Proceedings of the International Seminar on

"Integrated Crop Management in Tea: Towards Higher Productivity"

Colombo, Sri Lanka, April 26-27, 1994

International Potash Institute
Basel, Switzerland

Tea Research Institute
Talawakele, Sri Lanka

Integrated Crop Management in Tea
Towards Higher Productivity

International Seminar of the Tea Research Institute and the International Potash Institute

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Integrated Crop Management in Tea:

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Foreword

The Tea Research Institute of Sri Lanka and the International Potash Institute jointly sponsored a two-day International Seminar on Integrated Crop Management in Tea in Colombo on 26-27 April 1994. Over 300 delegates participated at the meeting at which 18 technical papers were presented by specialist scientists from Bangladesh, China, India, Indonesia, Kenya, Sri Lanka and Vietnam, besides representatives of the IPI.

The Seminar focused attention on the development of an environmentally acceptable blend of techniques for the global tea community to augment field productivity and enhance the quality of the end product. The deliberations also underlined the desirability of collaborative efforts in tea research among the producing countries. Such an approach, it was felt, would, through the optimisation of key inputs, help to control the steeply rising cost of production, which has become a significant feature of the world tea economy.

This publication incorporates the papers presented at the Seminar. They suggest possible strategies and lines of action that could be implemented, particularly at the country level, for upgrading the package of scientific, technical and management practices. Considering the keen interest evinced by the participants at the Seminar, we are confident that the publication will serve as a useful reference to industry managers.

We wish to take this opportunity to thank the Tea Research Board and the Ministry of Plantation Industries for their support and assistance in the successful conduct of the Seminar.

Dr. P. Sivapalan
Director

Dr. R. Härdter
IPI Coordinator Asia

Proceedings of the International Seminar of the Tea Research Institute and the International Potash Institute

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Inaugural Session at the International Seminar on Integrated Crop Management in Tea: Towards Higher Productivity

Welcome Address

Dr. *S.D.I.E. Gunawardena,* Chairman, Tea Research Board, Sri Lanka

Ladies and Gentlemen,

At the very outset, I wish to express my great pleasure and privilege in welcoming our chief guest, the Hon. Rupa Karunatillake, Minister of Plantation Industries, to this International Seminar on Integrated Crop Management in Tea: Towards Higher Productivity.

I also wish to express how pleased and privileged I am to welcome the State Minister for Plantation Services, Mr. Manodha Wijeratne; the Secretary to the Plantation Industries, Mr. R.S. Jayaratne; the Chairman of the Tea Board, Mr. Ronnie Weerakoon; the distinguished scientists from Bangladesh, China, India, Indonesia, Kenya, Sri Lanka and Vietnam, some among whom will serve as the resource personnel at this Seminar; the Director of the Tea Research Institute of Sri Lanka; the two representatives of the International Potash Institute, namely, Dr. Rolf Härdter and Dr. Wolfgang Maibaum; members of the Tea Research Board; the participants from the different Plantation Management Companies including their Chairmen, Chief Executive Officers, Managing Directors, Regional Managers, Managers and Superintendents; staff members of the Tea Research Institute, Sri Lanka; members of the Sri Lanka Tea Board; members of the Tea Smallholdings Development Authority; and representatives from those organizations and firms engaged in tea trading activities to this International Seminar on Integrated Crop Management in Tea: Towards Higher Productivity, jointly sponsored by the Tea Research Institute of Sri Lanka and the International Potash Institute, Switzerland.

This Seminar scheduled for today and tomorrow will include 4 technical sessions during which 18 presentations will be made by specialists from 7 tea producing countries and by the Coordinator for Asia of the International Potash Institute.

Today, the tea industry worldwide is experiencing reduced profits due to high costs of production (COP) and low prices.

To overcome this situation, the most obvious approach would be to reduce COP and increase productivity, simultaneously. This is easier said than done!

In any case, if this is to be achieved, the **efficiency of the production system** has to be increased and for this to happen, the essential ingredients are an effective management system and the adoption of improved scientific and technological practices.

I sincerely hope that the presentations due to be made at this Seminar, which are the outcome of current research in producer countries, will focus attention on management and other practices that could be readily adopted to overcome the constraints confronting the tea industry.

In conclusion, I would again extend a warm welcome to all of you and wish all participants every success in their deliberations at this International Seminar.

Thank you.

Introductory Observations

Dr. *W. Maibaum*, Scientific Coordinator of the International Potash Institute, Basel, Switzerland

Ladies and Gentlemen,

I have the pleasure to welcome you, on behalf of the Director of our Institute, to the International Seminar on Integrated Crop Management on Tea, in Colombo.

It is a great pleasure to extend a particular welcome to:

- Honourable Rupa Karunatillake, Minister of Plantation Industries,
- Dr. Gunawardena, Chairman of the Tea Research Board,
- Mr. Weerakoon, Chairman of the Sri Lanka Tea Board.
- Finally, I would like to welcome the Ladies and Gentlemen who come from the most important tea producing countries in the world. We are really grateful to them for coming.

I wish to thank Dr. Sivapalan, the Director of the Tea Research Institute, for his kind invitation and I am very grateful to him and his co-workers for the great efforts they have made in organizing the International Seminar.

It is gratifying to notice that our Seminar attracts so many managers, businessmen, experts, advisors and officials, not only because Colombo is a beautiful city on a marvellous island. Obviously, the timely subject "Integrated crop management in tea: Towards higher productivity" and the internationally well recognized Tea Research Institute of Sri Lanka and Sri Lanka's achievements in tea cropping are the main reasons of that attendance.

The objectives and the specific topics of the seminar are in full accordance with the general mandate of the International Potash Institute, which is to promote worldwide the application of scientific and practical methods for:

- sustainable amelioration of soil productivity, and,
- a balanced crop nutrition by integrated crop nutrient management, especially by the use of potash fertilizers.

Allow me to take the opportunity to briefly answer the questions of all who are not aware about what is IPI and what does IPI do.

Our Institute is an international, non-profit making association, which has been founded 42 years ago by the French and German potash producers, with its head office in Bern, which is now based in Basel, Switzerland.

The most important elements of our activities are the **regional projects**. They are aimed at:

- initiation and support of field research into fertilization in target areas
- provision of site/country specific recommendations on rational fertilizer use
- propagation of the significance of potash fertilization for sustainable production and crop quality

At present, IPI is implementing those projects worldwide in 5 target areas, in close cooperation with national agricultural research institutions. The tasks of IPI's regional offices are managed by highly qualified agronomists.

Table 1. IPI's regional projects to promote K use in agriculture.

REGIONAL OFFICES	COUNTRIES
Asia	China, India, Thailand, Sri Lanka, Vietnam
Central / Eastern Europe	Czech and Slovak Rep., Hungary, Poland
Community Independent States	Belarus, Russia and other States of CIS
North Africa / West Asia	Algeria, Egypt, Iran, Morocco, Turkey
Southern Africa / South America	Rep. South Africa, Zimbabwe, Argentina

The regional projects are focused on the developing countries, especially on Asia. In those countries, a sustainable increase in yields on cultivated land is the only rational way, firstly, to satisfy food needs for an ever growing population, and, secondly, to provide income and purchasing power for the population engaged in agriculture.

In this respect, proper management of plant nutrition is crucial.

Asian countries give a very convincing example that the increase in food grain production, from 1960 to 1990, is closely correlated with growing inputs in fertilizer nutrients.

But the amount of N used in Asia increased much faster than phosphorus and potassium consumption. This raises the question of balances in the amounts of nutrients applied.

At present, the very low N : K_2O ratios for the fertilizers used in Asia are of main concern. As a consequence, the supply of the P and K needs of high yielding crop varieties involves serious inroads into the K reserves of the soil every year. As the soils have less and less available potassium to offer to crops, it is obvious that this will reduce the yields.

An important and continuing task for the International Potash Institute is to make farmers, planters and decision makers aware of the dangers involved in allowing soil nutrient supplies to decline, with the risk of reduced crop yield, lower quality produce and losses in profit.

We are all quite aware that balanced fertilization in tea growing is a most important factor in sustainable increase of tea production and produce quality.

It is a very wise decision to discuss this subject within the general topic of the Seminar "Integrated crop management in tea".

A second important element of our activities is the publication and dissemination of scientific and technical information.

The best known periodical is certainly the Potash Review, presented in English, dispatched to about 4000 addresses, primarily to research workers.

The International Fertilizer Correspondent is another regular publication, which is directed to agronomists, extensionists and governmental authorities and gives comprehensive information on the results of IPI's Regional Projects.

Many other publications have been issued, for instance, the Proceedings of IPI's Colloquia and Congresses, the wellknown IPI Bulletins and Research Topics, dealing with specific subjects like K-recommendations for major crops or the effects of K on plant health.

Since these documents are published in English, the Regional Offices, in cooperation with local scientists, translate some of them in several languages, updated with regional data.

The organization and the support of international and national scientific meetings are the third involvement of IPI's activities.

The list of the International Colloquia and Congresses IPI has organized in different parts of the world is long, more than 36, between 1954 and 1992.

In this respect, the International Seminar in Colombo will be a further benchmark in IPI's activities.

I am sure that the many highly qualified and experienced speakers, who will share with you in the next 2 days their latest knowledge and experiences in tea production, will contribute to a very successful seminar.

I hope you will have an enjoyable time and that the meeting proves rewarding, not only in scientific and technical matters, but also for enhancing personal relationships and contacts, which will last long after this seminar is over.

I wish the seminar much success.

Inaugural Address

Hon. *Rupa Karunatillake*, Minister of Plantation Industries, Sri Lanka

Mr. Chairman, Invited guests, Distinguished participants,

I am greatly privileged to be with you at this inaugural session of the International Seminar on Integrated Crop Management in Tea, organized by the Tea Research Institute of Sri Lanka, in collaboration with the International Potash Institute.

The theme of this Seminar, integrated crop management for higher productivity, is timely and most appropriate for the entire tea industry not only in Sri Lanka, but in the whole world. World market prices of tea have been steadily declining for many years, and the future prospects at best are for stagnating real prices in the medium term. In the meantime, the costs of production of tea in most countries have been increasing, although to varying degrees. Such variations are the result of location specific agro-ecological and socio-economic factors. Declining tea prices and increasing costs have had serious implications on the living standards of tea growers as well as the workers. The very survival of the industry and, therefore, the interests of the consumers who are in need of a health giving beverage at an affordable price are at stake.

Tea producers must, therefore, look for appropriate strategies on all possible fronts. In very broad terms, potential alternatives are in strategies for increasing prices, strategies for increasing productivity and strategies for reducing costs. Among these, strategies for productivity increases and those of cost reduction are closely related although may not be identical. Cost reduction may be possible within a given technology where inefficiencies of resource use result in higher costs. However, increased productivity inevitably results in lower costs. Productivity increases are obtained by technological changes.

The deliberations at this Seminar will address issues related to technology. Whether technological change can be the sole answer to combat a continuing price decline is an issue I would like to pose to scientists. Can a plant, whether tea or any other, continue to produce more and more for less and less inputs without reaching some biological limit in spite of advanced breeding and other techniques is an interesting issue? This is perhaps of somewhat academic nature at present, when most scientists seem to agree that average productivity is far below the potential of the available clones.

However, scientists as well as the practitioners must bear in mind that marketing and pricing strategies must also be developed along with technological innovations if significant progress is to be made. This is a theme I would like to return to in a moment.

To start with, let us concentrate on agricultural technology for increased productivity. It is a commonly heard complaint from the side of the research scientists that there is a large technology gap. In other words, farmers apparently do not adopt available technology, and when they do adopt, they fail to realize the full potential.

In answering this question, researchers must ask themselves whether they have packaged the technology in a manner that suits the farmer. Biological scientists have no difficulty in appreciating the differences in agro-ecological conditions from one farm to the other. What is often overlooked is that access to resources also varies among the farmers.

The challenge then, is to package the findings and technological breakthroughs of the scientists in such a way that they can be effectively and profitably applied under different agro-ecological conditions as well as socio-economic backgrounds. In other words, technological packages must be tailor made to the extent possible by integrating the advances made within individual specialized disciplines which constitute scientific agriculture.

Scientific breakthroughs occur within different disciplines at different magnitudes at varying time intervals. Available knowledge at any given time is, therefore, imperfect, though superior to what was known prior to the latest breakthrough. Technological packages must, therefore, be constantly adjusted to allow for scientific discoveries. Further, they must be adjusted in response to socio-economic changes and input price changes.

It is clear, therefore, that what is needed is not a once and for all integration, but a suitable process and appropriate procedures for the same. Being aware of the calibre of the scientists who are listed to make presentations and the other participants, I am sure a significant contribution will be made in this direction as a result of this seminar.

I am pleased to note that all major tea producers are represented at this inaugural session. I am informed that the technical sessions will include contributions from all major tea producing nations. Such an international collaboration in technological areas in spite of the high degree of competition among us in the market place is most encouraging.

In my view, this is not the only possible area of cooperation among us in relation to the tea industry. I am firmly convinced that cooperation in economic and trade spheres of the tea industry will be of great benefit to all of us. I have been canvassing the case for an international tea producer forum at every possible opportunity, both here in Sri Lanka and abroad over the last few years. I must say that the responses received up to date have been most encouraging,the last occasion being the meeting I had with my counterpart of the People's Republic of China while visiting China a few days ago.

The cooperation among producers will benefit the producers by reducing opportunitism among us for short term gains, particularly in relation to pricing and related trade aspects and would strengthen the long term survival of the global tea industry. Since tea is a perennial crop with an economic life span of over 30 years, short term instability of prices can restrict future supply and thus hurt the consumer with increased prices. Tea is environment friendly and has positive health effects. At the same time, it is the cheapest drink next to water. In many markets, bottled water is more expensive than tea. If producers get together and ensure the survival of this wonderful beverage, then consumers will stand to gain.

The positive health image of tea is being tarnished by the dumping of very significant amounts of sub-standard teas by some producers. These teas reach the unknowing consumers via various blends and packages. Such teas can result in adverse health effects among the consumers. We, in Sri Lanka, have banned the export of teas which are below the ISO minimum standard. If the major producers cooperate, the export of teas below the standard can be curtailed and the interests of the consumers can be protected. At the same time, producers will benefit from improved prices since the overall supply of tea will be reduced to extent of the supply of sub-standard teas at present.

What I have just touched upon briefly are some potential benefits of a greater integration of the tea industry. Historically, we have had experience of vertical integration of the tea industry by large multi-national firms, at times against the national interests of the countries concerned. What I am proposing is a different type of integration - integration via international cooperation. I hope when you return to your places of work, these aspects will be given due consideration and discussed with the authorities.

Finally, I am sure that the realisation of the goal of broader integration via international cooperation on tea will result in a much greater impact of your contributions in the field of integrated crop management in tea towards higher productivity.

With these few remarks, I have great pleasure in declaring open this international Seminar. I wish the deliberations success.

Thank you.

Introduction of Theme

The Common Goals in Tea Research

Dr. *P. Sivapalan,* Director, Tea Research Institute, Talawakelle, Sri Lanka

Introduction

The tea producers of the world are presently operating in a situation that is beset with numerous problems, having to cope with the fast galloping costs of production on one hand and the stagnant if not declining international price situation on the other, both of which are fast eroding into the profitability that is needed for the continued sustenance of this gigantic industry. Looking at the brighter side, there is potential for the development of innovative technologies and strategies that will still help to control costs and produce end-products that will provide for the changing needs of the international tea trade at large. With the increasing awareness for maintaining the highest possible health standards, there is also a growing demand to produce a commodity that is free of any traces of extraneous pollutants.

Thus, tea research has progressed from its early beginnings investigating the mundane behaviour of the domesticated wild seedling progeny of *Camellia sinensis*, to generate a commercial crop for a developing tea industry, - more or less as an exercise in **traditional farming practices** with a bent for science - to the more sophisticated investigations of crop improvement and behavioral studies that are needed to cater to the demands of **a high-input agribusiness** it has presently turned out to be.

The broad objectives in tea research yet continue to remain the same - to attain productivity targets up to the attainable maximum practical limits within the most economic means and to generate a commodity with the required quality parameters that will cater to the prevailing market needs - to help sustain the desired profits per unit of cultivated land.

The attainment of such optimistic goals is, however, significantly influenced by state policies, fiscal policies and the market forces that determine the prices for the commodity. **The single motivating force behind a rising productivity trend is the profitability of generating the commodity.** When profitability gets eroded to almost a loss situation, investments and inputs get limited and, with time, the production is even likely to reverse to a declining trend.

Sri Lanka situation

The variations in growth and decline in production in the tea producing three elevational categories in Sri Lanka during the six-year periods, 1973 to 1978, 1980 to 1985, and 1986 to 1991 (Figs. 1, 2 and 3, respectively) illustrate the influence of profitability on production trends. It is strikingly evident to note that the production trend in the low-grown areas has steadily moved up from the bottom position during '73 - '78 to the top position at present. On the other hand, the situation in the high-grown tea areas remained almost static throughout this period ('73-'91), whilst the mid-grown production has gone down to the bottom position at present. It is due to such distinct variations in the production trends in the three elevational categories that the overall national production growth rate in Sri Lanka is reflected as a marginal increase.

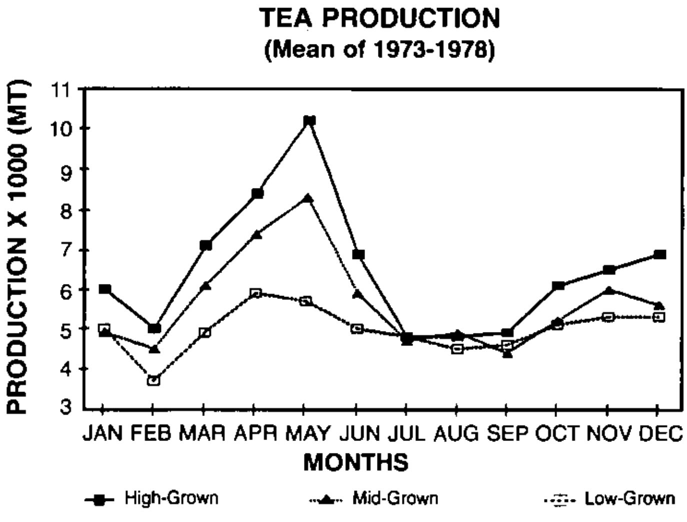

Fig. 1. Tea production (Mean of 1973-1978).

The main cause for the variation in growth rates is attributable to the profitability of tea cultivation in these respective elevational categories. The comparative low cost of production and the assured Gulf markets (following the oil boom) continue to motivate the low-country producer to increase production at the current rate of over 6.0% per annum. This rising trend is comparable to the situation prevailing in our neighbouring tea producing country, where the healthy production rate is motivated very largely as a consequence of the rapidly rising domestic demand for more than 75% of the produce, with assured profits.

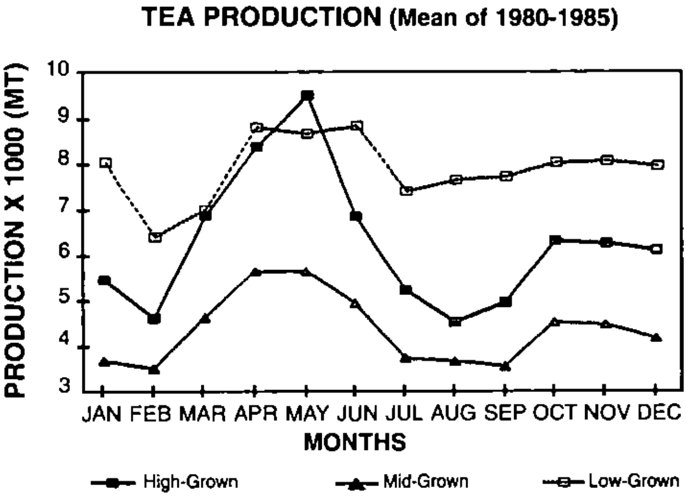

Fig. 2. Tea production (Mean of 1980-1985).

On the other hand, the entire produce from the mid and high elevation tea areas of Sri Lanka depend upon an uncertain global price situation, which is further compounded by a steadily rising cost of production, with the consequent narrowed profit margins, if not a loss situation.

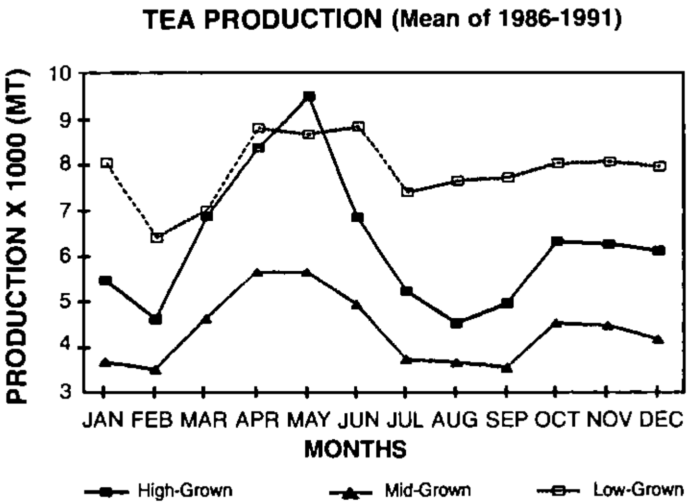

Fig. 3. Tea production (Mean of 1986-1991).

Such an unsatisfactory situation had not adequately motivated these producers to optimize on strategies that are geared towards increased productivity. Further, on account of the higher investment costs and the longer gestation period needed to bring into revenue the replanted old seedling tea lands, the annual rate of replanting in these higher elevations have also been far below expectations. As a consequence, there are significant extents of senile seedling tea areas, with low bush populations, with vacancies opened to large-scale erosion and further loss in soil fertility. The productivity level of such plantation areas are far too low for economic sustenance. In such a situation, it is for consideration whether field improvements do not justify a greater share of State assistance than presently available.

In a country such as Sri Lanka, which has a very small domestic market to absorb the non-selling marks, the declining international price situation for specific teas, coupled with rising costs of production, has had very significant effects on productivity leading to a situation of non-viability of some of the plantations. This is precisely what has happened to a large number of mid-grown tea plantations that once catered to a lucrative international "filler" market, which market got eroded by the availability of cheaper forms of teas and CTC teas from other competing tea producing countries.

Research goals

Having already set specific goals, the generation of new technology becomes more and more complex, requiring a far greater sophistication in the approaches to problem solving.

Obviously, the broad objectives of the new frontiers in tea research are similar if not common to all producer countries represented here at this forum. The sharing of knowledge and the exchange of ideas has become an essential key for the very survival of this gigantic industry, especially within the present context of the very high competition poised against this beverage from all forms of drinks and brews available in the international markets. Joint periodical meetings of this nature will go a long way in the mutual sharing of knowledge and the correct implementation of new ideas, as well as for future research plans. The usefulness of the outcome of such gatherings will however depend upon the sustained follow-up actions by all concerned.

Unnecessary duplication of expensive research efforts towards common goals is a wasteful effort, both in terms of time as well as human and material resources. A collaborative approach in specific identified research areas should be a welcome move to all producer countries and such an approach requires the unstinted support from the policy makers at the highest level in the respective countries.

Possible joint studies

The following are some possible areas for joint study that will prove to be helpful to all producer countries in the future:

(1) *Plant improvement*
(2) *Microbiology - role of tea soil microorganisms*
(3) *Fertilizer responsiveness in relation to soil and tea bush management*
(4) *Improvement of Harvest Index*
(5) *Health aspects of tea consumption*

Studies connected with **plant improvement** constitute an area that will be of mutual benefit through collaborative efforts. The available tea clones may have all been properly characterized and rated for their specific merits, as per the performance in the respective producer countries. If not already available, it will be useful to develop a computerized data base to include such useful information on all available clones, whether in commercial use or not. The possible exchange of planting material would help, not necessarily for the direct immediate use in the field, but to broaden the genetic base to help evolve specific hybrids most suited to the growing environments in the respective countries. The likely development of genetically altered "*transgenetic tea clones*" is a distinct possibility within the respective producer countries, in the not too distant future.

The **role of tea soil microorganisms** and their mitigating role in soil degradation and their respective beneficial role in fertility improvement is another area requiring much recognition and a greater in-depth investigation is warranted through collaborative research programmes. Industrial agriculture has tended to treat the soil as an "**expendable raw material**" which it proceeds to exploit and use up with time. The meaning of sustainability and the need for maintaining the soil as an active living medium appears to have receded from the minds of several agricultural land users, who treat plants as mere machines that need to be fuelled with fertilizers to generate the end-product.

The single most expensive field input in the production of tea in every producing country is **fertilizer**. The response to fertilizers is conditioned by a number of factors and consequently this calls for a rationalization on fertilizer use. Poor soil and poor bush management should not be blindly covered up by pumping in more and more fertilizers and making the tea become almost totally fertilizer-dependent, rather than make it more fertilizer-responsive through better soil and bush-management. One needs to take into consideration the net value of tea generated per unit of fertilizer and establish the maximum quantum of fertilizer at the point of the **critical marginal product** (CMP). If the CMP is reached at a high level of fertilizer input and at a relatively low productivity level, then one needs to seriously concentrate upon improving the prevailing status of soil and bush management, which are likely to be poor (Fig. 4).

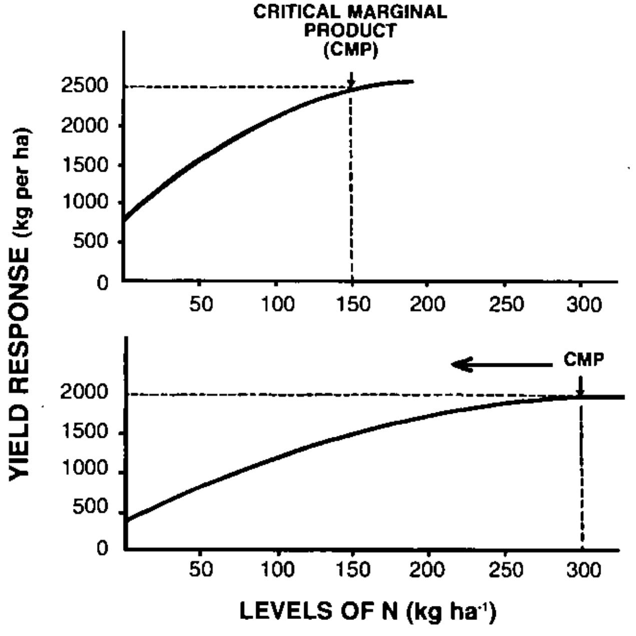

Fig. 4. Yield response to nitrogen application and critical marginal product at low and high productivity levels of tea.

Tea is one of those commercial crops with a very low **harvest index** (which is the proportion of the total dry matter generated by the bush that is partitioned towards the crop) and consequently a very poor convertor of radiant energy towards the harvest. Studies on the improvement of the harvest index will no doubt be linked to the types of teas and their respective anticipated quality parameters. In situations where quality is the overriding determinant, requiring a finer standard of plucking, the harvest index and consequently the yield is likely to be low, as it has traditionally been so in the high elevation tea areas of Sri Lanka, and in certain specific tea growing areas of other countries, such as in Darjeeling and certain estates in Upper Assam, in India, which are world-renowned for specific quality. Joint studies on bush management and harvesting styles influencing the partitioning of the dry matter are likely to yield useful information to all concerned, to help enhance the productivity without eroding into the desired specific quality.

The subject of **health benefits of tea consumption** is another aspect warranting collaborative efforts. Consumers all over the world are becoming more and more conscious about the quality of food and beverages they consume and in this regard tea has a distinct advantage in being a health related beverage. These claims have to be scientifically proven and there is much to be done in this area as part of the generic promotion for tea consumption.

Chairman of the Session 1

Mr. Sepala Ilangakoon

Session 1

Tea Production in the Various Tea Producing Regions

Influence of Improved Genetic Material Towards Higher Productivity of Tea in Bangladesh

Badrul Alam, A.F.M., Director, Bangladesh Tea Research Institute, Moulvibazar, Bangladesh

Abstract

The growth and evolution of Bangladesh tea in respect of area, production and yield are briefed. Gradual development of the tea seed stock is traced and characteristics of the surviving superior stocks are described. It can be claimed that Bangladesh tea was fairly rich in some introductions from original seed resources because of contiguity and easier exchange of plant materials within N.E. Indian tea zone in pre-partition days. But during the four noticeable periods of stagnancy and development since 1947, seed resources had rather eroded faster than prospered. The impact of research innovation in the establishment of biclonal stocks in particular is visible and encouraging. Though clonal development was started in mid-sixties, contribution of eight V.P. clones by BTRI and a few by estates along with introduction of even fewer exotic ones helped the growth of clonal plantation by about 10% mostly after emergence of Bangladesh. Only BTRI released clones have been characterized and highlighted here. Emphasis has been put forward for fertilizer policy, cultural practice and processing on specific requirements for full exploitation of individual potential in respect of yield and quality of the improved plants.

1. Introduction

Tea was first introduced in the present Bangladesh territory in 1840 at about the same time as it was introduced in North-East India (Ahmed, 1963). Since then and up to the first quarter of twentieth century, the tea plantation raised had some common ancestry as those in N.E. India tea zone because of intimate interaction and exchange of materials among the estates. Tea stock was thus enriched with various types of tea from different sources. The initial introduction of China or China hybrids was soon discouraged and indigenous *Assamica* variety of various types came into the new plantations. Due to local adaptation and selection pressure, only a few types particularly dark- to semi-dark green and medium to large-leaf plants became preponderant. Light green large-leaf dependent types were less preferred. In course of time, many seed orchards were established which mothered the seedling populations. Dark leaf hardy *Assamica* variety with intermediate leaf size and early flushing habit was the specialty of many seed Jats. Such stocks, e.g. Manipuri, Amo, Ballacherra, Mirtinga and Luskerpore jats noticed as early as 1918 were preserved in Tocklai germplasm bank (Bezbaruah and Dutta, 1977). Unfortunately, those original stocks and many valuable others are lost in Bangladesh. The oldest present-day tea plantation would not be the immediate progeny from the stocks or introductions earlier than 1910.

The evolution of genetical stock for Bangladesh tea may be collated to four major phases of stagnancy and development of the industry.

i) Decade of fifties of post-partition stagnancy and slow growth,
ii) Decade of sixties of mandatory extension and development,
iii) Decade of seventies of Bangladesh post-liberation period of planning for rebuilding activities,
iv) Decade of eighties of actual utilization of research innovations for development of the tea industry.

All these situations affecting the preservation, prospect and prosperity of genetical stocks were vitally important for growth of the tea industry.

In the above perspective, contribution of genetical materials already inherited or available and developed by the BTRI in the productivity of Bangladesh tea would be evident from the following discussions.

2. Area, production and yield trends in Bangladesh tea in Pre-Liberation and Post-Liberation period

India was partitioned in 1947 and Bangladesh was liberated in 1971. Table 1 briefly represents the picture of area, production and yield since partition to date.

Table 1. Area, production and yield of tea at different periods.

Year	Area (ha)		Production ('000 kg)		Yield (kg/ha)	
	Total	increase/ decrease	Total	increase/ decrease	Total	increase/ decrease
1947	30,353	-	18,884	-	622	-
1959	31,287	+934	25,549	6,665	820	+198
1970	42,688	+11,401	31,381	+12,497	735	-85
1980	43,732	+1,044	40,038	+8,657	916	+181
1993	47,888	+4,156	52,500	+12,462	1,096	+180

Source: Statistical Bulletin on Bangladesh Tea, 1993, PDU, BTB.

Figures 1, 2 and 3 represent the linear trend lines of area production and yield with the corresponding indices against time (years).

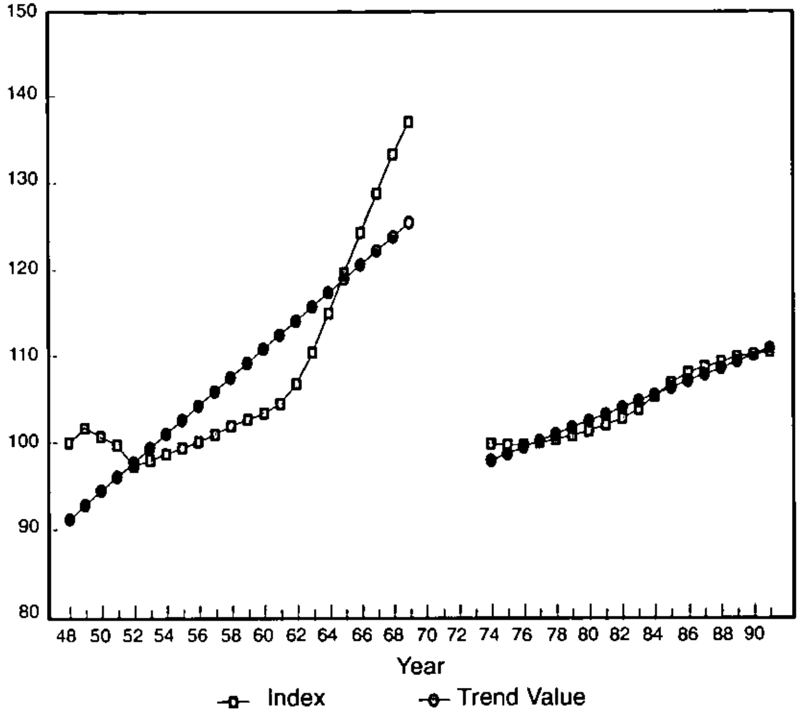

Fig. 1. Curve showing area trend.

For the convenience of the present analysis, the period from 1948 to 1970 has been taken as pre-liberation period and from 1973 to 1990 as the post-liberation period of activity in the research outputs vis-a-vis the growth of tea industry.

It appears that in spite of significant lower growth rate of area in post-liberation period, the production as well as yield growth rates are higher compared to pre-liberation period. This may be ascribed to the development in tea culture and rationalization in the production process. One of the principal factors is the use of high yielding and better quality vegetative clones and seed stocks in the new areas. Others are intensive cultivation, adoption of newer concepts and technologies and efficiency in management.

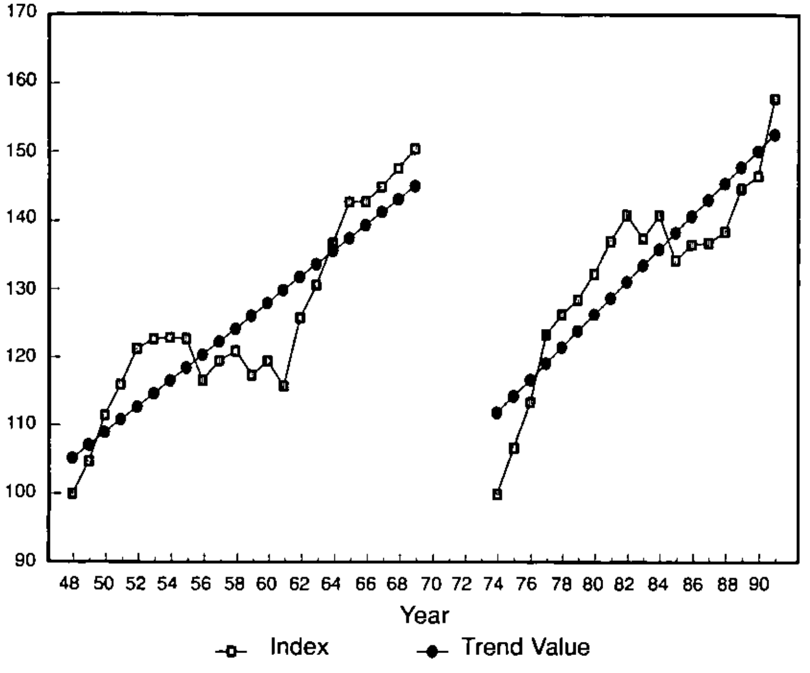

Fig. 2. Curve showing production trend.

3. Planting stock and its improvement in Bangladesh

3.1. The seed

It is evident from Table 1 that from 1947 to 1959 tea area increased insignificantly, only by a total of 934 ha whereas it increased significantly by a total of 11,401 ha in one decade of the sixties. This was the effect of compulsory "mandatory expension of tea" policy by the then Government. Till 1970, all the new tea that came into the field were mostly of seed jats available in the country and negligibly of some imported seeds. The industry had only 28.80 ha old general seed baries in 1947. However, in about next twenty years, some 183.00 ha new seed-baries were raised which were mostly of Assamica variety with predominant Manipuri or Burma dark-leaf habit, light or dark-leaf Assam being lesser and hybrids or predominant China the least.

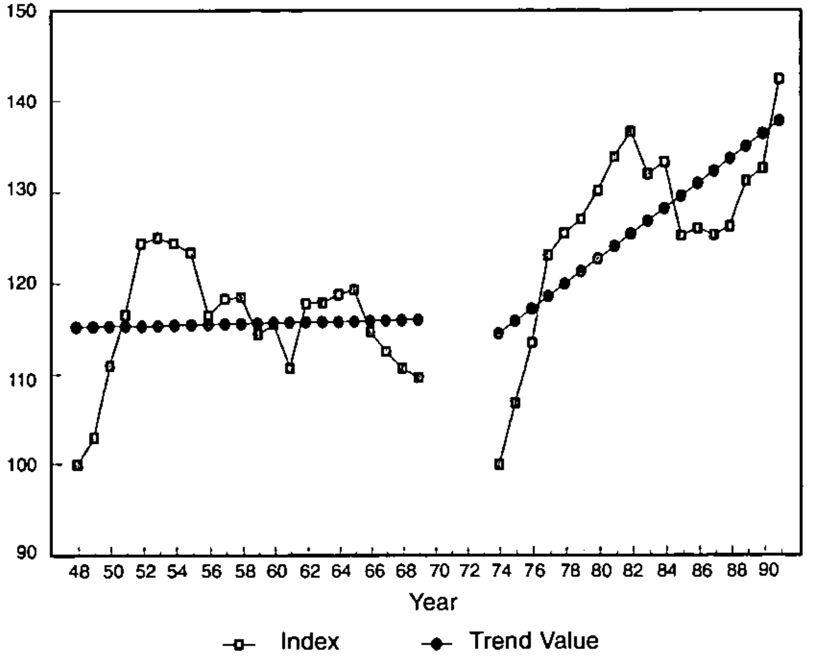

Fig. 3. Curve showing yield trend.

Table 2 gives a fair idea about the inland seed resources available during that time. In 1980, there were as many as 57 seed orchards which were to be reassessed for their stock value before the next phase of field development and extension activities initiated.

Tea management in Bangladesh can be distinguished into two broad categories - the **Sterling companies** and the **Native companies and proprietaries**. Though the Sterling companies cover 38% of the cultivated tea area, their production share is about 48% of the total crop. In a recent assessment, it has been calculated that out of the total plantation, at least 90% are still seedling tea, the rest 10% being clonal plantation comprising largely BTRI clones, some garden clones and a little introduced clones. Thus, seedling tea has been and will continue to play a dominating role in production in the near future too. Looking back at the mother seed-stocks for the standing teas, out of the superior 58.94% Assam and pre-dominant Assam stocks together, 76% is owned by the Sterling groups.

Table 2. Area and characteristics of existing seed stocks established at different periods.

Plant type in seed baries	Progeny leaf characteristics	Pre-1947 established		1948-1970		Total in 1970	
		Area ha	%	Area ha	%	Area ha	%
Typical Assam	Very large leaf, dark/semi dark light green and dependent leaf	7.75	26.91	31.58	17.10	39.33	18.51
Predominant Assam but Manipuri/Burma mixed	Large to intermediate leaf, definitely dark leaf	15.05	52.26	70.83	38.50	85.88	40.43
Typical Manipuri	Intermediate leaf size, very dark leaf not dependent, hardy plant	6.00	20.83	61.09	33.50	67.09	31.58
Mixed hybrids (Not any of above three categories), Intermediate/ China mixed	Intermediate/small leaf, semidark to light leaf, erectish pose	-	-	20.15	10.90	20.15	9.48
	Total	**28.80**	**100%**	**183.65**	**100%**	**212.45**	**100%**

Source: Unpublished work of Botany Division, BTRI.

