility factors affecting the growth of the plant.

Leaf-nutrient criteria can also be developed from the relationship between plant-nutrient concentration and plant performance, or yield, in fertilizer treatments. However, several years are often required before crops respond to added fertilizer, and many years of field data, collected over a range of conditions, are required to develop critical concentrations or ranges. Apart from the time duration, in the case of vegetatively-propagated tea in Sri Lanka, there exist variations among the cultivars or clones owing to clonal characteristics, and wide variations in soil and climatic conditions.

A relatively new approach to the study of crop productivity has been developed, in which the performance of the best in the sample examined is taken as a standard against which to judge the remainder (Webb, 1972). This is on the assumption that there exist reasons other than chance, which accounts for the inferior performance of part of the population. As an example, when the points in relation to nutrient status and crop yield, or relative yield, are plotted in a scatter diagram, there is always a line on the upper edge of the data range. It represents the highest yields observed over the range of nutrient values measured, and is called the 'boundary line'. The boundary line also describes the response to variation in the test parameter, where all the other factors do not limit crop yield (Lark, 1997; Schnug et al., 1996; Webb, 1972).

Walworth et al. (1986) and Evanylo and Sumner (1987) opined that it is possible to use the boundary-line approach to quickly derive sufficiency ranges for nutrients and other parameters. Surveying tissue composition in highly productive fields has been recognized as a tool in establishing sufficiency nutrient ranges (Poovarodom and Chatupote, 2002). Several researchers have effectively used this technique for various crops (Haneklause and Schnug, 1994; Khiari et al., 2001; Poovarodom and Chatupote, 2002; Sullivan et al., 1996; Walworth and Kilby, 2002; Zhenmin et al., 1999).

Optimum or critical nutrient levels, or norms, or standards, and even ranges, have been established in tissues from survey databases using this technique: for S in oilseed rape grown in Northern Germany (Haneklause and Schnug, 1994), for P in potatoes grown in Quebec (a critical nutrient diagnostic index, Khiari et al., 2001), and for N, P, K, Ca, Mg and Zn in durian grown in eastern Thailand (Poovarodom and Chatupote, 2002). However, hardly any information was found on the application of this technique for crops grown in Sri Lanka.

The objective of this study was to find out whether nutrient sufficiency, or diagnosis ranges, for vegetatively-propagated tea could be established using a large body of survey data, collected from the entire tea-growing area in the country.

MATERIALS AND METHODS

Survey methodology

An island-wide survey was carried out during July 2001 - March 2003 to collect detailed information from VP tea fields in 200 corporate-sector estates, out of a total of about 400, representing different climate factors, soil, ownership, and plantation management practices. High-yielding fields, not more than 10 to 15 years after first canopy pruning, were chosen. In general, no nutrient deficiency symptoms were observed in the chosen fields. The survey was primarily to identify the factors affecting responses to applied fertilisers, with special emphasis on potash and sulphur.

A multi-stage sampling method was used to select the estates, as shown in Fig. 2. Detailed information, on field management practices, bush characteristics, pest and disease records, yield data, and climate and site characteristics, was collected from a selected VP tea field on each estate.

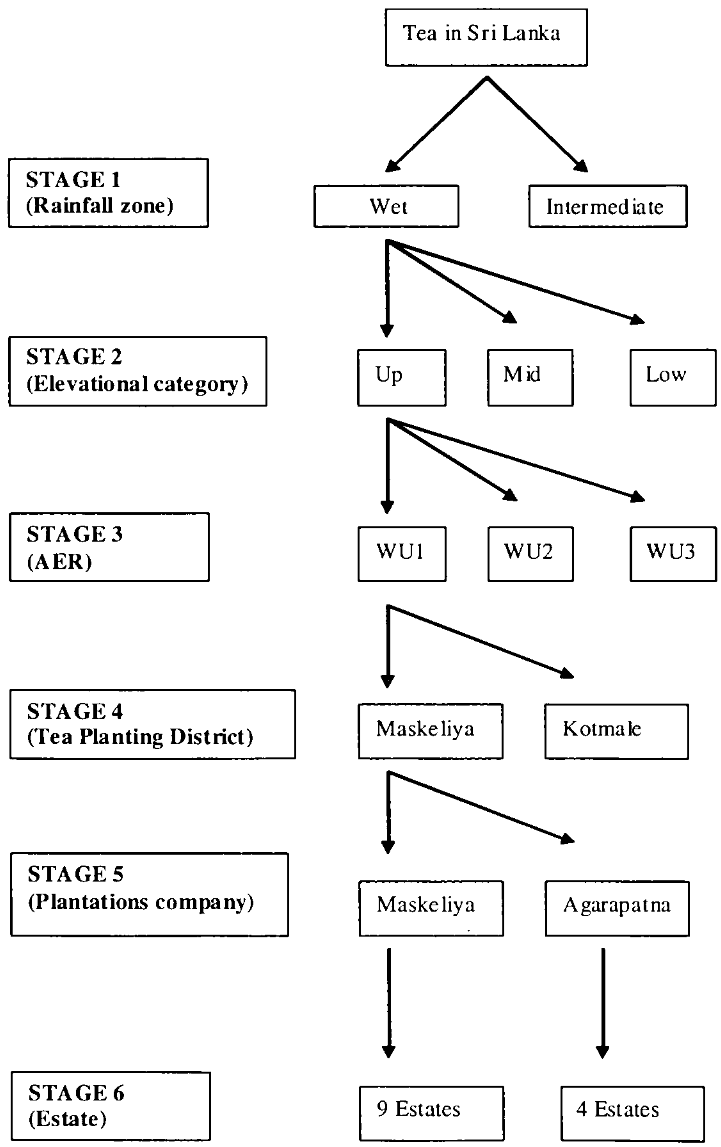


Fig 2. Multistage sampling scheme for the Islandwide survey

Sampling procedure

The first mature leaf, from whose axil the pluckable shoot emerges, was sampled for leaf-nutrient analysis. The sampled leaves were dried overnight at 80 °C, and ground in a leaf-grinding mill.

Leaf nutrient analysis

A ground leaf sample (0.2 g) was placed in a digestion tube, and ashed in a muffle furnace overnight at 480 °C. The ash content was dissolved in 0.5 ml of digestion mixture (HCl: HNO_3: H_2O in the proportion 1:1:2), and dried again over a hot plate.

Ten ml of 0.05 M HCl solution was added to the dried ash, and mixed well. Suitable aliquots were used to determine K and Mg using a flame photometer, and atomic absorption spectrophotometer, respectively. Phosphorus was determined by the vandamolybdate method (Jackson, 1958), and sulphate by the $BaCl_2$ method (Butters and Chenery, 1959), using an UV/visible spectrophotometer. The nitrogen content was determined by the Kjeldhal method (Bremner and Malvaney, 1982).

Statistical analysis

The yield data collected and leaf-nutrient concentrations estimated were tabulated, and the highest yields observed over the range of nutrient concentrations (the boundary-line points) were selected for plotting scatter diagrams. Models (linear, reciprocal, logarithmic, exponential and polynomial) were fitted using the Statistical Analysis System (SAS), version 6 (Anon., 1995 a) and Microsoft Excel (Anon., 2000) packages. The coefficient of determination (R^2) was used to select the best-fitted model.

Using the mathematical equation of the best-fitted boundary line, yield ranges representing low, deficient and optimum were estimated as < 60%, 60 - 90%, and 90 - 100%, respectively. Excessive nutrient ranges, which presumably cause decline in yield, were taken to be the concentration beyond the maximum point of the sufficiency range.

RESULTS AND DISCUSSION

The coefficients of determination (the R^2 values), which is an indicator of the degree of variation in a data set (the 'goodness'), and explained by the regression models on the highest yields over the range of leaf nutrient concentration, are given in Table 1, along with their respective probability values. The R^2 values, explained by the regression models fitted conventionally to select the best regression on yield over the nutrient ranges, are also given, along with their respective probability values, in Table 2.

The best-fitted models for the highest yield observed over the nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg) and sulphur (S) ranges, which are in fact the best-fitted boundary lines, are shown in Figs. 3 to 7, along with their respective distributions of total sample populations, as scatter diagrams.

The R^2 values have been significantly improved, following the elimination of inferior performances by a part of the population (compare values given in Tables 1 and 2). Based on the R^2 values of models tested for determining best-fitted boundary lines, and their P values, it was found that the polynomial models satisfactorily describe the variations in diverse sample populations accounting for 18 to 47 %

(Table 1). This is particularly so, as the goodness of fit (the R^2 value) primarily indicates the possible cause-and-effect relationship existing between two variables, despite the poor level of significance for a given model of regression as P values indicate the degree of probability for repetition. In fact, the degree of variation accounted for in the case of K was 25%, which was even higher than for S, although their P values were 0.4291 and 0.0431, respectively (Table 1).

Table 1. Coefficient of determination for different models fitted to select the best boundary-line regression on the highest yields over the nutrient ranges.

	Model; [Yield = *f* (plant nutrient concentration)]				
	Linear	Reciprocal	Logarithmic	Exponential	Polynomial
Nutrient	Co-efficient of determination (R^2)				
N	0.138 *(0.1421)*	0.226 *(0.0536)*	0.183 *(0.0867)*	0.031 *(0.4994)*	0.474 *(0.0112)*
P	0.039 *(0.5003)*	0.002 *(0.8808)*	0.014 *(0.6829)*	0.044 *(0.4742)*	0.340 *(0.0661)*
K	0.082 *(0.4547)*	0.031 *(0.6513)*	0.056 *(0.5416)*	0.110 *(0.3824)*	0.246 *(0.4291)*
S	0.107 *(0.0591)*	0.050 *(0.2033)*	0.079 *(0.1075)*	0.117 *(0.477)*	0.184 *(0.0431)*
Mg	0.237 *(0.0185)*	0.082 *(0.1859)*	0.154 *(0.0645)*	0.257 *(0.0135)*	0.311 *(0.0023)*

* Probability values (or level of significance) are given in parenthesis

Table 2. Coefficient of determination for different models fitted conventionally to select the best regression on the yields over the nutrient ranges.

	Model; [Yield = *f* (plant nutrient concentration)]				
	Linear	Reciprocal	Logarithmic	Exponential	Polynomial
Nutrient	Co-efficient of determination (R^2)				
N	0.004 *(0.5016)*	0.008 *(0.3355)*	0.006 *(0.4114)*	0.001 *(0.8177)*	0.002 *(0.6010)*
P	0.190 *(0.0001)*	0.143 *(0.0001)*	0.169 *(0.0001)*	0.193 *(0.0001)*	0.205 *(0.0001)*
K	0.024 *(0.0947)*	0.026 *(0.0828)*	0.025 *(0.0869)*	0.022 *(0.1102)*	0.023 *(0.1065)*
S	0.078 *(0.0022)*	0.067 *(0.0049)*	0.074 *(0.0021)*	0.079 *(0.0022)*	0.079 *(0.0021)*
Mg	0.003 *(0.5640)*	0.002 *(0.6379)*	0.002 *(0.6038)*	0.003 *(0.5512)*	0.003 *(0.5212)*

* Probability values (or level of significance) are given in parenthesis

Nutrient diagnosis ranges for the VP tea distribution were established for the first time from a single data set systematically collected, using the best-fitted polynomial boundary line equation with respect to standardized yield categories, as defined and given in Table 3. An attempt was also made to compare the diagnosis ranges with the range or ranges currently in use both in Sri Lanka (Table 3), and in other tea growing countries (Table 4), with a view to upgrading leaf-nutrient standards.

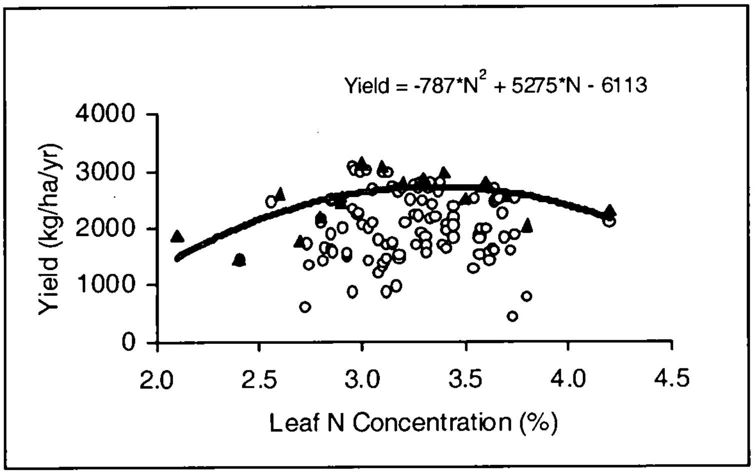


Fig 3. The best fitted boundary line for N concentration and yield.

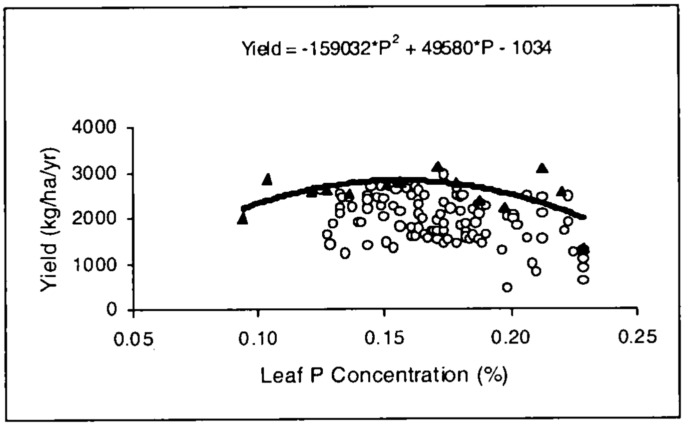


Fig 4. The best fitted boundary line for P concentration and yield.

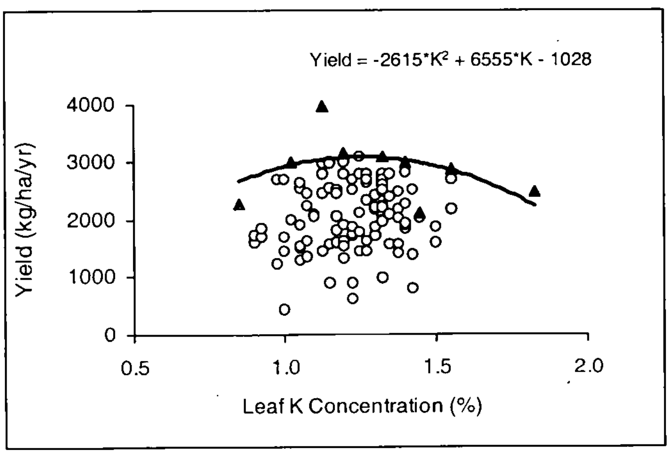


Fig 5. The best fitted boundary line for K concentration and yield.

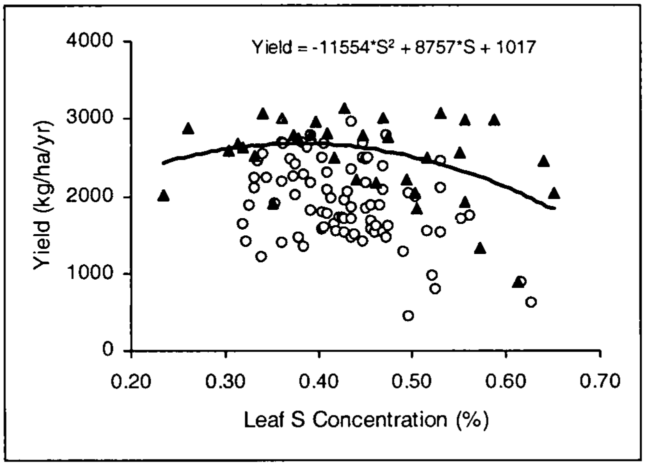


Fig 6. The best fitted boundary line for S concentration and yield.

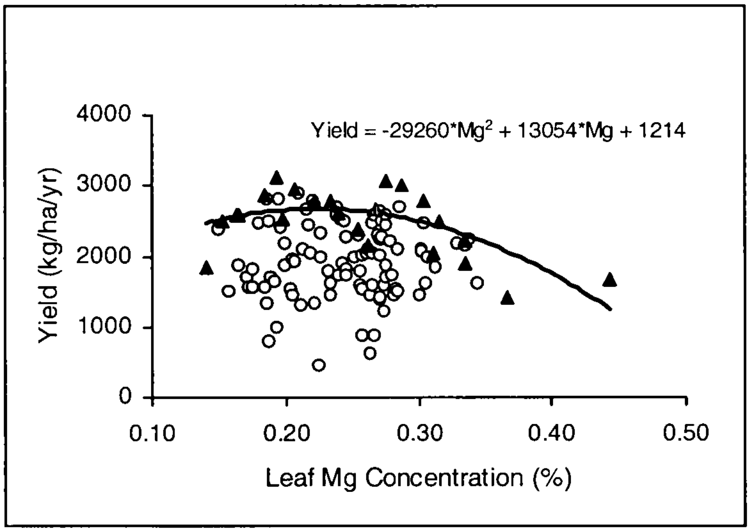


Fig 7. The best fitted boundary line for Mg concentration and yield.

Table 3. A comparison between the 'optimum' nutrient ranges currently in use in Sri Lanka, and nutrient diagnosis ranges obtained from the boundary-line technique.

	Plant nutrient (%)				
	Nitrogen	Phosphorus	Potassium	Sulphur	Magnesium
Nutrient diagnosis ranges obtained from boundary line technique					
Low	< 2.19	< 0.07	< 0.56	< 0.08	< 0.04
Deficient	2.19 – 2.78	0.07 – 0.12	0.56 – 0.91	0.08 – 0.23	0.04 – 0.13
Optimum	2.78 – 3.39	0.12 – 0.15	0.91 – 1.24	0.23 – 0.37	0.13 – 0.22
Excess	3.39 >	0.15 >	1.24 >	0.37 >	0.22 >
Nutrient ranges currently in use*					
	3.00 – 4.00	0.2 – 0.30	1.50 – 2.00	0.20 - 0.30	0.20 >
Anon, (1995b)*					

Source: Anon. (1995b)*

Table 4. Critical levels of nutrients in the uppermost mature and third leaf of the pluckable shoot, established by Kenya and East Africa respectively

	Plant nutrient (%)				
	Nitrogen	Phosphorus	Potassium	Sulphur	Magnesium
Critical levels of nutrients in the uppermost mature leaf *					
Deficient	< 3.0	< 0.15	< 1.20	-	< 0.10
Borderline	3.0 - 3.5	0.15 - 0.17	1.20 - 1.50	-	-
Adequate	3.5 >	0.17 >	1.50 >	-	-
Critical levels of nutrients in the third leaf of a shoot **					
Deficient	3.00	0.35	1.60	-	0.05
Subnormal	4.00	0.40	2.00	0.05	0.10
Normal	5.00	0.50	3.00	0.50	0.30

Sources; Owuor and Wanyoka (1983)*; and Bonheure and Willson (1992)**

In spite of the heterogeneous nature of seedling tea and variations among the cultivars owing to varietal characteristics, and the wide variations in soil and climatic conditions, a range for each nutrient supposedly 'optimum' (Table 3) have been arrived at.

These ranges appear to have been developed from a large body of data on growth and yield responses to nutrient status under different experimental conditions over a long period of time, along with the analytical data generated on soil- and leaf- samples and submitted by plantations for the last two to three decades (Jayman and Sivasubramanium, 1980; Pethiyagoda and Krishnapillai, 1970; Sivasubramanium and Jayman, 1976; Wettasinghe and Watson, 1980). Contrary to the optimum N and K ranges given, results from a recent trial, over a five-year pruning cycle, showed that the sufficiency range for leaf N varied from 3 to 3.5%, and for leaf K from 1.25 to 1.5% (Hettiarachchi et al., 2003).

The maximum concentrations of the best-fitted polynomial boundary lines, as shown in Figs. 3 to 5, were 3.39, 0.15 and 1.24 % while the optimum ranges were 2.78 – 3.39, 0.12 – 0.15 and 0.91 – 1.24, for N, P and K, respectively. These ranges are lower than the optimum ranges currently used in Sri Lanka, except for S and Mg (Anon., 1995 b).

A study was carried out by Pethiyagoda and Krishnapillai (1970) on the mineral nutrition of tea by inducing major nutrient deficiencies in sand culture. They did this by excluding from the supplied solution a single nutrient at a time, and were able to establish the leaf N, P, K, Ca and Mg concentrations associated with deficiency symptoms. Recovery to normalcy followed restoration of nutrient supply.

The results of nutrient analyses of soil- and leaf-samples from the first-ever designed 3^3 NPK factorial trial on low jat seedling tea, taken in conjunction with the corresponding yields following long-term fertilization, showed that leaf K reached a maximum value of approximately 1.8% when the water-soluble soil K content was around 12 ppm, with the yield response at 84 kg K_2O ha^{-1} yr^{-1} (Sivasubramanium and Jayman, 1976). Similarly, P reached approximately 0.24% when the borax-extractable soil P was around 20 ppm, with the yield response at 33 kg P_2O_5 ha^{-1} yr^{-1} (Jayman and Sivasubramanium, 1980). It appears that these values may also have been taken into consideration when the optimum nutrient ranges currently in use were arrived at, in spite of obvious differences between seedling and VP tea.

Wettasinghe and Watson (1980) studied the effect of three levels of N, P, K and Mg on leaf-nutrient composition, using long-term fertiliser trials with VP teas grown in low country conditions. They found that increasing the rate of N fertiliser resulted in an increase in leaf-N concentration. Although the leaf-N concentration increased with increasing levels of N fertiliser at each location, the relationship was not quite clear when the data were pooled, indicating the possible influence of other factors such as climate, soil type and clone, on the leaf-N content. The authors opined that there appeared to be a fine balance between N, K and Mg, but felt it was premature to attempt to define critical values for the various nutrients from these results.

Lately, a pot trial carried out to test the agronomic effectiveness of increasing rates of P using Eppawala rock phosphate and Triple super phosphate on assessing the growth of 8-month old tea plants from TRI 3072 in an Ultisol over a period of 10 months showed that the P concentration of the first mature leaf corresponding to 95% of the maximum dry matter yield was approximately 0.18% (Zoysa, 2000).

No attempt was made to compare the diagnosis ranges arrived at from the mother leaf, with the critical levels of nutrients in the third leaf of the shoot (Bonheure and Willson, 1992), as the concentration of N, P and K in the foliage decreases significantly with leaf maturity (Hettiarachchi et al., 1997). Also, there exist significant differences between the critical levels of nutrients in the uppermost mature leaf when compared to diagnosis ranges in the mother leaf, although they appeared to be quite similar.

In general, soil properties are related to climate, parent material, land relief and changes in use pattern. As the soils were also collected simultaneously with leaf samples from each field in this survey, an attempt will be made to correlate all the plant-available soil nutrient levels with leaf-nutrient concentrations, and yield data, in due course for a subsequent publication.

It is evident that the boundary-line approach can be used to upgrade nutrient-deficiency diagnosis in tea plantations. It is worthwhile considering the nutrient diagnosis ranges established for VP teas for implementation.

Another advantage of this technique is the identification of incipient nutrient-deficiency prior to the presentation of symptoms, and the possibility of early correction of such deficiencies to prevent a deleterious effect on the optimum rate of growth in VP tea plants.

CONCLUSION

It is apparent that the so-called optimum leaf-nutrient ranges for tea in Sri Lanka have been developed with limited information from only certain areas. It is now necessary to revise the standards, and the nutrient diagnosis ranges, established using the boundary-line approach, can be used to improve the utility of plant-testing in tea, when a more precise interpretation and narrower ranges of critical values are warranted.

REFERENCES

Anon, 1975 Soil taxonomy: A basic system of soil classification for making and interpreting soil surveys. USDA SCS, Agri. Hand book 436, US Government Printing Office, Washington DC, USA.

Anon, 1995 a SAS/ETS User's Guide, Version 6, 2nd Edition, SAS Institute, Cary, NC.

Anon, 1995 b *Field Guide Book.* Tea Research Institute, Talawakelle, Sri Lanka; pp. 22-35.

Anon, 2000 Microsoft Office 2000, Premium Edition, Microsoft Corporation, U.S.A.

Bonheure, D and Willson, K C 1992 Mineral nutrition and fertilizers. In: *Tea Cultivation to Consumption* (eds. K. C. Willson, M. N. Clifford), pp. 269-321. Chapman and Hall, London.

Bremner, J M and Malvaney, C S 1982 Total nitrogen. In: *Methods of Soil Analysis.* (ed. A L Page), Part 2, 2nd Edition, pp. 595-622. Am. Soc. Agron., Madison, Wisconsin, U.S.A.

Butters, B and Chenery, E M 1959 A rapid method for determination of total sulphur in soils and plants. Analyst 84, 239-245.

Dow, A I and Roberts, S 1982 Proposal: Critical nutrient ranges for crop diagnosis. Agron. J. 74, 401-403.

Evanylo, G K and Sumner, M E 1987 Utilization of boundary line approach in the development of soil nutrient norms for soyabean production. Commun. Soil Sci. Plant Anal. 18, 1379-1401.

Haneklause, S and Schnug, E 1994 Diagnosis of crop sulphur status and application of X-ray fluorescence spectroscopy for the sulphur determination in plant and soil materials. Sulphur in Agriculture 18, 31-40

Hasselo, H N 1965 The nitrogen, potassium, phosphorous, calcium, magnesium, sodium, manganese, iron, copper, boron, zinc, molybdenum and aluminium contents of tea leaves of increasing age. Tea Q. 36, 122-136.

Hettiarachchi, L S K, Balasingham, S Ananthacumaraswamy, S, Gunaratne, G P and Warnasiri, H A P 1997 Mineral composition in relation to leaf maturity from 2000, 3000 and 4000 clonal series: Leaf analysis as a guide in tea crop nutrition. S. L .J .Tea Sci. 65, 11-33.

Hettiarachchi, L S K, Ananthacumaraswamy, S, Gunaratne, G P and Zoysa, A K N 2003 Outcome of a collaborative trial on nitrogen and potassium: Tea Research Institute and Maskeliya Plantations Ltd. Proceedings, 206th Experiments and Extension Forum, Tea Research Institute, Talawakelle, Sri Lanka.

Jackson, M L 1958 *Soil Chemical Analysis*, pp.134-182. Prentice Hall, Inc., Englewood Cliffs, N.J., U.S.A..

Jayman,T C Z and Sivasubramaniam, S 1980 The use of fertilizers for tea in Sri Lanka. 3. Foliar and soil analysis with particular reference to P, Ca and Mn. Tea Q. 49, 137-141.

Khiari, L, Parent, L E and Tremblay, N 2001 The phosphorous compositional nutrient diagnosis range for potato. Agron. J. 93, 815-819.

Lark, R M 1997 An empirical method for describing the joint effects of environmental and other variables on crop yield. Ann. Appl. Biol. 131, 141-159.

Mapa, R B, Somasiri, S and Nagarajah, S 1999 *Soils of the Wet Zone of Sri Lanka*, p. 23-36. Soil Science Society of Sri Lanka, Colombo, Sri Lanka.

Mengel, K and Kirkby, E A 1987 *Principles of Plant Nutrition,* 103-104 pp. International Potash Institute, Bern, Switzerland.

Moorman, F R and Panabokke, C R 1961 Soils of Ceylon. Tropical Agriculturist 117, 5-65.

Othieno, C O 1988 Summary of recommendations and observations from TRFK. Tea 9, 50-65.

Owuor, P O and Wanyoko, J K 1983 Fertilizer use advisory service. A reminder to farmers. Tea 4, 3-7.

Panabokke, C R and Kannangara, R P K 1975 The identification and demarcation of the agro-ecological regions of Sri Lanka. Proc. Ann. Sessions. Sri Lanka Association for the Advancement of Science 31(3), 49.

Pethiyagoda, U and Krishnapillai, S 1970 Mineral nutrition in tea. Experimentally induced major deficiency. Tea Q. 36, 448-58.

Poovarodom, S and Chatupote, W 2002 Boundary line approach in specifying durian nutrient standards. 17th WCSS, Thailand.

Schnug, E, Heym, J and Achwan, F 1996 Establishing critical values for soil and plant analysis by means of the boundary line development system (Bolides). Commun. Soil Sci. Plant. Anal. 27, 2739-2748.

Sivasubramaniam, S and Jayman, T C Z 1976 The use of fertilizers for tea in Sri Lanka. 2. Foliar and soil analysis with particular reference to potassium. Tea Q. 46, 4-11.

Sullivan, N H, Bolstad, P V and Vose, J M 1996 Estimates of net photosynthetic parameters for twelve tree species in mature forests of the southern Appalachians. Tree Physiol. 16, 397-406.

Tolhurst, J A H 1972 A re-appraisal of the leaf-analysis advisory service. Tea 13, 17-21.

Wettasinghe, D T and Watson, M 1980 Effect of nitrogen, phosphorus, potassium and magnesium fertilizers on the leaf nutrient composition of low grown tea in Sri Lanka. Tea Q. 49, 44-52.

Webb, R A 1972 Use of the boundary line in the analysis of biological data. J. Hort. Sci. 47, 309-319.

Walworth, J L, Letzsch, W S and Sumner, M E 1986 Use of boundary lines in establishing diagnostic norms. Soil Sci. Soc. Am. J. 50, 123-128

Walworth, J L and Kilby, M 2002 Pecan leaf tissue nutrient concentrations: Temporal relationships and preliminary standards. Citrus and Deciduous Fruit Research Report, University of Arizona, College of Agriculture and Life Science.

Wickremasinghe, K N and Krishnapillai, S 1986 Plant Tissue Analysis. In *Handbook on Tea* (eds. P Sivapalan, S Kulasgeram, A Kathiravetpillai), p. 63-77. Tea Research Institute of Sri Lanka, Talawakelle, Sri Lanka.

Willson, K C 1974 Studies on the mineral nutrition of tea. 1. Experimental methods. Plant and Soil. 41, 1-12.

Zhenmin, T Chambers, J L and Barnett, J P 1999 Characterization of optimum physiological response of field-grown Loblolly Pine, p. 409-415. Tenth Southern Sivicultural Research Conference, Shreveport, LA.

Zoysa, A K N 2000 The fate of phosphate fertilizers in an Ultisol in Sri Lanka: Phosphorus availability to tea (*Camellia sinensis* L.). In Plantation tree crops in the new millennium: The way ahead. (Vol 1) Ed E. Pushparaj, pp 347-364. The Incorporated Society of Planters, Kuala Lumpur, Malaysia.

Mucuna bracteata as a Cover Crop for Rubber (*Hevea brasiliensis*) in Sri Lanka

Lalani Samarappuli, P Karunadasa, U Mitrasena and T Gunathilaka
Rubber Research Institute of Sri Lanka, Agalawatta, Sri Lanka

ABSTRACT

Efficiency of *Mucuna bracteata* as a cover crop for rubber was studied in comparison with *Pueraria phaseoloides*. Dry weights of green matter and litter production of *Mucuna* were found to be three times higher than *Pueraria*. Also, *Mucuna* exhibited 45cm and 106 cm thick layers of green matter and litter compared to 15cm and 36 cm thick layers of *Pueraria*, for green matter and litter, respectively. A significant contribution of N, P, K and Mg was made by both green matter and litter of *Mucuna* compared to that of *Pueraria*. Soil analysis indicated a build-up of nutrients, organic carbon and microbes in the soil under *Mucuna* in comparison to *Pueraria*.

Mucuna showed a lower transpiration rate than *Pueraria* and also had more deep rooted system than both rubber and *Pueraria*. The soils under *Mucuna* had significantly higher moisture content of 19.6% and 18.1% for the depths of 0-15 cm and 15-30 cm respectively, than the soils under *Pueraria*. Among the two species, *Mucuna* recorded a higher moisture profile storage capacity of 25.8 cm for a depth of 90 cm and also there was an increase of 41% in moisture storage capacity. It was found that growing *Mucuna* resulted in a better soil physical condition than *Pueraria*. Data on soil loss indicates that growing *Mucuna* can minimize soil loss significantly, in comparison with *Pueraria* and also weed infestation was lower under *Mucuna*.

Key words: cover crops, *Mucuna bracteata, Pueraria phaseoloides*, soil fertility

INTRODUCTION

During the early years after planting, young rubber plants provide insufficient protection to the soil, mainly due to poor canopy cover. It is therefore, necessary to adopt suitable management practices that will provide sufficient ground cover to prevent soil erosion and enhance soil fertility. The importance of leguminous ground covers has been emphasised by several researchers who regarded activities, which increase soil organic matter and promote biological diversity as a strategic approach in soil and water management. (Samarappuli, 1992a; Samarappuli et al., 1999; Yogaratnam et al., 1977; Yogaratnam et al., 1984). The most widely used leguminous cover crop in Sri Lanka is Pueraria phaseoloides. It is known that this traditional leguminous cover crop does not perform successfully against drought and shade and also does not compete successfully against weed growth. This situation leads to inefficient management of soil and moisture conservation under rubber. Therefore, investigation on new legumes species with superior characteristics has become essential. *Mucuna bracteata* is a wild leguminous creeper found in the forest area of Tripura State, North India and is recommended as a cover crop for rubber in India (Kothanduraman, *et al.*, 1997). This paper highlights the efficiency of *Mucuna bracteata* in relation to *Pueraria phaseoloides* on soil fertility and moisture management under rubber.

METHODS AND MATERIALS

Experiments were conducted at Perth estate, Horana, RRISL sub station at Kuruwita and Kumarawatta estate, Monaragala, to study the comparative efficiency of five different species of leguminous cover crops including both creeping and bush/tree types, *viz.*, *Pueraria phaseoloides* (creeping type), *Mucuna bracteata* (creeping type), *Flemingia macrophylla* (Bush/tree type), *Crotalaria micans* (Bush/tree type) and *Tephrosia vogelli* (Bush/tree type), which were arranged in a randomised block design with each treatment being replicated five times. Results with regard to *Mucuna* and *Pueraria* only are presented in this paper.

Plots with *Pueraria* and *Mucuna* had a pure growth of the legumes and a clean- weeded circle was maintained around the rubber plants for both treatments as recommended by the Rubber Research Institute of Sri Lanka. Green matter and litter collection were done by using a 1 m^2 frame and three measurements were taken in each plot (size of 0.1ha) and the mean value of the three measurements was extrapolated to get the per hectare value. Similarly, thickness of the green matter and litter layers was also measured. Green matter and litter were analysed for nutrient contents and microbial population. Organic carbon and soil nutrients were also measured by collecting soil samples under each treatment. Transpiration rate was measured using a porometer and root distribution was measured by cutting soil profiles.

The bulk density of the soil was measured by obtaining undisturbed core samples and a composite bulk sample consisting of soils taken from three places was obtained for aggregate analysis. The neutron probe was used to monitor soil water distribution profile under different soil management practices. Access tubes were installed in each experimental plot and weekly counts for soil water content were made at depths of 10 cm interval from 10 cm to 160 cm. The gravimetric soil moisture content was measured by taking three samples from each plot and moisture retention under different matric suctions was determined using the pressure plate apparatus where undisturbed core samples were obtained. Soil erosion under each treatment was recorded using collection tanks.

Statistical analyses of all experimental data were done by Analysis of Variance (ANOVA) followed by a mean separation procedure, Duncan's Multiple Range Test (DMRT), at the probability level of 0.05.

RESULTS

Data indicated that dry weights of green matter and litter production of *Mucuna* were three times higher than *Pueraria* (Table 1). Similar results were observed with regard to thickness of the green matter and litter layers and the *Mucuna* exhibited 45 cm and 106 cm thick layers compared to 15cm and36 cm thick layers of *Pueraria,* for green matter and litter, respectively (Table 1). Data also revealed a significant contribution of N, P, K and Mg by both green matter and litter of *Mucuna* compared to the contribution of *Pueraria* (Table 2). Soil analysis indicated a build-up of nutrients (Table 3), organic carbon and microbes in the soil under *Mucuna* in comparison to *Pueraria* (Table 4).

Table 1. Biomass production and cover thickness of *Pueraria* and *Mucuna*

Species	Biomass production (kg ha^{-1}) (dry wt.)		Cover thickness (cm)	
	Green matter	Litter	Green matter	Litter
Pueraria phaseoloides	2,200^{a}	2,000^{a}	36^{a}	15^{a}
Mucuna bracteata	6,250^{b}	6,750^{b}	106^{b}	45^{b}

(Means with the same letter are not significantly different)

Table 2. Contribution of nutrients by *Pueraria* and *Mucuna*

Item	Species	Nutrients (kg ha^{-1})			
		N	P	K	Mg
Green matter	*Pueraria phaseoloides*	84^{a}	6^{a}	30^{a}	7^{a}
	Mucuna bracteata	194^{b}	15^{b}	61^{b}	15^{b}
Litter	*Pueraria phaseoloides*	65^{a}	4^{a}	6^{a}	6^{a}
	Mucuna bracteata	192^{b}	9^{b}	18^{b}	14^{b}

(Means with the same letter are not significantly different)

Table 3. Effect of growing *Pueraria* and *Mucuna* on soil nutrients

Species	Nutrients			
	N (%)	P (mg/kg)	K (mg/kg)	Mg (mg/kg)
Pueraria phaseoloides	0.15^{a}	19^{a}	43^{a}	33^{a}
Mucuna bracteata	0.20^{b}	33^{a}	64^{a}	41^{a}

(Means with the same letter are not significantly different)

Table 4. Effect of *Pueraria* and *Mucuna* on soil organic carbon and soil microbial population

Species	Organic C (%)		Microbes (x10^{4} g^{-1} dry soil)
	0-15cm	15-30cm	
Pueraria phaseoloides	1.1^{a}	0.9^{a}	62^{a}
Mucuna bracteata	2.8^{b}	1.9^{b}	97^{b}

(Means with the same letter are not significantly different)

Data on transpiration rate indicated that *Mucuna* had significantly low transpiration rate compared to *Pueraria* (Table 5). Data also shows that *Mucuna* had more deep rooted system compared to both rubber and *Pueraria* (Table 6).

Table 5. Transpiration rate of *Pueraria* and *Mucuna*

Species	Transpiration rate (µg $cm^{-2} sec^{-1}$)
Pueraria phaseoloides	11.6[a]
Mucuna bracteata	1.4[b]

(Means with the same letter are not significantly different)

Table 6. Root distribution of *Pueraria* and *Mucuna*

Species	Depth of feeder roots (cm)
Pueraria phaseoloides	20
Mucuna bracteata	70
Rubber	30

Data on soil bulk density of the 0-15cm and 15-30cm depths indicated that soils under *Mucuna* had significantly low bulk density when compared with *Pueraria.* It was also found that growing *Mucuna* resulted in a significantly higher total aggregation percentage in the region of 17% over *Pueraria* (Table 7).

Table 7. Effect of *Pueraria* and *Mucuna* on bulk density and soil aggregation

Species	Bulk density (g cm^{-2})		Aggregation (%)
	0-15cm	15-30cm	
Pueraria phaseoloides	1.23[a]	1.52[a]	52.8[a]
Mucuna bracteata	1.08[b]	1.21[b]	61.9[b]

(Means with the same letter are not significantly different)

The soils under *Mucuna* showed significantly higher moisture content of 19.6% and 18.1% for the depths of 0-15 cm and 15-30cm respectively, in comparison to the soils under *Pueraria* (Table 8). Among the two species, *Mucuna* records higher moisture profile storage capacity of 25.8 cm for a depth of 90 cm. There was an increase of 41% in the moisture storage capacity as compared to *Pueraria* (Table 8). The amount of water retained at different soil potentials for the soils under two species of legumes is given in Table 9 and it indicates that *Mucuna* has improved the water retention at different soil potentials. Data on soil loss under two species of legumes indicated that growing *Mucuna* has minimized the soil loss significantly, compared to growing *Pueraria* (Table 10) and also weed control was better under *Mucuna* (Table 11).

Table 8. Effect of *Pueraria* and *Mucuna* on soil moisture content and soil moisture storage capacity (SMSC) for 90 cm soil profile

Species	Soil moisture content (%)		SMSC (cm)
	0-15cm	15-30cm	
Pueraria phaseoloides	16.1[a]	15.0[a]	18.3[a]
Mucuna bracteata	19.6[b]	18.1[b]	25.8[b]

(Means with the same letter are not significantly different)

Table 9. Effect of *Pueraria* and *Mucuna* on volumetric moisture content at different soil potentials

Species	Volumetric moisture content (%)		
	-10 kPa	-500 kPa	-1500 kPa
Pueraria phaseoloides	35.8[a]	32.9[a]	31.8[a]
Mucuna bracteata	42.9[b]	35.7[b]	32.9[a]

(Means with the same letter are not significantly different)

Table 10. Effect of growing different species of legumes on soil loss

Species	Soil loss (mt ha^{-1})
Pueraria phaseoloides	18[a]
Mucuna bracteata	3[b]

(Means with the same letter are not significantly different)

Table 11. Effect of growing different species of legumes on weed control during immature period

Species	Weed control (%)
Pueraria phaseoloides	52[a]
Mucuna bracteata	83[b]

(Means with the same letter are not significantly different)

DISCUSSION

Management of ground covers is well known to be an important aspect of soil and moisture conservation in rubber cultivation. It also known that the traditional leguminous cover crop *Pueraria* does not perform successfully against drought and shade and also does not compete successfully against weed growth. This situation leads to inefficient management of soil and moisture under rubber. Therefore, investigation on other possible legumes species with superior characteristics has become essential.

Data indicated that green matter and litter production of *Mucuna* were three times higher than *Pueraria*. This highlights the importance of growing *Mucuna* to enhance the organic matter content of the soil. Although decomposition of organic matter is rapid under tropical conditions, organic matter tends to accumulate in the form of litter due to continuous addition of decaying leaves, stems and roots of the fast growing cover crop, *Mucuna*. The lower soil organic carbon content under *Pueraria* is probably due to the poor return of litter to the soil and greater exposure of soil under *Pueraria* owing to its susceptibility to drought and shade conditions compared to *Mucuna*. It was reported that organic matter serves as a substrate for biological activity. Polar substances resulting from decomposition of organic matter are very effective in improving cultivated soils (Kroth and Page, 1946). Microbial gums and filamentous fungi are known to thrive well under increased organic matter content and this is confirmed by the data on microbial population under *Mucuna*. The influence of cover plants on soil improvement is of considerable importance. The gradual release of soil nutrients by the higher amount of biomass of *Mucuna* would have been a contributory factor in increasing the nutrient contents of soil. Another possible explanation for the better nutrient content under *Mucuna* is that weed growth was significantly less and the competition for nutrients is also less. Another advantage of *Mucuna* is the increase in soil cation exchange capacity. This probably contributed to an improved fertility condition of soils under *Mucuna*.

Some important physical soil parameters such as soil bulk density, soil porosity and soil resistance were improved under *Mucuna*. It is possible that the higher organic matter layer on the soil surface would have prevented the direct impact of raindrops, thus preventing the breakdown of soil structure. The higher porosity under *Mucuna* may have been due to the better soil structure. An organic matter layer on the soil surface is also known to serve as a cushion against the pressure exerted by raindrops.

The highest aggregation percentage was observed under *Mucuna*. There was an increase of 10% in aggregation was observed under *Mucuna* and it appears that the loss of finer-fraction ultimately resulted in the formation of coarser water stable aggregates. The relatively low amount of aggregates in soils under *Pueraria* can be attributed to structural breakdown by the impact of raindrops due to exposure of soil to rainfall. It is possible that high organic matter content under *Mucuna* played an important role in the formation of water stable aggregates. The amount of soil aggregates plays a dynamic role in the changes of soil structure (Zainol, 1993). The percentage aggregation is known to be a measure of ability of the soil structure to with stand the disruptive forces of erosive rain in the tropics. There may be two reasons for the effect of *Mucuna* in reducing soil erosion. Firstly, the thick organic matter layer on the surface intercepts the raindrops and dissipates their energy, thus preventing detachment of soil particles and sealing of the soil surface. Secondly, there may be a decrease in the run-off due to reduced flow rate and carrying capacity of the run-off. It is therefore, possible that growing *Mucuna* may have minimized run-off and controlled erosion. Further, on land replanted with young rubber, soon after planting, there is a loose surface layer of soil, which could easily be washed away with the run-off unless some protection is provided early (Samarappuli, 1992b; Samarappuli, 1995; Samarappuli and Yogaratnam, 1984).

The data on soil moisture content indicates that soils under *Mucuna* had the highest moisture content of 20% and 18% for the 0-15 cm and 15-30 cm depths respectively, in comparison to soils under *Pueraria*. Among the two species, the highest moisture profile storage capacity of 25.8 cm was observed under *Mucuna* for 90 cm profile depth. There was an increase of 41% in the moisture storage capacity as compared to the soils under *Pueraria*. Similarly, at different suction, more water was retained in the soils under *Mucuna*. Thick organic matter layer would have influenced the moisture content of the soil by their effect on water intake through the immediate surface layer and also by decreasing losses due to soil evaporation probably by suppressing weed growth (Samarappuli and Yogaratnam, 1995). Also, an improved structure decreases crusting and surface sealing and permits greater infiltration, thereby increasing the water holding capacity. Moreover, the transpiration rate of *Mucuna* is ten times lower than *Pueraria* thus allowing more moisture to remain in the soil for a longer period of time. Any reduction in evapo-transpiration of soil moisture would be beneficial to crop growth in the same manner as additional water. Further, it was observed that *Mucuna* has a deep root system than *Pueraria*, which allows uptake of water from deeper layers of soil thus reducing the competition for water with young rubber plants. It therefore, appears possible to eliminate or at least minimize the adverse effects of moisture stress by growing *Mucuna*. The higher soil moisture content may increase the water uptake by young plants thereby increasing their growth especially during dry periods. These results also seem to suggest that when *Mucuna* is grown under rubber, it is possible that the performance of *Hevea* plants could be improved as a result of improvement in soil fertility.

ACKNOWLEDGEMENT

The authors wish to thank Ms Wasana Wijesuriya, Biometrician for her valuable assistance in statistical analysis.

REFERENCES

Kroth, E M and Page J B 1946 Aggregate formation in soils with special reference to cementing substances. *Soil Sci. Soc. Amer. Proc.*, 11, 29-34.

Samarappuli, Lalani 1992a Effects of some soil management practices and moisture regimes on the performance of *Hevea*. *PhD Thesis, University of Peradeniya.*

Samarappuli, Lalani 1992b Some agronomic aspects in overcoming moisture stress in *Hevea brasiliensis*. *Indian Journal of Natural Rubber Research*, 5, 127-132.

Samarappuli, Lalani 1995 The Contribution of Rubber Plantations Towards a Better Environment. *RRISL Bulletin*, 33, 45-54.

Samarappuli, Lalani and Yogaratnam, N 1984 Some aspects of moisture and soil conservation in rubber plantations. *Proc. Int. Rubb. Conf.* 1984, 1, (II), 529-543.

Samarappuli, Lalani and Yogaratnam, N 1995 Rubber plantations as a self-sustaining agro forestry system. *The Sri Lanka Forester*, xxii, 1&2, 13-24.

Samarappuli, Lalani and Yogaratnam, N 1996 Soil degradation and development practices in *Hevea* plantations. *Jl. NIPM*, 12 (1), 48-60.

Yogaratnam, N, Perera, A M A and De Mel, J G 1984 Management of ground covers for optimum production. *Proc. Int. Rubb. Conf., 1984, Sri Lanka,* 1 (2) : 521 - 527.

Yogaratnam, N, Sulaiman, H, Karunaratna, A D M and Pieris, K S A C 1977 Management of covers under *Hevea* in Sri Lanka. *J. Rubb. Res. Inst. Sri Lanka*, 54 : 291 - 298.

Zainol, E and Mokhtaruddin, A M 1993 Effects of intercropping systems on surface processes in an acid Ultisol. 1. Short-term changes in soil physical properties. J. Nat. Rubb. Res., 8(1), 57-67.

8202

Evaluation of Major Nutrient Availability of Soils by Green-house Study

D M D I Wijebandara, N A Tennakoon and L L W Somasiri
Division of Soils and Plant Nutrition, Coconut Research Institute, Lunuwila, Sri Lanka

ABSTRACT

The major nutrient availability in the soils of Boralu series, Wariyapola series and Kurunegala series was evaluated by greenhouse pot experiment using *Panicum maximum* as the indicator plant. Panicum was grown on soils, which were collected from different locations of each soil series. All the soils were treated with eight treatments; +All (0.16 g $(NH_4)_2SO_4$, 1.0 g TSP, 0.2 g KCl, 0.1 g $MgSO_4.7H_2O$ per 2 kg soil in the pot),-N, -P, -K and –Mg and -All respectively. Experiment was in randomised block design with three replicates. Two months after planting, *Panicum* was cut at one-month interval and dry weight and total N, P, K and Mg content were obtained. Percent Relative Yield (RY%) of *Panicum* cuttings was calculated.

The cumulative dry weight of *Panicum* showed that three soils were not supplying N nutrient sufficiently to the plant to get the maximum vegetative growth. Phosphorus nutrient supply by Boralu series soils also seems to be low, but K and Mg supply is satisfactory in Boralu series and P, K and Mg supply also satisfactory in Kurunegala and Wariyapola series soils.

The RY% showed that response of *Panicum* to N (81 %) and P (30 %) fertiliser was high on Boralu compared to Wariyapola and Kurunegala series soil. Response of *Panicum* to K and Mg fertiliser was very low (0.1 % to 16 %) on three soil series. For -All treatment, *Panicum* showed a very high response (106 %) on Boralu while it showed moderate response to Wariyapola series and Kurunegala series (77 % and 55 % respectively).

The N, P, K and Mg availability of all three soils was low but that of Boralu series was lower than other two soils. Therefore application of N, P, K and Mg fertiliser mixture will have beneficial effects on crop growth improvement. The greenhouse results revealed that the beneficial effect of application of N, P, K and Mg fertiliser is highest in Boralu series soils and lowest in Kurunegala series while Wariyapola series soils are in moderate status.

Key words: Dry matter, percent Relative Yield, plant response, and fertiliser, major nutrients, availability

INTRODUCTION

The coconut palm takes up Nitrogen (N), Phosphorus (P) and Potassium (K) in larger quantities and Magnesium (Mg) in moderate quantities as major nutrients. The soil may get rapidly depleted of these nutrients due to prolonged coconut cultivation. Potassium and Mg deficiency symptoms are often visible in coconut plantations. Such deficiencies can be corrected by application of NPK and Mg containing fertilisers. Those elements are included in both young and adult palm coconut fertiliser mixtures (Mahindapala and Pinto, 1991).

Apart from the nutrient removal by the coconut palms, one of the factors that determine the necessity of nutrient input to the soil by fertiliser is the nutrient supplying power of the soils. Knowledge in fertility status of widespread soils in the coconut growing areas is very important for fertiliser recommendations.

The objective of the present experiment was to determine the availability of N, P, K and Mg of three coconut growing soils in coconut triangle viz., Boralu series, Wariyapola series and Kurunegala series by a greenhouse pot experiment.

MATERIALS AND METHODS

A greenhouse pot experiment was carried out to obtain a plant indices for N, P, K and Mg status of each soil. Three widespread coconut growing soils, viz., Boralu series, Wariyapola series and Kurunegala series (Somasiri et al., 1994) in mantled plain of the Intermediate Zone Low country of Sri Lanka were used for this study. Representative soil samples were taken from the previously nutrient status studied sites from Kurunegala series, Boralu series and Wariyapola series where the nutrient status has been previously studied. (Annual Reports, 1998 to 2002. CRI), At each site composite soil samples were taken up to the depth of 0 – 25 cm (in top soil) from the centre of the four coconut palms of unmanured coconut plantation. Some characteristics of the soils used for the pot experiment are given in Table 1.

Table 1. Description of soil used for pot experiment

Soil series	Great soil group	Texture	pH 1:5 (w/w) soil : H_2O	EC µmho/cm	Total N Mg/kg	Available P 2.5 % Acetic acid	Ex. K meq/100 g	Ex. Mg meq/100 g
Wariyapola	Non Calcic Brown	Sandy loam	5.00	79	1102±100	9.13±0.52	0.42±0.01	1.22±0.08
Boralu	Red Yellow Podzolic	Sandy loam	5.10	32	914±42	8.11±0.41	0.12±0.02	0.13±0.06
Kurunegala	Red Yellow Podzolic	Sandy loam	5.26	31	555±38	12.51±0.53	0.12±0.02	0.33±0.09

Soil was passed through 6-mm sieve at the field moist state, and filled into pots (2-kg soil per pot). Each soil, filled into pots was treated with the following treatments and arranged in a greenhouse in Randomised Block Design with three replicates. Treatments comprised of (T_1) +All [(0.16 g $(NH_4)_2SO_4$, 1.0 g TSP, 0.2 g KCl, 0.1 g $MgSO_4$ $7H_2O$ per 2kg soil], (T_2) -N (- $(NH_4)_2SO_4$), (T_3) -P (TSP), (T_4) -K (-KCl), (T_5) -Mg (-$MgSO_4.7H_2O$) and –All (T_6) (-N, -P, -K and –Mg). After treatment application, *Panicum maximum* cuttings were planted in each pot. The moisture content in the soil was maintained at field capacity level. Dry weight of *Panicum* cuttings were obtained at monthly interval for two years and cumulative dry weight was calculated.

Percentage Relative yield (%RY) increase of cumulative dry weight of *Panicum* in each soil series was calculated as,

$$\frac{(\text{Dry matter weight with fertiliser} - \text{Dry matter weight without fertiliser}) \times 100}{\text{Dry matter weight without fertiliser.}}$$

All plant samples were analysed for N by kjeldahl method (Manual of analytical methods, 2000), P, K and Mg (digest with $HClO_4$:HNO_3 mixed at 1:4 ratio) (Manual of analytical methods, 2000) and cumulative removal of those elements were calculated.

RESULTS AND DISCUSSION

Significant difference ($P<0.001$) of the cumulative dry weights of the vegetative parts among treatments over the two-year period are given in Table 2.

It showed that N is not adequately supplied to *Panicum* from Boralu and Wariyapola series soils. The results of Table 2 further shows that in Boralu series soils, P is also not adequately supplied. Application of N and P fertiliser to Boralu series soils has beneficial effects on *Panicum* growth improvement. Absence of P, K and Mg from the fertiliser mixture [+All (T_1)] did not significantly reduce the vegetative growth of *Panicum* on Kurunegala series and Wariyapola series soils. It follows that supply of P, K and Mg is adequate for *Panicum* in those soils. Similarly in Boralu series soils only K and Mg supply was adequate. Although the difference of vegetative growth between +All (T_1) and –N (T_2) was not significant, the growth of *Panicum* on Kurunegala series was lower than +All (T_1) treatment. Therefore it is possible that application of N fertiliser to Kurunegala series soil also has a beneficial effects on *Panicum* growth improvement. The application of N fertiliser to Wariyapola series soil also has beneficial effects on growth improvement.

Table 2. Cumulative dry weight of *Panicum* cuttings in response to different treatments

Treatments	Soil series		
	Boralu	Wariyapola	Kurunegala
+All (T_1)	12.02	15.21	12.97
-N (T_2)	6.62	11.36	9.84
-P (T_3)	9.32	12.31	12.46
-K (T_4)	10.75	13.12	12.63
-Mg (T_5)	12.00	13.10	12.96
-All (T_6)	5.83	8.60	8.39
Level of significance	***	***	ns
LSD ($p< 0.05$)	2.42	3.68	ns

*** $P < 0.001$ ns-not significant

Percent Relative Yield is a plant index of response of growth of *Panicum* to applied fertiliser. If the RY % value is close to 100 or above it indicates the high response and if it much lower than 100 % it indicates the low response to applied fertiliser (Wijebandara, 1997). According to that the RY value of 100 % or above indicates high response, 50 % indicates medium response and 25 % indicates low response.

As shown in Table 3 the %RY values for N fertiliser in Boralu series, Wariyapola series and Kurunegala series were 81%, 34% and 32% respectively. It showed that *Panicum* had a response level between moderate to high for N fertiliser treatment on Boralu series whereas it showed low to moderate response for N treatment on the other two soils. *Panicum* showed moderate and low response to P fertiliser application on Boralu and Wariyapola series (30% and 23% respectively) while it showed very low (RY = 4 %) response to P treatment on Kurunegala series. The response of *Panicum* to K fertiliser application was very low on all three soils (RY = 12 %, 16 % and 3 % for Boralu, Wariyapola and Kurunegala series soils respectively). The response of *Panicum* to Mg fertiliser was also low on Wariyapola series (RY = 16 %) whereas no response was obtained on other two soils. However for +All (T_1), *Panicum* on Boralu series soils showed a very high response (RY = 106%) while that on Wariyapola and Kurunegala series soils showed high to moderate responses (RY = 77 % and 55 % respectively). It indicated that application of complete NPKMg mixture to all three soils was effective on *Panicum* growth than incomplete mixtures. The above results showed that N fertiliser application was highly effective in Boralu series and moderately effective in other two soils. P fertiliser application was moderately effective in Boralu and Wariyapola series and effect was very low in Kurunegala series. It also implied that P fertility of Kurunegala series soil was high. Application of K and Mg was not very effective in all three soils which implied that K and Mg fertility of all three soils were high (Table 1).

Table 3. Increase in Percent Relative Yield of Panicum maximum in response to different treatments

Treatments	Soil series		
	Boralu	Wariyapola	Kurunegala
-N (T_2)	81 %	34 %	32 %
-P (T_3)	30 %	23 %	4 %
-K (T_4)	12 %	16 %	3 %
-Mg (T_5)	0.2 %	16 %	0.1 %
-All (T_6)	106 %	77 %	55 %

As shown in Table 3 the %RY values for N fertiliser in Boralu series, Wariyapola series and Kurunegala series were 81%, 34% and 32% respectively. It showed that *Panicum* had a response level between moderate to high for N fertiliser treatment on Boralu series whereas it showed low to moderate response for N treatment on the other two soils. *Panicum* showed moderate and low response to P fertiliser application on Boralu and Wariyapola series (30% and 23% respectively) while it showed very low (RY = 4 %) response to P treatment on Kurunegala series. The response of *Panicum* to K fertiliser application was very low on all three soils (RY = 12 %, 16 % and 3 % for Boralu, Wariyapola and Kurunegala series soils respectively). The response of *Panicum* to Mg fertiliser was also low on Wariyapola series (RY = 16 %) whereas no response was obtained on other two soils. However for +All (T_1), *Panicum* on Boralu series soils showed a very high response (RY = 106%) while that on Wariyapola and Kurunegala series soils showed high to moderate responses (RY = 77 % and 55 % respectively). It indicated that application of complete NPKMg mixture to all three soils was effective on *Panicum* growth than incomplete mixtures. The above results showed that N fertiliser application was highly effective in Boralu series and moderately effective in other two soils. P fertiliser application was moderately effective in Boralu and Wariyapola series and effect was very low in Kurunegala series. It also implied that P fertility of Kurunegala series soil was high. Application of K and Mg was not very effective in all three soils which implied that K and Mg fertility of all three soils were high (Table 1).