As a result, their plantations have the most potential population for yield as well as quality. Typical dark leaf Manipuri stock of lower yield and quality contributes 31.58% of the total seed stock of which native groups possess 66.14%. The only advantage with Manipuri type is that they are hardy, well adapted and long-lived. As a consequence, the dark leaf Manipuri type is so preponderant and popular in the native estates. Hybrids are not always inferior in quality and yield to the other types. The type comprises only 9.48% of the stocks of which Sterling companies share 62.13%.

The seed gardens developed in the past were built up from prolonged experience and best available choice of the time of their establishment. Those valuable stocks which have been already lost but still represented by standing tea sections may be possible to reconstitute by proper survey of existing seed populations tracing the exact history of their origins.

Yield and quality performance of some seed jats

To assess the qualitative status of the tea seeds produced in our 57 existing seed gardens, 44 have been surveyed and critically examined for seed success, germination potential, growth habit and seedling characteristics in the nursery. However, these characteristics have not been discussed in this paper. After scrutiny in the nursery, progenies of eighteen such promising stocks were reassessed for their performance in the field in two sets against a standard biclonal seed stock, BTS1 developed by this Institute. These were compared in two separate trials in tillah slopes in 1987 at Bilashcherra Experimental Farm of the Institute.

Comparative yield performance is tabulated in Tables 3 and 5 and quality attributes in Tables 4 and 6. These revealed in general that most Assams and predominant Assams fairly competed with improved biclonal stock BTS1 in terms of yield, while some Manipuris appeared inferior. Only one light-leaf Assam and one typical Manipuri were below average in the cup. Others were of acceptable average to above average in quality. As such, BTRI plans to preserve them all.

Table 3. Comparative performance of seedling tea jats, Set 1 (Yield of made tea kg/ha).

Seed jat	Noyapara (Rajghar)	Horincherra	New Samanbag (Tingamira)	Noyapara (Dumduma)	Amo (Rajghar)	Allynugger (Kamarcherra)	Allynugger (Polyclonal)	Kodala	Nalua (New)	BTS1	Remarks
Plant type	Assam light-leaf	Assam semi-dark leaf	Assam light-leaf	Predom. Assam	Predom. Assam	Manipuri	Manipuri	Manipuri	Manipuri	Biclonal light leaf hybrid	
3rd Yr. (1990)	829.00	1027.00	829.00	708.00	678.00	760.00	1005.00	659.00	678.00	791.00	*
4th Yr. (1991)	1785.00	1586.00	1450.00	1535.00	1437.00	1539.00	1344.00	1310.00	1503.00	1387.00	NS
5th Yr. (1992)	1475.78	1445.38	1351.43	1363.32	1385.29	1448.00	1421.78	1155.28	1470.74	1321.63	NS
6th Yr. (1993)	2138.84	2036.88	2059.24	1995.32	1823.22	2193.65	2184.48	1913.68	2140.11	2206.49	NS

Source: BTRI Annual Reports, 1990-91, 1992 and 1993 (in press).
* Statistical significant yield differences at $p = 0.05$.

Table 4. Cup-quality of different seedling jats, Set 1 (Average of 3 years observation).

Seed jat	Noyapara	Horincherra	New Samanbag	Noyapara	Amo	Allynugger	Allynugger	Kodala	Nalua	BTS1
Characteristic & score	(Rajghar)		(Tingamira)	(Dumduma)	(Rajghar)	(Kamarcherra)	(Polyclonal)		(New)	
Infusion (10)	6.50	6.53	6.25	6.50	6.30	6.41	6.34	6.59	5.87	6.58
Liquor colour (10)	6.63	6.92	6.78	6.80	6.61	6.62	6.69	6.81	6.80	7.00
Briskness (10)	5.86	6.50	7.25	5.30	5.92	5.91	6.38	6.04	6.16	7.50
Strength (10)	5.40	6.75	6.28	6.11	6.42	5.70	6.23	6.50	6.33	7.50
Creaming down (10)	3.40	4.64	4.21	4.03	3.96	3.50	4.07	4.04	3.83	4.16
Total score (50)	27.79	31.34	30.77	28.74	29.21	28.14	29.71	29.98	28.99	32.74
Overall quality	BA	A	A	A	A	A	A	A	A	AA

AA = Above Average   A = Average   BA = Below Average

Source: Unpublished work of Botany Division, BTRI.

Table 5. Comparative performance of seedling tea jats, Set 2 (Yield of made tea kg/ha).

Seed jat	Doloi	Patrakhola	Chundeecherra	Amo (Boh)	Shumshernugger	Chatlapore	Mirtinga	Kurmah	Nurjahan	BTS1	Remarks
Plant type	Assam semidark	Predom. Assam	Predom. Assam	Predom. Assam	Predom. Assam	Manipuri	Manipuri	Manipuri	Manipuri	Biclonal hybrid	
3rd Yr. (1990)	663.00	716.00	910.00	703.00	613.00	566.00	670.00	747.00	609.00	871.00	*
4th Yr. (1991)	1388.00	1483.00	1778.00	1438.00	1299.00	1238.00	1438.00	1649.00	1338.00	1572.00	NS
5th Yr. (1992)	1640.00	1571.00	1660.00	1701.00	1192.00	1226.00	1483.00	1458.00	1434.00	1636.00	NS
6th Yr. (1993)	2332.00	1931.00	2241.00	2084.00	1513.00	1866.00	1913.00	2296.00	1893.00	2378.00	*

Source: BTRI Annual Reports, 1990-91, 1992 and 1993 (in press).
* Statistical significant yield differences at $p = 0.05$.

Table 6. Cup-quality of different seedling jats, Set 2 (Average of 3 years observation).

Seed jat	Doloi	Patrakhola	Chundeecherra	Amo	Shumshernugger	Chatlapore	Mirtinga	Kurmah	Nurjahan	BTS1
Characteristic & score				(Boh)			(Polyclonal)			
Infusion (10)	6.29	6.42	6.66	6.36	6.45	6.42	6.33	6.38	6.30	6.34
Liquor colour (10)	6.87	6.64	6.87	6.77	6.95	6.84	6.91	6.65	6.50	7.00
Briskness (10)	5.91	6.39	6.20	5.90	7.20	5.92	6.37	6.11	5.80	7.65
Strength (10)	6.00	6.42	6.41	6.18	6.95	6.07	6.41	6.03	5.00	6.61
Creaming down (10)	3.95	4.39	4.41	4.13	4.52	4.36	4.33	4.19	3.50	4.76
Total score (50)	29.02	30.26	30.55	29.34	32.07	29.61	30.35	29.36	27.10	32.36
Overall quality	A	A	A	A	AA	A	A	A	BA	AA

AA = Above Average A = Average BA = Below Average

Source: Unpublished work of Botany Division, BTRI.

Biclonal and Polyclonal seed

Very few managements in the tea industry of Bangladesh knew of polyclonal or biclonal seed of Tocklai. Till 1970, the planters hardly had any idea about them and their importance. BTRI developed its first two biclonal seed stocks, namely, BTS1 and BTS2 in 1974 (Alam, Chakraborty and Ali, 1974), but the industry realized its importance only in 1979 when compulsion for improved seeds along with clones in the extension and replanting was imposed in the Bangladesh Tea Rehabilitation Project (BTRP). As a result, interest was created among the planters to have their own biclonal stocks. Since 1978 till to date, about 15 ha of stock BTS1 (where clone BT1 and TV1 are the two generative clones) have been established in 22 tea estates. These have been producing certified seeds and had been used in the BTRP programme quite extensively. The new generation of seedling tea comprises a substantial proportion of this stock. The yield performance of BTS1 seed in a separate field in the main station is presented in Table 7.

Table 7. Yield of stock BTS1 in a gentle tillah slope field at BTRI main station.

Year of planting	Pruning operation	Made tea kg/ha
2nd (1986)	Decenter	791
3rd (1987)	Skiff	1916
4th (1988)	Prune	1851
5th (1989)	Deep skiff	2685
6th (1990)	Light prune	2733
7th (1991)	Deep skiff	3279
8th (1992)	Medium skiff	3667
9th (1993)	Light skiff	3744

Source: BTRI Annual Reports 1986-1993.

Polyclonal seed stocks are limited to only three in number. The two stocks developed by garden are Manipuri types. These are Mirtinga Polyclonal and Allynugger Polyclonal seed baries (cf. Tables 4-7). The third one was developed by BTRI with seven generative clones (BTRI Circular No. 82, 1987). Only two tea estates have grown this stock so far.

3.2. The clone

Though the concept of clonal development was quite old and Tocklai released its first two V.P. Clones in 1949, the Institute could develop its first clone in 1966. Bangladesh tea inherited a few clonal plants of TV1 from Tocklai's out-station at Shumshernugger Tea Estate (now in Bangladesh) in the Surma Valley. This clone was sporadically restricted to few hundred plants distributed only to a few estates. Clonal plantation, in actual practice, was not done to a worth-mentionable figure until 1970.

As could be seen from Table 1, that new tea put out in the field in the immediate decade of seventies after liberation was only 1,044 ha. The area increased by another 4,156 ha in the next 13 years till 1993. The above two increments comprised virtually the whole of accounted approximately 10% clonal plantation in Bangladesh. As mentioned earlier (cf. Art. 3.1.) in the clonal plantation, BTRI released clones figure most dominantly. Highlights and characteristics of these clones are described in Tables 8 and 9.

At present, there are about forty clones in various stages of trial of which eight promising clones from different sources of selection and breeding lines are in advanced stage of pre-release trials. When released, they are expected to contribute visibly in production system in the beginning of next century.

4. Improved plants vis-a-vis cultural practice and processing

Irrespective of field conditions, specific fertilizer requirement, neither for clone or improved seeds nor for particular agrotype has so far been determined. It used to be applied on a blanket recommendation basis. Only recently have yield profiles been given due importance in the fertilizer policy. Agrotype, jat and clone-specific fertilizer requirements in different soil series as per soil map in individual estates will be given due attention in future for full exploitation of yield potentials.

Some agronomic practices like determination of plant population, young tea growing, pruning operation, choice of field, have been determined but not mentioned here. But there is need for some specific crop physiological studies. Pest infestation on genotypic variation has been determined to some extent which has been useful in deciding the pest management strategy.

Though advantage in specific processing methods has been determined for individual clones, its exploitation has not yet been practised industrially. Rather, all clones in a garden are processed in bulk and labelled as "clone" for marketing which get dividend in price. Individual manufacture and marketing will be of interest, particularly for bigger gardens when a substantial plantation of a clone has been raised.

Table 8. Source of selection, year of release and characteristics of BTRI released clones.

Clone	Source of selection	Year released	General habit	Pruning recovery	Nursery rooting	Drought tolerance	Planting preference	Quality characteristics	Manufacturing preference
BT1	Baraoorah T.E.	1966	Leaf size-medium, semi-dark green, bush compact and plagiotropic, early flushing	Very good	Very high	Moderate	Cooler face and flat area	Above average, coloury and brisk liquor	CTC
BT2	Rajghat T.E.	1975	Leaf size medium, darker, ortho-plagiotropic, early flushing	Very good	Very high	Very high	Hot or cooler face and flat	Above average, coloury liquor consistent touch of **flavour**	Orthodox CTC
BT3	Rajghat T.E. (Udnacherra)	1975	Leaf size medium, light green, plagio-orthotropic, early flushing	Very good	Moderate to high	Moderate	Cooler face and flat	Above average, coloury, brisk, full and creamy liquor	CTC Orthodox
BT4	Baraoorah T.E.	1981	Leaf size smaller, dark green, plagio-tropic and compact	Good	Moderate	High	Hot or cooler face and flat	Excellent very coloury, brisk, full and very creamy liquor	CTC

Table 8. Second part.

Clone	Source of selection	Year released	General habit	Pruning recovery	Nursery rooting	Drought tolerance	Planting preference	Quality characteristics	Manufacturing preference
BT5	Hybrid line	1987	Leaf size larger, semi-dark green, ortho-plagiotropic, early flushing	Very good	Very high	High	Not too hot face and flat	Above average, colouty and brisk liquor	CTC Orthodox
BT6	Hybrid line	1988	Leaf size medium, light green, ortho-plagiotropic	Good	Moderate to high	Moderate	Cooler face and flat	Excellent, very coloury, brisk, full and very creamy liquor	CTC
BT7	Rajghat T.E. (Burmacherra)	1991	Leaf size larger, dark green, glossy, compact bush, ortho-plagiotropic	Good	Very high	High	Hot or cool face of tillah and flat	Above average, coloury, brisk with good strength	CTC
BT8	Baraoorah T.E.	1992	Leaf size medium, dark green, plagio-orthotropic, good flushing habit	Good	Very high	High	Hot or cooler face and flat	Average, coloury and brisk liquor	CTC

Source: Circulars Nos. 54, 68, 80, 86, 95 and 96 and unpublished works of Botany Division, BTRI.

Table 9. Yield and quality performance of BTRI released clones and seedling tea at different fields.

BTRI clones vs Ordinary seed	Releasing year	Yield of made tea (kg/ha) Young	Mature Average	Highest recorded	Overall cup quality
BT1	1966	1614	3298 (14)	4683 (17)	Above average
BT2	1975	1820	3627 (14)	4874 (17)	Above average, flavour
BT3	1975	1476	3431 (14)	4504 (17)	Above average
BT4	1981	1418	2581 (14)	3757 (17)	Excellent
BT5	1987	2083	2555 (5)	3270 (8)	Above average
BT6	1988	2189	2669 (5)	3263 (8)	Excellent
BT7	1991	1646	2573 (5)	3089 (8)	Above average
BT8	1992	2140	3316 (12)	5410 (15)	Average
Ordinary seedling	-	798	1574 (12)	2081 (15)	Below average

Note: Figures in parenthesis indicate number of years observed.

Source: Unpublished compilation of works of Botany Division, BTRI.

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Tea Science in the Year 2000 with special reference to China

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Introduction

Tea is the cheapest hot beverage in the world. It is consumed by various age groups in all sections of society. Some three billion cups of tea are drunk daily worldwide. This paper reviews the past, present and future of tea production and tea science.

1. Tea production and trade

The following statistics have been extracted from the 1993 Annual Bulletin of Statistics issued by the International Tea Committee.

World tea production in 1992 amounted to 2 409 000 tons, 5% below the figure for 1990. 83% was produced in Asia, 12% in Africa. India, China excluding Taiwan, Sri Lanka and Kenya accounted for 29.2, 22.3, 7.4 and 7.8% of world production respectively. World output grew at 2.53% per annum between 1980 and 1992 with growth rates of 2.88 and 4.50% for Asia and Africa. An estimated total of 2.43 million ha was harvested in 1992, only 2.8% more than in 1980. About 86% of this area was in Asia, 8½% in Africa and the remainder in Latin America and Russia.

World tea exports amounted to about one million tons in 1992, 17% higher than in 1980 but the lowest for 5 years. 69% of exports came from Asia. Sri Lanka exported more than India in 1990 when it became the largest exporter.

World imports stood at 976 000 t (40% of world production) and 14% higher than in 1980. The UK was the largest importer (144 600 t), followed by Pakistan (118 900), USA (91 315), Egypt (76 000), Russia (73 000) and Iran (51 500).

Consumption per head (in kg) was highest in Ireland (3.00) followed by UK (2.56), Turkey (2.25) and Qatar (2.02). The highest consumption in producing countries was in India followed by China; consumption was growing by 4 and 7% in India and China respectively.

Tea yields have increased steadily in almost all producing countries and the present world average is about 1 t ha^{-1} made tea. Yield was highest in Kenya (1.85 t ha^{-1}) and decreased in order: India (1.68), Indonesia (1.62), Japan (1.51).

Green tea accounted for 23.4% of world production, 69% of which was produced by China; black tea accounted for 71.7% of total world tea production, 53% of which was CTC. African produced only CTC, Sri Lanka mainly orthodox black tea and India both CTC and orthodox.

Tea output is expected to grow less rapidly than the 3.3% recorded in the 1980s owing to limited consumption growth. A fair estimate is that world production will reach 2.648 mio t in 1995 and 3.1 mio t in 2000. Exports are expected to grow at 1.5% p.a. up to the end of the century as consumption in producing countries increases giving world exports of 1.048-1.057 mio t in 1995 and 1.135-1.200 mio t in 2000.

2. Breeding

Much of the increase in tea production since 1970 was brought about by increased planting of clonal cultivars which give higher yield and present an even plucking table suited to mechanical plucking but the rate of progress varies between countries. In more recently developed countries, like for example Kenya, all tea gardens are under clonal material; this practice will grow in all tea producing countries over the next seven years.

The germplasm collection is a rich resource for tea breeding, possessing various outstanding characters which have long been sought. Some are listed in Table 1. There has been great success in planned breeding from the most promising parents. For example, hybridisation between the Indian Assam varieties (A_1 system, A_k system) and Chinese varieties in Japan, resulted in a whole series of new tea varieties (Hakawata, 1993). Tea breeding for the year 2000 will be directed to various targets aiming for high quality, high yield, high functional components, etc.

Table 1. Some outstanding characters included in the collected tea germplasms.

Index	Parameter
Polyphenols	> 43%
Caffeine	< 1.5%
Amino acids	> 6.5%
Argenine/Theanine ratio	< 0.1
Net photosynthetic rate	> 0.8 $\mu mol\ m^{-2}\ s^{-1}$
Resistance to anthracnose	High
Resistance to blister blight	Nearly immune

2.1. Breeding for quality

Breeding for the next century will concentrate on improving flavour. Tea flavour chemistry has identified biochemical constituents such as the hexenal, hexenol, linalool in roasted green tea, hexenol and dimethyl sulphide in steamed green tea, linalool, geraniol theaflavin and thearubigin in black tea and geraniol and nerolidol in oolong tea. These determinants of flavour provide indices for selection (Yamanishi, 1992).

Investigation over the past ten years has shown tea to contain substances which are beneficial to human health, the most important of these being various catechins and flavonoid compounds. Selection for high content of such compounds will be an important aim of tea breeding in the next century.

2.2. Breeding for yield

Tea yield is determined by shoots population per unit area and shoot weight. Thus, cultivars with high shoot density and desirable growth pattern will be selected.

The potential of cultivars with semi-erect leaves is well established (Benerjee, 1991). High net photosynthetic activity is required for high yield. Tea, as a C_3 plant, has relatively low net photosynthetic activity as compared with other crops; averaging 0.5-1% in Chinese tea gardens, it compares with rice at 3.2, sorghum at 4.5 and maize at 4.6% (Chen Zongmao *et al.*, 1988). The estimated maximum yield in the tropics is about 25 t ha^{-1} and 11-21 t ha^{-1} in the subtropics (Chen Zongmao *et al.*, 1988) so that average world yields are only 1/11 or even 1/25 of the potential. According to research in China, there are marked differences in net photosynthetic rate (P_n) between cultivars tested. The maximum P_n was near 8.0 $\mu mol\ m^{-2}\ s^{-1}$ and minimum 2.4 $\mu mol\ m^{-2}\ s^{-1}$ (Table 2).

Table 2. Group data distribution of net photosynthetic rate (P_n) of tea germplasm (Tong *et al.*, 1992).

P_n ($\mu mol\ m^{-2}\ s^{-1}$)	
Range	%
2.3 - 3.0	4.6
3.1 - 4.0	20.7
4.1 - 5.0	31.0
5.1 - 6.0	23.0
6.1 - 7.0	17.2
7.1 - 8.0	3.5

2.3. Breeding for the needs of the times

The modern market demands various kinds of tea to satisfy the needs of various sections of the community and different age groups. There is a need for teas low in caffeine and some cultivars with less than 1.5% caffeine have appeared. Some of the young prefer tea that is less bitter and astringent, resulting in the introduction of cultivars low in catechins in Japan (Hakawata, 1993).

A possible avenue for progress in breeding is biotechnology. Tissue culture with bud tip and immature embryo has been successful in achieving rapid propagation of new cultivars. "Synthetic" seed has been investigated in India, Japan and China using the clonal embryo encapsulated in tubes in sodium alginate (Palni *et al.*, 1992). Commercialization of this process will speed up the substitution of seedling teas by clonal material.

3. Tea garden management

Most important of all is soil management; many tea soils are low in inherent fertility, subject to erosion and low in major nutrients. There has been an appreciable increase in fertilizer usage since 1960 to alleviate successfully nutrient deficiencies in tea gardens. Optimum soil pH for tea is between 5.0-5.6. The use of large amounts mainly of ammonium containing N-fertilizers may cause a faster soil acidification with deterioration in microbial activity, reduced root activity, poorer frost resistance and toleration of disease, pests and drought. The reduced use of organic manures evident over the past ten years is a further cause of soil deterioration

The nitrogen requirement for shoot growth is high but N utilisation efficiency is low, estimated in China at 30-50%. The preferred N source is NH_4^+. Soil analysis in Japan has shown that nitrate N may accumulate at 200-600 kg ha^{-1} in tea soils. One reason for this is the very low activity of nitrate reductase (NR) in the tea plant, much lower than in other crops (Wu Xin *et al.*, 1993). Only one-third of nitrate N was reduced to NH_4^+ and, evidently, improvement of NR activity should be a priority. Molybdenum improves NR activity and the Mo content of the soil is frequently low (0.01-0.5 mg kg^{-1}). Soil application of molybdenum could be helpful as could selection of cultivars with high NR activity.

Tropical and subtropical tea soils are low in available phosphorus due to P fixation with 90% of soluble P converted to Al^-, Fe^- and Ca^-P. Phosphatase promotes conversion of organic to inorganic P thus increasing plant availability; both acid phosphatase (ACP) and neutral phosphatase (NEP) are correlated with tea yield (Wang Xiaping *et al.*, 1989). Organic acids secreted by tea roots promote transformation of organic P and VA mycorrhiza have the same effect in increasing P availability.

Tea inoculated with mycorrhiza showed P contents 41% higher than control plants receiving no P fertilizer and 87% higher than plants to which rock phosphate had been applied (Li Zhi, 1993).

Analysis of 200 soil samples from various parts of China indicated available K contents ranging from 15.3 to 1031 mg kg^{-1}, the values declining from north to south. Mg content varied from some to several hundred mg kg^{-1} but 73% of Chinese tea soils were below 40 mg kg^{-1} Mg. S content ranged from 3 to 221 mg kg^{-1} averaging 65 mg kg^{-1}. 69% of soils were below 80 mg kg^{-1} S.

There will be further developments in soil analysis and in rapid detecting equipment which will enable monitoring of soil N content and major nutrient status to optimise routine fertilizer treatment (Li Mulien *et al.*, 1991).

Compound fertilizer including microelements formulated for individual soil conditions will increasingly replace the use of straight fertilizers. Another means of improving nutrient efficiency may be the use of slow-release fertilizers.

In the future, there will be increased mechanisation in tea gardens on account of high and increasing labour costs. Various types of plucking machines will be used and a degree of automation is possible. Laying tracks between tea rows has made possible, on an experimental scale, the automation of plucking, pruning, spraying and fertilizer application in Japan and Taiwan. While the high cost of such arrangements will restrict large scale application, it will probably be used on a small scale by the more developed tea producers.

Management programmes based on constant monitoring of growth and environmental (including soil) conditions could ease decisions on plucking date, labour arrangements, pest control, fertilizer treatment, etc. Now a research project, this type of management could be used in practice in the next century.

4. Pest control

The loss of production to pest and disease is estimated at 10-15%. While the use of chemical pesticides over the past 40 years has doubtless increased yields, there have been some undesirable effects including development of immunity to pesticides, accumulation of residues and environmental contamination. It has now been recognised that pesticide usage should be brought under control in a system of integrated pest management (IPM), applying pesticide only when pest population exceeds the tolerable economic threshold. Rules relating to pesticide dosage and safety interval between application and plucking must be strictly observed. Biological control will play an increasing role.

There has been some success in ecological control of pests based on chemical relationships between pest, plant and parasite. For example, the use of the sex pheronome of tea roller (*Adoxophyes* spp.) in Japan and successful control of tea stem borer (*Euwallacea fornicatus* Eich.) by inhibiting the synthesis of the moulting hormone of the pest by potassium acetate in Sri Lanka. The use of such methods should improve the effectiveness of IPM.

Pesticide residues have attracted attention since 1960. Residue accumulation is more pronounced in tea than in other crops because tea is a beverage. More than 300 maximum residue limits (MRL) have been issued by 16 tea producing and tea consuming countries and two international organizations (Chen Zongmao, 1992). The limits may well be lowered by some importing countries in Europe and Japan and this will present a problem for the producers.

5. Tea processing

Two-thirds of world tea production is made into black tea which will continue to be the main product. CTC as a proportion of black tea increased from 38% in 1975 to 44% in 1985 and 54% in 1992. The proportion will probably reach 60% by the end of the century.

Green tea production has increased by 46% in the past 10 years and is expected to remain steady or increase only slightly by 2000.

Tea drinking has increased rapidly in the past five years; it suits modern fast moving society and the younger generation. Tea drinking increased spectacularly in Japan since 1981 (Hakawata, 1993). Supermarkets in the USA took more than a million US$ from tea sales in 1992.

Tea consumption grew more than coffee, fruit juice and soft drinks (Gill, 1992). Total sales China-Taiwan exceeded 4.4 mio US$ in 1993, representing one-third of the total drinks market. It included not only green, black, oolong and jasmine tea, but also others with addition of milk, chrysanthenum, rose, osmanthus and various health products. Important problems in manufacture are the elimination of "retort" odour produced in high temperature autoclaving and preservation of colour. Ultra-high-pressure (300-700 mpa) and low temperature disinfection improve drinking tea quality.

There has been less progress in manufacture of instant tea than has been the case for coffee and production stood at 3789 t in 1992, twice as much as in 1980. Speciality and herbal teas have been developed, e.g. Gabaron tea made from green tea treated under nitrogen gas which is effective in reducing blood pressure (Chen Zongmao, 1993). Developments in other countries are low-caffeine, aroma and health-protecting teas. It is estimated that consumption patterns will change over the next 10-15 years in favour of such speciality teas (Gill, 1992).

Automation and quality control in manufacture have made progress for steamed green tea in Japan, black tea in Russia and in China.

Tea by-products have received attention in recent years mainly in the utilisation of low quality made tea for tea pigment, tea polyphenol, caffeine. Antioxidant properties of tea extracts have been exploited for preservation in the food industry and as an antisenile agent. Tea pigment is used in the food industry; tea caffeine is preferred on account of its natural origin and tea saponin finds a place in medicine preparation. Saponin has high surface activity and is used in the cosmetic and chemical industries.

6. Tea and human health

Food evaluation should pay attention to human health regulation. Tea is a fine modulator of physiological functions in the human. It has beneficial effects in antisenescent activity, immune function, intestinal microflora deodorising and detoxication. It depresses blood pressure and prevents coronary heart disorder, lipid depression, corpulence depression, antiviral and germicidal activity and prevents dental decay. Most notably, it is anticarcinogenic and antimutagenic (Chen Zongmao, 1993). Though no clear-cut conclusion can yet be drawn, research has demonstrated the inhibition of tumor formation and growth in vitro and in vivo by tea preparations and tea polyphenol. Table 3 lists reported anticarcinogenic effects of Chinese tea since 1986. Such prevention is targeted on two groups: the general public for whom tea drinking may be a cheap and practical chemipreventive included in a healthy diet and the high risk group where the prevention of lung, liver, skin and gastro-intestinal cancers is so important.

It can be expected that the investigation of medicinal effects will make much progress in the last seven years of this century.

Table 3. Anticarcinogenic effects of Chinese tea.

Tea samples	Carcinogens	Animals	Indicators	Inhibition	References
Jasmine tea	NMBzA	mouse	forestomach	(+)	Duan *et al.* (1986)
Black tea, green tea	AFBI-AAF	rat	liver r-GT foci	(+)	Chen *et al.* (1987)
Green tea (3 kinds)	AFBI-AAF	rat	liver r-GT foci	(+)	Yan *et al.* (1987)
Green tea	AFBI	rat	liver tumors	(+)	Qin *et al.* (1988, 1990)
Green tea extracts	3-MC	mouse	skin tumors	(+)	Cheng *et al.* (1988)
Oolong tea	MNNG	rat	G.I. tumors	(+)	Ruan *et al.* (1988)
Oolong & jasmine tea	DENA	mouse	lung tumors	(+)	Wu *et al.* (1988)
	Urethane	mouse	lung tumors	(-)	ibid
Green tea, black, green & jasmine tea	Urethane	mouse	lung tumors	(+)	ibid
	B(a)P	mouse	skin tumors	(-)	ibid
Green tea extracts	DMBA/TPA	mouse	skin tumors	(+)	Cheng *et al.* (1989)
Green tea	DENA	rat	liver r-GT foci	(+)	Qin *et al.* (1989)
Oolong, green & black tea	Na nitrite + methyl	rat	esophageal tumors	(+)	Xu *et al.* (1990)
Oolong green & black tea	NMB_2A	rat	esophageal tumors	(+)	Han *et al.* (1990)
Green, jasmine black & oolong tea	NMB_2A	rat	esophageal tumors	(+)	Xu *et al.* (1991)
Green tea extracts	N_2NO^2	mouse	skin tumors	(+)	Yan *et al.* (1992)
Green tea extracts	AFB_1	rat	liver tumor	(+)	Tan *et al.* (1991)
Green tea	$NaNO_2$	mouse	stomach and esophageal tumors	(+)	Lin *et al.* (1990)

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Plant Improvement and Field Practices Towards Improved Productivity of Tea in Indonesia

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Introduction

In Indonesia, tea is mainly grown in Java and Sumatra, though recently an estate has been established in Sulawesi. In 1992, the total area under tea was 136 571 ha of which 56 590 comprised smallholdings, 55 414 State plantations and 24 567 ha private plantations, yielding respectively 930, 2320 and 1880 kg ha^{-1} made tea. The difference in yield between the groups is due to the difference in the extent to which new cultivation practices are applied. Smallholdings and private plantations are characterised by low plant populations of unhealthy bushes and slow growth.

As compared with other countries like Sri Lanka, India and Kenya, there is in Indonesia a great potential for development through the introduction of high yielding clones and application of the latest cultivation methods, especially in the case of smallholdings and private plantations.

Plant improvement

Most of the tea in Indonesia is under seedling bushes which are extremely heterogeneous due to natural outcrossing. Most seedling individuals are low yielding and a small proportion of plants contribute most of the yield (Glover, 1957; Green, 1971).

Great improvements in yield and quality have been achieved by the use of vegetatively propagated clonal planting material. By definition, all individuals of a single clone have the same genetic constitution and a clone is, therefore, more selective to environmental and cultural conditions which influence the adaptability and yield potential of the clone.

Selection of clones for high yield and quality began in 1910 and by 1940, 300 had been selected, 14 of which were recommended in 1956. Vegetative propagation commenced in the early thirties by budding on seedling rootstocks, but this method proved too expensive and was not adapted on any appreciable scale. The planting of clonal material was adopted on a wide scale only after a nursery technique for growing cuttings was evolved.

Genetic variability was improved when clones TRI 2024, TRI 2055, TRI 777 and TRI 1526 were introduced from Sri Lanka in 1956 for use in the breeding programme and after adaptability trials as commercial planting material.

Clones recommended for large scale planting (Astika and Muchtar, 1978) under various conditions are:

(1) Low elevation (below 800 m above sea level): TRI 2025, TRI 2024, Skm 116, PS 125, Cin 143, Cin 176 and Skm 123.

(2) Medium elevation (800-1200 m above sea level): TRI 2024, TRI 2025, PG 18, KP4, PS1, Kiara 8 and Cin 143.

(3) High elevation (over 1200 m above sea level): Cin 143, TRI 2025, Kiara 8 and PS1.

At high elevations (1600 m and above), susceptibility to blister blight is increased while in the valleys tea is subject to night frost during the dry season; dry season drought may adversely affect tea at low elevations.

Resistance to pest and disease varies between clones and there is inherent danger in planting whole areas with one or two clones only; therefore, it is recommended to use at least 4 or 5 clones for replanting or extension. A further objection to the use of only one or two clones by many estates is that the teas produced will be too uniform and thus lose their individuality.

However, some estates still plant only one or two clones because some of the recommended clones have been found to have defects such as susceptibility to blister blight and slow growth in the establishment phase.

Inter-clonal crossing was started in 1973 in order to widen the choice of planting material. This offers the possibility of combining the characters of both parents and producing cultivars exhibiting all desired properties - high yield, good quality, drought tolerance, pest and disease resistance.

By 1988, five clones emerged which could be recommended especially for medium and high elevations. They have the potential to yield over 5 t ha^{-1} yr^{-1}, are resistant to blister blight and with high first leaf density (Astika *et al.*, 1991).

Plucking and pruning

Plucking

Harvesting involves the removal of the apical bud, the internodes and two or three leaves immediately below. The old method can be described as mother leaf plucking with the formula p+2/k+1 and medium plucking with formula p+2/k. This method will meet the carbohydrate requirement of the bud but bush height increases too rapidly, becoming unmanageable and the plucking table cannot be kept level.

The new method of level plucking has been adopted which was used in the past to control blister blight (de Weille, 1959). In this method, shoots are taken to the fish leaf especially in the centre and at the edges of the bush for maintaining a flat plucking table.

Janam-flat plucking, harder and more intensive than fish leaf method was introduced in 1984. A disadvantage of this method is that maintenance foliage becomes older and thinner with adverse effects on the yield. This can be avoided by increasing the plucking table by one or two leaves every six months (Sukasman, 1986).

Pruning

In the appropriate climatic conditions, pruning can be done monthly but the climate of Indonesia has marked dry and wet seasons. During the rains, blister blight may adversely affect crop performance and in the dry season, growth is very slow on account of soil moisture deficit. This means that pruning can be done only over 5½ months of the year, from January to March and from October to December.

Fertilizer recommendations

As with all perennial crops, cultural practice and fertilizer treatment have long-term effects and it is necessary to keep nutrient supply at a steady and adequate level if yield is to be maintained.

Soil types are differentiated according to topsoil depth, slope, structure, organic matter content, total P and nutrient contents. In theory, there should be 27 fertility classes for each soil type but our soil survey distinguishes only 5 main classes because generally speaking topsoil depth, soil organic matter and nutrient content of Indonesian tea soils range from medium to high (Darmawijaya, 1985). The nutrient ratio of fertilizers is adjusted in accordance with deficiency of major and minor soil nutrients in the relevant soil type (Wibowo, 1992). Rates of fertilizer recommended for young and mature tea on different soil types are given in Tables 1 and 2.

Table 1. Dose of fertilizer in kg/ha/year applied in young tea in different soil types.

Soil organic matter	The age after planting	Andisol/Regosol				Latosol/Podzolic			
		N	P_2O_5	K_2O	MgO	N	P_2O_5	K_2O	MgO
<5%	1st year	100	60	40	-	100	50	50	-
	2nd year	150	60	40	20	150	75	75	40
	3rd year	200	75	50	30	175	75	75	40
5-8%	1st year	80	50	30	-	80	40	40	-
	2nd year	120	50	30	20	120	60	60	30
	3rd year	150	60	50	30	160	60	60	30
>8%	1st year	70	50	20	-	70	30	30	-
	2nd year	100	50	30	20	110	50	50	25
	3rd year	130	60	40	20	140	50	50	25

Table 2. Dose of fertilizer in kg/ha/year of mature tea to produce 2000 kg/ha/year.

Fertilizer	Nutrient	Optimal dose	Frequency of application
Urea, SA	N	250 - 350	3 - 4 times
TSP, PARP	P_2O_5	60 - 120 *)	1 - 2 times
		15 - 40 **)	1 - 2 times
MOP, SOP	K_2O	60 - 180	2 - 3 times
Kieserite	MgO	30 - 75	2 - 3 times
Zinc Sulphate	ZnO	5 - 10	7 - 10 times

*) Applied in Andisol/Regosol

**) Applied in Latosol/Podzolic

Plant protection

Diseases

The most important disease on tea in Indonesia is blister blight, which was observed for the first time in North Sumatra in 1949 and in West Java in 1951. The disease changed a number of tea cultivation methods such as plucking, shade and pruning policy.

Blister blight so far has been successfully suppressed to permissible level by applying shorter plucking period, i.e. 6, 7, 8 days. This method eventually increased the crop yield compared to plucking period of 9 to 13 days.

In epidemic areas, application of copper sprays is recommended but systemic and contact fungicides should be applied occasionally. Various forecasting systems have been developed to improve the efficiency of fungicides but there are difficulties in using them.

Red root (*Ganoderma pseudoferrum*) is the most important root disease, especially at low elevations; higher up black root rot (*Rosellinia arcuata*) is more important. The chief control measures used are conventional: digging of isolation trenches (60-100 cm) and burning of diseased bushes. Planting Guatamela grass for a period of 2-3 years or Vavam at 8 ml per hole or methylbromide at 0.5 kg/10 m^2 two months before replanting are also recommended.

Pests

In the dry season, pests can play an important role. The two major pests are Helopeltis and mite. Maintenance of tea estate sanitation to eradicate host plants and short plucking interval less than 7 days may reduce Helopeltis attack. Chemical control is used especially for certain epidemic areas. The use of copper fungicide in controlling blister blight disease may increase mite attack and, therefore, contact and systemic fungicide should be applied intermittently.

Weeds

Weeds are a problem in young tea and after pruning but weeding should be done with the minimum soil disturbance. Strip weeding every two rows can reduce runoff by 80% and soil erosion by 64% (Wibowo and Yulianti, 1989), and herbicides minimise Helopeltis attack and blister blight.

Vacancies during the pruning year should be replaced with clonal material, thereby reducing weeding costs and eventually increasing yield. Mulching Guatamela grass at 45 t ha^{-1} or tea prunings can be effective in reducing weed growth (Sanusi, 1977).

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Practices adopted in North-East India to Enhance Tea Productivity

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Abstract

Production of tea in India has increased from 275 million kg in 1950 to 758 million kg in 1993, while the production in NE India has increased from 231 million to 579 million kg. For the same period, productivity in NE India increased from 932 kg to about 1706 kg/ha. It was made possible due to availability of a large number of high yielding and quality clones and hybrid seed cultivars. Improvement of the technique of bringing up young tea resulted in higher yield during the formative years and reduced the gestation period from planting to full bearing. Use of optimum plant population, longer pruning cycle, shade, drainage and irrigation, use of growth substances, judicious use of specific purpose herbicide and time to time soil amendments were the main contributing factors for increased production. The optimum requirement of NPK and micronutrients were determined for different agro-climatic districts. Dependence on chemicals for pest and disease control was reduced and crop loss was minimized by taking up an integrated approach for pest and disease management.

Introduction

Production in NE India increased from 231 in 1950 to 579 million kilogram in 1993 (Table 1). The unit yield for the same period increased from 932 kg/ha to about 1706 kg/ha (Anon., 1987-88; Anon., 1993). Not the entire tea area gets the benefit of R & D. Tocklai extends its service to those who are members of the Tea Research Association. However, about 75% of the tea area and 80% of NE India's production come from TRA member tea estates. The impact of R & D can be measured not only by the overall increase of 250% during the last forty three years but also by the differences in yield of about 56% between those who directly used R & D information and those who did not (Table 2).

Table 1. Production of tea in million kg and productivity kg/ha.

Year	Production	Productivity
1950	231	932
1955	246	987
1960	243	947
1965	271	1003
1970	317	1122
1975	381	1312
1980	439	1430
1985	514	1576
1990	545	1585
1993	579	1706

Table 2. Yield of made tea in kg per hectare.

Year	1963	1973	1978	1988	1990
Members [1)]	1153	1377	1626	1840	1860
Non Members	827	917	1070	1190	1200
% Difference	39.9	50.1	51.9	54.6	55.5

[1)] Tea Research Association

This improvement in productivity was made possible by R & D breakthroughs and adoption of new technologies. Contribution of research and its application in some of the important areas are highlighted in this paper.

Planting material

Tea cultivation in NE India was started with seeds brought from China and later from Indochina region. Tea was also found growing wild in the hills of NE India. Since the seeds were obtained from non-descript sources and were highly heterogeneous, their productivity was low. But they provided an excellent base for breeding and selection of cultivars for higher yield and better quality. The first set of three clones developed through selection was released in 1949. New cultivars were developed either from existing natural variability in the population or by creating variability artificially through hybridization, mutation and polyploidy. So far, 30 clones and 11 hybrid seed varieties have been released to the industry. Besides, 134 region specific clones were developed by selection in the estate fields (Bezbaruah and Singh, 1980; Singh and Pradhan, 1985; Singh, 1989). The performance of some of the cultivars is shown in Tables 3-5.

Table 3. Characteristics of cultivars TV series clones.

Cultivar	Index		
	Yield	Quality	
		C.T.C.	Orthodox
TV1	100	7	3
TV2	86	2	8
TV3	80	3	7
TV4	92	3	7
TV5	82	3	7
TV6	85	3	7
TV7	82	2	8
TV8	90	5	5
TV9	105	6	4
TV10	110	7	3
TV11	110	4	6
TV12	112	4	6
TV13	93	3	7
TV14	112	6	4
TV15	90	3	7
TV16	114	7	3
TV17	115	7	3
TV18	118	7	3
TV19	134	7	3
TV20	135	7	3
TV21	110	3	7
TV22	125	7	3
TV23	130	7	3
TV24	125	6	4
TV25	130	7	3
TV26	135	7	3
TV27	125	7	3
TV28	139	7	3
TV29	191	7	3
TV30	176	7	3

Table 4. Tocklai seed stocks.

Cultivar	Index		
	Yield	Quality	
		C.T.C.	Orthodox
TS378*	100	-	100 (Flavour)
TS379*	104	-	104 (Flavour)
TS397	94	6	4
TS449	100	6	4
TS450	105	6	4
TS462	110	6	4
TS463	107	6	4
TS464	107	6	4
TS491	104	6	4
TS520	110	6	4
TS506	110	6	4

* Stocks suitable for Darjeeling and other hilly areas only.

Table 5. Some of the region specific clones under district selection scheme.

Region	Cultivar	Index		
		Yield	Quality	
			C.T.C.	Orthodox
Assam	TV1	100	7	3
	Heeleakah 2319	92	2	8
	Heeleakah 2214	95	2	8
	Kaliapani 20	118	6	4
	Sangsua 40A	119	8	2
	Bukhial 46	113	6	4
	Mokrung 76	113	4	6
	Koomsong 29	103	3	7
	Choibari 38	117	3	7
	Bagmari 20	120	3	7
	Tarajulie 34	117	3	7
	Bormajan 2	129	2	8
	Bormajan 5	115	8	2
	Longai 17	118	8	2

Table 5. Continued.

Region	Cultivar	Index		
		Yield	Quality	
			C.T.C.	Orthodox
Dooars & Terai	Hantapara 12	120	5	5
	Huldibari 19	107	7	3
	Leesh River 9/34	120	6	4
	Mohurgong & Gulma 25	116	7	3
	Sanyasithan 27	130	3	7
	Sukna 23	125	6	4
	Kamalpur 6	130	6	4
			Flavour	
Darjeeling	Nandadevi	100	100	
	Phoobsering 312	146	141	
	Bannockburn 157	146	131	
	AV2 (Balai)	175	134	
	Tukdah 78	144	121	
	Tukdah 383	99	147	
	CP-1	175	98	
	Teesta Valley-1	169	117	

About 5000 hectares are brought under tea every year by extension and replanting with the largest released clones and seeds.

Plant population

Experiments on bush population and planting pattern were conducted at Tocklai since 1948-49 with plant population ranging from about 5,600 to 14,000/ha. In these trials, closer spacing gave higher yield in early years and then the difference was reduced with the age of tea. New sets of experiments laid out in 1973-74 with plant population varying from 4451 to 4,44,444/ha, the yield-population relationship was observed to be parabolic. The optimum plant population was found to be between 12,600 to 17,000/ha (Rahman and Fareed, 1979; Barua, 1989).

Young tea management

Young tea management has undergone considerable changes over the last 25 years. The gestation period from planting to full bearing was reduced from 6/7 years to 2/3 years. Establishment of a three-tier bush architecture (Barbora *et al.*, 1984; Barbora and Sarkar, 1988) together with better planting material and higher plant population have resulted in the harvest of more crop during the formative years than before.

Table 6. Yield trend from young tea kg/ha.

Years	Age	+1	+2	+3	+4	+5
1965-70		120	425	650	1000	1400
1981-86		260	2320	3070	5200	3235

Pruning cycle

Tea was under annual prune until the beginning of the sixties when different forms of skiffs and unprune were introduced with a view to increasing the total crop and obtaining an even distribution of annual harvest (Tables 7 and 8). With the same objective, longer pruning cycle came into vogue (Dutta, 1969). Longer pruning cycle from annual prune to 2-year, 3-year and 4-year cycles resulted in about 7-9%, 12-15% and 19-20% increase in crop (Anon., 1989-90).

Table 7. Effect of longer pruning cycle on relative yield of tea.

Pruning cycle	Annual crop
1. Annual prune	100
2. 2-year cycle LP-DS	107
3. 3-year cycle LP-DS-UP	112
4. 4-year cycle LP-UP-DS-UP	119

Table 8. Effect of pruning cycle on crop distribution (%).

Pruning cycle	Early season				Main season			Back-end season		
	M	A	M	J	J	A	S	O	N	D
LP	-	2	6	9	18	20	20	14	8	3
DS	-	3	11	14	17	18	14	14	7	2
UP	6	9	11	11	15	18	13	10	6	1
LP-DS-UP	2	5	9	11	16	19	16	13	7	2
LP-UP-DS-UP	3	7	11	13	15	17	14	12	7	1

Maintenance foliage

The size of the maintenance leaf canopy was determined by the first dormancy horizon (Barua, 1959). In young tea, the optimum LAI was found to be 3.5 to 4 (Barbora *et al.*, 1983). The peak photosynthetic efficiency of maintenance leaf remained for six months and then gradually declined finally to drop off due to senescence after 12-18 months (Barua, 1960). The need for replenishing the maintenance foliage was highlighted for better yield and crop distribution (Anon., 1989-90).

Table 9. Effect of raising a leaf in autumn on yield mt.kg/ha.

Plucking	Year: 1	2	3	Remark
Janam plucking	1954	2709	2751	
Raising a leaf in autumn & janam plucking	1999	2833	3064	6% increase in crop

Nutrition

Long-term manurial trials established that yield increased in proportion to the nitrogen applied up to a limit and that the rate of N was region-specific, varying from 90 kg to 200 kg N/ha. High dose of nitrogen was found to result in the accumulation of theanine (Dev Chowdhury *et al.*, 1988; Biswas *et al.*, 1984) in the roots and destruction of the feeder root system.

The response to nitrogen was increased in the presence of phosphate and potash (Sharma *et al.*, 1977; Sinha and Thakur, 1988). Recent studies have shown that the optimum requirement of phosphate varied between 20 and 50 kg/ha/year. Potash is applied with nitrogen at the ratio of 1:0.6 to 1:1 depending on the soil test value of K_2O (Table 10).

Table 10. NPK manuring in mature tea.

Average yield of a pruning cycle made tea (kg/ha)	N (kg/ha)	P_2O_5 (kg/ha)	K_2O (kg/ha)		
			Available soil K		
			L	M	H
			< 60 ppm	61-100 ppm	> 100 ppm
Below 1500	90	20-50	90	70	50
1500-2000	90-110	20-50	90-110	70- 80	50- 70
2000-2500	119-140	20-50	110-140	80-120	70-100
2500-3000	140-165	20-50	140-165	120-140	100-120

Deficiency syptoms for important nutrient elements were identified. Foliar application of zinc sulphate @ 12.5 to 20 kg/ha enhanced yield by about 10%. Crop increase was obtained from sulphur, boron, manganese and magnesium by 4-6, 2.5, 6.6 and 0.5 per cent respectively (Sharma, 1971; Barua and Dutta, 1972; Ghosh and Chakravortee, 1980). Some of the growth promoters were found to increase early season as well as total crop (Barbora *et al.*, 1990) (Table 11).

Table 11. Effect of growth promoters on yield and its seasonal distribution.

Treatment	Total yield kg/ha	Early season (March-June)	Main season (July-Sept.)	Back-end (Oct.-Dec.)
Control	3708	1686	1495	527
Triacontanol + Sterol	4338	1974	1953	611
"Biostimulant"	4340	1992	1815	592
Zinc + Urea	4427	1982	1800	644
Multimicronutrient	4076	1809	1698	569

Shade

Tocklai has established that a light even canopy of shade is essential for the tea plantations in NE India, except in the high elevations of Darjeeling (Barua, 1973). Shade trees cut off the high insolation detrimental to photosynthesis. Shade reduces tea leaf temperature and saves the leaf from sunscorch. It helps to increase the leaf area and accumulation of dry weight (Hadfield, 1974). Shade adds organic matter and nutrients to the soil. It also reduces the incidence of pests and diseases. Shade trees contribute 2500 to 5000 kg of dry organic matter by leaf drop, pod and twig drops.

Table 12. Nutrient contents in shade tree litters (kg/ha).

Nitrogen	63-126
P_2O_5	18- 36
K_2O	22- 44
CaO	32- 64
MgO	16- 32

Soil rehabilitation and replanting

The economic life span under NE India conditions normally varies between 40-50 years. The need for rejuvenating the soil by keeping it under rehabilitation crop for two to three years was well documented (Dutta *et al.*, 1980; Anon., 1986-87). Rehabilitation has resulted in the improvement of soil organic matter, soil aggregate, permeability and detoxification reflecting in 10-16% increase in crop (Tables 13 and 14).

Table 13. Effect of soil rehabilitation on yield of young and mature tea (kg/ha).

	Young tea	Mature tea
- Rehabilitation	1303	2619
+ Rehabilitation	1506	2878

Table 14. Effect of rehabilitation on organic matter, soil aggregate and permeability.

Soil parameter	- Rehabilitation	+ Rehabilitation
Organic matter (%)	1.56	1.73
Aggregate (%)	61.00	79.00
Permeability (m/day)	0.556	0.953

Soil water management

It has been estimated that more than 50% of the tea suffers from either waterlogging or drought or from both. The drainage design and layout are determined on the basis of catchment and soil-water parameters. Improvement of drainage resulted in about 22% increase in crop (Table 15) with very attractive cost-benefit ratio (Anon., 1985-86).

Table 15. Effect of improved drainage on yield of tea (kg/ha).

Year	Yield (kg/ha)	Increase (%)
0 year	1968	-
+ 1 year	2188	+ 11.2
+ 2 year	2394	+ 21.7

The soil moisture deficit varies from 8 mm to 300 mm during the most critical period from November to April as the tea extends from the east to the west of the region (Biswas, 1981). On the average, irrigation by sprinkler system increased crop by 10-20%.

Rejuvenation and consolidation

About 40% of the existing tea is above 50 years old. Because of vacancy, age, high frame and low plant population, the productivity of this group of tea is low. Such teas are to be replaced in a phased manner. Rejuvenation pruning and consolidation by infilling/interplanting is a stop gap measure and not an alternative to uprooting and replanting. Loss of crop due to rejuvenation pruning could be recovered in 4-5 years by infilling alone, while infilling with interplanting reduced the period of crop recovery to 2-3 years (Table 16).

Table 16. Yield trend from rejuvenation pruning, infilling and interplanting (% ± over control).

Treatment	0 yr	+1yr	+2yr	+3yr	+4yr	+5yr	+6yr	+7yr
Infilling	-44	+4	+4	+12	+17	+14	+22	+21
Infilling + Interplanting	-36	+27	+35	+47	+40	+55	+41	+41

Weed control

Till the mid sixties, weeds were kept under control by hoeing, cheeling, sickling, forking and hand removal. Chemical weed control was introduced in 1965 with contact herbicide paraquat. Since then, a wide range of contact, translocated and pre-emergent herbicides were tested against both di- and monocot weeds and a cost effective spraying schedule was available to deal with the wide spectrum of weeds (Barbora and Dutta, 1972; Rahman, 1974; Rao, 1981; Sharma *et al.*, 1986). Keeping weeds under control is no longer considered as a major constraint to productivity.

Introduction of chemical weed control resulted in the saving of about 130 mandays/ha/year and about 6% increase in crop over manual control (Barbora, 1971).

Pest and disease

Crop loss due to damage by pests and diseases was estimated to be about 15% (Jain, 1977). Loss of crop was minimized by the use of pest-specific chemicals. Tocklai is also very much aware of the possible hazards of the indiscriminate use of pesticides vis-a-vis environmental pollution, residue build up and tainting of tea. This has led to the search for the use of safer chemicals and ways and means for effective pest control by adopting an Integrated Method of Pest Management (Das, 1990; Barbora *et al.*, 1994).

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Agronomic Practices for Higher Tea Productivity in Kenya

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Abstract

Continuous pragmatic review and adoption of improved and/or new agronomic practices, recommended by the Tea Research Foundation of Kenya, often complimented with tea companies/organizations internally generated improved and/or new practices, have and continue to contribute to higher tea yields being realized by the Kenya tea growers. From site suitability evaluation (climate and soil suitability assessment), search for and planting only high yielding/good quality material, appropriate cultivation/crop husbandry methods including pest management are the major agronomic practices responsible for the upward trend in yields of the Kenyan tea.

Introduction

For a farmer, tea is a cash crop and is produced primarily to make money which the tea farmer could then use to purchase goods or could be used in exchange for goods (barter trade). A farmer invests money to make money. He must make a profit to talk of making money; otherwise he would be talking of losses. Profit is, therefore, one basic objective for which tea is grown. Profit may be direct to the farmer, direct or indirect within and for the country growing tea. As tea is mainly grown in poor developing countries, its economic value is direct on a national basis, in terms of providing employment, increasing wealth, providing infrastructure in rural areas and finally earning foreign exchange.

The importance attached to tea production, as indeed is with any agricultural or any other business enterprise, whether it is at individual farmer's level or at national level is, therefore, enormous. But the bottom line is the ability to produce more tea profitably. The tea farmer, wherever he may be, is, therefore, always asking for agronomic practices which could give higher tea productivity at renumerative returns.

The factors which contribute to higher tea productivity can be put in a simplified brief sequence:

1) Ecological suitability of an area —> 2) Planting material —>
3) Cultivation/Crop husbandry —> 4) Manufacture —> 5) Sales —>
6) Profit or loss.

The last three terms in the sequence are not agronomic but have direct influence on agronomic practices hence productivity. This paper reviews some of the agronomic practices used by tea farmers in Kenya to achieve higher tea productivity.

The Tea Research Foundation of Kenya (TRFK) is the technical arm of the Kenya tea industry. Its mandate is to conduct scientific research and undertake advisory work for the advancement of all aspects of tea production in Kenya. Most of its practical agronomic recommendations have been collected and published in "Tea Growers Handbook" which is revised as and when enough new information generated from the TRFK research activities justify to do so. The last revision was done in 1986 and new information since then is presently being studied to see if it justifies a revision.

To complement the work of TRFK, a number of tea companies/organizations conduct their own practical experiments such as clonal selections, manuring, etc. Often, TRFK scientists are consulted on these practical experiments, because all have the same objective, i.e. higher productivity of good quality Kenyan tea.

1. Ecological suitability for tea planting

Tea has specific ecological requirements which must be met if it has to be grown as a viable cash crop. Both climate (Carr, 1971) and soil (Mann, 1935; Othieno, 1991) requirements are specific.

In Kenya, evaluation for suitability of areas intended for tea growing is taken very seriously, especially since the introduction of smallholder tea scheme in the late 1950's/early 1960's. Indeed, a detailed survey was carried out in all areas with potential for tea growing and the resultant report (Brown, 1965) has been the cornerstone of tea expansion in Kenya. The exercise has continued with TRFK carrying out additional surveys either to verify the Brown report on certain specific areas or to carry out surveys in new areas with potential for tea growing but which were not accessible at the initial survey mentioned above. The importance of these surveys is that tea planting is allowed by the Kenya Government only in areas with suitable ecological conditions for tea growing to give economic yields.

2. Planting material

At the time of introduction of tea into Kenya in 1903 and the subsequent early commercial planting in the 1920's, the material used consisted of tea seeds from seed-baries in India. However, after the second World War, when major commercial tea growing expansion took place, a number of seed-baries were developed within East African region from where tea seeds were obtained to supplement seeds from India.

Until the end of 1940's, the objective was to expand with whatever available commercial jat. Plant improvement programme in Kenya started with the establishment of the Tea Research Institute of East Africa (TRIEA), now Tea Research Foundation of Kenya (TRFK) in 1950 when work on vegetative propagation (VP) started. With the establishment of better methods of raising tea plants through VP, work on clonal selection to develop high yielding/good quality planting material followed in 1954. However, it was not until ten years later in 1964 when the first release to tea growers of TRIEA approved clonal plants was made. The TRIEA clonal release opened doors to expansion in search for high yielding, good quality planting material not only by TRIEA but also by tea growers (large estates and the smallholder organization). The search, which is still continuing, has to-date produced very good results as the Kenya tea growers have some of the highest yielding clones in the world (Oyamo, 1991).

The search for even better planting material is continuing, using the traditional clonal selection/breeding methods. On research side, TRFK scientists are not only carrying out clonal selection/breeding work but are also studying reasons, down to cell level, why a tea plant of a given variety/clone behaves the way it does especially when it is grown in a different environment. The ultimate objective is to have a set of reliable selection criteria and/or genetic characters for use in such for higher yield/good quality planting material.

Multi-disciplinary studies on genotype x environment which results could lead to the development of a reliable mechanistic yield prediction model are continuing. For instance, from TRFK's work, it is now known that within the Kenyan's main tea growing district of Kericho, at altitudes ranging between 1600 m and 2200 m a.m.s.l., time required for an auxiliary bud of tea to reach pluckable size of 2 leaves and a bud increases by 3.3 days for each 100 m rise in altitude (Mwakha, 1985). This has been found to correspond to yield of seedling tea to decrease by 200 kg mt/ha/year for each rise of 100 m (Obaga *et al.*, 1988). If developed, such a model could be of immense importance to individual tea growers, the tea industry and the Government.

3. Cultivation/Crop husbandry

Having selected a site with high potential for growing tea and having planted high yielding/good quality material, the expected high yields can only be realized if the cultivation/crop husbandry practised is optimum. Most of the Kenyan tea growers use recommendations contained in the TRFK's Tea Growers Handbook (TGH, 1986), often complemented by individual companies/ organizations own developed practices to active higher productivity.

Planting density

In the early years of the tea planting in Kenya, very low plant density was used. A number of fields planted in the 1920's had only 3000-3500 plants per ha. This was improved between the 1950's and 1960's to between 6000 to 9000 plants per ha. At present, majority of tea planters are using higher plant population density of 10000 to 14000 plants per ha. This change was brought about because of the results of work done in Malawi (Laycock, 1961), and has been repeated in nearly all the tea research institutions of the world with the same results, i.e. in the early years following planting, higher plant densities give higher yields up to 15 or more years after planting. Yields tend to level off as the wider spaced plants spread to cover the area. Tables 1a, b and 2 give results of such experiments carried out in Kenya.

Fertilizer use and plant nutrition

The Kenyan tea growers, especially the large estates, continued to use straight nitrogenous fertilizers, especially sulphate of ammonia from the 1940's. It was not until the mid 1960's that deficiencies of other nutrients, especially P and K started to be noticed. From *ad hoc* chemical analysis of both nutrient deficient and normal tea leaves in 1965/66, it was crudely established that the Kenyan tea plants needed a fertilizer of NPKS 25:5:5:5 or NPK 20:10:10.

Use of the above mentioned NPKS or NPK fertilizer started in 1967/68. This was accompanied by rigorous chemical leaf analysis for advisory purposes. In many tea fields, potash was found to be a major limiting factor and remedial applications were used, in addition to what was in the NPKS/NPK. The result of these changes in terms of yields was dramatic and rates of up to 450 kg N/ha/year as NPKS/NPK were being used until the "Oil Crisis" when continuous rise in fertilizer cost forced the Kenya tea growers to review the situation. Again, from *ad hoc* survey carried and evaluation of data collected from the survey carried out on large estates by TRFK, it was observed that the optimum returns for majority of tea fields were being obtained at fertilizer rates between 200 and 250 kg N/ha/year as NPKS/NPK, although for very high yielding clones, the rates between 250 and 350 kg N/ha/year could still give good returns (Table 3a, b, c). It should be pointed out here that direct responses of tea to straight P and K fertilizer application in Kenya have been rare. These have now been confirmed by field experiments (Owuor *et al.*, 1990, 1991) (Figure 2).

Other aspects of fertilizer use and tea nutrition in Kenya are contained in the Tea Growers Handbook (1986).

Plucking

Under normal growing conditions in Kenya, tea plucking is on 10/11 days rounds to give leaf of acceptable quality. In more favourable conditions, the rounds can be shortened to 7, 8 or 9 days and in unfavourable conditions such as in dry seasons or damage by hail, 14 days or more. It is recommended to be flexible on plucking rounds taking into account the prevailing environmental conditions, jat or clone being plucked. TRFK's results from the plucking frequency experiments show that short plucking rounds produce more leaf which make high quality tea than long rounds when standard plucking of two leaves and a bud is maintained (Figure 1). Tea growers who have adopted this TRFK's experimental observation have confirmed the results.

Pruning

In Kenya, pruning of mature tea is done on three or four year cycle, depending on how plucking table is managed from one pruning to the next. Where plucking is "soft" and/or the rounds are long, the table rises fast hence short pruning cycles. On the other hand, where plucking is "hard" and/or at short intervals, the table is maintained hence long pruning cycles.

Lung (leaving "breathers") is recommended and is becoming popular in the large estates sector. It is recommended not to prune at the end of a prolonged severe drought especially "down or reduction" pruning. It is also recommended to cover the pruned branches with the prunings, immediately after pruning, to reduce damage to pruned branches by sun-scorch. Prunings must be left *in situ* for the supply of organic matter and maintenance of soil fertility.

Effect of pruning on physiology of the tea bush, however, remains elusive. For instance, what physiological benefit does a lung-pruned bush get as opposed to clean cut-across pruned bush? This is a question which, it is hoped, is being addressed by many tea research institutions around the world.

Weed control

Prior to the introduction of Gramoxone (paraquat) for annual broad-leafed and later, Round-up (glyphosate) for perennial, especially grasses, weed control in Kenya was a problem. Unless for economic reasons like either lack of funds to buy these chemicals or unavailability of the chemicals, weed control in Kenya has been very successful.

The success of weed control together with leaving the prunings *in situ* have increased the level of soil organic matter and improved general soil fertility tremendously. This has contributed to improved fertilizer use efficiency by the tea bush, resulting in reduction in fertilizer rates without decline in yields. Indeed, yields have continued in the upward trend.

Pests and diseases management

The Kenya tea areas continue to be endowed with environment free of major tea pests and diseases of economic importance. We pray that this situation will remain the same for many years to come. However, there are a few pests and diseases which, if left unchecked, could establish to be of economic importance.

These are:

<u>Pests</u>	Tea thrips (*Scirtothrips kenyensis* Mound), Red spider mites (*Oligonychus coffeae* Nietner), Red crevice mites (*Brevipalpus phoenicis*) and purple mites (*Calacarus carinatus* Green).
<u>Diseases</u>	*Armillaria mellea* root rot and *Hypoxylon serpens* wood rot.

Whereas chemicals are available for the control of these pests (insecticides/acaricides) and diseases (fungicides), the increase in sensitivity to these chemicals in the consuming countries is restricting their use. In Kenya, attempts are being made to find alternative safe, i.e. non-chemical ways of managing the mentioned pests and diseases, especially the biological control methods.

A collective approach to establishing Maximum Residue Limits (MRL) data for the pesticides and fungicides commonly used in tea by the producing countries is long overdue, especially if the urgency of the recently introduced EC Draft regulations or MRL is considered.

4. Dissemination of information on agronomic practices

The major source of information, especially relating to the local environment, available to the Kenya tea growers both smallholders and large estates is the Tea Research Foundation of Kenya. The Foundation disseminates its agronomic research findings through:

(a) Publications: (i) Annual Reports and (ii) "Tea" a journal published by the Foundation twice a year.
(b) Advisory visits
(c) Field or Open Days
(d) Demonstration on farmers' fields
(e) Seminars/Courses

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Table 1a. Harvest indices (%) and yields in kg m.t./ha at various stages of growth of the clonal tea bushes planted at various spacings and plucked at two different heights.

		Record period											
		1 (1980/81)		2 (1981/82)		3 (1982/83)		4 (1983/84)		5 (1984/85)		6 (1985/86)	
Spacing	Plucking height	HI	Yield kg mt/ha	HI	Yield kg mt/ha	HI	Yield kg mt/ha	HI	Yield kg mt/ha	HI	Yield kg mt/ha	HI	Yield kg mt/ha
0.3 m × 0.3 m	25 cm	27.1	330	18.7	2023	27.7	2367	28.6	3308	22.4	2343	22.7	2868
(111,111 p/ha)	50 cm	7.1	103	19.3	2532	22.3	2661	24.1	3478	22.2	2122	21.7	2176
	mean	17.1	217	19.0	2278	25.0	2514	26.4	3393	22.3	2232	22.2	2522
0.61 m × 0.61 m	25 cm	21.8	139	22.8	1109	19.9	1462	24.2	2893	19.0	2071	20.5	2288
(27,027 p/ha)	50 cm	9.5	42	13.3	1488	18.9	2291	16.9	3196	19.1	2090	20.2	2031
	mean	15.6	91	18.0	1298	19.4	1876	20.5	3044	19.1	2080	20.4	2160
1.22 m × 1.22 m	25 cm	22.3	42	22.5	382	22.4	698	15.2	1601	11.6	1341	13.3	1764
	50 cm	7.0	19	10.4	632	14.6	1253	13.8	2162	17.6	1722	15.7	1906
(6,711 p/ha)	mean	14.7	31	16.4	507	18.5	975	14.5	1882	14.6	1541	14.5	1835
Overall plucking	25 cm	23.7	171	21.3	1171	23.4	1509	22.7	2601	17.7	1918	18.8	2307
Height mean	50 cm	7.9	55	14.4	1551	18.6	2086	18.3	2945	19.6	1978	19.2	2037
C.V. (%) spacing		12.3	20.9	5.1	5.4	5.6	5.4	5.6	7.1	3.8	7.0	3.5	8.3
Plucking height		28.3	25.3	17.3	9.9	10.8	12.2	8.2	10.6	10.9	11.7	11.4	13.0
LSD (P=0.0.5) spacing		NS	49	NS	152	3.8	201	3.7	408	2.2	281	2.1	371
Plucking height		5.2	23	3.6	107	2.6	174	1.9	234	NS	NS	NS	224
Height in same spacing		8.9	39	6.2	186	4.5	301	3.4	405	NS	314	NS	389

HI = Harvest Index.

Table 1b. Cumulative yields (kg m.t./ha) of the bushes initially plucked at two different heights from 1980 to 1991.

Plucking height	Spacing 0.3 m × 0.3 m	0.61 m × 0.61 m	1.22 m × 1.22 m	Plucking height
25 cm	32228	28201	20386	26938
50 cm	31791	28085	22598	27491
Mean spacing	32009	28143	21492	

C.V. (%)	Spacing	4.05
	Plucking height	5.07
LSD (P=0.05)	Spacing	2272
	Plucking height	NS

Table 2. Effects of plant population and fertilizer rates on yields (kg mt/ha) (January-December 1993). Seedling tea planted in 1961.

	Fertilizer rates (kg N/ha)				
Plant population	0	80	160	320	Population means
5883	2465	2676	2675	2666	2621
7179	2558	2580	2805	2753	2674
8611	2496	2701	2919	2870	2747
10766	2904	3124	2912	2882	2955
Fertilizer means	2606	2770	2828	2793	
	Population:	N-rates:	population × N-rates		
C.V. %	6.6	1.1	1.0		
LSD P = 0.05	154	116	NS		
0.01	NS	175			
0.001		NS			

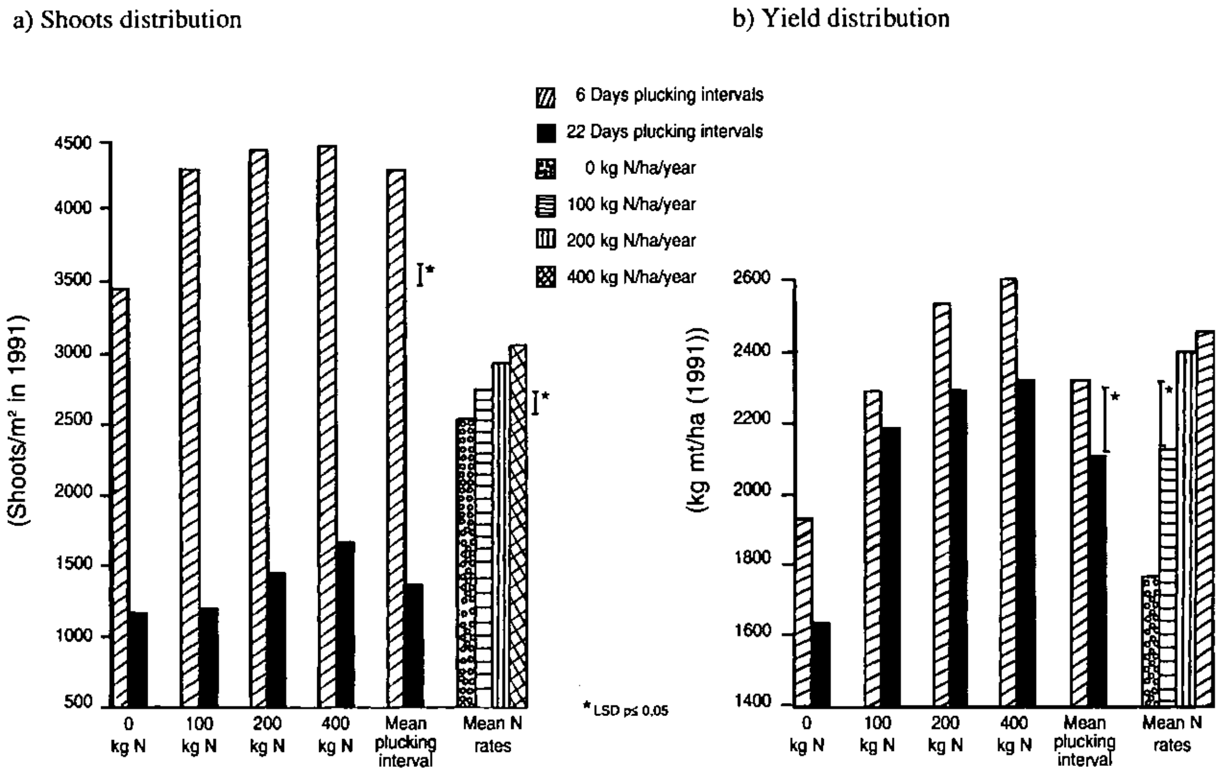

Fig. 1. Shoots (shoots/m^2) and yield kg m.t./ha/year distribution in 1991 due to rates of nitrogen and intervals of harvesting.

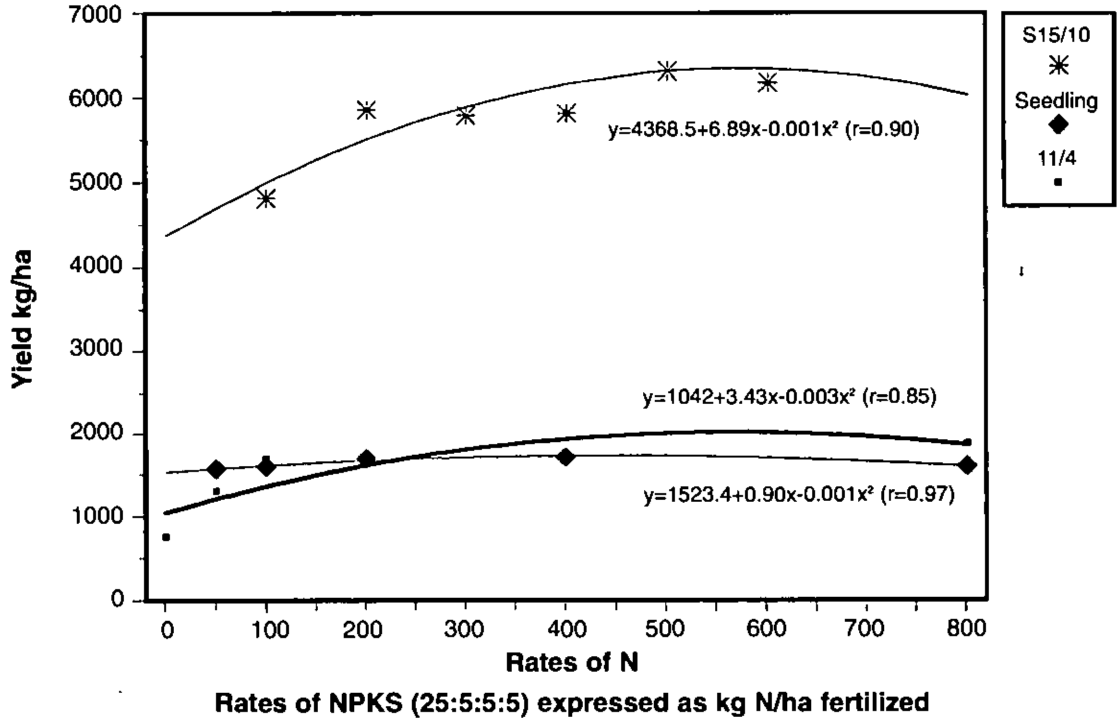

Fig. 2. Effects of compound fertilizer NPKS (25:5:5:5) rates on yield (kg mt/ha) of seedling and clonal tea.

Table 3. Data on economics of compound fertilizer use in Kenyan tea plantations.

a) Economics of NPKS (25:5:5:5) application.

1	2	3	4	5	6	7
Rate (kg N/ ha/yr)	kg mt/ha/yr	kg GL/ ha/yr	Fert. cost (Shs)	Cost of fert. appl. (1×d/c) (Shs)	Plucking cost (Shs)	Cess 3 × h (Shs)
0	1440	6400	0	0	6080	2432
50	1506	6693	1704	43	6358	2543
100	1565	6956	3408	85	6608	2643
150	1616	7182	5112	128	6823	2729
200	1659	7373	6816	171	7004	2801
250	1695	7533	8520	213	7156	2863
300	1724	7662	10224	256	7279	2912
400	1759	7818	13632	341	7427	2971
450	1765	7844	15336	384	7452	2980
500	1764	7840	17040	427	7448	2979
550	1756	7804	18744	469	7414	2966
600	1736	7729	20448	512	7343	2937
650	1716	7627	22152	555	7246	2898
700	1685	7489	23856	597	7115	2846
750	1646	7316	25560	640	6950	2780
800	1601	7116	27264	683	6750	2704

a = Fertilizer cost of NPKS 25:5:5:5 KShs. 34.08/kg N
b = Price paid for green leaf KShs. 5.25/kg green leaf
c = Fertilizer application of 3 bags/manday = KShs. 37.5 kg N
d = Fertilizer application cost per manday = KShs. 32.05
e = Plucking cost = KShs. 0.95/kg green leaf
f = Pruning cost of 150 plants/manday = KShs. 33.50
h = Cess KShs. 0.38/kg green leaf
i = All figures rounded up to nearest KShs. or whole number
j = kg Mt = kg green leaf × 0.225
* = Difference between total cost at one level of output and total cost of preceeding level
** = Difference between total revenue at one level of output and total revenue of preceeding level.

Table 3a) Continued.

8	9	10	11	12	13	14
Pruning cost/year over 4 yrs (Shs)	Weeding/ year (Shs)	Total cost (4+5+6+ 7+8+9)	Marginal cost* (Shs)	Total revenue (3×b) (Shs)	Marginal revenue** (Shs)	Profit (12-10) (Shs/ha)
376	250	9138	-	22600	-	24462
376	250	11273	2135	35138	1538	23865
376	250	13370	2097	36519	1381	23149
376	250	15418	2048	37705	1186	22287
376	250	17418	2000	38708	1003	21290
376	250	19378	1960	39548	840	20170
376	250	21297	1919	40226	678	18929
376	250	24997	1828	41045	326	16048
376	250	26778	1781	41181	136	14403
376	250	28520	1742	41160	-21	12640
376	250	30219	1699	40971	-189	10752
376	250	31866	1647	40577	-394	8711
376	250	33477	1611	40041	-536	6564
376	250	35040	1563	39317	-724	4277
376	250	36556	1516	38409	-908	1853
376	250	38037	1481	37359	-1050	-678

Table 3b) Economics of NPKS (25:5:5:5) application.

1	2	3	4	5	6	7
Rate	kg mt/ha	kg GL/ha	(1 × a) (Shs)	Appl. cost (1×d/c) (Shs)	Plucking cost (3 × e) (Shs)	Cess 3 × h (Shs)
		NPKS		25:5:5:5		
0	3546	15760	0	0	13869	5989
50	4243	18858	1185	39	16595	7166
100	4849	21551	2370	78	18965	8189
150	5366	23849	3555	118	20987	9063
200	5794	25751	4740	157	22661	9785
250	6131	27249	5925	196	23979	10355
300	6378	28347	7110	235	24945	10772
350	6536	29049	8295	274	25563	11039
400	6604	29351	9480	314	25829	11153
450	6585	29267	10665	353	25755	11121
500	6470	28756	11850	392	25305	10927
550	6269	27862	13035	431	24519	10588
600	5978	26569	14220	470	23381	10096

a = Fertilizer cost (i) NPKS 25:5:5:5 (KShs/kg N) 23.70
(ii) NPK 20:10:10 (KShs/kg N) 28.87

b = Price paid for green leaf (KShs/kg) 5.25

c = Fertilizer application rate (i) NPKS 25:5:5:5, 3 bags/manday = 37.5 kg N
(ii) NPK 20:10:10, 3 bags/manday = 30 kg N

d = Fertilizer application cost per manday = KShs. 29.40

e = Plucking cost @ 150 plants per manday = KShs. 30.50

g = Weeding costs (KShs) 200/year/ha

h = Cess (KShs/kg GL) 0.38

i = All figures rounded to the nearest KShs.

j = kg Mt = kg green leaf × 0.225

* = Difference between total cost of one level of output and total cost of preceeding level

** = Difference between total revenue of one level of output and total revenue of preceeding level.

Table 3b) Continued.

8	9	10	11	12	13	14
Pruning cost/year over 4 yrs (Shs)	Weeding/ year (Shs)	Total cost (4+5+6+ 7+8+9)	Marginal cost* (Shs)	Total revenue (3xb) (Shs)	Marginal revenue** (Shs)	Profit (12-10) (Shs/ha)
		NPKS		25:5:5:5		
684	200	20742	-	82740	-	61998
684	200	25869	5127	99005	16265	73136
684	200	30486	4617	113143	14138	81657
684	200	34607	4121	125207	12064	90600
684	200	38227	3620	135193	9986	96966
684	200	41339	3112	143057	7864	101718
684	200	43946	2607	148822	5765	104876
684	200	46055	2109	152507	3685	106452
684	200	47660	1605	154093	1586	106433
684	200	48778	1118	153652	-441	104874
684	200	49358	580	150969	-2683	101611
684	200	49457	99	146276	-4693	96819
684	200	49051	-406	139487	-6789	90436

Table 3c) Economics of NPK (20:10:10) application.