Nutrient removal per 1-g dry matter of *Panicum* (Table 4) showed that removals of P and K from all three soils were significantly lower in the absence of the respective fertiliser than in the presence. In case of Wariyapola series and Kurunegala series, there were no significant difference in removals of both N and Mg between + All (T_1) and –All (T_6) or –N (T_2) and + All (T_1) and –All (T_6) or –Mg (T_5) treatments respectively. However, the above difference was significant in case of Boralu series. The P and K removals by *Panicum* increased in the presence of respective fertilisers which suggests that the availability of those elements in all three soils increased due to treatments. However, in the case of Wariyapola and Kurunegala series soils, the availability of both N and Mg was not affected by respective fertiliser addition according to removal data. The availability of all four nutrients was increased due to application of respective fertilisers in case of Boralu series as shown by nutrient removal data (Table 4). A high relative yield was obtained for +All (T_1) treatment compared to other treatments from all three soils. The initial soil analysis revealed that total N, exchangeable K and Mg were significantly higher in Wariyapola series compared to the other two soils. The available P in Kurunegala series was higher than other two soils.

Table 4. Nutrient removal (N, P, K and Mg) in Boralu, Wariyapola and Kurunegala series soils in response to different treatments

Treatment	Boralu series soil Nutrient removal in mg g^{-1} (dry weight)				Wariyapola series soil Nutrient removal in mg g^{-1} (dry weight)				Kurunegala series soil Nutrient removal in mg g^{-1} (dry weight)			
	N	P	K	Mg	N	P	K	Mg	N	P	K	Mg
+All (T_1)	12.60	4.63	23.90	2.54	10.98	6.43	21.00	3.4	11.66	6.05	22.48	3.10
-N (T_2)	9.34	5.63	19.37	2.76	8.56	8.14	20.27	2.78	8.02	9.26	19.74	2.92
-P (T_3)	14.82	1.04	24.29	3.05	11.09	1.45	22.72	3.37	11.84	1.48	24.10	2.82
-K (T_4)	14.45	5.11	8.20	1.92	10.26	6.80	13.58	3.09	14.21	5.80	11.77	3.05
-Mg (T_5)	10.11	3.91	23.37	1.58	10.66	6.37	21.89	2.48	10.16	6.52	23.07	2.16
-All (T^6)	10.42	1.32	12.60	2.98	9.74	1.09	17.84	2.0	7.91	1.27	10.43	2.63
Significance	***	***	**	***	ns	***	*	ns	ns	***	***	ns
LSD ($p<0.05$)	1.89	1.91	5.71	0.58	-	1.06	5.59	-	-	2.80	5.11	-

*** $P < 0.001$, ** $P < 0.01$, * $P < 0.05$ ns-not significant

CONCLUSION

The availability of all four nutrients in the three soils is low and application of N, P, K and Mg fertiliser will have beneficial effects on the improvement of crop growth greenhouse results revealed that the beneficial effect of application of N, P, K and Mg fertiliser is highest in Boralu series soils and lowest in Kurunegala series while Wariyapola series soils are in moderate status.

REFERENCES

Annual Reports 1998-2002 Coconut Research Institute, Lunuwila, Sri Lanka.

Mahindapala and Pinto, J L J G 1991 Coconut cultivation, Coconut Research Institute, Sri Lanka.

Manual of analytical methods of Soils and Plant Analysis 2000 Soils and Plant Nutrition Division, Coconut Research Institute, Lunuwila, Sri Lanka.

Somasiri, L L W, Nadarajah, N, Amarasinghe, l and Gunathilake, H A J 1994 Land suitability Assessment of coconut growing areas in the coconut triangle. Occasional Publication series No 3, Coconut Research Institute, Lunuwila, Sri Lanka.

Wijebandara, D M D I 1997 Comparison of laboratory methods for the determination of plant available phosphorus in coconut growing soils in the Low Country Intermediate Zone of Sri Lanka. M. Phil. Thesis, postgraduate Institute of Agriculture, University of Peradeniya, 101 p.

Technical Session 3

Crop Improvement

Improved Seed Cultivars of Tea (Camellia sinensis L.): A Source of Planting Material

M T K Gunasekare, J H N Piyasundara and P D Upali
Plant Breeding Division, Tea Research Institute of Sri Lanka, Talawakelle, Sri Lanka

ABSTRACT

Tea seed progenies, derived through open-pollination of known vegetatively propagated (VP) cultivars, were assessed against standard VP cultivars, in order to identify promising sources of improved seeds for use as planting material. Eleven seed progenies, from bi- and poly-clonal seed sources, were evaluated in a preliminary yield trial.

The average yield potential of all the seed cultivars tested were lower than that of a standard cultivar, TRI 2023. However, seed progeny from the seed garden at the Salawa Estate, Hanwella gave yields comparable to TRI 2023. Of the 11 seed cultivars tested, five showed yields comparable to that of the standard cultivars, TRI 4046 and DG 39. The results of the present study suggest that seed progenies from seed sources at the Salawa, Karadupona, Halpe, St Coombs and Reucastle Estates are more promising than other seed progenies, in terms of average yield and uniformity among individual stands based on yield attributes.

Key words: seed progenies, cultivars, seed garden.

INTRODUCTION

In Sri Lanka, tea (*Camellia sinensis* L.) is grown in different agro-climatic regions differing widely in elevation, climate and soil. These differences have a profound effect on productivity (Pethiyagoda, 1968). When varieties are compared in different environments, their relative rankings usually differ, and considerable genotypic differences in response to changes in environment were found (Wachira et al., 1990; Wickramaratne, 1981 a). This causes difficulties in demonstrating any significant superiority in a particular cultivar, thus affecting the efficiency of the selection process. Inconsistencies in performance, which makes interpretation of yield data difficult, were claimed to be due to the existence of a significant Genotype-Environment Interaction, GEI (Wickramaratne, 1981 a).

GEI is of major importance to the plant breeder in developing improved varieties. However, information on the type of interaction present in tea is scanty.

The use of genetically-mixed genotypes rather than homozygous, or pure-line varieties, has been suggested as a means for reducing the GEI (Jensen, 1952). Allard and Bradshaw (1964) showed that heterozygous and heterogeneous populations offer the best opportunity for producing cultivars which show a smaller GEI, because they exert a population-buffering effect.

Since the tea plant is highly heterozygous and virtually self-sterile, the progeny from tea seeds are not true-to-type, and show a wide range of variation in growth, vigour, morphological characters, yield potential, quality and resistance to pests and diseases. Hence, populations derived from natural hybridization between VP cultivars, with known traits, could exhibit population buffering and give wide regional adaptability. In addition, the desirability of maintaining genetic heterogeneity in tea plantations emphasizes the need for developing seeds as planting material.

The present study aims at evaluating the performance of some open-pollinated progenies, derived from bi-clonal and poly-clonal seed gardens, against the performance of promising VP cultivars, based on yield and yield components of seed populations.

MATERIALS AND METHODS

Tea seed bearers, established on various tea and rubber estates, were used to collect seed material for evaluation. Open-pollinated (naturally cross-pollinated) seeds were collected from 11 seed gardens (Table 1).

Bi-clonal and poly-clonal progenies were raised from mature seeds, collected directly from the tea seed bearers. Seeds were subjected to sinker–floater assessment, and the sinker seeds were sown on a germination bed made of river sand. After 3-4 weeks, germinated seeds were transferred to standard-size, nursery bags filled with soil.

Vigorous seedling plants were selected at the end of the nursery period, and planted in Field No. 2, St Joachim Estate, TRI, Ratnapura, in February 2000, to establish preliminary yield trials. The seedling progenies were planted in replicated plots, along with the popular commercial VP cultivars, TRI 2023, TRI 4046 and DG 39. Each plot consists of 40 plants, and the progenies were replicated thrice.

Table 1. Parental combinations of bi-clonal and poly-clonal seed sources.

Type of Seed Garden	Seed Source and year of establishment	Parental combination
Bi- Clonal	Densworth Estate, Dehiowita (1991)	TRI 2026 and TRI 3055
	El-teb Estate, Passara (1973)	TRI 2025 and DN
	Reucastle Estate, Dehiowita (1991)	TRI 3063 and S-106
Poly-Clonal	Aislaby Estate, Bandarawela (1956)	TRI 2023, 2024 and 2025
	Anhettigama Estate, Dereniyagala (1991)	TRI 2023, 2025, 2027, 2043 and 62/9
	Halpe Estate, Tummodara (1991)	TRI 2016, 2026, 2027, 2043, 3063, 4014 and S-106
	Karadupona Estate, Kegalle (1991)	TRI 2016, 2021, 2023, 2025, S 106 and DG 39
	Poonagala Group, Poonagala (1936)	Seed bearers raised from seedlings
	Salawa Estate, Hanwella (1991)	TRI 2016, 2023, 2027, 3047, 3055, KEN 16/3 and S 106
	Sapumalkanda, Estate, Dehiowita (1991)	TRI 2023, 2025, 2043, 3055, 4056, KEN 16/3 and S 106
	St. Coombs Estate, Talawakelle (1959)	TRI 777, 1114, 2024, 2025, 2026, 2043, 2142, 62/9, DT 1, DT 95 and ASM 4/10

The yield of green leaf was recorded weekly for a two-year period.

The following measurements were used to evaluate yield components of individual genotypes in each seed progeny, and to assess uniformity.

1. The shoot density (the number of shoots per unit area of bush). Measurements were taken using a 30 cm x 30 cm quad-rod, on the day prior to harvesting of shoots. Measurements were repeated three times during a period of one month.

2. The dry weight of harvested shoots. The oven-dry weight of the harvested shoots from each bush in each progeny was recorded. Measurements were repeated three times to obtain the average dry weights of harvested shoots per bush, from all the progenies.

Data were analyzed using the SAS software package, version 8.2. Dunnett's T test was used to compare the average yields of seed cultivars with that of the controls, namely the three standard VP cultivars. Parameters measured to assess uniformity were analyzed using univariate analysis.

RESULTS AND DISCUSSION

The average yield of the seed progenies was always less than that of the standard cultivars, TRI 2023 and 4046 (Table 2). However, there were instances where the average yield difference between the standard and the seed progeny was not significant.

Table 2. Average yield of seed progenies and standard VP cultivars.

Seed Progeny and ***standard VP cultivars***	Average Yield * (made tea kg/ha/year)	Mean comparisons with standard cultivars		
		TRI 2023	***TRI 4046***	***DG 39***
TRI 2023	3790	——		***
TRI 4046	3342		——	***
Salawa	2931			
Karadupona	2825	***		
Halpe	2788	***		
St. Coombs	2754	***		
Reucastle	2488	***		
DG 39	2437	***	***	——
Sapumalkanda	2430	***	***	
Densworth	2350	***	***	
Aislaby	2126	***	***	
Anhettigama	2125	***	***	
El-teb	1970	***	***	
Poonagala	1756	***	***	

* Yield was estimated on the basis of 12,500 bushes/ha and an out-turn of 23% made tea. The values represent means of three replicates over 43 plucking rounds per year.

*** Comparisons of mean yield significant at the 0.05 level by Dunnett's T test

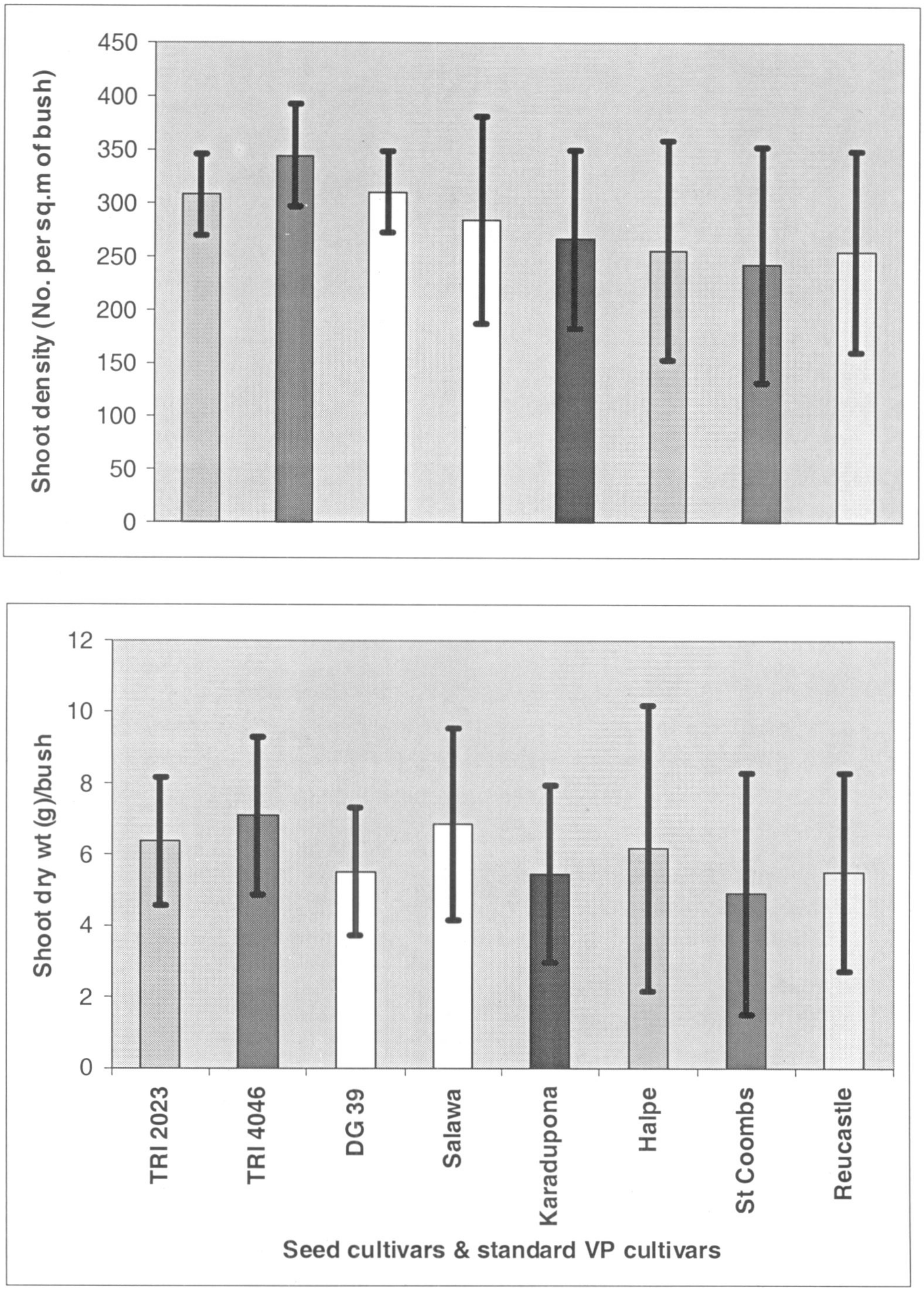


Fig. 1. Averages of yield components of seed progenies and VP cultivars.

Generally, it is an observed fact that a field planted with commercial seed gives a much lower average yield than a field planted with high-yielding clonal material (Wickramaratne, 1981 b). In comparison to the standard cultivar, TRI 2023, all the seed cultivars, except those from Salawa, showed significant differences in yields. On the other hand, in comparison to the standard cultivar, TRI 4046, yields were not significantly different in the seed progenies from Salawa, Karadupona, Halpe, St Coombs and

Reucastle. These same seed progenies gave similar yields in comparison to the standard cultivar, DG 39.

Hence, according to all possible comparisons made with the three standard cultivars, it could be deduced that the five seed progenies are superior to the other seed cultivars tested, and comparable to the standard cultivars, TRI 4046 and DG 39, in terms of their average yields.

The data in Fig. 1 clearly show that variability of yield components, among stands of VP cultivars, is much less than that of any of the seed cultivars tested. However, it should not be overlooked that the tea plant is highly heterozygous, and therefore seed populations may show great heterogeneity. Although uniformity of plants within a progeny is important, owing to the absence of homozygous lines in tea, the production of seedlings with morphological uniformity appears to be impractical (Kulasegaram, 1978; Portsmouth, 1954).

Among the promising seed progenies selected based on yield, the Salawa cultivars recorded the highest shoot density, ranking next to the VP cultivars. Further, the Salawa cultivars showed the highest shoot dry weights compared to all the other seed progenies tested. These results suggest that the Salawa seed cultivars would be outstanding in yield performance.

It has been proved that shoot density (number of shoots per unit area of the bush), and shoot weight, are the major factors that determine tea yield, and that more than 80% of the variation in tea yield is accounted for by these two yield components (Wijeratne, 1994). This substantiates the validity of the high average yield of the Salawa seed progeny and its outstanding performance.

Richards (1966) and Kulasegaram (1978,1980) stated that the progenies obtained from poly-clonal seed gardens are less predictable than those from bi-clonal mating. It was found that the range of variability in yield components was wider in bi-clonal progenies than in poly-clonal progenies., and a more promising performance in terms of morphological uniformity was observed in poly-clonal progenies, compared to bi-clonal progenies, in the present study.

The variation observed in the yield components among individual bushes, within a seed progeny, may be partly due to genetic variability (Wickramarathne, 1981 b). Hence, predicting the performance of seedling populations, in terms of biotic and abiotic stress tolerance, as can be done with VP cultivars, is virtually impossible because seedling populations consist of individuals with different genetic identities. Unless pure lines can be developed, which is an extremely difficult task in tea, seed will inevitably give a mixed population.

As a result, the progeny performance of populations derived from seeds varies, and may be quite inconsistent. It is advisable, therefore, to use promising seed stocks as an alternative source of planting material, especially in areas where extreme conditions prevail. It is also necessary to carry out commercial trials on multi-locations, prior to making a recommendation on the suitability of seed cultivars initially selected for commercial planting.

ACKNOWLEDGEMENTS

The authors are grateful to Dr T I Anandappa, former TRI plant breeder, for her valuable suggestions and contribution to the establishment of the seed gardens. The authors also wish to thank the managers of the Estates, where seed gardens were established, for their cooperation in maintaining them. The assistance given by Mr A K Mudalige and Ms T U S Peiris in conducting field evaluations, and statistical analysis of data, respectively, is also gratefully appreciated.

REFERENCES

Allard, R W and Bradshaw, A D 1964 Implications of genotype-environment interaction in applied plant breeding. Crop Sci. 4, 503-507.

Jensens, N F 1952 Inter-varietal diversification in oat breeding. Agron. J. 44, 30-34.

Kulasegaram, S 1978 Progress in tea breeding. Tropical Agric. Res. 11, 151-160.

Kulasegaram, S 1980 Technical developments in tea production. Tea Quarterly 49, 157-183.

Pethiyagoda, U 1968 Report of the Plant Physiology Division. Annual Report of the Tea Research Institute of Ceylon, p. 53-61.

Portsmouth, G B 1954 Vegetative propagation and clonal seed production. Tea Quarterly XXV (IV), 75-79.

Richards, A V 1966 The breeding, selection and propagation of tea. Tea Quarterly 37, 154–160.

Wachira, F N, Ng'etich W, Obaga S and Othieno C 1990 Genotype x Environment Interactions and genotypic stabilities in tea – A preliminary indication. Tea 11, 51-57.

Wickramaratne, M R T 1981a Genotype-Environment interactions in tea (*Camellia sinensis* L.) and their implication in tea breeding and selection. J. Agric. Sci. Camb. 96, 471-478.

Wickramaratne, M R T 1981b Tea clones and seeds - an appraisal. Tea Bull. 1, 7-20.

Wijeratne, M A 1994 Effect of climatic factors on the growth of tea (*Camellia sinensis* L.) in the low country wet zone of Sri Lanka. PhD thesis, Wye College, University of London.

Performance of Some Seedling Progenies Derived by Crossing of Selected Hevea Cultivars

[1]S P Vithanage, [1]K W Rupatunge, [2]D P S T G Attanayake and [2]N E M Jayasekera
[1]Rubber Research Institute of Sri Lanka, Agalawatta, Sri lanka
[2]Faculty of Agriculture and Plantation Management, Wayamba University of Sri Lanka

ABSTRACT

Six seedling families derived by crossing selected clones were evaluated for growth and yield. The between family difference for growth was not significant in the third year after planting, but was significant at the age of five years. The mean girth and the yield of the seedling progeny of the cross RRIC 100 X PB 255 was distinctly better than that of the other families. Progenies of the three families viz; RRIC 100 x PB 255, RRIC 121 x PB 255 and RRIC 100 x PR 309 were qualified for tapping at the fifth year of age. The same three families gave higher mean g/t/t yield over the overall mean of 28.57. Eighty percent of the individuals of the family RRIC 100 x PB 255 have yielded more than 20 g/t/t during the three year period studied.

Ten mother trees were selected based on the individual selection for yield for subsequent vegetative propagation. Five of these trees had come from the RRIC 100 X PB 255, which was the highest-ranking family for both yield and girth. The secondary characters of these trees were also acceptable for selection for limited scale planting as Estate/RRI collaborative clone trials (ECTs).

Key words: *Hevea* breeding and selection, *Hevea* seedlings

INTRODUCTION

In *Hevea* breeding, superior clones in one generation are used as parents to produce the seedling progenies for the next cycle of selection. This process is generally referred to as Generation wise Assortive Mating (GAM) because the best is crossed with the best in each cycle Simmonds (1986). The seedling progenies derived by GAM are then selected in the nursery, vegetatively propagated and evaluated in Small Scale Clone Trials (SSCTs) and Large Scale Clone Trials (LSCTs) to identify the superior clones. *Hevea* breeders have always sought alternative methods to this scheme in order to reduce the time involved in selecting new clones for planting (Attanayaka and Karunasekera, 2001 Ong et al., 1985). The main objectives of this study are to identify the best parental combinations to produce synthetic populations of rubber seedlings for planting and select mother trees from the population (ortet selection) in order to produce improved cultivars. This paper presents the results of a breeding trial where six seedling families derived by controlled pollinations of selected *Hevea* clones were evaluated.

MATERIALS AND METHODS

Hybridisation

Details of the clones involved in the hybridisation programme and the crosses made are given in Table1. The hybridisations were done in 1992 flowering season at Dartonfield estate, Agalawatta.

FIELD PLANTING

Seeds derived from successful pollinations were planted in polybags and maintained for ten months in the nursery. Plants were then transplanted in the field in 1993 using completely randomized design giving between and within row spacing of 5.5 m x 3.5 m. The number of seedlings planted from each family is given in Table 1. Any form of selection of seedlings was not imposed at planting. The trial was maintained under estate-managed conditions according to the recommendations of the Rubber Research Institute.

Table 1. Details of the 1992 crossing programme

Mother clone	Origin and parentage	Pollen clone	Number of pollinations	% Fruit-set	No. of seedlings planted
RRIC 100	Sri Lanka (RRIC 52 x PB 86)	RRIM 712	1136	2.99	68
		PB 255	1124	3.74	81
		PR 255	504	6.15	75
		PR 309	504	3.17	33
RRIC 121	Sri Lanka (PB28/59x IAN45/873)	PB 255	1235	2.27	55
		PR 255	53	5.66	19
		PR 309	314	1.27	08
		RRIM 712	296	0.34	01
RRIC 102	Sri Lanka (RRIC 52x RRIC 7)	PB 255	914	1.64	41
		PR 309	672	0.15	03
BPM 24	Indonesia (BPM 24xAVOROS 1734)	RRIM 712	528	1.14	06

Measurements and analyses of data

Growth of the plants was monitored from the third year of planting by taking yearly girth measurements. Pre-tapping and post- tapping girth measurements were taken at 120 cm and 150 cm above the ground level respectively.

Tapping was started in the year 2000. Yield was recorded by taking one yield measurement per month from each tree as grams per tree per tapping (g/t/t). In wet spells recording of the yield data was not possible. Families having progeny size below 19 seedlings were not included in the analysis. Therefore, only the data from six families were analysed.

After three years of tapping the trees were ranked in descending order of their mean yield for mother tree selection. The highest yielding 4% were chosen for field scoring of secondary characters.

RESULTS AND DISCUSSION

Girth

Analysis of variance showed that the girth differences between families were not significant in the third year at the probability level of 0.05 but was highly significant during the 5^{th} year of age indicating the presence of genetic differences between families.

Summary statistics on the mean, standard deviation, coefficient of variation (CV) and significant grouping of the girth of the six families for 3rd and 5th year are presented in Tables 2 and 3 respectively. In both years, the family RRIC 100 x PB 255 has shown a significant good girthing ability over other families. The CV values were also the lowest in this family. Mean girths of other five families were not significantly different from each other in the 5th year of growth (Table 3).

Table 2: Means and variation of third year girth of seedling families

Family	Progeny size	Mean	SD	CV	Duncan grouping
RRIC 100 x PB 255	78	34.69	6.23	17.9	A
RRIC 100 x RRIM 712	58	33.13	6.14	18.5	AB
RRIC 102 x PB 255	33	33.12	7.74	23.3	AB
RRIC 121 x PB 255	45	32.76	7.79	23.7	AB
RRIC 100 x PR 309	31	31.90	7.46	23.4	AB
RRIC 100 x PR 255	61	31.24	5.82	18.6	B
Combined	306	32.97	6.75	20.4	

Table 3: Means and variation of fifth year girth of seedling families

Family	Progeny size	Mean	SD	CV	Duncan grouping (DMRT)
RRIC 100 x PB 255	78	57.53	10.66	18.5	A
RRIC 102x PB 255	33	52.27	12.04	23.0	B
RRIC 100 x PR 309	31	51.95	10.86	20.9	B
RRIC 121 x PB 255	45	51.92	12.72	24.5	B
RRIC100 x RRIM 712	58	50.72	9.73	19.1	B
RRIC 100 x PR 255	61	49.36	9.52	19.2	B
Combined	306	52.65	11.11	21.1	

For economic reasons, 60% of the trees in a clearing should reach the tappable girth i.e. more than 50 cm at 120 cm for harvesting ideally in five years. On this basis three families viz., RRIC 100 x PB 255, RRIC 100 x PR 309 and RRIC 121 x PB 255 qualified for harvesting in the 5th year after planting (Table 4). The seedling progenies of RRIC 100 x PB 255 had the highest tappability value of 79.4%.

Table 4: Percentage Tappability of the six families after 5 years.

Family	% Tappability	Family	% Tapability
RRIC 100 x PB 255	79.48	RRIC 102 x PR 309	57.14
RRIC 100 x PR 309	64.51	RRIC 100 x RRIM 712	54.83
RRIC 121 x PB 255	60.00	RRIC 102 x PR 255	51.61

YIELD

Analysis of variance of the first three years yield data of the six families indicated highly significant differences between families (P>0.0001). This reflects the existence of genetic differences for yield between the families.

Means, CV and significant groups of families for first three years of yield are summarised in Table 5. The mean yield (g/t/t) of the whole population was 28.57 g with a CV value of 57%. High CV values for rubber yields of seedling populations have been frequently reported in many early studies when seedling rubber was the major planting material. For example, as cited by Senanayake in 1975, Larue (1921), Shepard (1940) and Hardur (1969) have reported CV of 60% and 40-60% respectively for rubber yields of seedlings populations. A comparatively low CV of 50% has been reported by Shepard (1940) for logitimate seedling families created by controlled pollinations.

Table 5: Means, variation and significant grouping of first three years yield.

Family	Progeny size	Mean g/t/t	SD	CV	Duncan grouping (DMRT)
RRIC 100 x PB 255	70	34.91	17.91	51.3	A
RRIC 121 x PB 255	34	32.57	20.15	57.3	AB
RRIC 100 x PR 309	25	28.65	14.50	50.6	AB
RRIC 100 x RRIM 712	49	25.97	14.31	55.1	BCD
RRIC 100 x PR 255	51	23.75	13.03	54.8	CD
RRIC 102 x PB 255	23	19.56	8.23	42.0	D
Combined	252.	28.57	16.30	57.0	

The mean g/t/t yield of the family RRIC 100 x PB 255 was significantly higher than the means of the rest of the families. There were three families with mean values greater than the population mean. The mean yield of the family RRIC 102 x PB 255 was the lowest.

The genetic worth of a family to provide seedlings for planting depends on the frequency of occurrence of high yielding individuals in a particular family. Table 6 shows the proportion of the individuals yielding more than the population mean of 28.57 g/t/t in each family based on the standard normal variate.

It is seen that 63% and 58% of the individuals of the two families, RRIC 100 x PB 255 and RRIC 121 x PB 255, to have the ability of giving more than the population mean g/t/t yield of 28.57. The occurrence of trees giving more than 20 g/t/t/ mean yield could be considered commercially acceptable. In these two families therefore, the proportion of individuals that can yield more than the 20 g/t/t/ was around 80% and 73%. In the best family therefore only 20% culling is necessary to further enrich the population for high rubber yield. The correlation between the third year girth and the yield in each family was observed for possible use of girth in identifying low yielding trees (Table 6). On average the correlation

Table 6 : Percentage of the individuals in each family yielding higher g/t/t than the population mean.

Family	Z value	% of individuals better than the population mean	Correlation between 3rd year girth and yield
RRIC 100 x PB 255	-0.3539	63.68	0.3838**
RRIC 121 x PB 255	- 0.2001	58.32	0.5736***
RRIC 100 x PR 309	-0.0056	51.99	0.2972ns
RRIC 100 x RRIM712	0.1810	42.86	0.3406*
RRIC 100 x PR 255	0.3639	35.57	0.1043ns
RRIC 102 x PB255	1.0940	13.79	0.3106ns

coefficients were very low indicating girth as a poor indicator of the yield potential of the tree except for the family RRIC 121 x PB 255 where a correlation coefficient of 0.57 was observed. In this family therefore, early selection for girth will have a positive effect on improving the proportion of high yielding individuals. From tables 5 and 6 it is evident that a direct positive correlation exists between the family mean and the proportion of the high yielding trees in a family. This reflects that family means have not largely depended on the extreme values of the individuals, therefore the genetic worth of the families has been adequately represented by the family means. Rank of the family mean would therefore provide useful guidance for selection. Size of the family is an important factor in selection because the larger the family the closer is the correspondence between mean phenotypic value and mean genotypic value Falconer (1960).

Mother-tree (Ortet) Selection

Mother–tree or ortet selection from a population to develop favorable cultivars is an accepted method in *Hevea* breeding. The possibility of selecting mother trees for subsequent propagation as clones was explored form this seedling population based on individual selection for yield. The highest yielding 4% of the trees in the population was selected for grafting for subsequent assessments in clone trials and their tree numbers, girth, mean yields and canopy characters scored in the 2003 south-west monsoon season by percentage defoliation are given in Table 7. All the trees selected exceeded the 60 g/t/t/ mean yield and over 50 cm girth. All the trees showed to possess a healthy canopy though the HP 279 and HP 29 showed 30% and 25% defoliation respectively. Fifty percent of the trees selected has come from the family RRIC 100 x PB 255 which was the highest ranking family for mean girth and yield. Further it is interesting to note that the superiority of the RRIC 100 clonal seedlings for planting from the fact that nine out of the ten ortet trees had the RRIC 100 as the female parent.

Table 7: Selected mother trees for clonal propagation and their characteristics.

HP number	Family	Mean yield (g/t/t)	Mean years girth at 5 years	Canopy characters
HP 132	RRIC 100 X PB 255	105.54	75.5	B
HP 279	RRIC 121 X PB 255	104.52	64.5	C
HP 29	RRIC 100 x RRIM 712	83.02	68.0	C
HP 124	RRIC 100 X PB 255	76.46	68.0	B
HP 129	RRIC 100 X PB 255	72.57	70.5	B
HP 358	RRIC 100 X PR 309	69.79	69.5	B
HP 153	RRIC 100 X PR 255	67.87	52.0	C
HP 35	RRIC 100 x RRIM 712	64.79	65.0	B
HP 86	RRIC 100 X PB 255	62.29	74.5	A
HP 108	RRIC 100 X PB 255	61.73	79.0	A

A= less than 5% defoliation B= 6-25% defoliation C = 26-75% defoliation

CONCLUSION

Out of the six families evaluated the seedling family of the cross RRIC 100 x PB 255 was significantly better than the other families for growth and yield. Around 80% of the trees in this family has the ability to give more than 20 g/t/t mean yield during the first three years with a tappable percentage of 79.4% at the end of the fifth year after planting. Seeds derived from this cross could therefore be considered for planting as seedling planting material with minimum level of selection. The seedling population derived from RRIC 121 x PB 255 was more variable with respect to both characters, girth and yield yet 73% of trees had given more than 20 g/t/t mean yield. More stringent selection will be required in this family for further enrichment for yield and it may possibly be done since a comparatively higher correlation between girth and yield was observed in this family.

The ten mother trees selected on the basis of the yield had the mean g/t/t yield over 60 and mean girth over 50 cm with disease free canopies. The trees numbering HP 132, 124, 129, 86 and 108 could be expected to have a high genetic value since they have been selected from the highest ranking family for yield i.e. RRIC 100 x PB 255.

ACKNOWLEDGEMENT

The able technical assistance given by Mrs. A K Gamage is gratefully acknowledged. Authors wish to thank Mrs. Wasana Wijesuriya, biometrician, RRISL for her comments and suggestions and the Staff of the Plant Pathology Department for canopy screening.

REFERENCES

Attanayaka, D P S T G and Karunasekera, K B 2001 Grower Scientist collaboration in Clonal Development. Bulletin of the Rubber research Institute of Sri Lanka, 43, 6-10.

Jayasekera, N E M, Karunasekera, K B and Kearsey, M J 1994 Genetics of production traits in *Hevea brasiliensis* (rubber).I. Changes in genetical control with age. Heredity. 73. 650-656.

Ong, S H, Tan S K, Khoo and Sultan M O 1985 Selection of promising clones through accelerated evaluation of *Hevea*. Proceedings of the International Rubber conference, Kuala Lumpur.

Samuddin Z, Tan H and Yoon P K 1985 Variations, Heritabilities and Correlations of Photosynthetic Rates, Yield and Vigour In Young Hevea Seedlings Progenies. International Rubber Conference 1985, Kuala Lumpur.

Senanayake, Y D A 1975 Yield variability in clonal rubber (*Hevea brasiliensis* Muell. Arg.). Journal of Plantation Crops 3 (2). 73-76.

Simmonds, N W 1986 Theoretical Aspects of Synthetic/Polycross Populations of Rubber Seedlings. Journal of Natural Rubber Research 1(1). 1-15.

8203

Sri Lanka Tall x San Ramon: The Best Received Coconut Cultivar in the Country

J M D T Everard, R Jayathilaka and C K Bandaranayake
Coconut Research Institute, Lunuwila, Sri Lanka

ABSTRACT

CRI over seven decades of coconut breeding produced two improved cultivars, an intra-varietal hybrid, SLT (Sri Lanka Tall) x SLT (CRIC60) and an inter-varietal hybrid, SLT x DG (Sri Lanka Green Dwarf) (CRIC65) for large scale replanting in the country. Multi-locational field trials established by CRI in 1984 exemplified the superiority of the two hybrids, DG x SLT and DY x SLT over SLT x SLT and various estate selections of SLT. However, the appearance of CRIC65 under stress with drooping fronds and bunches distracted the coconut grower declining the demand for planting material and thereby forced the breeder to look for developing much sturdy cultivars of coconut. With the limited genetic diversity in the country crossing of San Ramon (SR), the Pacific coconut with SLT became prospective and progeny trials were established in early eighties. The experiment established at the Ratmalagara Research Station of the CRI produced promising results in favour of the cross SLT x SR. Despite the better performance of DG x SLT being an inter-varietal hybrid SLT x SR performed better than SLT x SLT in all growth, precocity and yield parameters. Significant feature of SLT x SR is the higher copra out turn which is 302 g nut^{-1} in contrast to 269 g nut^{-1} in CRIC60 and 225 g nut^{-1} in CRIC65. Total out turn of copra too was better in SLT x SR (3.886 mt $ha^{-1} yr^{-1}$) than CRIC60 (3.551 mt $ha^{-1} yr^{-1}$). In addition SLT x SR because of the larger nuts size yields more kernel, husk and shell than CRIC60 and CRIC65 and these are gradually becoming more important in coconut export trade. Despite all above SLT x SR is rapidly becoming popular in the country due to its rapid growth rate at the early stage as witnessed by farmers in their own fields.

Key words: Coconut cultivars, breeding, San Raman coconut, dwarf and tall coconut, coconut hybrids

INTRODUCTION

Coconut Research Institute (CRI) from the outset focused on improving the *Sri Lanka Tall* (SLT), the coconut prevalent in countrywide commercial plantations by mass selection and progeny evaluation for increasing the copra production (Pieris, 1934 and 1935, Liyanage, 1956). Exceptionally high heritability values of certain yield characteristics, for instance 0.95 for dehusked nut weight in the Sri Lanka Tall (SLT) coconut (Liyanage and Sakai, 1960), which is directly correlated to copra per nut conceptualised the currently practised seed palm selection criterion and subsequently the basis of the isolated seed garden (ISG) for production of the planting material, selected SLT x SLT or CRIC60. In the ISG CRIC60 is mass-produced by directed natural pollination set among SLT individuals derived from superior palms in high yielding commercial plantations (Liyanage, 1956). Since the outset CRIC60 was the variety recommended for countrywide planting both in small and large holdings. Even to date around 50% of the national seed coconut requirement is met by CRIC60. More recent studies have clearly shown the potential of CRIC60 in agro-ecological zones more conducive for coconut growth (Everard, 2001). However, the credibility of CRIC60 became dubious among growers in certain parts of the country due to poor performance of the cultivar in certain agro-ecological regimes of the country under substandard management.

A major directional change in the coconut breeding strategy was observed in 1947 with the initiation of experiments aimed for improvement of desirable traits such as early flowering, nut yield and copra out turn by inter-varietal hybridisation *via* controlled pollination. After limited field trials the cross between *typica typica x nana pumila* (Sri Lanka Green Dwarf or DG) was found promising (Liyanage, 1955) in the ability to flower early and produce an excessively high number of nuts. Mean flowering period of the hybrid was only 36 months comparing to 52 months in the SLT coconut (Manthriratne, 1971). The productivity of the hybrid (SLT x DG) too was remarkable recording over 20,000 nuts ha^{-1} after 12 years of transplanting at the CRI's Ratmalagara Research Station (Manthriratne, 1978). A more methodical field trial established by Wickremaratne (1984) at the Bandirippuwa Estate, Lunuwila and four other sites in dry and dry intermediate zones of the country exemplified the superiority of the hybrid over other cultivars of coconut in Sri Lanka, Selected SLT x SLT (CRIC60), *Moorock tall* (MT) and *Plus Palm Tall* (PPT, a mixture of estate selections). The two hybrids *DG x SLT* (CRIC65) and *DY (Sri Lanka Yellow Dwarf) x SLT* (CRIC65) signified the domination in their ability to flower early and yield more consistently over a period of 18 years after field establishment in all the sites (Everard, 2001). The two hybrids attained 100% flowering before five years while the others exceeded seven years. The nine-year average per hectare yields (from 10-18 years of transplanting) of the hybrids were outstanding that both yielded above 13,000 nuts yr^{-1} compared to 9600, 8400 and 9400 respectively of CRIC60, MT and PPT (Everard, 2001).

The potential of these hybrids, however were disregarded by growers for the obvious reason that they exhibit high susceptibility to moisture stress despite their ability to recover more rapidly than pure tall cultivars when the stress is arrested (Jayasekera, 1989). It is even regrettable to note that the early bearing character, which is the prime attraction for planting in home garden and new settlements was also disdained for the same reason, the poor public perception. Grower's confidence is phenomenal in adopting a new cultivar, especially in perennials where replanting is strictly dependent on motivation of the grower unless it is driven by subsidy schemes. The appearance of the CRIC65 palm under stress with drooped fronds and bunches swayed the confidence of the grower and thereby forced the breeder to change the agenda for development of more sturdy coconut cultivars for a much broader category of growers; home gardens, small holders, estates and plantations in a range of climatic conditions.

Genetic diversity of coconut was known to be confined to Sri Lanka Tall coconuts comprising the commercially grown *typica typica* or SLT and a few forms (phenotypic deviants), forms of Sri Lanka Dwarf *(nana; pumila, regia, eburnea and braune)* and King Coconut (*aurantiaca*) or thembili (Liyanage, 1958, Perera and Peries, 1996). San Ramon (SR), an introduction from the Philippines by private growers was a more recent inclusion to the coconut breeders collection of the CRI (Fernando, 1987). SR is characterised by large erect stem both in height and girth compared to SLT and a massive bole at the base of the trunk (Fernando, 1998). It has mechanical properties of high quality timber (Palomar and Fernandz, 1994). Nuts of SR have a characteristic round shape with a flat bottom with a ratio of polar to equatorial circumference, 1.07. The corresponding value for SLT is 1.19. San Ramon is believed to be native to Mindanao Islands in the Philippines where climatic conditions frequently change and as a result is expected carry genes favourable for harsh conditions (Santos et al., 1984). It is also reported that San Ramon is relatively less heterozygous for bunch characters than many other coconuts in the Philippines (Balingsa and Carpio, 1983).

Robustness of San Ramon influenced the breeders for testing the vigour of the cross between *Sri Lanka SLT x SR* (*SLT x SR*). Series of multi-locational experiments, two in research fields and six in farmer's fields were established during the period 1985-87 to evaluate the performance of this cross along with CRIC60 (*SLT x SLT*) and reciprocal of CRIC65 (TD), the two improved cutlivars (Wickremaratne, 1985, 1986, 1987). Due to various unforeseen circumstances such as change of ownership, changing over of estate managers from time to time, in farmer's fields failed to generate information with adequate accuracy for statistical analysis. However, the experiments in research fields, Ratmalagara Research Station of the CRI in particular, mustered ample data on the performance of the three progenies. In parallel with this experiment CRI has also taken measures to establish small blocks of SLT x SR in farmer's fields of various agro-ecological zones. SLT x SR in these farmers' fields had impressed local farmers because the experience they have in local tall at early establishment was much slower. The purpose of this paper is to discuss the results of this experiment at the Ratmalagara Research Station in view of discussing the potential of SLT x SR under normal management in an average soil.

MATERIALS AND METHODS

Production of SLT x SR, SLT x SLT and SLT x DG:

Female and pollen parents for the three crosses were selected from Field 1, 2, 5 and 9 at the Isolated Seed Garden (ISG, Ambakelle) and Field 16 at Bandirippuwa Estate (BE) respectively as detailed in Table 1. Pollen was processed by the technique described in Liyanage (1954). Pollination was carried out manually by skilled climbers with the aid of a paintbrush inside a cotton bag made to conceal the inflorescence before female flowers become receptive. Records on setting of female flowers into buttons, young fruits and mature nuts were recorded and accurately labelled to avoid mishandling after harvest and at the nursery. Nuts were raised in the Research Nursery of the CRI in pre-nursery beds and subsequently in polybags before transplanting in the field as per guidelines of the CRI Advisory Circular A2.

Field establishment and caring of seedlings:

Seedlings were planted in 1986 at a distance 25' x 25' x 25' (7.6 m x 7.6 m x 7.6 m) at a density of 200 seedlings ha^{-1} as per instructions provided in CRI Advisory Circular A3. The seed hole was cut 3' x 3' x 3' and filled back with top soil enriched with 10 kg of cow dung and 1 kg of young palm mixture, YPM (13% N, 12% P_2O_5, 17% K_2O) before transplanting. Two layers of husk were laid in the seed hole before surmounting with the enriched soil. Mulch was maintained continuously around the seedling outside 1' radius extending up to 3' - 8' (increasing by about 1' per year after transplanting) by laying circles of fresh or partly dried husk. Inorganic fertiliser, YPM was applied at six monthly increasing of 500 g, 600 g, 800 g, 1000 g and 1200 g per seedling. After five years the N:P:K ratio was changed to APM (12% N, 6% P_2O_5, 32%K_2O) and rate of application was 3 kg $palm^{-1}$ (CRI Advisory Circular A5). In addition to NPK, dolomite was also applied at the rate of 1-2 kg yr^{-1} to supplement Magnesium. A leguminous creeper (*Pueraria phaseoloides*) was maintained as a ground cover in the field keeping the manure circle (8' around the seedling base) free. Irrigation was provided during extreme dry spells at the rate 40 L day^{-1} on weekly intervals. No special efforts were made to control pests and diseases other than sanitation, persistent watch for black beetle and by adhering to remedial measures.

Table 1. Details of female and pollen parents of the three crosses Sri Lanka Tall (SLT) x San Ramon (SR), Sri Lanka Tall x Sri Lanka Tall (SLT x SLT) and Sri Lanka Tall x Sri Lanka Dwarf Green (DG)

Female parents for all crosses	1.01	1.02	1.04	1.05	1.06	1.07	1.08	1.09	1.10
	1.11	1.12	1.13	1.15	1.20	1.21	1.22	1.23	1.32
Palms from Field 1 and 2 at ISG	2.01	2.04	2.05	2.13	2.14	2.28	2.36	2.38	2.39
	2.40	2.43	2.44	2.46	2.47	2.48	2.49	2.51	2.53
	2.54	2.55	2.57	2.58	2.60	2.61	2.62		
Pollen parents for the cross SLT	1.05	1.06	1.07	1.10	1.12	1.13	1.20	1.21	1.22
x SLT	2.01	2.13	2.37	2.39	2.40	2.43	2.46	2.47	2.51
Palms from Field 1 and 2 at ISG	2.54	2.55	2.58	2.60	2.61				
Pollen parents for the cross SLT x SR San Ramon from Field 16 at BE	4	14	15	16	17	18			
Pollen parents for the cross	5.02	5.03	5.07	5.10					
Sri Lanka Tall x Sri Lanka	9.01	9.02	9.03	9.04	9.05	9.07	9.08	9.10	9.11
green dwarf (T x DG): Sri Lanka Dwarf Green from Fields 5 and 9 at ISG	9.14								

Layout:

Seedlings were planted according to a randomised block design with three varieties, three treatments of fertiliser and three replicates with 10 seedlings per plot. The differential treatment of fertiliser was withdrawn half way during the experiment as CRI changed its blanket fertiliser recommendation system to site-specific application based on leaf nutrient status.

Experimental site:

The experimental site was located at the CRI's Research Station, Ratmalagara, and Madampe. This site is in the dry intermediate zone with an average annual rainfall of 1660 mm yr^{-1} (last 10-year average) with approximately 110 rainy days (rainfall between 0.25 - 1.02 mm yr^{-1}). The soil of the site is described as Andigama deep characterised by sandy loam to sandy clay loam with 20 - 30% ironstone, gravel and quartz below 70 cm from the surface. Based on soil and rainfall parameters the potential coconut yield of SLT in this soil is around 4500-5000 nuts ac^{-1} (Ranasinghe, 2004).

Data collection and analysis:

Early growth measurements; girth at the seedlings base and height at every six months for two years and leaf production at six months intervals for a period of five years were measured of every individual seedling. The approximate date of the appearance of the first inflorescence in each individual seedling was recorded. Mature nut harvest of every individual palm was recorded uninterruptedly and continued to date. Fruit components; fresh, dehusked, split and kernel weights of a sample (2 nuts $palm^{-1}$) of nuts harvested at every pick (bimonthly harvest) were assessed for three consecutive years 1999-2001. Data were analysed using the GLM procedure in the software SAS.

RESULTS AND DISCUSSION

Vegetative growth

Significant differences were noted in girth and heights of the three types of progeny at the age of two years (Table 2) with SLT x SLT, the inter-varietal hybrid and SLT x DG the intra-varietal hybrid, SLT x SR exhibiting a faster growth rate than SLT x SLT. Higher girth and height of seedlings is a clear indication of hybrid vigour as dwarf coconuts in general have a very faster growth rate. Higher girth and height of seedlings in SLT x SR probably could be attributed to the bigger structure of SR comparing to SLT. Girth and height however, are poor indicators of growth as they are subjected to severe measurement error at later stages of seedling growth. The leaf bases spread out non-uniformly from the collar making the measurement of girth extremely difficult. Shade affects the height and in this particular experiment few palms of the old stand remained in the field for more than three years after establishing the experiment. Therefore, the mean values obtained for girth and height of the individuals of the three progeny allows only a comparison of the growth in three progeny rather than magnitudes of the two parameters measured. This difference however, offset later when all progenies attained the reproductive age.

Table 2. Mean girth at collar and mean height at 12 and 24 months from transplanting in the three progeny, Sri Lanka SLT x SR (SLT x SR), Sri Lanka Tall x Sri Lanka Tall (SLT x SLT) and Sri Lanka Tall x Sri Lanka Green Dwarf (SLT x DG) at the Ratmalagara Research Station, CRI

Progeny / Age (months)	Girth at collar (cm)			Height (m)		
	SLT x DG	SLT x SLT	SLT x SR	SLT x DG	SLT x SLT	SLT x SR
12**	24.45	21.07	24.47	2.48	1.97	2.44
24	67.2	48.2	59.8	4.01	3.40	4.01

* S.E. differences for girth and height respectively are 1.50 and 0.07 (P<0.05%)
** S.E. differences for girth and height respectively are 1.97 (P<0.05%) and 0.07 (P<0.01%)

Table 3. Mean of cumulative leaf production at five years from transplanting in the three progeny, SLT x SR (SLT x SR), Sri Lanka Tall x Sri Lanka Tall (SLT x SLT) and Sri Lanka Tall x Sri Lanka Green Dwarf (SLT x DG) at the Coconut Research Institute's Ratmalagara Research Station.

Progeny	Mean of Cumulative leaf production at five years	SD	LSD (P<0.05)
SLT x DG	52.88[c]	4.96	2.37
SLT x SLT	42.42[b]	4.41	
SLT x SR	47.34[a]	4.96	

[abc]Means having the same letter are not statistically different

Leaf production (cumulative number of leaves emitted in the first five years) is a more accurate indicator of vegetative growth, especially in palms. Cumulative leaf at the age of five years clearly showed the superior growth rate of the inter-varietal hybrid, *SLT x DG* followed by *SLT x SR* and *SLT x SLT* (Table

3). The rate of leaf production in the three progeny, *SLT x DG, SLT x SR* and *SLT x SLT,* 52.88, 44.42 and 47.34 respectively at RE compares well with the observations of Santos et al. (1986) at Albay Research Station (ARC) in the Philippines which too share an average rainfall (app. 1600 mm yr^{-1}) similar to RE. At ARC *dwarfs x West African tall* hybrids and the local coconut, *Tagnanan* (an ecotype of Philippine tall coconuts like *San Ramon*) showed a similar variation in the cumulative leaf production where MYD (Malayan Yellow Dwarf) x WAT (West African Tall) at five years produced a total of 52.2 leaves surpassing the local tall, *Tagnanan,* which produced only 40.3 leaves. The five-year cumulative leaf production of *SLT x SR*, 47.34 at RE is a clear indication of hybrid vigour expressed by the cross between *Sri Lanka tall* (similar to WAT) and *San Ramon* (Pacific tall). The significantly faster rate of leaf production in *SLT x SR* comparing to *SLT x SLT* was indeed the consequential factor for the growing popularity of this cultivar among coconut farmer's since 2000. So far the farmer's experience in this cultivar is the faster growth of *SLT x SR* surpassing either SLT or *SLT x SLT* for which the growers are more accustomed (CRIC60).

Table 4. Cumulative percentage of flowering in the three progeny, Sri Lanka SLT x SR (*SLT x SR*), Sri Lanka Tall x Sri Lanka Tall (*SLT x SLT*) and Sri Lanka Tall x Sri Lanka Green Dwarf (*SLT x DG*) at the Coconut Research Institute's Research Stations, Bandirippuwa (BE) and Ratmalagara (RE)

Years after transplanting	Cumulative percentage of flowering in the three progeny at the two sites		
	SLT x DG	SLT x SLT	SLT x SR
4	10	0	1
5	48	2	1
6	64	3	11
7	67	9	26
8	64	30	78
9	100	83	91

Precocity:

The flowering period varied greatly between the progeny (Table 4). The hybrid *SLT x DG* began to flower from 3-4 years of planting and nearly 50% reached flowering in 5 years and 65% in six years. *SLT x SR* and *SLT x SLT* in contrast took much longer to flower with *SLT x SR* taking 7-8 years for to achieve 50% flowering while *SLT x SLT* took 8-9 years. The early flowering character of dwarf x tall hybrids is phenomenal in all instances except crosses involving Niu Leka dwarf (Bourdix, 1999). Niu Leka dwarf however, is uncharacteristic in it's stature and flowering time compared to other dwarfs which are known to be genetically close and resembling the genome of Pacific coconuts. Molecular marker studies based on micro-satellite and Amplified Fragment DNA comparisons of worldwide coconut by Teulat et al., (2000) have confirmed position of Niu Leka Dwarf as unique.

The time taken for 50% flowering in the SLT x DG, 5 years is much longer than expected and this may have probably attributed to the shade effect of the old stand at the RE site. In Albay the hybrid attained 50% flowering in 40 months comparing to Tagnanan the pure tall which had taken 76 months (Santos *et al.*, 1986). Though late than expected SLT x SR flowered a year earlier than the SLT x SLT the improvement probably obtained from San Ramon, which have already shown less precocity than Sri Lanka Tall in our observations at the Plant Genetic Resources Centre, Pallama. This character of SLT x SR also adds to receive growers acceptance in addition to its faster growth rate at early establishment.

Nut yield:

Notable nut harvests were recorded in all the three progeny from nine years after transplanting (Table 5). Throughout the nine-year period commencing from eight years after transplanting, the hybrid *SLT x DG* dominated the yield though with a greater degree of fluctuation than the other two with an average production rate of 14,800 nuts ha^{-1} yr^{-1}. This is however, less than the production potential of this hybrid shown in a different location at the same site earlier where an average yield of 20,000 nuts ha^{-1} yr^{-1} after 12 years of transplanting were recorded (Manthriratne, 1978). *SLT x SR* and *SLT x SLT* recorded the same rate of production with an average yield of 9,633 nuts ha^{-1} yr^{-1}. The yield trends of the three progeny clearly indicated the dominance of the SLT x DG throughout the period of study despite its high vulnerability for changes in weather. This relatively high susceptibility of the SLT x DG for moisture stress is expressed as drooping of fronds and bunches and heavy fall of immature nuts. This is very prominent in young plantations as the hybrid begins to show signs of wilting very much earlier than pure tall cultivars. This immediate response of the hybrid to moisture stress was also shown by studying the accumulation of proline in seedlings after inducing moisture stress (Jayasekera, 1989).

Table 5. Variation in production (nuts $palm^{-1}$) and productivity (nuts ha^{-1} yr^{-1}) of the three progeny, Sri Lanka SLT x SR (*SLT x SR*), Sri Lanka Tall x Sri Lanka Tall (*SLT x SLT*) and Sri Lanka Tall x Sri Lanka Green Dwarf (*SLT x DG*) at the Coconut Research Institute's Ratmalagara Research Station during the period from 1997-2002.

Year	1997	1998	1999	2000	2001	2002	Average
Years after planting	12	13	14	15	16	17	
Production (nuts $palm^{-1}yr^{-1}$)							
T x DG	50	50	110	89	100	45	74
T x T	30	30	60	66	72	31	48
T x SR	29	33	57	68	68	34	48
Productivity (nuts $ha^{-1}yr^{-1}$)							
T x DG	10,000^a	10,000^a	22,000^a	17,800^a	20,000^a	9,000^a	14,800
T x T	6,000^b	6,000^b	12,000^b	13,200^b	14,400^b	6,200^b	9,633
T x SR	5,800^b	6,600^b	11,400^b	13,600^b	13,600^b	6,800^b	9,633

^{abc}Means having the same letter in each year and each site are not statistically different

The yield per palm is strictly a function of the planting density and hence it is difficult to compare the current data across experiments world-wide. The average per palm yield of the three progeny over the six-year period was relatively low comparing to the performance of various other improved cultivars in other countries but this is perhaps due to the high planting density (200 palms ha^{-1}). Generally most experiments keep the plant density around 165 palms ha^{-1}. Exceptionally poor yields recorded in 2002 (the national coconut yields dropped by a half due to the severe drought witnessed in 2001) too have attributed for lowering of the six year average of per palm yields.

Components of nut, yields of copra and fibre:
The component analysis carried out on nuts harvested during the three-year period, 1999-2001 is shown in Table 6. It is well evident that the nuts of the hybrid progeny (*SLT x DG*) are lighter with less meat and husk than nuts of the progenies, *SLT x SR* and *SLT x SLT*. In contrast the nuts of the progeny, *SLT x SR* have nuts significantly larger in all components, especially meat and husk. The average meat content 448 g nut^{-1}, copra content 302 g nut^{-1} and husk content, 967 g nut^{-1} are outstanding features of *SLT x SR*..

Traditionally value of coconut was judged on its ability to produce copra. The out turn of copra per nut in SLT x SR, 302 g nut^{-1} is outstanding in terms of all known coconuts in the world. In a study at Ivory Coast (Bourdix, 1999) where about 50 worldwide coconuts were studied only two ecotypes of coconut, Kinabalan Green Dwarf (315 g nut^{-1}) and Cambodia Sre Cham Tall (303 g nut^{-1}) yielded more than 302 g nut^{-1}. Among hybrids tested only a similar tall x tall hybrid, PB213 (West African Tall x Rennel Island Tall) gave a much higher per nut yield (311 g copra nut^{-1}). It is further encouraging to note that SLT x SR has shown this potential under average management in a soil which is not too conducive for coconut growth. In contrast Ivory Coast is generally known to be highly favourable for growing coconut (high even rainfall above 2000 mm $year^{-1}$).