1	2	3	4	5	6	7
Rate	kg mt/ha	kg GL/ha	(1 × a) (Shs)	Appl. cost (1×d/c) (Shs)	Plucking cost (3 × e) (Shs)	Cess 3 × h (Shs)
		NPK		20:10:10		
0	3345	14867	0	0	13083	5649
50	4053	18013	1444	49	15851	6845
100	4676	20782	2887	98	18288	7897
150	5212	23164	4331	147	20384	8802
200	5663	25169	5774	196	22149	9564
250	6028	26791	7218	245	23576	10180
300	6307	28031	8661	294	24667	10652
350	6501	28893	10105	343	25426	10979
400	6608	29369	11548	392	25845	11160
450	6630	29467	12992	441	25931	11197
500	6566	29182	14435	490	25680	11089
550	6416	28516	15879	539	25094	10836
600	6180	27467	17322	588	24179	10437

a = Fertilizer cost (i) NPKS 25:5:5:5 (KShs/kg N) 23.70
(ii) NPK 20:10:10 (KShs/kg N) 28.87

b = Price paid for green leaf (KShs/kg) 5.25

c = Fertilizer application rate (i) NPKS 25:5:5:5, 3 bags/manday = 37.5 kg N
(ii) NPK 20:10:10, 3 bags/manday = 30 kg N

d = Fertilizer application cost per manday = KShs. 29.40

e = Plucking cost @ 150 plants per manday = KShs. 30.50

g = Weeding costs (KShs) 200/year/ha

h = Cess (KShs/kg GL) 0.38

i = All figures rounded to the nearest KShs.

j = kg Mt = kg green leaf × 0.225

* = Difference between total cost of one level of output and total cost of preceeding level

** = Difference between total revenue of one level of output and total revenue of preceeding level.

Table 3c) Continued.

8	9	10	11	12	13	14
Pruning cost/year over 4 yrs (Shs)	Weeding/ year (Shs)	Total cost (4+5+6+ 7+8+9)	Marginal cost* (Shs)	Total revenue (3xb) (Shs)	Marginal revenue** (Shs)	Profit (12-10) (Shs/ha)
		NPK		20:10:10		
684	200	19616	-	78052	-	58436
684	200	25073	5457	94568	16516	69495
684	200	30054	4981	109106	14538	79052
684	200	34548	4494	121611	12505	87063
684	200	38567	4019	132137	10526	93570
684	200	42103	3536	140653	8516	98550
684	200	45158	3055	147163	6510	102005
684	200	47737	2579	151688	4525	103951
684	200	49829	2092	154187	2499	104358
684	200	51445	1616	154702	515	103257
684	200	52578	1133	153206	-1496	100628
684	200	53232	684	149709	-3497	96477
684	200	53410	178	144202	-5507	90792

Chairman of the Session 2

Prof. Y.D.A. Senanayake

Session 2

Integrated Management Practices for Improving Tea Productivity

Pruning and Harvesting Practices in Relation to Tea Productivity In South India

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Introduction

Tea productivity in South India has recorded a phenomenol increase from about 1050 kg per ha in the year 1960 to 2120 per ha in 1993. Formulation of newer recommendations based on research into different crop husbandry practices and their faithful implementation by the industry over the years have been the major contributory factors towards such an increase.

Owing to their direct influence on the productivity over a short period, pruning, tipping and plucking gained priority attention in the agenda of tea research in South India. Intensive and extensive investigations into these aspects with the focus on improving the productivity, while maintaining health of the bush, have placed the package of recommendations on these aspects in an unassailable position. A concise but comprehensive account on these aspects is presented here.

1. Rejuvenation and consolidation

An important reason that could lead to crop stagnation is the poor, diseased frame of the bush. With the advent of blister blight disease in 1946, tea was pruned into hot, dry weather to ensure recovery in a period when the disease presented no danger (Venkata Ram, 1976). Unfortunately, exposure of bush frame to high temperature during such period led to severe sun scorch injury leading to the formation of canker. The fungal pathogen, *Hypoxylon serpens*, gained entry into the bush frame through the tissue damaged by sun scorch and in many instances reached the collar of the bush, causing wood rot.

It has been demonstrated that it is possible to revive such bushes by a drastic surgical operation called rejuvenation pruning. This operation is recommended to prune the bushes to healthy wood removing the cankered and diseased branches completely (Venkata Ram, 1976).

Pruning for rejuvenation calls for certain precautionary measures for it to be successful. Proper timing of pruning, bush sanitation, appropriate manuring, correct tipping and protection from pests and diseases are important to achieve the desired results.

Recent investigations have shown that the first three weeks of August are ideal for rejuvenation prune; the second best period is between the last week of April and the third week of May (Sharma, 1990). Resting the bushes for a period of four to six weeks has been found to be adequate to build up the carbohydrate reserves in the roots to sustain satisfactory recovery (Sharma *et al.*, 1990).

Sanitation of the bushes involves the application of a paste of copper oxychloride/wettable sulphur and linseed oil in the proportion of 1:1 on large cut surface of branches; also, a mixture of sand and tar in the proportion of 9:1 is to be filled in the cavities of the frame (Ranganathan and Chandra Mouli, 1984).

A mixture of N and K in the ratio of 1:2 in all the split applications in the pruned year is useful in developing a sound primary frame (Ranganathan and Natesan, 1987).

Tipping the rejuvenated bushes at a height of 70 cm is superior to other heights of tipping (Table 1).

Table 1. Influence of tipping height of rejuvenated bushes on yield.

Tipping height (cm)	Yield* (kg green leaf per plot)
50	410 a
60	426 ab
65	446 bc
70	492 d
75	460 c

* Cycle total

Values followed by the same letters are not significantly different at P=0.05.

Pruning the rejuvenated bushes at a height of 70 cm at the end of the rejuvenation cycle has elicited better response in terms of productivity when compared to pruning at other heights (Table 2).

Table 2. Influence of height of first prune following rejuvenation on yield.

Pruning height (cm)	Yield* (kg green leaf per plot)
50	943 a
60	951 ab
65	957 ab
70	985 c
75	960 ab

* Cycle total

Values followed by the same letters are not significantly different at P=0.05.

Combination of copper oxychloride and nickel chloride or copper oxychloride and antibiotic preparations, applied at intervals of about four days is necessary to control blister blight during recovery of the bushes from pruning (Chandra Mouli, 1993). Appropriate control measures of pests infesting bushes recovering from rejuvenation pruning have been recommended (Muraleedharan, 1991).

Another important aspect that has been helpful in increasing productivity is infilling of vacancies varying between 15 and 25 per cent in different estates. Rejuvenation pruning affords an excellent opportunity to infill the vacancies and consolidate the stand. Therefore, infilling is to be carried out along with rejuvenation pruning to maximize benefits due to this line of consolidation.

Consolidation by these measures has been found to enhance productivity ranging from 6.4 to 17.5 per cent in the rejuvenation cycle and between 20.7 and 39.5 per cent in the subsequent cycle (Table 3).

Table 3. Effect of rejuvenation pruning and infilling on productivity.

Year	Yield (kg made tea/ha)					
	Nilgiris*			Wynaad*		
	a	b	c	a	b	c
I	1035	946	1761	1402	1362	1344
II	2579	1892	2862	2759	2205	3599
III	2517	2500	3071	2974	3105	3646
IV	2055	3574	3181	3250	3554	3947
V	2260	3248	3694	-	3587	-
VI	-	2566	-	-	-	-
Cycle average	2089	2454	2914	2596	2763	3134
Crop increase		365	825		167	538
(%)		(17.5)	(39.5)		(6.4)	(20.7)

* Infilling at the rate of 15% vacancy

a- Cycle prior to rejuvenation pruning

b- Rejuvenation pruning cycle

c- First cycle after rejuvenation pruning

Source: Hudson, 1992.

Computation of the economics of rejuvenation and consolidation shows return on expenditure from the third year onwards (Table 4).

Table 4. Economics of rejuvenation pruning and infilling (Hudson, 1992).

Rejuve cycle	Yield (kg made tea/ha)	Expenditure* (Rs.)	Income** (Rs.)	Difference between expenditure and income (Rs.)	Progressive cash flow (Rs.)
1	700	40,000***	24,500	-15,500	-15,500
2	1500	45,000	52,500	+7,500	-8,000
3	2200	66,000	77,000	+11,000	+3,000
4	2700	81,000	94,500	+13,500	+16,500
5	3000	90,000	1,05,000	+15,000	+31,500

* Calculated at an average of Rs. 30 per kg from 2nd year

** Calculated at an average of Rs. 35 per kg

*** Calculated for 20% vacancy

2. Routine maintenance

Pruning

Tea bushes are pruned at periodic intervals to revive gross morphology and physiology of the bush. The most important variables that influence the response to pruning are timing, height and type of pruning.

The two periods of pruning that are ideal for rejuvenation pruning, namely, April/May and the first three weeks of August, have been found to be ideal for standard prune also. As regards the height and type, cut across between 60 and 65 cm is superior to low prune between 50 and 55 cm (Table 5).

Table 5. Influence of pruning heights on yield.

Pruning height (cm)	Yield* (kg green leaf per plot)				
	Year from pruning				Total for the cycle
	1	2	3	4	
50	7.4 a	9.2 a	8.1 a	8.9 a	33.6 a
55	7.6 a	9.1 a	8.0 a	8.9 a	33.7 a
60	8.9 b	10.3 b	8.7 b	9.5 ab	37.4 ab
65	9.3 b	10.1 b	8.4 b	10.3 b	38.2 b

* Mean of five replicates

Values followed by the same letters in a column are not significantly different at P=0.05.

Source: Satyanarayana *et al.*, 1993, modified (in press).

A majority of tea estates in South India resort to cut across between 60 and 65 cm for about three/four cycles. Since repeated cut across near about the same level leads to the formation of knots with adverse consequences on productivity, it is recommended to prune the bushes at a height between 50 and 55 cm once after three/four cycles of cut across (Sharma, 1984). Such need-based recommendation on pruning that is specific to the situation has been a significant factor in enhancing productivity.

Tipping

The benefits of pruning become amplified by optimising the operation of tipping. Tipping of pruned bushes ensures the retention of mature leaves in the canopy of a bush which are collectively called the maintenance foliage. Maintenance leaves support the growth and development of crop shoots and replenish the carbohydrate reserves depleted during recovery from pruning. Height of tipping determines the amount of maintenance foliage left on the bush.

Investigations on optimization of tipping heights in relation to different heights of pruning indicated that the optimal number of new tiers of leaves required for sustained high productivity decreases with an increase in the height of pruning (Table 6).

Table 6. Influence of tipping heights on productivity.

Tipping height	Yield (kg green leaf/plot/cycle)				
	UPASI-3 (Assam type) Pruning height (cm)		UPASI-10 (China type) Pruning height (cm)		
	35	60	35	50	60
71 cm from the ground	63.8 (3.5)*	62.7 (2.0)*	221 (4.8)*	222 (3.5)*	223 (2.2)*
4 tiers of leaves above the pruning cut	60.9 (73.5)**	58.9 (89.0)**	209 (65.0)**	216 (74.0)**	207 (81.0)**
C.D. at P=0.5	2.3		7		

* Number of tiers of leaves above the pruning cut

** Height of tipping (cm) from ground

Source: Sharma *et al.*, 1981 (modified).

This indicates that the optimal leaf area to support high productivity varies with the height of pruning. This could best be achieved by tipping in terms of number of tiers of leaves above the pruning cut (Table 7) rather than at a fixed height from the ground level as per certain recommendations (Templer, 1977; Barua, 1989).

Table 7. Current recommendations on tipping height and tipping-in material.

Jat	Pruning height (cm)	Tipping height (No. of tiers of leaves above the pruning cut)	Tipping-in material
'Assam'/'Assam' hybrid	35 to 55	4	4 leaves and a bud
	55 to 60	3	4 leaves and a bud
	60 to 75	2	4 leaves and a bud
	75	1	4 leaves and a bud
'China' hybrid	35 to 45	5	3 leaves and a bud
	45 to 55	4	4 leaves and a bud
	55 to 75	2	4 leaves and a bud

Source: Sharma *et al.*, 1982.

The number of leaves allowed to expand above the tipping height at the time of tipping has been found to influence productivity. In the clone UPASI-3 ('Assam' hybrid), irrespective of the height of pruning, removal of tipping-in material comprising four leaves and a bud was superior (Table 8).

Table 8. Productivity in relation to tipping-in material.

Tipping-in material	Yield (kg green leaf/plot/cycle)				
	UPASI-3 (Assam type) Pruning height (cm)		UPASI-10 (China type) Pruning height (cm)		
	35	60	35	50	60
2 leaves and a bud	62.0	60.3	N.A.	N.A.	N.A.
3 leaves and a bud	64.3	63.0	229	214	215
4 leaves and a bud	65.0	64.8	214	230	232
C.D. at P=0.5	3.8		11		

N.A. : Not available

Source: Sharma *et al.*, 1981 (modified)

In UPASI-10 ('China' hybrid), removal of tipping-in material comprising three leaves and a bud was superior in bushes pruned at 35 cm; in bushes pruned at 50 and 60 cm, removal of four leaves and a bud was superior. Such variation in response seems to be related to the morphology and degree of maturity of buds in the axils of leaves (Sharma *et al.*, 1981). These results have formed the basis for formulating precise recommendations on tipping-in material that are widely adopted by the industry (Table 7).

Plucking

Systems: Crop shoots developing on the bush surface are harvested at periodic intervals. Different severities of separation of crop shoots from the bush are resorted to in different tea-growing areas (Fig. 1). Several investigations have been carried out to identify the ideal system of plucking (Eden, 1947; Visser, 1960; Wettasinghe *et al.*, 1981; Barua, 1989).

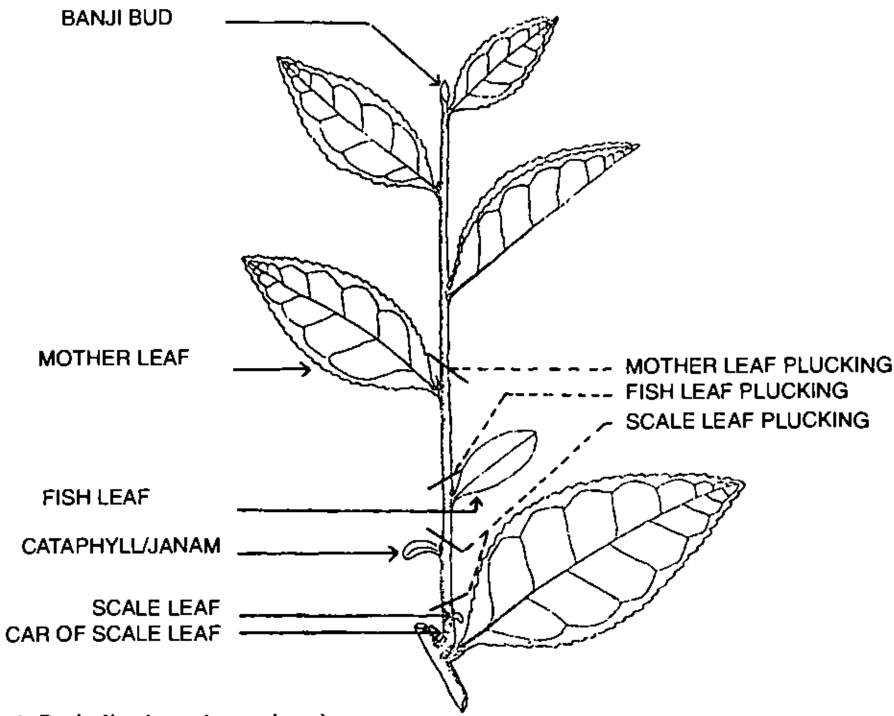

Fig. 1. Periodic shoot (crop shoot).

Many of these studies have been of short-term nature and do not include all the possible severities and their combinations.

Comprehensive, long-term studies on all the possible plucking styles and some of their combinations carried out in South India indicated that adoption of any single style, continually, was associated with adverse effects on productivity, maintenance foliage, creep in height of bush and health of the bush (Table 9).

Table 9. Effect of severities of plucking on yield and certain biometric parameters.

Treatment	Yield (kg green leaf per plot)	Leaf, stem and leaf/stem ratio in the top 20 cm profile of the bush — Dry wt. (g)			Ratio between yield and maintenance foliage
		Leaf	Stem	Leaf/stem ratio	
Continual mother leaf plucking	91.1 a*	233 b	189 a	1.13 c	0.9 a
Continual fish leaf plucking	132.4 d	167 a	285 c	0.66 b	1.7 b
Continual scale leaf plucking	126.9 cd	168 a	291 c	0.58 a	2.5 d
Continual level plucking	127.7 cd	175 a	299 c	0.58 a	1.7 b
Mother leaf plucking from Jan. to Mar. and level plucking from Apr. to Dec.	126.6 cd	160 a	231 b	0.70 b	2.0 c

* Values followed by the same letters in a column are not significantly different at P=0.5.

Source: Sharma *et al.*, 1990 (condensed).

Source: Sharma and Satyanarayana, 1990.

Treatments in which different severities of harvesting were integrated were found to elicit variable response.

Among these, the current recommendation of plucking to a mother leaf during the drought months of January, February and March and to the level, irrespective of the severity in the other months induced a consistent response in terms of increased productivity without adverse effects on the health of the bush (Table 9).

Plucking intervals: Interval between successive plucking rounds is another important factor that influences productivity and the type of shoots harvested (Barua, 1989). Comparison between harvesting at fixed seven day intervals and variable intervals based on the growth and development of shoots showed that the latter system is profitable (Sharma and Murty, 1989).

Visual examination of the field to decide on the variable intervals besides being laborious does not facilitate advance planning and effective deployment of labour. The system of predicting plucking intervals based on the 'Shoot Age Concept' evolved by Grice and Clowes (1986) has been found to have limitations in its applicability in South India.

The quest for rationalization and predicting the plucking intervals led to the development of an alternative system in South India which is based on the time taken for the expansion of a leaf in crop shoots. This system is referred to as the 'Leaf Expansion Concept' for the formulation of plucking intervals.

The oldest shoots left on the bush at the time of plucking possess one leaf less than the prescribed standard of shoots; such shoots will be ready for plucking after the expansion of one leaf. Therefore, optimum plucking interval is the time taken for the expansion of one leaf.

It has been demonstrated that it is possible to formulate the plucking intervals based on data on temperatures; this involves dividing the day degrees accumulated during the expansion of a leaf by the day degrees accumulated in a day in a given season to arrive at plucking intervals (Murty and Sharma, 1989). Usefulness in advance planning and effective deployment of labour coupled with favourable commercial implication (Table 10) makes the formulation of plucking intervals based on the 'Leaf Expansion Concept' an important factor in enhancing the productivity of the bush and the worker.

3. Mechanization of harvesting

The steep terrain on which tea is grown in South India and progressive increase in the height of bushes with advancing age from pruning impose physical limitations in the operation of pluckers. As a result, many ready crop shoots are left unplucked on the bush particularly in the peak growing season. The availability of workers has become a serious constraint to harvest the crop completely. These problems are accentuated during the high cropping periods from April to June and from mid-September to early-December resulting in crop loss. This has been successfully overcome by partial mechanization of harvesting.

Table 10. Commercial implication of plucking intervals based on the 'Leaf Expansion Concept'.

Details	Plucking intervals based on 'Leaf Expansion Concept'	Estate practice	Increase over the estate practice
Yield (kg made tea/ha)	2527	2350	177
Pluckers (No./ha)	469.6	437.6	32
Plucking average (kg green leaf/plucker)	36.3	34.9	1.4
Price realization (Rs. 35/kg)	88445	82250	6195
Wages to pluckers (Rs. 30/plucker)	14088	13128	960
Cost of manufacture (Rs. 5/kg)	12635	11750	885
Higher amount (Rs.) realised due to plucking at intervals based on the 'Leaf Expansion Concept'			4350

Source: Murthy *et al.*, 1991.

Topiarist's hand-operated, hedge-trimming shears with leaf collecting tray are the only implements that could be used for harvesting in the steep terrains of South India.

Experiments carried out in different agro-climatic regions of South India have demonstrated that continual shear harvesting depresses yield and adversely affects the health of the bush (Satyanarayana *et al.*, 1991). On the other hand, shear harvesting during the two high cropping seasons and hand plucking in the intervening, low cropping seasons, gave the same level of yield as that under continual hand plucking without adverse effects on the health of the bush (Table 11).

Table 11. Influence of shear harvesting on yield.

District	Yield (kg green leaf/plot)	
	Hand plucking	Shear harvesting during the two high cropping seasons
Anamallais	689 c	673 bc (630 a)
Central Travancore	565 a	667 c
High range	2408 abc	2374 ab
Nilgiris	721 a	748 a (665 a)

Values followed by the same letters in a column are not significantly different at P=0.5.
Values in parenthesis represent the yield under continual shear harvesting.
Source: Satyanarayana *et al.*, 1991 (condensed).

This schedule leads to considerable economy in plucking by way of fewer plucking rounds and higher plucking average (Table 12).

Table 12. Influence of shear harvesting on plucking economy.

District		Total No. of plucking rounds/cycle*			
		Plucking average (kg/plucker/round)	Hand plucking	Shear harvesting	Total
Anamallais	Hand plucking	24	114	-	114
	Shear harvesting during the 2 high cropping seasons	35	51	34	85
High range	Hand plucking	26	124	-	124
	Shear harvesting during the 2 high cropping seasons	34	96	16	112

* Pruning cycle of four years in Anamallais and five years in High Range.
Source: Satyanarayana *et al.*, 1991 (condensed).

Investigations carried out in some other tea growing areas confirm that mechanizing the harvesting operation enhances the plucking average (Ndamugoba, 1977; Kulasegaram, 1980; Anonymous, 1986; Othieno and Anyuka, 1982; Barua, 1989).

But it was reported that the use of mechanical aids led to an increase in the coarse leaf content, necessitating sorting and rejecting of the coarse components resulting in crop depression. The reason for such adverse effects appears to be the highly extended plucking intervals which in some cases were more than four times of that under hand plucking. Such adverse effects were not noticed in South India; this is due to the fact that the plucking interval did not exceed two phyllochrons.

The inferior quality of tea made from leaf harvested using mechanical aids reported by others has been found to be due to the extended plucking intervals (Owuor, 1989). In South India, the quality of made tea was not found to be adversely affected by shear harvesting (Ramaswamy, 1983). This is because the standard of shoots was maintained by adopting optimal plucking intervals.

Based on a comprehensive evaluation of the results of experiments on shear harvesting, it is now recommended to use shears only during the two high cropping seasons from April to June and from mid-September to early December; hand plucking as per the recommendations is suggested in the intervening low cropping seasons. It is recommended that this schedule should be adopted after 15 months from pruning in the case of 'China' hybrid jat and 18 months in 'Assam' hybrid jat. Shear harvesting during the first 15 to 18 months from pruning does not enhance the productivity of pluckers because even hand plucking on such bushes of a lower height is effective (Satyanarayana *et al.*, 1991).

Investigations into different aspects of pruning, tipping and harvesting have been of utmost use in formulating firm recommendations. Equally important has been the ready acceptance and quick implementation of these recommendations by the industry. Such an association between the Institute and the industry has been responsible in earning a prominent position for South India among the tea growing countries of the world.

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An Integrated Crop Management Programme to Optimise Tea Productivity

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The ecological interactions amongst all living forms are so interrelated and complex that the survival and development of any single organism cannot be viewed upon or studied in isolation.

Taking any growing plant as an example, its survival and growth performance in a given location on any part of this globe is determined entirely by the prevailing environment, which could range from being ideally suitable on the one hand, to being most unsuitable and hostile at the other extreme. Thus, the suitability of the environment for a given plant species will be within the limits of defined global latitudes, such as temperate, subtropical and tropical.

The environmental determinants that influence the growth of plant communities include the biological, physico-chemical and climatic variables.

The overall climate, including rainfall intensity and its distribution, prevailing ambient temperature, atmospheric humidity, day length and the photosynthetically effective solar radiation, are all beyond manipulative control.

Nevertheless, within a given crop environment, it is possible to modify the ambient temperature, humidity as well as the light intensity within specific limits to our advantage, by adopting specific cultural practices. Further, within the specified crop environment, there are other important physical and biological factors that are subject to considerable variations through human activity, which could be manipulated to our advantage to a significant extent. Such variables include the growing medium itself, i.e. the soil and its fertility status and the biological diversity that determines ecological stability within the crop environment.

The presence or absence of various other plant species, the occurrence of various organisms that become pests or disease causing agents, and thus posing limitations to productivity, the presence or absence of beneficial agents, including predators, parasites or pathogens that curtail the debilitative influence of pests and diseases (all of which form part of the biological environment) are important manipulative factors that significantly influence the growth of a particular crop in a given ecosystem.

As is the case with any other commercial crop that is grown and managed in a sustainable manner, in order to help achieve the optimum productivity of tea in the most economic manner, it is necessary to have a thorough knowledge of the growth and behaviour of the tea bush itself, as well as a proper understanding of the nature of the response elicited by the respective inputs, as is influenced by the interaction with the prevailing biological and physical environment, in the given location.

To help interpret such complex interactions, it is necessary to develop an **environmental data base** for a specific location, by undertaking appropriate surveys and inventorizing important environmental variables along with specific agricultural practices. These should include all climatic variables, the types and characteristics of soil, available water sources, plant diversity, the prevalence of the various pests and diseases, types of tea cultivars and the cultural practices adopted in the relevant locations. It is also necessary to continuously monitor the various biological changes, including the incidence and preponderance of various pests and diseases. My own studies in this area undertaken for more than 20 years have shown that changes in the preponderance of specific pests serve as excellent indicators of environmental changes.

In order to efficiently manage any plantation in the most economical manner, it is necessary to make use of the best combination of the appropriate available management strategies and develop an **Integrated Management Package**, that ensures the stability of the ecosystem on the one hand, and at the same time enables the growing of the crop a profitable venture.

An **Integrated Management System**, therefore, requires flexibility and should vary according to the situation prevailing in the given location, taking into consideration the prevailing market for the commodity and cost of the various inputs.

You are all aware that a wide spectrum of growth promoting technologies are available in the different tea growing countries to maximize productivity of tea. Although most of these technologies are time proven sound ones, it would be profitable to harness only those specific strategies that blend with the prevailing environment and the local situation to elicit the desired results. A specific technology that generates optimum results in a given country does not need necessarily to bring about similar results in another country. Even within a country, the response varies according to the location as also with the health and vigor of the tea bushes.

The practices adopted to develop the bush architecture including bringing into bearing, pruning, harvesting practices, fertilizer programmes, all vary from country to country as well as within a country. Thus, it would be inadvisable to blindly copy a technology that has proven to be successful in one country, without understanding the prevailing ecological situation in the given location as well as the markets to which the commodity is catered for.

During my visits to the different tea growing areas of the world, including East Africa, Central Africa, India, China and Japan, the most striking observation that I was able to make was the impact the overall standard of agricultural management had on yield response to the respective inputs. Besides the standard of management, the other important determinants for yield response are the inherent limitations posed by the depth and types of soil, as well as the prevalence and preponderance of various pests and diseases. Consequently, I was able to see tea fields in their prime of productivity as well as those that were marginal to being poor in almost all these countries.

My observations in Kenya have shown that in the greater majority of the tea growing areas, apart from the availability of deep soils, a well distributed rainfall pattern, together with the optimal availability of solar radiation throughout the year, linked to a situation of a minimal incidence of pests and diseases, has enabled this country to achieve enviable productivity targets. This is particularly so on the western side of the Rift Valley.

Conditions prevailing in Malawi, however, differ with a severe handicap in respect of available moisture, which situation requires irrigation and the need to adopt specific practices to help tolerate moisture stress to make the growing of tea economically viable.

One often wonders why certain time-proven beneficial agricultural practices do not give rise to the expected yield response at a given location. This is because under field conditions, there are several factors that interact with one another to the extent of even totally or partially masking the expected responses.

There are also instances when scientists working on the tea crop, as well as with other perennial crops, have been confronted with inconclusive results obtained in certain long-term field trials. However, when a proper in-depth study is made, such inconclusive results have often been traced to specific limitations caused by the fluctuations in the weather, as well as due to specific changes in the ecosystem, both at the macro and micro-levels. For example, the occurrence of unexpected growth restrictions caused by the incidence of a specific pest or a disease, triggered as a consequence of micro-climatic changes within experimental plots, can mask the crop response to the specific input that is being tested experimentally.

It is, therefore, very essential to be vigilant of all such changes throughout the trial period, in order for the results of the trial to be interpreted accurately and meaningfully.

When a scientist examines a specific problem, this should not be viewed within the narrow context of only his or her own specialization. It is necessary to have a broader holistic approach to the problem by examining all likely contributory factors as well as the prevailing physiological condition of the plant expressing a particular syptom.

Therefore, in order to enhance the growth performance of plants in any particular location and to help better understand the growth response to individual agricultural inputs, it is necessary to correctly recognize and identify the growth restricting factors that are within manipulative control. These limitations need to be minimized, if not eliminated altogether, to help generate optimum response to a given growth promoting recommendation.

For example, the efficiency of uptake of added nutrients would be limited in soils with high soil acidity, leading to poor nutrient holding capacity or in a bush where the feeder roots have been damaged by pests. In these instances, if corrective measures are not taken to improve the fertility status of the soil or to control the pest attack, the benefit of the added nutrient would be minimal and even uneconomic.

Further, it is also necessary to understand the effect each input would have on the environment, including the soil environment, since such changes can significantly influence the ecosystem at both the micro and macro level, which can in turn affect the crop itself.

The soil needs to be looked upon as "living medium" that is teaming with biological activity. Such biological activity is directly correlated to the humus content of the soil which together determine the "fertility status". Any form of treatment that is given to the soil, like a physical activity such as a soil disturbing agronomic practice or a chemical treatment, including the regular application of fertilizers, or the application of pesticides, has a varied influence on biological activity. Continuous abuse of the soil through frequent chemical treatment, coupled to a situation of inadequate recycling of organic matter, would soon render the soil to become virtually a non-living inert medium.

When a pesticide is applied to control a given pest, the ultimate goal should not be merely to eliminate the target pest, but it should also ensure that the applied chemical does not result in an ecological back-lash, in the medium to long-term. It is, therefore, necessary to ensure to furnish the minimal effective dosage at minimal frequency to help maintain the pest or disease causing organisms below its economic damage threshold. For example, frequent applications of copper fungicides can trigger mite out-breaks above the damage thresholds. Similarly, repeated applications of insecticides against a foliar pest can lead to an imbalance in the build-up of predators or parasites that help to maintain such pests under effective natural control. We are also already seeing the emergence of new species of weeds which were never encountered before in the tea plantations of Sri lanka, the emergence of which as a pest weed appears to have been triggered by the excess use of different herbicides.

Application of some pesticides which are persistent in the soil for a long time are also known to reduce populations of the beneficial micro-organisms that are required to maintain a critical balance of soil nutrients, as well as to help maintain soil pests under control, resulting in destabilizing of the natural ecological balance. Experience has often shown the danger of adopting a single control measure to combat a target pest. An integrated management approach using multiple pest management strategies has the highest probability of sustaining long-term crop protection.

When deciding upon the implementation of any given management strategy for a perennial crop, it is necessary to think of the long-term health of the crop, rather than the immediate increase in yield. Certain manipulations that are geared towards an immediate enhanced productivity result in unwanted stress to the plants, which turns out in the long-term to be detrimental to the overall health of the plant.

Although the main goal is to achieve optimum yield at economic levels, there are certain inputs that do not result in an immediate crop response, e.g. the enhanced application of potash is known to help in better frame development - which development will obviously be at the expense of a greater partitioning of the photosynthesized dry matter towards frame development and not towards immediate short-term crop response. The increased crop response would, perhaps, be seen in the following cycle.

Enhanced application of potash is also known to bring about physiological, biochemical and anatomical changes such as strengthening and thickening of the cuticle and epidermal cell walls (Von Uexküll, 1982), aid in phenol metabolism, protein synthesis and wound healing (Kiraly, 1976; Allington and Laird, 1954), and consequently reducing certain pest and disease incidence, increase photosynthetic efficiency (Jackson and Volk, 1968) and also overcoming drought stress (Humble and Hsiao, 1969; Krishnapillai *et al.*, 1988). Research carried out by me at TRI has shown that the application of higher levels of potash at the ratio of N:K at 1:1 or 1:1.5 has helped to reduce populations of the root lesion pathogenic nematodes (Gnanapragasam, 1982). In view of such protection, a balanced uptake of nutrients becomes possible through the undamaged root channels to help maintain the health and vigor of the bush, thereby enhancing the growth and productivity of the bush. Similarly, the Tea Research Institute of Sri Lanka has observed higher levels of potash helpful in reducing the debilitation caused by shot-hole borer attack (Muraleedharan, personal communication).

Although in some of these instances, the enhanced application of potash may not always show up in an immediate increase in yield, its long-term benefit in minimizing crop loss cannot be disputed.

It should, therefore, be noted that arresting crop decline by itself is a means of crop improvement - just as "a penny saved is a penny earned".

In order to help circumvent the inadequacies of soil fertility and the consequent poor nutrient absorption through feeder roots, attempts are sometimes made to resort to foliar feed with various cocktails of salt mixtures. It is only in the case of certain micronutrients that get fixed in the soil, such as Zinc, that it becomes essential to resort to the unconventional foliar feed. The leaf is meant to intercept solar radiation and to convert radiant energy to help synthesize carbohydrates. It is not meant as a channel for nutrient uptake. Therefore, the otherwise attempt to tamper with the nature and force feed nutrients through the foliage could result in the unusual enrichment of the foliage with various salts and thus leading to a situation where the leaf becomes attractive and susceptible to hitherto innocuous disease and pest outbreaks.

When costs are escalating and the price realized for the end product remains stagnant or declining, there is the natural tendency for cutting down on inputs! This is a dangerous exercise. Without taking into consideration the short-term economics, one should think of the medium to long-term influence on crop health and the associated delicate ecological balance.

For example, the often practised false economic measure is to cut down on nutrient inputs. Although there may not be an immediate set-back to the general health of the bush, such limitations do have a significant effect on the physiological vigor, so much so that the plant could even become susceptible to specific stress factors that are generally innocuous to a plant which is growing in a vigorous state.

The entry and debilitation by innocuous disease causing organisms such as the "Thorny Stem Blight" caused by the fungus *Tunstallia aculeata*, and even "*Hypoxylon* sp" leading to severe wood rot, are cases at hand to illustrate the correlation between poor vigor and the consequent plant susceptibility to hitherto innocuous secondary diseases, caused by weak parasites.

The style and frequency of harvest also have a very significant influence on the health and vigor of the tea bush. Continuous hard plucking leaves very little chance for the partitioning of the required amount of photosynthates (dry matter) towards the storage organs to help overcome subsequent stress situations such as a drought or pruning. Besides affecting the health of the bush, the style and frequency of harvest also have a direct bearing on the photosynthetic efficiency as well as the quality of the end-product, as per specific market needs and the consequent profitability per unit land.

As stated earlier, the pruning of the tea bush is also a crucial cultural operation. The timing, style and frequency of which operation have all a significant bearing upon the immediate, as well as the medium to long-term health and vigor of the bush. The recovery from pruning to a state of being once again in a vigorous condition to generate adequate flushing points is very much dependent upon the availability of adequate food reserves, as well as the previling environmental conditions during the recovery phase from prune.

Thus, the timing of various cultural operations, like the routine harvesting of tea, fertilizer application, pruning, planting or infilling vacancies along with the relevant protective measures, are all critical operations, the success of which depends largely on good timing and methodology based upon sound management decisions made to suit a particular situation, as well as the prevailing environment to bring about optimal economic returns.

In conclusion, I would like to emphasize that the overall crop improvement at a sustainable level cannot be achieved by the piece-meal *ad hoc* adoption of specific practices in isolation.

It is very essential to recognize the need to blend the various cultural strategies in the form of a balanced agronomic package to ensure ecological stability to maintain a sustainable crop environment on one hand and profitability on the other hand.

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Technology Transfer in the Plantations and Tea Smallholdings of South India

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Introduction

It has been estimated that in the agricultural sector in India, only one-third of the research findings are transferred to the field. This is mainly due to the lack of proper coordination or linkage between the scientists working in the universities and the extension wing of the Department of Agriculture. However, the secret behind the high yield of tea in South India is the intensive research carried out by the Tea Research Institute, practical field training imparted by the Krishi Vigyan Kendra and the effective transfer of technology by the extension wing of UPASI Tea Scientific Department; all the three units functioning in an integrated manner. For getting the maximum return out of every rupee invested in the research, an efficient transfer of technology unit is a must. In this paper, an attempt has been made to explain the integrated system of tea reaserch, training and extension functioning in the United Planters' Association of Southern India.

1. Profile of the South Indian tea industry

In South India, tea is grown in about 85,000 hectares, spread over seven planting districts, in the three states of Tamil Nadu, Kerala and Karnataka (Table 1). Nearly 57% of this tea is located in Tamil Nadu, 41% in Kerala and the remaining 2% in Karnataka.

The characteristic feature of South India is the preponderance of the small tea gardens, co-existing with the large corporate sector estates, medium sized proprietory gardens and the public sector undertakings like Tamil Nadu Tea Plantation Corporation (Table 2). On an all India basis, nearly 95% of the small tea gardens (less than 8.09 hectares) are situated in South India. Another unique feature of the industry in this part of the country is the production of all types of teas like black tea (both Orthodox and CTC), green tea and instant tea.

Table 1. Area under tea in South India.

States/Districts	Area (hectare)
TAMIL NADU	
Nilgiris	36,524
Coimbatore	10,200
Others	2,172
Total	48,896
KERALA	
Idukki	23,541
Wynaad	5,350
Kottayam	2,024
Quilon	1,362
Others	2,345
Total	34,622
KARNATAKA	
Chickmagalur	1,417
Others	656
Total	2,073
South India	85,591
Total India	419,600

Table 2. Holding size and area.

Size of the holding	Tamil Nadu		Kerala		Karnataka		Total	
	No. of units	Area (ha)	No. of units	Area (ha)	No. of units	Area (ha)	No. of units	Area (ha)
upto 8.09 ha	40000	18272	5000	2543	2	9	45002	20824
8.09 to 50 "	133	2380	52	1010	3	64	188	3454
50 to 100 "	23	1660	18	1306	2	145	43	3111
100 to 200 "	26	3953	26	3826	5	791	57	8570
200 to 400 "	52	15346	52	14967	4	1064	108	31377
Above 400 "	15	7285	20	10970	-	-	35	18255
Total	40249	48896	5168	34622	16	2073	45433	85591

Tea Research in South India is carried out entirely by the UPASI Tea Research Institute located in the Anamallais, Coimbatore district of Tamil Nadu. The Association also runs the prestigious, innovative training centre known as Krishi Vigyan Kendra (Farm Science Centre) with the financial assistance of the Indian Council of Agricultural Research (ICAR). The UPASI Krishi Vigyan Kendra is the first of its kind to promote plantation crops specific to the remote hilly areas of South India. There are seven Advisory or Extension Centres serving the major planting districts of South India - three each in Tamil Nadu and Kerala and one in Karnataka.

2. Training on tea cultivation

Fully realising the importance of proper training, the Association established a Krishi Vigyan Kendra (KVK) during 1983 with the assistance of the ICAR. Need-based, practical-oriented training on individual topics pertaining to the season is imparted to the farmers, farm women, estate workers, supervisors, field staff, executives and extension personnel of the various departments, school teachers and rural youth. The duration of the training varies from one-day to six months depending on the objectives. The training is given both at the Kendra (on-campus) as well as at various villages, Industrial Cooperative Tea factories and estates (off-campus). During the last decade, the KVK has trained more than 16,000 persons (Table 3).

Table 3. Training courses organised and persons trained.

Year	No. of courses organised	No. of persons trained
1983	30	373
1984	56	1,487
1985	67	1,382
1986	53	1,095
1987	32	713
1988	45	1,439
1989	54	1,693
1990	76	1,946
1991	83	1,848
1992	76	2,098
1993	86	2,265
Total	658	16,339

2.1. Uses of mass media

Farm Radio School (FRS)

For the benefit of the farmers who could not attend either the on-campus or off-campus training programmes, a Farm Radio School has been organised in collaboration with the All India Radio. Thirteen lessons covering the entire gamut of tea cultivation was broadcast on Sunday evenings. These lessons were again rebroadcast on the following Wednesday afternoons before broadcasting the next lessons. More than 3000 farmers registered their names for this programme.

An assessment on the impact of the programme revealed that more than 90% of the registered participants listened to the programme with the purpose of using the message. The programme had not only influenced the registered listeners but also reached a large number of other farmers through the registered participants thus bringing about the desired multiplier effect.