Despite the low copra out turn per nut SLT x DG still out numbered SLT x SLT and SLT x SR in annual productivity of copra, 4.44 mt ha^{-1} yr^{-1}. SLT x SR followed with 3.87 mt ha^{-1} yr^{-1} and 3.55 mt ha^{-1} yr^{-1}. There is however, a concern among copra millers in the country with respect quality of copra in the hybrid although there is no clear experimental evidence for such. This conception too has demoralised growers on cultivation of hybrid coconuts. SLT x SR on the other hand has once again proved its superiority over SLT x SLT with an outstanding rate of copra production. This rate of copra production as a pure tall is only next the tall ecotype, Thailand Sawi Tall (3.6 mt ha^{-1}) in experimental plots at Ivory Coast (Bourdix, 1999).

Coconut is now in an era of transition form an oil crop to a multipurpose crop for its sustenance due to the diminishing demand for oil in the world market. More recently a wide range of new coconut products, especially those coming from various components of the fruit; kernel, husk and shell have come to the market. During the last 30 years new products have been developed from the fresh kernel such as DC, milk, powders and creams. Numerous products of husks such as Tawashi brushes, brooms and rubberised coir products have reached the world export market. In addition shell products such as activated carbon and charcoal too share a fare proportion in world's export coconut products (Jayawardene and Everard, 2004). In view of these developments the characteristics of Tall x San Ramon, relatively larger kernel, husk and shell than the hybrid and the local tall (Table 6) adds to its importance as new coconut cultivar especially for commercial scale planting. Relatively large kernel of SLT X SR (approximately 450 g nut^{-1}) in particular in this regard has a distinct advantage because thickness in the meat reduces the loss of meat while peeling.

Table 6. The component analysis carried out on nuts harvested during the three-year period 1999-2001 of the three progeny, Sri Lanka SLT x SR (*SLT x SR*), Sri Lanka Tall x Sri Lanka Tall (*SLT x SLT*) and Sri Lanka Tall x Sri Lanka Green Dwarf (*SLT x DG*) at the Coconut Research Institute's Ratmalagara Research Station

Year	1999	2000	2001	3-year average	3-year average kg per ha
Tall x Dwarf Green					
Fresh nut weight	1,223	1,373	1,362	1,319	26,387
Dehusked nut weight	568	631	670	623	12,460
Split nut weight	502	544	531	526	10,513
Kernel weight	325	371	353	350	6,993
Shell weight	177	173	178	176	3,520
Copra weight	210	237	221	223	4,453
SLT x SLT					
Fresh nut weight	1,541	1,587	1,621	1,583	20,896
Dehusked nut weight	731	717	780	743	9,803
Split nut weight	613	645	623	627	8,276
Kernel weight	380	419	407	402	5,306
Shell weight	233	226	216	225	2,970
Copra weight	259	278	269	269	3,546
SLT x SR					
Fresh nut weight	1,873	1,942	1,913	1,909	24,439
Dehusked nut weight	930	946	1,024	967	12,373
Split nut weight	690	838	660	729	9,335
Kernel weight	439	472	434	448	5,739
Shell weight	251	366	226	281	3,597
Copra weight	302	319	284	302	3,861

Table 7. The average production of copra and husk during the three-year period, 1999-2001 of the three progeny, *Sri Lanka SLT x SR* (*SLT x SR*), *Sri Lanka Tall x Sri Lanka Tall* (*SLT x SLT*) and *Sri Lanka Tall x Sri Lanka Green Dwarf* (*SLT x DG*) at the Coconut Research Institute's Ratmalagara Research Station.

Progeny	Nuts^{-1} Palm^{-1} yr^{-1} (3-year mean)	Copra kg palm^{-1} yr^{-1} (3-year average)	Husk kg palm^{-1} yr^{-1} (3-year mean)	Copra kg ha^{-1} yr^{-1} (3-year average)	Husk kg ha^{-1} yr^{-1} (3-year average)
T x DG	100	22	62	4,445	12,418
T x T	66	18	49	3,551	9,808
T x SR	64	19	62	3,886	12,442

CONCLUSION

Coconut production sector in Sri Lanka is dominated by the small holder with 24% of the area coming under home gardens (< 0.8 ha) and 50% belonging to small landowners (< 8 ha). Mostly coconuts are not well managed in these lands apart from traditional cultural practices. General cultivation practices including fertilising are seldom practised. In the recent past even large plantation owners have resorted to low input management strategies due to increase in fertiliser prices and labour wages. Therefore, genetic improvement of coconut for low input cultivation systems is strategic for sustenance and meeting future challenges of the coconut industry in Sri Lanka. A coconut cultivar suitable for range of agronomic and climatic conditions, in particular with the ability to perform profitably in predominantly coconut grown drought prone sandy soils of the intermediate zone is the farmer's prospect. The performance of the cross SLT x SR exhibits great potential as a cultivar favouring the coconut farming conditions in Sri Lanka. SLT x SR with substantially better production rate for copra, kernel, husk and shell under normal management conditions is a bonus for coconut growers in Sri Lanka. The acceptance of SLT x SR to date by the growers is extremely encouraging as its early growth vigour made a tremendous impact on the grower.

ACKNOWLEDGEMENT

Patient efforts of all Research, Technical and Field staff of the Genetics and Plant Breeding Division and Estate Staff over a period of 18 years are gratefully appreciated in helping to maintain this experiment at the Ratmalagara Research Station of the CRI.

REFERENCES

Balingsa, E B and Carpio, C B 1983 Genetic Potential of some coconut populations of Philippines in Coconut Research and Development. Ed. N M Nayar. pp. 71 - 81.

Bourdix, R 1999 Selection and breeding (in) Modern Coconut Genetics. Ed. J G Ohler, FAO 1999.

Everard, J M D T 2001 Annual Report of the Coconut Research Institute. pp. 23.

Fernando, W M U 1987 Genetic improvement of the coconut cultivar San Ramon. Cocos 13: 30 - 39.

Fernando, W M U 1987 San Ramon big with promise. Coconut Bulletin 4: 15.

Jayasekera, C 1989 Annual Report of the Coconut Research Institute: 147.

Jayawardene, G and Everard, J M D T 2004 Coconut Industry In Sri Lanka - Current Status and Future Challenges. *Proceedings of the Ceylon Planters (150th Anniversary Session)*: Colombo 2004 (Unpublished).

Liyanage, D V 1954 Controlled pollination of coconut palms. Ceylon Coconut Quarterly 5: 135-139.

Liyanage, D V 1956 Intraspecific hybrids of coconuts. Bulletin (7), CRIC, Sri Lanka: 1-13.

Liyanage, D V 1955 Ceylon Coconut Quarterly 6: 24.

Liyanage, D V and Sakai, K I 1960 Heritabilities of certain yield characters of the coconut palm. Journal of Genetics 57: 245 -252.

Liyanage, D V 1958 Varieties and forms of coconut palms grown in Sri Lanka. Ceylon Coconut Quarterly 9: 1-10.

Manthriratne, M A P 1978 Ceylon Coconut Quarterly 29: 103-112.

Manthriratne, M A P 1971 Ceylon Coconut Quarterly 22: 107-113.

Palomar, R N and Fernandz, V A 1994 Variability of some mechanical properties of coconut wood. Philippine Journal of Science 19: 5 - 14.

Perera, L and Peries, R R A and Padmasiri, M H L 1997 The brown dwarf: a recent addition to the varieties and forms of the coconut palm grown in Sri Lanka. COCOS: 12 : 82-84.

Pieris, W V D 1934 Studies on coconut palm I. Tropical Agriculture: 82 : 75-97.

Pieris, W V D 1935 Studies on coconut palm II. Tropical Agriculture: 85 : 208 -220.

Ranasinghe, K L 2004 Coconut Research Institute. Personnel communication.
Sangare, A, Nuce de Lamothe, M de and Le Saint J P 1983 Promising hybrid coconuts: PB-111 and PB-213. Oleagneux 38: 8-9.
Santos, G A, Bahala, R T, Cano, S B and dela Cruz, B V 1986 Yield and agronomic traits of four variety hybrids and some local tall coconut populations in the Philippines. Oleagneux 41 (6): 269 -280.
Santos, G A, Cano, S B, dela Cruz, B V, Ilagan, M C and Bahala, R T 1984 Coconut germplasm collection in the Philippines. Philippine Journal of Science 9: 1 - 9.
Somasiri, L L W, Nadarajah, N, Amarasinghe, L and Gunathilake, H A J 1994 Land suitability assessment of coconut growing areas in the coconut triangle. Occasional Publication Series No. 3 Coconut Research Institute, Sri Lanka.
Teulat, B, Aldam, C, Trehin, R, Lebrun, P, Barker, J H A, Arnold, G M, Karp, A, Baudouin, L, Rognon, F 2000 An analysis of genetic diversity in coconut (Cocos nucifera) populations from across the geographic range using sequence-tagged microsatellites (SSRs) and AFLPs. Theoretical and Applied Genetics 100: 764-771.
Wickremaratne, M R T 1984 Annual Report of the Coconut Research Institute: 42.

Technical Session 4

Plant Health and Protection

Incidence and Severity of Corynespora Leaf Fall Disease of Rubber in Sri Lanka

C K Jayasinghe, W P K Silva, T H P S Fernando, N Nishantha
Rubber Research Institute of Sri Lanka, Agalawatta, Sri Lanka

ABSTRACT

Corynespora leaf fall disease caused by *Corynespora cassiicola* is currently considered as the most destructive leaf disease of *Hevea* rubber in Asian and African continents. Several outstanding clones in the world namely RRIM 600, GT 1, RRII 105, RRIC 103 and RRIC 110 have already succumbed to the disease. During the years 2002 and 2003 an island-wide disease screening programme was launched using an internationally accepted protocol and determine the present disease situation of clones planted in Sri Lanka. The ranking of clones based on a disease severity index revealed that eight clones among the 34 clones screened were susceptible to the disease at varying intensities. No clone recommended for large scale planting was found to be infected with the disease. Two heavily affected clones namely RRISL 202 (a clone recommended for small scale planting) and RRISL 200 (experimental clone) were removed from the recommendation list and experimental trials respectively. Moderate, infections have been detected on two clones recommended for small scale planting namely RRISL 201 and RRISL 217 and it was decided to make further observations on these clones before recommending for growers. The other Group 2 clone susceptible to the disease was RRISL 133 and it showed very light infection. The rest of the susceptible clones represented the Group 3, genetic materials recommended for estate/research institute collaborative trials.

Key words : *Corynespora* leaf fall, disease screening, *Hevea brasiliensis*, resistant clones

INTRODUCTION

Corynespora leaf fall (CLF) caused by the fungus *Corynespora cassiicola* has now become a serious threat to the world natural rubber industry. It is spread in Malaysia, Thailand, Sri Lanka, Indonesia, India, Vietnam and Central Africa attacking several outstanding rubber clones. CLF was first reported on rubber from India in 1958 (Ramakrishnan and Pillay, 1961). During this initial period *C. cassiicola* was considered as a weak pathogen of *Hevea* rubber and it was limited only to budwood nurseries and deficient seedling nursery plants.

In Sri Lanka the first epidemic was spread during 1986 devastating RRIC 103, the most prestigious clone recommended by the Sri Lankan scientists in the 20th century. Total area affected was 4,500 ha representing nearly 3% of the cultivated rubber lands. At that time Rubber Research Institute of Sri Lanka (RRISL) had no other alternative rather than forcing rubber growers to destroy clearings with RRIC 103 with the view of minimizing the inoculum potential in the island. As a result, rubber growers especially smallholders were compelled to suffer a considerable hardship. The second epidemic was experienced in 1995/96 when RRIC 110, another Sri Lankan outstanding clone succumbed to the disease.

During recent past more than a dozen of potential clones have been withdrawn from the experimental sites as they became highly susceptible to CLF.

An interesting feature of this fungus is it's ability of producing different types of symptoms depending on the type of clone. The typical symptom which was described as railway track appearance or fish bone pattern is unique for the *Hevea* clones; RRIC 103, RRIC 52, RRIM 600, IAN 873, RRIM 725 and in seedlings in seedling nurseries. The symptoms produced on the leaves of the clone RRIC 110 are either irregular or polyhedral in shape and surrounded by an extended yellow halo when leaflet is viewed against the light. Appearance of blackish linear lesions on midrib of leaflet is the common symptom on the clone RRIC 133. Lesions produced by *C. cassiicola* on the clone RRIC 132 is more or less similar to the lesion of Bird's eye spot disease caused by *Drechslera hevea* (Jayasinghe et al., 1998).

Another unique feature of the pathogen is the selective nature in attacking different clones. This has been shown since the first epidemic in 1985 in Sri Lanka. During the initial period; RRIC 103, RRIC 52, FX 25, RRIM 725, PR 263, PR 265, were highly susceptible, while clones RRIC 100, RRIC 121, RRIC 110 were considered as disease tolerant clones. However, after a decade from the first epidemic, several other clones, which were regarded as tolerant became susceptible in all rubber growing countries especially in South and South East Asia. For instance, RRIM 600 and GT 1 the most widely grown *Hevea* clones in Malaysia and Indonesia respectively have now succumbed to the disease. Another classic example is the RRIC 110, a prestigious clone bred by RRISL scientists. This clone became highly susceptible to CLF in Sri Lanka, Malaysia, Vietnam, Indonesia and Ivory Coast. With in the latter part of 1990's. Under the light of this situation the present study was undertaken to assess the disease susceptibility of recommended and potential clones planted in Sri Lanka using an internationally accepted protocol.

MATERIALS AND METHODS

Thirty four clones recommended by the Rubber Research Institute for estate/RRISL collaborative trials, small scale and large scale planting were screened at 12 locations depending on the availability of the test plants. Severity of the disease was assessed on a 0 to 4 scale, based on intensity of lesions and leaf fall (Table 1).

Table 1. Index for the scoring disease severity

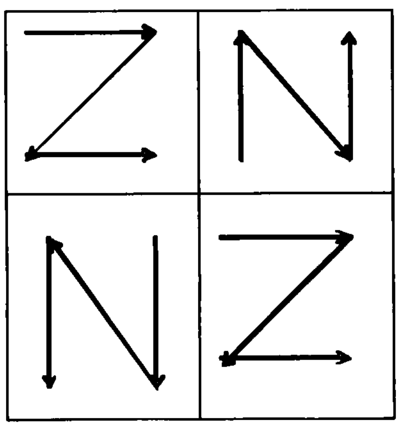
Index for scoring disease severity (score index)	Description
0	Highly resistant clones under field conditions. No symptoms on any of the leaves
1	Clones having few (less than 25%) leaves of the canopy with CLF symptoms and no detectable defoliation due to CLF. (Light infections)
2	Clones having few (less than 25%) leaves of the canopies with CLF symptoms and upto 25% defoliation of the cano pies due to CLF (Moderate infections)
3	Clones having more than 25% of the leaves with symptoms and 26 – 75 % defoliation due to CLF (Severe infections)
4	Clones having more than 76% defoliation due to CLF (Very severe)

Sampling technique

Ten randomly selected plants per each clearing and another five plants per every 100 trees of the clearing were examined.

Random selection of test plants:

Each field was divided into four quadrants. Then plants were selected along the directions given in the diagram.



Sampling of each test plant : Removed four shoots randomly from the canopy. Counted the number of leaves having lesions and recorded it as a percentage. Percentage of the fallen leaves was assessed on the visual basis.

Development of Average Disease Severity Index (ADSI)

ADSI was calculated using the following formula (adopted from Azher *et al.*, 1995).

$$ADSI = \frac{[(0 \times n1) + (1 \times n2) + (2 \times n3) + (3 \times n4) + (4 \times n5)]}{N}$$

Where,

n1 = number of plants representing score index 0
n2 = number of plants representing score index 1
n3 = number of plants representing score index 2
n4 = number of plants representing score index 3
n5 = number of plants representing score index 4
N = Total number of plants examined.

Ranking of clones: Ranking was carried out based on the average disease severity index

ADSI value	Description
0	No disease (**highly resistant**)
0.01 - 1.00	light infections (**mild**)
1.01 - 2.00	moderate infections (**moderate**)
2.01 - 3.00	severe infections (**severe**)
3.01 - 4.00	very severe infections (**very severe**)

RESULTS AND DISCUSSION

Observations revealed that eight clones among the 34 clones screened are susceptible to *Corynespora* leaf fall at varying intensities (Table 2,3 and 4)

Table 2. Disease intensity score of the clones recommended in Group 1 (recommended to be planted upto 10% of the extent)

Clone	Average Disease Severity Index
RRIC 100	0
RRIC 102	0
RRIC 121	0
RRIC 130	0
PB 217	0
PB 28/59	0

Table 3. Disease intensity score of the clones recommended in Group II (recommended to be planted upto 3% of the extent).

Clone	Average Disease Severity Index
RRIC 117	0
RRIC 133	0.67
RRISL 201	1.57
RRISL 202	2.86
RRISL 203	0
RRISL 205	0
RRISL 206	0
RRISL 211	0
RRISL 215	0
RRISL 217	1.76
PB235	0
PB 260	0
BPM 24	0

Table 4. Disease intensity score of the clones recommended in Group III (recommended to be planted as estate/RRI collaborative clone trial. Each clone to be planted upto 2 ha)

Clone	Average Disease Severity Index
RRISL 200	3.83
RRISL 204	0
RRISL 208	2.86
RRISL 218	0.133
RRISL 220	0
RRISL 221	0
RRISL 222	0
RRISL 226	0
GPS 1	0
PB 255	0
PR 255	0.03
RRII 105	0
RRISL 2000	0
RRISL 2001	0
RRISL 219	0

The ranking of clones planted in Sri Lanka based on ADSI resulted in five categories. Very severe infections were noticed on two clones and another two clones showed severe infections. Moderate infections were also found on two clones and mild infections were observed on three clones. The rest of the clones were highly resistant and they were absolutely free from the disease.

According to the Table 2, it is clear that all the clones recommended for large scale planting are free from the disease. The clone RRISL 202 which represents Group 2 (recommended for small scale planting) and clone RRISL 200 (a potential clone planted in collaborative clone trials) have been removed from the list of recommendation and experimental fields respectively due to their very high susceptibility to the disease.

Clones RRISL 201 and 217 which showed moderate infections have been transferred from Group 2 to Group 3, which represents the estate/RRI collaborative clone trials which are conducted under close supervision of the RRISL Officers.

Similar screening programmes have been carried out in most of the rubber growing countries in Africa and South and South East Asia (Anon, 2000; Dung and Hoan, 1999; Gobina et al., 1999; Idicula et al., 2000; Sujalno and Suhendry, 2000). The outcome of these surveys revealed that CLF has become a great threat to the several outstanding clones namely RRIM 600 (the most prestigious clone introduced by the Rubber Research Institute of Malaysia during the 20th century), GT 1 (about 50% rubber plantations are under this clone in Indonesia), RRIC 103 (The most out standing clone bred by Sri Lankan scientists upto 1980's) and RRII 105 (The most widely accepted clone by the Indian growers and presently 80% of their cultivated lands are under this clone). The most recent study comes from India and it was shown that CLF is present at varying intensities in all the clones planted in costal Karnatake & North Malabar region of Kerala (Manju et al., 2001). In this context it is worthy to note that majority of the clones planted in Sri Lanka are free from infections and tolerate the disease well. However, rubber growers should be extremely cautious as breaking down of the disease resistance can take place at any moment and disease may spread to another outstanding clone, destroying it.

With regard to the management of CLF in mature clearings no chemical control is recommended in any part of the world as it is not economically feasible. The only hope is the cultivation of tolerant clones. With this background all rubber growing countries should strengthen their vigilance and accelerate the introduction of a wider genetic base. Our study on grouping of clones into various resistance categories will further facilitate the selection of resistant germplasm before commencement of the conventional crossing programme.

List of abbreviations

CLF - Corynespora leaf fall disease
ADSI - Average Disease Severity Index
RRISL - Rubber Research Institute of Sri Lanka

ACKNOWLEDGEMENTS

The authors wish to thank Mrs. P Amarasekera for word processing. This project was partially funded by Sri Lanka Council for Agricultural Research Policy (12/497/370) and their financial assistance is gratefully acknowledged.

REFERENCES

Anon 2000 Malaysian country report. International Rubber Research and Development Board *Corynespora* Leaf Fall Disease Workshop in Kuala Lumpur. Malaysia from 6th to 9th June 2000.

Azhar I, Long G E, and Musa MJ 1995 Qualitative and Multivariate analyses of clonal cocoa resistance to cocoa pod borer (Lepidoptera : Gracillariidae). The Planter 71, 307-321.

Dung, P T and Hoan N T 1999 *Corynespora* leaf fall on rubber in Vietnam, International Rubber Research and Development Board *Corynespora* Leaf Fall Disease Workshop, 2000, Kuala Lumpur, Malaysia and Medan, Indonesia.

Gobina M S, Achu E A and Chuba P N 1999 Field evaluation of *Hevea* clones for leaf disease resistance. Proceedings of the IRRDB Annual Meeting, Hainan, China 1-15.

Idicula S P, Jacob C K, Manju M J and Kothandaraman R 2000 Current status of *Corynespora* leaf fall disease in India. International Rubber Research and Development Board *Corynespora* Leaf Fall Disease Workshop, 2000, Kuala Lumpur, Malaysia and Medan, Indonesia.

Jayasinghe C K, Silva W P K and Wettasinghe D S 1999 *Corynespora cassiicola* : A fungal pathogen with diverse symptoms on *Hevea* rubber. Bull. of the RRISL 39, 1-5.

Manju M J, Idicula S P, Jacob C K, Vinod K K, Prem E E, Suryakumar M and Kothandaraman R 2001. Incidence and severity of *Corynespora* leaf fall (CLF) Disease of rubber in coastal Karnataka and North Malabar region of Kerala. Indian J. of Nat. Rubb. Res. India, 14; 137-141.

Ramakrishnan T S and Pillay P N R 1961 Leaf spot of rubber caused by *Corynespora cassiicola* (Berk & Curt) Wei. Rubb. Bd. Bull. 5, 52-53.

Sujalno and Suhendry I 2000 *Corynespora* leaf fall disease on *Hevea* rubber in Indonesia. International Rubber Research and Development Board *Corynespora* Leaf Fall Disease Workshop, 2000.

Towards Developing an Integrated Pest Management Programme for Coconut Mite

L C P Fernando, I R Wickramananda and N S Aratchige
Crop Protection Division, Coconut Research Institute, Lunuwila, Sri Lanka

ABSTRACT

The coconut mite, *Aceria guerreronis* Keifer (Acari: Eriophyidae) was first reported in Sri Lanka from Kalpitiya peninsula in late 1997. It has subsequently spread to over 54,000 ha of coconut plantations in North, North central, North-western, Western, Eastern Provinces and recently to the Southern Province of the country. According to an ongoing survey 11%, 13% and 10% loss of nuts occur in Puttalam, Anuradhapura and Polonnaruwa districts respectively. Migration pattern, population dynamics and distribution pattern in the palms relevant to its control were studied. Estimation of pest populations on nuts and laboratory rearing of them are being perfected. No sustainable method has yet been developed to manage the pest effectively. Chemical control methods have not provided complete control of the pest. Although chemical control is not cost effective and practical low toxic chemicals are being evaluated to use in outbreak situations and to integrate with other methods if necessary. Studies so far conducted indicated that the native predatory mite, *Neoseiulus* aff paspalivorus (Acari: Phytoseiidae) is a promising candidate for biological control of the pest. It appears that the natural population level of the predatory mite is not sufficient to lower the pest population adequately. Experiments are underway to mass-produce and augment the field population and determine release technology and effectiveness of the releases. The efficacy and persistence of the promising entomopathogenic fungus, *Hirsutella thompsonii* for the management of the pest is being evaluated. Specific problems related to the nature of the pest, crop, grower and the industry and the management of coconut mite are discussed. A holistic approach in which biological control based integrated pest management package combined with other crop management practices is suggested for sustainable management of the pest. Future directions to be incorporated in an grower acceptable integrated pest and crop management programme is outlined.

Key words: Coconut mite, chemical control, integrated pest management, *Neoseiulus paspalivorus, Hirsutella thompsonii*

INTRODUCTION

The coconut mite, *Aceria guerreronis* (Acari: Eriophyidae) was first reported from Sri Lanka in late 1997. It is thought to be an introduced pest. Since the first report of the pest in Mexico in 1965, it has spread to over 25 countries in the Americas and Africa (Hall and Espinosa, 1981; Mariau, 1977; Mariau and Julia, 1970; Zuluaga and Sanchez, 1971) and recently to India (Sathiamma et al., 1998) and Sri Lanka (Fernando, 1999; Fernando et al., 2002). Coconut mite has proven to be one of the most serious and intractable pests of coconut in the world. Efforts in the last four decades to develop effective and sustainable management methods have failed. The only known effective way to suppress the pest is the use of chemicals. The need for frequent and repeated applications, high toxicity, harmful effect on the environment and natural enemies, difficulties in application and uneconomical nature has made this method unacceptable as a long term measure. Other methods such as use of the entomopathogenic fungus, *Hirsutella thompsonii* has shown some promise, but effective management methods have not been developed yet (Cabrera, 1995; Lampedro and Rosas, 1989; Rabindra and Kumar, 2003).

It has been said that coconut mite has not received due research attention in the past. The characteristics and habitat of the coconut mite and nature of the coconut palm may have contributed to this situation. Moreover, priority given to other serious and fatal diseases of coconut such as lethal yellowing has prevented long-term research. Therefore, in addition to lack of effective management strategies many gaps in knowledge of the pest biology and ecology and its interactions with natural enemies still exist. Arrival of the pest in the Indian sub-continent has prompted re-addressing the problem and exploring all possibilities in managing the pest. This is more so because coconut is an economically important crop in the livelihood of people in this region. However, managing a serious pest effectively, economically, in a sustainable manner and up to growers' expectations is a challenge. Considering all these factors and our experience in the past it is strongly felt that, coconut mite should be best managed by an integrated pest management programme with emphasis on biological control and crop management. However, it should be understood that such a programme cannot be developed overnight but will require painstaking research and time.

Present distribution and nut loss

The coconut mite was first reported from Kalpitiya of the North-western Province (NWP) in late 1997. It spread fast to Vanathavillu, Puttalum, Madurankuliya and Rajakadaluwa Divisional Secretariat areas of the District and to two isolated pockets in Chilaw (Puttalum District, NWP) and Kuliyapitiya (NWP) up to 1999. In 2000 the pest was reported from the Northern Province and Polonnaruwa (Eastern Province). Simultaneously it emerged in estates at Wariyapola (NWP), Mirigama (Western Province) and Dankotuwa (NWP). The first report of the pest in the North-central Province was from Rajangane area and at Batticaloa District in 2001. From these areas it gradually spread to many dry areas in the country. According to the data provided by the Coconut Cultivation Board in September 2003 approximately an area of 53,720 ha (9400 ha in North Province, 6800 ha in North-central Province, 31,300 ha in Puttalam District, 4300 ha in Kurunegala District, 1400 ha in Pollonnaruwa District, 300 ha in Amparai District and 220 ha. in Gampaha District) areas are affected. This is nearly 15% of total coconut area of the affected districts and about 13% of the total coconut area of the country. Additionally, the pest was reported from Hambantota District in late 2003.

Coconut mite colonises the bracts and feeds on the meristematic tissues underneath the bracts. Extensive feeding by a large number of mites result in scarring of the nut surface and in severe infestations leads to immature nut fall, and reduced nut size or malformed nuts. Except, for very small nuts, which are usually rejected other affected nuts are marketable. Smaller and malformed nuts fetch usually half the price of a normal nut. Normal sized nuts with scarring can be sold at the normal price. A study initiated in 2003 to assess crop loss at the harvest due to coconut mite indicated a loss of 11%, 13% and 10% nuts in Puttalam, Anuradhapura and Polonnaruwa districts respectively (Fernando and Peiris, personal communication). The study is being extended to assess nut fall due to coconut mite infestation in different districts at different times of the year.

Studies on pest biology and ecology relevant to its control

Understanding the biology and ecology of coconut mite is important to develop management strategies. All such studies require development and perfection of sampling techniques to assess the population of the pest. Also, laboratory rearing of coconut mite is required to study its biology and to develop techniques for field studies.

Assessment of population density

Methods developed to assess the population of coconut mite on nuts (Howard et al., 1989; Moore and Alexander, 1987) are not accurate enough and convenient to use. Therefore, a new sampling technique ("wash method") was tried out. This involves washing off the mites on the nut and bracts using a detergent solution and estimating the actual population by counting the number of mites in a sub sample. Population estimation using a formula was developed (Siriwardene, unpublished data). This was found to be an accurate and a quick method of estimating mite populations of coconut mite on a single coconut. The method is being further improved by developing a computer-based digital imaging process to count coconut mites.

Distribution pattern in palms

The distribution patterns and numerical variability of coconut mite on young bunches (3- to 7-month-old) in infested palms were studied to determine the age of nuts suitable for sampling. The spatial and temporal distribution of coconut mites on infested palms differed significantly. The number of coconut mites per nut increased up to 5-month-old bunch and declined thereafter. Variability in the numbers of mites among palms and bunches of the same age was great, but was relatively low on 6-month-old bunches (Fernando et al., 2003). Therefore, it was concluded that selection of several 6-month-old nuts are suitable for obtaining a reliable estimate of the population density of coconut mite.

Population dynamics

A three-year study showed that coconut mite density on nuts varies considerably over time responding to weather conditions. In general, it appears that the pest population reaches high levels either during dry periods or soon after dry periods. Therefore, it seems necessary to apply management measures at the onset of the dry period to reduce mite damage.

Migration patterns

Some aspects of migration of coconut mite were studied. It was clear that majority of the mites leaving the perianth for migration are mature females. The largest number of mites to leave was from the 4th bunch. A study of the diurnal pattern of migration of mites revealed that active migration occurs in the night. The peak time of mites leaving the perianth for migration occurs around 4 a.m. in the morning.

Laboratory rearing

A method for rearing of coconut mite in the laboratory was developed. Coconut mites were successfully reared on tender buds of coconut (De Silva, 2002). However, the leaf tissues need to be renewed regularly to prevent fungal growth. To overcome this problem studies are underway to rear mites on tissue culture plantlets and promising results have been obtained (De Silva, unpublished data).

Attempted control measures and their effectiveness

Chemical methods

Use of chemical pesticides is extremely important to suppress outbreaks and as a short- term strategy in an integrated management programme to reduce pest populations. In the initial outbreak of the pest trunk injection of monocrotophos was recommended and nearly 350,000 palms in the Puttalam district were treated (Fernando et al., 2002). Injection of 20 ml of Monocrotophos 60 resulted in average 90% mortality of coconut mites in 4 weeks after treatment. However, the effect lasted for only 6 weeks after treatment (Fernando et al., 2002). In the palms of which 100% control was not achieved the pest multiplied rapidly and also re-infested the neighbouring palms that had been completely controlled by the treatment. Therefore, repeated application at 1-2 month intervals is necessary for long-term control of the pest. This was not possible because the treatment cause permanent injury to the palm trunk and lead to subsequent infections. Further, residues of the pesticide accumulate in the palm kernel and therefore nuts could not be used until 2-3 months after injection. Although monocrotophos is an effective pesticide to suppress outbreaks of coconut mite its use was discontinued as soon as the outbreak was managed. Thereafter, the emphasis was to determine effective botanicals and low toxic chemicals. Such methods are less hazardous to the environment and compatible with other management methods. Over 15 pesticides have been tested, but only few were effective in managing coconut mite. Currently spraying a mixture of 2% neem oil, garlic and soap water or Neemazal (azadirachtin 1%) is recommended for the management of the pest. Each method resulted in about 60% reduction in the pest population (Fernando et al., 2002; Wickramanda et al., 2003). However, repeated application at 1-2 monthly interval is required to obtain successful results. The disadvantage of this method is that it affects the predatory mite population to some extent (Fernando et al., 2002) and repeated applications are costly and labour intensive especially in large plantations. Therefore, it is not widely used and accepted by the growers.

Unfortunately, no pesticide that could control coconut mite completely by a single application has been known so far. The efficacy of the insecticide Marshal 20 SC (Carbosulfan 20%) by root feeding, trunk injection and crown spraying was determined. Preliminary investigations revealed that application of Marshal considerably reduced both mite populations and damage in new bunches. Large-scale trials with Marshall are being conducted to further confirm its efficacy. Another study where application of 30% used (burnt) engine oil mixed with surfactant was applied to the perianth of infested nuts was found to be effective in managing coconut mite (Chandrasiri and Fernando, 2003). Almost 100% mortality of mites occurred after the application resulting in no further damage to treated nuts. Also, development of fresh damage on treated bunches was very low compared to the untreated palms. In 2-month old bunches, fresh damage was 4.9% compared to 71.4% in the untreated bunches and in 4-month old bunches it was 1.2% in the treated palms compared to 63% on untreated bunches. Furthermore, percentage of undamaged nuts was considerably higher in treated bunches than in untreated ones. Although no adverse effects of engine oil application on nuts were observed the predatory mite population was drastically affected by the treatment. Studies are being continued to determine the optimum frequency of application and presence of any residues of heavy metals in treated nuts. Many other neem formulations and low toxic chemicals are being tested.

Biological methods

Use of natural enemies which are self perpetuating and sustainable will play the major role in the integrated management of coconut mite. Predatory mites and entomopathogenic fungi have scope in this respect.

Use of predatory mites

Although several predatory mites of *A. guerreronis* have been recorded in many countries (see Moraes and Zacarias, 2002), their potential as biological control agents have not been explored. Moraes and Zacarias (2002) suggested that *Neoseiulus* spp. have potential as prospective candidates for biological control. Also, *Proctolaelaps bickleyi* was found to feed on *A. guerreronis*. High population levels of *P. bickleyi* have been associated with high numbers of dead and low numbers of live *A. guerreronis* on coconut in Mexico (Estebanes Gonzales, 1976) and Brazil (Moraes, personal communication). In Sri Lanka, *Neoseiulus* aff. *paspalivorus* (Phytoseidae) was found to be abundant in all infested areas of mite. It was found to feed on all stages of the pest and generally number of live coconut mites was low in nuts with high numbers of predatory mite. Both laboratory and field studies strongly suggested *N. paspalivorus* as a promising candidate for biological control of coconut mite in Sri Lanka. A study conducted in two locations of coconut mite infested area revealed that the numbers of predatory mites followed a pattern similar to that of coconut mites with the maturity of nuts, but the predatory mites peaked one month later than the coconut mites suggesting that the predator density has a strong relationship with the pest density (Fernando et al., 2003). However, predatory mites were not found on all nuts although they were present in all the palms in varying numbers (Fernando et al., 2003). Generally, the distribution and density of predators on nuts have increased over time (Fernando and Aratchige, 2003). A preliminary study also indicated that release of the predatory mite in the field would reduce pest density considerably (Fernando and Aratchige, 2003). Nevertheless, field studies indicate that predatory mite densities found in nature are not sufficient to effectively reduce damage hence increase in their numbers need to be attempted. This could be achieved by augmenting the field population with laboratory–bred predators and as well as by conserving natural population of the predator in the field.

In order to obtain predatory mites for field release methods for mass breeding are being developed. Different food sources necessary for the development and reproduction of *N.* aff. *paspalivorus* were tested. Although they developed satisfactorily on many diets, their reproduction was very low. A satisfactory fecundity was obtained only when fed on newly hatched larvae and eggs of the mite *Tyrophagus putriscentiae.* Methods are being developed to breed *N.* aff. *paspalivorus* on this host. Also, field studies to develop release technology and effectiveness of released predators are planned. Furthermore, introduction of the promising predatory mite *P. bickleyi* from Brazil will be made.

Use of entomopathogenic fungus

The fungus, *Hirsutella thompsonii* has been considered as a promising candidate for biological control of coconut mite. Several studies have shown that the fungus causes considerable mortality of coconut mites (Becerril and Sanchez, 1986; Cabrera, 1995; Cabrera, 2002; Lampedro and Rosas, 1989; Rabindra and Kumar, 2003). However, consistent results have not been obtained in field studies (Cabrera and Rabindra, personal communication). Preliminary studies conducted in Sri Lanka have indicated that over 80% mortality of coconut mites could be achieved in 1-2 months after spraying of the fungus (Wijesinghe, personal communication). However, the fungus failed to establish and persist long in the environment Further studies will be directed to improve the persistence of the fungus in the field.

Problems specific to coconut mite management

The characteristics and behaviour of the pest and the nature of the crop, grower and industry pose several difficulties in managing coconut mite. Therefore, strategies developed should be sound enough to overcome these constraints.

Coconut mite has a short generation interval of 10-12 days and a very high reproductive rate. A few mites could multiply to numbers that causes economical damage in a shorter period. Therefore, control measures applied for the management of the pest should be effective enough to reduce the pest numbers to a very minimum level. Because the coconut mite colonizes under the bracts, which are tightly adhered to the nut surface they are well protected from many natural enemies and less affected by changing climatic factors. Furthermore, many contact pesticides that are effective in managing mites are not as effective on coconut mite because the chemicals do not directly get contacted with the pest underneath the perianth except, the ones that are on the surface of nuts or edges of the bracts.

The coconut palm produces an inflorescence every month and therefore coconut mites have abundance of food to multiply all year round. Due to this fact, the control measures such as chemicals should be applied throughout the year to keep their population levels low. Coconut is a tall palm and reaching the crown for application of control measures is difficult. Pesticides may be applied by spraying, trunk injecting and root feeding. Apart from the availability of limited number of effective chemicals, their application requires skilled labour and high-pressure sprayers. Although trunk injection of systemic pesticides are more convenient application causes permanent injury to palm trunks. Feeding through roots is laborious and time consuming. In this situation repeated application of chemicals are uneconomical and impractical especially in large plantations.

In Sri Lanka small holders belong to the low-income group and the nature of the coconut plantations are such that there are a large number of scattered small-holdings giving poor returns to the growers. Therefore, vast majority of them will not invest money or labour on expensive control measures.

Considering all the above factors it is obvious that the management strategies that are being developed should be cost effective, convenient to apply and long lasting. This also emphasises the necessity of an integrated management strategy placing priority on biological control methods.

FUTURE DIRECTIONS

Establishment of a pest on a crop plant and the degree of damage caused by that pest is a result of a series of complex interactions between the crop, pest and the environment. The damage severity expressed by the crop plant depends on the pest numbers and the nature of their feeding, susceptibility of the crop to pest establishment and environmental factors affecting both the pest and the crop. While the environmental factors cannot be controlled in a plantation the first two factors can be manipulated. The aim of integrated management is to manipulate these factors in such a way to reduce the pest population below economic damage level. This could be achieved by combining two or more methods that would lower pest density and/or improve crop tolerance.

Although current research on coconut mite is directed towards developing independent strategies, the final objective is to develop a management programme by integrating all methods in a compatible manner. Such a programme may be location and season specific. As the pest density increases with the onset of dry period it seems appropriate to target IPM strategies during that period. During this period, if the pest density in a specific area is high it may be necessary to use a low toxic chemical to bring down the pest density and thereafter release *N.* aff *paspalivorus* once or few times to maintain pest densities below economic damage level. Also, predator mite release could be combined with application of the fungus *H. thompsonii*, which has shown no deleterious effect on *N. paspalivorus*. To increase tolerance of coconut palms to coconut mite attack it is important to improve the plant vigor. This could be achieved by the application of a balanced fertiliser mixture. Incorporating organic matter to improve nutritional status of the palm and soil properties and use of other agronomic practices such as irrigation, soil moisture conservation etc. These aspects have been neglected in coconut cultivation. India, where severe damage has been experienced has now strongly recommended the improvement of palm vigor as a means of reducing coconut mite damage (Rethinam et al., 2003). The areas most suitable for application of individual strategy, degree of effectiveness of each strategy and frequency and timing of applications will be addressed in future studies. Without that knowledge ways of integrating different management methods could not be planned.

In addition to the ongoing studies it is hoped to undertake the following management strategies.

a. The modes of long distance dispersal of the coconut mite are not well understood. Studies will be undertaken to determine the role of wind, insects etc. in this regard.
b. In-depth studies on the biology and ecology of the pest, host plant interactions and inter relations between pest, natural enemies and the coconut eco system are essential to understand the pest and design appropriate strategies.
c. Search for prospective natural enemies from the Americas where the pest is known to have originated will be made to introduce them to the country to complement the natural enemy complex.
d. A commercial preparation using *Hirsutella thompsonii* will be produced to establish the fungus.
e. Effect of plant nutrition and impact of agronomic practices in reducing the damage by the pest will be determined.
f. Research should also focus on identification of resistant and tolerant coconut cultivars.
g. The current trend in management of the coconut mite in India takes a more holistic approach. In addition to managing the pest and improving palm tolerance, crop sanitation, imposing quarantine measures and intercropping with suitable short term cash crops to increase the income of the farmers and have been identified as future strategies (Rethinam et al., 2003). Sri Lanka should also follow a similar approach. Some of the key strategies such as quarantine measures are already in place but its implementation has to be strengthened.

Management of a pest such as coconut mite would require not only persistent and long-term research but also a concerted and collective effort between scientists, policy makers, extension officers and most importantly the coconut growers who are the actual beneficiaries. It is hoped that though painstaking research an acceptable solution towards management of coconut mite will be made available to coconut growers.

ACKNOWLEDGEMENTS

We sincerely thank the staff of the Crop Protection Division for their great efforts and dedication in carrying out the studies. The Coconut Cultivation Board is acknowledged for providing data on the distribution of the pest. Our sincere gratitude is extended to Professor Jayanthi Edirisinghe for her valuable comments on the manuscript. Financial assistance provided by Coconut CESS, Department for International Development, U.K. and the Council for Agricultural Research Policy (CARP) is gratefully acknowledged.

REFERENCES

Becerril, A E and Sanchez, J L C 1986 El hongo *Hirsutella thompsonii* Fisher en control del eriofid del cocotero *Eriophyes guerrronis* (Keifer). Agricultura Tecnica en Mexico. 12, 319-323.

Cabrera, R I C 1995 Un 'medio a base de soya mas azucar para la var. *thompsonii* en medio liqido. 111 Encuentro Nac. Cient-Tec. De Bioplaguicidas. Expo-CREE. La Habana, Cuba. pp. 11-12.

Cabrera, R I C 2002 Biological control of the coconut mite *Aceria guerreronis* (Acari: Eriophyidae) with the fungus *H. thompsonii* and its possible integration with other control methods. *In* Proceedings of the International workshop on coconut mite (*Aceria guerreronis*). Eds. L C P Fernando, G J de Moraes and I R Wickramanada, pp 89-103. Coconut Research Institute, Sri Lanka, January 6-8, 2000.

Chandrasiri, K A S and Fernando, L C P 2003 A new method to control coconut mite. Agricultural Research News. 4(2), 11.

De Silva, P H A P 2001 Investigation on some aspects of laboratory rearing and management of coconut mite, *Aceria guerreronis* Keifer. Report submitted for the partial fulfilment of the Bachelor's degree of Agricultural Science, University of Ruhuna.

Estabanes Gonzalez, M.L. 1976 Acaros depredadores de Eriophyes guerreronis (Keifer) en la zona de Tecpan de Galeana, Gro. Folia Entomol. Mexicana 39/40:41-42.

Fernando, L.C.P. 1998 Annual Report of the Crop Protection Division, Coconut Research Institute, Sri Lanka.

Fernando, L C P, Wickramanada, I R and Aratchig, N S 2002 Status of coconut mite, *Aceria guerreronis* in Sri Lanka. *In* Proceedings of the International workshop on coconut mite (*Aceria guerreronis)* 2000. Eds. Fernando, L.C.P., Moraes, G.J. de and Wickramananda, I.R., Coconut Research Institute, Sri Lanka, January 6-8.

Fernando, L C P and Aratchige, N S 2003 Use of predatory mite *Neoseiulus* aff. *paspalivorus* in management of coconut mite (*Aceria guerreronis*). *In* Coconut eriophyid mite – Issues and strategies. Eds. H P Singh and P Rethinam. pp. 43-49. Proceedings of the International workshop on coconut mite. Bangalore, India, 2003.

Fernando, L C P, Aratchige, N S and Peiris, T S G 2003 Distribution patterns of coconut mite, *Aceria guerreronis*, and its predator *Neoseiulus* aff. *paspalivorus* in coconut palms. Expt. Appl. Acarol. 31, 71-78.

Hall, R A and Espinosa, B A 1981 The coconut mite, *Eriophyes guerreornis*, with special reference to the problem in Mexico. Proc. 1981 British Crop Protection Conference – Pests and diseases, British Crop Protection Council, Farnham, U.K. pp. 113-120.

Howard, F W, Abreu-Rodriguez, E and Denmark, H A 1990 Geographical and seasonal distribution of the coconut mite, *Aceria guerreronis* (Acari: Eriophyidae), in Puerto Rico and Florida, USA. J. Agric. Univ. Puerto Rico. 74, 237-251.

Lampedro, L and Luis Rosas, J 1989 Selection of *Hirsutella thompsonii* Fisher strains to fight coconut mite *Eriophyes guerreronis* Keifer. 1. Pathogenecity experiments. Revista Mexicana de Micologia. 5, 225-231.

Mariau, D 1977 *Aceria guerreronis* : un important ravageur des cocoteraies africanes et américaines. Oléagineux. 32, 101-108.

Mariau, D and Julia, J F 1970 L'acriose à *Aceria guerreronis* (Keifer), ravageur du cocotier. Oléagineux. 28, 133-135.

Moore, D and Alexander, L 1987 Aspects of migration and colonization of the coconut palm by the coconut mite, *Eriophyes guerreronis* (Keifer) (Acari: Eriophyidae). Bull. Entomol. Res. 77, 641-650.

Moraes, G J de and Zacarias, M S 2000 Use of predatory mites for the control of eriophyid mites. *In* Proceedings of the International workshop on coconut mite (*Aceria guerreronis*). Eds. L C P Fernando, G J de Moraes and I R Wickramanada, pp 78-88. Coconut Research Institute workshop, Sri Lanka, January 6-8, 2000.

Rabindra, R J and Sreerama Kumar, P 2003 Prospects of biological control of coconut mite. *In* Coconut eriophyid mite – Issues and strategies. Eds. H P Singh, and P Rethinam. pp 35-42. Proceedings of the International workshop on coconut mite, Bangalore, India, 2003.

Rethinam, P, Singh, S P, Hallikeri, V and Gopalakrishnan, R 2003 Eriophyid mite in coconut. Coconut Development Board, Kochi, India p. 32.

Sathiamma, B, Radhakrishnan Nair, C P and Koshy, P K 1988 Outbreak of a nut infesting eriophyid mite *Eriophyes guerreronis* (K.) in coconut plantations in India. Indian Coconut Journal. 29(2), 1-3.

Wickramananda, I R and Fernando, L C P 2002 Efficacy of four botanical pesticides on three major pests of coconut (*Cocos nucifera* L.). *In* Plantation Crops Research in the New Millenium. Eds. R Rethinam, H H Khan, V M Reddy, P K Mandal and K Suresh. pp 214-217. PLACROSYM XIV. 12-15 Dec 2000. Hyderabad, India.

Wickramananda, I R, Fernando, L C P and Aratchige, N S 2003 Use of chemicals for management of coconut mite: Sri Lanka Experience. *In* Coconut eriophyid mite – Issues and strategies. Eds. H P Singh and P Rethinam. Proceedings of the International workshop on coconut mite held in Bangalore, India. 5-7 April 2003.

Zuluaga, C I and Sanchez, P A 1971 La rona o esoriacion de los frutos del cocotero (*Cocos nucifera* L.) en Colombia. Oléagineux. 26, 767-770.

Technical Session 5

Biochemistry and Processing Technology

Preformed and Induced Chemical Resistance in the Tea Plant Against *Exobasidium vexans* Infection

[1]Nimal Punyasiri, [2]Gregory J Tanner, [3]Vijaya Kumar, [2]Peter M Campbell, [1]N H L Pradeepa and [1]I S B Abeysinghe

[1] The Tea Research Institute of Sri Lanka, Talawakelle, Sri Lanka
[2] Plant Industry, CSIRO, Canberra, Australia
[3]University of Peradeniya, Sri Lanka

ABSTRACT

Analysis of tea cultivars revealed that the levels of (-)-epicatechin in tea cultivars resistant to blister blight leaf disease were significantly higher than those in susceptible cultivars, while the reverse was true for (-)-epigallocatechin gallate. The higher levels of epicatechin suggest its involvement in the resistance of the tea plant against blister blight, while the lower levels of epigallocatechin gallate indicate a decrease in activity of enzymes catalyzing the formation of epicatechin derivatives in resistant cultivars.

The content of the methylxanthines, caffeine and theobromine in the leaf was found to increase significantly in the initial translucent stage of the disease, probably as a defence response of the plant to fungal attack. Epicatechin and epigallocatechin levels were significantly less at this stage when compared with healthy tissues, but the observed increases in their gallate esters suggest that they were being converted into the esters. Although epicatechin and epigallocatechin levels decreased from the translucent to the mature blister stages, the decrease was not significant.

The decrease in levels of epicatechin, epigallocatechin and their esters on infection, together with the formation of cyanidin and delphinidin on acid-catalyzed oxidation of the blisters, suggests that catechins are converted into fungitoxic proanthocyanidins as part of the defence mechanism. The very high resistance of a purple green-leafed cultivar, TRI 2043, is attributed to the additional catechin source provided by anthocyanins present at high levels in the leaves. Anthocyanidin reductase present in tea leaves is known to convert anthocyanidins, the aglycone form of anthocyanins, into catechins.

Infection of leaves of tea [(*Camellia sinensis* (L.) O. Kuntze, cv TRI 2025)] by blister blight (*Exobasidium vexans* Massee) also resulted in a shift of the proanthocyanidin stereochemistry away from 2,3-*trans* (e.g. catechin and gallocatechin) and towards 2,3-*cis* (e.g. epicatechin and epigallocatechin). Infection also resulted in increased gallic acid esterification of the initiating subunits of proanthocyanidins. This was shown by both mass spectroscopy and hydrolysis of purified proanthocyanidins in the presence of phloroglucinol.

Proanthocyanidins isolated from healthy tissue had a predominantly 2,3-*trans* stereochemistry which accounted for 51% and 61% of the total initiating and extension units of proanthocyanidin, respectively. Conversely, in infected tissue, proanthocyanidin subunits with a 2,3-*trans* stereochemistry accounted for 27% and 40% of the total initiating and extension units, respectively.

Infection had little impact on the hydroxylation state of the B-rings of proanthocyanidins. The products of acid hydrolysis had predominantly di-hydroxylated B-rings, with cyanidin accounting for 58.3 ± 0.05% and 60.4 ± 0.2% of the total anthocyanidin recovered, following hydrolysis of proanthocyanidin isolated from infected and healthy leaves, respectively. Similar results were obtained by hydrolysis in the presence of phloroglucinol.

The stereochemistry of proanthocyanidin in infected leaves was changed as a result of a coordinated defense response to the disease.

Key words: Blister blight, defence mechanism, chemical resistance

INTRODUCTION

Blister blight leaf disease of tea (*Camellia sinensis* (L.) O. Kuntze), which is caused by the fungus, *Exobasidium vexans* Massee, is endemic to all tea-growing areas in Asia (Arulpragasam, 1986). The disease is of major economic importance as heavy losses of the tea crop have been reported (Agnihothrudu and Moulli, 1991), caused by infested stems breaking off and die back resulting in retarded growth (Arulpragasam, 1992). The pathogen completes its entire life cycle of 11-28 days in the tea leaf (Agnihothrudu and Moulli, 1991; Gadd and Loos, 1948). The first symptoms are yellow-green translucent spots, which appear 6-9 days after infection (the translucent stage). They develop into blisters which rupture and release spores when the life cycle is completed.

Tea cultivars have been categorized as resistant or susceptible to blister blight (Balasooriya et al., 1996), and some morphological and anatomical characters have been correlated with resistance (Martosupono, 1991). Little attempt has been made to correlate resistance with the chemical composition of the tea leaf, although changes in saccharide metabolism (Pius et al., 1998), and increased activity of polyphenol oxidase, peroxidase and decrease of chlorophylls and carotenoids (Rajalakshmi and Ramarethinam, 2000), induced by blister blight infection, have been shown. A preliminary report has been made (Nagahaulla et al., 1996) on the formation of phytoalexins, probably polyphenolic in nature, during blister blight infection. Variation in chemical composition and quality of tea, with increased severity of blister blight, has also been studied (Gulati et al., 1999).

The most abundant chemical component of tea is polyphenols, with catechins being predominant. The role of phenolic substances in disease resistance is well documented (Nicholson and Hammerschmidt, 1992; Vidhyasekaran, 1988). Polyphenols are known to be fungitoxic and antibacterial substances, with varying levels of toxicity to spore germination, mycelial growth and fungal enzyme production (Vidhyasekaran, 1988). In addition to these major compounds, various proanthocyanidins have been reported in tea (Kiehne et al., 1997; Lakenbrink et al., 1999). Caffeine has been shown to play a role in the resistance of tea to attack by the shot-hole borer, *Xyleborus fornicatus* (Kumar et al., 1995).

Proanthocyanidins are widely-distributed plant defense compounds (Treutter and Feucht, 1999), and have a general toxicity towards fungi, yeasts and bacteria (Scalbert, 1991). Proanthocyanidins isolated from *Pinus sylvestris*, *Anona squamosa* and *Cassia javanice* are fungitoxic to *Rhizoctonia solani* (Rao and Rao, 1986). Grape proanthocyanidins have also been shown to inhibit the macerating enzymes of *Botrytis cinerea* (Pezet et al., 2003). Proanthocyanidin oligomers specifically and sensitively inhibit protein kinase and stilbene oxidase, with IC50s in the micromolar range (Perret et al., 2003; Polya and Foo, 1994). Galloylated flavonoids, such as epigallocatechin-gallate, also specifically inhibit fatty acid synthase and lipoxygenase (Skrzypczak-Jankun et al., 2003; Wang et al., 2003).

The present study was initiated in order to investigate the role, if any, of flavan-3-ols (catechins) and methylxanthines, on the resistance of tea cultivars to blister blight disease. In addition, a study was undertaken to isolate and characterize proanthocyanidins in healthy and *E. vexans* -infected tea leaves.

MATERIALS AND METHODS

PLANT MATERIAL

Tea plants used in this study were grown in experimental plots at the Tea Research Institute of Sri Lanka, Talawakelle. The plants were raised by vegetative propagation using standard procedures (Kathiravetpillai and Kulasegaram, 1986). Flush (two leaves and a bud) from each of the following tea cultivars, belonging to *E. vexans* -resistant and -susceptible groups, were used for the comparison of catechin and caffeine content.

Resistant cultivars: DT 1, TRI 777, TRI 2043, N 2, TRI 4067, TRI 4052, NAY 3, TRI 3073.
Susceptible cultivars: TRI 2025, TRI 2024, TRI 2023, TRI 62/5, TRI 3015, TRI 3014, TRI 62/1.

Plants selected for the study on infection were those in experimental plots which were naturally infected with *E. vexans*, during the rainy season. Leaves were harvested, brought immediately to the laboratory and sorted into those which were healthy, and those in the three stages of infection: the translucent spot stage, the mature blister stage 1 (convex lesions which are green in colour) and the mature blister stage 2 (convex lesions which are white in colour owing to sporulation). Leaf discs were cut from each stage, transferred to glass tubes and stored at –20° C until use.

EXTRACTION AND HPLC ANALYSIS OF CATECHIN AND METHYLXANTHINES

Tea flush (10 g), or discs from tea leaf (1 g), was plunged into boiling 70% aqueous methanol and boiled for 10 minutes. The extract was cooled and homogenized for three minutes using a top-drive macerator (Ultra-Turrax, USA). The homogenate was centrifuged (4000 rpm x 15 minutes) and the supernatant was decanted into a volumetric flask (100 ml). The residue was re-extracted with the solvent (40 ml), centrifuged, and the supernatant was transferred to a volumetric flask. The volume of the pooled extract was made up to 100 ml with 70% aqueous methanol. After suitable dilution, the sample was filtered through a 0.45 μm filter, and 10 μl of this was injected into the HPLC system (Waters Alliance 2690XE separation module, coupled to a Waters 996 photodiode array detector (PDA) and Waters Millennium 32 data system). All samples were replicated eight times.

Standards of caffeine, theobromine, (+)-catechin, (-)-epicatechin, (-)-epigallocatechin, (-)-epigallocatechin gallate and (-)-epicatechin gallate (Sigma, St Louis, USA) were prepared. A phenomenex-phenyl hexyl column (4.6 x 250 mm), and a linear gradient of mobile phase A (9% acetonitrile containing 2% acetic acid), and B (80% acetonitrile), was used for the separation.

HISTOCHEMICAL STAINING OF INFECTED LEAF TISSUES

Tea leaves infected with *E. vexans* were rinsed with distilled water and soaked in ethanol:glacial acetic acid (3:1 v/v) for 30 minutes. The decolorized leaves were stained with vanillin (5% vanillin in ethanol/ 4 N HCl; Broadhurst and Jones, 1978) and 4-dimethylaminocinnamaldehyde (0.3% DMACA in methanol/

6 N HCL; Li et al., 1996) for 20 min at 25°. Excess stains were washed away with distilled water, and the leaves were observed for colour changes.

DETERMINATION OF PROANTHOCYANIDINS IN INFECTED AND HEALTHY LEAF MATERIAL

Acid hydrolyses were carried out, as described by Porter et al. (1986), using material from healthy tea leaf tissues, and from tea leaf tissues infected with the three stages of blister blight. The leaf tissues (1 g) were homogenized with 70% acetone (containing 0.1% ascorbic acid). The extract was centrifuged, and the volume of the supernatant was made up to 10 ml with the extracting solvent. To an aliquot of the above extract (1 ml), BuOH:conc. HCl 95:5 v/v (5 ml) and iron reagent (2% solution of $NH_4Fe(SO_4)_2.H_2O$ in 2 M HCl) (0.2 ml) were added. The resultant solution was placed in a water bath and heated at 95 °C for 40 min, cooled, and decanted into a 10 ml volumetric flask, and the volume made up with BuOH:HCl 95:5 v/v. A small aliquot was filtered through a 0.45 µm filter (Millipore, USA), and 10 µl was injected into the HPLC system. Calibration curves were constructed using standards of cyanidin and delphinidin (Carl Roth Gmbh, Germany).

DETERMINATION OF MOISTURE CONTENT IN TEA LEAVES

Moisture content of all leaf samples were determined by drying at 103 °C for 6 hours (ISO 1573, 1980).

IDENTIFICATION OF ANTHOCYANIDINS IN THE TEA CULTIVAR, TRI 2043

Flush from the cultivar, TRI 2043, (50 g) was homogenized with methanol containing 0.01% HCl (100 ml). The extract was centrifuged (4000 rpm, 10 min), and the volume of the supernatant made up to 100 ml with the extracting solvent. To an aliquot (5 ml) of the above homogenate, 2 N HCl (5 ml) was added, and the mixture heated on a water bath at 95 °C for two hours. The acid hydrolysate was chromatographed on cellulose TLC plates (20 cm x 20 cm, E. Merck, Germany) and on Whatmann No. 3 paper (Whatmann Inc, USA) and developed in the Forestal (acetic acid:water:HCl, 30:10:3) solvent system (Harborne, 1967). The chromatographic bands were separately removed, dissolved in methanol (0.01% HCl), and spectroscopically analyzed (Cintra-5-UV-Visible Spectrophotometer, GBC, Australia).

HPLC OF ANTHOCYANIDINS

The acid hydrolysate of TRI 2043 flush was filtered through a 0.45 µm filter (Millipore, USA), and injected into the HPLC system. The anthocyanidins, cyanidin and delphinidin were detected at 520 nm.

Purification of proanthocyanidin

Proanthocyanidins were extracted from 20 gm of freeze-dried *C. sinensis* leaf disks from either healthy, or *E. vexans*-infected, leaves. The proanthocyanidins were extracted in 70 % (v/v) acetone, and purified by solvent partition and chromatography on Sephadex LH 20 as described by Tanner et al. (1994). Reference proanthocyanidins were also similarly isolated and purified from *Hordeum vulgare* (cv Himalaya), *Onobrychis viciifolia* (cv Othello) or *Medicago sativa* (cv Aquarius) seeds.

Purified *C. sinensis* proanthocyanidins were dissolved in methanol, separated by thin-layer chromatography (TLC) on cellulose-HPTLC plates (Merck) in water-saturated s-BuOH, and visualised by spraying with a 20-fold dilution in acetone of 2% (w/v) DMACA, dissolved in 6M HCl in ethanol (Li et al., 1996).

Hydrolysis of proanthocyanidins

Purified *C. sinensis* proanthocyanidins were subjected to acid hydrolysis in the presence of phloroglucinol (Abrahams et al., 2003). Flavan-3-ols were identified by monitoring the effluent at A280, and quantified by comparison with authentic standards (Sigma). Phloroglucinol adducts were identified by comparison with retention times of known hydrolysis products, as described online. The average Dp of proanthocyanidins was calculated as the ratio of the sum of total extension units divided by the sum of total extension and initiating units.

MASS SPECTROSCOPY OF PROANTHOCYANIDINS

Purified proanthocyanidins were dissolved in MeOH and mixed with 3ß-indoleacrylic acid matrix solution, as described by (Hedqvist et al., 2000). Positive-ion MALDI-TOF mass spectra were collected in reflectron mode, averaging about 250 scans on a Voyager Elite mass spectrometer (Perseptive Biosystems) with delayed extraction and an accelerating voltage of 20,000 V. Masses in the range 800-3,000 Da were examined with external calibration against peptides of mass 927.4940 and 2045.0285, from a trypsin digest of bovine serum albumin (Campbell et al., 2001).

RESULTS AND DISCUSSION

A study of the flavan-3-ol and caffeine content of resistant and susceptible tea cultivars showed that significantly higher levels of (-)-epicatechin (22.4 mg g^{-1}) were present in cultivars of tea resistant to blister blight, compared with that in susceptible cultivars (11.3 mg g^{-1}) (Tables1 and 2). A significantly higher level of (-)-epigallocatechin gallate was present in susceptible cultivars compared with resistant cultivars. No significant differences were seen between cultivars in the content of (+)-catechin, (-)-epigallocatechin, (-)-epicatechin gallate and caffeine.

Higher levels of epicatechin had been positively correlated to apple cultivars resistant to *Venturia inaequalis* (Treutter and Feucht, 1990). Epicatechin has also been shown to be a modulator of the antifungal diene, 1-acetoxy-2-hydroxy-4-oxoheneicosa-12-15-diene, in anthracnose (*Colletotrichum gloeosporiodes*) infection in avocado (via inhibition of lipoxygenase, which is responsible for the inactivation of the antifungal diene) (Prusky et al., 1996). Epicatechin has also been found to inhibit the macerating enzymes, polygalacturonase and pectate lyase, and the resistance of unripe avocado to *C. gloeosporiodes* has been attributed to this activity (Prusky, 1996). Epicatechin may therefore be directly or indirectly involved in the resistance mechanism of tea against blister blight.

Resistant cultivars with higher levels of epicatechin have lower levels of epigallocatechin gallate, suggesting that there is a decrease in the activity of enzymes catalyzing the formation of derivatives of epicatechin in these cultivars.

Analysis of leaf material for flavonols and methylxanthines showed that significant changes occurred in flavan-3-ol and methylxanthine content during infection. The methylxanthines, caffeine and theobromine were found to increase significantly in the translucent stage of the disease (Fig. 1). The

Table 1. EC and EGCG contents (on dry weight basis) in *E.vexans* resistant and susceptible tea cultivars

CLONE	R/S	EC (mg/g)	EGCG (mg/g)
DT1	R	20.15	98.05
TRI777	R	26.64	107.15
TRI2043	R	21.17	68.87
N2	R	19.08	113.82
TRI4067	R	20.98	81.27
TRI4052	R	21.37	93.65
NAY3	R	25.23	130.13
TRI3073	R	24.63	90.14
Mean		**22.41**	**97.88**
TRI2025	S	8.16	142.72
TRI2024	S	13.4	141.73
TRI2023	S	11.45	152.77
TRI62/5	S	13.3	132.06
TRI3015	S	13.92	133.68
TRI3014	S	9.23	138.8
TRI62/1	S	12.43	113.95
Mean		**11.70**	**136.53**
Prob>1T1 (P=0.05)		0.0001	0.0005

R = Resistant; S = Susceptible; EC = (-)-epicatechin;
EGCG = (-)- epigallocatechin gallate

Table 2. Means of catechins and caffeine contents (on dry weight basis) of *E.vexans* resistant and susceptible tea cultivars.

	C (mg/g)	EGC (mg/g)	EC (mg/g)	EGCG (mg/g)	ECG (mg/g)	CAFFEINE (mg/g)
Mean (Resistant)	5.48	47.96	22.41	97.89	39.49	37.02
Mean (Susceptible)	7.19	38.87	11.70	136.53	39.89	38.51
Prob> I T I (P = 0.05)	0.1264	0.1825	0.0001	0.0005	0.9390	0.3811

C = (+)-catechin; EGC = (-)-epigallocatechin; ECG = (-)-epigallocatechin gallate

increase in methylxanthine content could be the initial defence response of the plant to fungal attack, as reported to occur in infestation of tea by the shot-hole borer beetle, *Xyleborus fornicatus* (Kumar et al., 1995), and in fungal attack on cocoa leaves (Aneja and Gianfagna, 2001).

The content of epicatechin and epigallocatechin significantly decreased upon infection (Fig. 2). Epicatechin levels significantly decreased in the translucent stage when compared with healthy tissues.

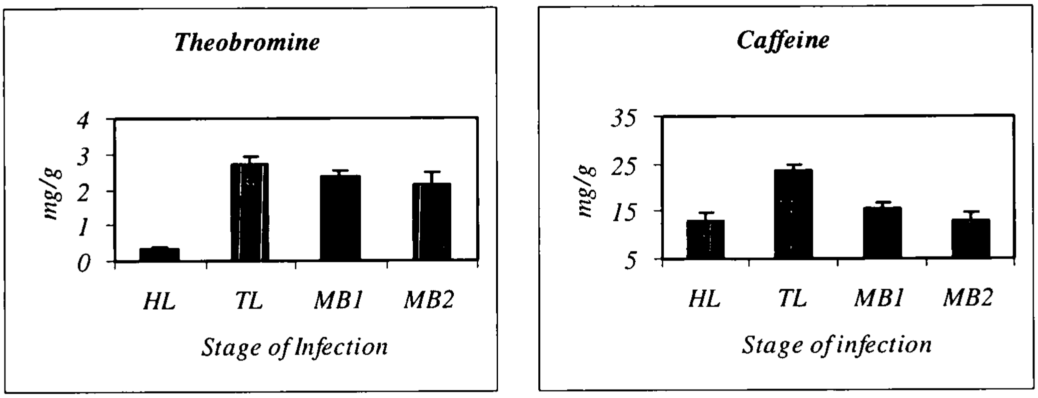


Fig. 1.Changes of theobromine and caffeine content (on dry weight basis) following *E.vexans* infection. HL- Healthy, TL- Translucent stage, MB1- Mature blister 1, MB2-Mature blister 2

A two-fold reduction of epigallocatechin levels (from 42 mg g^{-1} to 21 mg g^{-1}) was observed in the translucent stage of the infection. However, the observed decrease in epicatechin and epigallocatechin content from the translucent stage to the mature blister stage was found not to be significant. The content of epicatechin gallate and epigallocatechin gallate increased in the translucent stage of infection, but the increase was significant only for the former. The content of the gallate esters however decreased significantly during the mature blister stage (Fig. 3).

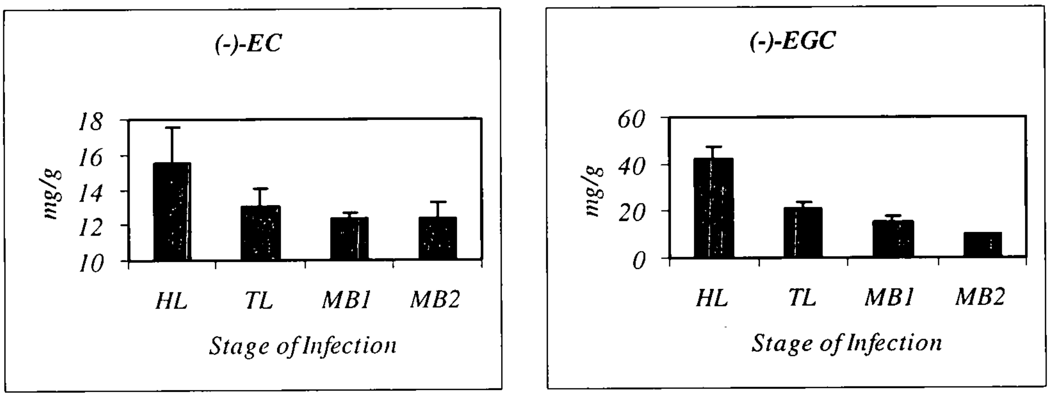


Fig. 2.Changes of catechins (on dry weight basis) following *E.vexans* infection

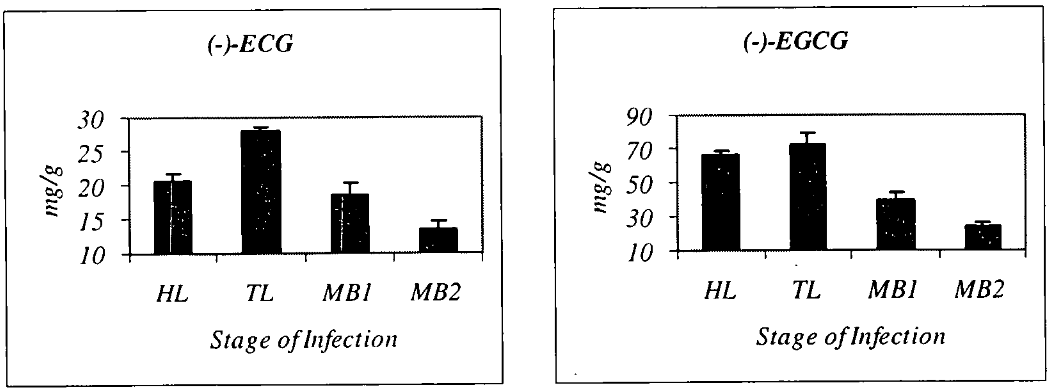


Fig.3.Changes of catechins (on dry weight basis) following *E.vexans* infection

It has been reported that when plants are under stress conditions, catechins could be converted to fungitoxic proanthocyanidins by condensation with flavan-3,4-diols in the flavonoid pathway (Rao and Rao, 1986; Winkel-Shirley, 2002).

Histochemical staining of tea leaves with vanillin reagent (Broadhurst and Jones, 1978), and 4-dimethylaminocinnamaldehyde (DMACA) reagent (Li et al., 1996), confirmed that proanthocyanidins were accumulated in the infected areas of the leaf tissue. Vanillin reagent gave a deep red colour in the infected areas, suggesting the presence of flavan-3-ols or proanthocyanidins, while the blue-green colour shown by DMACA (Fig.4) indicated that proanthocyanidins were formed upon blister blight infection. DMACA has been shown to be more sensitive to soluble proanthocyanidins (Joseph et al., 1998), reacting only with the terminal units of proanthocyanidins (Rohr, 1999).

Conversion of catechins into fungitoxic proanthocyanidins may form part of the defence mechanism of the tea plant against blister blight infection. The reduction in levels of epicatechin and epigallocatechin on infection, observed in the present work, support this hypothesis. Proanthocyanidins from resistant grape cultivars have been shown to inhibit macerating enzymes of *Botrytis cinerea*, and have been suggested as playing a role in resistance to fungal disease (Pezet et al., 2003). A similar role could be played by the proanthocyanidins formed during blister blight infection in the tea leaf.

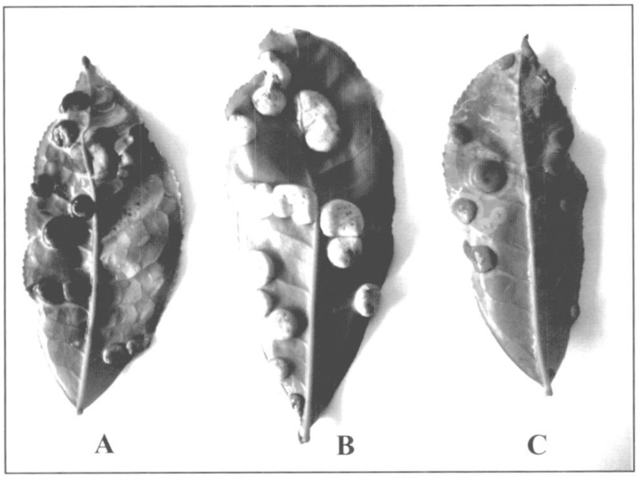


Fig. 4.Histochemical staining of tea leaves with mature *E.vexans* blisters
A – DMACA staining
B – without staining
C – Vanillin staining

The acid-catalysed oxidation of proanthocyanidins to cyanidin and delphinidin has been used to detect their levels in plants (Porter et al., 1986). The acid-catalysed oxidation of the infected leaf area with Porter's reagent gave high levels of cyanidin and delphidin compared with healthy tissue, providing further support for this hypothesis (Fig. 5).

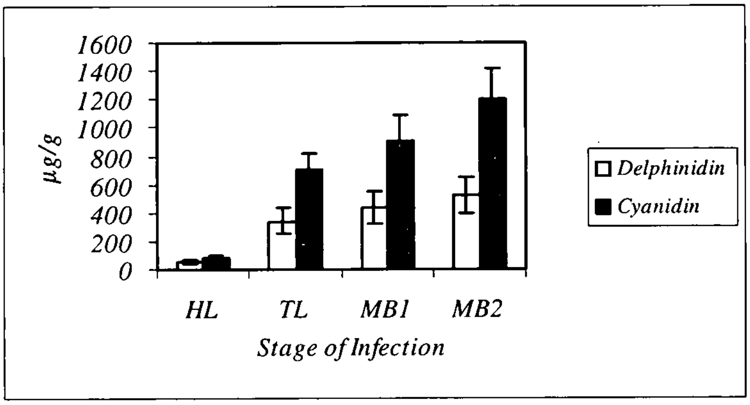


Fig. 5. Contents (on dry weight basis) of cyanidin and delphinidin liberated from proanthocyanidins following aicd catalysed oxidation of *E.vexans* infected leaf tissues

The purple-green colour of the leaf of the tea cultivar, TRI 2043, was shown to be due to the presence of high levels of anthocyanins by acid hydrolysis to the anthocyanidins, cyanidin and delphindin. Their identity was confirmed by UV-visible spectral, paper chromatographic TLC, and HPLC, studies. (Harborne, 1958, 1967).

Of the cultivars studied in the present work, TRI 2043 is known to be the cultivar most resistant to blister blight. It has been recently reported that anthocyanidins are converted to the respective catechin analogues by an anthocyanidin reductase (ANR) enzyme in *Arabidopsis thaliana* and *Medicago truncatula* (Xie et al., 2003). The presence of ANR activity in tea-leaf enzyme preparations has been shown by the conversion of cyanidin into epicatechin by these preparations (Punyasiri et al., 2004). The anthocyanins, present at high levels in the cultivar TRI 2043, suggest that its higher tolerance is due to the elevated levels of the proanthocyanidin precursors (Tanner et al., 2003) formed by this cultivar (Fig. 6).

The significant increase of epicatechin gallate at the translucent stage could be due to the conversion of epicatechin into its gallic acid ester on infestation, since the translucent stage is accompanied by a significant decrease in epicatechin content. Similar observations were made with regard to epigallocatechin gallate and epigallocatechin content, although the increase in the former at the translucent stage was not significant (Fig. 3). The decrease in catechin content, observed in the mature stage, may be ascribed to the utilization of catechins for the formation of proanthocyanidins as part of the defence mechanism.

Acid hydrolysis, in the presence of phloroglucinol, was used to determine the nature of the initiating and extension units of the proanthocyanidin polymer, from both infected and healthy leaves.

Phloroglucinol hydrolysis of proanthocyanidin, isolated from infected *C. sinensis* leaves, yielded three dominant HPLC peaks (Fig. 7A), which were absent from chromatograms of unhydrolysed controls. The major peak represents the extension units, and co-chromatographed with epicatechin-(4ß-2)-phloroglucinol, produced by hydrolysis of procyanidin B2 and *Medicago sativa* (alfalfa)

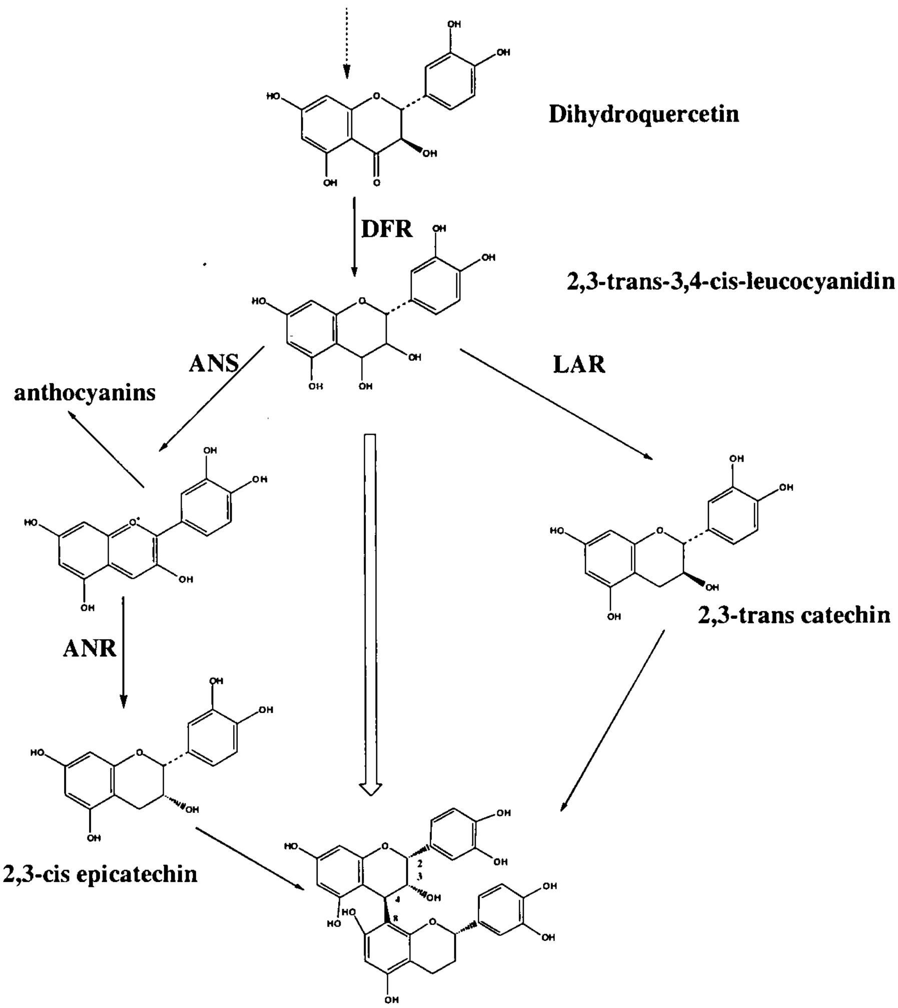


Fig 6. Late stages of flavonoid biosynthesis leading to the formation of proanthocyanidins (adapted from Tanner *et al.*, 2003).

proanthocyanidin. This peak was resolved but not completely separated from a minor peak, which co-chromatographed with catechin-(4a-2)-phloroglucinol, produced by hydrolysis of procyanidins B3 and C2. The other major peak co-chromatographed with authentic epigallocatechin-gallate, and represents the units which initiate proanthocyanidin polymerisation. A smaller peak corresponded to gallocatechin-(4a-2)-phloroglucinol, produced by the hydrolysis of proanthocyanidins from *H. vulgare* and *Onobrychis viciifolia* (sainfoin), and represents gallocatechin extension units. There were smaller peaks corresponding to gallocatechin, and epicatechin (Fig. 7A), representing flavan-3-ol initiating units. The initial peaks corresponded to ascorbate and phloroglucinol, and the last peak contained unhydrolysed proanthocyanidin.

The same compounds were present in chromatograms of hydrolysed proanthocyanidin from healthy *C. sinensis* leaves (Fig. 7B). Unhydrolysed control chromatograms of proanthocyanidin, from healthy leaves, contained approximately 60% of the epigallocatechin-gallate in the hydrolysed chromatograms, and this was subtracted from the amount produced by hydrolysis. Quantitatively, the composition of the two proanthocyanidins differed, most notably in the relative increase of epicatechin-(4ß-2)-phloroglucinol and epigallocatechin-gallate and the decreased levels of catechin-(4a-2)-phloroglucinol in proanthocyanidin isolated from infected leaves (Table 3).

The hydroxylation state of the B-ring, in flavonoids of proanthocyanidin extension units, may also be estimated by summing the total di- and tri-hydroxylated compounds derived from extension units (Table 3). This confirms that on a molar basis the proanthocyanidins contained mainly di-hydroxylated B-rings (61.3% and 63.3% di-hydroxylated B-ring in healthy and infected leaves, respectively), and compares well with the estimates produced by the acid hydrolysis above.

The majority of the peak area in phloroglucinol hydrolysates was assigned to known flavonoids. In hydrolysates of proanthocyanidin from both infected and healthy *C. sinensis* leaves, the areas assigned to known standards accounted for over 70 % of the total peak area, excluding ascorbate, phloroglucinol and unhydrolysed proanthocyanidin. No suitable standard was available for unequivocal identification of epicatechin-3-O-gallate-(4ß-2)-phloroglucinol, resulting from epicatechin-gallate extension units. This adduct has been reported to elute on HPLC between catechin and epicatechin (Kennedy and Jones, 2001), and no significant peak was seen in this area of our chromatograms. It is therefore likely that there were no significant amounts of this compound in the hydrolysates.

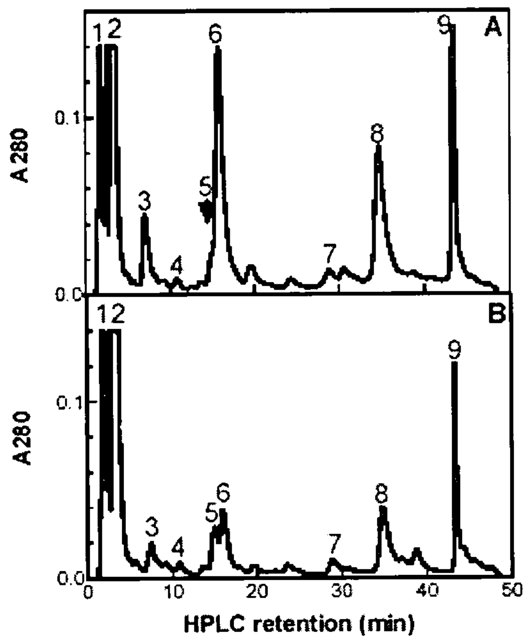


Fig. 7. HPLC of phloroglucinol hydrolysates of *C. sinensis* proanthocyanidins.

Fifty micrograms of proanthocyanidin purified from *C. sinensis* leaves either (A) infected with *E. vexans* or uninfected (B), was hydrolysed in the presence of excess ascorbate and phloroglucinol and the products resolved by HPLC. Peaks produced by thiolysis were identified by comparison with authentic commercial standards or hydrolysis products of known proanthocyanidins; ascorbate (1), phloroglucinol (2), gallocatechin-(4á-2)-phloroglucinol (3), gallocatechin (4), catechin-(4á-2)-phloroglucinol (5), epicatechin-(4â-2)-phloroglucinol (6), epicatechin (7), gallocatechin gallate (8), and unhydrolysed proanthocyanidin (9).

For purified proanthocyanidins, an estimate of the degree of hydrolysis is obtained by comparing the amount of unhydrolysed proanthocyanidins in hydrolysed extracts with that in unhydrolysed controls. The estimate suggests that there was 46.2 ± 4.8 % and 38.9 ± 8.4 % (mean of three hydrolyses ± S.E.) hydrolysis of proanthocyanidins from infected and healthy leaves, respectively. These values are typical of the hydrolysis yields observed with complex proanthocyanidins. It is therefore likely that the products of hydrolysis are representative of the overall composition of the proanthocyanidins.

Table 3. Composition of *C. sinensis* proanthocyanidins.

Compound	Uninfected nmol/ 50 ìg proanthocyanidin (% of total recovered)	Infected nmol/ 50 ìg proanthocyanidin (% of total recovered)
Initiating Units		
gallocatechin	11.5 ± 3.8 (44.5%)	5.2 ± 1.1 (21.8%)
epigallocatechin-gallate	5.8 ± 1.6 (22.6%)	12.6 ± 1.0 (52.6%)
epicatechin	5.8 ± 1.0 (22.6%)	5.1 ± 0.8 (21.3%)
catechin	1.6 ± 0.3 (6.3%)	1.0 ± 0.5 (4.3%)
Extension Units		
gallocatechin-(4á-6)-phloroglucinol	21.1 ± 4.3 (38.8%)	31.3 ± 2.7 (36.7%)
epicatechin-(4â-6)-phloroglucinol	21.1 ± 4.1 (38.9%)	51.4 ± 3.0 (60.2%)
catechin-(4á-6)-phloroglucinol	12.2 ± 2.5 (22.4%)	2.6 ± 0.3 (3.1%)

The mass spectra of proanthocyanidins, from both infected leaves and healthy leaves, were compared with the spectra of proanthocyanidins isolated from mature *H. vulgare* grains (Figs. 8A, B, C). The position of dimeric proanthocyanidins was obscured by matrix molecules, and is not shown. Only very low abundance mass peaks were seen above 2,200, and are not shown.

The *H. vulgare* testa/pericarp accumulates heteropolymers of catechin or gallocatechin units with Dp up to about six (Jende-Strid and Moller, 1981). Mass spectrometry does not distinguish between catechin and its 3-hydroxyl epimer, epicatechin. However, increasing B-ring hydroxylation of proanthocyanidin oligomers gives rise to a mass series which increase by 16, the weight of oxygen. Proanthocyanidins, extracted from infected or healthy *C. sinensis* leaves, gave similar spectra to that obtained from *H. vulgare* proanthocyanidins, with (epi)catechin heteropolymers of Dp up to seven, containing one or more trihydroxylated B-rings (Figs. 8 A, B and C). Observed masses for oligomers were within 0.5 mass units of the calculated mono-isotopic mass: for example, masses of 1177.6, 1177.3 and 1177.5 were observed for (epi)catechin homo-tetramers from proanthocyanidin, isolated from infected or healthy *C. sinensis* leaves, or *H. vulgare*, respectively. These compare well to a mass of 1177.26 calculated for the sodiated catechin homotetramer. There was a similar correspondence between calculated and observed mass for larger polymers. The higher-order oligomers were more intense in the spectra of proanthocyanidins from healthy *C. sinensis* leaves compared with the spectra from infected leaves (Fig. 8 A and B).

In addition to the series of hetero-oliogomeric proanthocyanidins seen in *H. vulgare*, another series of oligomers was observed in *C. sinensis*, formed by the addition of a single gallate ester to (epi)catechin oligomers. For example, masses corresponding to (epi)catechin trimers carrying 0, 1, 2 or 3 B-ring trihydroxyls, and a single gallate moiety, were observed in the spectra of proanthocyanidins, isolated from infected *C. sinensis* leaves at masses of 1041.5, 1057.5, 1073.5, and 1089.5 (Fig. 4 A), corresponding to the calculated masses of 1041.21, 1057.20, 1073.20 and 1089.19 for the corresponding sodiated ions. Similarly, gallate esters of tetramers, pentamers, hexamers and heptamers were also observed in the spectra of proanthocyanidins, isolated from infected *C. sinensis* leaves (Fig. 8 A). The intensity of the corresponding gallate esters was significantly less in the mass spectrum of proanthocyanidins isolated from healthy *C. sinensis* leaves, and galloylated proanthocyanidin oligomers were not detected with Dp above four, in proanthocyanidins from healthy leaves (Fig. 8 B).

In the spectra of proanthocyanidins from infected *C. sinensis* leaves, relatively small additional peaks were seen at masses of 1449.3 and 1737.4, corresponding to the loss of one oxygen molecule from an (epi)catechin homo-pentamer and hexamer, respectively. These peaks could represent a polymer with one monohydroxylated B-ring unit (pelargonidin-like), with the rest of the units consisting of dihydroxylated B-rings.

In spectra of all proanthocyanidin samples, low-intensity peaks were generally observed two mass units below the more intense polymer peaks. For example, these peaks were seen in the spectra of the proanthocyanidins purified from infected leaves at masses of 1175.65, 1191.61, and 1207.62, each two mass units below the main peaks observed for tetramers with 0, 1, or 2 additional tri-hydroxylated B-rings, respectively. These might correspond to the loss of two hydrogens from the adjacent proanthocyanidin in the spectrum, or two hydrogens and an oxygen (a dehydration) from the next molecule in the hydroxylation series. Such products have not previously been reported, and it is not clear if this represents an artifact of preparation, or an unreported native proanthocyanidin structure.

MS revealed masses corresponding to heteropolymers of (epi)catechin and (epi)gallocatechin, and the galate esters of these. In addition, MS detected relatively small mass peaks corresponding to oligomers containing units with one mono-hydroxylated B-ring (that is propelargonidins). This is not unexpected, as mono-hydroxylated intermediates have been isolated from *C. sinensis* (Myres et al., 1958). However, they usually only accumulate in plants when the activity of the flavonoid-3'-hydroxylase enzyme is blocked by mutation (for example, in *Arabidopsis*; Abrahams et al., 2002).

Infection of *C. sinensis* leaves by *E. vexans* resulted in a shift of the proanthocyanidin stereochemistry away from a 2,3-*trans* stereochemistry (for example, catechin and gallocatechin) and towards 2,3-*cis* stereochemistry (for example, epicatechin and epigallocatechin). In addition, infection also resulted in increased gallic acid esterification of the initiating subunits of proanthocyanidins. These changes were inferred by changes observed in the relative composition of mass spectra of whole proanthocyanidins, and changed subunit composition, following hydrolysis in the presence of phloroglucinol.

Phloroglucinol hydrolysis of *C. sinensis* proanthocyanidins indicated that the dominant terminal unit was gallocatechin in uninfected tissue, and epigallocatechin-gallate in infected tissue. This is consistent with the identification of relatively more intense peaks, in mass spectra of proanthocyanidins, from infected tissue containing gallate esters. Care must be exercised only to compare intensity of similar polymers when interpreting mass spectrograms, since the relative intensity of mass peaks does not necessarily reflect quantitative differences in the content of different polymers as different polymers may ionize to a different extent during MS.

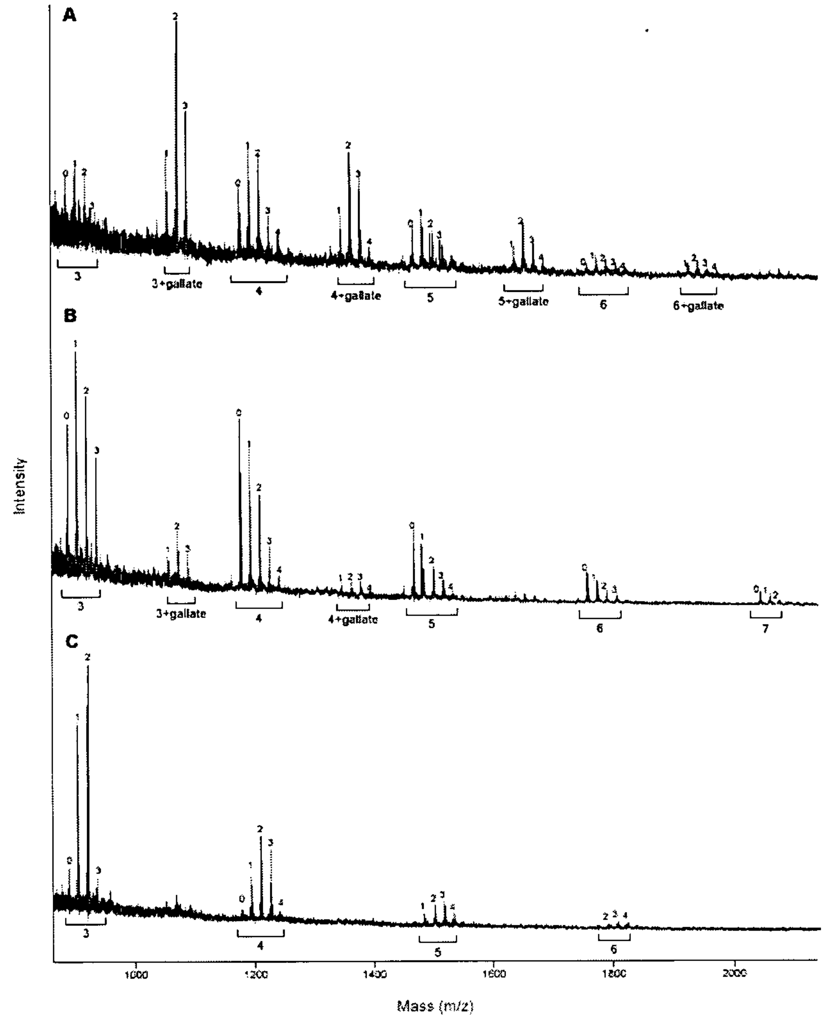


Fig. 8. Mass spectroscopy of *C. sinensis* proanthocyanidins.

Proanthocyanidins were purified from *C. sinensis* leaves either infected with *E. vexans* (A) or uninfected (B) and examined by mass spectroscopy as described. Control proanthocyanidins were also isolated from *H. vulgare* (C). The degree of polymerisation is indicated below each group of peaks while the number of additional B-ring hydroxyls is indicated above each peak. See also online supporting tables of predicted and observed masses. Some very small peaks can be observed above the noise and are noted in the tables but not indicated here.

The shift in proanthocyanidin stereochemistry was also reflected in changes in the relative composition of proanthocyanidin initiating and extension units, determined by phloroglucinol hydrolysis (Table 3). In uninfected tissue, these subunits had a predominantly 2,3-*trans* stereochemistry which accounted for 51% and 61% of the total initiating and extension units, respectively (Table 3). Conversely, in infected tissue the situation was reversed, and subunits with a 2,3-*trans* stereochemistry accounted for 27% and 40% of the total initiating and extension units, respectively (Table 4).

Table 4. Stereochemistry of *C. sinensis* proanthocyanidins

Compound	Uninfected (% of total recovered)	Infected (% of total recovered)
Initiating Units		
2,3-*trans*	51.2 ± 5.6	26.6 ± 4.3
2,3-*cis*	48.8 ± 5.6	73.4 ± 4.3
Extension Units		
2,3-*trans*	61.0 ± 0.5	39.7 ± 0.9
2,3-*cis*	39.0 ± 0.5	60.3 ± 0.9

The shift in proanthocyanidin stereochemistry, away from 2,3-*trans* and towards 2,3-*cis* compounds, may reflect relative changes in metabolic flux through the respective biosynthetic pathways. This may involve a decreased flux through leucoanthocyanidin reductase (Tanner et al., 2003), and/or an increased flux through anthocyanidin reductase (Xie et al., 2003).

The change in stereochemistry could alter the biological properties of the proanthocyanidins, which may have profound effects on invading fungi. The biological properties of flavonoids are sensitive to stereochemical changes. The 2,3-*cis* isomer, epicatechin, reduced membrane fluidity more than the 2,3-*trans* isomer, catechin (Tsuchiya, 2001). Different isomers of catechin have vastly different phytotoxicity, with (-) catechin being phytotoxic at micromolar levels, whilst (+)catechin is not (Bais et al., 2002; Bais et al., 2003). Gallic esters of catechins show higher antibacterial, antiviral and antioxidant activity than catechins without the galloyl ester (Kajiya et al., 2001, 2002). It is possible that the increased resistance of some *C. sinensis* cultivars to *E. vexans* is a result of higher levels of epicatechin, or a changed proanthocyanidin composition (Punyasiri et al., 2001, pers. comm.)

CONCLUSIONS

Epicatechin plays an important role in the resistance mechanism of tea against blister blight disease. Methylxanthines appear to act as antifungal agents in the translucent stage during the initial attack by the fungus, *E. vexans*. Catechins are converted into fungitoxic proanthocyanidins, as part of the defence mechanism of the plant against blister blight infection. The very high resistance of the cultivar, TRI 2043, is attributed to the high level of anthocyanins present, and their ready conversion into proanthocyanidins via catechins. A change in the stereochemistry of proanthocyanidins in infected leaves may represent a coordinated defense response of the infected leaves.

REFERENCES

Abrahams S, Lee E, Walker A R, Tanner G J, Larkin P J, Ashton A R, 2003. The Arabidopsis *TDS4* gene encodes leucoanthocyanidin dioxygenase (LDOX) and is essential for proanthocyanidin synthesis and vacuole development. Plant Cell 35, 624-636.

Abrahams S, Tanner G J, Larkin P J and Ashton A R, 2002. Identification and biochemical characterization of mutants in the proanthocyanidin pathway in *Arabidopsis*. Plant Physiol. 130, 561-576.

Agnihothrudu V and Moulli B C, 1991. Blister blight of tea, its control and future lines of research. In: *Proceedings of International Symposium on Tea Science* , p. 655-659. Shizuoka, Japan.

Aneja M and Gianfagna T, 2001. Induction and accumulation of caffeine in young, actively growing leaves of coca (*Theobroma cacao* L.) by wounding or infection with *Crinipellis perniciosa*. Physiol. Mol. Plant. Pathol. 59, 13-16.

Arulpragasam P V 1986. Common diseases of tea. In: *Handbook on Tea* (eds. P Sivapalan, S Kulasegaram, A Kathirvetpillai), p. 123-142. Tea Research Institute of Sri Lanka, Talawakelle, Sri Lanka.

Arulpragasam P V 1992. Disease control in Asia. In: *Tea Cultivation to Consumption* (eds. K C Wilson, M N Clifford), p. 353-374. Chapman and Hall, London.

Bais H P, Walker T S, Kennan A J, Stermitz F R and Vivanco J M, 2003. Structure-dependent phytotoxicity of catechins and other flavonoids: flavonoid conversions by cell-free protein extracts of *Centaurea maculosa* (spotted knapweed) roots. J Agric Food Chem. 51, 897-901.

Bais H P, Walker T S, Stermitz F R, Hufbauer R H and Vivanco, J M, 2002. Enantiomeric-dependent phytotoxic and antimicrobial activity of (±)-catechin. A rhizosecreted racemic mixture from spotted knapweed. Plant Physiol. 128, 1173-1179.

Balasooriya A, Pallemulla D and Ratnayake A, 1996. Report of the Plant Physiology Division. Annual Report of the Tea Research Institute of Sri Lanka, p. 80-81.

Broadhurst R B and Jones W T, 1978. Analysis of condensed tannins using acidified vanillin. J. Sci. Food Agric. 29, 788-794.

Campbell P M, Harcourt H L, Crone E J, Claudianos C, Hammock B D, Russell R J and Oakeshott J G, 2001. Identification of a juvenile hormone esterase gene by matching its peptide mass fingerprint with a sequence from the *Drosophila* genome project. Insect Biochemistry and Molecular Biology 31,513–520.

Gadd C H and Loos C A, 1948. The basidiopores of *Exobasidium vexans*. Trans. British. Mycol. Soc. 33, 229-233.

Gulati A, Gulati A, Ravindranath, S D and Gupta A K, 1999. Variation in chemical composition and quality of tea (*Camellia sinensis*) with increasing blister blight (*Exobasidium vexans*) severity. Mycological Research 103, 1380-1384.

Harborne J B, 1958. Spectral methods in characterizing anthocyanins. Biochem. J. 70, 22-28.

Harborne J B, 1967. Anthocyanins. In *Comparative Biochemistry of Flavonoids,* p. 1-30. Academic Press, London.

Hedqvist H, Mueller-Harvey I, Reed J D, Krueger C G and Murphy M, 2000. Characterisation of tannins and in vitro protein digestibility of several *Lotus corniculatus* varieties. Animal Feed Science and Technology 8, 41-56

ISO, 1980. ISO 1573. Tea - determination of loss in mass at 103°C. ISO Central Secretariat, International Organization for Standardization, Geneva, Switzerland, p. 1-4.

Jende-Strid B and Moller B L, 1981. Analysis of proanthocyanidins in wild-type and mutant barley (*Hordeum vulgare* L.). Carlsberg. Res. Commun. 46, 53-64.

Joseph R, Tanner G and Larkin P, 1998. Proanthocyanidin Synthesis in the forage legume, *Onobrychis vicifolia.* A study of chalcone synthase, dihydroflavonol-4-reductase and leucoanthocyanidin-4-reductase in developing leaves. Aust. J. Plant. Physiol. 25, 271-278.

Kajiya K, Kumazawa S and Nakayama T, 2001. Steric effects of interaction of tea catechins with lipid bilayers. Biosci. Biotechnol. Biochem. 65, 2638-2643.

Kajiya K, Kumazawa S and Nakayama T, 2002. Effects of external factors on the interaction of tea catechins with lipid bilayers. Biosci. Biotechnol. Biochem. 66, 2330-2335.

Kathiravetpillai A and Kulasegaram S, 1986. Nursery and nursery practices. In: *Handbook on Tea* (eds. P Sivapalan, S Kulasegaram, A Kathirvetpillai), p. 20-35. Tea Research Institute of Sri Lanka, Talawakelle, Sri Lanka.

Kennedy J A and Jones G P, 2001. Analysis of proanthocyanidin cleavage products following acid-catalysis in the presence of excess phloroglucinol. J Agric Food Chem. 49, 1740-1746.

Kiehne A, Lakenbrink C and Engelhardt U H, 1997. Analysis of proanthocyanidins, in tea samples. Z. Lebensm Unters Forsch. 205,153-157.

Kumar N S, Hewavitharanage P and Adikaram N K B, 1995. Attack on tea by *Xyleborus fornicatus*: Inhibition of the symbiote, *Monacrosporium ambrosium*, by caffeine. Phytochemistry 40, 1113-1116.

Lakenbrink C, Engelhardt U H and Wray V, 1999. Identification of two novel proanthocyanidins in green tea. J Agric Food Chem. 47, 4621-4624.

Li Y G, Tanner G and Larkin P, 1996. The DMACA-HCl protocol and threshold proanthocyanidin content for bloat-safety in forage legumes. J.Sci. Food Agric. 70, 89-91.

Martosupono M, 1991. Some factors influenced in the tea resistance to blister blight. In: *Proceedings of International Symposium on Tea Science*, p. 651-654. Shizuoka, Japan.

Myres M, Roberts E A H and Rustidge D W, 1958. Some trace constituents of black tea. Chemistry and Industry 3, 950-951.

Nagahaulla K S M, Herath N and Punyasiri N, 1996. A preliminary study of the phytoalexins produced in the tea leaf in relation to the blister blight leaf disease caused by *Exobasidium vexans* Massee of tea. Sri Lanka Journal of Tea Science. 64, 5-11.

Nicholson R L and Hammerschmidt R, 1992. Phenolic compounds and their role in disease resistance. Annu. Rev. Phytopathol. 30, 369-389.

Perret C, Pezet R and Tabacchi R, 2003. Qualitative analysis of grapevine tannins by mass spectrometry and their inhibitory effect on stilbene oxidase of *Botrytis cinerea*. Chimia 57, 607-610.

Pezet R, Viret O, Perret C and Tabacchi R, 2003. Latency of *Botrytis cinerea* Pers.: Fr and biochemical studies during growth and ripening of two grape berry cultivars, respectively susceptible and resistant to grey mould. Journal of Phytopathology 151, 208-214

Pius P K, Krishnamurthy K V and Nelson R, 1998. Changes in saccharide metabolism induced by infection of *Camellia sinensis* by *Exobasidium vexans*. Biol.Plantarum. 41, 127-132.

Polya G M and Foo L Y, 1994. Inhibition of eukaryote signal-regulated protein kinases by plant-derived catechin-related compounds. Phytochemistry 35,1399-1405.

Porter L J, Hrstich L N and Chan B G, 1986. The conversion of procyanidins and prodelphinidins to cyanidin and delphinidin. Phytochemistry 25, 223-230.

Prusky D, Hamadan H, Ardi R and Keen N T, 1996. Induction of biosynthesis of epicatechin in avocado suspension cells treated with an enriched CO_2 atmosphere. Physiol.Mol.Plant.Pathol. 48, 171-178.

Prusky D, 1996. Pathogen quiescence in postharvest diseases. Annu. Rev.Phytopathol. 34, 413-434.

Punyasiri N, Abeysinghe I S B and Kumar V, 2001. Chemical and biochemical basis of the resistance and susceptibility of Sri Lankan tea cultivars to blister blight leaf disease (*Exobasidium vexans*). In: *Proceedings of International Symposium on Tea Culture*, p. 94-97. Shizuoka, Japan.

Punyasiri N, Abeysinghe I S B, Kumar V, Treutter D, Duy D, Gosch C, Maretens S, Forkmann G and Fischer T C, 2004. Flavonoid Biosynthesis of the tea leaf (*Camellia sinensis*): Properties of enzymes of the prominent epicatechin and catechin pathways (Submitted to Archives of Biochemistry and Biophysics).

Rajalakshmi N and Ramarethinam S, 2000. The Role of *Exobasidium vexans* in flavonoid synthesis *Camellia assamica*. Journal of Plantation Crops 28, 19-29.

Rao S S R and Rao K V N, 1986. Fugitoxicity of proanthocyanidins. Indian. J. Plant Physiol. 29, 278-280.

Rohr G E, 1999. Analytical investigation on and isolation of procyanidin from *Crataegus* leaves and flowers. Ph D Thesis, ETH, Zurich, p. 42-43.

Scalbert A, 1991. Antimicrobial properties of tannins. Phytochemistry 30, 3875-3883.

Skrzypczak-Jankun E, Zhou K J and Jankun J, 2003. Inhibition of lipoxygenase by (-)-epigallocatechin gallate: X-ray analysis at 2.1 angstrom reveals degradation of EGCG and shows soybean LOX-3 complex with EGC instead. International J of Mol Med. 12, 415-422.

Tanner G J, Francki K T, Abrahams S, Watson J M, Larkin P J and Astion A R, 2003. Proanthocyanidins Biosynthesis in Plants. J. Biol. Chem. 278, 31647-31656.

Tanner G J, Moore A E and Larkin P J, 1994. Proanthocyanidins inhibit hydrolysis of leaf proteins by rumen microflora *in vitro*. British J of Nutrition 71, 947-958.

Treutter D and Feucht W, 1990. The pattern of flavan-3-ols in relation to scab resistance of apple cultivars. Journal of Horticultural Science 65, 511-517.

Treutter D and Feucht W, 1999. The Role of flavan-3-ols and proanthocyanidin in plant defense. In: *Principles and Practices of Plant Ecology*. (eds. K M M Dakshini, C L Foy), p. 307-338. CRC Press, Boca Raton.

Tsuchiya H, 2001. Stereospecificity in membrane effects of catechins. Chemico-Biological Interactions 134, 41–54.

Vidhyasekaran P, 1988. Phenolics and disease resistance. In: *Physiology* of *Disease Resistance in Plants*, Vol. 1, p. 49-78. CRC Press, Boca Raton, USA.

Wang X, Song K S, Guo Q X and Tian W X, 2003. The galloyl moiety of green tea catechins is the critical structural feature to inhibit fatty-acid synthase. Biochem. Pharmacol. 66, 2039-2047.

Winkel-Shirley B, 2002. Biosynthesis of flavonoids and effects of stress. Current Opinion in Plant Biology 5, 218-223.

Xie D Y, Sharma S. B, Pavia N L, Ferreira and Dixon R, 2003. Role of anthocyanidin reductase, encoded by BANYULS in plant flavonoid biosynthesis. Science 299, 396-399.

Needs of the Latex Dipping Industry
Bridging the Gap - Research Centres/ Academia and Industry

L P Nethsinghe
Group Technical Manager, Dipped Products Ltd

ABSTRACT

Although the annual production of raw natural rubber in Sri Lanka has been dwindling during the last couple of years, the consumption of rubber in dry form as well as in latex form has increased. Out of the total global annual consumption of over 7 million tonnes of NR, almost 1 million tonne of NR is in the form of latex. The challenge in the industry today is to maintain the consistency in quality of the latex products. The problem becomes more acute due to variations of the quality of raw latex. To solve the complications arising out of quality variations, the rubber technologists and the chemists should have a sound understanding of the technological behaviour of raw latex and of latex compounds. They also should have innovative ideas to develop new products and to fine tune the formulations in order to meet the customer requirements in the global competitive market.

In this context, the research and academic centres have a big role to play by better interaction with the industry. The research centers can do this by short and long term product and process development, by providing consultancy and by testing of products. The academic centers can do this by producing graduates of high calibre in order to innovate new products to meet the customer needs in the ever increasing competition in the global market.

Key Words: Natural rubber, latex products

The Sri Lanka rubber industry consists of the plantation industry and the rubber products manufacturing industry. The plantation sector grows rubber trees, harvests latex and converts it processed into raw rubbers of different types. The rubber products manufacturing industry converts raw rubber into value added rubber goods. The latter sector through its exports is a major revenue earner for the country.

Rubber was established in Sri Lanka in 1876 with the planting of rubber plants imported from Brazil. Rubber products manufacturing meaningfully began in the 1950s primarily to retread tires. The industry expanded rapidly after the introduction of free trade policies in the 1970s. Production of raw natural rubber was 86,000 metric tons in 2001, 96,000 tons in 2002 and 93,000 tons in 2003. Of this approximately 18,000 to 20,000 tonnes was utilised in the latex industry of which 80-85% is consumed by the glove industry. Other smaller scale industries of significance include latex foam products, mattresses, balloons and rubberized coir.

Almost the entire production of gloves is exported and consequently the industry contributes significantly to foreign exchange earnings.

Forty years ago Sri Lanka was only a natural rubber latex supplier. Today Sri Lanka is considered to be a global producer of high quality medical, industrial and household gloves. Infact, Sri Lanka has built a core expertise in regard of glove manufacture.

The global annual consumption of NR latex is reported to be running at just over 7 million tons. Almost 1 m tons is used in the in the latex industry which include medical gloves, household gloves, industrial gloves, thread and condoms. Gloves command 60% of the global latex goods market centre.

Natural rubber latex is obtained by tapping the trees of *Hevea brasiliensis*. The latex is extracted as a milky liquid and is called field latex. The composition of the rubber is cis –1:4- polyisoprene (with 4% trans structure in the polymer backbone). It exists as a colloidal dispersion of rubber particles in water. The aqueous portion or serum as it is commonly called, comprises of a variety of chemical species which include sugars, lipids, proteins, fatty acid soaps, amino acids and a range of organic and inorganic soluble salts of calcium, magnesium and alkali metals. On a microscopic scale, the natural latex particles are believed to be stabilised by the presence on their surfaces of adsorbed carboxylic anions from the fatty acid soaps which are present in the latex. Field latex is not utilised in its original form due to its high water content and susceptibility to bacterial proliferation. It is necessary to both preserve and concentrate it, so that it is stable and contains 60% or more of rubber. In Sri lanka, practically all the latex is preserved with ammonia in combination with tetramethyl thiauram disulphide and zinc oxide. Such latex is called LATZ latex.

Common to all the latex based industries, whatever the product manufactured, is the requirement for collection of good quality latex, conversion into a usable version usually by centrifuging, mixing into it various chemicals to enhance processability and strength, shaping it into various products from the liquid state, and then drying / vulcanising the product.

Up to a dozen chemicals may be added to the latex. They include:

1. Stabilisers such as fixed alkali, soaps, anionic and non ionic surfactants
2. Thickners e.g salts of acrylates, carboxymethyl cellulose
3. Vulcanising ingredients- e.g sulphur, zinc oxide and rubber accelerators (such as dithiocarbomates and mercaptobenzothiazoles)
4. Protective agents- antioxidants and waxes
5. Fillers e.g. calcium carbonate
6. Pigments e.g. Titanium dioxide, colourants

Solid materials are added as finely ground aqueous dispersions.

A typical sequence of operations from latex to product is shown schematically in Figure 1.

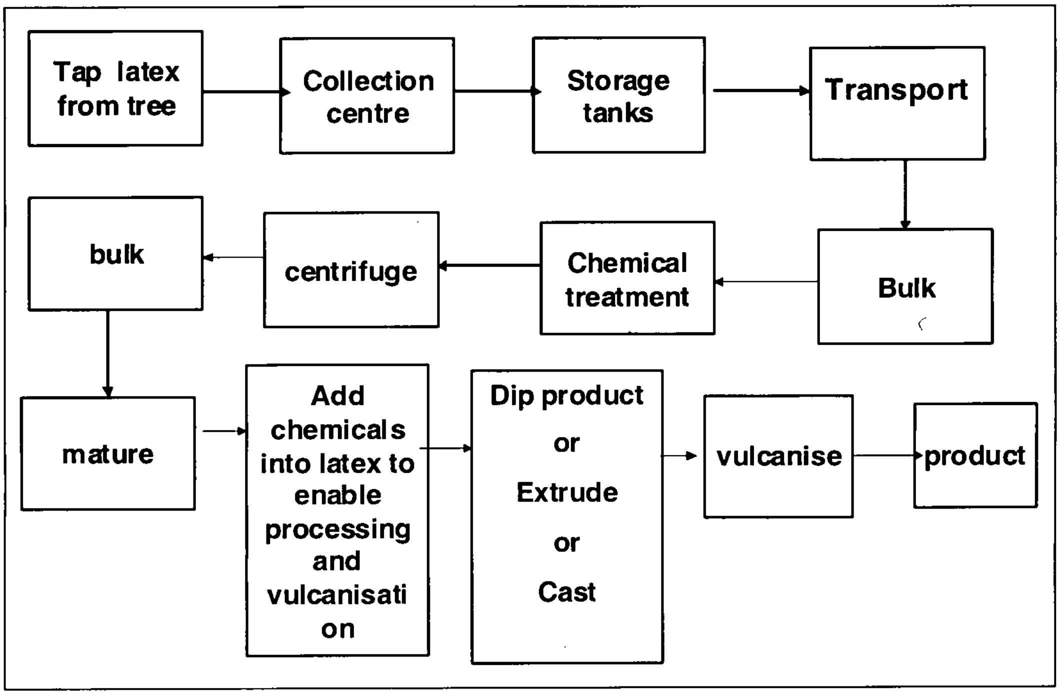


Figure 1. A typical sequence of operations from latex to product

In the dipping process suitably shaped formers are coated with a coagulant (e.g. calcium nitrate) and dipped into the latex to coat them with a thin film of latex. The coagulant converts the liquid latex film into a wet-gel on the former. Subsequent passage through a warm oven completes the coagulation process. The latex deposit is then leached, dried and vulcanised before the rubber product is removed from the former.

A typical sequence for a glove dipping operation is shown in Figures 2 and 3.