Radio talks

Periodical talks by the extension personnel on vital cultural operations pertaining to the season were broadcast over the radio. This media was also used to announce the control measures whenever there was any outbreak of pests or diseases. Seminars and quiz programmes were conducted for the progressive farmers and the proceedings were also broadcast. Periodical announcements over the radio regarding the training programmes, farmers meeting and field days have helped them in participating in these programmes. Thus, the popular mass media (Radio) was fully utilised in arousing interest on scientific tea crop husbandry techniques.

Doordarshan (Television)

Several programmes with suitable visual aids were telecast on important subjects pertaining to tea culture and information on institutional support available to the farmers. These televised programmes had helped the farmers in creating an awareness about the various benefits available to them and the agency to be contacted besides information on technical know-how.

2.2 Print media

Books

The Tea Research Institute has published a Handbook on Tea Culture with add on facility to file new recommendations as and when released.

The Krishi Vigyan Kendra has published two books on tea cultivation, in English and Tamil. These books serve as ready reckoners for students, field staff and extension personnel.

Newsletters and Advisory Circulars

The Tea Research Institute brings out Newsletters once in six months highlighting the new research findings. Monthly advisory circulars are sent out by the extension centres providing information on weather and crop figures during the previous month along with the details on the calendar of operation to be carried out for the current month. The KVK brings out a bi-monthly newsletter in Tamil entitled 'Seithimadal' which caters to the needs of the small growers.

3. Extension service to corporate sector

Advisory visits

Periodical advisory visits are undertaken to the estates to study the limiting factors for crop production and to suggest suitable remedial measures. This also provides an opportunity for the extension functioneries to get a feedback on the recommendations made by the Scientific Department. Therefore, the extension wing functions as a bridge between the scientists and the planters.

Field experiments

All the Advisory Centres also carry out a number of field experiments on varietal performance, nutrition management, crop production and plant protection aspects in collaboration with the subject matter specialists at the Research Institute. This helps in gathering data under local agroclimatic conditions and in making authentic recommendations in a particular district where the Advisory Centre is located.

Area Scientific Meetings

Annual meetings are held in the various planting districts which provide an opportunity for the planters to have a direct dialogue with the scientists on the various field problems encountered by them. These meetings also help the scientists to perform the first line transfer of technology by discussing the latest findings of their departments with the planters.

Research-Extension Meetings

This is another annual event where the scientists and the extension officers have elaborate discussions on the research programmes of the different divisions and the extension activities of the advisory centres. These meetings not only help scientists in providing information on new technologies to be transferred to the field, but also give an opportunity to get the feedback on the recommendations released by them earlier - both Lab-to-Land and Land-to-Lab problems are analysed. This opportunity is also availed in designing research projects based on the new problems faced by the extension wing. Several of these experiments are carried out in all the districts to gather information under varying agro-climatic zones, and these are critically reviewed during the subsequent meetings.

Joint Area Scientific Symposium (JASS)

These symposia organised once in two years in different planting districts provide a forum for the senior executives from all the planting districts to interact with scientists, extension workers and fellow planters. Importance is given to the field visits so that the participants could have exposure to the cultural practices adopted in that particular district and exchange information. The field visits are followed by sit down sessions wherein the participants share their views based on the field visits.

Scientific conferences

These conferences are conducted during alternate years at Coonoor coinciding with the UPASI Annual Conference, in which the scientists and advisory officers from the UPASI Tea Research Institute and from other tea growing countries present papers. There are times when experienced planters were invited to speak on selected topics. The proceedings of the scientific conferences and JASS are published by the Scientific Department.

4. Transfer of technology to small tea holdings

4.1. Profile of small tea holdings

Out of the total tea area of 85,000 ha in South India, around 21,000 ha are cultivated by about 45,000 growers in Nilgiris, Idukki and Kottayam districts. The average size of the small tea holding is around 0.5 ha. On the national scenario, about 75% of the small growers are in Tamil Nadu, another 20% in Kerala and the remaining 5% in Himachal Pradesh.

During early 80s when the average yield of tea in large estates was around 2000 kg per ha, the small growers were harvesting a deplorably low yield of 800 kg per ha. This was mainly due to:

- Scattered nature of holding due to repeated subdivision of property among the family members. This fragmentation led to poor attention to the holdings.
- Adoption of traditional cultural practices and improper input management.
- Presence of large number of vacancies - low bush population per unit area.
- Existence of inherently low yielding China jat.
- Difficulty in procuring essential inputs in small quantities.
- Weak marketing base.
- Indebtedness - multiple source of borrowing.

4.2. UPASI and small tea holdings

The UPASI is too alive to its obligation to the small tea holdings which require cropping up for greater contribution to tea production in the country. Under the definition of the Tea Act any holding below 8.09 hectares constitutes a small grower unit. Since 1972, the UPASI has been extending its services to the small tea holdings for augmenting the yields. These activitites were further strengthened with the launching of the Tea Board - UPASI Small Growers Development Projects during 1979 and the establishment of Krishi Vigyan Kendra in 1983.

Technology development

One of the objects of the KVK is to develop new innovative technologies to suit the socio-economic conditions of the local farming community. UPASI-KVK has developed a number of technologies in agriculture and allied subjects. One such relevant technology developed for the small tea holdings is inter-cropping in tea new clearing.

Training

As mentioned earlier, the KVK is giving priority for imparting need based production and practical oriented training on the basis of learning by doing. For this purpose, the Kendra is maintaining an Instructional Farm with an area of 16.16 hectares. In addition to training, the following extension activities are also undertaken for improving the production of small tea holdings.

Demonstration plots

The main objective of the demonstration plots is to break the mental barriers of the small tea growers who think that the innovations are beyond their capabilities and resources. These plots are also helpful in having free discussions with them to identify any technical, social or economic constraint in adopting scientific cultural practices and the modifications required to make them acceptable.

Typical small tea gardens with an extent of 0.4 ha, located in the midst of small tea holdings are adopted. These demonstration plots are run for one pruning cycle and all vital cultural operations are carried out under the direct supervision of the technical personnel of the scientific department, by supplying the inputs, free of cost.

Pamphlets containing necessary technical information on the cultural operations along with the economics are distributed to the growers during demonstrations. Systematic records containing details of the cultural operations, crop harvested, price realised, etc., are maintained for each plot for proper monitoring and critical analysis of cost:benefit ratio.

In most of the plots, we have been able to double the yield over a pruning cycle. Such plots have served as eye-opener for the small tea growers in shedding their traditional, out-moded cultivation practices and switching over to scientific crop husbandry techniques.

Supply of planting material

Availability of suitable planting material is one of the constraints faced by the growers, who are otherwise convinced with the necessity for infilling and consolidating their holdings. In order to overcome this problem, nurseries have been established at UPASI and suitable drought tolerant tea clones are supplied to them at a subsidised cost of 50 paise per plant. Each grower is given a maximum of 1000 plants for infilling. Before taking up infilling, the reasons for the casualty of the plants are assessed and advice on suitable remedial measures are given.

Field visits

The contact with the trainees is kept alive by undertaking periodical field visits to their holdings by the technical personnel. This ensures good relationships between the KVK and the small tea growers besides solving their day-to-day problems in implementing scientific cultural practices, taught to them during the training and suggestions are given for improving the yield. A report in the local language containing the recommendations is also sent to them subsequently.

Crop diversification

With the object of demonstrating proper method of planting tea in non-traditional areas, a pilot project was launched with the assistance of the Tea Board. The project also aims at preserving the ecology of the area and providing assured, regular income to the farmers besides increase of the tea production.

Normally, a block of about 10 hectares suitable for planting tea is identified for this purpose. Since the farmers are totally new to tea, the beneficiaries are trained in scientific tea cultivation prior to planting. Preparation of land, layout of the field, soil and water conservation measures, contour planting in staggered double hedge, post-planting care, training of young tea, etc., are carried out under the supervision of the officials of the scientific department. A maximum of 5000 clonal tea plants and the required number of Grevillea seedlings for shade are supplied free of cost.

The success of the Crop Diversification Scheme has opened the eyes of other development agencies and is also being now implemented by them. This has led to a tremendous horizontal expansion of tea area to the tune of about 1000 hectares annually in the small grower sector in South India.

Establishment of commercial tea nurseries

The massive tea planting programme under crop diversification has led to acute shortage of planting materials. To cope up with the increasing demand for the tea plants, the areas suitable for raising tea nurseries were identified and the growers were motivated to take up tea nursery as a commercial venture. They were also trained in clonal tea nursery management and helped in getting bank loan as well as marketing of tea plants produced in South India by them. Today in South India, there are more than 600 clonal nurseries propagating around 50 million plants per annum.

Farm Science Club

Farm Science Clubs have been established in the villages to act as liaison between the KVK and the local community to create awareness on crop husbandry practices, to facilitate interaction among members of the different clubs, to organise discussions and study tours.

Awards

In order to motivate, recognise and reward the progressive farmers, the Kendra is annually awarding prizes to the farmers who are adopting scientific cultural practices properly and harvesting high yields.

Other extension activities

Mass contact programmes like village meetings, seminars, field days, exhibitions and film shows are organised periodically to educate and facilitate sharing of information among the farmers.

5. Conclusion

Periodical reviews have established that implementation of the above transfer of technology programmes, both in large and small grower sectors, have brought about a lot of awareness among the planting community, particularly in respect of adopting scientific cultural practices. This has also led to a number of benefits, the most important being a concomitant improvement in the yield of South India plantations in general and the smallholdings in particular. A recent survey has revealed that the productivity of the small tea gardens had risen to 1750 kg per ha - more than 100% increase over a decade (Table 4). Still, there is tremendous scope for increasing the productivity of tea in South India. This would also help in generating employment opportunity for thousands of workers besides earning the much needed foreign exchange for the nation.

Table 4. Productivity of tea in South India.

Year	Productivity	
	Big estates kg/ha	Smallholdings kg/ha
1981	1,645	825
1982	1,665	825
1983	1,559	950
1984	2,147	1,250
1985	2,009	1,150
1986	1,868	1,140
1987	1,965	1,275
1988	2,342	1,540
1989	2,125	1,575
1990	2,266	1,600
1991	2,451	1,600
1992	2,083	1,650
1993	2,354	1,750

Chairman of the Session 3

Dr. R.L. de Silva

Session 3

Balanced Fertilization for Increased Tea Production

Response of Tea to Potassium and Magnesium in Indonesian Tea Soils

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Summary

Results of soil survey on 20 tea estates in West Java showed that soil Mg status was unusually low and K status low to moderate. There was little response in the nursery to either K or Mg.

There was significant response to K and strong positive N×K interaction in young tea. One trial indicated that applying K at above 150 kg ha^{-1} raised leaf litter but did not affect leaf yield. Field trials on mature tea showed the desirable rate for Mg to be 25-50 kg ha^{-1} MgO with K:Mg at 3 to 4 and P:Mg 0.5 to 1.

A general recommendation for a fertilizer mixture for mature tea gardens yielding less than 4 t ha^{-1} made tea is:

$N:P_2O_5:K_2O:MgO$ = 5 : (0.5-1) : (2-3) : (0.5-1) applied to give a maximum of 360 kg ha^{-1} N.

Introduction

Daily temperatures are high near sea level and decrease with increasing elevation. The better teas are grown above 800 m asl and the best at over 1300 m. Parent materials of upland tea soils are volcanic tuffs formed in the tertiary and quarternary eras which have developed into reddish soils at 800-1000 m and blackish soils higher up. Indonesian tea soils comprise Oxisol, Alfisol and Ultisol in the lowlands and Andisol and Entisol in the highlands (Wibowo, 1986).

Natural fertility of these soils depends on organic matter and mineral nutrient contents. In the first generation of seedling tea plantings, organic matter was at or above 5% but this decreased to 3% or less on replanting with clonal tea.

There has been investigation of possible means of restoring the fertility of tea soils to the original level and of the part that can be played by K and Mg fertilizers in this.

Response to potassium

Theoretically, response of tea to K will depend upon clay content, type of clay mineral and the contents of available K, Ca and Mg. Ca and Mg are quite low (<30% of CEC) in most Indonesian tea soils and the CEC is dominated by Al and H (Wibowo *et al.*, 1987). Soils of this kind bevave quite differently from temperate soils in their reaction to fertilizer application.

Table 1 shows exchangeable Ca, Mg and K contents of soils from 20 tea estates together with K activity ratios.

Table 1. Mg and K classification of some Indonesian tea soils and its K activity ratio.

	No. of	Mg			K			$\frac{K}{\sqrt{Ca+Mg}}$		
Estate	sample	Low	Medium	High	Low	Medium	High	Low	Medium	High
Go Estate XIII										
Region I	241	233	8	-	182	55	4	211	25	5
Region II	169	142	20	7	114	48	7	137	26	6
Region III	506	439	52	15	222	235	49	413	72	21
	916	814	80	22	518	338	60	761	123	32
Go Estate XII										
Region I	409	278	81	50	211	150	48	283	90	36
Region II	218	176	28	14	109	85	24	155	43	20
	627	454	109	64	320	235	72	438	133	56

in which:

	Low	Medium	High
Mg me/100 g soil	< 1.0	1.0 - 1.5	> 1.5
K me/100 g soil	< 0.5	0.5 - 1.0	> 1.0
$\frac{K}{\sqrt{Ca+Mg}}$	< 0.4	0.4 - 0.6	> 0.6

Though most of these soils formed from volcanic tuff are young, the K and Mg contents are low but, fortunately, so also is the activity ratio. Response of tea to K fertilizer at different growth stages appears to be influenced by plucking density in mature fields.

K response in the nursery

The standard fertilizer applied in all nurseries regardless of soil type was formerly "UTM" (urea-triple superphosphate-muriate of potash). This was applied at 300-160-140 g/m^3 of the topsoil used in plastic slaves.

The main effects of P, K and Mg applied in an experiment to topsoil on growth in the nursery are shown in Table 2. While P significantly improved growth when N was applied as foliar spray, there was no response to K or Mg.

Table 2. Plant growth in the nursery expressed by its height, diameter and dry weight, 6 months after P, K and Mg application on top soil of Andisol (from Yusuf *et al.*, 1985).

Fertilizer	Plant height (cm)	Plant diameter (mm)	Dry weight (g)
Phosphate (g/m^3 soil)			
P_0	13.42 a	2.2 a	13.43 a
P_{100}	13.52 a	2.5 b	13.34 a
P_{200}	14.97 ab	2.5 b	15.91 bc
P_{300}	16.35 b	2.6 b	17.81 c
Potassium (g/m^3 soil)			
K_0	15.40 a	2.5 a	14.01 a
K_{100}	13.53 a	2.4 a	15.07 a
K_{200}	14.52 a	2.5 a	15.36 ab
K_{300}	14.77 a	2.4 a	16.06 b
Magnesium (g/m^3 soil)			
Mg_0	9.49 a	2.5 a	15.79 b
Mg_{50}	9.90 ab	2.5 a	11.26 a
Mg_{100}	11.70 b	2.4 a	10.97 a

K response by young tea

Investigation by Wibowo (1979) showed that there was no significant fixation of K in Indonesian tea soils so that response to K fertilizer would be expected to be related to available soil K content.

Figure 1 illustrates the results of an experiment in which N and K fertilizers were applied to tea in combination at increasing rates from transplanting to 5 years. There was a marked positive interaction.

In the absence of K, tea responded only up to 150 kg ha^{-1} N, whereas in the presence of 100 kg ha^{-1} K, response was virtually linear up to 300 kg ha^{-1} N applied.

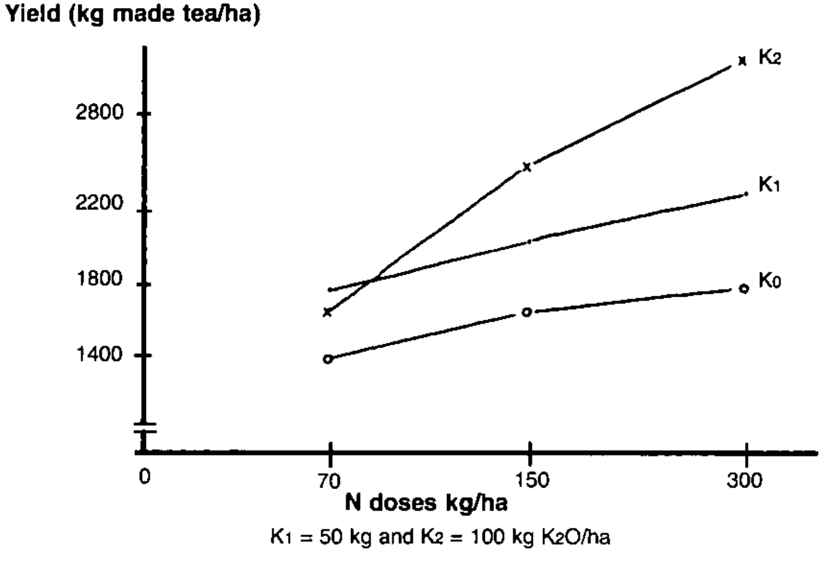

Fig. 1. Interaction between N and K applications on yield of tea at 5 years after transplanting, in which $y = 6.48 \times +1.31$ and $r = 0.99$ (Wibowo and Dimulyo, 1982)

K response by mature tea

In an experiment on older tea (exch. K 0.5 me/100 g soil) receiving N fertilizer at up to 360 kg ha^{-1} N, there was no response to K so far as yield of made tea was concerned (Table 3), though some indication of response in prunings weight. It was recommended to apply K at rates from 60-180 kg ha^{-1} K_2O and N:K ratio from 5:1 on high K to 5:3 on low K soils respectively.

Table 3. Effect of K application on tea yield, N also applied at up to 360 kg ha^{-1} N (Wibowo and Dachman, 1985).

K doses (kg K_2O/ha)	Yield (MT made tea/ha)	Weight of pruning litter (MT/ha)
0	2.890	81.5
50	2.843	82.0
100	3.168	76.5
200	3.023	85.2
P = 0.05	NS	NS

A trial by Wibowo and Rachmiati (1989) in the RITC experimental tea garden at Gambung (exch. Mg 0.7 me and K 0.5 me per 100 g soil respectively) showed no definite interaction effect between K and Mg applied at 60 to 240 kg ha^{-1} K_2O and 25-75 kg ha^{-1} MgO (Table 4).

Table 4. Effect of K (60-240 kg K_2O/ha) and Mg (25-75 kg MgO/ha) application on tea yield within 2 years after application.

Combination	Doses of Mg (kg MgO/ha)		
	25	50	75
Doses of K (kg K_2O/ha)	Yield (MT made tea/ha)		
60	3.908 a (a)	4.315 a (b)	4.197 a (ab)
120	4.291 b (a)	4.071 a (a)	4.395 b (a)
180	4.081 a (a)	4.720 b (b)	4.033 a (a)
240	4.103 a (a)	4.321 a (a)	4.399 a (a)

Note: The same letters located in one column or row indicate no significant difference at p = 0.05.

Table 4 indicates some K×Mg interaction, suggesting that the desirable K_2O:N ratio is between 3 and 4. If soil exchangeable K and Mg are both low, leaf analysis should be used for guidance in accordance with the following:

- K:Mg in leaf > 7. K and Mg to be applied at 1:1 approx. In other words, the K dressing in the usual fertilizer mixture reduced and Mg increased by both soil application and spray.

- K:Mg in leaf < 3. It is vital to apply K which may be followed by spray application of Mg, should Mg deficiency symptoms appear.

Response to Mg

Symptoms of Mg deficiency in both young and old plantings have been evident on Indonesian tea estates since 1976. See Table 1 for Mg contents in representative soils. Leaf contents $\leq$ 0.2% have been shown to indicate Mg deficiency.

As Table 2 shows, there was no significant effect of Mg fertilizer applied in the nursery and the same applies to immature plantings. Growth of young tea is much affected by N and P and it seemed that Mg applied to nursery and immature tea acted as a complement to other major nutrients.

One clone (PS 1), unlike others, shows Mg deficiency symptoms in early growth and application of 75 kg ha^{-1} MgO has increased yield. This clone is low yielding requiring only 150 kg ha^{-1} N.

Mg fertilizer has been tested on mature tea in combination with N, P and K. In this experiment, no interactions of Mg with other nutrients were observed. The main effects of K are given in Table 3 and those of N and Mg in Table 5. An experiment with a different clone to which combinations of P and Mg were applied also showed no interaction; the main effects of P and Mg are listed in Table 6. There were signs of P×Mg interaction suggesting that a P_2O_5:MgO ratio of 1:1 in fertilizer should be suitable.

Table 5. Main effects of N and Mg on tea yield of clone PS1 within one pruning cycle of 1984 to 1986 (Wibowo and Salim, 1988).

Doses (kg/ha)*		Yield (MT made tea/ha)
N	100	2.604 a
	150	2.742 b
	200	2.780 b
	250	2.790 b
	300	2.794 b
	350	2.767 b
MgO	25	2.715 a
	50	2.766 a
	75	2.834 b
	100	2.680 a
	200	2.739 a

Note: Duncan's test = 0.05. * N and Mg applied jointly.

Table 6. Main effects of P and Mg on tea yield of clone TRI 2024 within one pruning cycle of 1985-1987 (Wibowo *et al.*, 1988).

P and Mg doses	Yield (MT made tea/ha)
Phosphate (kg P_2O_5/ha)	
0	1.862 a
30	2.215 b
60	2.231 b
90	2.319 b
Magnesium (kg MgO/ha)	
0	1.815 a
25	2.512 c
50	2.149 b
75	2.181 b

Note: Duncan's test = 0.05.

It is quite evident that Mg is an important major nutrient for tea. The following reasoning is applied in making Mg fertilizer recommendations:

- As with Ca and K, response to Mg is quite slow and long-term planning is necessary if its benefits are to be realised. The higher the contents of clay and organic matter, the slower the response to Mg.
- K activity ratio also governs availability of Mg. Leaf K:Mg ratio is a means of diagnosing requirements as to K:Mg ratio in fertilizer.
- It is important to use the correct material for supplying Mg. Dolomitic limestone is not suitable on account of its alkaline nature (tea is a calciphobe plant) and low solubility of Mg. It tends to reduce yields after two years. The best available Mg fertilizer is kieserite in which the Mg is completely soluble.

Practical recommendations for K and Mg application

Both soil and plant analyses are used in diagnosing K and Mg requirements. Results of field trials have been correlated with contents of exchangeable K and Mg and with K activity ratio. K rates are adjusted in line with the rate of N fertilizer which in relation to soil fertility mainly determines yield. Mg rate is also affected by N rate, most soils being low in Mg and medium in K (Table 1) and the K:Mg ratio will thus be from 2 to 4. Useful guidance is also obtained from results of K and Mg applications in the previous year.

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Role of Potassium Towards Higher Productivity of Tea in Bangladesh

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Abstract

This experiment is a part of the coordinated "Potash Research Project" of Bangladesh Tea Research Institute under the sponsorship of CIDA. This part discusses the effect of different major and minor elements on the growth and dry matter production of a test crop, sorghum in greenhouse and results of the field experiments on tea. Greenhouse experimental results indicated that there is a general need of N, Ca, K, P, Mg in the soil. Based on sorption studies and greenhouse experiments, field trials on tea were laid out at four different sites covering four distinct soil series with the application of 0, 20, 40, 60, 80 and 100 kg K_2O/ha/yr along with basal doses of other fertilizers. It has been observed that the application of 40-60 kg K_2O/ha/yr significantly raised the yield of tea depending on different soil series. Economic analysis of different rates of potassium was also done.

Introduction

Potassium is an essential element for the normal plant growth. Tea growing soils of Bangladesh are not rich in potassium and it varies widely. It is revealed from the analytical data that the available K-concentration of the soil varies from 20 to 150 μg/g. Usually, low areas contain higher amount of K as compared to hilly areas. The potassium requirement of tea plants is higher and shortage of potassium causes physiological disturbances resulting in poor yield, high mortality of the plants and susceptible to diseases. With this view in mind, the present experiment was undertaken to investigate the effect of potassium on the yield of mature tea under Bangladesh conditions.

Methods and material

Four experimental sites were selected considering similar topography, plant age, spacings, vacancy and shade uniformity. Bulk soil samples at a depth of 0-23 cm were collected from each site for thorough examination. Samples were air-dried and passed through 2 mm sieve and stored for subsequent analysis. Besides, soil profile studies and identification of soil series were made. Soils were examined layer wise by opening profile upto a depth of 120 cm. Soil texture was determined in the field by finger feeling test and pH was recorded by Mellige trough test kit and the descriptive terms used as outlined in the U.S.D.A. Soil Survey Manual (1951). Soil samples were also collected for mineralogical examinations.

However, the data on soil profile studies, mineralogical examination and sorption studies are not included in this portion of the paper. Economic analysis of different doses of potassium was also done. Variable cost of potassium was only taken for the purpose while the other costs were considered to be constant for all other treatment.

Physical and chemical properties of the soils were analysed at the laboratory by following standard analytical methods. Greenhouse studies were conducted with four sets of soil samples by using sorghum as a test crop. The rates of different nutrients were calculated on the basis of sorption studies. 150 ml soil with three replications were taken in plastic pot of 200 ml size which did not allow any light to pass through. A hole was made at the bottom of the pots and 0.5 × 0.5 cm cigarette filters were inserted in the hole for capillary movement of water solution. Nitrogen was applied through irrigation water as NH_4NO_3 solution. The optimum treatment received all the elements, while minus (-) indicated the omission of any element and plus (+) indicated the addition of any element over the optimum (Table 1). After 5 weeks, plants were cutted 1 cm above the soil surface and then dried in a forced draft oven at a temperature of 70°C. Dry weight of individual treatments were recorded.

Four field trials were laid out at Shumsernugger, Phulcherra, Sathgaon and Phulbari tea estates. Fertilizer applications as per treatment combinations were made after a few good showers (about 50 mm rainfall) when the soil was moist followed by a light forking. Lime (CaO) application was made one month ahead of fertilizer application in all plots.

During the experimental period, cultural operations like weeding, pruning, pest and diseases control were done as and when needed. Regular weekly plucking data were recorded and statistically analysed.

Table 1. Treatments showing the different nutrient combination used in the greenhouse study.

Treatment No.	Description	Amount of element to be added to treatment if the element is not added to optimum treatment
01.	Optimum	Including all nutrients
02.	Optimum ± Ca	0.100 g $CaCO_3$ = 2 meq Ca/100 ml soil
03.	Optimum ± Mg	0.084 g $MgCO_3$ = 2 meq Mg/100 ml soil
04.	Optimum - N	No N will be added to soil or irrigation water
05.	Optimum ± P	100 µg p/ml soil
06.	Optimum ± K·	0.2 meq K/100 ml soil
07.	Optimum ± B	2 µg B/ml soil
08.	Optimum ± Cu	4 µg Cu/ml soil
09.	Optimum ± Fe	20 µg Fe/ml soil
10.	Optimum ± Mn	30 µg Mn/ml soil
11.	Optimum ± Mo	2 µg Mo/ml soil
12.	Optimum ± S	60 µg B/ml soil
13.	Optimum ± Zn	10 µg Zn/ml soil
14.	Check	Nothing added

The treatments included in tea field experiments are:

T_1 = 0 kg/ha K_2O + all basal doses of fertilizers
T_2 = 20 kg/ha K_2O + all basal doses of fertilizers
T_3 = 40 kg/ha K_2O + all basal doses of fertilizers
T_4 = 60 kg/ha K_2O + all basal doses of fertilizers
T_5 = 80 kg/ha K_2O + all basal doses of fertilizers
T_6 = 100 kg/ha K_2O + all basal doses of fertilizers.

Basal dose of fertilizers in tea field trials:

Nitrogen : 120 kg N/ha from ammonium sulphate
Phosphorus : 30 kg P_2O_5/ha from triple super-phosphate
Magnesium : 20 kg Mg/ha from magnesium sulphate
Zinc : 10 kg zinc sulphate/ha
Calcium : 500 kg CaO/ha once during the experimental period one month before fertilizer application.

Table 2. Characterization of experimental sites (results are expressed on air-dry basis).

Sl. No.	Experimental sites	Textural class	pH	% Organic matter	% Total nitrogen	Ex. cations (meq/100 ml)			Ca/Mg ratio	Mg/K ratio
						Ca	Mg	K		
1.	Shumshernugger Tea Estate	Clay loam	4.0	2.40	0.12	0.60	0.12	0.30	6.67	0.40
2.	Phulbari Tea Estate	Loam	4.3	2.20	0.10	0.80	0.10	0.25	6.00	0.40
3.	Phulcherra Demo. Plot	Loam	4.2	2.00	0.09	2.10	0.20	0.18	10.50	1.11
4.	Sathgaon Tea Estate	Sandy loam	3.8	2.00	0.07	0.70	0.16	0.16	5.65	1.00

Sl. No.	Experimental sites	Expressed as µg/ml						
		Phosphorus	Sulphur	Boron	Copper	Zinc	Manganese	Iron
1.	Shumshernugger Tea Estate	30.0	14.0	1.50	3.5	2.4	17.0	475.0
2.	Phulbari Tea Estate	4.0	35.0	0.30	2.0	2.0	49.0	415.0
3.	Phulcherra Demo. Plot	18.0	16.0	0.20	3.0	1.0	14.0	440.0
4.	Sathgaon Tea Estate	19.0	17.0	0.72	0.5	1.0	7.0	441.0

Results and discussion

Soil analytical results are presented in Table 2. Results show that texturally soils vary from clay loam to sandy loam (top soil) with low pH values. The organic carbon and nitrogen vary from 2% to 2.4% and 0.07% to 0.12%, respectively. The exchangeable cation contents are also very low, of which calcium is the dominant. The available phosphorus status varies widely from 4-30 µg/g. Thus, the soils of the experimental sites are rather low in fertility status. The results of the greenhouse studies are given in Table 3 and Figure 1.

Table 3. Average dry matter production of test crop sorghum in the greenhouse study.

Nutrient treatments	Average dry weight of sorghum in gramm.				
	Shumser-nugger T.E.	Phulbari T.E.	Phulcherra Demo. Plot	Sathgaon T.E.	Mean
Opt	15.37	27.37	20.75	11.40	18.72
-Ca	6.22	13.33	10.58	1.53	7.91
-Mg	8.62	11.07	10.65	9.17	9.87
-N	8.30	14.70	2.43	2.03	6.86
-P	9.00	12.97	7.90	4.67	8.63
-K	8.20	9.50	12.90	8.37	9.74
-B	9.62	29.50	15.48	11.03	16.40
-Cu	10.77	19.90	15.05	10.10	13.95
+Fe	12.55	20.23	11.42	4.23	12.10
+Mn	9.95	19.90	12.33	4.90	11.77
-Mo	6.97	18.00	13.12	6.90	11.24
-S	8.85	27.83	14.35	5.03	14.01
-Zn	13.17	20.23	11.23	9.50	13.53
Check	0.30	6.00	1.40	0.73	2.10

The Shumshernugger soil showed the following trend of decrease in dry matter production Ca > Mo > K > N > Mg > S > P > Cu > Zn due to the withdrawal of respective nutrient element. The reduction of dry matter ranged from 40-60%, while zinc gave the lowest reduction of 14.3%. Further addition of Mn and Fe reduced the yield 30.0% and 18.3% respectively. Thus, it can be said that Shumshernugger soil needs Ca, Mo, K, N and Mg for better growth of sorghum in the greenhouse.

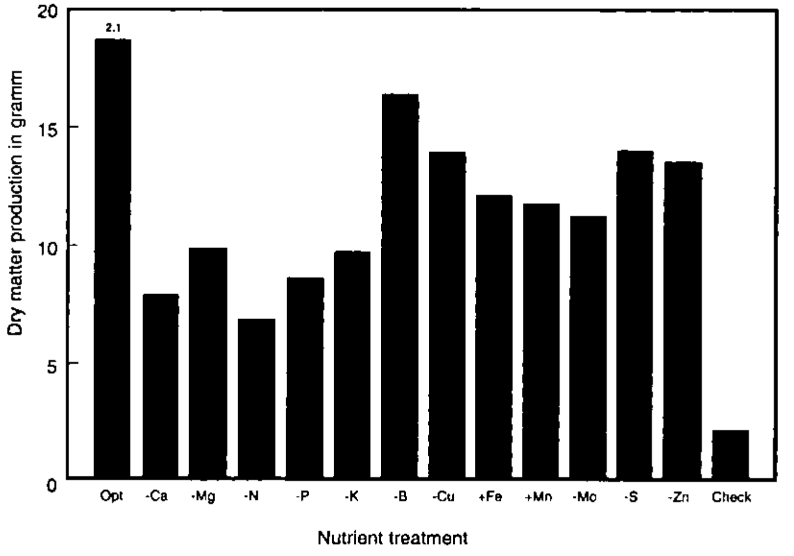

Fig. 1. Dry matter production of test crop Sorghum in the greenhouse (mean of tested soils).

The Sathgaon site revealed the following trend of reduction of yield due to withdrawal of nutrient elements Ca > N > P > Mn > S > Mo > K, the reduction being highest in case of Ca (86.6%) and nitrogen (82.2%). In case of other elements, it ranged from 39% and 26%. The withdrawal of B and the addition of Mn and Fe had no significant effect in increasing the dry matter production.

The Phulbari site showed that the dry matter production decreased due to the removal of nutrient elements and the trend of decrease was K > Mg > P > Ca > N. 35% reduction was noted due to the withdrawal of K, while B and S removal did not affect the yield at all and the addition of Mn and Fe reduced the yield.

The Phulcherra Demonstration Plot showed the following trend of decrease in dry matter production owing to the removal of nutrient elements N > P > Ca > Mg > Zn > Mn > K. The reduction of yield was highest in case of nitrogen (88.3%) and in others, it ranged from 38-60%. The further addition of Mn and Fe did not prove to be useful in increasing the dry matter production of test crop.

It was observed in the greenhouse study that the Phulcherra Demonstration Plot did not show any significant response due to K removal from the nutrient solution and in fixation study also, the sorption of K was not pronounced. Thus, in both sites, field trials are quite in conformity in a sense that K response was obtained with lower rates of K application.

It has been observed from the greenhouse experiment that the need for calcium in the test crop is related with the pH values as well as exchangeable calcium status of the soil. The lower the pH value and exchangeable calcium content, the higher is the response due to removal of calcium from the optimum nutrient solution. However, the mean result (Fig. 1) shows that the shortage of nitrogen is the most limiting factor for plant growth followed by calcium, phosphorus, potassium and magnesium. As such, an integrated fertilizer policy is needed to achieve maximum crop production.

The yield data of four experimental sites are presented in Table 4 and in Figures 2-3. Results show that there is a significant yield increase due to application of potassium although the response is not uniform in all sites.

Table 4. Effect of potassium on the average made tea production at four different experimental sites.

Treatments	Average made tea production as kg/ha			
	Shumsernugger	Sathgaon	Phulcherra Demo. Plot	Phulbari
T_1 = 0 kg/K_2O/ha	1369.7	1674.5	1467.6	997.5
T_2 = 20 "	1504.4	1798.3	1547.3	1141.2
T_3 = 40 "	1609.9	2001.3	1731.0	1316.7
T_4 = 60 "	1710.1	1981.5	1715.2	1504.6
T_5 = 80 "	1645.1	1991.1	1628.8	1437.1
T_6 = 100 "	1607.7	1926.9	1615.2	1366.9

In Shumsernugger site, T_4 consistently gave the highest yield followed by T_5 and T_3. Yield differences were significant at 1% level in the 1st year and at 5% level in the 3rd year. In the second year, the differences were insignificant. It has been observed in the greenhouse trial that the withdrawal of potassium from the nutrition exerted a significant effect on dry matter production. The potassium fixation curve also showed highest amount of K adsorbed as compared to other experimental sites. This seems to be probable reason for response of K at higher rate (60 kg K_2O/ha) under field condition.

In Phulbari tea estate, potassium application significantly raised the yield over the control plot. Treatment T_4 consistently maintained the highest yield followed by T_5 and T_6. However, difference between T_5 and T_6 is not significant. In the greenhouse study, K seemed to be most deficient although fixation of potassium was not very high. The trend of field response is in conformity with greenhouse study.

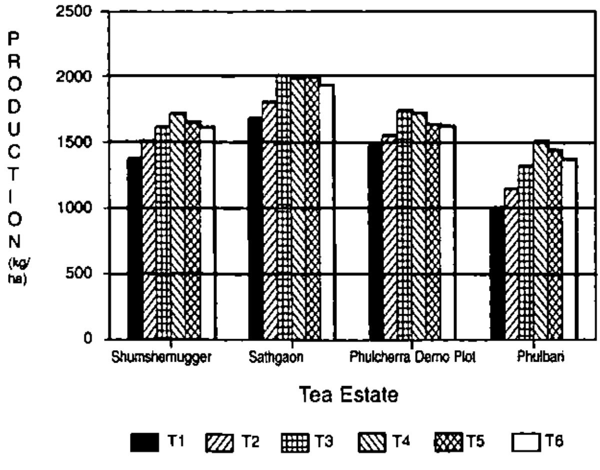

Fig. 2. Effect on the average made tea production at four experimental sites (Average made tea production in kg/ha).

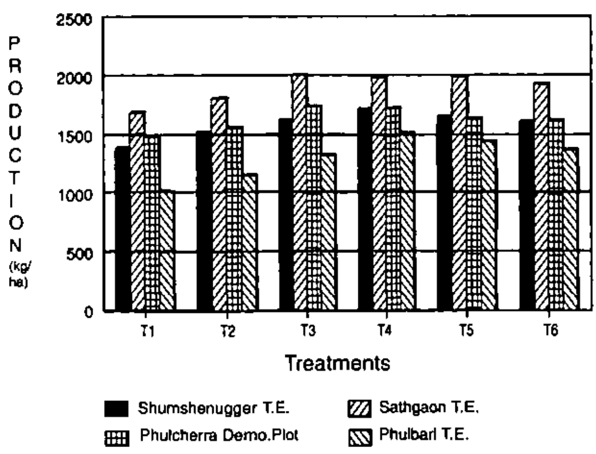

Fig. 3. Effect of potassium on the average made tea production at four experimental sites (Average made tea production in kg/ha).

In Phulcherra demonstration plot, the response of K was noted with relatively lower rates of K application. The treatment T_3 (40 kg K_2O/ha) gave the highest yield increase followed by T_4 and T_5. The differences between T_3 and T_4 as well as T_5 and T_6 were not significant. Yield data for the first and third year were significant at 5% level but it was not significant in the second year of the trial. In the greenhouse experiment, K nutrition had less pronounced effect and in the field trial, K response was obtained at lower dose of K application. In the fixation study also, the rate of K adsorption was less. Thus, the field observation is in full conformity with those of greenhouse and fixation studies. Likewise, at Sathgaon site also K responded significantly (5% level) at a lower level of K application (40 kg K_2O/ha) in all the years. While in the first year, it was significant at 1% level. Treatment T_3 gave the highest yield followed by T_4 and T_5. The difference between treatments T_3, T_4 and T_5 was found to be insignificant.

The average yield, gross return, gross margin and variable cost of potassium are shown in Table 5. It is observed from the table that the yield is highest in treatment T_4 by applying 60 kg K_2O/ha. The gross margin shows the following descending trend $T_4 > T_5 > T_3 > T_6 > T_2 > T_1$ (Fig. 4). It shows that the highest yield and also the highest gross margin were obtained in treatment T_4. Marginal analysis of undominated treatment are presented in Table 6.

Table 5. Partial budget of potassium fertilizer trials on mature tea.

Treatment	Fertilizer use/treatment	Average yield (kg/ha)	Gross return (Tk/ha)	Variable cost (Tk/ha)	Gross margin (Tk/ha)
T_1	0	1377	66371	0	66371
T_2	20	1498	72204	240	71964
T_3	40	1665	80253	480	79773
T_4	60	1728	83290	720	82570
T_5	80	1675	80735	960	79775
T_6	100	1628	78470	1200	77270

Table 6. Marginal analysis of undominated treatment of potassium fertilizer on mature tea.

Treatment	Gross margin (Tk/ha)	Variable cost (Tk/ha)	Marginal gross margin (Tk/ha)	Marginal variable cost (Tk/ha)	Marginal rate of return (%)	Average rate of return (%)
T_4	82570	720	2797	240	1165	2250
T_3	79773	480	7809	240	3253	2792
T_2	71964	240	5593	240	2330	2330
T_1	66371	0	-	-	-	-

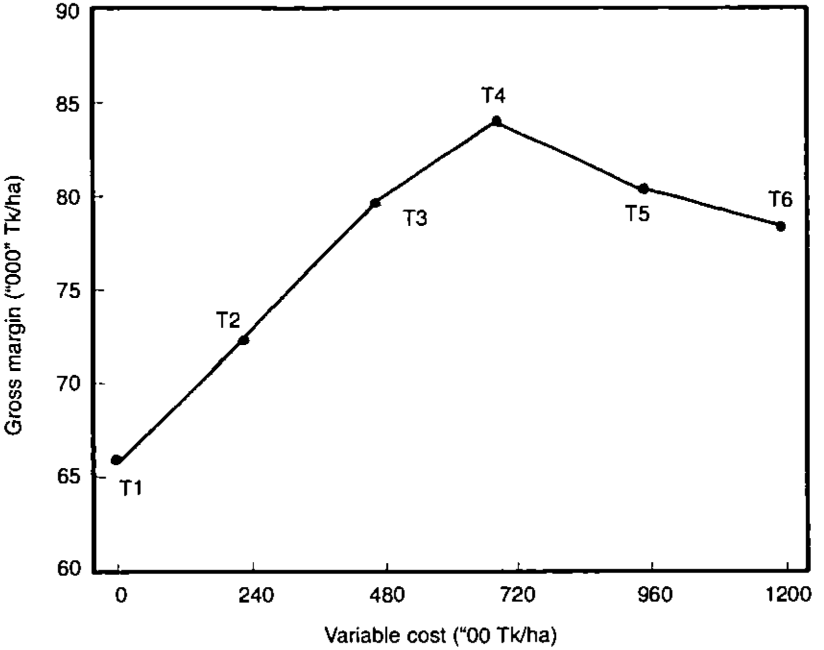

Fig. 4. Gross margin curve for potassium fertilizer treatment on mature tea.

It appears that the marginal rate of return was highest in T_3 which was 3253% though the yield was lower than T_4. Thus, for general use of potassium fertilizer, 40 kg K_2O/ha seems to be the most economic dose.

But, K requirement varies with the type of soil series and seems to be one of the most important criteria for K recommendation. The recommendations of potassium for different soil series are as follows:

1. Jafflong soil series 40 kg K_2O/ha/yr (Sathgaon site).
2. Srimangal soil series 40 kg K_2O/ha/yr (Phulcherra site).
3. Kulaura soil series 60 kg K_2O/ha/yr (Shumsernugger site).
4. Baralekha soil series 60 kg K_2O/ha/yr (Phulbari site).

However, it must be kept in mind about the other nutrients applied as basal fertilizers. In other words, an integrated fertilizer approach is needed to maximise the production.

The response of tea crop to K fertilization depends mainly on the prevailing soil K status and the ability of the soil to meet the K requirement of the plant. Thus, K supply of a soil largely depends upon the nature of the soil from which it is originated. Experimental results obtained in different countries also varied widely.

In North-East India, a review of results of earlier experiment carried out since 1931 shows, although inconsistent, responses upto 75 kg K/ha/yr (Sen, 1964 and Sharma, 1964). However, the present recommendation of K for mature tea varies from 33 to 100 kg K/ha/yr (Rahman, 1977), while earlier experiments (1949-53) in Southern India on K showed the increase in yield upto 37 kg/ha/yr, subsequent investigations of K responses showed that pruned sections needed more K as compared to skiffed areas. K rates vary between about 83 to 250 kg K/ha/yr for fields yielding between 1000 and 5000 kg of made tea/ha/yr (Ranganathan and Natesan, 1983).

It is difficult to make an universal recommendation when one considers different soil series, topography, yield potential and cultural operation and climatic factors. Moreover, K responses to tea and its recommendation vary greatly in different tea growing countries of the world. Child (1964) observed that K treatment in Sri Lanka gave significantly higher yield only after 12th year and the response was evident with 18.5 and 37 kg of K/ha/yr. However, the present recommendation for fields yielding less than 1600 kg/ha/yr is 25 to 50 kg K/ha/yr while 75 kg K/ha/yr is for fields yielding more than 1600 kg/ha/yr (Fernando *et al.*, 1969; Kulasegaram, 1980).

Tea in East Africa did not respond to K fertilizer in the early 1950s and hence the general advice was not to apply potassium (Child, 1957). With the gradual decline of K reserve in the soils, there results K deficiency (Willson, 1963).

Recently, two complex NPKS in the ratio of 25-5-5-5 for areas of reasonable levels of K reserve of soil and NPK in the ratio of 25-10-10 for lower levels of K reserve in the soil have been in practice. Remedial doses of 83 to 166 kg of K/ha in areas showing severe K deficiency are often recommended (Tolhurst and Green, 1973; Othieno, 1980).

Ali *et al.* (1977) reported that the requirement of potash for old and mature tea is 70 to 90 lbs/a while in case of young tea, it is 40 to 60 lbs/a seemed to be economic under Bangladesh conditions.

The present experimental results indicate that K requirement is not so high. The reason behind this may be due to low nutrient status with strong acidic condition and low cation exchange capacity of these soils. The requirement of other essential elements must be considered simultaneously. Valverde *et al.* (1966) mentioned that other nutrients can affect K nutrition. For example, if NP or other nutrients are limiting, K deficiency may not be a problem. In other words, a balanced nutrient supply is needed for better yield response. The rates of K application ranged from 0 to 100 kg K_2O/ha/yr. But, significant responses were not obtained with higher rates of K treatment.

Acknowledgement

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Potassium-Nitrogen Interaction in Tea; Its Genesis and Effects on Yield and Quality

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Summary

NK interaction on productivity and quality is a natural consequence of soil factors in tea growing areas to meet the specific requirement of the tea plant. NK interactions of practical value in tea are discussed.

Nutrient interactions on uptake, productivity and quality are subjects debated frequently. Nutrients are required in proportion to biomass produced to achieve a certain productivity level of economic end product for which the plant is grown. Only a fraction of biomass produced is harvested as crop. The amount of nutrient ions that soil can mobilize in unit time through weathering and natural recycling process is limited and can support only a threshold level of productivity - each nutrient ion has its own threshold level of productivity. The productivity achievable is then determined by the law of limiting factors - the yield is determined by the nutrient ion which restricts the productivity most. The threshold level of productivity of nutrient ions available through weathering and natural recycling process in the soil and the nutrients to be applied to sustain productivity at different levels in South Indian tea soils are shown in Table 1.

Table 1. Nutrients related threshold productivity level of tea in South Indian soils.

Nutrient ion	Threshold productivity kg/ha	Productivity level kg/ha	Nutrients to be applied
N	800	Up to 800	Nil
K	1000	800 to 1000	N
Zn	1500	1000 to 1500	NK
P	1800	1500 to 1800	N,K,Zn
Mg	3000	1800 to 3000	N,K,Zn,P
Si	3000	3000 to 3500	N,K,Zn,P,Mg,Si
B	3500	3500 to 4000	N,K,ZN,P,Mg,Si,B
Mo	4000	4000 & above	N,K,Zn,P,Mg,Si,B,Mo
CO_2	8000	4000 & above	*
H_2O	8000	4000 & above	*

* Nutrients and more attention on i) organic matter maintenance, ii) irrigation during dry months, and iii) liming to maintain soil pH between 4.5 and 5.0. (Tandon and Ranganathan, 1988).

Nutrient interactions emerge as a consequence of the law of limiting factors taking into account both the quantities of nutrients available from natural sources and extraneous inputs in the form of fertilizers in the quest to sustain the growth rate in productivity in any commercial system. N and K contents of tea, their requirement for different yield levels and amounts available through natural sources are shown in Tables 2 and 3.

Table 2. N and K contents of tea and their requirements (Natesan and Ranganathan, 1990).

	Shoot [a]	Mature leaf [b]	Small stem [b]	Thick wood [c]	Root [d]	Whole plant
A) Nutrient content %						
N	4.15	3.20	1.37	1.04	1.06	1.78
K	2.15	1.24	1.00	0.55	0.83	0.96
Dry matter Distrib.	10	18	12	35	25	100
B) Elements assimilated to produce 1000 kg made tea						
N, kg	41.5	57.6	16.4	36.4	26.4	178.3
K, kg	21.5	22.3	12.0	19.3	20.8	95.9

a) Harvested as crop for making commercial tea - amount removed from the system.
b) Retained in the field at the time of pruning.
c) A portion of it is removed for fuel.
d) Retained in the system itself.

While deciding the actual rates of application, losses that occur and limitations imposed by kinetic factors of transport of ions in the soil are to be given due weight (Ranganathan, 1986b). Theoretically, the response curve for any one nutrient is linear in an ideal medium with abundant supply of all other nutrients, carbon-dioxide and water. But the limiting factor at different levels of productivity pulls down the response making it asymptotic or parabolic depending on its intensity of occurrence. Manifestation of the response swing in presence and elimination of limiting factor(s) on productivity, quality or both to a nutrient application is known as the interaction between that nutrient and the limiting nutrient factor. This paper will restrict discussions on N and K interaction in tea cultivation.

Table 3. Soil N and K contents in tea growing areas.

Nutrient	Source	Content	Influencing factor
N	Organic matter	2 to 10%	Annual mean temp. (Lattitude and altitude)
	Total N	1000-4000 ppm	Annual mean temp.
	Available N	100- 400 ppm	Annual mean temp., soil texture, rainfall
	Actual recorded utilization from natural sources	100- 500 kg/ha	Productivity level and biomass recycled
K	Total K	2000-5000 ppm	Mineralogy, rainfall
	Available K	30- 300 ppm	Mineralogy, texture, rainfall
	K from organic matter decomposition	50- 200 ppm	Annual mean temperature
	Release from weathering	36 ppm/annum	Annual mean temperature
	Actual recorded utilization from natural sources	90- 100 kg/ha	Productivity level and biomass recycled

Plant factors

Tea requires more K than Ca compared with other dicotyledons (Table 4), but it is grown mostly on acidic soils in humid zones low in bases particularly K.

Table 4. Chemical composition of some crop plants.

Crop		K (%)	Ca (%)	Si (%)	Type of metabolic behaviour
Cotton (Dicot)*		1.54	1.18	0.108	Calcium accumulator
Corn (Moncot)**		1.30	0.42	1.070	Silicon accumulator
Tea	(1)**	0.63	0.64	0.750	-
	(2)	0.73	0.58	0.850	-

* Cooper and Hall (1955)

** Ranganathan (1978)

Its low root cation exchange capacity to compete with other exchange surfaces, such as clay colloids and other root surfaces in the rhizosphere to get a greater share of manovalent K, compared to divalent Ca and Mg as governed by Donnan Distribution and mechanisms to regulate the translocation of absorbed Ca to shoots by precipitating excess Ca in the roots and collar zone are adaptive mechanisms to efficiently utilize K from a medium which has low buffering capacity to replenish and sustain K availability through natural recycling process against plant uptake (Ranganathan and Narayan, 1975; Ranganathan, 1986b). In high yielding fields with greater demand for K, Donnan Distribution is broken by law of mass action - applying more potash than required to sustain uninterrupted flux of K in the rhizosphere to meet the demand made by the high yielding plants. No antagonistic effect on Mg uptake is observed under the levels of K recommended until the Mg threshold limit of productivity is reached.

Soil factors

Tea is grown all over the world in acidic soils in humid zones where the content of bases (K, Ca, Mg) is low. These soils are also mostly kaolinitic and as such, K is as ephemeral as N. Therefore, potassium does not accumulate in the soil. Potassium release through weathering and decomposition or organic matter is either taken up by the plant or lost by leaching. In illitic soils, as in Assam, K is fixed, thus limiting its availability to plants and warranting special techniques to apply K fertilizers to reduce fixation. The main source of nitrogen is the decomposition of organic matter recycled in the cultivation system. Organic matter flux in tea soil is described by Ranganathan, Ganesan and Natesan (1980). Nitrogen released by decomposition is also either taken up by the plant or lost by denitrification and leaching (Ranganathan, 1977). The quantities of N available in a soil profile appear very high; but the quantities actually available to plants are only a small fraction to them. This is because i) roots exploit only a fraction of the soil volume and ii) as they are distributed over large volume and area, their concentration in soil solution is too low to maintain diffusion rates sufficient to transport adequate amounts to the rhizosphere.

As such, the quantities recycled may not sustain the productivity and the growth rate in productivity in as much as only a fraction recycled is made available and the quantum available decreases with time unless supported with inorganic fertilizers and recycled biomass. Efficiency of N and K is affected by both productivity levels (Table 6) and soil pH (Table 5). Nutrient balance sheet for N and K actually assimilated by plants, amount utilized from natural sources, amount to be applied taking into account efficiency factors, is given in Table 6. Various factors that affect the efficiency of N and K utilization by tea plant are discussed in detail by Ranganathan (1981).

Table 5. Relative efficiency of N and K in relation to soil pH.

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

(taking efficiency of K at pH 5.5 to 6.6 as 100 and that of N at pH 4.8-5.0 as 100) (Ranganathan, 1981).

Thus, N and K availability from natural sources and their utilization are delicately balanced in nature and unless they are supported by way of fertilizers in balanced quantities, either one of them tends to become a limiting nutrient affecting both productivity and quality.

Physiological factors

Once N and K are made available in optimum quantities in the rhizosphere, there is no difficulty for the plant to absorb the required quantities because of mutual synergetic effect of nitrate and cations (K) on their uptake by plants. High calcium in leaf tissues depresses crop and reduces N efficiency (Ranganathan, 1978). Optimum Ca in leaf tissues is also essential as a nutrient and to reduce the toxic effects of heavy metal ions. N increases Ca uptake and K decreases it (Clements, 1970). By manipulating N/K ratios in the fertilizers, optimum Ca concentration which will maximize the efficiency of utilization of N and K could be maintained (Ranganathan, 1978). Optimum calcium concentration in soil solution is also essential to reduce the efflux of root-absorbed nutrients, particularly that of N and K - efficiency of N is more affected by soil pH warranting adjustments in N and K ratios to be adopted (Ranganathan, 1981).

Thus, N and K interaction also result from plant and soil factors, which determine their requirement and availability, and kinetic factors pertaining to transport to rhizosphere and uptake by plants and, the differential interaction between them and other nutrients, particularly Ca.

NK interaction on productivity

Reports on NK interactions and the need for balanced NK applications have been reviewed in full by Ranganathan and Natesan (1985). NK interaction is more pronouced in young tea and pruned tea as both N and K are required for building sound and healthy frames and to create high productivity levels in the shortest possible time.

Table 6. Nutrient balance sheet for N and K applications in tea fields.

Yield level kg/ha	Actual amount assimilated kg/ha		Amount** utilized from natural sources kg/ha		Balance to be applied kg/ha		Efficiency* of utilization %		Amount of fertilizers to be applied kg/ha		Current recommendation (S. India) kg/ha	
	N	K	N	K	N	K	N	K	N	K	N	K***
800	142	77	140	94	-	-	30	80	-	-	-	-
1000	178	96	150	96	28	-	30	80	93	-	120	60-120
2000	356	192	270	106	86	92	40	80	215	115	200	100-200
3000	534	288	370	104	164	184	50	75	328	245	250	125-250
4000	712	384	500	108	212	276	60	65	353	425	350	350

a) amount utilized from natural sources increases with yield level as biomass recycled increases.

b) amount of fertilizers to be applied does not include adjustments for increasing the efficiency of urea with higher K applications.

* after Ranganathan (1981).

** from the rates of organic matter decomposition and the quantities recycled.

*** depending on source of N and time interval envisaged for target yields.

Moreover, in South India, there is interaction between K and N forms which has led to recommendation of N/K ratios for different sources of nitrogen (Ranganathan, 1981). The NK interaction obtained in the 11th cycle of a long term fertilizer experiment in Sri Lanka and in young tea in South India are depicted in Figures 1 and 2.

A higher N:K ratio is also reported to be useful for maintaining leaf succulence for extending plucking intervals by 2 or 3 days, besides increasing the response to fertilizers (Figure 3).

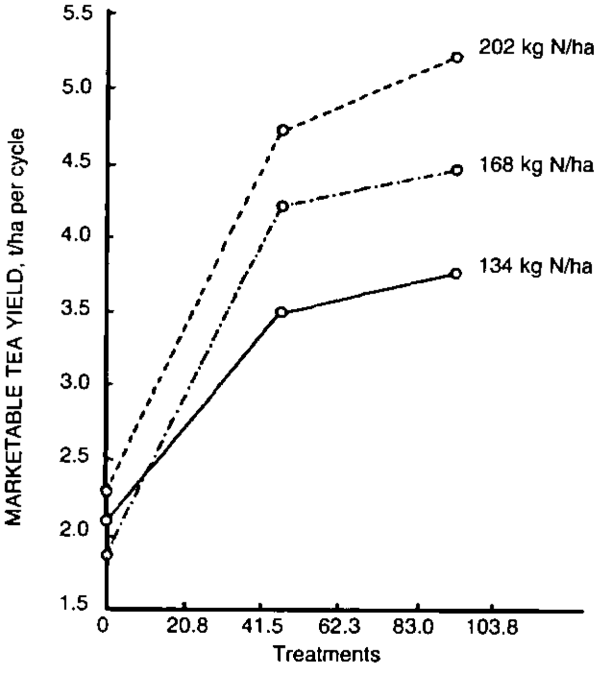

Fig. 1. Response of mature tea to K at different N levels (Bhagavanandan and Manipura, 1969).

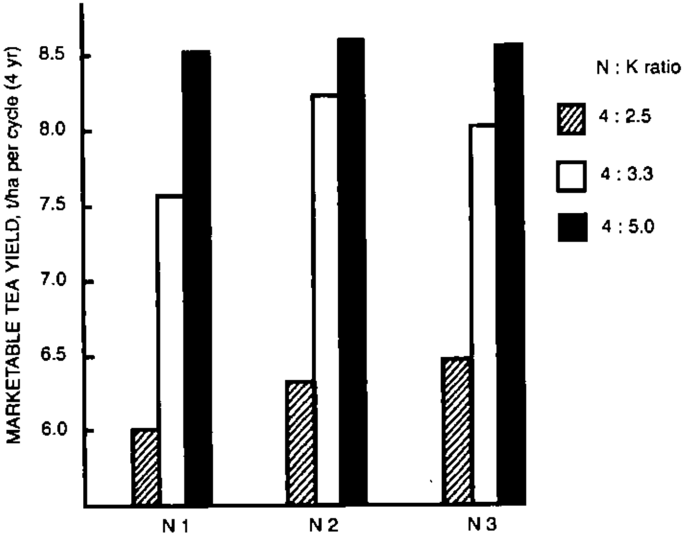

Fig. 2. Response of young tea to K at different N:K ratios (4:2.5 to 4:5.0) and N rates (total N applied in the pruning cycle 650, 975 and 1300 kg ha^{-1}) (Natesan *et al.*, 1984a).

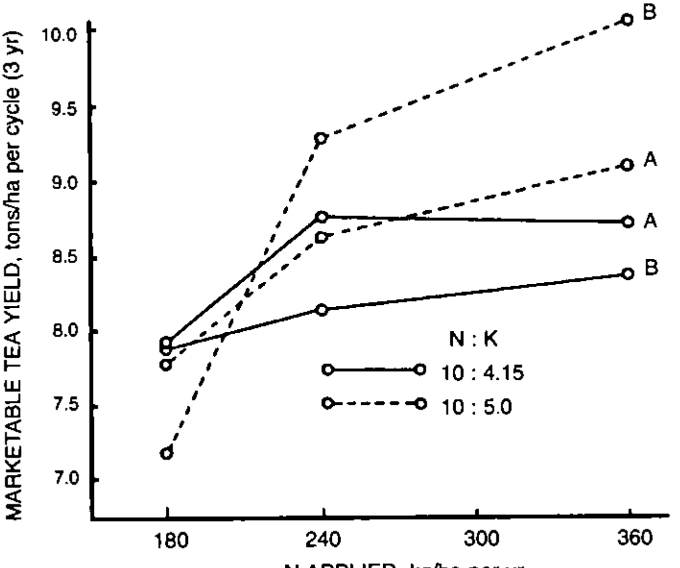

Fig. 3. Interaction of plucking intervals (A = short round, B = extended round) with the N level and N:K ratio (Natesan *et al.*, 1984b).

NK interaction on quality

Quality of made tea depends on the composition of leaves both organic and inorganic which in turn is influenced by nutrition with all the essential nutrients required for growth and also the accumulation of one or more of non-essential elements entering the system though availability in soil depending on soil pH and impurities in agro-chemicals used for various cultivation purposes. A review of data available made by Ranganathan (1987) revealed that application of nutrients, generally, has no effect on quality provided such application is associated with yield increase which acts as a buffer to keep the content of nutrients in tissues in the optimum range. Only when the yield stagnates with application of nutrients and extreme conditions of deficiency or excess of one or more nutrients occurs, quality is impaired from the dislocation of such of those metabolic processes controlled by the deficient or accumulated element(s).

Excess nitrogen impairs flavour, decreases tannins and water extractives, represses enzyme activity for biosynthesis of nitrogen compounds and has varied influence on caffeine. Potassium was long associated with crude fibre because of its effect on strengthening the tissues as opposed to weakening effet of nitrogen. The studies done in South India and elsewhere have been reviewed by Ranganathan and Natesan (1987) and they show that i) potassium has a positive influence on overall quality of tea, ii) as potassium regulates the tissue moisture and prolongs the vegetative phase, it does not increase the fibre content, iii) it offsets the adverse effects of nitrogen. Summary of results of certain recent investigations are given in Tables 7 and 8. To sum up, the evidence is so far showing that the increasing N level alone impairs the quality parameters but in combination with potassium and supported with adequate P, the increasing levels of N and K manuring have very little influence in practical terms on quality of tea.

Table 7. N and K - effects on quality (Ranganathan, 1987).

Nutrient	Effect	Reference
N	1) No effect on colour, strength & valuation	a
	2) Negative on quality due to levels	a, b
	3) Impairment of flavour	c
	4) Repression of enzyme activity for biosynthesis of N compounds	d
	5) Negative on tannins and water extractives	e
	6) Positive on caffeine	f
	7) No effect on quality	g
	8) Association with TF and valuation	h
K	1) Positive on overall quality	e
	2) No effect on flavour	c
	3) Offsets adverse effects of N on quality with or without P	e
	4) No effect on crude fibre content	i

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i) Jayaraman, V. (1956): Bull. UPASI Tea Sci. Dep. 15: 21-23.

Table 8. Nutrient elements and quality parameters - results of recent investigations (Ranganathan, 1987).

Effect on	Dominate factors
1) Moisture content	1) Clone, age from pruning marginal but marked 2) Manuring levels-marginal but weak
2) N, P, K, ash contents	1) Jat/clone-marginal but marked 2) Manuring levels-fable & positive influence 3) Age from pruning on ash content-marginal & positive
3) Crude fibre	1) Jat/clone-Assam > China 2) Age from pruning- & positive 3) Manuring levels-slight negative 4) Associated with growth and response to yield
4) Fermentation time	1) Clonal effects - dominant 2) Manurial effects - no effect
5) Other chemical parameters of black tea	1) Clone, manuring levels-marginal weak effect
6) Organoleptic parameters and valuation	1) NK levels and NK ratios-no effect 2) Clones, age from pruning-marginal but significant effect

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Site Specific Fertilizer Recommendation - A Tool for Optimizing the Nutrient Supply to Crops

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Summary

The potential for improved fertilizer application systems for potassium based on site specific advisory is discussed. Empirical determination of fertilizer rates by balance sheets do often fail in adjusting the requirements of the site, owing to the fact that important factors affecting the K dynamics in the soil are not considered.

An information system KALIPROG is presented which uses digitised soil, geological, precipitation and temperature maps in order to identify and describe site specific factors which are important for the K dynamics and K status of the soils and thus the K supplying power of a site. On the basis of numerous long-term fertilizer trials, covering a large scale of site conditions and detailed description of the latter, the KALIPROG can be used in order to extrapolate trial results and fertilizer recommendations from trial areas to sites with the same factor combination. The use of such a data based information system allows a more precise adjustment of site specific soil K status and opens perspectives to use soil and fertilizer nutrients more effectively.

Introduction

Measures to improve the productivity of a crop or of cropping systems, respectively, are closely linked to the fertility management of the soils the crops are grown on.

Mineral fertilizer application in this context has become the crucial factor to improve and sustain a high fertility level of the soils in order to achieve high crop production. For economic and environmental reasons, there is a high demand for a high efficiency of the applied nutrients. However, the efficiency of a fertilizer application depends largely on the natural environment on which agricultural production is based and, therefore, varies from one location to the other.

Therefore, high emphasis has to be given to the optimization of the nutrient supply by taking into account the natural potential of the environment (climate and soil) and the yield potential of the crop.

For the time being, most of the fertilizer application rates are simply determined by the use of balance sheets based on the assumption that nutrients which had been removed during harvest have to be replaced by fertilizers again. With this approach, serious under-supply or over-supply with negative effects on the economics and environment can be avoided. However, this method has the disadvantage that existing nutrient imbalances cannot be corrected by fertilizer application and that the nutrient dynamics in the soils are not taken into account.

The latter is especially important for nutrients such as potassium which occurs in different fractions in the soil and where the plant availability is to a large extent influenced by the equilibrium of the various fractions. Therefore, soil analyses are commonly used to get an indication of the nutrient requirement of a certain soil under a certain cropping intensity. In various European countries, soil test values have thus become the basis for the fertilizer recommendation. However, in numerous field trials, trying to correlate soil K test values with crop production, it was realized that there is no consistent relationship between the two parameters. Therefore, K recommendation systems today take into consideration soil texture or cation exchange capacity of the soils to determine critical values and fertilizer requirements. However, even when these parameters are taken into account, the values obtained are rather approximate estimates of soil K reserves and K demand by plants. Precise predictions of the K needs of a crop require the knowledge of the soil-plant interaction with regard to K response, taking into account the site specific conditions such as climate and management conditions at farm level.

The target of this paper is, therefore, to review approaches which have been undertaken to improve K fertilizer recommendations by employing the most recent knowledge in K research and advanced scientific technologies in this field.

Conventional methods for the determination of K requirements

The simpliest way to determine the fertilizer requirement is to estimate the nutrient uptake by the crops based on the yield level (Table 1). This is based on the assumption that the K removal increases with higher yields. However, such an estimate can give only a weak indication of the true requirement, due to the fact that nutrients which are supplied by the soil, fertilizer nutrients which are immobilized in the soil or nutrients which are lost by leaching are not taken into consideration.

Furthermore, this method does not take into account the changes in the K redistribution in the plant which varies with the yield level and the K which is recycled by these plant parts, remaining on the field at harvest.

Table 1. Potassium removals of selected crops as affected by yield level.

Crop	Yield (t/ha)	Removal (kg K_2O/ha)
Maize	6	120
Rice	6	160
Cassava	40	350
Sweet potato	40	340
Coconut	10000 nuts	200
Groundnut	2	110
Soybean	3	170
Tea	2.5 (made tea)	90
Tobacco	2 (dry leaf)	240
Cotton	1 (lint)	90
Jute	2 (dry fibre)	160
Rubber	2.5 (dry latex)	65
Sugar cane	100	340

As indicated above, fertilizer recommendation has to consider the availability of potassium which is to a large extent depending on the K dynamics in the soil (Figure 1).

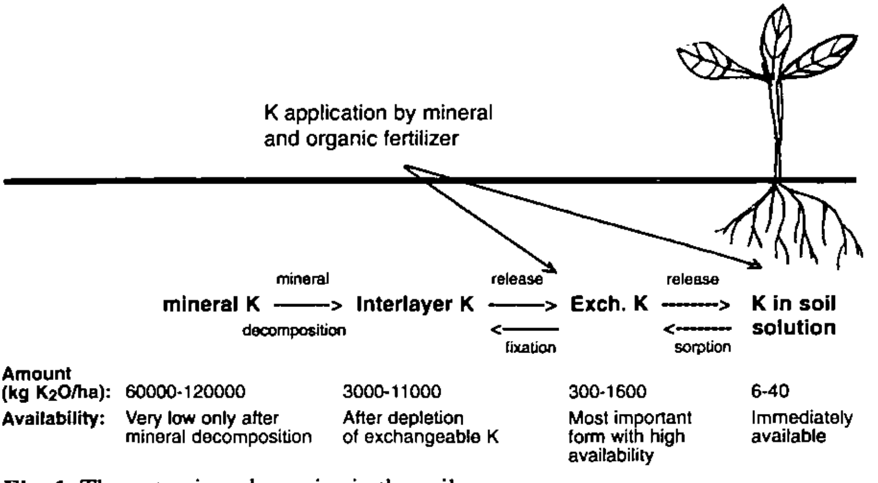

Fig. 1. The potassium dynamics in the soil.

Through mineral decomposition and ion exchange potassium is released into the soil solution. The exchangeable K is absorbed at the surfaces of clay minerals, whereas the non exchangeable K is located in the interlayers of clay minerals. The mineral K is only available after mineral decomposition.

Owing to the structure of surfaces of the clay minerals, the latter are the most important factors of the K dynamics in the soil.

Most fertilizer recommendation systems, therefore, take into consideration the clay content of the soil as it is shown by the critical K values which have been established by the official fertilizer advisory service in Germany (Table 2).

Table 2. Critical K values for arable soils for respective fertility classes in Germany (mg exchangeable K_2O/kg soil).

Fertility class Fertilizer requirement	A very high	B high	C maintenance	D half maintenance	E zero
Clay content (%)					
0 - 12	< 40	40-100	100-175	175-250	> 250
12 - 25	< 60	60-125	125-215	215-330	> 330
> 25	< 75	75-165	165-280	280-415	> 415

Based on Früchtenicht *et al.*, 1993.

However, K availability and response to K application seem to be also largely depending on factors other than K content and clay content as indicated in Figure 2. If all the measurements of this survey would be pooled, the result would indicate that with increasing K content of the soil the yields declined, although on each individual site the observations revealed that increased K availability led to higher yields (Orlovius, 1984). Despite similar clay contents, the formulation of a single fertilizer recommendation to all the sites, therefore, consequently would lead to an uncertain result. Therefore, the advice for the fertilizer application has to aim at a higher precision in order to adapt the K rates accordingly. This means that on top of K test values and clay content, which are conventionally used by the advisory services to adjust the K rates, site specific parameters are required to optimize fertilizer rates for a certain crop. These include:

- Soil texture
- Type of clay
- Soil structure
- Organic matter content
- Rooting depth
- Temperature, water and gas household of the site
- Specific K efficiency of the plants.

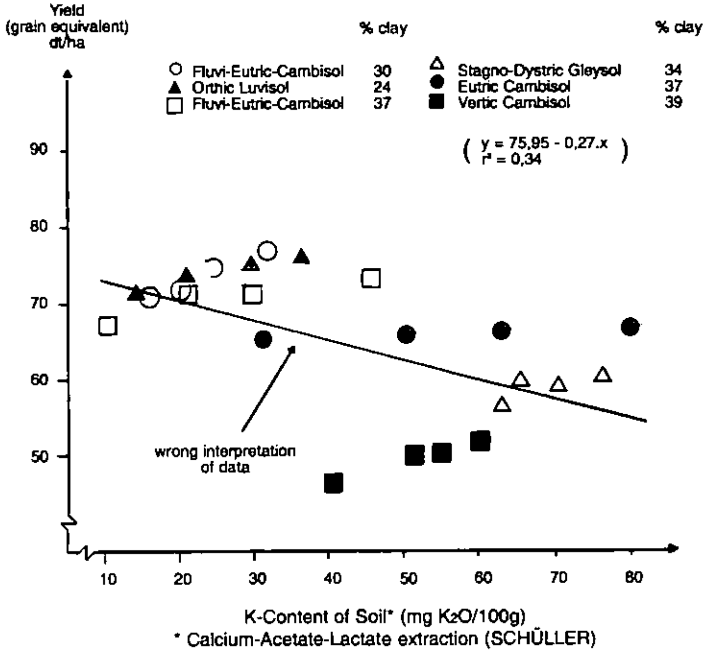

Fig. 2. Site specific relations between K-content of soils and plant yield.

Computerized data based fertilizer recommendation

The best fertilizer recommendation for a certain crop at a certain site would be achieved if all the variables of the site, including the parameters listed above, are known and fertilizer experiments would have been carried out for each individual site. Since this is a very time and money consuming procedure, scientists in France and Germany have separately developed computer programmes, based on data banks which had been established with the aid of long-term fertilizer experiments, in order to give site specific K recommendations (Andres and Orlovius, 1987; Collin, 1990).

These programmes are based on the assumption that the K dynamic of a site is similar under the same or very similar site factor combinations. Therefore, the crop response to K application should also be very similar.

In the following, the principles and the working schedule of KALIPROG, a system that has been developed by agronomists of Kali & Salz GmbH (Andres and Orlovius, 1987) will be described more in detail.

With KALIPROG, site-specific information obtained on a test field are applied to another site with the same or very similar site factor combination. The basis for this system are a network of long-term field experiments in which optimal K reserves and the respective K fertilizer rates are determined. The site is further described in detail according to climatic and soil factors which influence the availability and response to K fertilization. Special purpose maps have been developed in order to offer to advisors and farmers specific information on optimal K status and respective K rates for a respective crop at a given site (Figure 3).

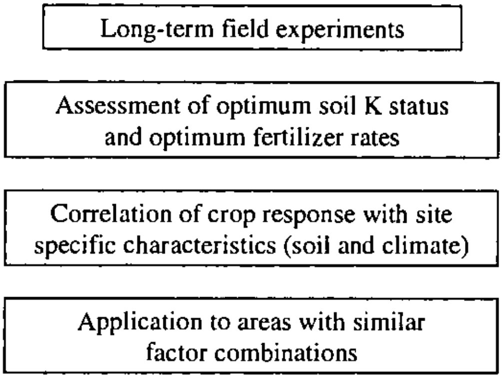

Fig. 3. Development of K fertilizer recommendation based on site factors.

The data base for the crop response on a particular site is derived from about 150 long-term K fertilizer experiments in almost all agricultural areas of Germany which allow an economic and ecological optimization of the K status and the fertilizer rates. An overview regarding the long-term field experiments for the former Federal Republic of Germany is given in Figure 4.

The identification of regions with similar site factor combinations is achieved by a geographical information system, based on digitised maps, in particular soil maps, geological maps, precipitation maps, temperature maps, maps of natural areas and geographic maps. The structure of KALIPROG which may be translated into POTASH PROGnosis is shown in Figure 5.

The maps containing qualitative parameters (soil type) as well as quantitative parameters (rainfall) in the digitised form had to have the following properties in order to serve a complete coverage of a country:

- the maps had to cover the whole area
- the maps had to be correlated with the respective site factors
- the data base had to be available to all users.

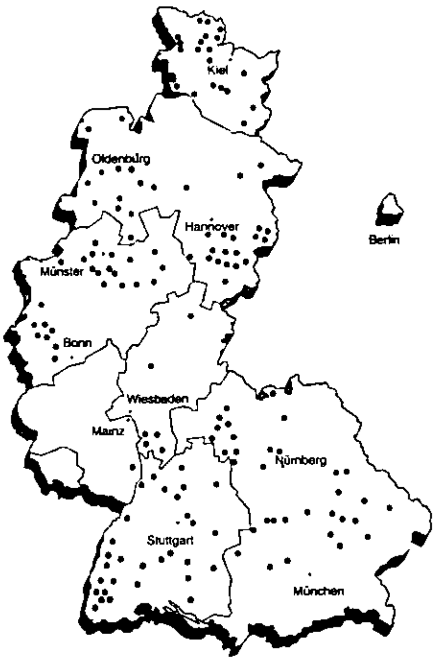

Fig. 4. Long-term field experiments on arable land of the Advisory Service of Kali und Salz GmbH.

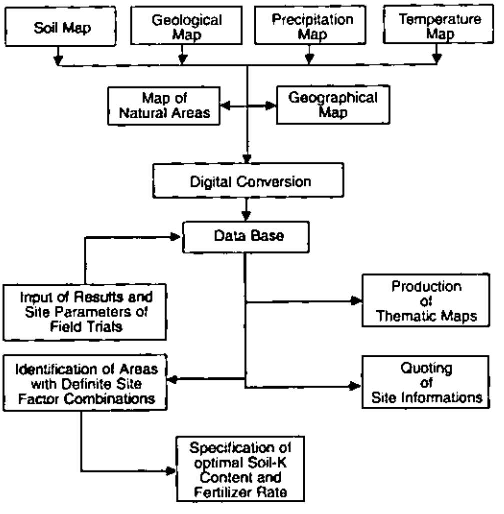

Fig. 5. Structure of the site information system KALIPROG.

The maps which met the requirements had a scale of 1:1 Mio (soil map, geological map, natural regions and administrative areas) and 1:2 Mio (rainfall map and temperature map).

By superimposing the different maps including the digital site information, the following possibilities were provided:

- detailed individual information for given coordinates
- generation of factor combinations from the different maps
- identification and presentation of areas with identical factor combinations
- correlation of areas with identical soil K status and respective optimal economical K fertilizer rates based on the field trial network.

The accuracy of this system is, of course, closely linked to the resolution of the maps and the reliability of the field data which were based on a minimum of results from 6 years and/or two crop rotations.

Use of KALIPROG in the advisory practice

The working principle can be shown with the aid of two long-term experiments on loessal soils in Southwest Germany.

The first trial site "Pforzheim" shows a distinct response of sugar beet to K application whereas the succeeding wheat did not show any response to K application which may be explained by the recycling of the sugat beet tops at harvest (Table 3). The latter contained about 180 kg K/ha. Barley which followed wheat in the rotation did not benefit much from recycled K of the preceding crop and responded to mineral K application with a yield increase.

Table 3. Yields of a sugar beet - wheat - barley rotation as affected by K application on a loessal soil at Pforzheim.

K application ($kg\ K_2O/ha$)		Sugar/grain yield (t/ha)			Net profit	Soil potassium
Beet	Cereal	Sugar beet	Wheat	Barley	(US$ ha/yr)	(mg K/kg)
0	0	11.4	7.83	6.37	0	191
120	50	11.8	7.89	6.71	53.1	224
250	100	12.1	7.85	6.79	73.2	257
400	160	12.2	7.95	6.79	74.4	324

Owing to the differences in the soil K status of the second trial site, different K application rates have been applied due to the fact that K status had to be adjusted prior to the establishment of the experiments. The K application is based on K removals of the crops (Table 4).

Table 4. Yields of a sugar beet - wheat - rye - wheat rotation as affected by soil K status on a loessal soil at Biberach.

K application ($kg\ K_2O/ha$)		Sugar/grain yield (t/ha)				Net profit	Soil potassium
Beet	Cereal	Sugar beet	Wheat	Rye	Wheat	(US$/ha)	(mg K/kg)
300	150	10.8	7.36	5.23	5.62	0	171
300	150	11.5	7.51	5.34	5.75	73.8	249
300	100	11.4	7.62	5.68	5.71	73.2	315

All crops respond to higher K availability in the soil with increased yields. At the lowest K status of the soil, K application had a reduced effect on yields which may be due to K fixation. As in the previous experiment, the highest response to K application was observed with sugar beet. However, wheat also responded to K application which may be explained by the removal of the sugar beet tops at harvest.

Extrapolation of trial results to validity areas

Based on the detailed description of the conditions at the trial site, it is now possible with the aid of KALIPROG to identify areas with the same factor combinations as in the trial in order to find out optimum soil K values and deduct K recommendations.

In Southwest Germany, about 595 000 ha soils are derived from loessal sediments (Figure 6). The identification of loessal soils with a deep horizon as in the experiment is possible by superimposing the soil map with the geological map. About 209 900 ha are representative for these conditions (Figure 7).

Taking into consideration the precipitation data for the trial site "Pforzheim", the validity area of the experiment narrows to about 27 700 ha which represents about 13% of the deep loessal soils in Southwest Germany (Figure 8).