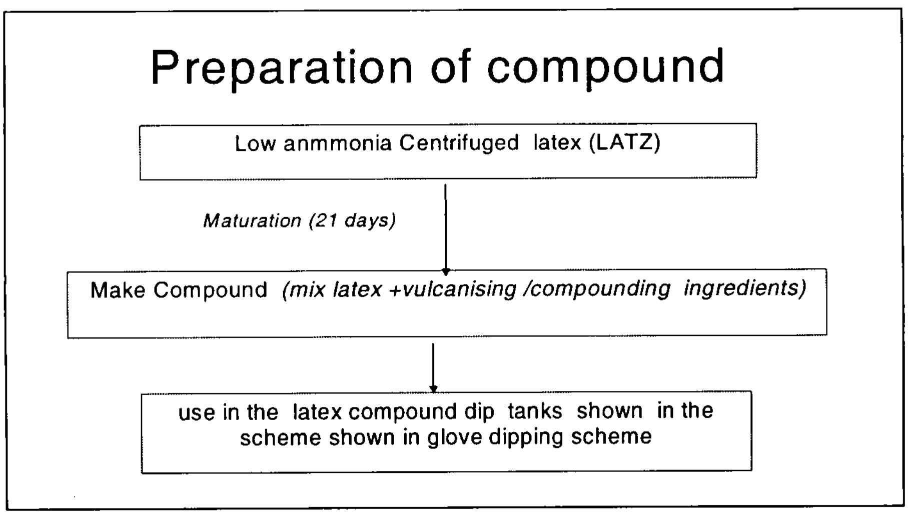


Figure 2. Preparation of compound for glove dipping

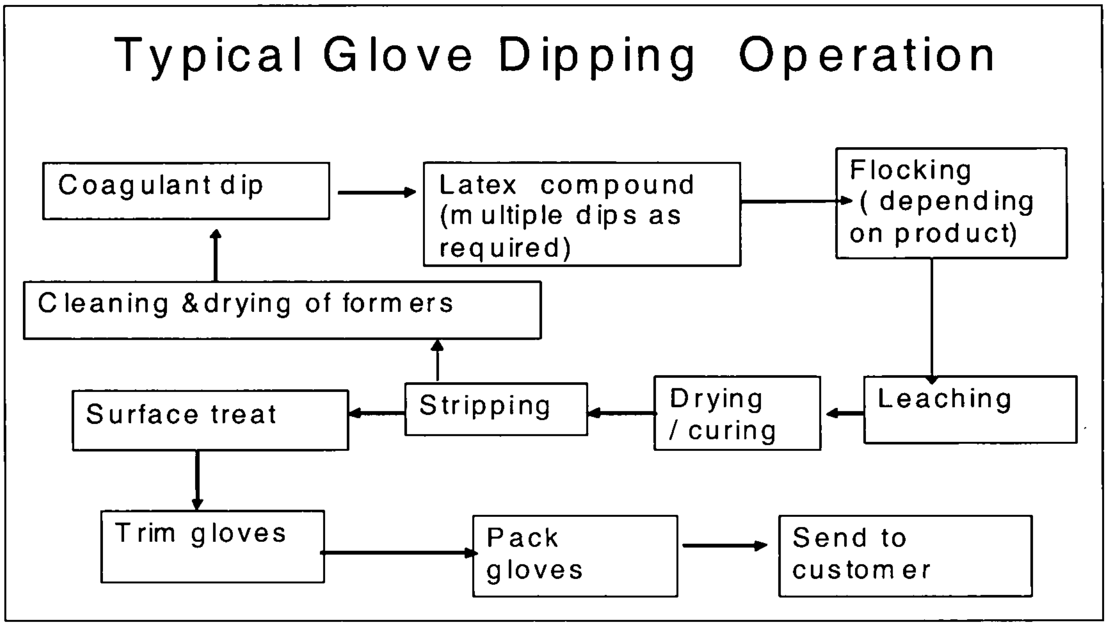


Figure 3. Sequance of glove dipping operations

The dipping is done using dipping lines. There are basically two types of dipping lines: in one type, the formers move downwards to the dip tanks. In the other type, the dip tank is brought up to the former. Machines of the moving former type are normally used in conjunction with continuous production assemblies. They are usually called chain plants. The other type is referred to as batch plants. Chain plants are ideal for high volume production of a limited range of products. Batch plants may be manual or semi automatic and can be designed to produce a wide range of products.

In the industry, complications arise due to the need to make a consistent quality product day in and day out. An essential requirement for all the latex processes is to maintain the colloidal stability of the latex until at a desired time it is made unstable and converted to solid product. This is the secret of working with latex and is the primary job of the latex technologist.

In order to fulfil this requirement and overcome inherent variations in the latex, chemical additives and processes, the latex technologist must have a good understanding of the role of formulation ingredients with respect to maintaining the colloidal stability of latex and determination of crosslink network required for the desired performance of the rubber product.

In addition a good understanding of the following is also required

- Understanding of the technological details of the process
- Understanding what happens during vulcanisation and subsequent surface treatment operations
- Understanding of customers needs and the ability to fine tune the formulation / process in order to meet his requirements.

In all of the above, the chemist plays a significant role in the industry through his/her good understanding of the basics, ability to innovate and ability to work in teams to implement the ideas in order to meet new challenges and to enable the industry remain competitive. In this regard it is necessary to address the following:

- Evaluation the effectiveness of new raw materials and less costly raw materials
- Process and product improvements for increased productivity and to meet new requirements (customer and legislation)
- New product and new process development to meet new challenges
- Trouble shooting and setting up preventive systems
- Evaluation of sustainability of formulations/operations /etc.
- Devise and Implement solutions for environmental aspects for sustainability of manufacturing operations and preserving environment for future generations.

The above cannot be done by industry alone. A vital role needs to be played by the Research Centres and academia. There needs to be better interactions with industry in regard to the following :

- Short term and long term products and process development
- Consultancy
- Testing of products

Academia also needs to provide high calibre graduates in science and technology who can innovate

- To create new products focused to customer needs
- for process/productivity improvement and development.

In this regard some issues of relevance to the industry and for which we need answers are cited below:

- **Consistency of high quality latex**

  This is a primary requirement to sustain viable manufacturing operations. We have found that the consistency is poor in respect of parameters such as volatile fatty acid (VFA) and mechanical stability time (MST).

- **Maturation of latex**

  It is known that during the maturation of centrifuged latex hydrolysis of proteins and lipids occur which results in an increase in the natural higher fatty acid soaps. The soaps increase with time and reach a constant value in three to five weeks. Over 90% of the soaps are adsorbed on to the latex particles which results in an increase in the colloidal stability of the latex.

  An understanding of a means of accelerating the hydrolysis process would enable the latex technologist to ensure optimum hydrolysis at the time of use of the latex and consequently reduce process related problems during dipping operations

- **Former staining**

  Continuous dipping of ceramic formers in natural rubber latex compounds results in a stain development on the formers. This is undesirable as it results in poor wetting of the former by coagulant and latex and consequential film defects.

  We know that the degree of staining increases when the KOH number of the latex is high. We also know that the stain may be removed either on or off the dipping plants by use of oxidising agents/acids.

We lack knowledge about the chemical constituents of stain , the reasons for how and why staining occurs and how to prevent it.

- **Development of low/zero protein latex**

  Over the last 10 years, natural rubber latex has suffered adverse publicity from increased reports of allergic reactions owing to the latex protein issue. Today many glove industries tackle the issue on-line as a part of the production operation after the product is manufactured. This approach addresses the issue in the finished product.

  The challenge to the scientist is to reduce the protein content in latex itself possibly by employing chemical methods prior to and during centrifuging. In this regard, use of proteolytic enzymes offers an opportunity.

- **Product development and quality improvement**

  Develop gloves which have improved cut/puncture/solvent permeability/heat and oil resistance. This may be achieved by blending different type of synthetic lattices, viz. Polar and Non polar rubbers with each other or in combination with natural rubber latex. In this regard fundamental studies need to be undertaken in respect of the latex types, formulations and morphology of the blends.

- **Chlorinated gloves**

  Gloves are often subjected to a secondary treatment process such as Chlorination in order to make the glove surface slippery thus making it easier to put on. It is an essential process for gloves without a cotton flock-lined interior or where there is no powder to help ease them on. The process is sometimes also done to enhance aesthetic appearance of the glove. A bonus is that in natural rubber gloves extractable protein levels in the finished glove are reduced. Drawbacks are glove discolouration and in the case of thin walled items loss of mechanical performance during storage. The challenge to the chemist is to develop a means of preventing the glove discoloration and the poor ageing behavior.

- **Effluent disposal**

  The waste water effluents from the dipping industry could contain Nitrates, Nitrites, Calcium salts, soaps, ionic and non-ionic surfactants, non-rubber substances, ammonia, sulphur, zinc salts, cotton /other textile fibres and residual accelerators or chemicals from accelerator origin. The disposal of such effluent safely is a big challenge.

- **Latex availability**
  - The future prospects for the natural rubber latex industry in Sri Lanka will also depend on the ability for the local latex suppliers to supply the latex needs of the industry.
  - As it is, over the last few years, many latex goods manufacturing industries have had to import latex to sustain their production goals.
  - Having to import latex on a regular basis would be a deterrent to new ventures and even present difficulties for existing industries due to the higher cost of the latex.
  - It is not too late for our research centres and universities to instigate studies on how to increase

the yield of latex from the rubber trees and advice the plantation sector and small holders accordingly.

The author is aware that currently isolated pockets of research in some of the above areas are being addressed, however the work appears to be disjointed and industry is not kept informed of findings. Therefore there is a need to better coordinate the activities using a system similar to what was /is adopted in Malaysia *and make results available to industry within tight time frames.* Some suggestions in this regard are ventured by the author viz:

- Universities and research centres to have very close interaction with industry.
- A part of the tax imposed on industries to be fed back into the industry by funding of R and D activities at universities and research centres to answer needs of the industry.
- Academia and research centres to organise regular workshops to appraise industry of their findings

This will provide the much needed Quantum leap to take our Industry into the future, face new challenges and increase the contribution of Sri Lankan latex products globally. This article has focused primarily on latex industry. However the concepts are also applicable to the solid rubber industry, plastics industry and other industries as well.

8204

Study on Kernel Development and Variation of Oil Composition in Some Coconut Cultivars (*Cocos nucifera* L) of Sri Lanka

J M N Marikkar, P Hewavitharanage, and C Jayasekera
Coconut Processing Research Division, Coconut Research Institute, Lunuwila, Sri Lanka

ABSTRACT

Varietal differences in nut and copra characters, kernel development and variation of oil composition with maturity are important background information for product development and processing. A study was conducted collecting samples from Bandirippuwa Estate and Isolated Seed Garden (ISG) to examine the above characters. Nuts collected from the Bandirippuwa Estate were processed in the Coconut Research Institute (CRI) standard Ceylon copra kiln to obtain copra out turn. A separate series of palms were identified in the Tall x Tall (TxT) varietal block to collect nuts with varying maturity. Nuts collected from the ISG were used for analysis of coconut oil (CNO) composition by gas liquid chromatography (GLC). The highest copra out turn was recorded for Tall x San Ramon (TxSR) cultivar. The kernel development study showed that the oil content gradually increased from 1% (wet basis) to 32% (wet basis) starting from sixth month to twelfth month. Comparison of fatty acid (FA) composition of cultivars showed that oil of TxT contained the highest lauric acid content (54 %). Although kernel characters of 'dikiri' nuts are quite different from those of normal coconuts collected from the same tree (normal 'dikiri'), there is no significant difference between them in terms of FA composition.

Key Words: Coconut cultivars, Copra out turn, Fatty acid, Oil composition, San Ramon, Variety

INTRODUCTION

Development of improved cultivars of coconut has been carried out in Sri Lanka for several decades. There are a number of cultivars, which are already established in the field. Some of the improved cultivars introduced to farmers are identified as: Tall x Tall (TxT), Tall x Dwarf (TxD), Dwarf x Tall (DxT), Tall x San Raman (TxSR). In the past, evaluation of these cultivars was mainly done on the basis of yield potential, resistance to pest and diseases, and other agronomical characteristics. However, there is not much information of nut characteristics such as copra yield and FA composition of oil of these cultivars in the literature. Also a detailed investigation on the kernel development and compositional variation during different stages of maturity of coconut has not been previously undertaken. The knowledge of coconut kernel development is nutritionally important for product diversification. An evaluation of copra and oil characteristics produced by these cultivars may generate some valuable information required for processing industries. The first objective of this study was to investigate the kernel development and oil composition variation during different stages of maturity of coconut. Secondly, the copra yield and oil composition of different improved cultivars were compared with those of open pollinated ordinary tall and dwarf varieties.

MATERIALS AND METHODS

Materials

Nuts of cultivars TxT, DGxT, DYxT were collected from Isolated Seed Garden, Ambekelle. Nuts of open pollinated ordinary tall and dwarf varieties, and TxSR were collected from Bandirippuwa estate. Nuts of 'dikiri' and normal 'dikiri' were collected from a private estate. All chemicals and solvents used were of analytical grade unless otherwise specified.

Methods

Moisture content was determined by oven (Memmert 854, Schwahbach, Germany) drying at 105 °C for 4 hrs and then to constant weight (AOAC, 1984).

Oil content determination was carried out for 10 g portions of ground samples of copra by soxhlet extraction (6 h) procedure using petroleum ether (B.P. 40-60 °C) as solvent (AOAC, 1984).

Fatty acid methyl esters (FAME) were prepared using anhydrous methanol containing sodium methoxide. FAME was analysed using a gas chromatograph (Shimadzu GC-14 A) fitted with a FID detector and a capillary column (supelcowax TM 10). Nitrogen (99.99%) was used as the carrier gas at the column pressure of 10 psi. Injector port and the detector were maintained at 250 °C and 260 °C, respectively. The column temperature was programmed from 120 to 240 °C at rate of 10 °C min^{-1} (PORIM Test Methods, 1995).

Coconuts collected from the varietal field blocks of Bandirippuwa Estate were kept for four weeks of seasoning. After taking husked nut weight, nuts were split opened and processed into copra in the standard Ceylon copra kiln. Husked nut weight and per nut copra yield were recorded using a top pan balance.

RESULTS AND DISCUSSION

Variation of oil content and FA composition with maturity

Studies conducted with TxT showed that kernel formation in the developing drupe started between fifth and sixth months of maturity. The oil content of the six month old nut was approximately 1% (wet basis) while that of a twelfth month old nut was approximately 34% (wet basis) (Figure 1). There was a 300% increase in oil content in the developing kernel during the interval between 7 and 8 months (Figure 2). However, the rate of increase of oil content gradually decreased as the nut reached its full maturity. FAME analysis of oil showed that tender nuts in the age of 6 and 7 months are rich in oleic (a monounsaturated FA), and linoleic acids (Table 1). In fact, these two FA are highly regarded for their nutritional value. Therefore, kernel of the tender nut should not be thrown out after drinking its water as usually practised in urban areas. However, the proportion of oleic and linoleic acid in the developing kernel was found to decrease as the maturity of the nut increases (Figure 3). As for lauric acid (%) there was a steady increase while palmitic, oleic and lenoleic acid were tended to decrease. Myristic acid (%) of the oil of course remained almost stable through out the stages of kernel development.

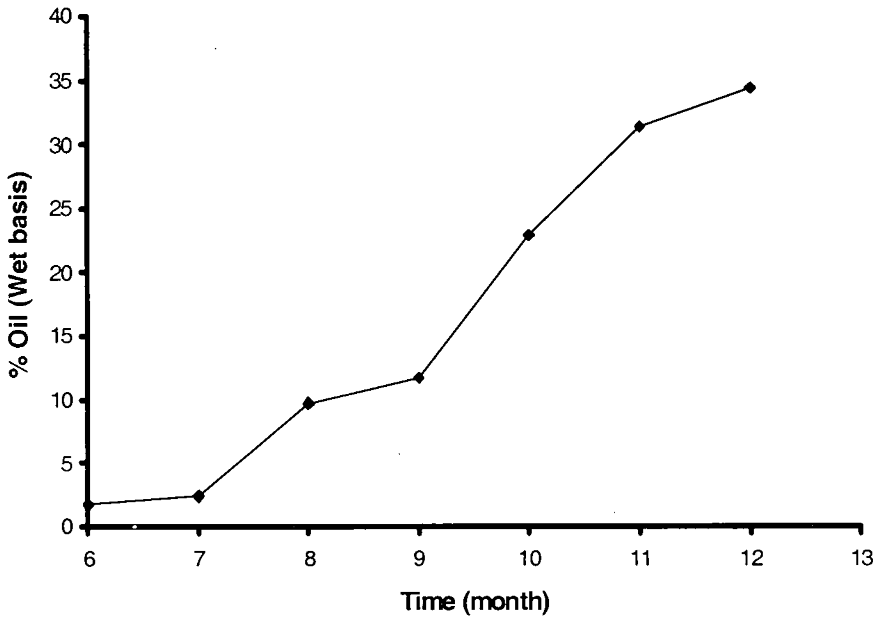


Figure 1. Oil Content Variation of the Developing Kernel of TallxTall

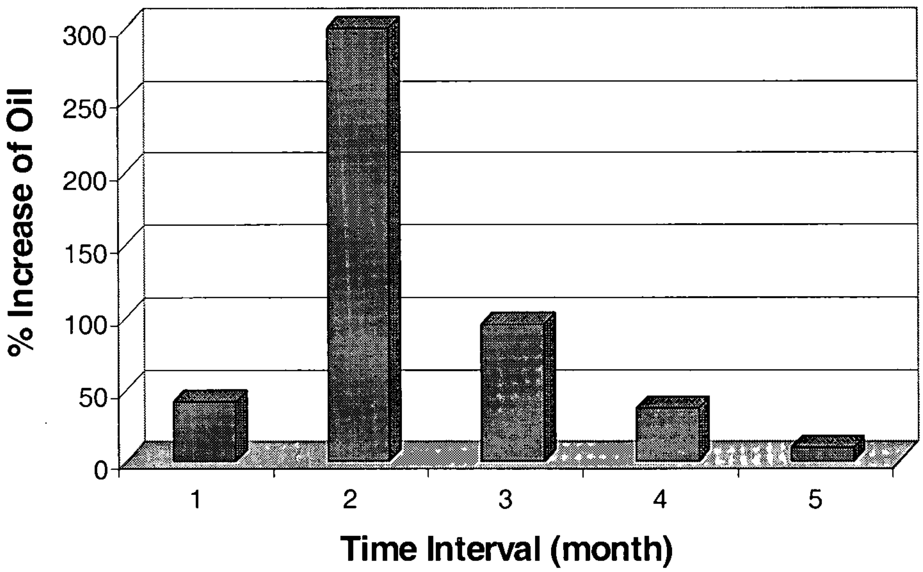


Figure 2. Progressive Increase of Oil Content in the Developing Kernel of TallxTall

Variations of copra out turn and oil composition among different crosses

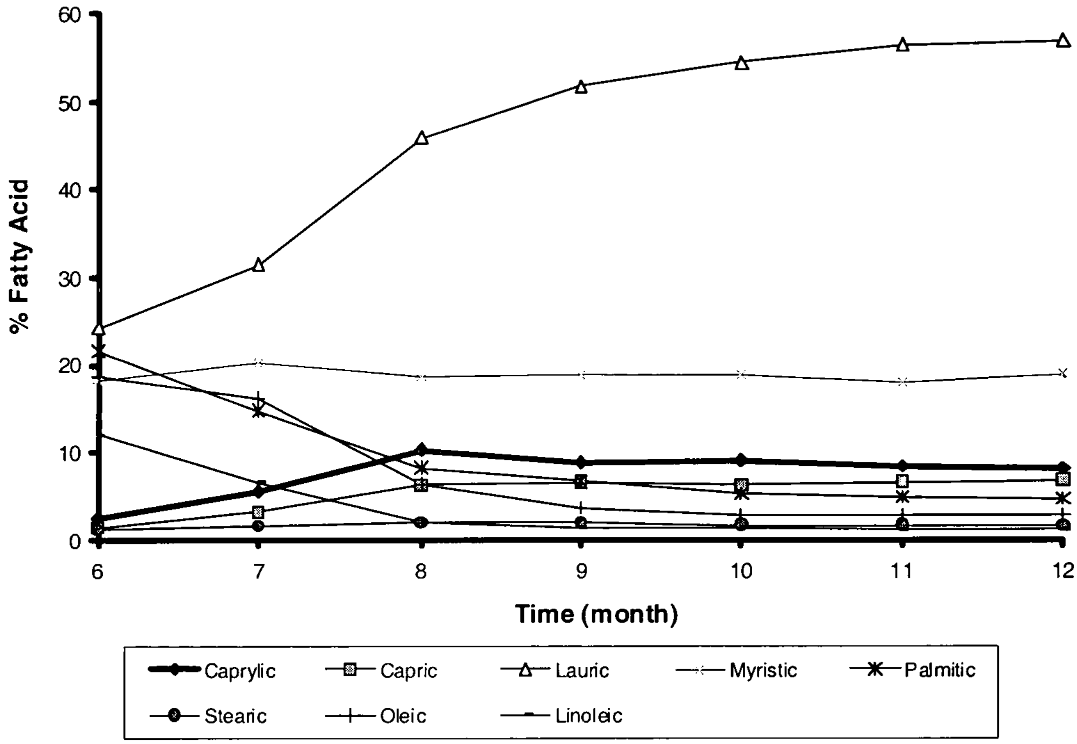


Figure 3. Variation of Fatty Acid Composition of the Developing Kernel

Table 1. Percentage variation of fatty acid composition in cultivar TallxTall at different stages of maturity (Average of coconuts from eight trees)

Maturity stage / Fatty acid	6	7	8	9	10	11	12
	Months						
Caprylic ($C_{8:0}$)	2.5	5.6	10.3	8.9	9.1	8.4	8.2
Capric ($C_{10:0}$)	1.4	3.2	6.3	6.6	6.3	6.6	6.8
Lauric ($C_{12:0}$)	24.3	31.5	45.9	51.7	54.4	56.4	56.8
Myristic ($C_{14:0}$)	18.3	20.4	18.7	18.9	18.9	18.0	19.0
Palmitic ($C_{16:0}$)	21.6	14.8	8.3	6.7	5.3	4.9	4.7
Stearic ($C_{18:0}$)	1.2	1.6	2.0	2.0	1.7	1.7	1.6
Oleic($C_{18:1}$)	18.7	16.3	6.4	3.7	2.8	2.8	2.8
Linoleic ($C_{18:2}$)	12.0	6.6	2.0	1.4	1.4	1.2	1.2

Kernel is the most valuable component of coconut. In Sri Lanka, kernel is mainly used for home food preparation, production of DC and copra, and extraction of cream. Therefore, a coconut cultivar producing high kernel content is of particular interest to processing industries since it will help reduce not only cost of raw material but also the cost involved for various related activities such as handling, counting, husking, cracking, shelling etc. According to the data presented in Table 2, TxSR is the most attractive option for kernel products such as copra and desiccated coconut since it was found to give the highest copra outturn.

Table 2. Variation of nut weight and copra content in different coconut cultivars (Average of eighty nuts from each cultivar)*

Cultivar	Husked Nut Wt. g Nut^{-1}	Copra g Nut^{-1}	Nut Equivalent mt of Copra
TxT	832.5	201.2	4,970
TxD	692.7	178.5	5,600
DxT	711.2	180.6	5,540
TxSR	1,293.8	282.5	3,540
OT	821.5	197.8	5,060

*Abbreviations: TxD, TallxDwarf; DxT, DwarfxTall. For other abbreviation see Table 1.

The principle nutritional component of kernel is oil. The physio-chemical characteristics of the oil depend mainly on FA composition. In order to make best use of CNO in various food applications, it is advantageous to have a good knowledge about its FA composition in different cultivars. According to Table 3 the highest amount of caprylic acid (C8:0) was observed in normal nuts of 'dikiri' (8.7%) while the lowest amount of this acid was found with Dwarf variety (5.5%). It is a well-known fact that lauric acid is the most abundant FA in CNO. Its relative percentage varies from 45 to 54%, TxT containing the highest amount. Myristic is the next dominant FA in CNO. The highest myristic acid (%) was found in variety Dwarf (21.2%) while the lowest amount was recorded in DYxT (17.3%).

Palmitic and stearic acids are two long chain saturated FA. However, they occur in very low amounts in CNO. The highest amount of palmitic acid was found with variety ordinary Tall and the highest amount of stearic acid was found with cultivar DGxT. CNO does not have higher amounts of unsaturated FA. Among the unsaturated FA, oleic acid occurs in higher amounts in cultivar DGxT (7.1%) while lenoleic acid occurs in higher amounts in variety Dwarf (2.6%).

There was considerable interest to study the FA profile of 'dikiri' coconuts. Unlike ordinary coconut, there was no liquid endosperm and fibrous kernel in 'dikiri' coconuts. Due to its gel-like structure, soxhlet extraction of oil was difficult. However, the notable feature is that the FA composition of 'dikiri' nut was still comparable to that of normal 'dikiri' nuts plucked from the same tree (Table 3).

For nutritional evaluation purposes, FA composition of edible oils is sometimes expressed as medium chain fatty acids (MCFA) ($C_{8:0}$-$C_{12:0}$), long chain saturated FA (LCSFA) ($C_{14:0}$-$C_{18:0}$), and long chain unsaturated FA (LCUFA) ($C_{18:1}$-$C_{18:3}$). Although the oil composition of fully matured nut is 92% saturated

FA and the balance is unsaturated FA (Canapi et al., 1996; Tan and Che Man, 2000), the saturated FA of CNO are quite different from those of animal fats. The principal difference is that the triglycerides of CNO are largely composed of medium and short FA. The importance of medium and shorted FA in the nutrition has now been realised. As reported by Kintanar (1989) metabolism of medium and short chain FA is different from that of saturated long chain FA. The medium and short chain FA are easily digested and absorbed by the intestine and therefore, not involved in cholesterol synthesis (Rajmohan et al., 1997).

Table 3. Percentage distribution of fatty acid in different coconut cultivars*

Cultivar	Caproic ($C_{6:0}$)	Caprylic ($C_{8:0}$)	Capric ($C_{10:0}$)	Lauric ($C_{12:0}$)	Myristic ($C_{14:0}$)	Palmitic ($C_{16:0}$)	Stearic ($C_{18:0}$)	Oleic ($C_{18:1}$)	Linoleic ($C_{18:2}$)
TxT	0.18	7.8	5.90	54.0	18.6	6.3	1.6	3.8	1.5
DGxT	0.32	5.5	4.5	45.1	21.1	9.9	3.1	7.1	1.8
DYxT	0.67	8.06	6.7	46.6	17.3	9.4	2.3	4.9	0.8
TxSR	0.45	8.0	6.4	51.2	18.5	6.7	1.9	3.5	1.8
OT	0.35	7.0	5.2	45.4	19.7	10.2	2.3	4.3	2.2
Dikiri	0.49	7.9	5.7	50.5	19.9	7.4	1.7	4.1	1.8
OD	0.47	8.7	5.8	50.3	18.8	6.3	1.5	3.3	1.5
DW	0.52	4.5	4.2	48.6	21.2	9.1	2.8	5.8	2.6
Significance	0.165	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
LSD	0.3392	1.59	0.87	2.22	1.57	1.72	0.67	1.15	1.72
CV	78.02	22.14	-	4.53	8.10	21.12	31.04	24.83	29.53

*Abbreviation: TxT, TallxTall; DGxT, Dwarf greenxTall; DyxT, Dwarf yellowxTall; TxSR, TallxSan Ramon; OT, Ordinary Tall; OD, Ordinary Dikiri; DW, Dwarf; LSD, least significant difference; CV, coefficient of variation.

Among the cultivars investigated, the highest amount of MCFA was found in TxT (68.0 %) while it was lowest in DGxT (55.6%). TxSR and variety 'dikiri' were also found to possess relatively higher amounts of MCFA. Similarly, the highest amount of LCSFA was found in variety DGxT (34%) while its amount was lowest in TxT (26.5%) (Table 4).

Table 4. Fatty acid composition of different coconut cultivars according to fatty acid chain length*

Cultivar	Medium Chain FA (%)	Long Chain Saturated FA (%)	Long Chain Unsaturated FA (%)
TxT	68.0	26.6	5.3
DGxT	55.6	34.3	8.9
DYxT	62.2	29.0	5.7
TxSR	66.1	27.2	5.4
OT	58.0	32.1	6.5
Dikiri	64.6	29.0	5.9
OD	65.4	26.6	4.9
DW	57.8	33.0	8.4
Significance	0.0001	0.0001	0.0001
LSD	3.59	2.25	1.43
CV	5.77	7.58	22.42

*Abbreviations: See Table 1

SUMMARY

This study showed that the kernel development in coconut takes place over a period of one year. There were significant changes in oil content and FA composition through out the different stages of maturity. The cultivar experiment showed that FA profiles of most of the coconut cultivars are comparable even though there are significant variations with regard to the distribution of certain FA. Due to its larger nut size, TxSR recorded the highest copra outturn and therefore its potential use in copra and DC industry is very high. Since TxT showed the highest lauric content among the cultivars, it will be a highly useful cultivar for non-edible applications such as surfactants, detergents, cosmetics etc. Both TxT and TxSR were found to show higher values for MCFA, and therefore, their oil could become a good raw material for the production of MCFA enriched high-energy products. Even though the kernel structure of 'dikiri' coconut is quite different from that of the normal coconuts, its FA composition appear to be comparable to that of the normal nut plucked from the same tree. This study will be useful for varietal selection of industries dealing with kernel and oil products.

ACKNOWLEDGEMENTS

Authors wish to express their gratitude to the Director, CRI of Sri Lanka for her motivation to start this study and providing approval to publish this paper. The authors also wish to thank Mr. G R A Dharmasena and Mr. R K M Rajapakse for technical assistance.

REFERENCES

Association of Official Analytical Chemists, *Official Methods of Analysis.* 1984 14th edn., AOAC, Washington, D. C.

Canapi, E C, Augustine, Y T V, Moro, E A, Pedrosa, E and Bendano, M L J 1996 Coconut oil, *In* Bailey's Industrial Oil and Fat Products, Ed. Y. H. Hui. pp. 97-124, Vol. 2, 5th edn. John Wiley and Sons, Inc., New York.

Kintanar, Q L 1988 Coconut oil: A Source of Metabolic Energy. *Coco. Today (Special Edition)*, 31-41.

PORIM Test Methods. 1995 Palm Oil Research Institute of Malaysia, Ministry of Primary Industries, Malaysia, pp. 72-100.

Rajmohan, T and Kurup P A 1997 Study on the Effect of Consumption of Coconut Oil and Coconut Kernel on the Serum Lipids in Humans. Ind. Coco. J. 2-4.

Tan, C P and Che Man, Y B 2000 Differential Scanning Calorimetric Analysis of Edible Oils: Comparison of Thermal Properties and Chemical Composition, *J. Am. Oil Chem. Soc. 77*, 143-155.

Classification of Tea Grades including Long Leaf Types by Sieve Analysis

[1]M T Ziyad Mohamed, [1]G L C Galahitiyawa, [1]M A Chamindra and [2]W C A De Silva
[1]Tea Research Institute of Sri Lanka, Talawakelle, Sri Lanka
[2]De Silva, Abeywardene & Pieris (Pvt) Ltd, State Bank of India Building, Colombo 1, Sri Lanka

ABSTRACT

Particle size distributions of Broken or Small leaf grades have been successfully analysed by sieve analysis techniques and it has been shown that these distributions are polydispersed mixtures of particle sizes that are lognormally distributed and based on a mathematical model, the two parameters which fully describe these distributions viz. the mean values and their standard deviations together with their confidence limits have been ascertained for BOP and BOPF (De Silva, 1972). Although earlier it was thought that the methods of sieve analysis were inapplicable to characterize the particle size distribution of long leaf grades because of the large differences in the maximum and minimum dimensions of the particles constituting long leaf grades, it is now established that the particle size distributions of long leaf grades too are polydisperse mixtures of particle sizes that are lognormally distributed provided sizes of long leaf particles are taken to mean the second largest of the dimensions of such particles. Applying the mathematical model proposed by De Silva (De Silva, 1972) the relationships between the probits of cumulative undersize and the corresponding fineness moduli of the particle sizes have been established for true to type grades corresponding to OPA, OP, OP1, BOP1, Pekoe, Pekoe 1, FBOP, FBOP1, FBOPF, FBOPF1. From these relationships the mean values and the standard deviations, which fully describe the particle size distributions of these grades, either within long leaf type or pekoe type or hybrid type are presented. However, further research is needed to establish the confidence limits of these parameters.

Key words: particle size analysis, long leaf grades

BRIEF REVIEW OF RESEARCH ON PARTICLE SIZE ANALYSIS

Earliest attempts to specify standards for graded teas were only successful in reporting results obtained by fractionating grades into three broad nominal particle size ranges in one series of experiments (Evans, 1931; 1932) and into eight nominal particle size ranges in another series of experiments (Lamb, 1937a; 1937b; 1939; 1940). Subsequently it has been established that High Grown BOP and BOPF grades are polydisperse mixtures of sizes distributed lognormally (De Silva, 1972) and that these distributions could be completely characterized by the means and the standard deviations of the particle size distributions measured on a logarithmic scale or a "Fineness Modulus" scale which is a more convenient scale and bears a known relationship to a logarithmic scale.

Based on this work, the Technical Committee on Tea of the International Organization of Standardization (ISO/TC 34/SC 8), in 1994 proposed a method of classification of tea grades based on collections of data on grades produced in various countries. In this method, titled "ISO 11286 - Tea - Classification of grades by particle size analysis" – according to which, a particular tea grade is defined mainly based on the particle size distribution, using meshes having aperture sizes between 0.125 mm and 2.0 mm.

A Mathematical Model

The average particle size of a polydisperse mixture could be computed from the distribution of particle sizes. Even though sieve analysis techniques had been used to generate the distribution of particle sizes of High Grown BOP and BOPF, it has been stated that this technique may be unsatisfactory for characterization of grades such as Orange Pekoe and some of the other Low-Country grades, where large differences are observed between the maximum and minimum dimensions of particles (De Silva, 1972). This concept needs review.

In the mathematical model proposed by De Silva (De Silva, 1972) to accommodate the results of sieve analysis of Broken grades the average size of particles transmitted through a B.S. sieve and retained on another B.S. sieve one step smaller having a nominal No. N has been defined as the arithmetic average of the aperture sizes of the two sieves defined by

$$D_N = \tfrac{1}{2} [d_N + \sqrt[4]{2}.d_N]$$

i.e. $$D_N = \tfrac{1}{2} d_N [1 + \sqrt[4]{2}] \qquad - (1)$$

The average size, defined by equation (1) refers to the average equivalent diameters of the tea particles considered as spheres, which is more or less true for true to type grades such as Pekoe, Pekoe 1, BOP, BOPF, D1, etc. In the case of grades such as OPA, OP, OP1, BOP1, etc it is quite inappropriate to convert their average particle sizes to diameters of equivalent spheres. The particles of these grades in no way resemble spheres. They are highly eccentric and elliptic in shape. Therefore it is necessary to find a meaning to, the sizes of the particles corresponding to grades such as OPA retained on sieves during sieve analysis.

Whether an irregularly shaped particle will pass through a given sieve or will be retained depends usually on the second largest linear dimension of the particle. This is true not only for more or less spherical particles associated with tea grades such as Pekoe, BOP, BOPF, etc. but also for long leaf particles having circular or elliptic cross sections associated with tea grades such as OPA, OP, OP1, BOP 1 etc. Accordingly, once the average particle size given by equation (1) is taken to mean or specify the average of the second largest linear dimension of irregularly shaped tea particles, the mathematical model proposed by De Silva will accommodate the results of sieve analysis of not only Broken grades of tea but also of long leaf grades of tea.

Using British standard set of sieves (BS 410, 1960) where the aperture size of one sieve is $\sqrt[4]{2}$ times as large as the next smallest sieve, De Silva's (1972) model gives teh following equation

$$d_{N+Z} = d_N (\sqrt[4]{2})^Z \qquad - (2)$$

where

d_N = aperture size of reference mesh having a nominal mesh number N

d_{N+Z} = aperture of mesh Z steps larger than the aperture size of mesh having a nominal number N.

It follows from equation 1and 2 that

$$D_{N+Z} = \frac{1}{2} d_N (\sqrt[4]{2})^Z [1 + \sqrt[4]{2}] \quad - (3)$$

Where D_{N+Z} = average size of particles retained on a B.S. sieve Z steps larger than a reference mesh having a nominal No. N

Following the classification system devised by D.A. Abrams (Henderson and Perry, 1955) which has been used by the American Society of Agricultural Engineers for determining the performance of feed grinders, De Silva (De Silva, 1972) in introducing his mathematical model has defined Z in equation (3) as the "Fineness modulus" of tea particles retained on a B.S. sieve Z steps larger than a reference sieve having a nominal number N during sieve analysis using a complete set of B.S. sieves.

If the B.S. test sieve corresponding to nominal No. 60 and having an aperture size of 250 microns is taken as the reference sieve, then from equation (3) it follows that Z is zero for the reference sieve and that

$$D_{60} = \frac{1}{2} d_{60} [1 + \sqrt[4]{2}]$$

$$= 125 [1 + \sqrt[4]{2}] \quad - (4)$$

If the fineness modulus of particles retained on a sieve Z steps larger than the reference sieve is taken as F_{60+Z} then

$$F_{60} = 0 \quad - (5)$$

$$F_{60+Z} = Z \quad - (6)$$

then equation (3) combined with equation (4) could be re-written as follows:-

$$D_{60+Z} = 125 [1 + \sqrt[4]{2}] [\sqrt[4]{2}]^Z$$

$$\therefore \quad = 125 [1 + \sqrt[4]{2}] [\sqrt[4]{2}]^{F_{60+Z}} \quad - (7)$$

Equation (7) gives the relationship between average particle size retained on a mesh Z steps higher than the reference mesh No. 60 and Fineness Modulus of such particles during sieving operations using a complete set of B.S. Test Sieves. This equation could be transformed into form in equation (8).

$$\log D_{60+Z} = (\tfrac{1}{4} \log 2) F_{60+Z} + \log 125 [1 + \sqrt[4]{2}] \quad - (8)$$

Equation (8) establishes a linear relationship between average particles sizes retained on B.S. sieves measured on a logarithmic scale and Fineness Moduli measured on an arithmetic scale.

During preliminary attempts to classify long-leaf and semi-leafy grades by Sieve Analysis it was found, that under modified conditions of operating the sieve shaker, that the sizes of particles as redefined in this paper and retained on different meshes of a complete set of B.S. Test Sieves were lognormally distributed, thereby justifying the use of the mathematical model proposed by De Silva (De Silva, 1972), even for the characterization of long leaf grades. If the particle sizes are transformed to a Fineness Modulus scale then the particle sizes measured on this scale will be normally distributed. Accordingly Ž, the mean of this distribution and s, the standard deviation of the distribution, completely define the particle size distribution of the tea grade in question. The equation describing this distribution will be

$$\varnothing (Z) = \frac{1}{s\sqrt{2\Pi}} e^{-\frac{(Z-\check{Z})^2}{2s^2}} \qquad \text{——} \qquad (9)$$

The two parameters which define the above normal distribution viz. Ž and s could be estimated graphically by plotting values of cumulative per cent undersize and the corresponding fineness modulus values, on probability paper having probability co-ordinates for one axis and linear co-ordinates for the other axis or mathematically using probit transformations followed by regression analysis, as described below.

For the normal distribution given by equation (9) the expected percent by weight retained on a sieve z steps higher than mesh No. 60 is

$$Y_{60+Z} = \frac{1}{s\sqrt{2\Pi}} \int_{Z}^{Z+1} e^{-\frac{(Z-\check{Z})^2}{2s^2}} . dz \qquad \text{——} \qquad (10)$$

And the relationship between probit of cumulative per cent of sizes less than a size corresponding to a Fineness modulus Z (Finney, 1947) is given by

$$Y_z = 5 + \frac{(Z-\check{Z})}{s} \qquad - \quad (11)$$

Equation (11) indicates a linear relationship between the probit of proportion undersize (i.e Y_z) with respect to Fineness Modulus (i.e. Z). Accordingly the parameters Ž and s could be estimated using linear regression analysis. These estimates could be further refined by adoption of maximum likelihood solutions (Finney, 1947).

Materials & Methods

An Endecott Sieve Shaker and a complete set of 17 B.S. Test sieves (BS 410) supplemented with a further 3 sieves having apertures larger than No. 4 B.S. Test Sieve corresponding to aperture sizes of 4 ($\sqrt[4]{2}$), 4($\sqrt[4]{2}$)^2, and 4 ($\sqrt[4]{2}$)^3 mm were used in sieve analysis. The diameter of each test sieve was 8" (20.3 cm) and the specifications of the sieves are given in Appendix 2.

The shaking machine was capable of accommodating ten test sieves. These were nested one above the other, so arranged that any one sieve had screen openings larger than the ones below. A solid pan (receiver) was placed under the bottom sieve. A lid was placed on the top most sieve and the whole assembly was fixed tightly to the vibratory platform of the sieve shaking machine.

The sieve shaking machine was capable of vibrating the test seives electro- magnetically at 50 Hz and their movement combined vertical motion with a rotational action. This gave thorough stratification and caused the presentation of the particles at all angles to the sieve apertures. The shaking machine had a built-in control with a scale reading from 0 to 10 to vary the intensity of vibration, and a 0-to-60-min. time switch. A stop clock, however, was used instead of the built in timer, to determine intervals of shaking.

Having decided to use 100g samples for sieve analysis, preliminary experiments were directed to determine (a) suitable period of shaking and (b) suitable intensity of vibration and (c) aprticle degradation. It was possible to obtain more or less reproducible results with 100 g replicate samples having a common origin by adopting a period of 10 minutes for sieve shaking at the maximum intensity of vibration (corresponding to a scale reading of ten of the machine). This standardized method of fractionating was adopted in all the experiments reported, here.

True-to-type samples of the Grades investigated were prepared from Grades commercially produced at St Joachim Tea Factory located in the Ratnapura District, Sri Lanka as depicted in the flow charts given in Appendix 3.

Duplicate samples of each of the true-to-type grades extracted in the manner described (Appendix 3) were fractionated in accordance with the standardized procedure into size ranges reported under results.

Results

The results of sieve analysis of true to type grades giving the percentage weights retained on B.S. Test Sieves are presented in Appendix 4. Cumulative percent undersize corresponding to percent weight retained on B.S. Test Sieves, derived from data presented in Appendix 4 are presented in Appendix 5.

Provisional regression equations were first computed without attaching any weights to the probits of percentage undersize for each of the grades investigated. These equations were subsequently used to obtain maximum likelihood solutions. The method of computation is illustrated in Appendix 6.

Correlation co-efficients corresponding to the provisional regression equations were highly significant ($P < 0.001$) for all the grades investigated being greater than 0.9. The maximum likelihood solutions were utilized to obtain estimates of the parameters, which completely describe the particle size distribution, viz. Ž, the mean Fineness Modulus of the grades and s, the standard deviation of the distributions of particle size as measured on a Fineness modulus scale.

The maximum likelihood solutions obtained together with the corresponding mean Fineness Moduli and their standard deviations, are given in Table 1.

Table 1. Maximum Likelihood Solutions describing the Particle Size distribution of Grades together with Mean Fineness Moduli of the distributions and their Standard deviations

Family	Grade	Maximum Likelihood Solutions	ž	s
Long Leaf	OPA	$Yz = 0.617\,z - 4.743$	15.8	1.6
	OP	$Yz = 0.780\,z - 5.653$	13.6	1.3
	OP 1	$Yz = 0.724\,z - 3.258$	11.4	1.4
	BOP 1	$Yz = 0.762\,z - 2.819$	10.3	1.3
Pekoe	PEKOE	$Yz = 0.828\,z - 6.628$	14.0	1.2
	PEKOE 1	$Yz = 0.873\,z - 6.155$	12.8	1.1
Hybrid	FBOP	$Yz = 0.658\,z - 1.980$	10.6	1.5
	FBOP 1	$Yz = 0.723\,z - 2.181$	9.9	1.4
	FBOPF 1	$Yz = 0.712\,z - 1.826$	9.6	1.4
	FBOPF	$Yz = 0.665\,z - 0.188$	7.8	1.5

DISCUSSION

For the purpose of discussing the results presented in Table 1, we have classified tea grades produced in Sri Lanka into three broad categories whose brief descriptions are as follows:

(a) Long Leaf Family:

In the grades belonging to this family, there are very large differences in the minimum and maximum dimensions easily discerned visually and the particles are elliptic in shape. The relevant grades are OPA, OP, OP 1 and BOP 1.

(b) Pekoe Family:

In the grades belonging to this family, the three dimensions taken in directions mutually at right angles are more or less the same, for the simple reason that the actual differences cannot be discerned visually. Grades belonging to this family consists of Pekoe, Pekoe 1, BOP, BOPF, FBOPF 1 (non tippy) etc.

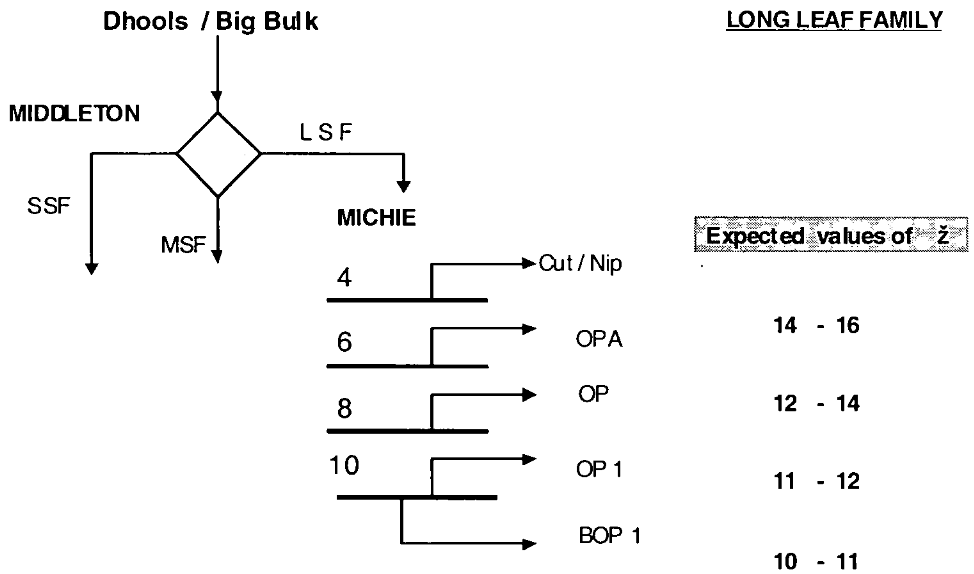
(c) Hybrid Family:

In the grades falling into this category of hybrids lying between long leaf type and Pekoe type, whilst some of the particles are elliptic in shape, and some others are near spherical in shape. For example in the grade FBOPF 1 (tippy type) the tippy particles are elliptic in shape and non tippy particles are near spherical in shape.

Even though the broad classification of grades is a new concept it needs to be accepted in order for research to proceed on the correct lines, to enable the research workers to establish standards for tea grades in accordance with trade requirements and to achieve this, we solicit the co-operation of the trade in our future research plans.

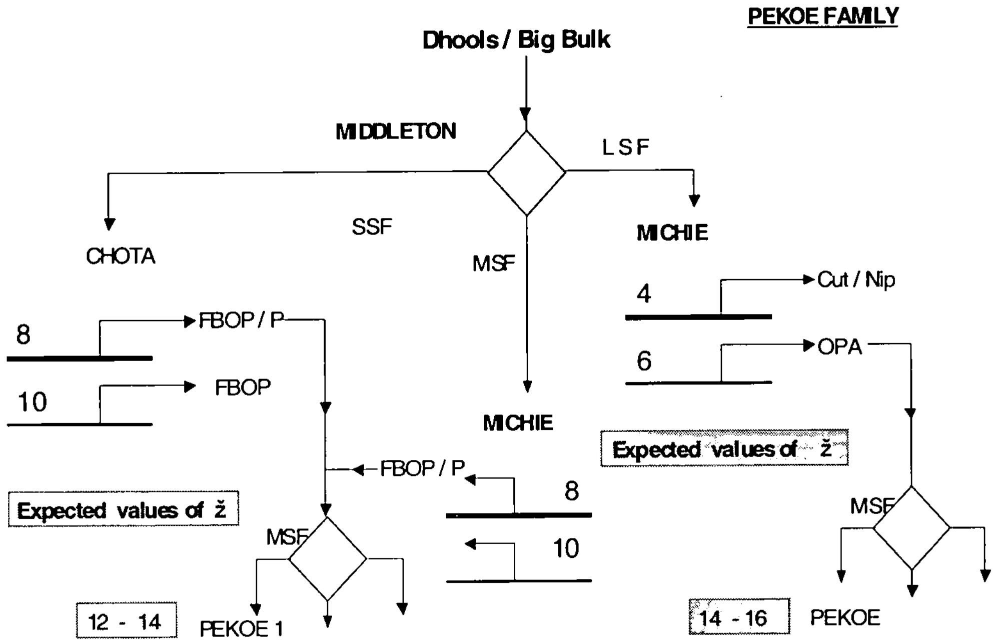
Results establish the fact that sieve analysis provides a reliable method of characterizing grades belonging to the long leaf family consisting of OPA, OP, OP 1, BOP 1 as well as grades belonging to the Pekoe family viz. Pekoe and Pekoe 1 etc. by the particle size distribution. The values of Ž, the mean Fineness Moduli of the grades and s, the standard deviation of the distributions given in Table 1, completely characterize the grades that have been investigated under three categories, namely long leaf type, Pekoe type and hybrid type. The values of Ž are the mean sizes of the grades as measured on a fineness modulus scale and these values are in accordance with the sizes of measures used for extraction of these grades as described below:

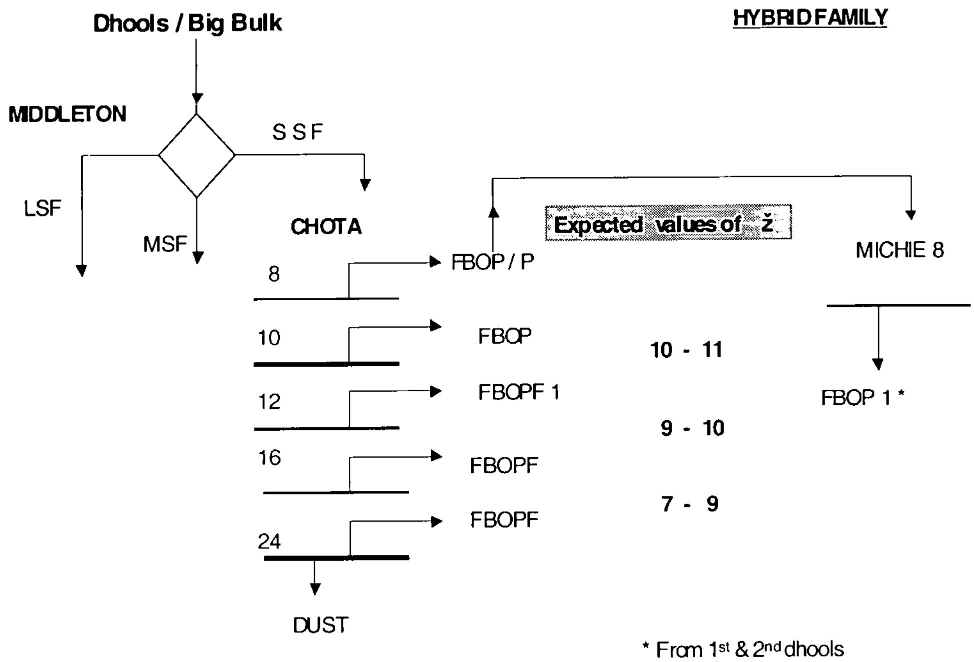
Commercially, the grades belonging to the long leaf family are first separated from the grades belonging to the Pekoe family and other hybrid grade by the use of the Myddleton sifter. Thereafter, these grades are fractionated into OPA, OP, OP 1, BOP 1 using Michie sifters as depicted in the flow chart below, which also includes expected means of the particle sizes of these grades, as measured on a fineness modulus scale.



Comparison of the observed mean values of Ž given in Table 1, with the expected values shown in the above flow chart indicates that the observed values are in accordance with the meshes used for the extraction of the relevant grades.

Grades belonging to the Pekoe family and other hybrid family extracted from the Myddleton sifter as the undersize fractions corresponding to mesh sizes of 5 and 8 mm are further fractionated into Pekoe, Pekoe 1 etc. as depicted in the flow charts below





The present work establishes the fact that with the adoption of large size meshes it is possible to characterize long leaf types as well as pekoe types and hybrid type. However, further research is needed to establish the confidence limits of these parameters, which characterize the particle size distributions.

Furthermore, based on the findings from this study, it was also concluded that method proposed by the Technical Committee on Tea of the International Organization of Standardization (ISO/TC 34/SC 8) is not applicable to long leafy grades of tea. This is because meshes with larger perforations, up to 6.70 mm, have to be used for separation, as the particle sizes and shapes are too eccentric, compared to more or less spherical shape of broken grades.

REFERENCES

British Standards Institution (1969). B.S. 410:Specifications for Test Sieves. British Standards Institution, London.

De Silva, W C A. (1972). The Tea Quarterly, Volume 43, Parts 1 & 2,21 - 35.

Evans, D I, (1931). Annual Report of the Tea Research Institute of Ceylon 1930, 30 - 39.

Evans, D I, (1932). Handbook Concerning Tea Manufacture at St Coombs - Tea Research Institute of Ceylon Bulletin No. 9, 72 pp

Finney, D J, (1947). Probit Analysis. Cambridge University Press, Cambridge. 256 pp

Fisher, R. A. & Yates, F(1938):Revised in 1963; Statistical Tables for Biological, Agricultural & Medical Research, Oliver & Boyd Press, London.

Henderson, S M. & Perry, R L. (1955). Agricultural Process Engineering. *John Wiley & Sons, Inc. New York*, 402 pp

Lamb, J. (1937 a). Annual Report of the Tea Research Institute of Ceylon 1936, 60 - 89.

Lamb, J. (1937 b). Grading tea with stamped aluminium sieves-I. Tea Quarterly 10, 191-195.

Lamb, J. (1939). Grading tea with stamped aluminium sieves-II. Tea Quarterly 12, 79 –182.

Lamb, J. (1940). Grading tea with stamped alumunium sieves-III. The Arnott Filter Sifter. Tea Quarterly 13, 82 – 85.

Appendix 1

Nomenclature

(A complete set of British Standard test sieves is implied where applicable)

a	=	½ dN [1 + ^{4}"2] the average size of particles retained on a mesh having a nominal No. N (microns)
b	=	^{4}"2 (dimensionless constant)
D	=	Geometric average size of particles of a polydisperse mixture (microns)
D_N	=	Average size of particles retained on a sieve z steps larger than N (microns)
$D_N + z$	=	Average size of particles retained on a sieve z steps larger than N (microns)
d_N	=	Average aperture size of sieve having a nominal No. N (Microns)
F_N	=	Fineness Modulus of particles retained on a sieve having a nominal No. N (dimensionless) defined by $F_{60} = 0$, $F_{60} + z = z$
F_{N+Z}	=	Fineness Modulus of particles retained on a sieve z steps larger than a Sieve having a nominal No. N, F_{60} being taken as zero
g	=	Abbreviation for grams
N	=	Nominal Mesh No. (dimensionless)
Y_z	=	Probit of cumulative percent of sizes less than a size corresponding to a Fineness Modulus z (dimensionless)
y_{60}	=	Per cent by weight of particles retained on Mesh No. 60 (dimensionless)
y_{60+z}	=	Percent by weight of particles retained on a mesh z steps larger than mesh No. 60 (dimensionless)
z	=	Fineness Modulus of particles retained on a sieve z steps larger than a sieve having a nominal No. 60 (dimensionless)
ž	=	Mean Fineness Modulus of a poly-disperse mixture of particles (dimensionless)
s	=	Standard deviation of normally distributed particles sizes of tea grades as measured on a Fineness Modulus scale.

In addition to these, other standard mathematical symbols have been adopted.

Appendix 2

Specification of test sieves

A complete set of sieves conforming to BS 410 (1969) having a ration between successive sieves equal to "2 or 1.19, was used.

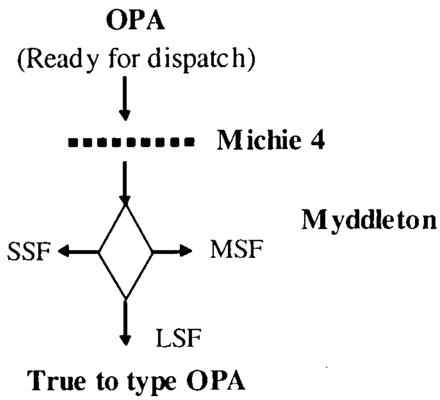
Nominal mesh No.	Aperture width (microns)	Mean size of particles retained (microns)	Fineness modulus of particles retained
3	6700	-	-
3-	5600	6150	18
4+	4700	5150	17
4	4000	4350	16
5	3350	3675	15
6	2800	3075	14
7	2400	2600	13
8	2000	2200	12
10	1680	1840	11
12	1400	1540	10
14	1200	1300	9
16	1000	1100	8
18	850	925	7
22	710	780	6
25	600	655	5
30	500	550	4
36	420	460	3
44	355	388	2
52	300	328	1
60	250	275	0

Appendix 3:

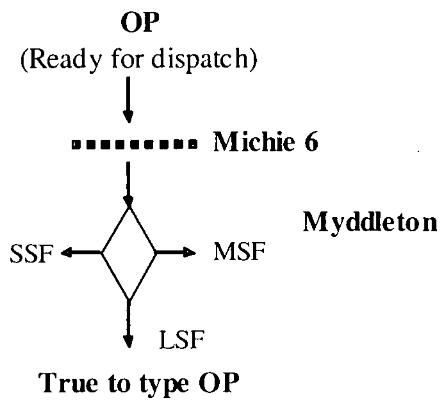
Flow chart describing the method of preparing true to type grades

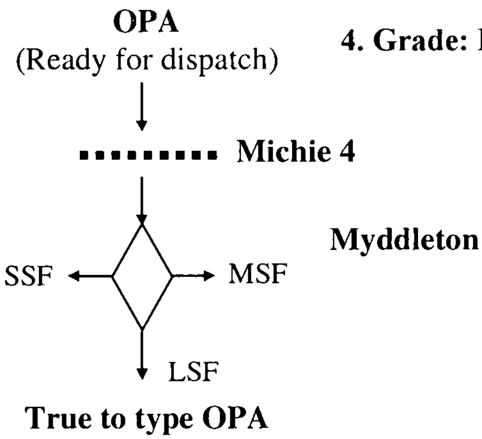
Family: Long leaf

1. Grade: OPA

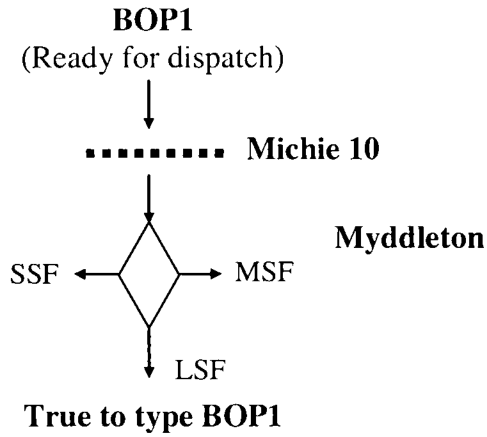


2. Grade: OP



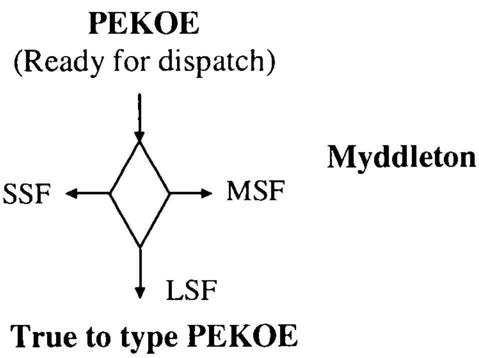


4. Grade: BOP1

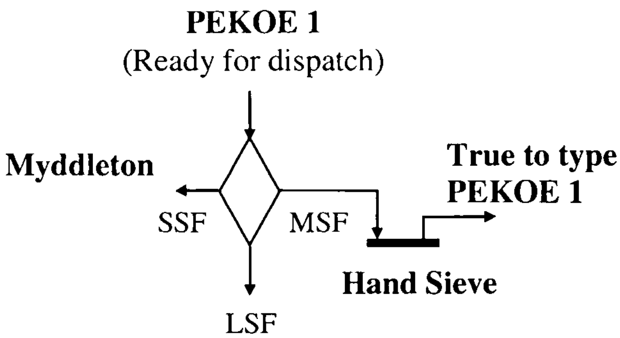


Family: Pekoe

1. Grate: Pekoe

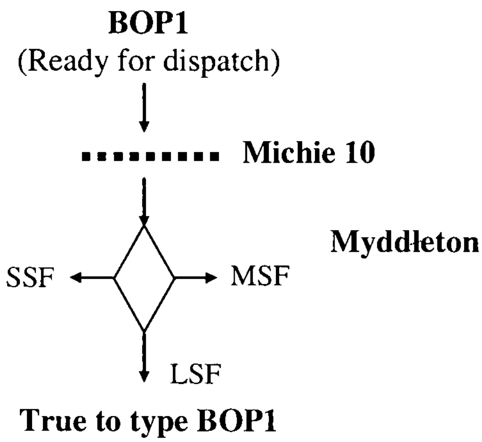


2. Grade: Pekoe 1

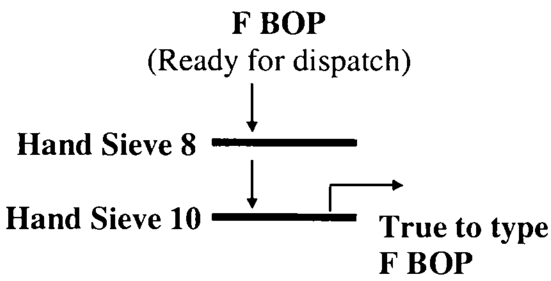


Appendix 3 Contd....
Hybrid Family

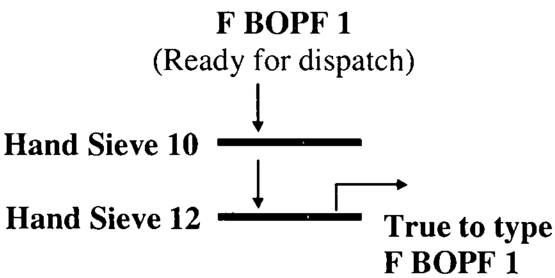
1. Grade: F BOP 1



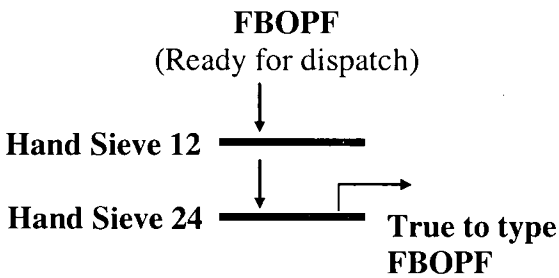
2. Grade: F BOP



3.Grade: F BOPF 1



4.Grade: F BOPF



Key to abbreviations:

SSF – Small size fraction – undersize fractions coming through a 5 mm mesh in a Myddleton sifter

MSF – Medium size fraction – fraction over 5 mm and through 8 mm mesh in a Myddleton sifter

LSF – Large size fraction – fraction over 8 mm mesh in a Myddleton sifter

Appendix 4

Results of sieve analysis of true to type grades																						
SIEVE	N	3	3^{-}	4+	4	5	6	7	8	10	12	14	16	18	22	25	30	36	44	52	60	BP
SPECIFI-	d_N	6700	5600	4760	4000	3350	2800	2400	2000	1680	1400	1200	1000	850	710	600	500	420	355	300	250	0
CATIONS	D_N	_	6150	5180	4380	3675	3075	2600	2200	1840	1540	1300	1100	925	780	655	550	460	387.5	327.5	275	_
	F_N	_	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	_
GRADE	REP	Weights (%) retained on B.S.sieves																				
OP A	R1	0.61	3.49	14.96	24.45	34.62	13.15	4.29	2.33	1.06	0.84											0.20
	R2	0.81	4.09	17.16	26.42	29.32	13.32	4.03	2.33	1.30	0.94											0.27
OP	R1	0.00	0.02	0.20	0.46	7.92	41.90	24.92	13.68	6.85	2.70											1.36
	R2	0.06	0.04	0.36	0.43	6.25	45.61	22.75	14.21	6.15	2.60											1.55
OP 1	R1					0.35	1.32	7.66	29.11	30.91	18.05	6.94	4.84	0.67	0.12							0.02
	R2					0.31	0.84	7.10	27.39	31.31	18.13	8.10	5.80	0.77	0.18							0.06
BOP 1	R1				0.01	0.06	0.16	0.33	1.68	39.42	21.83	16.13	15.88	3.24								1.26
	R2				0.01	0.04	0.17	0.45	2.33	34.37	26.09	16.61	14.80	3.53								1.61
FBOP 1	R1				0.04	0.00	0.09	0.22	1.79	24.34	30.91	15.36	17.98	5.77								3.50
	R2				0.01	0.02	0.10	0.23	1.57	22.44	33.99	15.06	17.53	5.86								3.18
FBOP	R1					0.00	0.07	1.07	6.91	29.74	32.94	10.44	13.15	3.73	1.35							0.60
	R2					0.02	0.27	4.72	19.26	30.47	20.16	10.97	10.10	2.78	0.86							0.39
PEKOE	R1	0.00	0.01	0.55	3.91	16.91	36.81	28.23	10.13	2.38	0.65											0.41
	R2	0.00	0.01	0.05	3.43	13.73	35.20	28.44	13.34	4.27	0.99											0.54
PEKOE 1	R1	0.00	0.01	0.01	0.08	1.44	11.01	29.62	42.65	12.32	1.78											1.07
	R2	0.00	0.01	0.06	0.05	1.99	12.86	26.33	33.97	15.81	4.60											4.32
FBOPF	R1						0.00	0.01	0.01	0.23	3.31	21.31	28.01	20.73	14.79	6.63						4.99
	R2						0.00	0.01	0.01	0.22	2.87	18.81	27.95	20.55	15.53	7.99						6.06
FBOPF1	R1						0.00	0.05	1.19	9.16	37.57	19.29	19.20	8.42	3.52	1.21						0.40
	R2						0.02	0.19	1.99	11.84	34.59	20.46	19.08	7.40	3.08	1.04						0.33

Appendix 5

Results of sieve analysis of true to type grades

SIEVES	N	3	3^-	4+	4	5	6	7	8	10	12	14	16	18	22	25	30	36	44	52	60	BP
PECIFI-	d_N	6700	5600	4760	4000	3350	2800	2400	2000	1680	1400	1200	1000	850	710	600	500	420	355	300	250	0
CATIONS	D_N	_	6150	5180	4380	3675	3075	2600	2200	1840	1540	1300	1100	925	780	655	550	460	387.5	327.5	275	_
	F_N	_	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	_
GRADE	**REP**	**Weights (%) undersize corresponding to B.S.sieves**																				
OP A	R1	99.39	95.90	80.94	56.49	21.87	8.72	4.43	2.10	1.04	0.20											
	R2	99.19	95.10	77.94	51.52	22.21	8.89	4.86	2.54	1.23	0.27											
OP	R1	100.00	99.98	99.78	99.32	91.40	49.50	24.59	10.90	4.06	1.36											
	R2	99.94	99.90	99.54	99.11	92.86	47.26	24.50	10.29	4.15	1.55											
OP 1	R1					100.00	99.65	98.33	90.67	61.56	30.65	12.60	5.66	0.81	0.15							
	R2					99.69	98.85	91.74	64.35	33.04	14.91	6.81	1.01	0.24	0.06							
BOP 1	R1				99.99	99.93	99.76	99.43	97.76	58.34	36.51	20.38	4.50	1.26								
	R2				99.99	99.95	99.78	99.32	97.00	62.63	36.54	19.93	5.13	1.61								
FBOP 1	R1				100.00	99.96	99.96	99.87	99.65	97.86	73.52	42.61	27.24	9.27								
	R2				100.00	99.99	99.97	99.87	99.64	98.07	75.63	41.64	26.58	9.04								
FBOP	R1					100.00	99.93	98.86	91.94	62.21	29.27	18.83	5.68	1.95	0.60							
	R2					99.98	99.71	94.99	75.73	45.26	25.09	14.13	4.02	1.25	0.39							
PEKOE	R1	100.00	99.99	99.44	95.53	78.62	41.81	13.58	3.44	1.06	0.41											
	R2	100.00	99.99	99.94	96.51	82.78	47.58	19.14	5.80	1.53	0.54											
PEKOE 1	R1	100.00	99.99	99.98	99.90	98.46	87.44	57.83	15.18	2.85	1.07											
	R2	100.00	99.99	99.93	99.88	97.88	85.02	58.69	24.72	8.91	4.32											
FF	R1						100.00	99.99	99.98	99.75	96.44	75.14	47.13	26.40	11.62	4.99						
	R2						100.00	99.99	99.98	99.76	96.89	78.08	50.13	29.58	14.05	6.06						
FF1	R1						100.00	99.95	98.76	89.60	52.03	32.74	13.55	5.13	1.61	0.40						
	R2						99.98	99.79	97.80	85.97	51.38	30.92	11.85	4.44	1.36	0.33						

Appendix 6

Method of arriving at the maximum likelihood solution to describe the Particle size distribution of tea grades

The method is illustrated by taking sieve analysis results relating to the OPA grade from Appendix 5. The percent undersize particles and corresponding fineness moduli values together with their corresponding probit values are as follows:

	Replicate 1		Replicate 2	
F M	Cum. Under %	Probit	Cum. Under %	Probit
18	95.90	6.7392	95.10	6.6546
17	80.94	5.8756	77.94	5.7701
16	56.49	5.1637	51.52	5.0381
15	21.87	4.2227	22.21	4.2348
14	8.72	3.6418	8.89	3.6531
13	4.43	3.2940	4.86	3.3454
12	2.10	2.9665	2.54	3.0400
11	1.04	2.6737	1.21	2.7429
10	0.20	2.1218	0.27	2.2522

Probit values were calculated for various undersize percentages from statistical tables [Fisher & Yates, 1938]. The regression analysis of the above data yields the following provisional equation, with a correlation coefficient of 0.979.

$$Y = 0.5415\, Z - 3.5010$$

The mean value of the distribution is 15.7, with a standard deviation of 1.8.

Provisional equation thus arrived at, gives equal weightage for all the data points. As in a normal distribution, it is necessary to give higher weightage for data points closer to the mean value, than to the points at the tail end of the distribution.

Weighting coefficients were arrived at using values from statistical tables (Fisher and Yates, 1938: Table IX).

Corresponding to the expected probits calculated from the provisional regression equations, the maximum working probits, ranges and the weighting coefficients are tabulated in Table 2

Table 2. Weighting coefficients and probit values used to arrive at the first maximum likelihood solutions.

	Proportion	Expected Probit from provisional equation	Minimum Working Probit	Range	Weighting Coefficients	New probit
z	p	Y	Y-P/Z	1/z	W=Z^2/PQ	Y-P/Z+p/Z
18	0.96	6.25	1.3362	5.4926	0.35310	6.5816673
17	0.79	5.70	3.2724	3.2025	0.53159	5.8163572
16	0.54	5.16	3.7272	2.5421	0.63018	5.0999297
15	0.22	4.62	3.6711	2.6967	0.60363	4.2652001
14	0.09	4.08	3.3955	3.8331	0.46488	3.7326696
13	0.05	3.54	3.0148	7.3041	0.28224	3.3534935
12	0.02	3.00	2.5786	18.5220	0.13112	3.0061356
11	0.01	2.46	2.1101	63.6800	0.04578	2.8265
10	0.00	1.91	1.6130	298.0000	0.01139	2.3133

The first maximum likelihood solutions arrived at, using these weighting coefficients, was

$$Y = 0.6167\ Z - 4.7432$$

Corresponding to this solution, the mean value of the distribution is 15.8 with a standard deviation of 1.6. Proceeding in the same manner using the first likelihood solution, further refinements were carried out to arrive at the next most likelihood solution which was $Y = 0.6345\ Z - 5.0337$. This equation gives a mean value of 15.8 and standard deviation of 1.6 from the distribution. Mean values and standard deviations of the second maximum likelihood solution are more or less the same as those given by the first likelihood solution. Accordingly, the first likelihood solution worked out was taken as the most appropriate equation.

For varying values of Z there exists one to one correspondence between the probits given by the equation $Y = 0.6167\ Z - 4.7432$ and the percent undersize leading to a linear relationship between percent undersize and fineness modulus as illustrated by the straight line in Figure 2 (using the grade OPA as an example), along with data plots corresponding to experimentally determined average percent undersizes and their fineness moduli values. From these graphs the provisional values of the mean of the particle size distributions and their standard deviations could be computed by taking $\check{Z}$ as the value of $\check{Z}$ corresponding to a percentage undersize of 50% and taking as the standard deviation (s) the difference in the values of $\check{Z}$ corresponding to 84.13% and 50% undersize or 50% and 15.87% undersize as illustrated in Figure 1.

Similarly maximum likelihood solutions were worked out for other grades as well. These equations are presented in Table 1.

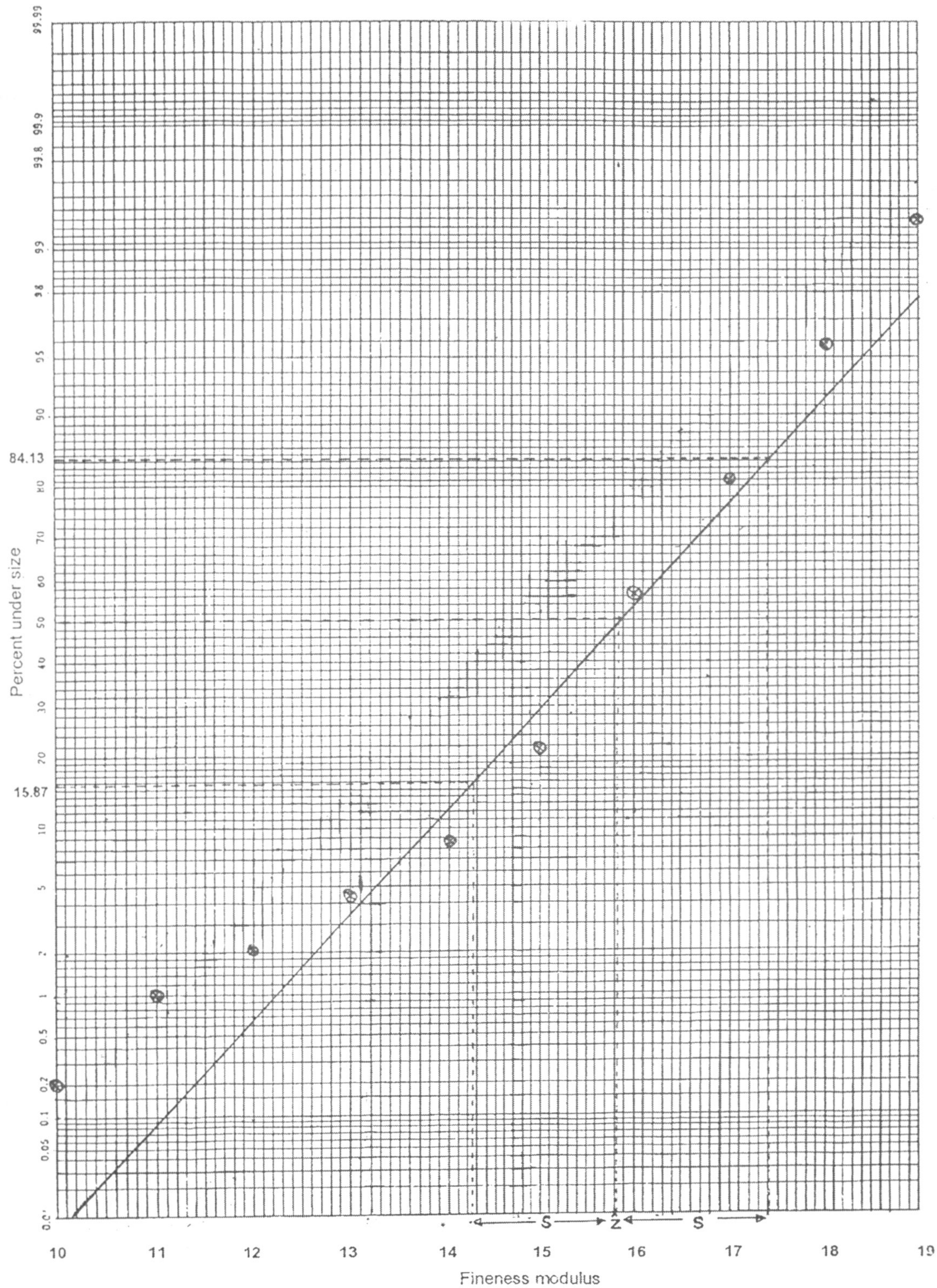


Figure 1. Mean particle size distribution of well-sorted OPA grade as measured on a fineness modulus scale

The Development of the Rubber Product Manufacturing Industry in Sri Lanka - Dry Rubber Sector

M R N Fenando
Director -Research and Development, Soli deal Co. Ltd.

ABSTRACT

Although Sri Lanka was traditionally known as a raw rubber exporter, developments during the last two decades have led to a situation where the country is considered as a major rubber product manufacturer and exporter. It has also become the market leader in some selected areas, while further progress in new fields is also being achieved with continuing consistency. The accompanying technology advancement has also been considerable and today, rubber products are manufactured in Sri Lanka following upto date technologies, and the products are exported to the entire world. Product diversification is also taking place while not losing the position already achieved in some core product areas. Industrial tyres, dipped latex goods, foam rubber, flooring, technical products, engineering components etc. constitute the important product mix.

Key words: rubber products

Rubber Product Manufacturing Industry

The consumption of rubber products in day to day life is definitely going to continue and is on the rise. With an average per capita consumption of rubber near 3 kg, the world demand for manufactured rubber goods is expected to be on the rise. Rubber is an essential and non-replacable raw material for this sector, and this is why the rubber consumption of the world has continuously shown an increase (Table 1).

Starting with only natural rubber in the 1920's, the synthetic rubbers have also become important since 1940's. Today if one analyses the data, it is possible to see that the component of NR usage is maintaining near 38-40%. This trend is not expected to change in the future . At the same time , the requirement of rubber is foreseen to increase from today's 18 Mn tons to about 26 Mn tons in 2020. This means that the world demand for NR in 2020 could be near 10 Mn. tons. Today both natural and synthetic rubbers play important roles in the Sri Lankan industry. In fact, the shortage of natural rubber available locally has caused a serious concern among rubber product manufacturers, and recently there have been noticeable imports of NR to the country.

The actual consumption of rubber is presented in Table 2.

Until recently, USA has been the largest consumer of rubber, both natural and synthetic. However, China has recently emerged as the largest, and according to recent forecasts, the biggest growth in rubber product manufacture could also be seen in China. About 14 countries consume nearly 77% of all rubber produced. The ratio of NR:SR varies from country to country, and the high use of NR by India, Malaysia, and Thailand , and the high use of SR by Russia are noteworthy. This picture is also dependent on the type of products manufactured in a given country.

Table 1. World Rubber Production & Consumption (Tonsx000)

	Production				Consumption		
Year	NR	SR	Total		NR	SR	Total
1970	3,102	5,875	8,977		2,992	5,625	8,617
1974	3,475	7,488	10,963		3,525	7,288	10,813
1984	4,260	8,335	12,595		4,240	9,005	13,245
1988	5,020	10,160	15,180		5,140	10,000	15,140
1993	5,310	8,600	13,910		5,430	8,630	14,060
1994	5,720	8,800	14,520		5,680	8,820	14,500
1995	6,040	9,400	15,440		5,980	9,250	15,230
1996	6,360	9,700	16,060		6,140	9,580	15,720
1997	6,470	10,080	16,550		6,460	10,000	16,460
1998	6,820	9,880	16,700		6,560	9,870	16,430
1999	6,820	10,380	17,200		6,640	10,270	16,910
2000	6,730	10,870	17,600		7,300	10,790	18,090
2001	7,240	10,530	17,770		7,170	10,300	17,470
2002	7,340	10,930	18,270		7,520	10,790	18,310
2003	7,970	11,540	19,510		7,880	11,320	19,200
Future Demand							
Year 2004					8195	11734	**19,929**
Year 2005					8638	12291	**20,929**
Year 2020							
Based on per capita consumption at 3 kg/person					10400		**26,000**
Other forecasts					12180		**30,450**

Sources: IRSG Bulletin and EDB

Table 2. Largest Rubber Consuming Countries

Rubber Consumption - (x000 MT)

	1997	1998	1999	2000	2001	2002	2003
China	1905	1839	2137	2535	2790	3060	3640
USA	3367	3512	3334	3384	2814	3006	2968
Japan	1876	1823	1867	1889	1814	1845	1895
India	730	735	783	809	802	872	921
Germany	723	829	791	882	859	859	866
France	609	674	694	752	747	700	793
Rep. Of Korea	708	560	727	714	705	710	676
Russian Federation	459	364	451	575	611	570	651
Brazil	471	485	493	547	550	577	606
Malaysia	411	413	443	460	496	520	526

Sources: IRSG Bulletin and EDB

Out of all rubber produced, 10-15% is in the latex form. The balance is dry rubber, and most of this rubber usage is in the transport sector, while there are several other uses as well. The tyre and related items consume nearly 2/3 of all the rubber produced in the world. Although there are more than 50 large manufacturers of tyres in the world, 3 of them hold about 60% of the market.

2. Position of Sri Lanka as a product manufacturer

Sri Lanka has been known as a traditional producer of Natural Rubber for more than a century. Natural Rubber can be considered as the most important raw material available in the country from a technological point of view. Nearly all the natural rubber we produced was exported in the raw form , which was used in the industrialized world to manufacture finished technical products. Although the advantages of converting the raw rubber into finished products are many, our rubber product manufacturing sector was showing very slow growth over a long period of time. During the last 20 years, this situation has changed considerably. Many large and medium scale rubber industries have been started, and they have grown with time. As the domestic market is very small, any possible growth in the product-manufacturing sector can only be expected in the export oriented industry, and this is exactly what has been achieved. Today we are world recognized as leading manufacturers in some product sectors. We consume the bulk of our natural rubber production within the country, to manufacture value added products for export. The export income from rubber products is much higher than the income from export of raw rubber (Figure 1).

In the export industry, our main achievements are in Industrial tyres, latex gloves, flooring, engineering components etc. The level of technology has also improved, and the industry has provided considerable employment avenues. While making a noticeable contribution to the national income, the rubber product manufacturing industry has also made a serious impact towards industrialization in the country.

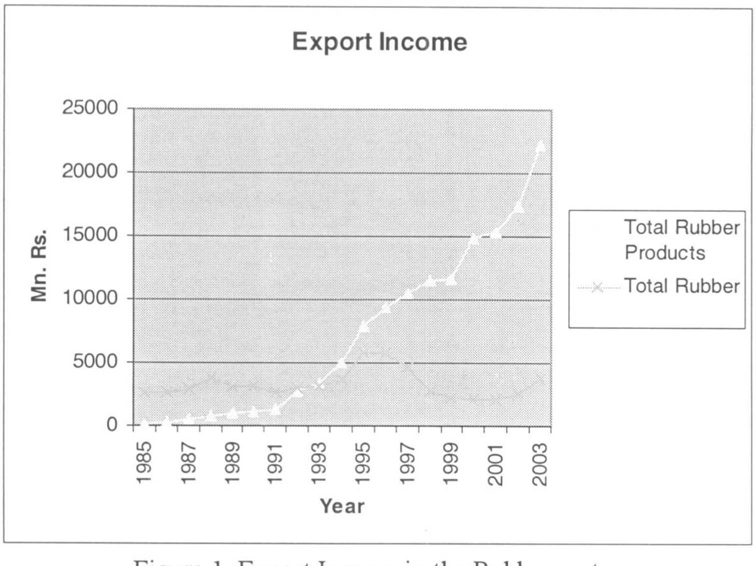


Figure.1. Export Income in the Rubber sector

2.1.Products manufactured with Dry rubber

2.1.1. Industrial Solid tyres

The actual initial advancement in rubber product manufacturing in Sri Lanka occurred with the beginning of solid tyre production in the country. Solid tyres are bulky rubber products, and there are some special features with regard to their manufacture and application. As the curing times of these large tyres could reach several hours, it is essential that the vulcanizing systems used in the recipes of solid tyre compounds are extremely reversion resistant. The use of semiev systems is very common here. With regard to performance during application, dynamic properties including heat build up, rolling resistance are very important characteristics required. Being a material with poor thermal conductivity, heat dissipation from solid tyres is slow, and the resulting accumulation of heat can lead to catastrophic failure. In this regard, compounds based on NR represent the ideal tyre material although some synthetic rubber can also be used. A solid tyre manufactured with NR will always have a cooler running temperature in comparison to a tyre made with synthetic rubber. Tables 3 and 4 indicate the pattern in which important properties vary when the type of rubber in tyre tread formulations is varied from Natural to Synthetic.

Table 3. Properties of some tread formulations

Property	Unit	60/40 NR/SR	75/25 NR/SR	100% NR	100 % NR
Hardness	Shore A	64	68	65	63
Density		1.12	1.15	1.12	1.12
Tensile properties					
300 %Modulus	kg/cm2	122	141	137	135
Tensile strength	kg/cm2	231	228	250	241
El.at break	%	517	484	513	515
Rheometer -150'c.					
MH	dNm	90.4	86.3	84.1	86.9
ML	dNm	20.2	27.5	20.6	25.4
ts2	min	7.16	5.4	2.9	3.4
T90%	min	14.6	14.8	7.6	9.2
Dynamic properties -25c					
E'	N/mm2	4.150	5.130	3.650	4.100
E"	N/mm2	0.602	0.761	0.260	0.265
Tangent Delta		0.132	0.141	0.071	0.065
Rebound		44	38	47	56
DIN Abrasion	mm3	92	109	99	123
Tear -Die B	kg.cm	71	51	80	74

- Tan delta at 60^{0}C correlated with rolling resistance
- E'' related to heat build up
- E' represents elastic modulus , related to the strength

While the presence of synthetic rubber (mainly SBR) improves the wear characteristics of the compound, natural rubber contributes to high rebound, lower heat build up and rolling resistance as refelcted by the dynamic properties. Comparison of properties is made between several different tread compounds as well as between two compounds where the only difference is in the type of rubber, while all the other ingredients remain unchanged.

Table 4. Comparison of properties between 100% NR based compound & 60% SBR based compound

Property	Unit	100% NR compound	60% SBR compound
Hardness	Shore A	63	64
Density		1.13	1.13
Tensile properties			
300% Modulus	kg/cm2	110	117
Tensile strength	kg/cm2	215	185
El.at break	%	524	468
Rheometer -150'c.			
MH	dNm	77	81.42
ML	dNm	22.5	17.75
ts2	min	5.65	9.08
T90%	min	11.5	20.29
Dynamic properties -25c			
E'	N/mm2	4,22	5.248
E"	N/mm2	0,51	0.826
Tangent Delta		0,12	0.157
Rebound		34.5	37
DIN Abrasion	mm3	142	112
Tear -Die B	kg.cm	112	47

The manufacture of industrial solid tyres in Sri Laka started in 1981, and today there are several leading manufacturers of these tyres in the country. This industry has expanded seriously during the last 20 years, as a result of which the country is known worldwide as a very large solid tyre producer for the world market. The contribution of this industry to the national income is large, and continues to show further growth (table 5).

Table 5. Export Income (Rs. Min) from different product categories

Year	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Total rubber and rubber products	8614.1	13623.5	15108.7	15163.2	14335.8	14004.5	17101.9	17538.1	19986.2	26010.5
Total Rubber Products	4995.4	7829.0	9333.8	10480.3	11470.6	11598.6	14854.2	15388.9	17391.1	22231.0
Total Raw Rubber	3582.2	5709.7	5744.7	4648.5	2807.6	2303.9	2179.0	2121.4	2523.2	3716.5
Rubber Compounds etc	36.5	84.8	30.2	34.4	57.5	102.0	68.7	27.8	71.9	63.0
	8614.1	13623.5	15108.7	15163.2	14335.8	14004.5	17101.9	17538.1	19986.2	26010.5
Latex	110.4	158.1	38.8	13.9	2.0	26.4	16.4	30.6	80.3	47.0
Dry rubber	3471.8	5551.5	5705.9	4634.5	2805.6	2277.6	2162.6	2090.8	2442.9	3669.5
Latex thread, gloves etc.	2391.9	3588.6	4282.4	4749.1	4380.3	3998.2	5089.5	5601.2	6429.7	7709.7
Flooring and mats	227.5	357.3	373.0	487.9	507.5	618.5	768.2	741.5	791.8	755.3
Solid tyres	1642.4	2579.7	2663.7	2996.5	3772.2	3617.8	5238.7	4908.7	5023.5	7517.4
Pneumatic tyres	196.3	568.3	990.9	1217.8	1610.9	1780.6	2355.7	2419.0	3064.2	4044.0
Inner tubes	14.9	48.0	107.0	109.0	109.7	435.5	111.0	175.1	202.9	103.7
Other	558.9	772.0	946.9	954.4	1147.6	1249.9	1359.8	1571.3	1950.9	2163.9
Total rubber and rubber products	8614.1	13623.5	15108.7	15163.2	14335.8	14004.5	17101.9	17538.1	19986.2	26010.5

The current production of solid tyres in Sri Lanka is more than 50,000 tons/year. This should account for a rubber consumption of about 25000 tons.

Industrial solid tyres are used on many vehicles among which forklift trucks occupy a major position, while trailers and some other vehicles too operate with such tyres. The important characteristics of these tyres are the durability, load stability, puncture resistance, suitability for use in hazardous environments etc. These tyres are usually made by compression moulding , although injection moulding is also sometimes used for smaller sizes.

There are two major types of solid tyres, named as Press-On-Solid and Resilient. They are usually available as black tyres, made up of carbon black containing rubber compounds, while non-marking tyres containing silica are also made for special applications. In the market, there are other special types too, with specific characteristics such as low rolling resistance, cut resistance, electrical conductivity , fire resistance, oil resistance etc.

2.1.1.1. Press-On Solid Tyres

Press-On type solid tyres have been the earliest form of industrial solid tyres. Here, the tyre consists of a relatively thin working rubber layer (tread), which is firmly attached to an internal steel ring (band). The thickness of the steel band is between 8-10 mm. The tyre is fixed to the wheel of the vehicle only by a forced-fit between the outer surface of the wheel and the inner surface of the steel band. A strong hydraulic press is needed for mounting and de-mounting these tyres (Fig.2).

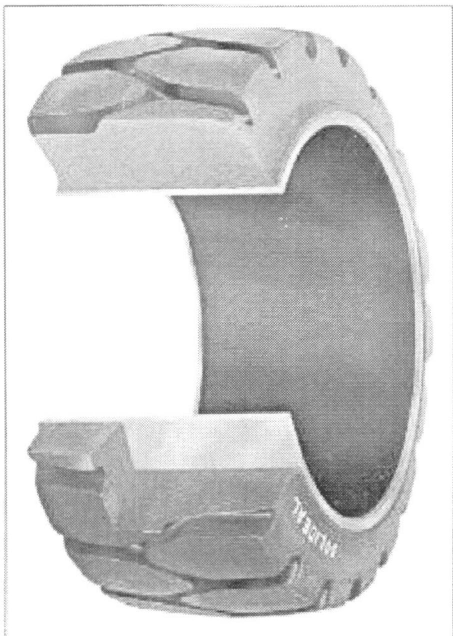


Figure 2. Cross section of a press-on solid tyre

The only method by which the rubber layer is fastened to the steel band is by efficient rubber-to-metal bonding. Chemical bonding agents based on chlorinated polymers are mostly used here. The rubber layer usually consists of one compound, while in some instances, a thin layer of a specially formulated bonding compound may be used just over the steel. There are also special purpose tyres with multi layer compounds, available for selected applications.

Sizes of these tyres vary from very small ones with about 4 inches in inner diameter up-to very large ones with 30 inches in the same dimension. The thickness of the rubber layer usually varies from about 2 inches up-to 5 inches.

2.1.1.2. Resilient Solid Tyres

These tyres have become popular during the last four decades. The resilient tyre resembles a pneumatic tyre on the outside, while the entire cross section is filled with rubber. They fit to the standard rims where pneumatic tyres are fitted, although a press is needed for mounting and de-mounting.

The Resilient tyre usually consists of three basic layers, viz. the Heel, Middle and Tread.
There could be additional intermediate layers to facilitate a smooth transition in the properties from one layer to another.

The function of the heel is to maintain a good slip-proof hold on to the rim, and thus has to be made out of an extremely tough material. The rubber compounds used here contain very high levels of reinforcing fillers, in addition to textile fibbers as well as hardening resins. Often, some metal reinforcement is also included to ensure that the tyre remains firmly attached to the rim while in service.

The Middle layer functions as a virtual innertube, providing the riding comfort and is usually made of a low hardness rubber compound. As this layer has no requirement for wear resistance, semi reinforcing fillers are used here.

The tread layer is very similar to that of a pneumatic tyre, and consists of a wear resistant rubber compound (Fig 3).

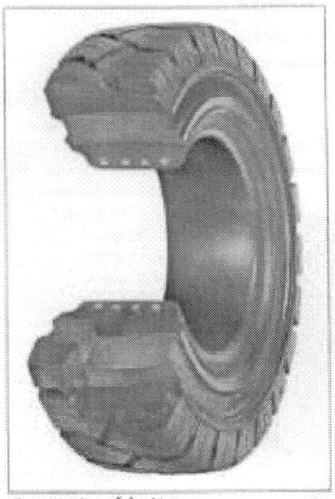


Figure. 3- Cross section of a resilient solid tyre.

2.1.2. Industrial pneumatic tyres

In addition to being the leading solid tyre producer, Sri Lanka has also started manufacturing pneumatic tyres for Industrial, Agricultural and Construction vehicles in a noteworthy manner. Today, these tyres are produced in the country for Backhoes, Cranes, Compactors, Wheel loaders, Skid steers, Dumpers, Graders etc. to be exported to the world market in large numbers. The production process of these tyres is exactly similar to the production of pneumatic tyres for highway use. The income generated from export of such tyres is showing an upward trend as seen in table 3.

2.1.3. Flooring and Engineering products

Another sector which has seen remarkable progress is the manufacture of flooring and engineering components for the export market. Rubber mats are produced in Sri Lanka in a large multitude of designs for different end uses. Manufacture of engineering products has also started to show considerable progress. Many seals, gaskets and other mouldings are being supplied to world reputed heavy industries by local producers. Both Natural and Synthetic rubbers are used in the manufacture of these products. Up-do date technology employing compression moulding, transfer moulding and injection moulding processes are utilized in their manufacture.

2.1.4. Rubber products for domestic use

This has been the beginning of the local rubber product industry where, tyre retreads, new pneumatic tyres for road vehicles, bicycle and motor cycle tyres, footwear, extruded and moulded goods etc. have been produced during the last 60 years and this sector of the industry is continuing to show, slow yet steady progress.

3. Chemistry and Technology

3.1. Chemistry and Materials

Dry rubber product manufacture involves with complex chemistry, and it is possible to say that the most developed chemical industry in the country is also the same. A variety of complex ingredients and other materials including polymers, resins processing aids and Fillers are being used today in large quantities. Environmentally safe methods of handling them are also in place. It is also noteworthy that although Sri Lanka had the intention of using only Natural rubber in all the products manufactured, today a number of Synthetic rubbers in considerable quantities are also being used by the industry.

3.1.1. Polymers

In addition to consuming about 55,000 tons (both latex and dry rubber), Sri Lankan rubber industry consumes today at least 20,000 tons of synthetic rubbers such as SBR (styrene butadiene rubber), BR (poly butadiene rubber), CR (chloroprene rubber), NBR, (acrylonitrile butadiene rubber), EPDM (ethylene propylene diene rubber) and IIR (isoprene isobutylene rubber).

3.2. Technology

Manufacturing rubber products out of dry rubber involves the use of advanced technology and very heavy equipment. Advancements in rubber technology are being continuously made, and they are also applied to the local industry. Large investments are necessary for starting and maintaining manufacturing facilities. The energy consumption in this sector is also very high.

3.2.1. Mixing

The most widely used and upto date technologies are used in the manufacture of compounds for rubber products. Mixing of rubber compounds constitutes one major section of the industry and the use of internal mixers and roll mills is common. In contrast to the situation which occurred about 20 years ago, today there are more than 40 internal mixers and over 200 roll mills in operation in the country. The installed compound mixing capacity in the country could be at least 80,000 tons per year, and this is expanding further. Coupled with the compound mixing are the modern environmentally friendly bulk material handling systems, which are also now common.

3.2.2. Other processes and equipment

Calenders, Extruders, Injection moulding presses, Curing presses, tyre building machines etc. are the other important equipment used in the manufacture of dry rubber products. Manufacturing products where technologies for rubber to metal bonding, rubber to fibre bonding are used, is also taking place in a considerable manner.

4. Testing

In order to carry out testing to control the production process as well as to evaluate the finished products, a large array of testing equipment is available with the individual product manufacturers and also at the institutes which provide technical support to the industry. It can be said that it is possible to test almost any property of a rubber compound or a product using test equipment locally available.

5. Conclusions

Rubber product manufacturing industry in Sri Lanka is an industry which has shown considerable progress in the recent past. The industry is gradually growing and every effort should be made to maintain the positions already achieved in the export market. Advancements in science and technology related to this industry should continue to be applied in order to maintain our competitiveness in the global market. The local short fall in the availability of natural rubber is beginning to appear as an area of concern in relation to further progress.

8205

Studies on Improvement to Copra Drying Process and Quality of Copra

[1]J M M A Jayasundera, [2]U Samarajeewa, [1]C Jayasekera, [1]A R Kulatunga and [1]M Rajapakse
[1]Coconut Research Institute, Lunuwila, Sri Lanka
[2]Department of Food Science & Technology, Faculty of Agriculture
University of Peradeniya, Peradeniya, Sri Lanka

ABSTRACT

The copra kiln of the Coconut Research Institute was modified for the use of charcoal powder as fuel, understanding drying patterns in the kiln and working out the most appropriate height between charcoal bed and the copra drying platform to improve quality of copra. The most suitable height was assessed to be 1.2 m and the drying method as three rounds of firing using charcoal as fuel. Charcoal powder bed (width 30-40 cm) was laid down lengthwise in the drying chamber, each bed containing 15 kg. Three hundred grams of sulphur was used to fumigate the kiln to manage insects. The optimum conditions established for drying using charcoal powder for kernels of 1500 coconuts are as follows. Sun drying of kernels was followed by three firings each using 45, 45 and 30 kg of charcoal powder. The final moisture content of copra was 7.0 ± 1.0 %. The mean percent of grade 1 copra was 90 ± 3 %. The copra (grade 1 and grade 2) was stored separately in gunny bags under ambient conditions (RH 72-83 % and temperature 30 ± 2 °C) to observe moisture equilibration, both grades remained for 4 weeks without microbial spoilage. In shelf life assessment experiments, copra stored in open buckets under ambient conditions maintained 6.5 ± 0.5 % moisture with no mold growth up to 8 weeks. When copra was stored in gunny bags for three weeks with a known % of insect infested kernels, the infestation spread only within the infested kernels.

Key words: Coconut kernel, copra, copra grader, copra kiln

INTRODUCTION

In Sri-Lanka copra is mostly dried in the 'Standard Ceylon Copra Kiln', which was designed about 50 years ago by Coconut Research Institute with the objective of obtaining quality copra. The drying process requires 5 days with 8-9 firings using double rows of shells.

A few copra kiln owners have moved into the use of charcoal powder. Judging by the overall grades of copra produced as determined by an expert on quality, the use of charcoal powder provides distinctly better quality copra (MS grades) (Rodrigo, 1998).

The use of charcoal powder provides a much more uniform and low heat compared with shell firing with double or single rows (Rodrigo, 1998). The charcoal powder is a low cost fuel (Rs. 2100 per 500 kg) compared to the shells. Another advantage of the use of charcoal powder is that it reduces polycyclic aromatic hydrocarbons (PAH) to a level below the tolerance limits (<25 ppb) (Wijeratne et al, 1996).

The Coconut Research Institute modified the 'Standard Ceylon Copra Kiln' in 1996 (unpublished work) for the use of charcoal powder as fuel with the aim of producing quality copra with the desired attributes expected from its use. The modifications were done to the firing chamber since the width and the height (charcoal bed to drying platform) of firing chamber are critical in the drying process (Rodrigo, 1998). The dimensions of the firing chamber are as follows. The height (charcoal bed to drying platform) is 2.1 m, the width is 2.0 m and the length is 3.7 m. Several trials were conducted in this firing chamber. However, copra on the front side of the copra bed didn't dry properly leading to microbial spoilage after three to four firings. If copra is not dried to moisture contents below 8 %, fungal growth may occur during storage reducing the quality of the end product (Rodrigo, 1998).

The objective of this study was to identify possible improvements to the 'Modified Ceylon Copra Kiln' with the use of charcoal powder as fuel in producing high quality copra.

MATERIALS AND METHODS

Development of the Kiln

Two chambers of the 'Improved Ceylon Copra Kiln' were modified stepwise experimenting to achieve the highest efficiency and uniformity of drying using charcoal powder. Preliminary experiments were carried out to find out the most appropriate height of firing chamber, ventilation holes per chamber and the method of laying charcoal (row or flat). The experiment was continued with the most appropriate height of the firing chamber with the required number of ventilation holes and the better method of laying charcoal. Four firing levels (1^{st} firing - soon after loading the sun dried halves of coconuts on the copra drying platform, 2^{nd} firing - 24 hours after the 1^{st} firing, 3^{rd} firing - 48 hours after the 2^{nd} firing and 4^{th} firing - 24 hours after the 3^{rd} firing) with different amounts of charcoal for each firing (1^{st} firing -36 kg in 2 rows, 45 kg in 3 rows, 60 kg in 4 rows and 64 kg in 4 rows; 2^{nd} firing -36 kg in 2 rows, 45 kg in 3 rows, 60 kg in 4 rows and 64 kg in 4 rows; 3^{rd} firing - 22 kg in 1 row, 30 kg in 2 rows and 45 kg in 3 rows ; 4^{th} firing - 22 kg in 1 row and 30 kg in 2 rows) were applied to find out the optimal number of firings and the optimal amount of charcoal for each firing. Three hundred grams of sulphur was burnt to fumigate the kiln before the first firing of each trial.

Data Collection

Moisture in copra and temperature in copra bed were taken for each combination of firing level and the amount of charcoal at 3 different time intervals (3 hrs, 15 hrs and 21 hrs after each firing) to decide the best combination of firing level* amount of charcoal* time.

Estimation of moisture

Copra (5 g) sliced into pieces of < 2.0 mm thickness was dried at 102 °C for 2 hrs for the estimation of moisture (Pearson, 1976). Sampling was done from three different locations of the copra bed (rear end, middle and front).

Estimation of temperature

The temperature of air at the drying platform (copra bed) was measured during drying by locating 50 ml bottles containing water at different locations (rear end, middle and front) of the copra bed and measuring the temperature of water.

Grading of copra

The copra produced by the modified charcoal fuelled kiln was graded on the basis of commercially used grading systems for copra produced from shell-fired kiln (The Ceylon Copra Kiln, 1965).

Storage of copra under ambient conditions (30±2 °C and 72-83 % RH)

Hundred kilograms each of grade 1 and grade 2 copra, produced by the modified charcoal fuelled kiln were stored separately in gunny bags under ambient conditions till initial signs of spoilage were observed.

Storage of copra under laboratory RH conditions

Ten cups each of copra were exposed to different RH at (30±2 °C) in buckets equilibrated with saturated solutions of 33 % - magnesium chloride, 70 % - sodium chloride, 100 % - distilled water, atmospheric - open bucket with no solution (varied between 72 % to 83 %) and closed bucket with no solution (88 %). Each sample was observed for visible growth of molds for 10 weeks.

Spread of insect infestation on storage

Fifty insect infested cups were stored with 50 uninfested cups in gunny bags for 3 weeks and each cup was visually examined for insect and fungal growth.

STATISTICAL ANALYSIS

Data analysis was based on the Proc ANOVA in SAS.

RESULTS AND DISCUSSION

Results of Preliminary experiments

There was no statistically significant difference ($P>0.05$) in the temperature between copra beds of 0.9 m and 1.2-m heights. Since the laying of charcoal powder has to be done manually, 1.2 m was selected as the acceptable height. Spreading of charcoal powder in rows found to give a significantly ($P<0.05$) better temperature distribution than flat spread.

Optimal number of firings

The operational system needed 3 firings to bring down the moisture content to less than 8 % (Table 1). There was no significant ($P>0.05$) decrease in moisture by a fourth fire.

Table 1. Mean moisture % of copra and mean temperature (°C) of copra bed at each firing in the charcoal fuelled chamber

No. of Firings	Mean Temperature (°C) ±SE	Mean Moisture %±SE
1	44.2±0.9 A	28.6±0.6 P
2	47.8±1.0 B	16.8±0.4 Q
3	41.6±0.9 C	7.1±0.5 R
4	41.6±1.7 C	7.0±0.6 R

SE- Standard Error
Means with different letters significantly different from each other

Optimal charcoal amount for each firing

Optimal amount of charcoal for each firing was investigated (Table 2). In the 1st firing the lower moisture content of copra and higher temperature in copra bed were observed with 45 kg, 60 kg and 64 kg of charcoal compared to those of 36 kg. Since there was no significant difference in moisture of copra and temperature in copra bed with the 3 charcoal amounts (45 kg, 60 kg and 64 kg) the least amount of charcoal (45 kg) among these 3 amounts was selected for the 1st firing. Forty-five kilograms (45 kg) and 30 kg were selected for 2nd and 3rd firings respectively on the same principle as for the 1st firing.

It was found that at each firing the moisture content of copra and temperature of copra bed reduced with time (Table 3 and Figure 1). The temperature of the copra bed varied from 69 °C to 34 °C. The moisture content of (7.0±1.0 %) of copra was reached after 21 hrs of the 3rd firing. Case hardening was not observed in copra so produced. Recommended-operation schedule for copra drying is given in Table 4.

Table 2. The moisture and temperature at each combination of firing level* amount of charcoal

No. of Firings	Total Amount of Charcoal (kg)	No. of Rows	Mean Temperature (°C)±SE	Mean Moisture %±SE
1	36	2	36.1±2.2 a	28.9± 0.7 A
1	45	3	43.7± 1.0 b	24.5± 0.2 B
1	60	4	45.1± 1.0 b	23.7± 0.8 B
1	64	4	46.4±0.7 b	23.0± 0.6 B
2	36	2	41.1± 0.4 p	19.3±0.5 P
2	45	3	45.9± 0.3 q	17.7±0.1 Q
2	60	4	48.1±1.2 q	17.5±1.2 Q
2	64	4	48.9±3.3 q	17.0±0.9 Q
3	22	1	37.5±0.8 x	12.2±0.2 X
3	30	2	41.8±1.1 y	7.2±0.1 Y
3	45	3	42.0±0.6 y	7.1±0.2 Y

SE- Standard Error
Means with different letters significantly different from each other

Table 3. The temperature of the copra bed during firing and the remaining moisture content in copra after firing

No. of Firings	Total Amount of Charcoal (kg)	Time (hours)	Mean Temperature (°C)±SE	Mean Moisture %±SE
1	45	3 14 21	57.3±2.1 a 42.0±1.0 b 36.7±0.7c	32.4±0.7 A 28.0±1.2 B 24.6±1.0 C
2	45	3 15 21	69.0±1.2 p 45.6±1.0 q 37.3±0.5 r	21.0±1.0 P 17.4±0.9 Q 14.1±0.8R
3 2	30 64	3 15 21	58.6±2.2 x 39.2±1.1 y 33.5±0.7 z	9.2±0.5 X 8.8±0.3 X 7.0±1.0 Y

Grades of Copra

The copra produced using charcoal powder resulted in 90±3 % grade 1 copra (Table 5).

Table 4. Recommended operation schedule for copra drying

Day	Time	Operation
1	7.00 a.m.	Split the nuts and sun-dry on the cement floor
	5.00 p.m.	Load the drying platform with halves of 1500 nuts Arrange charcoal powder (45 kg) in three rows of 15 kg eachand start firing (1st firing)
2	3.00 p.m.	Mix halves (exchanging cups in the front and rear ends of the drying platform)
	5.00 p.m.	Arrange charcoal powder (45 kg) in three rows of 15 kg each and start firing (2nd firing)
4	12.00 noon	Remove the shells
	5.00 p.m.	Arrange charcoal powder (30 kg) in 2 rows of 15 kg each and start firing (3 rd firing)
5	5.00 p.m.	Drying complete and cups are ready for storage(Copra produced contain less than 8 % moisture)

Shelf life of stored copra under ambient conditions

The moisture absorption by grade 2 was greater than that of grade 1 at all times (Fig. 2). Both grade 1 and 2 could be stored up to 4 weeks. Fungal growth was observed in both grades on the 5th week. The moisture contents of grade 1 and 2 copra on the 5th week were 8.6±0.1 % and 9.0±0.1 % respectively.

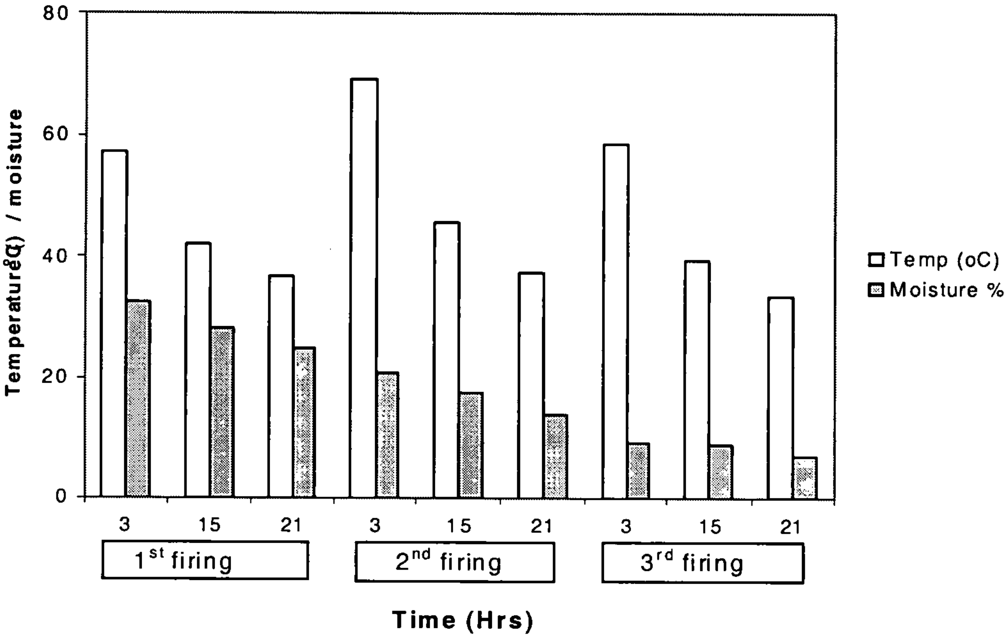


Figure 1. The temperature of the copra bed during firing and the retained moisture content in copra after firing

Table 5. Mean grade percentages of copra in charcoal fuelled chamber

Grades	Mean %±SE
1	90±3
2	8±2
3	2±1

SE- Standard Error

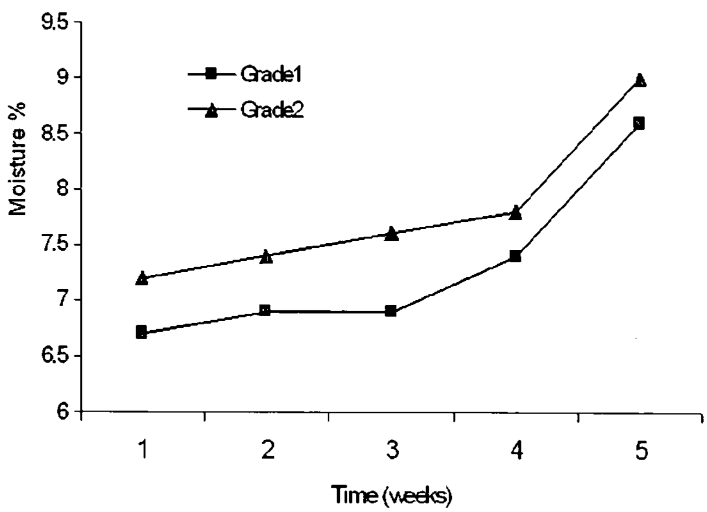


Figure 2. Variation of moisture content of grade1 and 2 copra with time

Moisture equilibration of copra under laboratory RH conditions

Copra kernels stored in airtight buckets at RH 100 % and RH 70 % continued to absorb moisture leading to microbial spoilage in 2 weeks (moisture was 8.6±0.2 %) and 4 weeks (moisture was 8.2±0.2 %) respectively. Copra kernels stored in airtight buckets under ambient conditions too continued to absorb moisture leading to microbial spoilage in 3 weeks (moisture was 8.8±0.1 %). Copra kernels stored in airtight buckets at RH 33 % continued to lose moisture until the 10th week of storage with no mold growth (moisture was 5.8±0.1 %). Copra stored in open buckets had a shelf life of 8 weeks maintaining a mean moisture of 6.5±0.5 % with no mold growth. However, when moisture of copra was more than 8.0 % the mold growth became visible irrespective of the relative humidity of the stored environment. The best RH for storage of copra was found to be at 33 % RH among RH tested. Copra could be stored for 8 weeks without affecting the quality of copra in open buckets (72-83 % RH). The reason for long shelf life of copra in open buckets may be due to the movement of air in open buckets, which prevented surface deposition of moisture on cups in contrast to a fixed RH in airtight buckets (70 %, 88 % and 100 % RH).

Insect infestation on Storage

The number of insect infested cups did not increase on storage of copra in gunny bags for 3 weeks. However, in the already infested cups the number of holes created by the insects increased over the period.

CONCLUSION

The charcoal-fired chambers designed can be used effectively to produce better quality copra, which could be stored under ambient conditions for 4 weeks.

ACKNOWLEDGEMENT

The authors wish to thank the staff of Biometry Division of Coconut Research Institute for assisting in statistical analysis of data.

REFERENCES

Pearson, D 1976 The Chemical Analysis of Foods. Chemical publishing Company Inc., New York .7th Edition. 357 p.

Rodrigo, M C P 1998 Smoke Curing and Aflatoxin Contamination in Coconut Kernel Products. M.Phil Thesis, PGIA, University of Peradeniya, Peradeniya. 58 - 70.

Samarajeewa, U, Illeperuma, C D K 1985 Moisture Adsorption through Packaging Materials used for Desiccated Coconuts. J. Natn. Sci. Coun. Sri Lanka. 13, 45-52.

The Ceylon Copra Kiln 1965 Coconut Research Institute Leaflet No.15.

Wijeratne, M C P, Samarajeewa, U and Rodrigo, M C P 1996 Polycyclic aromatic hydrocarbons in coconut products. J. Natl. Sci. Coun. Sri Lanka. 24 (4): 285-297.

Technical Session 6

Socio Economic Aspects

Marketing in the Smallholder Rubber Sector: Existing Status and Possible Improvements

[1]J Edirisinghe, [2]W Wijesuriya, [1]D M A P Dissanayake,
[2]M Wijeratne, [1]K Herath and [1]V Abeywardene
[1]Rubber Research Institute of Sri Lanka, Agalawatta, Sri Lanka
[2]Faculty of Agriculture, University of Ruhuna, Sri Lanka

ABSTRACT

Smallholders contribute significantly to the natural rubber production in Sri Lanka. However, it was seen in the recent past that the smallholder extents declining and they were moving out of the industry. The main reason associated with this was the low prices received by the smallholders. Though a recent hike in prices was observed, the income status of the small farmer is still very low. Therefore, it is necessary to understand why the high prices quoted at the auctions are not received by the producers and the reasons why smallholders are not keen on producing high quality rubber sheets.

The inquiries into marketing of smallholder production hitherto have been very minimal and have been limited to study of marketing channels. Therefore, this research attempted to study the existing status of the smallholder rubber marketing through quantitative and participatory approaches, taking into consideration the marketing channels of smallholder production, marketing efficiency in terms of technical (production) and pricing efficiency. Possible improvements on the existing system of marketing are also discussed in this paper.

Key words: Participatory Rural Appraisal (PRA), pricing efficiency, rubber marketing, rubber smallholder, technical efficiency

INTRODUCTION

Agricultural marketing has been defined in many ways. In most of the definitions the flow of goods and services from the producer to the consumer has been highlighted. According to Purcell (1979) it is difficult to separate production and marketing and states that marketing can be defined as a set of economic and behavioral activities that are involved in coordinating the various stages of economic activity from production to consumption. Production agriculture, in most cases are said to be in pure competition and thus the farmers are price takers rather than price makers. The price is decided at the industry level and the individual producer (farmer) has to adjust the quantity he is producing to obtain profits. However, in such situations farmer is said to be facing a "micro-macro paradox" (Purcell, 1979). Where, the increase in industry price levels due to an increase in the industry demand pushes the farmer to increase production. But in macro level, more farmers enter into production and the prices decrease again.

There are many approaches to study marketing, its problems and potentials. These include the commodity approach, institutional approach, functional approach and the systems approach. Out of these, systems approach is deemed to be more suitable as it places emphasis on total marketing system rather than individual parts of the system. The behavior/economic activity of each stage of the marketing system are discussed in the context of the total system. This study attempts to understand the coordination between interfaces of different stages in the rural rubber marketing systems and to discuss the problems and possible improvements that affect the overall systems' efficiency.