Based on the same principle, the trial results of the second site "Biberach" can be extrapolated to 110 500 ha or almost 53% of the deep loessal soils in Southwest Germany. By superimposing in addition the temperature map, the validity area of the trial site "Pforzheim" shrinks to 12 600 ha (Figure 9).

With this procedure, the estimation of the optimum soil K values and the K fertilizer recommendation can be distinctly improved, owing to the fact that the major parameters which are responsible for the K dynamics can be taken into account.

The use of such a system in the advisory and the accuracy of the fertilizer recommendation obtained through this procedure, however, largely depends on the number of long-term fertilizer trials with a detailed description of the site and the resolution of the maps.

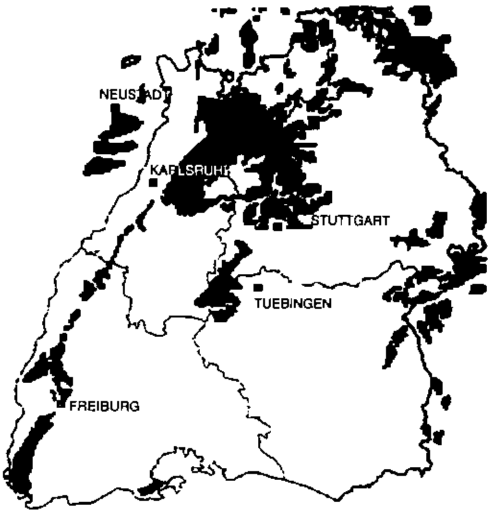

Fig. 6. Areas in Baden Württemberg with soils derived from loessal depositions (Andres, 1993).

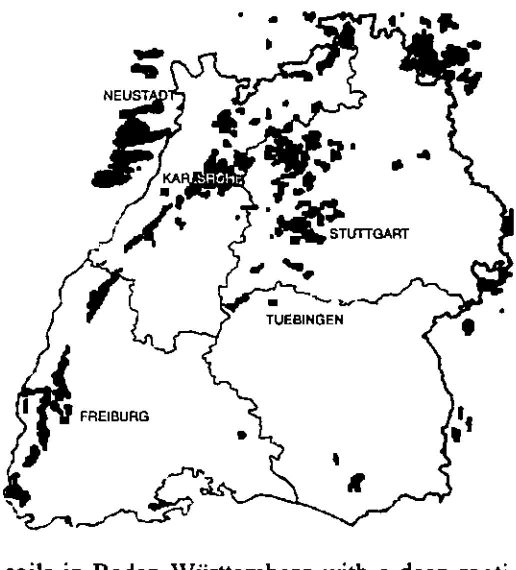

Fig. 7. Loessal soils in Baden-Württemberg with a deep rooting zone (Andres, 1993).

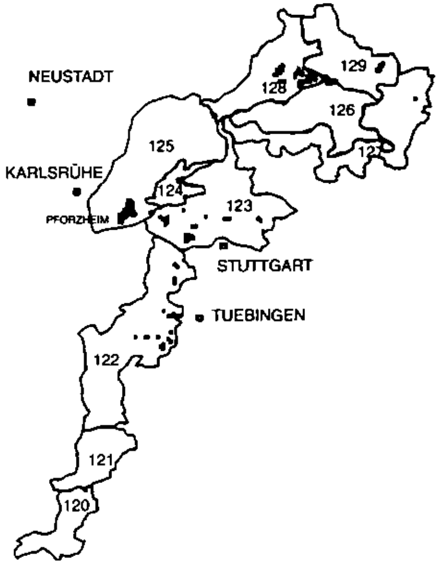

Fig. 8. Validity area of the trial site "Pforzheim", based on geology, soil and precipitation (Andres, 1993).

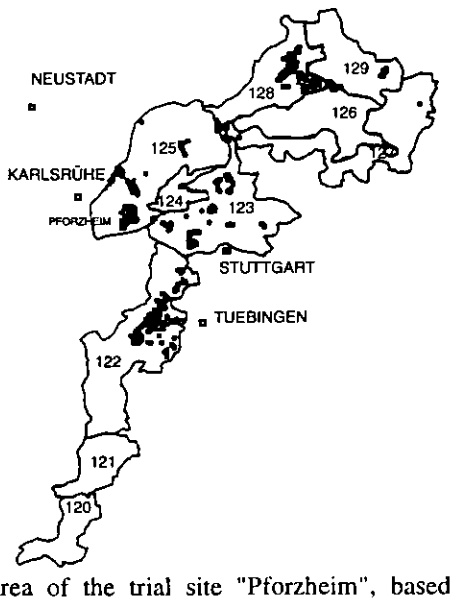

Fig. 9. Validity area of the trial site "Pforzheim", based on geology, soil, precipitation and temperature (Andres, 1993).

Implications for other countries, areas and crops

In most countries, K application is based on average rates by considering only the yield target in order to balance for the removed amount of K at harvest. In the tea production, K application is linked to N application which depends on the yield target, using fixed N:K ratios for certain stages of growth and pruning cycles. The fertilizers are generally applied as mixtures with fixed nutrient ratios in order to supply adequate amounts of fertilizers according to the estimated requirement.

However, spatial variability of the soil and climatic conditions may be considerable and may result in significant deviations from expected response to the fertilizer application. This is especially true for hilly areas where most of the tea is grown. Kantor (1971) identified significant gradients in nutrient reserves down the slope by analysing a catena in the Kitale basement of Kenya (Table 5).

Leaching of nutrients from the upper slope and accumulation of nutrients in the lower part of the hill leads to a significant differentiation in the fertility status of the two sites.

Table 5. Differentiation of soil nutrient reserves along a soil catena developed from granite/gneisses in the Kitale basement of Kenya (Kantor, 1971).

Slope position Soil	Upper slope Palehumult	Lower slope Tropaquult
Nutrient reserves (kg/m^3)		
K	2.10	7.50
Ca	0.35	0.63
Mg	5.53	4.18

Applying the same amount of fertilizer to both sites would accordingly lead to inadequate nutrient supply with the consequences of probable under-supply on the upper slope and/or over-supply at the bottom.

A site specific fertilizer recommendation introduced under such conditions would enable the advisor to differentiate could improve the recommended fertilizer application rates.

A site specific advisory system could thus increase the economics and could improve the ecology of a cropping system by a higher efficiency of soil and fertilizer nutrients.

Acknowledgement

The author acknowledges the assistance of the agronomists of the Kali & Salz Advisory Department, Dr. E. Andres, Dr. K. Orlovius for providing the information and material on KALIPROG, Dr. A. Krauss for providing graphs and tables and his assistance in preparing this paper.

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Management Practices and Experiences with Balanced Nutrition for Tea Cultivation in Vietnam

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Introduction

Tea cultivation can be considered as a highly sustainable system in terms of soil conservation, controlling erosion and leaching and economic implication for the farmer households. Tea cultivation on sloping land is one of the traditional experiences of Vietnamese farmers in order to decrease soil erosion, protect ecological environment (Table 1). It is one of the most profitable sectors of the Vietnamese economy. Therefore, the Government affirmed tea as a strategic plant on upland soils thanks to its high economic value.

Table 1. Crops and soil erosion.

Crops	Amount of soil loss (t/ha/yr)
Cassava	137.3
Maize	86.1
Coffee of 10-years old	22.0
Tea of 10-years old	32.0

Tea has almost been planted everywhere from the Northern to the Southern parts of Vietnam. At present, with the economic open policy plus the introduction of advanced technology into production, the cultivated area of tea and its production have gradually increased.

However, the quality of the marketable tea is not so high as compared with that of some other countries. The main reasons are, on one hand, the unbalanced nutrition, on the other hand, the technology and equipments for manufacturing are backward.

How to increase the yield and quality of tea is at present an urgent demand for tea production in Vietnam.

In recent years, under the assistance of the IPI, PPI and PPIC, the Institute for Soils and Fertilizers (ISF) has carried out various studies on balanced fertilization in tea, based on existing results of long-term experiments of the tea research stations and scientists, in order to achieve the above mentioned target.

1. Main technical practices in tea cultivation in Vietnam

1.1. Some ecological conditions for the tea plant

Tea can be grown everywhere, but some ecological conditions suitable for the tea plant are as follows:

Climate: The annual mean temperature is around 18-23°C, the air humidity above 80% and the rainfall at least 1200 mm.

Topography: Tea can be found at different altitudes: in the North it can grow from above 30m, in the South 200-300m. The landform can be: undulating, semi-orange shape, etc, but the slope cannot be more than 55%.

Soils: Different types of upland soils are used for tea cultivation. In Vietnam, most of them are Ferralsols and Acrisols. The depth of the topsoil must be more than 50 cm. Soil must have a good structure, well drained and high moisture retention. The groundwater level must be at depth of 100 cm or deeper. Soil OM-content is higher than 2%, pH ranges from 4.0 to 6.0.

1.2. Some farmers' practices and experiences in tea cultivation

Field construction: - If the slope is 13% or less, preparing the straight rows paralleled with the contours

- If the slope is more than 13%, constructing narrow terraces or ridges paralleled with the contours in order to limit the runoff, to prevent soil losses. Erecting the wind-break bands with trees 5-10 m large and the distance between them is about 200-300 m. Keeping a continuous green cover on the surface by planting green manure plants, such as: *Tephrosia candida*, *Vigna sinensis*, *Crotalaria*, etc, and other grain leguminous plants.

Transplanting time:	by seed	:	October - November
	by clone	:	January - February and July - August

Plant density: 10 000-20 000 plants/ha as single hedge.

Distance between two rows:	- if the slope is more than 33%:	125 cm
	- if the slope is from 7% to 33%:	150 cm
	- if the slope is less than 7%:	175 cm.
Distance between plants:	- by seed:	40 cm
	- by clone:	60 cm.

Distance between plants is shorter if the slope is more than 33% (30 cm by seed and 50 cm by clone).

Fertilization: Farmers usually use farmyard manure (FYM) combined with phosphate rock or single super phosphate to apply straight to planting holes at a depth of 15-25 cm as basal application. Application rates vary from 15 to 20 t/ha of FYM and 50 kg/ha of P_2O_5.
Nitrogen (Urea) and potash (MOP) fertilizers are applied only as top dressing. For young tea, the N:K_2O ratio used is 1:1, for mature tea it varies from 2:1 to 3:1.

Pruning

- Dressing of the plant:
  in the 2nd year: pruning from the surface: 15 cm,
  in the 3rd year: 30 cm,
  in the 4th year: 45 cm.
- light pruning: when the tea plant reached 70 cm height, pruning 1-2 cm yearly.
- time of pruning: December - January.

Cultivation and maintenance: Young tea is used to be intercropped with green manure and leguminous plants in order to get biomass to return back to the soil, to prevent weeds, to limit the evapotranspiration, and to limit the runoff in the rainy season, to provide biomass for mulching in dry season.

For mature tea, in early spring season, after weeding by shallow hoeing (about 10 cm) burying the fallen leaves of tea and dry weeds into the soil surrounding the tree foot. Farmers usually make shading for tea plant by planting *Cassia siamea, Acacia mangium*, etc.

Harvest: For young tea, plucking tea shoot from the surface 40-45 cm, make inclined plane to the slope.

For mature tea, all shoots should be plucked when 30% of shoot (two or three primary leaves and a bud) have appeared.

2. Balanced nutrition to increase yield and quality of tea

Intercropped green manure plants in young tea

Results of long-term research of the Phu ho Tea Research Station (TRS) showed that in the young tea plantation, green manure plants and leguminous plants could decrease soil loss above 30%, while increasing the soil retention capacity from 6% to 15% decreasing the quantity of weeds.

Buried biomass provides to the soil a lot of N and P; it especially releases phosphorus through the complex mechanism with iron. It also improves soil structure and fertility.

Though FYM use is a habit of farmers, it is common only in rice-growing areas in the plain. In upland areas, organic manure is mainly green manure.

Unbalanced fertilization can only increase the yield but not the quality of tea.

The nitrogen fertilizer application with the rates of 100 kg ha^{-1} N and 200 kg ha^{-1} N has increased the yield of fresh shoots only in some first years after planting. Then, in later years, tea shoot yield did not increase, lots of dead tea plants were even observed. The effect of N-fertilizer application on yield and quality of tea is presented in Table 2.

Table 2. The effect of N-fertilizer application on yield and quality of tea (mean of 10 years).

	No fertilizer	N-rate (kg ha^{-1})	
		100	200
Yield (t/ha/yr)	3.13	3.60	4.15
Tanin content (% dry matter)	32.1	30.7	29.3
Soluble matter	46.4	45.8	45.4

Source: Phu ho TRS (1980).

Balanced fertilization has not only increased the yield, but also the quality of tea.

In recent years, in order to contribute to the balanced fertilization of tea, with the assistance of IPI, PPI and PPIC, ISF has carried out experiments on potash fertilizer efficiency for tea planted on Ferralsols on clayshale. The results are presented in Table 3.

3. Recommending balanced fertilization to the farmers - the best way to increase yield and quality of tea.

In fact, tea production in Vietnam showed that the tea-growing farmers have usually gone in to increase their output. They did not pay much attention to the quality of tea. This is why the farmers have applied a lot of nitrogen fertilizer, causing an unbalance of other nutrients.

Table 3. K Response on yield and quality of tea (27 years old).

Treatments	Fresh shoot yield (kg/ha)	Yield increase (kg/ha)	Tanin content (% dry matter)	Soluble matter content (% of dry matter)
1992				
1. 5t FYM+160 N +50 P_2O_5 = B	11,756	-	21.2	36.6
2. B+ 80 K_2O	12,590	840	21.5	36.6
3. B+120 K_2O	12,630	880	22.4	37.5
4. B+160 K_2O	13,003	1,247	22.6	38.6
5. B+240 K_2O	12,443	687	21.6	38.5
1993				
1. 5t FYM+240 N +50 P_2O_5 = B	12,553	-	25.7	37.6
2. B+ 80 K_2O	13,332	779	27.4	39.1
3. B+120 K_2O	13,615	1,062	29.4	39.4
4. B+160 K_2O	14,065	1,512	30.1	40.3
5. B+240 K_2O	14,226	1,673	29.9	39.8

Very high rates of N-application caused heavy losses due to pests and diseases, therefore, many pesticides must be sprayed. That leads to decrease the tea quality and affects the manufacture processing.

From the above mentioned, some demonstrative models of intensive farming have been established in order to demonstrate to the farmers the advantage of balanced fertilization.

For mature tea grown on Ferralsols on clayshale, applied ratio of 1.5:1 for N:K_2O with the rates of 240:160 kg/ha is recommended.

4. Conclusion

- Vietnam is a country having suitable ecological conditions and potential manpower resources for tea production. Tea cultivation on upland soils gives not only a high profit, but also protects the environment.
- Research on balanced fertilization for higher productivity of tea on different soil types is an urgent demand that should be continued. The recommended N:K_2O ratio should be widely introduced to the farmers.
- In order to get high quality of the market tea, advanced technology and manufacturing equipment should be introduced. For this, foreign investments, joint-venture partners are required.

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Some Aspects of the Chemistry and Mineralogy of Soil Magnesium in Relation to Growth of Tea on Sri Lanka Acid Soils

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Abstract

Tea representative profiles of Sri Lanka acid tea soils overlying dolomitic mineral belts and six profiles from different tea growing regions were subjected to a detailed mineralogical investigation with special reference to the understanding of the chemistry of soil Mg. Despite tea soils being sampled at locations in the central hills of Sri Lanka where dolomitic bands are known to occur, no significant quantities of Mg-containing minerals were found to a depth of 75 cm. These extremely weathered soils contained predominantly kaolinite/halloysite, gibbsite and quartz along with vermiculite, interstratified mica/vermiculite and mica, and with alkali - and plagioclase - feldspars as primary minerals.

Plant available soil-Mg from both 0-15 and 15-30 cm depths of Sri Lanka acid soils, obtained from six different tea growing regions, was measured by intensive cropping with ryegrass, in the glasshouse. No significant difference in the release of Mg was found due to type of soil obtained from above regions. However, release of Mg was influenced by the level of Mg in the soil.

1. Introduction

The soils from different climatic regions, suitable for tea in Sri Lanka, fall into three major soil-groups (Watson, 1986). The major soil groups are ultisols, oxisols and inceptisols of which the largest extent is ultisols (Anon., 1973). Higher yields in clonal mature tea are restricted due to limited supply of plant-available soil-Mg in Sri Lanka acid soils (Sivapalan and Krishnapillai, 1988). Nursery- and young- tea plants in Sri Lanka are fertilized with NPK, along with Mg in the form of Epsom salt and Kieserite, respectively. Generally, the supply of Mg nutrient for mature tea plants is met by the application of crushed dolomitic limestone (Anon., 1989). Application of Kieserite to mature tea plants is specifically recommended for plantations which have previously applied dolomitic limestone, if the soil-Mg extracted by ammonium -acetate or -chloride solution adjusted to pH 7 is lower than 60 mg kg^{-1} soil (Anon., 1993).

The availability of soil-Mg is related to the structure and weathering of Mg-containing minerals (Salmon, 1963; Rice and Kamprath, 1968; Metson, 1974). The crystalline limestones, mainly dolomitic, are confined to the central hills of Sri Lanka and associated with quartzites and other metamorphic rocks (Herath, 1980). These dolomitic limestones are generally found as narrow well defined bands and distributed across the districts of Matale, Kandy and Badulla (Fig. 1). Some tea soils are located on top of these naturally occurring dolomitic limestone bands. A detailed mineralogical investigation was, therefore, undertaken with a range of soil profiles sampled at different tea growing regions, including locations in the central hills of Sri Lanka where dolomitic limestone bands are known to occur, in order to characterize the Mg-containing minerals. The plant available soil-Mg from soils collected from different tea growing regions was assessed under intensive cropping with ryegrass (*Bastian* L.) in the glasshouse for 48 weeks.

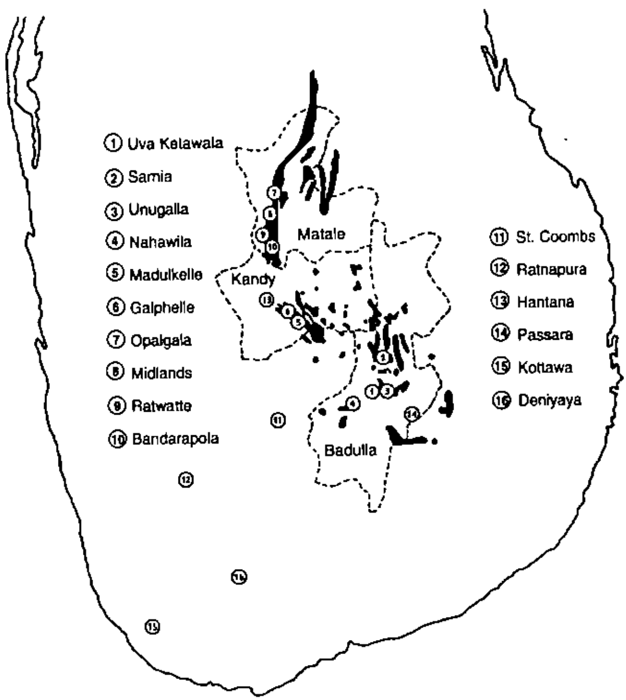

Fig. 1. A part of the map of Sri Lanka showing the locations where soil samples were collected (areas where dolomitic limestone occur are shaded).

2. Materials and methods

2.1. Soils

Ten representative profiles of Sri Lanka acid tea soils overlying dolomitic mineral belts (sites Nos. 1 to 10 in Fig. 1) and six profiles from different tea growing regions (Nos. 11 to 16) were used for mineralogical investigation. The soils were air-dried, passed through a 2 mm sieve. Top (0-15 cm) and sub (15-30 cm) soils of numbers 11 to 16 were used in the ryegrass glasshouse experiment with intensive cropping.

2.2. Mineralogy

Soil (2 mm), coarse (200-2000 μm) and fine (20-200 μm) sand, silt (2-20 μm) and clay (<2 μm) samples were subjected to X-ray fluorescence spectroscopy (XRF), X-ray diffractometry (XRD) and differential thermal analysis (DTA).

2.3. Ryegrass glasshouse experiment

Both 0-15 and 15-30 cm soils obtained from six different tea-growing regions were cropped with perennial ryegrass (*Bastian* L.) without addition of Mg over 48 weeks, with each harvest at 4 to 7 weeks intervals.

3. Results

3.1. Mineralogy

Soils, developed over dolomitic and non-dolomitic sites, and their soil fractions, were analyzed by XRF, XRD and DTA techniques.

Magnesium concentration in soil at different depths

The total concentrations of Mg in acid tea soils (2 mm) at successive 15 cm depths down to about 75 cm were measured by XRF and reported in Table 1.

Total Mg concentrations (%) of the Sri Lanka soil profiles, whether located over dolomitic or non-dolomitic sites, are fairly uniform (Table 1). The highest Mg concentration was observed from the Bandarapola (dolomitic) and St. Coombs (non-dolomitic) locations. Total Mg concentration in soil profiles varied from 0.03 to 0.48% for the soils located over dolomitic sites, whereas it was 0.04 to 0.34% for soils over non-dolomitic sites.

Table 1. Total soil Mg concentration (%) at different depths of Sri Lanka acid tea soil profiles.

Location	Depth (cm)				
	0-15	15-30	30-45	45-60	60-75
Madulkelle	0.10	0.08	0.04	0.07	0.07
Galphelle	0.09	0.13	0.14	0.14	0.12
Opalgala	0.12	0.09	0.11	0.07	0.13
Midlands	0.20	0.21	0.25	0.23	0.16
Ratwatte	0.24	0.26	0.16	0.16	0.16
Bandarapola	0.48	0.43	0.38	0.45	0.46
Uva Ketawala	0.11	0.14	0.10	0.12	0.11
Sarnia	0.05	0.10	0.12	0.05	0.03
Unagalla	0.11	0.21	0.08	0.10	0.10
Nahawila	0.19	0.13	0.17	0.18	0.18
St. Coombs	0.27	0.34	0.21	0.19	0.20
Ratnapura	0.30	0.24	-	-	-
Hantana	0.08	0.06	0.08	0.07	0.08
Passara	0.07	0.04	-	-	-
Kottawa	0.05	0.07	-	-	-
Deniyaya	0.08	0.07	-	-	-

Magnesium concentration in soil fractions

The first two 15 cm soil depths and the second two depths were mixed because of the uniform Mg concentrations found in the soils. The Mg concentration in soil fractions were, therefore, determined in selected soils covering the full range of Mg concentration to a depth of 0-30 cm and the results are reported in Table 2.

Percentage of Mg decreased as the size of the soil fraction increased (i.e. from 2 to 2000 µm) except for Bandarapola and Sarnia locations. Despite the soils being developed over dolomitic or non-dolomitic sites, no significant difference in Mg concentration was observed in the distribution. Highest Mg concentrations in the soil fractions were found at 0-30 cm depth of the Bandarapola and St. Coombs soils, as was in the case of total soil-Mg.

Table 2. Mg concentrations (%) in the clay, silt, fine and coarse sand fractions at 0-30 cm depth in Sri Lanka acid tea soils.

Location	Fraction (μm)			
	< 2	2-20	20-200	200-2000
Bandarapola	0.40	0.37	0.43	0.35
Madulkelle	0.20	0.21	0.03	0.05
Midlands	0.39	0.28	0.20	0.08
Nahawila	0.33	0.26	0.16	0.11
Sarnia	0.02	0.04	0.04	0.08
St. Coombs	0.53	0.45	0.29	0.19
Hantana	0.19	0.16	0.08	0.01

Mineralogy in the clay fraction

The XRD traces for the clay fractions of Sri Lanka acid tea soils at the depths of 0-30, 30-60 and 60-75 cm show that the soil profiles were usually dominated either by kaolinite/halloysite or by gibbsite, the minerals with spacings of 7.1 to 7.3 Å and 4.84 Å respectively (Figs. 2 to 5). A mineral with 14 Å spacing was dominant to 30 cm depth in St. Coombs location (Fig. 5). Substantial quantities of the same mineral appeared even at 30-60 and 60-75 cm soil depths from St. Coombs location. This mineral also appeared at all depths from Madulkelle, Midlands and Hantana locations but to a much lesser extent (Figs. 2 and 5). The interlayer spacing of 10 Å corresponding to mica was observed at all depths from Midlands, Bandarapola and Nahawila locations (Figs. 2, 3 and 4), and at 30-60 and 60-75 cm depths from Madulkelle location. X-ray reflections for the clay fractions at 4.84 Å, 4.15 Å and 3.34 Å (Figs. 2 to 5) indicated that some clay fractions contain gibbsite, goethite and quartz respectively. In addition, some fractions contained traces of alkali feldspars.

Samples were re-analyzed by XRD following auxiliary treatments, in order to identify clay minerals in the range of 7 to 15 Å. Results show the absence of smectite and chlorite minerals, presence of vermiculite and interstratified mica/vermiculite, and the presence of hydroxy-Al species in the interlayer positions of 2:1 type minerals.

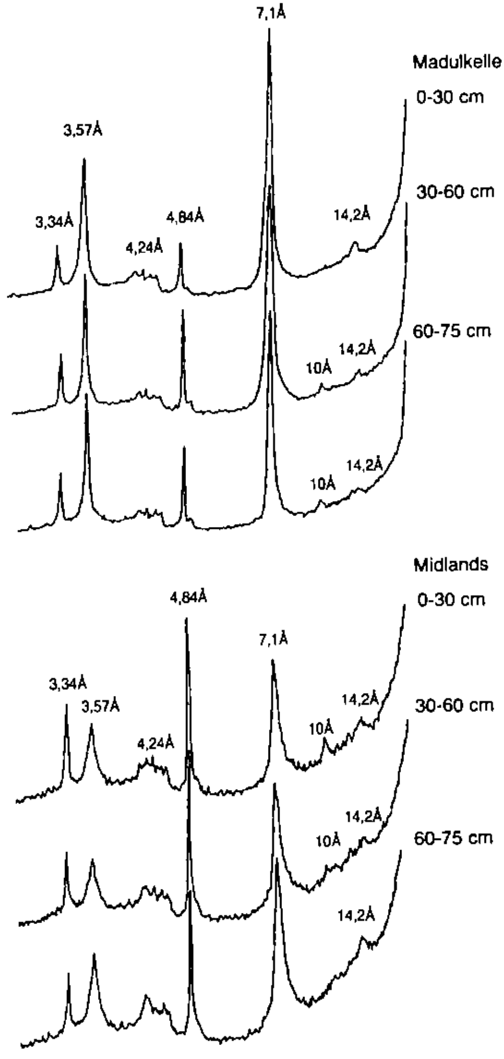

Fig. 2. XRD traces for the clay fractions across Madulkelle and Midlands soil profiles located over dolomitic belts from Kandy and Matale districts in Sri Lanka.

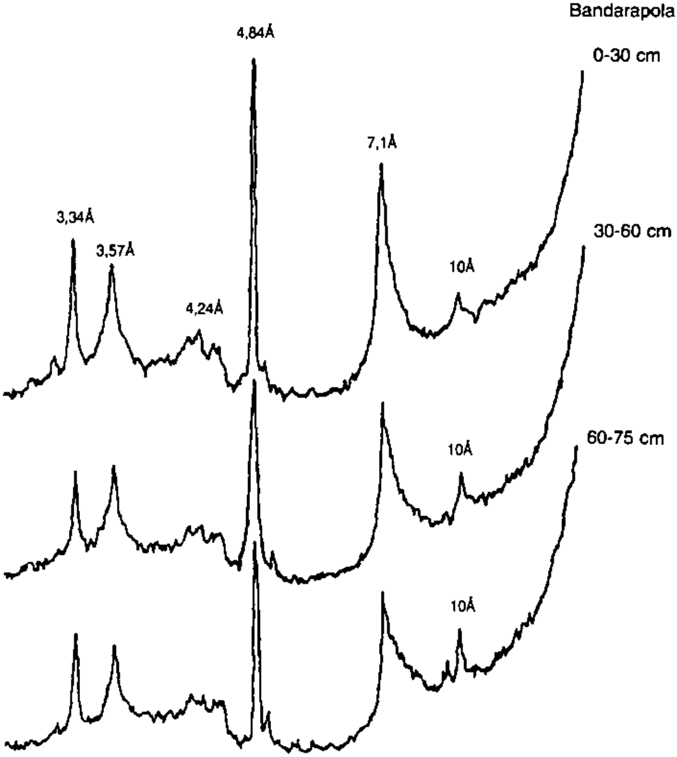

Fig. 3. XRD traces for the clay fractions across Bandarapola soil profile located over dolomitic belts from Matale district in Sri Lanka.

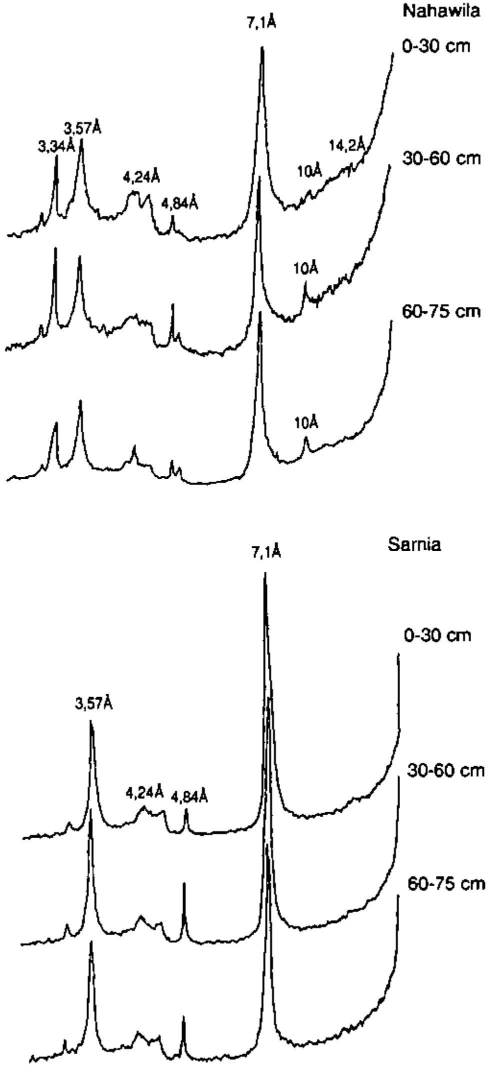

Fig. 4. XRD traces for the clay fractions across Nahawila and Sarnia soil profiles located over dolomitic belts from Badulla district in Sri Lanka.

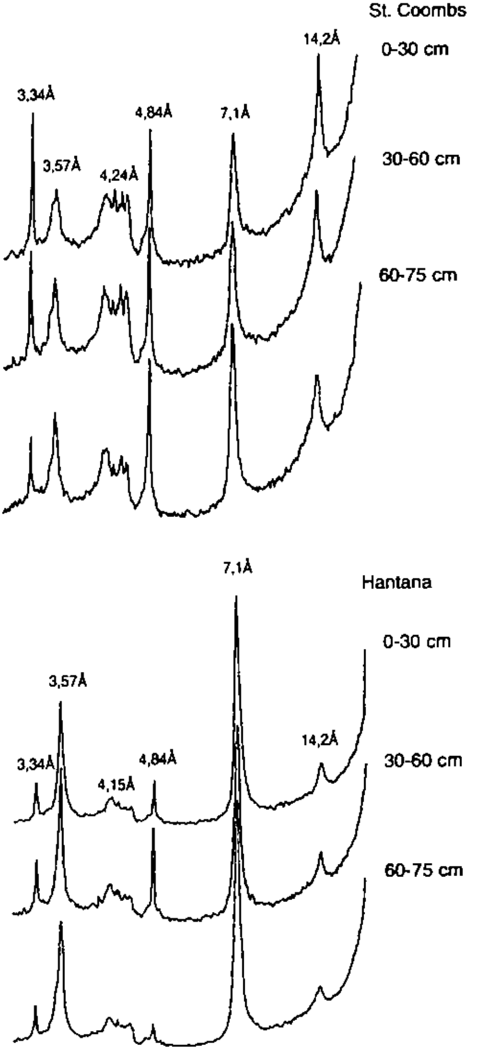

Fig. 5. XRD traces for the clay fractions across St. Coombs and Hantana soil profiles located over non-dolomitic sites from different tea growing regions in Sri Lanka.

Extractable magnesium

Extractable Mg in 1.0 M ammonium acetate solution at pH 7, for the soils for which mineralogical data (XRF and XRD) are available, are shown in Table 3.

Table 3. Ammonium acetate extractable Mg at pH 7 (expressed as mg kg^{-1} air-dried soil).

Location	Depth (cm)		
	0-30	30-60	60-75
Bandarapola	24.9	9.5	6.9
Madulkelle	5.5	2.8	2.8
Midlands	4.9	3.5	2.9
Nahawila	6.6	3.6	5.6
Sarnia	8.3	5.1	5.4
St. Coombs	34.8	9.3	7.7
Hantana	42.3	5.2	3.9

No significant difference was found in extractable Mg down to a depth of 75 cm, despite soils were developed over dolomitic or non-dolomitic sites of the Sri Lanka soils. Although clay fractions obtained from some locations (Bandarapola, Nahawila, St. Coombs and Hantana) contained considerable amounts of vermiculite and mica, no significant difference was found in soil-Mg extracted by ammonium acetate solution at pH 7.

3.2. Ryegrass glasshouse experiment

Percentage and uptake of magnesium

The concentration of Mg in ryegrass, grown on 0-15 cm soil of each location, was higher than that of 15-30 cm soil, except for Kottawa (Figs. 6a and b). Leaf Mg concentration obtained from 15-30 cm Kottawa soil was often higher than that of 0-15 cm soil. No marked drop of Mg concentration in leaves was found over 48-weeks of intensive cropping.

The total uptake of Mg (i.e. roots + stubbles + leaves) obtained from 0-15 cm soil of each location was significantly higher ($P<0.01$) than that of 15-30 cm, except for Kottawa during the entire cropping period (Figs. 7a and b). A significant uptake of Mg ($P<0.01$) was found from 15-30 cm Kottawa soil compared with all other 15-30 cm soils (Fig. 7b).

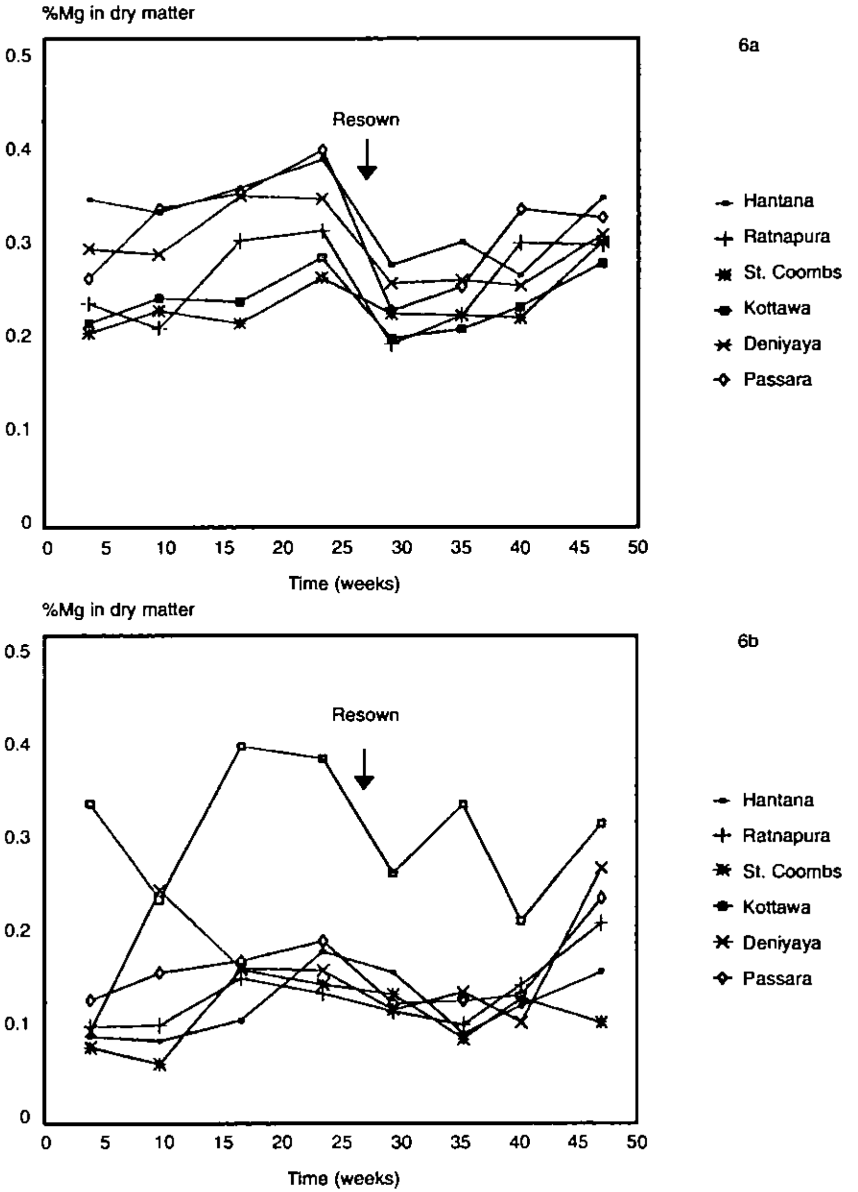

Fig. 6. % Mg in ryegrass at each harvest: a. from 0-15 cm soils
b. from 15-30 cm soils.

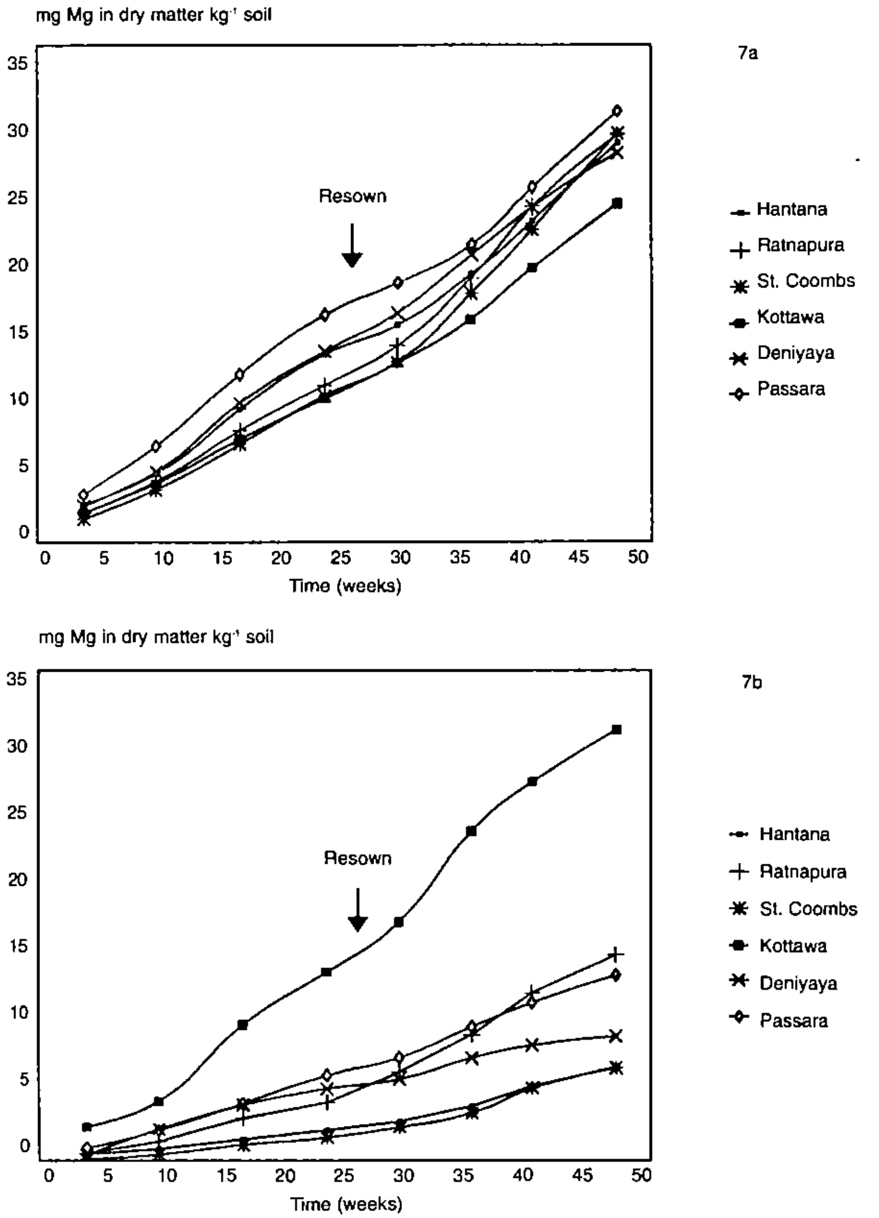

Fig. 7. Cumulative uptake of Mg by ryegrass at each harvest (roots + stubbles + leaves): a. from 0-15 cm soils b. from 15-30 cm soils.