METHODOLOGY

For the purpose of data collection two methods were employed; a conventional socio-economic survey and a Participatory Rural Appraisal (PRA). The participatory tools involved include mobility mapping and institutional analysis.

Out of the five major rubber growing districts in Sri Lanka, three rubber growing districts were identified for the study *viz.* Kegalle, Kalutara and Ratnapura. A socio-economic survey was carried out in nine villages representing three villages from each district (Table 1).

Table 1. The sampling schedule for survey

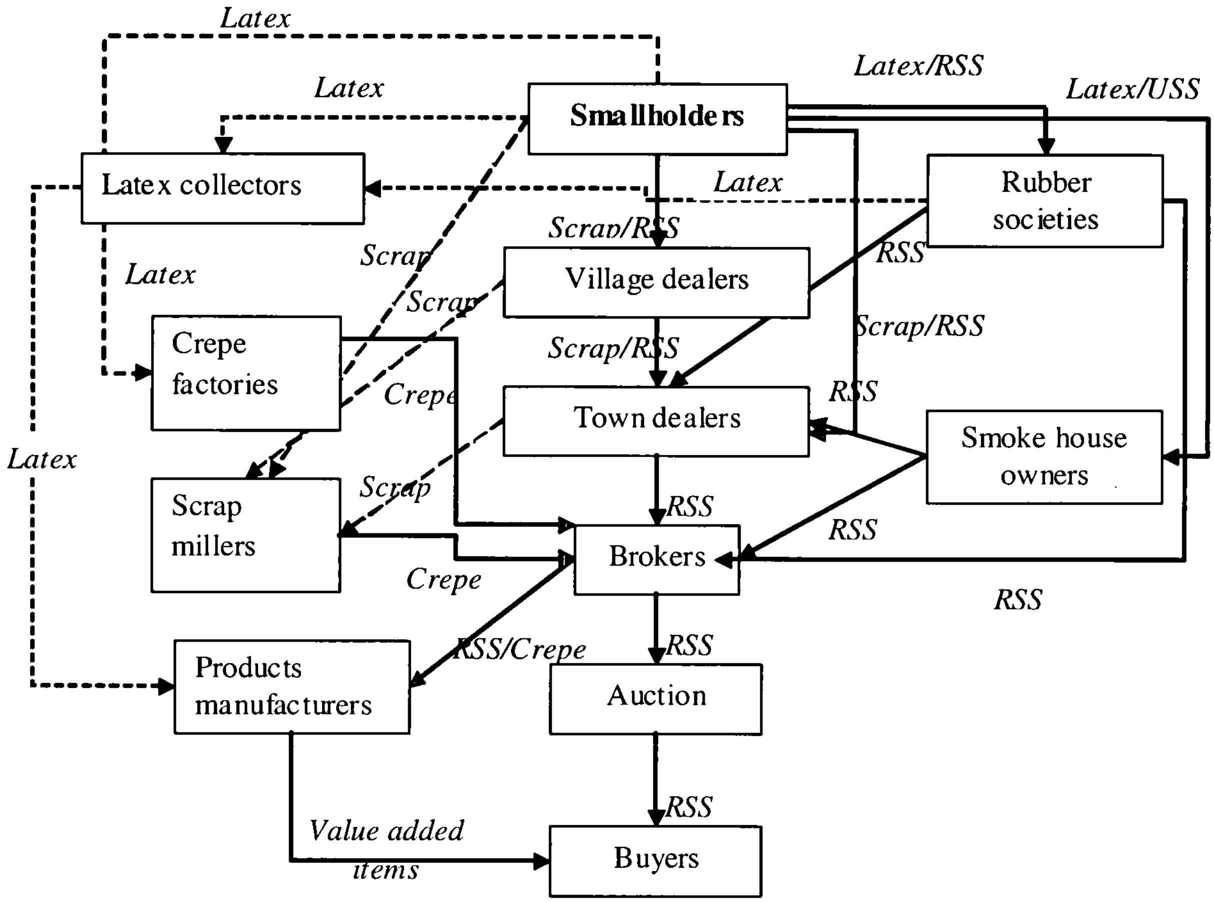
	No. of smallholders surveyed		
	Kegalle	Kalutara	Ratnapura
Village 01	99	61	107
Village 02	73	59	80
Village 03	59	45	71
Total	231	165	258

Out of the 9 villages selected for the socio-economic survey, three villages (one from each district) were selected to conduct participatory studies. They were Welihelatanne, Batugampola and Pohorabawa from Kegalle, Kalutara and Ratnapura districts, respectively. Additional information from secondary sources were also employed in the study.

RESULTS AND DISCUSSION

The market channel of rubber smallholder

Data generated from the socio-economic survey and PRA were used to develop the smallholder market channel laid out in Fig. 1. It is evident from Fig. 1 that output of the small rubber farmers is of 3 main types; *viz.* Ribbed Smoked Sheets (RSS), Unsmoked Sheets (USS) and latex. In addition, farmers sell the scrap collected, as well. Though rubber is sold as latex as well, it is predominantly sold as sheet rubber (as RSS or USS). Table 2 presents the summerised data generated from three villages from each district on output type sent to the market by small farmers.



RSS – Ribbed smoked sheets
USS – Unsmoked sheets

Fig. 1. Market channel for smallholder rubber

Table 2. Output type of smallholders by district

Output type	% output of different types in districts*		
	Kegalle	Kalutara	Ratnapura
RSS	77%	61%	95%
USS	6%	39%	1%
Latex	17%	-	4%

* Data generated from all 9 villages

It is evident that in all three major rubber growing districts, production of sheet rubber is above 80% of the total output of small farmers. Therefore, the major pathway the smallholder production moves to the ultimate buyer is the marketing channel for sheet rubber. Hence, emphasis is placed upon the marketing channel for sheet rubber in this study. The major reason for not selling more rubber as latex is not that it is not profitable, but the lack of latex collectors in every district, though recently some private companies have started latex collection in some areas. Another reason is that sheet rubber can be stored for sometime with the producers if they wish to do so. However, it is important to note that with the increase in local consumption the demand for latex may increase due to the dipped products industry.

The other important factor to note is the involvement of quite a number of middlemen in the market channel. The roles and the functions of some of these middlemen are described below.

Village Dealer

Village dealers are the traders who buy rubber directly from farmers. Though a grading system is prevailing for sheet rubber, they tend to buy in bulk, improving their chances of better profit margins. They undertake following functions.

1. Negotiate price with the farmers depending on the price they receive from larger dealers (town dealers).
2. Collect and store sheet rubber until taken to town dealers (mainly).
3. Transport rubber to town dealers.
4. Sort rubber into different grades.
5. Offer credit facilities to small farmers.
6. Transmit price signals to farmers.
7. In most cases they carry out retail business in addition to rubber trading and thus attract small farmers to them by providing credit in terms of essential items for household consumption

Town Dealers

These are traders in most occasions, larger than the village dealers and collect rubber received from different villages.

They undertake following functions.

1. Negotiate price with village dealers and in some cases with farmers directly.
2. Collect and store sheet rubber and have higher storage capacity than village dealers.
3. Sorting and grading of rubber.
4. In some cases undertake transport from village dealers to their warehouses.
5. Offer credit facilities to small farmers as well as village dealers.
6. Comparatively higher bargaining power than village dealers.
7. Maintain close contact with brokers and aware of changes in prices.
8. Collect rubber from smoke house owners, village dealers and rubber societies.

Smoke house owners

These are involved in marketing as well as in the production process. They convert unsmoked sheets to smoked sheets improving value of the rubber sheet. They have following characteristics.

1. Convert unsmoked sheets to smoked sheets (RSS) and thus involved in value addition of the rubber sheet.

2. Inputs to the smoke house owners can be unsmoked sheets, latex or half smoked sheets
3. Sell rubber to village dealers, town dealers or brokers directly.
4. In some cases undertake transport as well.

Broker

The brokers' role is seen in the rubber auction. The rubber brokers currently involved in the trade are;

1. Forbes and Walker Group of Company,
2. John Keels Ltd.,
3. H W J Dias Brothers,
4. Somerville and Co.,
5. De Silva Abeywardana Co. and
6. Western Brokers.

The most important function of the broker is providing the link between the growers, millers and traders with the buyers, shippers and the local consumers. Brokers represent the owners of rubber in the auction floor and earn a commission for the service they provide. They provide following additional services to their clients.

1. Transport rubber to town.
2. Generate and disseminate information on price and market trends.
3. Sell rubber either on the auction floor or by forward contracts.
4. Attend to any queries regarding the developments on the rubber market.
5. Some provide advance payments up to 50% of the value of rubber.

The marketing efficiency

Marketing efficiency is measured in terms of two aspects *viz*; technical efficiency and pricing efficiency.

The technical efficiency of small farmer

The technical efficiency refers to the input-output relationship in the task of producing utiltiy throughout the marketing system. Studying the technical efficiency throughout the marketing system by treating each stage in the marketing system as an input output system is a huge task. However, the techncal efficiency of the focal point in this paper, the smallholder, is discused here.

Factors affecting technical (production) efficiency at smallholder level

(a) Size of the holding

The size of the holding has an effect on the efficiency of production and marketing since the economies of scale comes into operation. In addition, when the holding size is higher, the production become higher. This leads to increased bargaining power of the smallhloder. The average size of the smallholder sector in the studied districts is given in Fig.2.

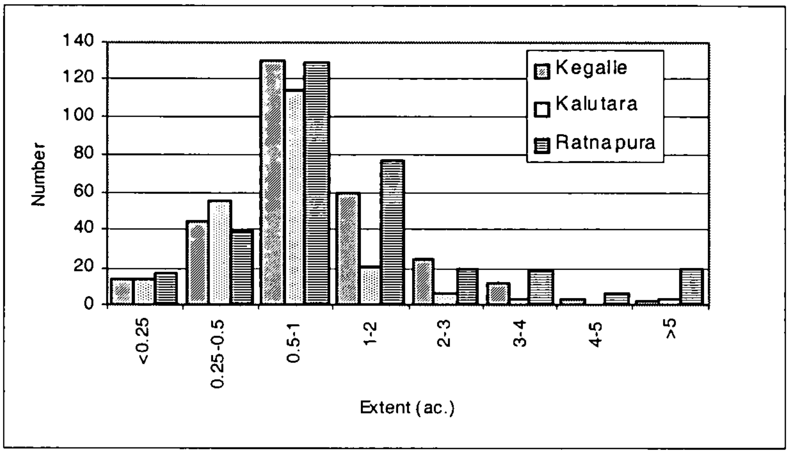


Figure. 2. Distribution of land extent of smallholdings

It is evident from Fig. 2, that majority of farmers have 0.5 – 1 acre holdings and thus are not in a position to have a higher bargaining power or obtain benefits of economies of scale.

(b) Nature of rubber lands

Table 3 presents data on the percentage of rubber lands under immature, mature and in abandoned status.

Table 3: Present status of rubber lands

Status	Percentage of lands in each district		
	Kegalle	Kalutara	Ratnapura
Immature	22%	24%	30%
Mature	73%	68%	63%
Abandoned	5%	5%	5%

The percentage of rubber lands under immature stage is too high in each district, indicating low adoption of recommended technologies. It is also a notable factor that a considerable portion of rubber extent is abandoned due to poor management or low prices received. The age distribution of immature rubber holdings in the three districts studied is given below in Fig.3.

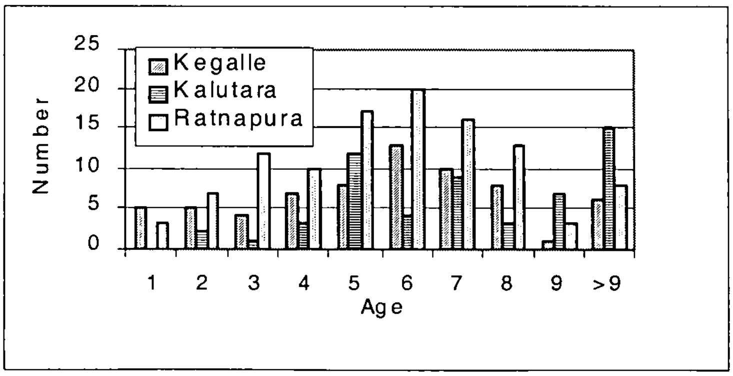


Figure. 3. Age distribution ofimmature rubber holdings

The normal length of the immature period of rubber is 6 years. However, above data indicates that there are lands that are above 8 years as well. The percentage of lands aged 8 years or above is 28%. This has a serious impact on technical efficiency. This is mainly due to poor adoption rates of recommended technologies during the immature phase of rubber.

(c) Use of improved clonal material

Use of improved clonal material in the smallholdings improve the productivity and thus the technical efficiency. According to Table 4, though there is a higher percentage of improved clones in the immature holdings, the percentage of improved clones in the mature holdings which contribute to the productivity, is very low. It is below 50% in all three districts.

Table 4: percentage of improved clones in smallholdings

Stage	% of improved clones in the selected districts		
	Kegalle	Kalutara	Ratnapura
Immature holdings	82	71	91
Mature holdings	22	45	47

(d) Use of fertilizer

Another important input in rubber production is the use of fertilizer. It is evident form Fig. 4, that the use of fertilizer in the mature rubber is very low. Possibly the awareness on the importance of fertilizer application is poor with smallholders. Low income levels is also another reason for the low adoption rates. This may hamper the productivity of the rubber lands.

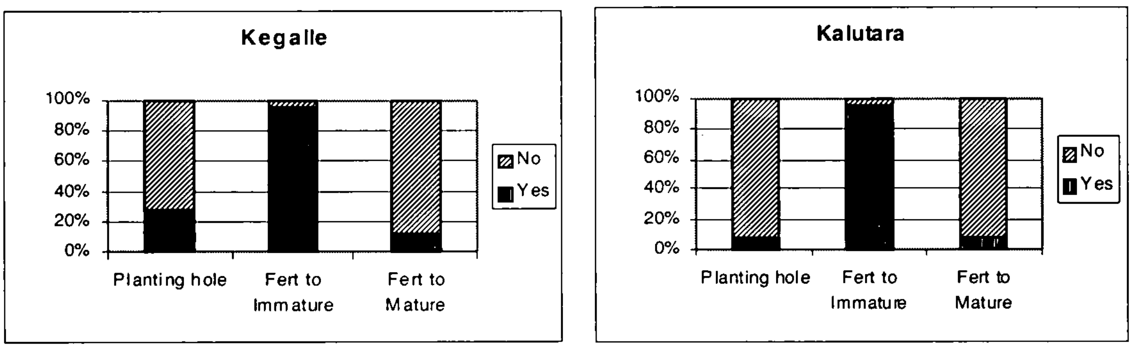


Figure.4. Use of fertilizer in Kegalle & Kalutara Districts

The pricing efficiency

The pricing efficiency refers to the capacity of the system to effect change and to prompt a reallocation of resources to maintain consistency between what is produced and what is demanded (Purcell, 1979). In short, what is demanded by the buyers should be transmitted to producers through prices. However, the economic environment within which the smallholder rubber marketing takes place does not always facilitate this. Table 5 presents data on the buyer and seller concentration in three villages where participatory studies were carried out.

Table 5: Rubber farmers and dealers in 3 selected villages

Village (Region)	No. of rubber growers	No. of rubber dealers
Welihelatanne (Kegalle)	91	7
Batugampola (Kalutara)	61	2
Pohorabawa (Ratnapura)	107	6

The dealers (buyers) of smallholder rubber in rural rubber markets are very low compared to the number of sellers (producers). Therefore, an oligopsony is evident in the market. Hence, farmers are price takers rather than price makers. The farmers have to adapt to prices set by the industry. However, it should be emphasized that local rubber price is dependent on international markets (Wijesuriya *et. al.*, 1995). Therefore, the situation is worse and the farmers have to depend on the prices set internationally.

The communication system of price and information

The communication system of a market is the system by which the prices and other important information flow from the ultimate buyer to the producer. In smallholder rubber sector the price signal is transmitted through the marketing channel to the farmer. The information on prices can be obtained by the farmer through following sources.

1. Daily papers
2. By direct contact with the brokers
3. Through the middlemen
4. Published information by brokers
5. Through Government institutions (RRI, Rubber Development Department etc.)

However, the major pathway of information movement to farmers is through the marketing channel (middlemen).

The market margins

It was found that the middlemen involved in smallholder rubber markets retain at least Rs.10 per kg of rubber (Table 6). Further, it can be noted from Table 6, that a certain amount of price discrimination is prevalent in the three areas. The prices are slightly different in each area and the farmers do not receive the prices set at the auction level. The major reason for this type of price discrepancy is associated with the grading system involved. Sheet rubber is graded visually. This is highly subjective and hence, the middlemen take the advantage of it by buying the rubber sheets in bulk regardless of their grade. The middleman sorts this according to higher and lower grades and improves their profits. This has two impacts. First being the smallholders income is foregone and the middleman grab smallholders' income. Second, the demand by the buyers is not correctly passed onto the producers and hence producers shun away from producing quality rubber although it is highly demanded. This prevents the prices from acting as a rationing mechanism and there is price inefficiency prevalent. Hence, the smallholder farmer does not produce high quality sheet rubber due to following reasons.

1. The benefits of quality of the product is not passed onto the producer
2. Lack of information on the demand
3. Lack of facilities such as smokehouses, rollers etc.

Table 6. Market margins involved in Ribbed Smoked Sheets (RSS)

Village	Farm gate price (September, 2003) Rs/kg	Auction price (RSS1) (September, 2003) Rs/kg	Margin (Rs/kg)
Welihelatanne	97	107.21	10.21
Batugampola	94-96	107.21	13.21-11.21
Pohorabawa	95-98	107.21	12.21-9.21

The Government intervention in the smallholder rubber marketing system

The government intervention can be seen in the form of subsidies and direct intervention in the marketing channel. This study focuses on a qualitative assessment on the recent intervention to form farmer groups called the *Thurusaviya* societies.

Thurusaviya fund was established under the *Thurusaviya* Fund Act No. 23 of year 2000 and functions were started from 12th December 2000. The grass root level *Thurusaviya* societies were formed with the following objectives.

- Enhance social status and income levels of rubber smallholders through savings
- Promote investment opportunities in the rubber industry
- Establishment, improvement and provision of facilities such as; processing units, rubber factories and other needs of smallholders
- Enhance sales and marketing of rubber products processed in processing units and rubber factories
- Establishment, registration and organizing of Thurusaviya Societies and to provide monitory assistance and other required facilities to the society members

The main aim of these societies was to improve the bargaining power of the farmers as in any other farmer group. However, in light of the above objectives the farmers' perception of these societies was evaluated using a PRA tool called the institutional analysis. Table 7 (a and b) summarizes the expectations of farmers from these societies and the present level of achievement of these objectives as perceived by the farmers.

Most of the characteristics farmers expected from a society would have not been in existence in these two *Thurusaviya* societies studied. Though the intention of the Government is to eliminate middlemen or at least to minimize the role-played by the middlemen in the marketing channel through these societies, it has not been efficient. Farmers receive most of these expectations from the private trader. Therefore, if these societies are to be activated from the present state of inactiveness, the expectations of the farmers need to be taken into consideration in a serious manner. If not the role of the society will be of that of another village dealer and nothing more.

CONCLUSIONS AND SUGGESTIONS

It was evident from this study that to improve the marketing efficiency, the technical efficiency or the input-output relationship of the producer and the pricing efficiency of the total market system has to be improved. Technical efficiency is affected due to fragmentation of land (holding size), less use of improved clones (planting material), long immature period (due to low adoption of recommended technologies) etc. These can be overcome by way of improved information/education of the farmers through proper extension and provision of quality inputs, especially planting material (as it has a bearing on the productivity) so that the contribution from the smallholder sector to the national production can be improved significantly. Also, the holding size is increasingly reducing with division of land among children. Therefore, policy measures in this regard are of immense importance to reduce/minimize the fragmentation.

Table 7: Expectations of Thurusaviya societies and the satisfaction

(a) Village: Welihelatenna

Expectations	Farmers' perception on achievement of objective (%)
Leadership	30
Fair number of members	0
Intimacy between members	0
Honesty of officials	35
Finding a good market for rubber	0
Fertilizer and chemicals through the society	0
Collection of membership fees	0
Insurance scheme for the society	0
Meetings to be held at 3 months intervals	0
Providing technical know-how to farmers	0
Keeping up with the discipline of the society	5
Active roles of officials	5

The pricing efficiency is heavily affected by the subjective grading system prevalent in the rubber sector. The market margins kept by the middlemen can be reduced by increasing competition among buyers and also by intervention through forming farmer groups. However, in establishing farmer groups such as *Thurusaviya* societies, a more bottom up approach is necessary where farmers' expectations are met. In addition, improving the latex market through promotion of latex collecting centers or by involving private sector in latex collection is important, as at the moment the volume of rubber sold as latex is low.

(b) Village: Pohorabawa

Expectations	Farmers' perception on achievement of objective (%)
Free from politics	100
Honest devotion of members	40
Devotion of officials	75
Interactions with relevant government officials	75
Educating the farmers on how marketing	
arrangements could be made through the society	0
Marketing through the society	10
Providing needy inputs through the society	5
Providing credit facilities through the society	0
The society should have sufficient funds	15
Introducing a farmer insurance scheme	0
Introducing a farmer pension scheme	0
A fair number of members	20

• Note: these results were obtained in 2002

ACKNOWLEDGEMENT

The participatory studies and questionnaire surveys mentioned in this article were conducted under the project "Interactions between the Environment, Society and Technology" (INTEREST). The authors acknowledge the financial support given by the European Commission for this project

REFERENCES

Anon 2003 1st annual report of Interactions between the Environment Society and Technology (INTEREST).

Anon 2004 2nd Annual Report of Interactions between the Environment Society and Technology (INTEREST).

Central Bank of Sri Lanka. Annual Report, various issues

Plantation Sector Statistical Pocket Book, Ministry of Plantation Industries, various issues

Purcell, W 1979 Agricultural Marketing, Systems, Coordination, Cash and Futures Prices, Reston publishing Co. Reston, Virginia.

Wijesuriya, B W, Thattil, R O, Samarappuli, I N, 1995 Behavior of Natural Rubber Prices in the Colombo Market, 51st Annual session, SLAAS, Colombo.

ABREVIATIONS

RSS – Ribbed Smoked Sheets
USS – Unsmoked Sheets
PRA – Participatory Rural Appraisal
INTEREST –Interactions Between The Environment Society and Technology

8206

Influence of Socio-economic and Communicative Factors on the Adoption of Coconut-Based Intercropping Systems in Sri Lanka

M T N Fernando
Agronomy Division
Coconut Research Institute, Lunuwila, Sri Lanka

ABSTRACT

Coconut-based intercropping (CBI) is a strategy to intensify the inefficient land use of monocrop coconuts, and to provide an additional income to growers. Despite efforts of successive governments in Sri Lanka to popularise CBI for nearly two decades, its level of adoption by farmers is still low. This study analyses the effect of socio-economic and communicative factors on the adoption of CBI. These factors are availability of cash and labour, highland and riceland ownership, farmer's age, farming experience, education, contacts with extension workers and time allocation of farmers in farming. Categorical data analysis was carried out and a multiple regression model was specified using data collected from a survey of 150 farmers in three main coconut-growing districts – Kurunegala, Puttalam and Gampaha. The results suggest that the adoption of CBI is positively and significantly influenced by the availability of cash and by extension contacts, while it is negatively and significantly affected by rice cultivation, the age of the farmer and highland ownership. Increased access to loans and strengthening the extension service is suggested to enhance the adoption of CBI. The need for the consideration of the above socio-economic aspects, often neglected in the development and dissemination of CBI technology, is also emphasised.

Key words: coconut based intercropping, socio-economic and communicative variables

INTRODUCTION

Coconut, which is the largest plantation crop (in terms of land use) in Sri Lanka, is traditionally grown as a monocrop, which uses biophysical resources sub-optimally. A mature coconut palm in monocrop cultivation utilises only about 25 per cent of the soil mass. Considering that coconut occupies relatively fertile soils in Sri Lanka, the low land productivity of monocrop coconut has a grater opportunity cost due to the foregone benefits of an intensive land use alternative, coconut-based intercropping (CBI). Despite the concerted efforts of successive governments to popularise the CBI over the last two decades, the level of adoption of CBI systems by farmers is still as low as some 25 per cent of the agronomically potential area of 100,000 ha (Gunathilake, 2004). The national level of adoption of CBI is determined by two components at individual farm level, the *incidence* and the *intensity* (*incidence* refers to the probability of adoption of CBI at individual farm level, where the adoption is represented in dichotomous terms, i.e. adoption/non-adoption, and *intensity* refers to the level of adoption of CBI in a given individual farm, i.e. the proportion of land brought under CBI (Feder et al., 1982)[1]. Low levels of both of these attributes contribute to the low adoption of CBI at aggregate level. The objectives of this study were:

[1] The emphasis on *incidence* and *intensity* of adoption is due to two reasons. First, any approach to increase the level of adoption at aggregate level should focus on increasing the *incidence* and *intensity* of adoption at individual farm level. Second, two definite techniques are required to analyze these two situations.

i) to identify the effects of socio-economic and communicative variables on the *incidence of adoption* of CBI systems, and
ii) to quantify the relative contribution of socio-economic, demographic and communicative variables on the *intensity of adoption* of CBI.

HYPOTHESES

i) Socio-economic variables, namely age, educational attainment, experience in farming, income, wealth, labour availability, extent of rice and highland, farmer's time allocation in the farm and communicative variables, namely intensity of extension contact, memberships in associations: all influence the *incidence of adoption* of CBI

ii) The identified variables determine the *intensity of adoption* of CBI

The reminder of this paper is structured as follows. Section 2 discusses the theory of adoption of an innovation. The conceptual basis of selection of variables for this study is presented in Section 3. Section 4 discusses the methodology, which comprises data collection procedure and analytical methods. Results are discussed in Section 5 and Section 6 concludes.

THEORY OF ADOPTION OF AN INNOVATION

A wide range of economic, social, physical and technical factors and risk attitudes of farmers' influences the adoption of an innovation. Since only the agronomically potential areas of the coconut triangle (as will be discussed in Section 4) were selected for the survey of the present study, it is assumed that the variability of the physical and technical factors such as rainfall and soil suitability etc. across the survey area is relatively low. This assumption enables one to exclude the investigation of the influence of these factors on the adoption of CBI. Consequently, the theoretical framework developed in this section consists of the investigation of only social and economic factors on the adoption of CBI.

A lucid review of the theory of the diffusion and adoption of an innovation mainly in relation to the social and economic factors will be found in Rogers (1962), Rogers with Shoemaker (1971), and Rogers (1983), while empirical studies are found in Rogers with Svenning (1969), Opare (1980), Voh (1982), Lariosa and Gomez (1983), Rahm and Huffman (1984), Igodan *et al.* (1988), Wijeratne and Chandrasiri (1988), Niranjan and Jayathilake (1991), Niranjan *et al.* (1991), Papa and Sison (1991), Obinne (1996), and Nkonya *et al.* (1997), *inter alia*. In addition, Feder *et al.* (1982) provide a comprehensive survey on various theoretical and empirical studies on adoption diffusion of agricultural innovations.

Rogers (1983) theorises that the adoption of an innovation is influenced by a range of concepts[2] in relation to the characteristics of the decision-making unit (DMU) and by some attributes of the innovation itself. The characteristics of the DMU can be sub-divided into three categories, namely socio-economic, personality and communication (Table 1).

[2] A *concept* is a dimension stated in its most basic terms and exists only at theoretical level. An *operation* is the empirical referent of a concept, which may be an index, an observation etc. Cosmopoliteness is an example for a concept and number of trips made by an individual to city is the empirical operation of that concept.

Table 1. Factors influencing adoption of an innovation by a decision-making unit (DMU)

	Concept	Measurable variable
(A) Characteristics of the DMU (an individual or a group)		
(I) Socio-economic characteristics	a) literacy b) socio-economic status c) characteristics of the unit (farm, school, business) d) age * e) experience in farming *	years of formal education income wealth farm size number of years number of years
(II) Personality characteristics	a) empathy b) fatalism c) achievement motivation	empathy scale fatalism scale sentence completion scale
(III) Communication behaviour (i) mass media channels	a) exposure to mass media	- no. of radio programs listened per week - no. of television programs watched per week etc.
(ii) Interpersonal communication Channels	a) social participation b) cosmopoliteness c) contact with change agent and opinion leaders	- no. of memberships held in organisations - no. of visits to cities - intensity of extension contact
(B) Attributes of the innovation	a) relative advantage b) compatibility c) complexity d) trialability e) observability	NPV, B/C ratio etc.

Note: * not essentially concepts but measurable variables.
Source: Adapted from Rogers (1962) and (1983).

Theoretical explanation as to how these concepts influence the adoption behavior of a DMU is found in Rogers (1962), Rogers with Shoemaker (1971) and Rogers (1983).

Although the above wide range of variables explains the adoption of a typical innovation, the relevance of these variables may vary with the type of the technology in question. Therefore, a conceptual framework, which could be used to guide the empirical investigations with regard to the adoption of CBI, has to be developed.

CONCEPTUAL FRAMEWORK FOR THE COCONUT-BASED INTERCROPPING SYSTEMS

The concepts associated with the personality characteristics of the DMU, namely empathy, fatalism, and achievement motivation have not been widely considered in adoption studies in view of the measuring difficulties associated with them. In addition, Rogers with Shoemaker (1971) argue that these concepts often add little in explaining the adoption behavior of farmers. These same arguments were extended for this study and the empirical measurement of these concepts was excluded mainly due to measurement difficulties. The concept of exposure to mass media was not considered because programs concerning CBI are hardly publicised through radio, television, film, news papers and magazines in Sri Lanka. The lack of measures to operationalize the concept of cosmopoliteness precluded its inclusion. Consequently, only such concepts as literacy, socio-economic status, social participation, contact with extension agent and two other measurable variables, namely age and the farming experience of the chief householder, were used in the empirical analysis. The measures used to operationalize the above concepts in relation to the present study are explained below which is preceded by the operational definition of the innovativeness.

Operational definition of innovativeness

The textbook definitions of the concept of innovativeness, e.g. Rogers (1983), refer to the degree to which an individual or other unit of adoption is relatively earlier in adopting new ideas than other members of a system. This implies that the empirical referent of this concept has to take a time dimension into account. Hence, the number of farmers who adopted CBI in different years may be one possible operational definition of this concept. However, the dearth of availability of time series data of this nature precluded this operationalization. Moreover, the aim of this study is to identify the major socio-economic factors that influence the *incidence of adoption* of CBI. Hence, the adoption or non-adoption of CBI is the potential dependent variable and not the early or late adoption of CBI. Consequently, the incidence of adoption of CBI, i.e., adoption or non-adoption, was operationalized as the definition of innovativeness.

Measures used to Operationalize the Concepts shown in Table 1

a) **Socio-economic characteristics of the DMU**

i) **literacy:** Years of formal education achieved by the chief householder was the variable used to measure this concept.

ii) **socio-economic status:** Income and wealth of farmers were the variables considered to measure this concept. In addition, the income from off-farm sources were also separately included in the analysis to test the hypothesis that the adopters always tend to have income security from other income sources. The income and wealth of respondents were calculated as follows. Income refers to the total annual household income of farmers, which includes income from the following sources: i) upland[3] coconut, ii) upland intercrops, iii) lowland rice, iv) livestock, v) occupation, vi) off-farm activities, vii) hiring out machinery, viii) pensions.

The incomes from a) off-farm activities such as fibber; rice mills, b) occupation, and c) hiring out machinery were added together to compute the off-farm income.

Wealth refers to the farmer's status with respect to their material possessions. The following three components were valued at prevailing market prices and added to obtain the level of wealth of an individual farmer.

[3] The lands of coconut growers of the survey area are often characterized by a piece of puddle land usually located in the lower basin of the landscape which is continually devoted for growing rice and an unpuddled land area usually located in the upper part of the landscape which is continually devoted for growing coconut and other intercrops. The former is called lowland while the latter is called upland or highland.

- land (upland and lowland owned)
- livestock (cattle, poultry, pigs)
- agricultural machinery (2 wheel drive 4-wheel tractors, 2-wheel tractors, ploughs, sprayers, harvesting and pruning knives, mammoties[4])

iii) **characteristics of the unit:** Farm size (ha) is the variable used to measure this.

iv) **age:** This itself is a measurable variable and the units of measurement are in years.

v) **farming experience:** Measured in years.

b) **Communication behavior of the DMU**

i) **Social participation:** The number of memberships held by the chief householder in agriculture-related organisations was considered as the operational measure of this concept.

ii) **Contact with extension agents:** The operational measure of this concept was the number of contacts with the agricultural extension officer per year.

METHODS

Data

Data were collected by a field survey of 113 intercroppers and 37 monocroppers, conducted in three main coconut-growing districts, namely Kurunegala, Gampaha and Puttalam. Although these three districts cover four different agro-climatic Zones, viz. Wet Zone, Intermediate Wet Zone, Intermediate Dry Zone and Dry Zone, agronomic potential for intercropping is more favourable in the Wet and the Intermediate Wet Zones. Therefore, only the coconut growers of the above two agro-climatic Zones were selected. These two agro-climatic Zones comprise two main agro-ecological regions, IL_1 and WL_3.

Table 2 shows the allocation of sampling units in the two-agro ecological regions among monocroppers and intercroppers.

Table 2. Allocation of sampling unit

	Agro-ecological region		
	IL_1	WL_3	Total
Monocroppers	22	15	37
Intercroppers	68	45	113
Total	90	60	150

[4] Mammoty is an instrument with a wooden handle and a metal blade, and is used by farmers for ploughing, weeding etc.

The sampling units of monocroppers and intercroppers of each agro-ecological region were equally allocated to Coconut Development Officers' (CDO)[5] ranges in each agro ecological region. However, as the number of sampling units allocated to each agro-ecological region under monocroppers and intercroppers are not divisible equally, some CDO ranges had more sampling units while some had fewer (Table 3).

Table 3. Allocation of sampling units for monocroppers and intercroppers in each CDO range

Agro-ecological region					
	WL_3			IL_1	
CDO range	Intercroppers	Monocroppers	CDO range	Intercroppers	Monocroppers
Nittambuwa	7	2	Dummalasuriya	8	2
Mirigama	7	2	Kuliyapitiya	7	2
Pallewela	8	3	Welpalla	7	2
Minuwangoda	8	3	Yackwila	8	3
Urapola	8	3	Dambadeniya	7	2
Weke	7	2	Weerambugedara	7	2
			Udubaddawa	8	3
			Dankotuwa	8	3
			Hamangalla	8	3
Total	45	15		68	22

Two different structured interview schedules for monocroppers and intercroppers were prepared. The data were collected through a single visit by a personal interview.

DATA ANALYSIS

- **Relationship of Socio-economic and Communicative Variables and the *Incidence of Adoption* of CBI**

This section identifies the appropriate analytical techniques to measure the influence of the relevant concepts on the *incidence of adoption* of CBI.

This study is concerned with not concerned with investigating the socio-economic and communicative variables associated with the adoption or non-adoption of intercropping. Given this discrete technological choice, correlation and regression analyses are not appropriate to measure the association between the *incidence of adoption* of CBI and the socio-economic and communicative variables.

Logit probability analysis, which employs a binary choice dependent variable, is one of the most appropriate techniques in adoption studies concerning non-divisible innovations (e.g. adoption of harvesters). The dependent variable of this study, which is the incidence of adoption of CBI, i.e., adoption of CBI or otherwise, represents a binary choice variable. However, the logit model cannot be employed because it requires that each farmer must have an equal chance of being selected as an adopter or a non-

[5] A CDO is a village-level coconut extension officer.

adopter. This condition is not satisfied in this study because the number of monocroppers and intercroppers were predetermined as 37 and 113 respectively (see Section 4).

The independent variables measuring socio-economic and communicative concepts represent interval measurements, e.g. the concepts of literacy and social participation are measured respectively by the number of years of formal education and by the number of memberships held in social organisations, and so on.

It was hypothesised that the socio-economic variables of farmers' influence the *incidence of adoption* of CBI. The chi-square test is an appropriate technique to measure the association of categories of interval data. The hypothesis tested by the chi-square statistic (χ^2) is that the values of row and column variables in a contingency table are independent in a random sample of observations. Adoption of CBI or otherwise by individual farmers can be represented by a 0-1 dummy variable dependent on a number of independent variables. Since the number of adopters and non-adopters was pre-determined in sampling, the chi-square test cannot be performed[6]. However, the approach described below can be adopted to make the chi-square test applicable. The independent variables were categorised into an appropriate number of ranges to form the column variables. For instance, the number of years of formal education can be categorised into ranges, i.e. grade 1 to 5 for primary education, grade 6 to 12 for secondary education etc. The number of respondents, which fall into each category of a given independent variable, is a random event and therefore the chi-square test can be employed.

The null hypothesis is that adoption is independent of the variables considered such as income ranges, age and educational classes of farmers, etc. χ^2 is calculated by summing the squared residuals of all cells and dividing by the expected frequencies (Norusis, 1986).

In addition to the chi-square test, percentage analysis is used to find out the distribution of adopters and non-adopters in different categories of independent variables.

Converting independent variables into categorical data

The scope of the results of the chi-square analysis is limited to providing insights on the potential association of the different classes of independent variables on the adoption status of the CBI. Therefore, the basis used for categorising independent variables into different classes has to be selected with care. One possible approach for this purpose is to base published data of the survey area in relation to the independent variables under consideration. Whenever possible, this approach was taken in this study but in instances where data availability was limited, the authors' intuitive discretion was exercised.

(1) Socio-economic characteristics of the DMU

(a) Literacy-educational attainment:

The widely used criteria taken by many Sri Lankan studies in categorising people in terms of formal education is to group them by primary, secondary and tertiary education. This approach was taken in this study too.

Group 1: 1 to 5 grade (primary education)
Group 2: 6 to 12 grade (secondary education)
Group 3: Formal education after grade 12 (tertiary education)

(b) Socio-economic status:
Income and wealth are the variables measuring the concept of socio-economic status. In addition, the risk-spreading influence of off-farm income on the adoption of CBI, was investigated.

(i) Income:
Recently published data on various categories of household income, off-farm income and wealth, of the survey area were not available and therefore the farmers were categorised into four income and four off-farm income groups and three wealth groups based on author's intuitive knowledge.

Range	Income range (Rs per year)
1	12 ,000 to 50 ,000
2	50, 001 to 100 ,000
3	100 ,001 to 200, 000
4	> 200,000

(ii) Off-farm income:

Range	Off-farm income range (Rs per year)
1	0 to 50, 000
2	50, 001 to 100, 000
3	100 ,001 to 200 ,000
4	> 200, 000

(iii) Wealth: Three wealth categories were identified.

Range	Wealth range (Rs per year)
1	225, 900 to 500, 000
2	500, 001 to 1,000, 000
3	> 1,000, 000

c) Characteristics of the farm:
Upland area is used to measure this concept. Three categories of land sizes were used - small, medium and large.

Group	Upland area (ha)
1 (small)	0.8 to 2 (2 to 5 ac)
2 (medium)	> 2 to 4 (5 to 10 ac)
3 (large)	> 4 (10 ac)

(d) Age :
Three different age groups, namely less than 15 years, 15 to 59 years and 60 and over, respectively representing children population, economically active population and old population are conventionally used. However, in the survey area of the present study, 17 years is the lowest age of farmers reported; hence the lower limit was set at 17 years.

The definition of economically active population, which categorises farmers between the ages of 15 and 59, is too general to investigate the association between age groups and CBI. It could be expected that the younger farmers exhibit a higher propensity to adopt new ideas than older farmers. This suggests that segregating farmers into different age groups based on their level of maturity would be more meaningful. Based on this argument, farmers were categorised into three age groups, based on the age of the chief householder.

group 1: 17 to 30 years (younger farmers)
group 2: 31 to 40 years (middle-aged farmers)
group 3: 41 and above (older farmers)

(e) Experience in farming: The number of years that farmers had been engaged in farming was considered as the measurement. In view of the unavailability of published statistics on the number of farmers of the survey area in different farming experience groups, the author's knowledge was used to categorise the respondents into three groups based on the number of years of their involvement in farming.

Group	**Years of farming experience**
1	0-5 (recently engaged farmers)
2	6-22 (intercropping was introduced in 1973 and this category of farmers are considered as medium-term experienced farmers)
3	over 22 (traditional farmers)

(2) Communication behavior

(a) Social participation (memberships in associations)

Farmers were categorised as members or non-members in agriculture-related organisations such as the Cultivation Committee and the Rural Development Committee assigning the value 1 for members and zero for non-members.

(b) Contacts with extension agents
The number of farm visits made by extension officers during the last year measured this. A single visit to the farm is very likely for a matter concerning subsidy administration and less often for technical advice. Therefore, the farmers with only one extension contact can be considered as farmers with virtually no extension contacts. So, farmers with no or a single extension contact were categorised into "no extension" group and those who with two or more extension contacts to the "other" category. Scores were assigned as follows.

0 - zero or one contact

1 - two or more contacts

- **Relative Contribution of Socio-economic Factors on the *Intensity of Adoption* of CBI**

This section posits an appropriate analytical technique to identify the selective contribution of each socio-economic variable to the *intensity of adoption* of CBI.

Operational definition of intensity of adoption

The intensity of adoption can variously be defined. One possible definition is to consider the absolute intercropped acreage of a given farmer, irrespective of the total highland area he owns, as the intensity of adoption of CBI. However, it does not provide an idea of the intensity of adoption relative to the total highland availability of a given farmer. The definition has to take into account the relative share of the land in which the intercropping is practised. Cropping Intensity (CI), which is the ratio of the highland area cultivated with intercrops, to the total highland area owned by a farmer, can be employed to overcome the weakness of the above definition.

$$CI = \frac{\text{highland area cultivated to intercrops}}{\text{total highland area owned by a farmer}} \quad (1)$$

Although the latter definition has an improvement over the former, it is still with limitations because different farmers with similar acreages under intercrops may still have varying intensities of intercropping. For instance, one farmer with one acre of land under intercrops may have exclusively one intercrop while another farmer with a similar acreage under intercrops may have more than one intercrop. The intensity of adoption of farmers with a greater number of intercrops in a given area is obviously higher than the farmers with fewer intercrops in a similar area because the resource requirements and output generation are greater with the increase in the number of intercrops.

The foregoing argument implies that "the annual actual expenditure on intercropping by a given farmer" may be more appropriate than "the highland area cultivated to intercrops" as the numerator of the equation (1). Thus, the new definition of CI is as follows.

$$CI = \frac{\text{annual actual expenditure on intercropping by a given farmer}}{\text{total highland area owned by the same farmer}} \quad (2)$$

However, the farmers of the survey sample were at diverse stages of their intercropping practices, i.e., some were in the crop establishment stage while others were in the harvesting stage, and so on. The level of expenditure of farmers who were at the crop establishment stage was often high compared to those in harvesting stage, even when both groups of farmers had an identical mix of intercrops. Explicit treatment of this differentiation in equation 2 is not easy. This problem precluded the practical application of equation 2 for the present study. Consequently, the CI was operationalized as the definition of the intensity of adoption of CBI (i.e. equation 1). Multiple regression analysis is the appropriate analytical technique to assess the selective contribution of socio-economic variables on the scale of intercropping operation.

The empirical model

Based on *a priori* knowledge of the author, it was hypothesised that the CI determined by such factors as: (i) annual average availability of cash per farm (CAP, in Rs/year), (ii) annual average family labour availability of a farm household for farm work (LAB, in man-days/year), (iii) rice land area owned by a farmer (RICE, in ac), (iv) age of the chief householder (AGE, in years), (v) farming experience of the chief householder (FE, in years), (vi) formal education of the chief householder (EDU, in years), (vii) highland area owned by a farmer (HLAND, in acres), (viii) intensity of extension contact represented by a dummy variable (EXT, 0 = no or single extension contact and 1 = two or more extension contacts) and (ix) farmer's time allocation in farming represented by a dummy variable (TIME, 0 = part-time and 1 = full-time). The regression coefficients with regard to the above variables are $\beta_1,\ldots, \beta_9$ respectively.

The relevance of each of the above variables to the model, and the expected signs of coefficients of regressors are discussed below and the appropriate hypotheses are developed.

Relevance of variables and the development of hypotheses

(i) Cash (CAP)

Intercropping is a cash-intensive system and it is therefore reasonable to hypothesise that the annual average availability of cash per farm is positively related to the intensity of adoption.

H_1^0: annual average cash availability of the farmer has no effect or negatively affects the intensity of adoption ($\beta_1 \leq 0$)

H_1^a: annual average cash availability of the farmer positively affects the intensity of adoption ($\beta_1 > 0$)

(ii) Family labour (LAB)

It is rational to hypothesise that the annual average availability of family labour for farm work is positively related to the intensity of intercropping, because CBI is also a labour-intensive operation.

H_2^0: average annual family labour availability for farm work has no effect or negatively affects the intensity of adoption ($\beta_2 \leq 0$)

H_2^a: average annual family labour availability for farm work positively affects the intensity of adoption ($\beta_2 > 0$)

(iii) Rice land ownership (RICE)

Rice cultivation competes for household labour (as well as for hired labour) and can therefore assume that the intensity of adoption of CBI is less, the greater the area of rice the farmer owns.

H_3^0: the rice land area owned has no effect or positively affects the intensity of adoption of CBI ($\beta_3 \geq 0$)

H_3^a: the rice land area owned and the intensity of adoption of CBI are negatively related ($\beta_3 < 0$)

(iv) Age of the chief householder (AGE)

This personal attribute of the farmer can have contradictory implications on the intensity of adoption. Researchers have found inconsistent evidence on the influence of age on adoption of innovations. Therefore, the influence of age on the intensity of adoption of CBI is *a priori* uncertain.

(v) Farming experience (FE)

Intercropping involves the cultivation of a range of crops, which requires more knowledge and skill in crop management compared to that of monocrop coconut. So, the farmers with many years of farming experience are expected to have a greater intensity of adoption. It may be expected that the farming experience and the age of farmers are linearly correlated (one variable out of the above two AGE and FE variables will be dropped depending on the severity of the collinearity if detected by the correlation analysis), implying that more experienced farmers are aged. This suggests that the age indirectly represents the farming experience and it follows that any theories concerning the influence of age on adoption of an innovation may be so applicable to farming experience. Hence, the influence of farming experience on the intensity of adoption is also *a priori* uncertain.

(vi) Education (EDU)

Literature shows inconsistent evidence on the influence of education on adoption of innovations. Hence, the effect of formal education on the intensity of adoption of CBI is *a priori* uncertain.

(vii) Highland acreage (HLAND)

When the farmer has a larger acreage of highland, he tends to obtain returns to scale of the land, which suggests that the higher landowners may cultivate a greater acreage of intercrops. Thus, the intensity of intercropping is hypothesised to be positively related to the highland acreage owned by a farmer.

H_4^0: the highland area owned has no effect or negatively affects the intensity of adoption ($\beta_7 \leq 0$)

H_4^a: the highland area owned positively affects the scale of intercropping operation ($\beta_7 > 0$)

(viii) Intensity of extension contacts (EXT)

Extension is one of the means of non-formal education of farmers on intercropping. The farmers with higher intensity of extension contacts may have a higher motivation to intercrop, resulting in a greater scale of intercropping operation. Hence, it is hypothesised that the intensity of extension contact is positively related to the intensity of adoption.

H_5^0: extension contacts have no effect or negatively affect the intensity of adoption ($\beta_8 \leq 0$)

H_5^a: extension contacts and the intensity of adoption are positively related ($\beta_8 > 0$)

However, it is not sensible to expect the intensity of adoption of CBI to be a linear function of the number of extension contacts. What is required is to make a distinction between farmers with no extension contacts and one or more extension contacts and then to test the appropriate hypothesis. Farmers with no or a single extension contact were categorised into "no extension" category and those who with two or more extension contacts to the "other" category for the same reasons discussed earlier. Dummy variables were used to model this situation.

(ix) Time allocation (TIME)

Time allocation for farming, i.e. full-time/part-time status of the farmer, influences the intensity of adoption. Farmers whose main occupation is farming may have a tendency to have a greater intensity of intercropping compared to that of farmers whose main occupation is salaried employment, business etc. Thus, the intensity of adoption is hypothesised to be positively related to the time allocation in farming.

H_6^0: farmer's time allocation in farming has no effect or negatively affects the intensity of adoption ($\beta_9 \leq$ 0)

H_6^a: farmer's time allocation in farming favourably affects the intensity of adoption ($\beta_9 > 0$)

Time allocation was also modelled as a dummy variable.

Specification of the functional form

Three functional forms, namely linear, quadratic, and power function (with natural base) were fitted, and finally the linear form was chosen.

Model I - Linear model

$$CI = b_0 + \sum_{n=1}^{9} b_n X_n + u \qquad (3)$$

where CI is the cropping intensity (proxy for scale of intercropping operation)

b_0 is the intercept to be estimated

X is the vector of socio-economic variables (n = 1 to 9)

b_n (n = 1 to 9) are the parameters to be estimated, and u is the random disturbance, which is assumed to have usual properties in order to employ the OLS estimation procedure

The above equation was estimated using OLS method, employing the stepwise method of the SPSS PC+.

(i) multicollinearity

Judge *et al.* (1988) suggests that if the correlation coefficient value between two regressors is greater than 0.8 or 0.9, then multicollinearity is a serious problem.

A correlation matrix was constructed using independent variables of the linear model (Appendix Table A1). As all elements of the matrix show correlation coefficients of less than 0.6, it is reasonable to assume that the multicollinearity problem is not severe.

(ii) heteroscedasticity

Residuals of the dependent variable were plotted against each independent variable (except dummy variables) to visually detect the heteroscedasticity problem. There was no discernible pattern of increase or decrease of residuals of the dependent variable with values of independent variables, which implies that a heteroscedasticity problem does not exist. The Goldfeld-Quandt test was also used (Pindyck and Rubinfeld, 1976, Gujarati, 1995), and found that homoscedasticity exists.

RESULTS AND DISCUSSION

Incidence of Adoption

• Socio-economic and Communicative Factors and the *Incidence of Adoption* of CBI

Simple percentage and categorical data analyses were performed to examine the relationship between the ***incidence of adoption*** of CBI, i.e. adoption or non-adoption, and the socio-economic and communicative factors.

Results of the percentage analysis

As Table 4 shows, there are some notable differences between the percentages of adopters and non-adopters falling within each category of independent variables.

The percentage of tertiary education (16%) was higher in adopters than non-adopters (11%) whereas the percentage of the secondary education is higher in non-adopters (86%) than adopters (79%). About 51 per cent of the adopters were in the highest income group (> Rs 200 000) while the relevant figure for the non-adopters was only 31 per cent. The percentage distribution of off-farm income of adopters and non-adopters is erratic.

Table 4. Distribution of adopters and non-adopters in each category of independent variables

Independent variables & their categories	Adopters (N=113)		Non-adopters (N=37)	
	No.	%	No.	%
Education (years)				
1 - 5 grade (primary)	6	5	1	3
6 - 12 grade (secondary)	89	79	32	86
above grade 12 (tertiary)	18	16	4	11
Total	113	100	37	100
Income (Rs)				
12 000 - 50 000	3	3	2	6
50 001 - 100 000	14	12	11	31
100 001 - 200 000	38	34	11	31
> 200 000	58	51	11	31
Total	113	100	37	100
Off-farm income (Rs)				
0 - 50 000	53	47	13	35
50 001 - 100 000	29	26	11	30
100 001 - 200 000	26	23	11	30
> 200 000	5	4	2	5
Total	113	100	37	100
Wealth (Rs)				
225 900 - 500 000	15	13	3	8
500 001 - 1 000 000	26	23	9	24
> 1 000 000	72	64	25	68
Total	113	100	37	100
Farm size (ac)				
2 – 5	62	55	18	49
> 5 – 10	24	21	12	32
> 10	27	24	7	19
Total	113	100	37	100
Age (years)				
17 – 30	10	9	3	8
31 – 40	29	26	7	19
41 and above	74	65	27	73
Total	113	100	37	100
Experience in farming (years)				
1 – 5	13	12	2	5
6 – 22	58	51	18	49
23 and above	42	37	17	46
Total	113	100	37	100
Memberships in organisations				
0	48	42	15	41
1 & above	65	58	22	59
Total	113	100	37	100
Intensity of extension contacts				
0	56	50	31	84
1 & above	57	50	6	16
Total	113	100	37	100

Contrary to expectations, a higher percentage of non-adopters (68%) were observed in the highest wealth group (> Rs 1 000 000) than the adopters (64%). The percentage of adopters in the more than 10 acre category is higher (24%) than the non-adopters (19%) in the same category. Non-adopters have a greater percentage (73%) of older people (41 years and above) while the relevant figure with regard to adopters is 65 per cent. Surprisingly, less experienced farmers, i.e. the farmers in the 1-5 years of farming experience category, were higher in the adopters group (12%) than that of the non-adopters (5%). There was no discernible relationship among adopters and non-adopters with regard to the number of memberships in associations. A greater percentage of adopters (50%) have more than one extension contact while the relevant figure with regard to non-adopters was only 16 per cent. In summary, the results of the percentage analysis suggest that a greater percentage of adopters: i) were in higher income groups, ii) had higher farm sizes, iii) were in younger age, and iv) had a higher intensity of extension contacts, compared to the non-adopters.

Although the percentage analysis suggests some interesting relationships between the ***incidence of adoption*** and the chosen categories of independent variables, it does not show that there is a statistically significant relationship. Hence, a chi-square test was employed.

Results of the chi-square test

Table 5 summarises these results. There is a statistically significant relationship between the ***incidence of adoption*** of CBI and each of: i) the annual average household income of farmers, and ii) the intensity of extension contacts, respectively at 0.05 and 0.01 levels of probability. This provides sufficient evidence to support the first hypothesis that the ***incidence of adoption*** of CBI is dependent on annual household income and intensity of extension contacts. One possible explanation for the significant relationship between the ***incidence of adoption*** and the annual average household income is that CBI is cash-intensive and therefore its adoption is associated with higher household income.

Based on the significant relationship observed between the ***incidence of adoption*** and the intensity of extension contacts, it can be inferred that the visits of the extension agent to the farm enhance the awareness and knowledge about the CBI, which stimulates adoption of the practice. Moreover, this finding is consistent with the notion of Feder *et al.* (1982) that the probability of adoption of innovations increases with the increased stock of information with regard to the innovation.

The other independent variables, namely education, off-farm income, wealth, farm size, age, experience in farming, memberships in agricultural organisations were not significantly related to the ***incidence of adoption*** of CBI, suggesting that the CBI adoption is not influenced by these variables. However, one cannot conclusively establish by the chi-square test that these independent variables are not associated with the *incidence of adoption* because these variables may have confounding effects, i.e. they may show a significant relationship with the ***incidence of adoption*** in the presence of other variables. For instance, although formal education does not have a direct effect on the ***incidence of adoption***, it may have some confounding effect on a communicative variable and therefore with the presence of a communicative variable such as mass media it may show a significant relationship with the adoption status. The reason for this is because formal education indirectly influences the adoption by way of enhancing the effective communication. In addition, there may be some interactions of the independent

Table 5. Summary results of the chi-square analysis

Independent variables	d.f.	Calculated chi-square value	Significance
Education	2	1.11006	0.57406 (ns)
Annual household income	3	8.78366	0.03231 *
Annual off-farm income	3	1.61788	0.65534 (ns)
Wealth	2	0.70453	0.70309 (ns)
Farm size	2	1.96161	0.37501 (ns)
Age	2	0.77802	0.67773 (ns)
Experience in farming	2	1.62232	0.44434 (ns)
Memberships in agric. organisations	1	0.03657	0.84834 (ns)
Intensity of extension contacts	1	13.40388	0.00025 **

Notes: d.f. - degrees of freedom, ns - not significant ($P > 0.05$)
* = $P < 0.05$; ** = $P < 0.01$

variables and therefore the association of independent variables on the adoption status might be better explained when the interaction terms are incorporated into the analysis. One possible approach to capture these aspects is to develop multivariate models (e.g. using the CATMOD procedure of the SAS statistical package), but this was not carried out due to its entirety.

Using the results of the Chi square test, the first hypothesis was tested.

Intensity of Adoption

- **Relative Contribution of Socio-economic Factors on the Intensity of Adoption of Intercropping**

Multiple regression analysis was employed to assess the relative contribution of the selected variables on the *intensity of adoption* of CBI and this section presents results.

Table 6 shows the results of the finally chosen regression model (linear model). The R^2 of the linear model was 0.29, which indicates that the 29 per cent of the variation of the intensity of intercropping is explained by the chosen independent variables. The relatively poor fit may be due the omission of other relevant variables, which were not identified. However, the poor fit does not mean that the included variables have no explanatory power. The overall significance of the explanatory variables chosen for inclusion in the model was tested using an F-test. The calculated F-value implies that the model is significant at better than 1 per cent probability level, i.e. the variables included in the model have an effect on the intensity of adoption of CBI.

Table 6. Estimated coefficients of the linear model

Variable	Estimated Coefficients ("B")	Standard Error	Beta	Significance Level
Intercept	.712865*** (7.075)	.100751		.0000
CAP	4.345889E-07** (2.730)	1.59208E-07	.235531	.0074
RICE	-.036611* (-2.013)	.018183	-.177263	.0466
AGE	-.003996* (-2.178)	.001834	-.182370	.0316
HLAND	-.016619*** (-4.012)	.004142	-.357904	.0001
EXT	.123167* (2.487)	.049516	.206651	.0144
LAB	(+) ve		-	ns
FE	(+) ve		-	ns
EDU	(-) ve		-	ns
TIME	(+) ve		-	ns

R^2 = 0.2928; Adjusted R^2 = 0.26
F = 8.78 Signif F = .0000
Notes: * P < 0.05; ** P < 0.01; *** P < 0.001
t values are in parentheses below each coefficient, ns - not significantly different from zero
Sample size is 112

The stepwise method included five explanatory variables in the final equation, namely CAP, AGE, HLAND and EXT, whose estimated coefficients were significantly different from zero at 1, 5, 5, better than 1 and 5 per cent probability levels respectively. This provides sufficient evidence to accept the hypothesis that the above variables significantly contribute to the *intensity of adoption* of intercropping.

In the SPSS output, the "B" values of different variables are not directly comparable because the units in which the variables are measured often vary. However, the "Beta" of the SPSS output are directly comparable to measure the relative contribution of each independent variable, because they are standardised regression coefficients, which result in when independent variables are measured in standardised units (Norusis, 1986). Hence, for the present purpose, "Beta" of the SPSS output was used.

Relative contribution of explanatory variables on Cropping Intensity (CI)

a) Annual average cash availability (CAP)

The coefficient of CAP has the expected sign. Based on the "Beta" values, it is evident that the marginal productivity of the intensity of intercropping with respect to a unit change in CAP variable is 0.23 (unitless as this is a ratio). This indicates that an increase of annual average cash availability of farm households by one Rupee results in an increase of cropping intensity by 0.23, the levels of other explanatory variables being held constant. This positive relationship can be explained by the cash-intensive nature of the CBI systems.

b) Rice land ownership (RICE)

The RICE variable has a coefficient, which is consistent with the expected sign. An increase of one unit of rice land decreases the intensity of intercropping by 0.17, *ceteris paribus*. The traditional coconut farming systems are characterised by the ownership of highland coconut land, and lowland rice land, both of which may be in few parcels. The staple food of the Sri Lankans is rice and growing rice is an integral component of their life. Rice growing competes for household resources particularly for labour. Coconut is relatively less labour-demanding and the coconut-rice system has apparently evolved in response to this relationship and other technical, social and economic circumstances with which farmers are associated. Intercropping coconut lands is a new technology to this traditional system, which is also labour-intensive. In view of this, CI is decreased with the increase in RICE variable. In the light of the above reasoning, the negative relationship between CI and rice land ownership can be justified. Although traditionally the labour involvement of the rice farming was based mostly on family and shared-labour, the emerging trend is to carry out all cultivation practices on a contract basis, meaning paying for hired labour on a task basis with regard to each cultural practice. So, one could argue that this negative relationship between the intensity of intercropping and rice land ownership might become less prominent in years to come. However, the counter argument is that it is doubtful because the hired labour availability itself is now increasingly declining.

c) Age of the chief householder (AGE)

The sign of the coefficient of AGE, which was *a priori* uncertain, has a minus value implying that the CI is negatively related to the farmers' age. Adoption studies have given inconsistent evidence on the influence of age of the farm decision-maker on the adoption of innovations. The present finding can be explained in that the older farmers are reluctant to adopt new technology of CBI due to their traditional nature.

d) Highland ownership of the farmer (HLAND)

Although the CI was hypothesised to be positively related to the HLAND, the sign of the variable was negative contrary to expectations. Increase in one acre of highland ownership will decrease the CI by about 0.35, *ceteris paribus*. Although the relationship is contrary to expectations, this finding is significant because it indicates that the ratio of land under intercropping to the total area of land owned by a farmer, which was used as the proxy for the intensity of intercropping is decreased with the increase in land area owned. This means that the area under intercropping is not positively related to land size, which suggests that the larger land size classes have a higher proportion of land area remaining unutilized for intercropping.

Feder *et al.* (1982) have emphasised the conflicting evidence provided by various adoption studies with regard to the relationship between intensity of adoption (adoption is, for instance, measured by proportion of land area allocated to a new variety) and the farm size. They found that the relative proportion of land taken under the new technology is higher in smaller farms in some studies while the opposite is the case in others. The results of the present study provide evidence for the former case.

One of the objectives of the government's CBI programme is to intensify the inefficient land use by monocrop coconuts given the decreasing arable land availability of the country. If a smaller area of large coconut holdings is intercropped while vast areas of their lands are still inefficiently used under coconut monocropping, alternative strategies have to be planned to meet the state's objectives in relation to CBI.

e) Intensity of extension contacts (EXT)

The EXT dummy variable has a coefficient, which is consistent with the expected sign. The contribution of EXT to the CI is about 0.21, when the intensity of extension contacts are two or more per year and the contribution is zero when the contacts are zero or one, *ceteris paribus*. One possible explanation for this is that the provision of technical knowledge by extension officers stimulates the expansion of intercropping. The potential of extension education in promoting the intensity of intercropping is thus clearly demonstrated.

Of the positively related two variables, namely CAP and EXT, the largest contribution to the CI is from the CAP. This suggests that the greatest scope (out of the considered explanatory variables) for the expansion of present intercropping systems lies with making more abundant the availability of farmers' cash.

The variables LAB, FE, EDU and TIME were not significantly different from zero at 5 per cent probability level and were thus not included in the final model by the stepwise method. Therefore, our hypothesis that the above variables significantly contribute to the intensity of intercropping is rejected. Of these variables, the signs of coefficients of LAB and TIME were consistent with the priori expectations. The signs of the coefficients of the variables FE and EDU were *a priori* uncertain and have been now established as negative. In what follows, possible reasons for the non-inclusion of these variables and about the signs of their coefficients are briefly discussed.

One possible explanation why the coefficient of the LAB variable was not significant is because the LAB variable includes only the family labour availability for farm work. However, the labour-involving activities of intercropping is carried out not only using the family labour but also the hired labour which was not considered in computing the LAB in view of the difficulties associated with recalling them from farmers memory. The implication of this is that the family labour availability for farm work alone does not influence the intensity of adoption of intercropping. Nevertheless, the interaction of the family labour availability and the actual use of hired labour for intercropping may influence the CI. Although this reasoning seems contradictory to the previous explanation given to justify the negative relationship between the intensity of intercropping and the RICE variable, rice is traditionally cultivated in the survey area and the principal source of labour supply for rice cultivation is family labour (though hired labour use is now emerging) and many rice operations are mechanised. Hence, rice undoubtedly competes for household labour resulting in a negative relationship between rice land ownership and the intensity of intercropping. However, intercropping being a new technology for this traditional system, more affluent farmers take the service of the hired labour to adopt this system. This means that the cash availability is a surrogate factor for hired labour. Therefore, the effect of the family labour availability alone on the intensity of intercropping is not much pronounced.

In effect, the non-inclusion of the FE variable in the final model complements the finding of the negative relationship of the AGE variable and the intensity of intercropping. Because the adoption of this new technology may be mostly done by younger farmers due to their risk taking behavior which influences the adoption. This may be a possible reason why the FE has no effect on the intensity of adoption of intercropping.

The sign of the coefficient of the variable EDU, which was a priori uncertain, has a negative value. Educated farmers may be involved with salaried occupations and therefore they may have less intention of expanding intercropping which may be a one possible explanation for the negative relationship of the EDU and the intensity of intercropping. The coefficient of the variable explaining farmer's full-time/ part-time involvement in farming (TIME) was also not included in the model. The non-inclusion of this variable complements the previous finding with regard to the EDU.

CONCLUSIONS AND RECOMMENDATIONS

- ***The percentage analysis*** revealed that there are some notable differences in the characteristics of adopters and non-adopters of CBI. A greater percentage of adopters: were in higher income groups, had larger farms, were in younger age, and had more frequent visits by extension agents compared to the non-adopters.
- The significance of the influence of hypothesised socio-economic and communicative variables on the discrete choice of the traditional technology (monocropping) or new technology (CBI) was determined employing χ^2 analysis. Only the annual household income and extension contacts were significantly different between monocroppers and intercroppers, indicating that the *incidence of adoption* of CBI is significantly influenced by these two factors.
- The significance of the relative contribution of hypothesised socio-economic and communicative variables on the intensity of adoption of CBI was determined by employing a multiple regression analysis. The cash availability and intensity of extension contacts positively and significantly influenced the *intensity of adoption* of CBI, while rice land ownership, age of the household head and highland availability negatively and significantly affected the *intensity of CBI adoption*.

The multiple linear regression model results suggest that the cash availability of the households has the largest effect on the intensity of adoption of intercropping. Intercropping is cash-intensive and a low capital base impedes the expansion of intensity of intercropping of smallholders. Provision of low-interest loans or subsidies (in cash or kind) for households having a shortage of cash may therefore be helpful in enhancing the scale of intercropping.

In addition, the results also suggest that the intensity of extension contact also significantly contribute to the intensity of intercropping. Investment in human capital such as training extension workers as well as efficient mobilisation of the presently available extension personnel to motivate present intercroppers may be a worthwhile method of increasing the intensity of adoption of CBI.

ACKNOWLEDGMENTS

Author is thankful to Dr (Mrs) C Jayasekera, Director of Coconut Research Institute of Sri Lanka for providing approval to publish this paper. He is also grateful to Dr Wijaya Jayathilake, Mr M E Daw, Prof. K J Thomson and Dr I E Edwards for useful comments. Mr S D J N Subasinghe and Mrs K V N N Jayalath are acknowledged for their support.

REFERENCES

Feder, G, Just, R E and Zilberman, D 1982 *Adoption of agricultural innovation in developing countries: A survey.* World Bank Staff Working Papers, No. 542, The World Bank, Washington, D. C., USA.

Gunathilake, H A J 2004 Personal communications. Coconut Research Institute of Sri Lanka.

Gujarati, D N 1995 *Basic Econometrics.* Third Edition. MacGraw-Hill, Inc.

Huffman, W E 1974 Decision making: The role of education. *American Journal of Agricultural Economics,* 56 (part 1), 85-97.

Igodan, C O, Ohaji, P E and Ekpere, J A 1988 Factors associated with the adoption of recommended practices for maize production in the Kainji Lake Basin of Nigeria. *Agriculture Administration and Extension*, 29, 149-156.

Judge, G G, Hill, R C, Griffiths, W E, Lutkepohl, H and Lee, T C 1988 *Introduction to the Theory and Practice of Econometrics.* Second Edition. John

Kivlin, J E, Fliegel, F C, Prodipto, R and Sen lalit, K 1971 *Innovation in Rural India.* Bowling Green: Bowling Green University Press.

Lariosa, E A and Gomez, E D 1983 *Philippine Journal of Coconut Studies*, 8(1& 2), 37-42.

Niranjan, S K D F F and Jayathilake, M W A P 1991 The information dissemination systems related to the six-row rice transplanter machine. *Tropical Agricultural Research*, 3, 226-241.

Niranjan, S K D F F, Jayathilake, M W A P and Thatil, R O 1991 Factors associated with the adoption of the six-row rice transplanter machine. *Tropical Agricultural Research*, 3, 276-289.

Nkonya, E, Schroeder, T and Norman, D 1997 Factors affecting the adoption of improved maize seed and fertilizer in Northern Tanzania. *Journal of Agricultural Economics,* 48(1), 1-12.

Norusis, M J 1986 *SPSS/PC+™: SPSS for the IBM PC/XT/AT.* SPSS Inc.

Obinne, C P O 1996 Adoption of improved livestock management innovations in Nigeria: The Benu state experience. *Outlook on Agriculture*, 25(2), 119-122.

Opare, K D 1980 Innovation adoption behavior of Ghana cocoa farmers. *Agricultural Administration*, 7, 289-296.

Ørskov, E R 1995 Constraints on the world's small farmers. Paper presented at the International Conference in Cambridge, 6-8 December 1995. *Proceedings No 370. The Fertilizer Society.*

Papa, A G and Sison, O F 1991 Intensity of extension contact and innovativeness of papaya farmers in four upland towns in Cavite, Philippines. *The Philippine Agriculturist*, 74(1), 11-22.

Pindyck, R S and Rubinfeld, D L 1976 *Econometrics Models and Economic Forecasts.* Second Edition. New York: McGraw-Hill.

Rahm, M R and Huffman, W E 1984 The adoption of reduced tillage: The role of human capital and other variables. *American Journal of Agricultural Economics*, 66, 405-413.

Rogers, E M 1962 *Diffusion of innovations.* New York: The Free Press.

Rogers, E M 1983 *Diffusion of Innovations*. Third Edition. New York: The Free Press.

Rogers, E M and Shoemaker, F F 1971 *Communications of Innovations: A Cross-cultural Approach*. Second Edition. New York: The Free Press.

Rogers, E M and Svenning L 1969 *Modernization Among Peasants: The Impact of Communication*. New York: Holt, Rinehart and Winston Inc.

Voh, J P 1982 A study of factors associated with the adoption of recommended farm practices in a Nigerian village. *Agricultural Administration*, 9, 17-27.

Wiley and Sons, Inc. p. 868.

Wijeratne, M and Chandrasiri, P A N 1988 *Farmer, extension and research in Sri Lanka: An empirical study of the agricultural knowledge system with special reference to Matara district.* Wageningen, The Netherlands Agricultural University.

APPENDIX

Table A1. The matrix of correlation coefficients between independent variables of the linear model

	CAP	LAB	RICE	AGE	FE	EDU	HLAND	EXT	TIME
CAP	1.0000								
LAB	0.1775	1.0000							
RICE	0.3528**	-0.0589	1.0000						
AGE	-0.1695	0.0147	0.0093	1.0000					
FE	-0.0902	-0.0706	0.1531	0.5919**	1.0000				
EDU	0.1078	-0.3690**	0.1436	-0.3626**	-0.2033	1.0000			
HLAND	0.3328**	-0.2061	0.4654**	0.0511	0.0797	0.1388	1.0000		
EXT	0.0921	0.0337	0.0361	-0.1394	-0.1226	0.1201	0.1092	1.0000	
TIME	-0.0219	-0.2230	0.1154	-0.0267	-0.0509	0.2492*	0.0256	-0.1284	1.0000

Notes: - number of cases 113.
- Two-tailed significance levels: * P < 0.01; ** P < 0.001;
- Abbreviations of variables are as explained in Section 4.

Recent Advances in Tea Research in South India

Dr N Muraleedharan
Director
UPASI Tea Research Foundation, Nirar Dam BPO
Valparai PO 642127, Coimbatore Dist, INDIA

Research on tea started in an organised way by the Indian Tea Association (ITA) in 1891 in North East India and by the United Planters Association of Southern India (UPASI) in 1926. The Tocklai Experimental Station in Jorhat (Assam) was opened in 1911, whereas the UPASI started the Tea Experimental Station at Davershola (Nilgiris) in 1926. Both these Research Institutes (TRA and TRF) have contributed significantly to the growth of the tea industry in terms of increase in production and productivity and improvement in processing technology and quality. Recently, certain Universities and Research Institutions have also taken up investigations on the improvement of biotechnological and pharmacological aspects of tea plant as an important area of research and the TRA has so far released 30 clones and 14 hybrid seed cultivars, whereas the UPASI TRI has released 28 clones, five biclonal seed stocks and six clonal graft combinations. Besides these, 152 region specific clonal cultivars are available for planting in North East India, half a dozen estate selections are also used for planting in South India. The nursery practices have been perfected especially on nursery grafting using high yielding clones as scion and drought hardy clones as root stocks. TRI has also developed grafting clips as well as a grafting machine to increase the productivity of the workers. Tocklai has been responsible for the development of a large number of polyploids, especially triploids and interspecific hybrids. In the biotechnology front, micropropagation, production of haploids and protoplast isolation have also been achieved. Attempts have been made to use molecular markers to characterise the tea germplasm. Research is also being done on the functional genomics in tea, especially on the pathway for catechin synthesis.

Standardisation of plant density, style of planting and bringing up of the young plants in to bearing are the other areas where research has helped the industry. Longer pruning cycles have been introduced in North East India in the sixties, whereas this was already the practice in the South. Harder forms of pruning have been substituted by cut across in young and mature tea. Two stage tipping in young and rejuvenated fields has been introduced in the South. Considerable work has been carried out on plucking and in South India plucking based on leaf expansion time is being followed. The use of shears for harvesting is being increasingly practiced in South India, and this helped to increase the productivity of the plucker and to complete harvesting of the crop, especially in the peak cropping periods. However continuous shear harvesting had shown adverse affects on the physiology of the bush, leading to a decline in productivity. A policy of integrated harvesting involving mannual and shear plucking is recommended. Research on rejuvenation pruning, infilling and consolidation has helped the tea industry to increase production and productivity.

Plant nutrition is an important area where significant contributions have come from the institutes. A basis has been suggested for determining the anticipated yield for estimation of N rate. Further, N:K ratios have been determined for young and mature tea. In South, recommendations on the rate of N are based on yield levels and organic matter status of the soil. Foliar application of MOP + Urea, DAP, $ZnSO_4$ and $MgSO_4$ and plant growth regulators are based on research results. Investigastions using radio tracer technique are in progress to determine the fertilizer use efficiency. The use of biofertilizers and vermiculture are two emerging areas of research in tea. Similarly work on dormancy, shade regulation and growth promoters is of immense significance in the study of the physiology of tea bushes.

Drainage is a matter of serious concern in North East India, whereas irrigation and drought management strategies are of great significance in South India. The tea research institutes have done commendable work on these aspects. The work by Tocklai Experimental Station on the use of remote sensing technology to identify the geomorphic units for formulating drainage planning based on topography and geomorphology is worth mentioning here.

Pests and diseases are serious limiting factors in the productivity of tea. Blister Blight disease caused by *Exobasidium vexans* is a serious problem in South India and Darjeeling. Different control schedules are now available against this disease. Recently, a computer based model has been developed for forecasting the incidence of blister blight disease. Detailed information is available on the ecology, crop loss and chemical control of major pests like mites, thrips, *Helopeltis*, looper and slug caterpillars. Several biocontrol agents have been recorded from the tea fields and attempts on biocontrol using entomopathogens, use of botanical pesticides and semiochemicals are in progress, especially in view of the problems caused by the residues of pesticides in tea. In the last five years, data have been generated for deciding the maximum residue levels (MRLs) of the most commonly used pesticides and to determine the safe harvest interval for these pesticides.

In the area of processing technology, the achievements of Tocklai are remarkable. The important machineries that are developed by Tocklai and extensively used are McTear Rotorvane, withering tunnel, continuous tea fermenting machine, Barbora leaf conditioner, Boruah continuous roller, Tocklai tea breaker and continuous withering machine. The split CTC process developed by TRF is useful for increasing theaflavin content and other colour constituents of black tea. Investigations on tea chemistry is in progress in all the research establishments, especially with a view to improve the quality of black tea. Development of a prototype UV fermenter and internal flights in the fermenting drum are some of the achievements in this field. There is considerable scope for modernisation of tea industry through the introduction of electronic process control instrumentation systems at certain critical unit operations. Energy efficeincy in tea processing is rather low, and therefore, all efforts are needed to develop strategies for reducing energy consumption in tea manufacture.

The tea industry is passing through a crisis, especially due to competition from soft drinks. The beneficial health effects of green tea are well known and the role of black tea in human health is being investigated. Several projects are being funded by the Tea Board and the National Tea Research Foundation on pharmacological and beneficial effects of black tea. This probably will be the most important area of research in the coming years. Research on product diversification, organic tea, speciality teas, herbal teas, instant tea and ready to drink tea need to be intensified.

The rapport between the tea industry and the extension wing of the research institutes has been excellent resulting in an efficient and quick transfer of technology. The research and extension linkage of these institutes comes under a single umbrella, unlike in many other institutions. These advisory centres play a pivotal role in identifying the reasons for the gap between the potential and actual yield and offer advice on undertaking suitable remedial measures. The recommendations on agronomic practices such as pruning, tipping, harvesting, shade management, manuring, foliar application of nutrients, correction of soil acidity and effective pest and disease management and weed control have received wide acceptance in the organised plantation sector. However, there is considerable scope for improving these practices in the small grower sector too.

8207

Strategies Towards Sustainable Coconut Production to Enhance Competitiveness in India

Dr M K Nair
Former Director
Central Plantation Crops Research Institute, Kasaragod 671 124, Kerala, India

ABSTRACT

Coconut is grown in more than 93 countries and globally total estimated area under coconut is 12.8 million ha (2001 - 2002), producing 10.9 million mt of copra equivalent. India occupies third position in area and production, next only to Indonesia and Philippines, contributing to 16.61 per cent of the area and 17.69 per cent of the production. A steady increase in area and production has been noticed in India during the last five decades. During the last five years, among the major coconut producing countries, India showed excellent growth rate in area and production of 3.79 and 2.25 per cent respectively. However a major part of the production is used for domestic consumption. India is not in a position to compete in the international market due to high cost of production and low prices.

In view of this to enhance competitiveness, it is necessary to achieve higher productivity, increased income from a unit area in unit time, through adopting suitable coconut based farming/cropping system models while giving emphasis for product diversification.

Among major coconut growing countries, India has the highest productivity of 6,776 nuts ha^{-1}. However, potential productivity is much higher than this, since the average productivity in two major coconut-producing states i.e. Andhra Pradesh and Tamil Nadu is 10,857 nut ha^{-1} and 9,808 nuts ha^{-1} respectively. There is considerable scope for increasing productivity of coconut in India by adopting improved technology and management practices, increasing the availability of planting materials with high yielding varieties and hybrids, nationalizing fertilizer inputs, developing irrigation systems, depending on climate, soil topography, ground water table etc. The practice of integrated pest and disease management, including use of biopesticides and ecofriendly chemicals, attractants and pheromones will also help not only increase productivity but also to reduce the cost of production.

By adopting suitable coconut based farming/cropping systems such as intercropping, mixed cropping, multistoried cropping and mixed farming, the cost of production can be reduced through increasing the total returns per unit land, particularly in small holdings.

The global coconut exports determine the stability of the coconut industry. India does not much in export of coconut oil and coconut kernel products because those products are mainly used for domestic consumption. To enhance the competitiveness, emphasis has to be placed on product diversification such as coconut cream, coconut milk, spray dried coconut milk powder, vinegar, packed tender coconut water etc.

INTRODUCTION

Coconut is grown in more than 93 countries and the crop contributes to the economic development of major producing countries. Globally, total estimated area under coconut is about 12.8 million ha producing 10.9 million mt of copra equivalent. Ninety per cent of the world area and 84 per cent of the production comes from APCC countries. Indonesia, Philippines and India contribute to nearly three-fourth (72 per cent) of the production. Sri Lanka with 4.1 per cent of area and 4.4 per cent of production occupies fourth position (Rethinam and Tanfikkurahman, 2002).

In peninsular India, coconut plays a vital role in the socio-economic life of large number of small and marginal farmers. It is estimated that more than 10 million people in India are dependent on coconut, as they are engaged in coconut cultivation, processing, marketing and other related activities. With an annual production of more than 13,000 million nuts of coconut, the share to GDP of the country is over Rs.70,000 million.

PRODUCTION AND PRODUCTIVITY

A steady increase in area and production has been noticed in India during the last five decades. Area under coconut was 0.63 million ha during 1950 - 1951 which increased to 1.89 million during 2001. During the same period production increased from 3,282 million nuts to 12,820 million nuts (copra equivalent to 1,785,000 mt) and productivity from 5,238 nuts ha^{-1} to 6,776 nuts ha^{-1}. During the last five years among the major coconut producing countries, India showed an excellent growth rate in area and production of 3.79 and 2.25 per cent respectively.

Kerala, Karnataka, Tamil Nadu and Andhra Pradesh are the major coconut producing States and together they account for about 91 per cent of area as well as production. Kerala accounts for almost 50 per cent of the area and 45 per cent of production. This is followed by Karnataka with 19.75 per cent of area and Tamil nadu with 17.75 per cent. Among four major coconut producing States, highest productivity is in Andhra Pradesh with 10,857 nuts ha^{-1} (All India final Estimate for 2001-2002).

Table 1. Area, production and productivity of coconut in leading coconut producing states in India

State	Area ('000 ha)	% share	Production (Million nuts)	% share of production	Production (Nuts ha^{-1})
Kerala	939.5	49.65	5744	44.80	6,114
Tamil Nadu	335.8	17.75	3,293.6	25.69	9,808
Karnataka	373.7	19.75	1,523.4	11.88	4,077
Andhra Pradesh	104.0	5.50	1,129.1	8.81	10,857
All India	1,892.3		12,821.7		6,776

HIGH PRODUCTION TECHNOLOGY

A. Factors responsible for increase in production and productivity during previous two decades

1. Availability of quality planting materials

(a) Varieties

India probably has the largest coconut germplasm with more than 300 accessions. Systematic evaluation, through multilocation trials resulted in selection and release of three high yielding varieties and one variety (COD) for tender nut purpose. The released cultivars give an average yield of more than 100 nuts palm^{-1} yr^{-1} increasing the net return by 45% (from Rs. 31,340 ha^{-1} to Rs. 45,430 ha^{-1}) (Rajagopal and Arulraj, 2003).

Table 2. Performance of released Indian coconut cultivars

Variety	Mean yield^{-1} palm^{-1} yr^{-1}		Copra yield		
	No. of nuts	%over WCT	Mean nut^{-1} (g)	Mean palm^{-1} yr^{-1} (kg)	Per cent over WCT
Chandrakalpa (LO)	97	21.2	195	18.9	32.3
Pratap (BGR)	151	88.8	152	22.7	57.6
Philippines Ordinary (PO)	110	37.5	198	21.8	57.9
Chowghat Orange Dwarf (COD)	93	Tender nut variety			
West Coast Tall (WCT)	80	—	180	14.4	

(b) Hybrids

Hybrid vigour in coconut was reported for the first time in India by Patil in 1937 based on the result of a cross between West Coast Tall and Chowghat Green Dwarf. In subsequent years' field trials, Dwarf as mother palm was found to be superior to both the parents, as well as to reciprocate in yield. More than 80 hybrid combinations have been evaluated over the years in India and a total of 11 hybrids have been released for commercial cultivation. Comparative yield performance of these hybrids are given in Table 3 (Nair, 2000).

These hybrids could give an average yield of about 110 nuts palm^{-1} yr^{-1}. Under uniform management conditions, cultivation of coconut hybrids could give a gross income of Rs. 77,000 ha^{-1} as compared to Rs. 56,000 ha^{-1} from West Coast Tall. On a commercial scale cultivation in Southern States of India, farmer could get an average yield of 150 nuts palm^{-1} yr^{-1} under irrigated conditions as compared to local cultivars with an additional net return of Rs. 40,000 ha^{-1} yr^{-1} (Rajagopal and Arulraj, 2003).

Table 3. Performance of released Indian coconut hybrids

Sl. No.	Hybrids/Varieties	Nut yield palm^{-1} yr^{-1}	Copra yield nut (g)	Copra yield Mean palm^{-1} (kg)	Copra yield ha^{-1} (t)	Oil content %	State for which recommended
1	Chandra Sankara (COD x WCT)	116	215	25	4.4	68	Kerala, Karnataka, Tamil Nadu
2	Kera Sankara(WCT X COD)	108	187	21	3.5	68	Kerala, Karnataka
3	Chandra Lakhsa(LCT x COD)	109	195	21	3.7	69	Kerala, Karnataka
4	Laksha Ganga(LCT x GB)	108	195	21	3.7	70	Kerala
5	Ananda Ganga(ADOT x GBGD)	95	216	21	3.6	68	Kerala
6	Kera Ganga(WCT x GBGD)	100	201	21	3.5	69	Kerala
7	Kera Sree(WCT x MYD)	112	216	24	4.2	66	Kerala
8	Kera Sowbagya (WCT x SS Apricot)	130	195	25	4.3	65	Kerala
9	VHC-1(ECT x CGD)	98	135	13	2.3	70	Tamil Nadu
10	VHC-2(ECT x GBGD)	107	152	16	2.9	69	Tamil Nadu
11	Godavari Ganga	140	150	21	3.7	68	Andhra Pradesh

(c) Integrated nutrient management

Being a perennial crop, coconut exports nutrients to the above ground parts continuously from a limited volume of soil through out its existence. Standardization of nutrient requirement of coconut palms through multilocation trials for a number of years and application of these results have contributed to increasing productivity. The palms are to be manured during first year itself for sustained productivity. If the plantation is neglected at the beginning, the productivity of palm is adversely affected, and even if fertilized at a later stage, the palms do not respond to achieve the level of expected productivity. The existing fertilizer recommendation for an adult coconut palm in West Coastal belt is 0.5 kg N, 2 kg P_2O_5 and 1.2 kg K_2O palm^{-1} yr^{-1} applied in two split doses (May-June and September-October). Application of organic manure at the rate of 50 kg palm^{-1} is required to supplement fertilizers (Nelliat et al., 1972). Palms growing without fertilizers can be revived by applying double dose of fertilizer in the first two years followed by recommended dose of fertilizer (Nelliat, 1984).

Application of phosphatic fertilizer can be skipped for few years if the available phosphorus is more than 20 ppm (Khan et al., 1990).

(d) Irrigation and Productivity

Quantity of irrigation water required is location specific and depends on climate, soil, topography, ground water table etc. Moisture stress results in reduction in number of bunches, number of female flowers, setting percentage and shedding of tender nuts. Reduction in size of nut and copra content also observed due to moisture stress.

Various irrigation methods adopted in coconut gardens are basin, perfo, sprinkler and drip irrigation. Water transpired by coconut is estimated to range from 28 L $palm^{-1}day^{-1}$ to 200 L $palm^{-1}day^{-1}$ (Reyne, 1948). In conventional basal irrigation in coastal Kerala and Karnataka, 200 L water once in four days has been recommended. Drip irrigation has the advantage of economizing water and improving the efficiency of water use. About 30 to 40 L water per day are found to be sufficient under coastal regions. Sprinkler irrigation or perfo irrigation are more suited for coconut plantation with inter or mixed cropping system. Drip irrigation is ideally suited for widely spaced crops like coconut as it saves water, energy and labour. A study at CPCRI indicated that yield of coconut is comparable with basin irrigation with added advantage of saving 34 per cent of water.

(e) Inter cultivation and productivity

In the management of coconut plantations, the importance of inter cultivation falls next to irrigation and manuring. Inter cultivation alone is found to increase yield substantially compared to plantation without inter cultivation as indicated in a long term field experiment at CPCRI.

Table 4. Response of WCT to different management practices

Treatment	No. of nuts $palm^{-1} yr^{-1}$
Organic + inorganic manure + tillage	110
Inorganic manure + tillage	97
Inorganic and forking basin	91
Intercultiation (tillage) alone	53
Weed control using herbicides	27
No manure, no tillage	8

(f) Pests and Disease Management

(i) Pests

A large number of insect and non-insect pests cause damage to various parts of the crop resulting in considerable crop loss. Rhinoceros beetle (*Oryctes rhinoceros* L.), red palm weevil (*Rhynchophorous ferrugineus* F.) and coconut leaf eating caterpillar (*Opisina arenosella* Wlk.) are the major pests occurring in coconut in India, reducing not only yield but also the life span. In the past, effective management practices using pesticides for important pests have been formulated to reduce crop losses. However, in recent years, increasing awareness on side effects of pesticides has resulted in use of botanical pesticides, eco-friendly chemicals, attractants and pheromones.

Red palm weevil

- Cleaning palm crown periodically
- Treating wounds with coal tar + 1% carbaryl.
- Prophylactic leaf axil filling with 20 g phorate 10G in 200 g of fine sand once in these months.

Economics

- 5.7% of palms infested in West Coast of India
- Yield loss upto 60% in affected palms
- Average loss due to pest – Rs. 1920 ha^{-1}
- Cost of IPM – Rs. 300 ha^{-1}
- Gain due to adopting IPM – Rs. 1620 ha^{-1}
- Benefit-cost ratio : 6.40

Rhinoceros Beetle

Integrated pest management packages and cost-economics of major pests are listed below:

IPM:

- Extraction of adult beetles and filling leaf axile with Dithane M-45 3 g + 1 kg sand.
- Treatment of all possible breeding sites with 0.01% Carbaryl.
- Maintenance of sanitation
- Biological suppression – release of adult beetle inoculated with baculovirus.

Economics

- Upto 36% of palms are infected
- Extent of yield loss – 6%
- Loss/ha - Rs. 672 yr^{-1}
- Cost of IPM – Rs. 350 ha^{-1}
- Gain due to adoption – Rs. 322 ha^{-1}
- Benefit cost ratio – 1.92

Leaf eating Caterpillar

IPM:

- Cutting and burning badly infested outer leaves
- Spraying 0.02% Dichlorovis
- Release of larval parasitoids *Goniozus nephantidis*, prepual parasitoids like *Elasmas nephantidis* and *Brachmarria nosatoi* at fortnightly intervals.

Economics

- Extent of yield loss – upto 65%
- Loss due to the pest – Rs. 7,280 ha^{-1} yr^{-1}
- Cost of IPM – Rs. 750 ha^{-1}
- Profit due to adoption – Rs. 6,530 ha^{-1}
- Benefit cost ratio: 9.70

Eriophyid mite (*Acaria guerreronis*)

Large scale infestation was found from 1998. Mites are harboured on the tender meristematic regions of the nut underneath the perianth. Severe infestation results in poor development of nuts with reduced kernel weight and poor quality fibre.

IPM:

- Wettable sulphur 0.4% or Dicofol 0.05% spray
- Spraying 2% neem oil garlic and soap mixture

- Recent recommendation – Stop Chemical control measures for two years to encourage multiplication of natural predators.
- Yield loss upto 40% - upto Rs. 8,960 ha^{-1}.

(ii) Diseases

Among 173 fungal species reported from coconut only bud rot, basal stem rot, leaf rot and stem bleeding are causing considerable crop loss (Joseph and Radha, 1978; Nambiar and Rawther, 1993).

Leaf rot:

Caused by many fungal pathogen, mainly *Colletotrichum gloeosporioides, Exserohilum rostratum* and *Fusarium solani.*

IPM

- Curring of rotten portion of the spindle
- Pouring either Contaf-5EC 2 ml or Diathane M-45 in the cavity around the base of the spindle leaf.
- Application of Furadan 3G 30g or Folidol dust around the base of the spindle leaf.

Economics

- Not computed

Bud rot :

IPM:

- Disease advanced palms are to be cut and burnt.
- All healthy palms surrounding the infected palms should be sprayed with 1% Bordeaux mixture on the spindle and 2-3 innermost leaves.
- Application of 10% Bordeaux paste on affected portion.

Economics

- Incidence upto 6.5%
- Yield loss upto 100% in advanced stage
- Average loss – Rs. 3,840 ha^{-1}
- Cost of IPM – Rs. 250 ha^{-1}
- Gain due to adoption – Rs. 3,590 ha^{-1}
- Benefit cost ratio – 13.36

2. **Stem bleeding:** caused by *Thielaviopsis paradoxa*

IPM:

- Apply neem cake at the rate of 5 kg $palm^{-1}$ yr^{-1} in the basin during September-October.
- Root feeding of 5% Calixin or 5% bavistin at quarterly intervals.
- Chip off affected bark and apply 5% Calixin, followed by hot coal tar.

Economics

- Incidence up to 10 per cent
- Yield loss upto 30%

- Yield loss in endemic areas – Rs. 1,728 ha^{-1}
- IPM technologies – Rs. 1000 ha^{-1}
- Gain due to IPM – Rs. 728 ha^{-1}
- Benefit cost ratio – 1.73

Basal Stem rot: Caused by *Ganoderma lucidum* and *G. applanatum*

- Disease incidence; 2.6 to 13 per cent

IPM

- Isolation of diseased palms through trenches
- Application of 5 kg neem cake $palm^{-1}$
- Root feeding Calixin 0.1 per cent

Root (wilt) disease – confined to Kerala

- Caused by phytoplasma
- Characteristics – bending of leaflets (flaccidity), foliar yellowing and leaf necrosis.
- Per cent incidence – upto 32.3
- Nutrient management/water management/control of pests and diseases
- Leaf rot management
- Uprooting disease advanced palms and replanting

Economics

- Yield loss upto 50%
- Loss due to the disease – Rs. 9,280 ha^{-1}
- Cost of IPM – Rs. 6,000 ha^{-1}
- Gain due to adoption – Rs. 3,280 ha^{-1}
- Benefit cost ratio : 1.55

B. Production constraints and remedies

1. **Planting materials:** The estimated annual seedling requirement in coconut is about 20 million. The high production potential of released hybrids and varieties has been indicated earlier. Coconut hybrids are produced only by CPCRI and State Agricultural Universities, and these organizations are not able to meet even 10 per cent of the requirement. Thus, there is a wide gap between demand and supply. This situation is being exploited by private nurseries, supplying poor quality seedling with doubtful parentage. Only remedy to this problem is establishment of seed gardens under the guidance of Coconut Development Board, by the Developmental departments and even private entrepreneurs. Establishment of seed gardens in a phased manner, to supply high yielding varieties and hybrids should receive immediate attention.

2. Input technologies available and their application: Input technologies for higher production detailed earlier, were developed particularly for the West Coast of India. In a vast country like India, there are several agro-climatic regions and situations where coconut is cultivated. Coconut farmer requires specific recommendation to suit farming situation in different agroclimatic conditions. The Central Institute has several limitations to develop technologies for specific problems and locations. It is irrational to recommend same manurial and irrigation schedule for different climatic and soil conditions.

3. **Holding size:** In a strict sense, coconut cannot be classified as a plantation crop in India. In the Coastal Kerala and Karnataka, coconut holding vary from 0.4 ha to 3.6 ha with 95 per cent of the holding having extents below 0.84 ha. However the holding size is comparatively larger in Tamil Nadu and Andhra Pradesh. In small holdings, coconut is only one of the component crops, with few other crops to meet basic requirement of farmer, viz., fruit, vegetables, tubers and even fuel from the holding. From small holdings, adequate income is not generated to support the family. Neglect of coconut in homestead garden leads to low productivity and high cost of production. High density planting with a number of component crops planted without proper spacing is the feature of neglected small homestead garden. Palms under such holdings face irrigation and nutrient constraints. A recent survey conducted in Southern Kerala indicated that as the holding size increases, the palm population decreases. This leads to improved cultural practices, proper spacing of component crops, higher productivity of coconut and increased income from unit area (Thampan, 1999). In another survey, it was found that about 90 per cent of small holdings received organic manures, while only 40 per cent received inorganic fertilizers. Low productivity and income from small holdings result in minimum input to coconut.

Small holdings also face irrigation constraints due to inadequate finance to develop water sources and install irrigation system.

It was also found that only about 30 per cent of small holding farmers adopt plant protection measures against pests and diseases. Low income, non-availability of climbers and sprayers and reluctance to use poisonous chemicals, as a precautionary measure against domestic animals and birds are the reasons for adopting low percentage of plant protection measures.

C. Strategies for improving production and productivity

1. Evaluation of high yielding varieties and hybrids has clearly established high production potential. In general, farmers are also confident that coconut hybrids perform well under good management conditions. Availability of proven quality seedling varieties/hybrids is to be ensured by establishing seed gardens on a regional basis. Simultaneously extension efforts are to be strengthened to convince all the farmers about the relative advantages of coconut hybrids.

2. So far breeding of coconut for disease tolerance has not been successful. Breeding programme has been strengthened in recent years to produce root (wilt) tolerant hybrids. As early as possible these disease tolerant hybrids are to be multiplied and supplied to disease endemic areas.

3. Location specific fertilizer and irrigation recommendations are to be developed to target yield levels, taking into consideration soil characteristics, nutrient status, rainfall distribution, temperature, relative humidity, ground water level etc.

4. Level of crop loss due to major pests and diseases has been detailed earlier. Effective and economic way of managing coconut pests and diseases would be to follow integrated approach incorporating more efficient methods. Efficient use of biopesticides and synthetic pheromones would greatly help towards this goal.

D. Enhancing competitiveness

As indicated earlier, coconut is primarily a crop of small and marginal farmers in India. As a sole crop, coconut provides employment only for about 150 man-days ha^{-1} yr^{-1} and income generated from these small holding is insufficient to meet farmers requirement. Thus other alternatives are to be envisaged to generate additional income and enhancing competitiveness.

1. Coconut based cropping systems

In the West Coast of India, coconut constitutes an essential and dominant component of homesteads and it occupies a preeminent position in the coastal agro-ecosystem. Instead of depending only on coconut, income alternatives are to be explored to obtain maximum return from a unit area of coconut plantations.

Spacing followed in coconut planting in India varies from 7.5 m x 7.5 m to 10 m x 10 m. This spacing is recommended to accommodate large crown of the palm. It has been estimated that at this spacing coconut roots utilize only 22-25% of the soil area, leaving ¾ of the soil area for exploitation. It is also estimated that about 56 per cent of sun light is transmitted through the canopy in palms above 25 years. Thus in a normal spaced coconut garden about 75 per cent of soil area and about 45% incident sun light is available for exploitation to cultivate a number of annual and perennial crops and thereby get additional income.

Depending on the age of the palm the life span of coconut can be divided into three distinct phases from the point of view of intercropping:

(i) up to 8 years – good light transmission initially, but decreasing with age felicitating for growing annuals and biennials;

(ii) young palms in the age group of 8-25 years with maximum coverage by the canopy with minimum light penetration. This stage is not suitable for multiple cropping.

(iii) above 25 years, the trunk height increases with a reduction in crown size and increased light transmission. This is an ideal situation for growing annual and perennials in the interspaces.

Based on this principle, a number of farm models have been developed in India to suit diverse soil and climatic conditions, preference of farmer, availability of labour, irrigation facilities etc. for achieving more efficient utilization of resources to maximize productivity and net returns.

Some of the crops found suitable for cultivation as intercrops in coconut gardens are:

Tuber crops	:	Tapioca, Sweet potato, Yam, Colocasia
Spices	:	Ginger, turmeric
Vegetables	:	Snake gourd, bottle gourd, brinjal, etc.
Mixed crops	:	Number of perennials like black pepper, cinnamon, banana, cocoa, clove, nutmeg, coffee

Summary of results obtained from various inter and mixed cropping systems (2002-2003) is furnished in the Table-5.

Table 5. Net income from various inter and mixed cropping trials (2002-2003)

Crop combination	Net income (Rs.ha^{-1})
Coconut monocrop	Rs. 32,000
Coconut + Elephant Foot Yam	Rs. 46,800
Coconut + Ginger	Rs. 67,500
Coconut + Tapioca	Rs. 65,700
Coconut + Clove	Rs. 53,120
Coconut + Banana	Rs. 70,470
Coconut + Bhendi	Rs. 50,000

(Source: Rajagopal and Arulraj, 2003)

2. Multistoried cropping

In this system three or four crops having different morphological structures are selected so that the component crops intercepts light at different levels and their roots forage the soil at different zones. The ideal combination which gives maximum net return was coconut – black pepper – cocoa and pineapple.

3. High Density Multistoried Cropping System

This involves a large number of compatible crops maintaining optimum level of plant density for each crop per unit area, so as to meet the diverse needs of the farmers, namely, food, fuel, timber, fodder and cash.

Coconut provides opportunities to grow a wide range of crops in the interspaces for maximizing productivity from unit area of land per unit time. The crops will have to be selected carefully so that the farmer derives the maximum advantage with lower inputs. The systems enables farmers of small holdings to diversify their crops, thereby reducing the risk of crop failure and price fluctuations, to intensify use of their land to maintain soil fertility. The systems indirectly enhances the competitiveness of the main crop, coconut, by getting more income and to meet varied requirement of family.

E. Strategies to enhance competitiveness through value added products

Among major coconut growing countries, India has the highest productivity of 6,776 nuts ha^{-1}. In spite of this, majority of the coconut farmers in the country, particularly for whom coconut is the primary source of livelihood are generally poor and struggle to have a decent living from the low income. The situation often changes due to fluctuation in price of coconut and coconut oil. Even now in India coconut is cultivated for limited uses, mainly copra and coconut oil. Cultivation is a way of life to the farmers rather than an economic proposition. Alternative available for enhancing competitiveness and improve the economy of coconut farmers in India is to increase income from unit area by coconut based farming system and develop technologies and innovations in food processing sector and increasing demand for processed and ready made food products to transform coconut industry in India. Though technologies for processed kernel products like desiccated coconut, defatted desiccated coconut powder, preserved and packed coconut cream, spray dried coconut milk powder, packed tender coconut water and *Nata-de-coco* have been developed in recent years, production is in the infant stage and not made on perceptible impact to the coconut industry.

Export performance of coconut shows that globally coconut oil determines the stability of coconut industry. Coconut oil alone commands 64 per cent of value of export and 12 per cent by desiccated coconut. The major exporter of coconut oil is Philippines which contributes to 63 per cent to export pool followed by Indonesia (20 per cent) and Sri Lanka. PNG, Indonesia and Vanuatu are the major copra exporting countries with share of 25, 21 and 19 per cent respectively. Again Philippines has a share of 33 per cent in export of desiccated coconut and Sri Lanka comes next with 20 per cent. Thus India does not figure much in export of coconut oil and coconut kernel products. However India is the major exporter of coir and coir products with foreign exchange of Rs. 3,000 million annually. Other products such as coconut wood, husk and shell have also scope for making value added products.

In India even now, coconut is mainly used for domestic consumption, in form of kernel, copra and oil, the traditional products. In general, fluctuating price of oil seeds and fats internationally has been influencing the price of coconut and coconut oil putting the coconut farmers in financial difficulties.

To enhance competitiveness, emphasis has to be on product diversification, such as coconut cream, coconut milk, spray dried coconut milk powder, vinegar, packed tender coconut water etc. Most of these products are in the process of commercial production. Aggressive promotional campaign for use of coconut products for boosting consumption of coconut products is to be given importance. Cost of production of coconut products is to be brought down, so that there is affordable acceptability by the Indian consumers. Slowly when the commercial production stabilizes, attempts should be made to penetrate export marketing.

REFERENCES

Khan Hameed, H, Biddappa, C C, Nagarajan, M, Thomas, G V and Cecil, S R 1992 Residual effect of long term phosphorus application on soil and plant nutrient contents, mycorrhizal association and yield of coconut. J. Plant. Crops 20(Suppl.): 14-18.

Nair, M K 2000 Coconut production and productivity. Proc. XXXVII COCOTECH Meeting/ICC 2000, 24-28 July 2000. pp. 31-57

Nelliat, E V 1972 NPK nutrition of coconut a review. J. Plant. Crops 1(Suppl.): 70-80.

Nelliat, E V, Gopalasundaram, P Sivaraman, K and Nair, R V 1984 Fertilizers management for coconut palms grown under neglect. PLCAROSYM-V, pp. 379-387.

Rajagopal, V and Arulraj, S (Eds.) 2003 Towards helping farming community. CPCRI Publication.

Rethinam, P and Tanfikkurahman, L 2003 Global scenario of coconut oil. Indian Coconut Journal 33(7): 1-8.

Reyne, A 1948 De Cocos Palm. In: *De landboua in the indiche Archipl* II. Eds. A Hall, C.J.J. Van and C. Van de Koppel. Van Hoeve, The Hague. pp. 427-525.

Thampan, P K 1999 Socio-economic features of coconut farming in Kerala. Tree World , 8 (10).

Indian Natural Rubber Sector: An Overview

Dr N M Mathew
Director
Rubber Research Institute of India
Kottayam - 686 009

ABSTRACT

The rubber plantation industry in India has completed a century of years since the crop was first introduced in the country on a commercial scale in 1902. Over the years, this industry has not only withstood the challenges of difficult times, but registered spectacular growth in terms of expansion in area and increase in production and productivity. Rubber cultivation has contributed substantially to the socio-economic development of the regions where it is undertaken. This paper is an attempt to review the salient features of the sector, the progress achieved with respect to production, processing, consumption etc. and also the changes in the commercial aspects of the commodity including price and external trade. An attempt also has been made to analyse the weaknesses and the programmes for further growth and development of the sector during the immediate future with special reference to the programmes included in the current Five Year Plan.

The production sector in the country is dominated by smallholdings, which account for 88 per cent of the production and area with an average holding size of 0.5 ha. There are nearly one million producers and about 0.4 million people engaged in the plantation sector as workforce, either directly or indirectly. About 10,000 tribal families, mostly in the North East, have been resettled with rubber-based rehabilitation programmes. India is now the fourth largest rubber producer next to Thailand, Indonesia and Malaysia, accounting for over 711,650 mt yr^{-1}. More importantly, the productivity of rubber in India, at 1663 kg $ha^{-1} yr^{-1}$, is the highest among the major producing countries. Now, rubber plantations spread over 5,70,000 ha in 16 states generating steady income for about a million farmers. The country is the fourth largest consumer of natural rubber with a strong manufacturing base producing over 35,000 different products out of rubber. Of the 4,931 manufacturing units, 40 per cent consume less than 10 mt of rubber per year. Although the manufacturing sector has been mostly inward oriented, the growth in external trade during the last few years has been significant and the sector has accounted for nearly Rs. 2,528 billion worth export during the year 2002-2003. Consumption has been growing at a faster rate than production during the last few decades. However, the annual growth rate in consumption has gone down during the years 1997-2002. However, it has picked up again reaching nearly 9 per cent in 2002-2003.

Although the plantation sector is now 100 years old, significant developments have taken place during the last 4-5 decades. There has been substantial growth in the area under cultivation as well as production during the 1980s and early 1990s. However, the annual growth rate in production has decreased from 8.4 per cent during 1996-1997 to less than 1 per cent in 2002-2003. Although the country has been producing all the major forms of raw rubber, ribbed smoked sheet (RSS) accounts for over ?2 per cent of the total production followed by concentrated latex (10.5 per cent), technically specified rubber (9.6 per cent) and others (7.7 per cent).

The price of NR in the domestic market has been moving in tandem with the international price ever since the new economic policies have been introduced by the Government in 1991. In general, the domestic price has been remaining slightly higher compared to the international price although during the recent past, the domestic price has been remaining lower than the international price. With the opening up of the economy, both imports and exports of rubber are possible and the balance between these two depends mainly on the relative prices in the domestic and international markets. The Government of India have recently introduced certain export promotion measures and hence export of rubber has increased during the last two years.

The weaknesses of the production sector in India include a relatively high cost of production in spite of the high productivity, dominance of sheet rubber grades in the raw rubber market and the relative inconsistency in quality of TSR produced in the country. Packaging and presentation of rubber also need some improvements to make them meet international standards. The various schemes, which are being implemented by the Rubber Board during the X Plan include measures to overcome the weaknesses and to make the NR sector in the country competitive with respect to cost and quality. Further increase in production is attempted mainly through productivity enhancement by replanting of low yielding areas and also by popularizing still higher yielding varieties. Additional income generation through intercropping, value addition to rubber wood, utilization of rubber seed and bee keeping in rubber plantations are being encouraged. Greater emphasis is being given to quality improvement and cost reduction in the processing sector. TSR processing factories are encouraged to modernize, so that cost of production is reduced and quality improved. They are also provided with assistance for implementation of quality management systems such as ISO 9000. Market development for natural rubber will be attempted through strengthening of research and development in the area of rubber technology, particularly with respect to development of non-conventional applications of natural rubber. The environment-friendly credentials of natural rubber will be further promoted and environmental issues related to rubber cultivation and processing will be addressed to promote NR as a green commodity.

With Best Compliments
from

☆

☆

ISLANDWIDE SCIENTIFIC (PVT) LTD.,

FOR:-

- ***Analytical Instrument***
  AAS / UV-VIS / HPLC / ICP / XRD / GC / Auto Analyzers / TOC / Elemental Analyzers / On-line Analyzers / Electron Microscope
- ***Laboratory & Scientific Equipment***
- ***Laboratory Glassware / Consumables***
- ***Laboratory Chemicals***
- ***Repairs & Servicing of Analytical Instrument, Laboratory & Scientific Equipment***

Islandwide Scientific (Pvt) Ltd.
41, Francis Road
Colombo 10

Tel.: 2681147 - 50 (4 lines)

Fax: 2696663

E-mail: islnwide@sltnet.lk
issgen@sltnet.lk
isservis@sltnet.lk

Tea	We Provide Solutions From Plucking to Packing
Rubber	Specialists in Drying Towers, Forced Draught Drying & Automated Crepe Cutting
Coconut	Specialists in Desiccated Coconut Drying, Automation of DC Mills, Designing & Fabricating of Machinery for Coco Peat Production.

HELIX
ENGINEERING (PVT) LTD
No 17, Horton Place,
Colombo 07,
Sri Lanka.

TP : 2681709,
4713533.
FAX : 2681710.
Email: helix@slt.lk

Government Owned

LAKPOHORA

The finest quality for maximum productivity

Ceylon Fertilizer Co.Ltd.
Hunupitiya , Wattala.

Ministry of Agriculture

Tel : 2947760, 2947762 Fax : 2930463

With Our Best Wishes

for

A Successful Symposium on

Plantation Crop Research

MACKWOODS
ESTD. 1841

MACKWOODS LTD.

AGROCHEMICALS

10, Gnanartha Pradeepa Mawatha,
Colombo 08.

Telephone: 2697965-9 Fax: 2699454 E-mail: mackwoods@sltnet.lk Website: www.mackwoods.com

SUPPLIER OF

Champion
- for the control of Blister Blight
(Copper Hydroxide 77% WP)

Bumper
- Systemic Fungicide for the Control of Blister Blight
(Propiconazole 25% EC)

Weedol
- for a total eradication of weeds
(Glyphosate 36% SL)

T, Stanes

Green Miracle
- Plant drought regulator

T, Stanes Microfood Foliar for Tea

Serving the Plantation Sector for Over a Century

Best Compliments from ....

Are your Tea, Rubber and Coconut Plantation receiving adequate Phosphorus?

Give them economically priced, well known

Eppawala Rock Phosphate Fertilizer (ERP)

All planters and Growers know the importance of Phosphorus for plant life. Phosphorus is classified as a major nutrient and is required by plants in considerable quantities. It is one of the three nutrients that are essential for plant growth (apart from Nitrogen and Potassium). Balanced nutrition for Tea, Rubber and Coconut plays a key role in the management of plantation. Sound fertilizer, practices enhance healthy growth and ensure productivity.

Eppawala deposit is a valuable asset and one of the important apatite deposits in the world. We wish to kindly advise you to use fertilizer mixtures containing Eppawala Rock Phosphate (ERP) as the source of Phosphorus for your plantation crops in accordance with the research findings of Tea, Rubber and Coconut Institute of Sri Lanka. Further it will ensure a saving of foreign exchange wasted on importing rock phosphate where an equally efficient source of phosphorus is available locally.

☞ Marketing Manager

LANKA PHOSPHATE LTD. (STATE COMPANY)

73 1/1, New Kelani Bridge Rd., Colombo 14.
Tel.: 011 2459906 / 7 Fax: 011 2459908
Phosphate Project, Eppawala Tel.: 025 2249121 Fax: 025 2249400

With the Best Compliments from

multiplex

Pioneers in Micronutrients Fertilizers for Plantation Crops

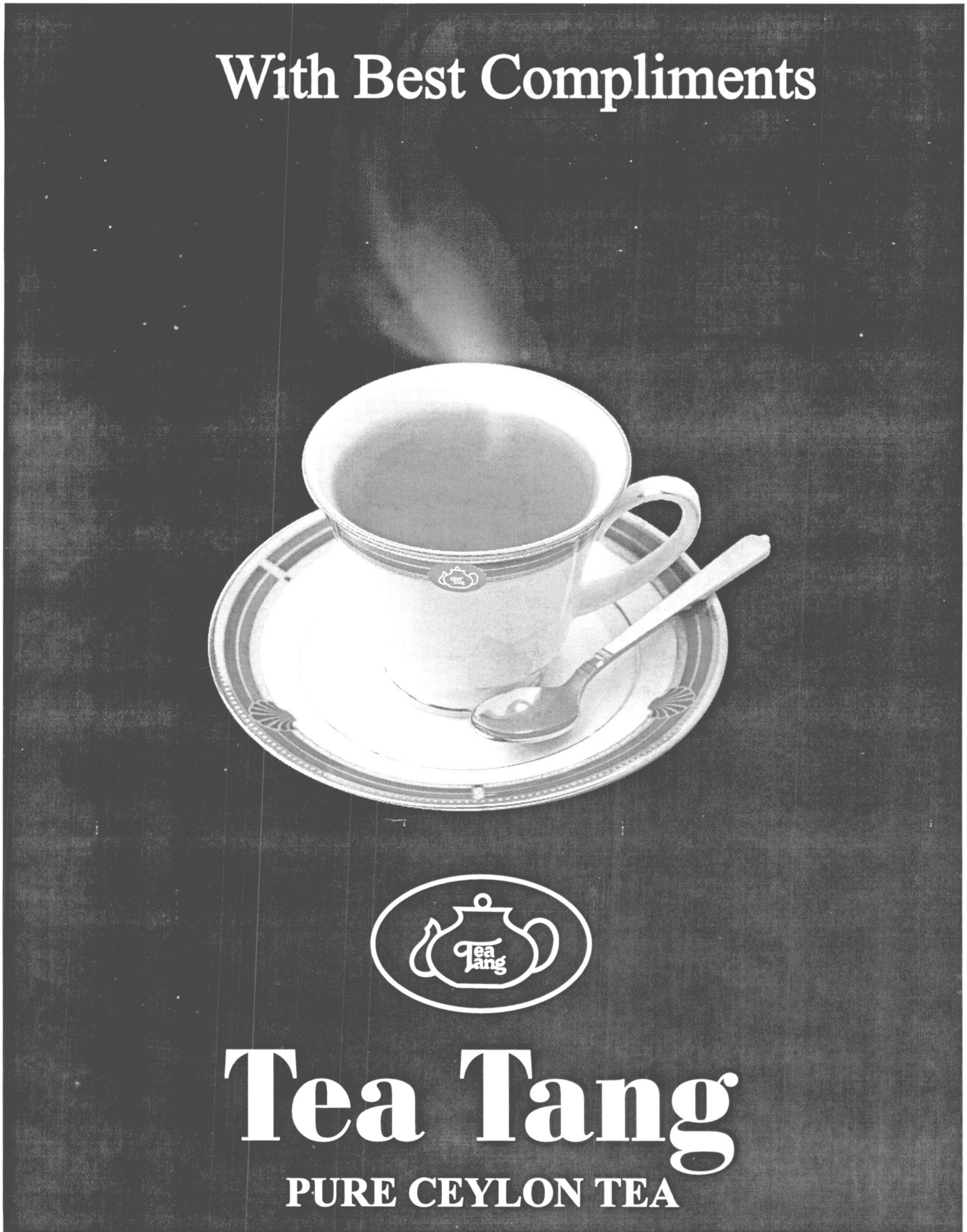
Multiplex Fertilizers Lanka (Pvt) Ltd

144, Srimath Bandaranaike Mawatha, Colombo 12

Tel: 0112 381041/2, Fax: 0112 324021

E-mail: multiplexho@stmail.lk

Grower's choice since 30 years



Tea Tang Ltd. 215, First Division, Colombo 10, Sri Lanka.
Tel: 2446214/5/6 Fax: 2449865
E-mail: teatang@sltnet.lk Website: http://www.teatang.com