Exchangeable magnesium (Mg_{ex})

The Mg in soil was extracted by 0.1 M ammonium acetate solution at pH 7 and referred to as exchangeable Mg. Initial level (i.e. uncropped) of Mg_{ex} at 0-15 cm depth of each location was higher than that of 15-30 cm depth, except for Kottawa (Fig. 8). The initial levels of Mg_{ex} varied from 28.1 to 69.5 and 8.4 to 45.9 mg kg^{-1} oven-dried soil Mg, for 0-15 and 15-30 cm soils respectively. After 48-weeks of intensive cropping, levels for 0-15 and 15-30 cm soils were decreased to ranges of 12.2 to 41.1 and 4.7 to 24.5 mg kg-1 oven-dried soil Mg respectively.

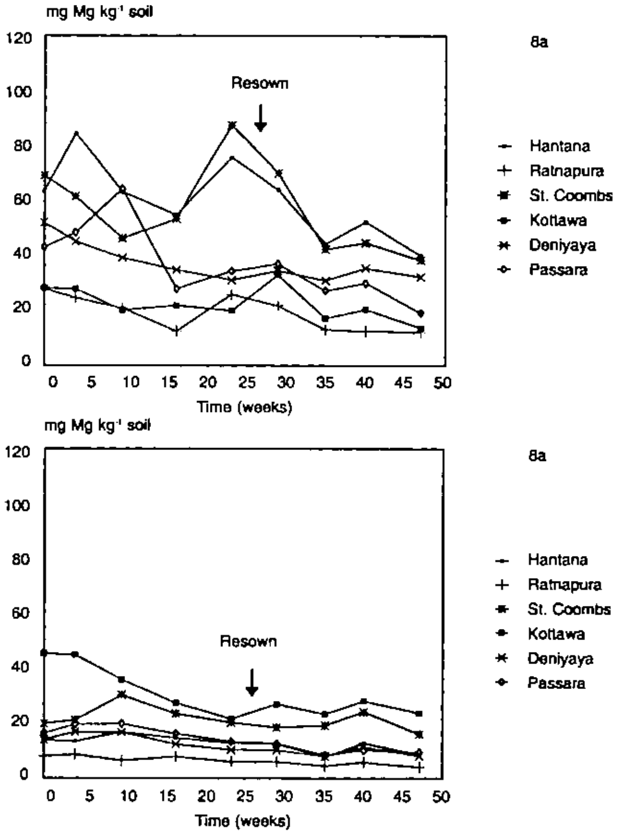

Fig. 8. Soil exchangeable Mg at each harvest: a. from 0-15 cm soils
b. from 15-30 cm soils.

Release of non-exchangeable magnesium (Mg_{ex})

Available Mg (i.e. $\delta Mg_{ex} \equiv Mg_{ex}$ [uncropped soil] - Mg_{ex} [at the final cut]) was subtracted from the cumulative uptake of Mg (Mg_p) and referred to as non-exchangeable Mg. Non-exchangeable Mg for both depths (0-15 and 15-30 cm) of each location is given in Table 4 along with dry matter yield, cumulative uptake of Mg, available Mg, initial level of Mg_{ex} and the initial soil pH.

Table 4. Cumulative dry matter of ryegrass, cumulative uptake of Mg (Mg_p), available Mg (δMg_{ex}), non-exchangeable Mg (Mg_{nex}) and the initial soil pH from intensive cropping experiment.

Location	DM*	Mg_p	δMg_{ex}	Mg_{nex}	Mg_{ex}	soil pH
Hantana						
0-15 cm	8.8	28.5	22.9	5.7	63.9	4.50
15-30 cm	5.8	7.1	5.1	2.0	14.2	4.20
Ratnapura						
0-15 cm	12.5	29.1	15.9	13.2	28.1	4.50
15-30 cm	8.3	15.2	3.7	11.5	8.4	4.40
St. Coombs						
0-15 cm	12.8	29.2	30.2	None	69.5	4.10
15-30 cm	5.1	7.0	3.5	3.5	20.2	4.00
Kottawa						
0-15 cm	10.8	24.3	14.9	9.4	28.5	4.50
15-30 cm	9.7	31.5	21.4	10.1	45.9	4.55
Deniyaya						
0-15 cm	10.5	27.8	20.0	7.9	52.8	4.52
15-30 cm	5.4	9.3	5.5	3.7	14.3	4.20
Passara						
0-15 cm	11.3	30.9	24.8	6.0	44.1	4.40
15-30 cm	7.8	13.6	6.8	6.8	16.8	4.25

* DM is the abbreviation for dry matter (g kg^{-1} oven-dried soil).
Mg_p, δMg_{ex}, Mg_{nex} and Mg_{ex} in mg kg^{-1} oven-dried soil Mg.

A minimum one fifth of total Mg uptake was obtained by ryegrass from non-exchangeable Mg forms, except 0-15 cm depth of St. Coombs. There was no significant effect of soil pH on the release of Mg_{nex}. Soils that contained less than 29 mg kg^{-1} oven-dried soil Mg as Mg_{ex} released 2.0 to 13.2 mg kg^{-1} oven-dried soil Mg_{nex} to ryegrass (Table 4), but not more than 13.2 mg kg^{-1} Mg was found as Mg_{nex} even though initial exchangeable Mg level was above 29 mg kg^{-1} oven-dried soil. This indicated that there was a tendency to release non-exchangeable Mg when level of exchangeable Mg was less than about 29 mg kg^{-1} Mg.

4. Discussion

4.1. Mineralogy

Mineralogical results showed that there were no distinctive Mg-containing minerals in the Sri Lanka acid tea soils even though some were located over dolomitic bands in the central hills. More soluble Mg-containing minerals such as magnesite, dolomite, magnesium sulphate and brucite are weathered and their levels in the soil (i.e. pedosphere) are reduced compared to that in the lithosphere (Barber, 1984). The chemical composition of the crystalline limestone found in the central hills of Sri Lanka vary from pure limestone to more abundant dolomitic limestones (Herath, 1980). Clay mineral investigation of these soils showed the presence of interlayered hydroxy-Al species in the 2:1 clays. Wimaladasa *et al.* (1988) also showed that interlayer positions of some 2:1 clays in the Sri Lanka acid tea soils were occupied by hydroxy-Al species and classified them as Al-chlorite. The mineral vermiculite which has a cation fixing capacity was absent in soils investigated by Wimaladasa *et al.* (1988).

4.2. Release of soil magnesium to ryegrass

Stahlberg (1960), Salmon (1963), Baker (1972), and Christenson and Doll (1978) reported that release of non-exchangeable Mg occurred mainly from the clay fraction. The easily weathered chlorite and vermiculite minerals were considered as main sources. Investigation of the mineralogy of Sri Lanka soils showed that clay fractions obtained from 0-30 cm St. Coombs and Hantana soils contained considerable amounts of vermiculite (Fig. 5). Furthermore, the total Mg (%) was highest in 0-30 cm St. Coombs clay fraction (Table 2), but no release of non-echangeable Mg (Mg_{nex}) was found from 0-15 cm St. Coombs soil (Table 4). No significant amount of non-exchangeable Mg was released even though the clay fraction obtained from 0-30 cm Hantana soil contained vermiculite. No detailed comparison based on the mineralogy of other soils was made to explain their behaviour.

Cumulative dry matter production of ryegrass at the end of 48-weeks cropping from 0-15 cm soil of each location was higher than that of 15-30 cm soil (Table 4), although in case of the Kottawa location the amount of dry matter production was similar in both soil depths. A significant correlation (r=0.63*) between total dry matter production and initial level of exchangeable Mg was found for all soils and depths. This showed that there was an effect of initial exchangeable Mg level on the dry matter production of ryegrass. The ryegrass grown on 15-30 cm Kottawa soil, that contained a higher level of exchangeable Mg, maintained a higher concentration of Mg just as with dry matter production.

Highly significant correlations for both % Mg in ryegrass averaged over each harvest (r=0.80***) and total Mg uptake (r=0.79***) were found with the initial level of exchangeable Mg. No greater difference in soil pH was found in between depths. These results show that the release of Mg to ryegrass was influenced by the level of Mg in soil.

5. Conclusions

5.1. Mineralogy

Despite tea soils being sampled at locations in the central hills of Sri Lanka where dolomitic bands are known to occur, no Mg-containing minerals were found down to a depth of 75 cm. Sri Lanka acid tea soils contained predominantly kaolinite/halloysite, gibbsite and quartz along with vermiculite, interstratified mica/vermiculite and mica, and with alkali- and plagioclase- feldspars as primary minerals.

5.2. Ryegrass glasshouse experiment

The total dry matter production of ryegrass, % Mg in ryegrass averaged over each harvest and the total Mg uptake were correlated significantly with the initial level of exchangeable Mg in soil. Further, no difference in soil pH was found in between depths as well as locations. These results show that the release of Mg to ryegrass was influenced by the level of Mg in soil. Also, no significant difference in the release of Mg was found due to type of soil obtained from different tea growing regions, under glasshouse conditions.

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Effects of Potassium and Magnesium Interaction in Tea Production and Quality of Green, Oolong and Black Tea in China

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Introduction

K, Mg and S are the important macronutrients of tea plant and significantly affect tea growth, yield and quality. Owing to the development of tea production in recent years, the use of nitrogen fertilizers (mainly urea) increased remarkably. As a result, the imbalance of soil nutrients was accelerated and this would decrease the efficiency of fertilizer use and restrict the further improvement of tea quality. Thus, more attention should be paid to the balanced fertilization in tea gardens for more economical benefits. In general, at the present time N and P fertilizer applications in tea gardens have complied with the requirement of tea plants. So, the importance of K, Mg and S application in tea cultivation is being realized by more and more tea planters. In order to provide the scientific basis for rational applications of K, Mg and S fertilizers in tea fields, we cooperated with the International Potash Institute, initiated a research project to study the soil backgrounds and application efficiencies of K, Mg and S, starting from 1992. Some views on the contents and application prospects of K, Mg and S in soils of Chinese tea gardens were proposed based on the above results.

1. Backgrounds of K, Mg and S contents in Chinese tea-growing regions

1.1. Background of K content

Based on the investigation (Table 1) in the process of soil genesis, potassium of tea soils tended to decrease. This tendency was strengthened from the north to the south of China. The results from about 200 soil samples indicated that the range of available K contents were 15.3 to 1031.0 mg/kg soil. Soils with available K content lower than 80 mg/kg soil accounted for 59.05% of the total number of tea soils in China, which are mainly distributed in tea growing regions of Guangdong, Guangxi and Yunnan provinces. Soils with available K content higher than 150 mg/kg soil accounted for 16.49% of the total tea soils and are mainly distributed in the tea growing regions of the north. The contents of available K in tea soils show a remarkable zonal characteristic with declining values from the northern to the southern regions (Table 2).

Table 1. K contents of tea soils developed from Quaternary red clay of different stages of weathering.

Sampling site	Zhejiang	Jiangxi	Hunan	Guangxi	Guangdong
Total K (%)	1.43	1.34	1.12	1.14	0.98
Total K in parent materials	1.68	1.63	1.54	1.59	1.35
Accumulation rate*(%)	-14.88	-17.79	-27.27	-28.30	-27.14

$$\text{*Accumulation rate (\%)} = \frac{\text{(Soil total - K) - (total - K in parent materials)}}{\text{total} - \text{K in parent materials}} \times 100\%$$

Table 2. Zonal pattern of available K content in the soil of low-hilly red earth tea gardens.

Item	Langxi (Anhui)	Lingyou (Zhejiang)	Changsha (Hunan)	Yulin (Guangxi)	Puwen (Yunnan)
Latitude (° N)	31.0	29.0	28.2	22.5	22.1
Content range (mg/kg)	60.6~200.7	23.9~148.8	26.3~104.8	26.1~59.3	15.9~38.1
Mean content (mg/kg)	79.2	66.6	52.4	36.7	24.3
Relation between latitude and K content	y=-88.7755+5.2943x (r=0.9635)				

1.2. Background of Mg content

Due to the differences of parent materials and climatic conditions, Mg contents in tea soils had a wide range. Total Mg contents varied from A × 10^{-2} to A × 10^{-3}. In general, total Mg contents in tea soils developed from limestone and basalt were higher than those from granite and sandstone. Available Mg contents, which had a close relation with tea growth, were between several to several hundreds ppm. According to our results for the low-hilly tea soils developed from the Quarternary red clay (Table 3), soils with available Mg contents lower than 40 mg/kg soil accounted for 72.66% of the total number sampled. The lowest available Mg content was only 1.25 mg/kg soil. It should be pointed out that in some old tea-growing regions producing famous teas, available Mg contents were very low because of the leaching of Mg as a result of long-term fertilization with nitrogen.

For example, the available Mg contents on 39 soils sampled from Longjing tea producing regions of Hangzhou were only 7.8 to 288.4 mg/kg soil with an average of 54.8 mg/kg soil.

Table 3. 0.1 mol/l HCl exchangeable-Mg contents in tea soils of the low-hilly red earth regions.

Content (mg/kg)	>100	70-100	40-70	10-40	<10	Range
Number of soil samples	16	3	19	57	44	1.25-1392.0
Frequency (%)	11.51	2.15	13.69	41.01	31.65	

The available Mg contents in tea soils obviously had a zonal characteristic. Table 4 showed that available Mg contents in tea soils gradually decreased from the north to the south. Therefore, Mg fertilizer should be primarily applied in the large-leaf tea growing regions in southern China and in old gardens in the middle-lower reaches of Yangtze river.

Table 4. 0.1 mol/l HCl exchangeable Mg contents in tea soils of China.

Tea soils	Brown earth	Yellow brown Earth	Reddish yellow Earth	Red earth	Laterite
Range	88.4-215.4	9.2-316.2	1.8-288.4	3.9-248.0	4.4-124.8
Average	125.4	94.2	35.3	22.3	17.1

1.3. Background of S content

The results on 130 soils sampled from eight tea growing provinces showed that total S contents in tea soils were 0.001 to 2.08% and averaged at 0.02%. Soils with total S contents lower than 0.03% accounted for 76.15% of total samples. Available S contents were 3.00 to 221.52 mg/kg, averaged at 65.23 mg/kg soil. The available S contents in 69% of total soil samples were below 80 ppm (Fig. 1).

S contents in tea soils had a close relationship with the productivities of tea fields. Table 5 indicated that in high-yield tea field (>2.25 tons of made tea/ha), total S and available S were 0.02% to 0.05% and 69.91 to 139.09 ppm, respectively. Their variation coefficients were 29.79 and 23.05, respectively. In low-yield tea field (<750 kg made tea/ha), total S and available S contents were 0.005 to 0.006% and 16.11 to 124.37 mg/kg, respectively. Their variation coefficients were 62.73 and 63.48. The variation coefficients of low-yield tea field was greater than that of high-yield tea field.

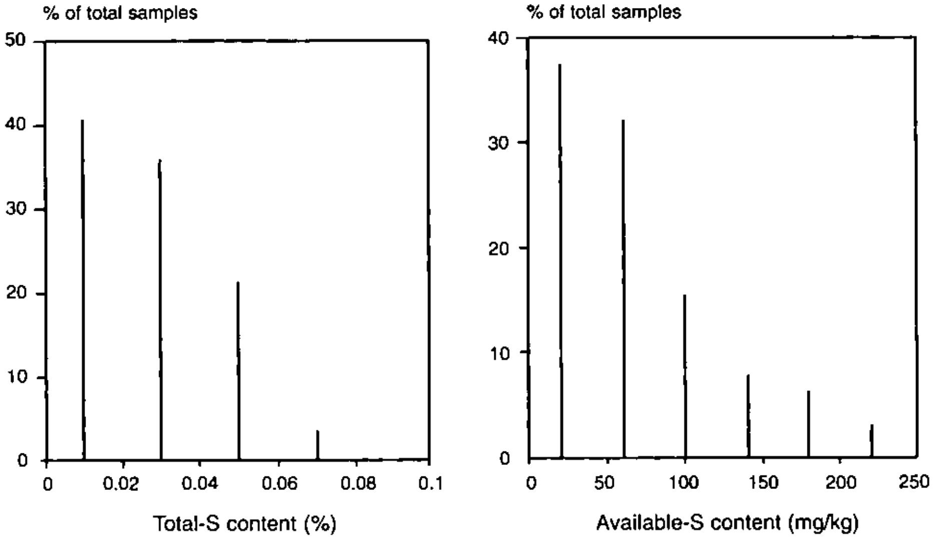

Fig. 1. Frequency distribution of S content in 130 soil samples from 8 tea planting provinces in China.

Table 5. Contents of S in soils of high-yield and low-yield tea fields.

S content	Yield level	Tea producing provinces Hunan	Jiangxi	Guangdong	Anhui	Guangxi	Guizou
Total S (%)	high	0.026	0.031	0.045	0.036	0.022	0.049
	low	0.012	0.013	0.005	0.036	0.015	0.018
Available S (ppm)	high	69.91	124.64	109.19	139.09	88.82	105.73
	low	35.75	42.28	16.11	124.37	65.71	75.79

Many other studies have demonstrated that a linear correlation existed between organic matter content and S content. Fig. 2 revealed this correlation in our study. The correlation coefficients between organic matter and total S, organic matter and available S were 0.925 and 0.836, respectively, indicating that organic matter had evident effect on S contents in tea soils.

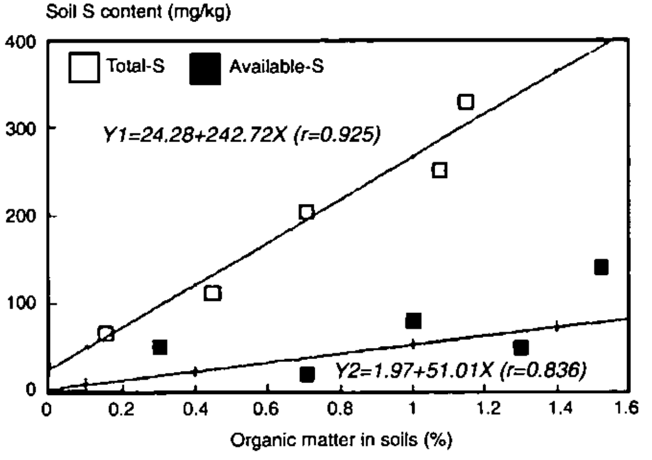

Fig. 2. Linear relationship between S content and organic matter in tea soils.

2. Effects of potassium, magnesium and sulphur on tea growth

2.1. Influences of potassium on tea growth

Effect of K application rates

According to our experiments under the condition of low soil available K (15 mg/kg), the effect of K on the growth of tea plants was substantial. The biomass of roots, stems and leaves increased with increasing K application rate and this trend was still shown even at a high rate of 800 mg K_2O/kg soil. Contents of K and amino acids in tea leaves also increased accordingly (Table 6).

Table 6. Effects of K application rates on tea seedling growth.

Items		Treatments (mg K_2O/kg)				
		K_0 0	K_1 100	K_3 200	K_4 400	K_5 800
Dry matter (g/plant)	roots	3.97	6.27	7.13	8.10	8.43
	stems	3.47	4.53	5.47	6.37	6.70
	leaves	1.20	1.67	1.97	2.33	2.57
Amino acids (%)		0.860	0.943	0.936	1.078	1.161
K concentration (%)		0.957	1.343	1.407	1.607	1.735

Effects of K_2SO_4 and KCl

K_2SO_4 and KCl are the two major sources of potassium fertilizers in tea gardens. The former contains sulphur and the later contains chloride. These two anions have different effects on tea growth. Results indicate that one year after fertilization, the biomass of tea plants supplied with KCl increased by 26% over control and that of those supplied with K_2SO_4 increased by 49%. Amino acids declined in the leaves of KCl treatments, but increased by 0.2% in those of K_2SO_4 treatments compared with the control. Nitrate reductase activity in K_2SO_4 treated plants was also higher than the control (Table 7).

Table 7. Effects of K_2SO_4 and KCl on tea seedling growth.

Items	Treatments		
	NP	NP + KCl	NP + K_2SO_4
Biomass (g/plant)	24.5	30.9	36.4
Percentage	100	126.12	148.57
	Amino acids in		
Leaves (%)	1.032	0.941	1.212
	Nitrate reductase		
(μmol NO_2^-/g.FW.h)	297.7	237.5	356.3

Effect of K on drought resistance of tea plants

Seasonal drought is a hazard to tea growth and the yield and quality. Injury by drought to tea seedlings is more vital. The results are shown in Table 8.

No seedlings survived when soil moisture was maintained at less than 45% of the field capacity (FC), regardless of K application. Under 55% of FC, seedlings with no K supply had a survival rate of 66.7%, those supplied with K had a survival rate of 88.9%. Under 65% of FC, application of K led to an increase in survival rate from 88.9 to 100%. Chemical analysis further indicated that K concentrations in plants increased under all water regimes, but significantly higher in the drought affected plants which may be explained by a dilution effect due to higher biomass production in the plants well supplied with water, showing a higher K uptake (Table 8).

Table 8. Effects of K on tea growth under different soil moisture regimes.

Items	Soil moistures (FC)									
	45%		55%		65%		75%		85%	
	CK	+K	CK	+K	CK	+K	CK	+K	CK	+K
Survival rate (%)	0	0	66.7	88.9	88.9	100.0	100.0	100.0	100.0	100.0
	roots									
Dry weight (g)	-	-	1.2	1.9	1.4	2.1	2.3	2.5	2.5	2.7
K concentration (%)	-	-	0.963	1.480	0.932	1.456	0.857	1.205	0.854	1.175
K content (g/10 plant)	-	-	0.116	0.281	0.130	0.306	0.278	0.301	0.214	0.317
	stems									
Dry weight (g)	-	-	2.1	2.3	2.3	2.5	3.0	3.1	3.5	3.6
K concentration (%)	-	-	0.417	0.510	0.381	0.507	0.381	0.507	0.331	0.483
K content (g/10 plant)	-	-	0.087	0.117	0.088	0.126	0.114	0.157	0.116	0.174
	leaves									
Dry weight (g)	-	-	1.0	1.2	1.2	1.4	2.0	2.2	3.0	3.6
K concentration (%)	-	-	1.463	1.969	1.463	1.910	1.431	1.743	1.378	1.668
K content (g/10 plant)	-	-	0.146	0.236	0.176	0.267	0.286	0.383	0.413	0.600
	total									
K content (g/10 plant)	-	-	0.349	0.634	0.394	0.699	0.678	0.841	0.743	1.090

2.2. Effect of Mg on seedling growth

According to our experiments, under the condition of low soil available Mg (<12 mg/kg), on the basis of N, P and K application, the supply of Mg increased the biomass of 2-year-old tea plants by 1.4 times. This was especially evident for the leaves which weight was 45% higher in NPK+Mg than in NPK treatment. The leaves of tea plants supplied with Mg also contained higher amino acid concentration and had a higher nitrate reductase activity (Table 9).

Table 9. Effects of K and Mg on tea seedling growth.

Items	Treatments			
	CK	NP	NPK	NPK+Mg
Biomass (g/plant)	14.2	22.1	27.4	33.8
Amino acid contents (%)	0.948	0.967	1.112	1.324
Nitrate reductase activity (μmol NO_2^-/g.FW.H)	236.2	296.9	317.1	391.3

2.3. Influence of sulphur on tea growth

Effect of S on photosynthesis

It was established in pot experiment with K_2SO_4 and KCl that K_2SO_4 was more beneficial tea growth. Whether this was due to S and in order to further clarify the physiological mechanism of S in stimulating the growth of tea, another experiment was conducted with various salts, with or without sulphur. Data obtained showed that with the supply of S regardless of the sources used, the photosynthetic rates and content of chlorophyll in S treated plants were much higher than those in non-S treated plants with equal amounts of the same cations (Table 10). However, the large differences in the results between the two K and the two Mg sources indicate that also the availability of the cations in the fertilizer formula was crucial for the photosynthesis and thus the biomass production.

Table 10. Effects of S sources on photosynthesis rate and chlorophyll contents.

Treatments	Photosynthesis rate (mg/hr/dm^2)	Chlorophyll (mg/kg)		
		total	chl a	chl b
K_2SO_4	8.889	1.307	0.984	0.323
K_2CO_3	1.481	0.755	0.469	0.286
$MgSO_4$	5.926	1.167	0.888	0.279
MgO	2.963	0.648	0.447	0.201
$(NH_4)_2SO_4$	11.852	1.276	0.970	0.306
Urea	8.889	1.116	0.806	0.310

Note: All treatments with S were significant at 0.05 level.

Effect of S on nitrate reductase activity

Owing to the low activity in its nitrate reductase, tea grown in soils containing both NH_4^+ and NO_3^- absorbs NH_4^+ preferentially and leaving much NO_3^- in the soils unassimilated which is then prone to leaching. To fully utilize the available NO_3^- in soils, a way has to be found to increase the activity of nitrate reductase in the cultivated tea crops. Our examination indicated that S application activated the nitrate reductase in tea leaves. For the spring shoots of tea plant, nitrate reductase activity was found higher in either K_2SO_4, $MgSO_4$ or $(NH_4)_2SO_4$ treatment than those treated with other salts containing the equal amounts of the same cations without sulphur. The activity increased by an average of 4.8 times with the highest in $MgSO_4$ treatment (5.7 times of the control). The total N contents also increased in S treated plants accordingly (Table 11).

Table 11. Effects of sulphur on the activity of nitrate reductase in shoots.

Items	Treatments					
	K_2CO_3	K_2SO_4	MgO	$MgSO_4$	Urea	$(NH_4)_2SO_4$
NR activity (μmol NO_2^-/g.FW.h)	207.8	944.6	186.2	1074.2	151.1	618.0
N concentration (%)	1.72	3.44	3.36	3.87	3.12	4.63

3. Effects of K, Mg and S on the yield

The results of three locations showed that K_2SO_4 and $MgSO_4$ both raised the yields. For K_2SO_4 the yields increased from 11 to 17% at Hangzhou, 5 to 8% at Yinde, and 1 to 9% at Anqi. The increasing rate rose when the application dose increased, but slightly declined as compared with that of 1992. Though the potassium content at Yinde, Guangdong was lower than that of Hangzhou, Zhejiang, the increase of yields at Guangdong was less significant. The reason for this might be that the yields at Guangdong were at a higher level. $MgSO_4$ plus K_2SO_4 increased the yields by 20% at Hangzhou, 11 to 13% at Yinde, and 9 to 27% at Anqi as compared with the treatments of no $MgSO_4$ and K_2SO_4 application (Table 12).

Table 12. Effects of K_2SO_4 and $MgSO_4$ on tea yields (fresh leaves, t/ha).

Locations	Year	Treatments				
		K_0	K_1	K_1+Mg	K_2	K_2+Mg
Zhejiang	1992	8.25	9.32	9.64	9.74	-
	%	100	113	117	118	-
	1993	8.68	9.66	10.42	10.17	10.35
	%	100	111	120	117	119
Guangdong	1992	20.80	23.09	22.88	23.82	-
	%	100	111	110	115	-
	1993	18.95	19.84	21.22	20.44	21.49
	%	100	105	112	108	113
Fujian	1993	7.43	7.51	8.12	8.12	9.47
	%	100	101	109	109	127

4. Effects of K, Mg and S on the quality

Tea is a healthy beverage. Good quality is one of the most important objectives for the cultivation. K, Mg, S, as the important nutrients of tea plants, cannot only promote the growth and increase the yield, but also effectively influence the quality of tea. As such, Mg is an activating factor for many enzymes and has a close relationship with tea quality. A comparison between the Mg concentration in made tea and the tea quality grade showed that the higher quality was positively correlated with the content in the leaves. The correlation coefficients (r) were above 0.789 (Table 13). Therefore, regular application of Mg-containing fertilizers to tea gardens is recommendable for improving tea quality. Mg being called "quality element" is reasonable.

Table 13. Correlation of tea quality grade (Y) and its Mg concentration (X).

Green tea	Y = a+bx	Correlation coefficient
Gunpowder tea	y = 25.2946-0.0122x	-0.9840**
Roasted tea	y = 8.9290-0.5500x	-0.7890**
Longjing tea	y = 61.3638-0.03023x	-0.8248**

Note: The higher the grade, the poorer the quality of the tea.

S can significantly increase not only the amino acid content (Table 14) but also the flavour component content in tea and the fragrance quality of made tea (Fig. 3).

Table 14. Effect of sulphur on the free amino acid components (mg/g) in leaves.

Amino acids	Fertilizer K_2CO_3	K_2SO_4	MgO	$MgSO_4$	Urea	$(NH_4)_2SO_4$
ASP	1.18	3.52	1.25	2.52	1.80	4.23
THR	0.25	0.60	0.28	0.43	ND	0.67
SER	0.38	1.00	0.38	0.66	0.60	0.96
GLU	0.40	1.23	0.40	0.32	0.69	0.47
GLY	0.37	0.92	0.29	0.52	0.53	0.76
ALA	0.24	0.66	0.24	0.50	0.38	0.31
CYS	0.16	ND	0.58	0.19	0.36	0.25
VAL	0.06	0.14	ND	0.19	0.24	0.44
MET	0.09	0.28	0.49	0.08	0.14	0.20
ILE	0.18	0.11	0.16	0.11	0.36	0.15
LEU	0.14	0.36	0.28	0.20	ND	0.27
TYR	0.06	0.07	0.54	0.04	0.20	0.11
PHE	0.11	0.34	0.24	0.11	0.19	0.29
LYS	0.06	0.28	0.02	0.11	0.04	0.05
HIS	0.21	0.43	0.36	0.22	0.34	0.37
ARG	0.43	2.67	ND	0.26	0.53	5.96
PRO	1.70	3.40	0.41	2.14	2.47	2.54
THE	1.73	12.90	1.38	14.00	3.17	22.40

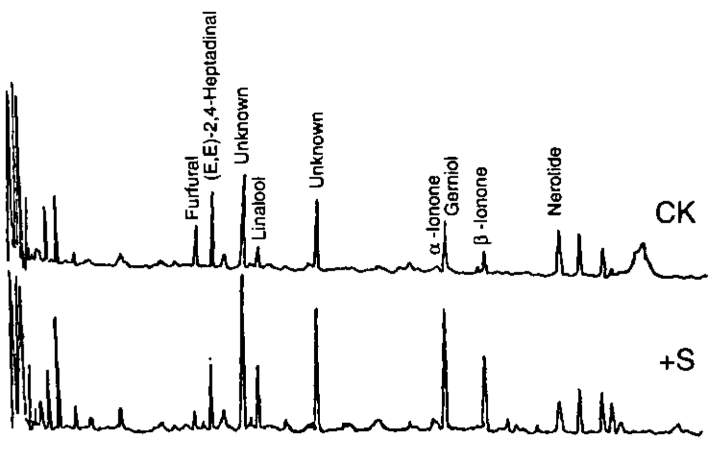

Fig. 3. Chromatographic analysis of aromatic component in tea with S treatment.

So, K_2SO_4 application combined with $MgSO_4$ had a good effect on regulating the biochemical quality components in black tea, oolong tea and green tea (Table 15).

Table 15. Effects of K and Mg on tea quality.

	Spring tea			Autumn tea		
	amino acids %	polyphenols %	caffeine %	amino acids %	polyphenols %	caffeine %
	Hangzhou, Zhejiang (green tea)					
K_0	2.950	26.02	3.548	1.214	23.98	2.703
K_1	3.071	26.64	3.619	1.420	24.18	2.912
K_1+Mg	3.247	26.26	3.736	1.540	23.94	3.130
K_2	3.122	26.46	3.850	1.450	24.75	2.900
K_2+Mg	3.408	25.12	4.047	1.665	24.52	3.109
	Yingde, Guangdong (black tea)					
K_0	2.722	25.96	3.786	1.193	24.99	2.628
K_1	2.792	26.53	3.790	1.256	25.43	2.712
K_1+Mg	2.977	25.77	3.791	1.378	22.32	2.706
K_2	2.835	27.50	2.785	1.337	25.70	2.766
K_2+Mg	3.176	25.14	2.795	1.527	22.22	2.722
	Anqi, Fujian (oolong tea)					
K_0	2.674	24.78	3.744	0.953	25.19	2.476
K_1	2.785	25.13	3.768	0.975	25.95	2.495
K_1+Mg	2.818	23.59	3.849	1.162	25.05	2.556
K_2	2.759	25.40	3.895	1.065	26.34	2.615
K_2+Mg	3.098	25.06	3.846	1.188	26.08	2.700

Therefore, we believe that high yielding, good quality and best profits are the principal tasks in present tea production. Scientific application of fertilizers is one of the most important measures. By increasing N and P fertilizers applications, K, Mg, S deficiency gradually aggravated, especially in big-leaf tea gardens in South China. At the present cultivated level, applying 300-400 kg K_2SO_4 per hectare generally increases the yield by 1%-20%. K application combined with Mg fertilizer increases the yield by 10%-27% and improves the quality of black tea and green tea, especially increases the contents of amino acids and tea polyphenols. Scientific applications of K, Mg and S fertilizers should be done as one of the most important measures in present tea production.

China is a large tea-producing country, the development of tea production having a significant influence on the development of economy and agriculture in red-yellow earth regions of China. Increasing input of K, Mg, S fertilizers will have a positive effect on promoting the development of agriculture in these regions.

Chairman of the Session 4

Dr. R.L. Wickremasinghe

Session 4

Nutritional Aspects of Tea Physiology

Effect of Potassium Nutrition and Growth Regulators on Photosynthesis and Assimilate Translocation in Tea

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Abstract

The role of agro-inputs such as potassium and bioregulators to improve the productivity of mature tea has been evaluated in South Indian tea plantations, over the past four years. Positive response in crop productivity has been observed. Physiological explanation for the crop response in terms of photosynthesis, partition of assimilates and drought tolerance was sought on field grown mature tea bushes.

Muriate of potash (MOP), foliar applied with urea, imparts drought tolerance by reducing the transpirational loss. Turgid cells sustain high rates of photosynthesis and rapid mobilisation of assimilates. Eco-friendly biostimulants also promote crop growth through improved photosynthesis, partition of assimilates and turgidity of cells.

Foliar application of NK and growth regulators play a positive role in achieving higher productivity through enhanced carbon metabolism and effective utilisation of nutrients.

1. Introduction

Drought is a recurring phenomenon in tea plantations as the crop is principally rain dependent. Impact of drought accounts for about 20% crop loss every year. Any remedial measure to minimise the impact of drought will go a long way in achieving higher productivity from the existing plantations, particularly in drought susceptible cultivars.

Similarly, most of the plantations have reached a plateau in production despite the concerted efforts of crop management. The key for boosting the productivity further, therefore, lies in the judicious use of plant growth regulators in integrated crop and nutrient management.

Conscious steps to alleviate the drought effet and judicious use of growth regulators are expected to contribute to a crop increase of 10 to 15% every year without unduly affecting the health of the bushes or quality of made tea.

Quite a few palliative measures against drought in tea plantations have been evaluated in the past four years and encouraging results have been obtained. Crop response and supporting physiological evidences for the response from field experiments in mature tea are brought out.

In order to explore the feasibility of breaking the yield barrier in high yielding areas, a few biostimulants were evaluated and positive results were obtained. Supportive evidences on physiological parameters such as photosynthesis and partition of assimilates of the treated plants in response to foliar applied K and different bioregulators were recorded.

2. Methodologies

The NK foliar and bioregulator experiments were conducted in randomised statistically laid out plots of mature tea (UPASI-3, planted in 1973) in the Anamallais. In the case of NK foliar application, 1% (2 kg in 200 litre of water) each of fertilizer grade muriate of potash (MOP) combined with urea in tank-mix was used. 200 liters of spray fluid were applied per hectare with hand operated backpack sprayers. Application commenced in November or December and continued till March/April at monthly intervals.

Three types of eco-friendly, indigenously produced anti-transpirants, namely, Antistress of Godrej Soaps, an amine based product, Hicodhan of Hico Products, a substituted long chain fatty acid alcohol and Humipic of ITC Ltd, a polymer of glycol, were evaluated to combat the moisture stress in tea, particularly on drought susceptible cultivars. The anti-transpirants were compared with the NK foliar application. The experiments were conducted for a minimum of 3 years to evaluate the responses.

Two types of eco-friendly, natural bioregulators such as Biozyme of Wockardt India Ltd and triacontanol based products, Paras Photosynth of Hindustan Lever Ltd, were evaluated in mature tea. Biostimulants were applied at beginning and end of peak flushes at 200 litre spray fluid per hectare in randomised plots of 40 to 60 bushes in mature tea yielding 4000 kg made tea per hectare. The experiments were conducted over the past four years and the response during the cycle was obtained. Photosynthesis was measured using LCA-3 portable photosynthesis system of Analytical Development Company, UK.

Shoot water potential (Psi shoot) was estimated using Scholander pressure chamber supplied by Soil Moisture Equipment Corp., California, USA. Three to five observations were made per treatment using randomly sampled shoots comprising three leaves and a bud.

Partition of assimilates was estimated on field grown treated mature bushes, using radioactive carbon (^{14}C) following the procedure of Hale and Weaver (1962). Crop records were maintained as usual and routine maintenance practices were uniformly given. Carbohydrate content in roots was estimated quantitatively in the treated bushes at the end of the season. For carbohydrate quantification, pencil-thick roots were random sampled and averaged over three estimations. Carbohydrate estimation was done in Skalar Autoanalyser, following the method of McCready *et al.* (1950).

3. Results

Potassium is a potential, highly mobile macronutrient for plant growth, though it does not form a constituent of any compound. Its role on stomatal regulation is well documented in many horticultural crops (Fischer, 1968; Dey, 1977; Anon., 1992). Absorption of K^+ is facilitated by including urea as an additive in the tank mix. NK foliar application to combat the drought in mature tea is a recommended practice in South Indian tea plantations (Manivel, 1993).

Foliar application of NK and anti-transpirants to combat the drought in mature tea was given during November/December. Results indicate that foliar application of NK and anti-transpirants minimised the impact of drought, sustained higher rate of photosynthesis (Table 1), effect favourable partition of assimilates (Table 2), retained turgidity of cells (Table 3), resulting in early recovery and higher productivity in drought susceptible "Assam" cultivars (Table 4) without affecting the health (Table 5).

Table 1. Effect of NK foliar and anti-transpirants on photosynthesis (mg $CO_2.dm^{-2}.hr^{-1}$).

Treatment	Photosynthesis
Control	7.70
Antistress 350 ppm	9.15
Hicodhan 1000 ppm	9.70
Humipic 1000 ppm	9.85
MOP, urea 1% each	9.15
C.D. P = 0.05	0.91

Table 2. Effect of NK foliar and anti-transpirants on partition of assimilates.

Treatment	% translocated
Control	21.0
Antistress 350 ppm	23.0
Hicodhan 1000 ppm	32.0
Humipic 1000 ppm	13.0
MOP, urea 1% each	38.0

Table 3. Effect of NK foliar and anti-transpirants on shoot water potential (turgidity).

Treatment	Psi shoot (- bars)
Control	12.8
Antistress 350 ppm	10.3
Hicodhan 1000 ppm	9.9
Humipic 1000 ppm	10.1
MOP, urea 1% each	9.9
C.D. P = 0.05	0.7

Table 4. Effect of NK foliar and anti-tranpirants on productivity (KMTH).

Treatment	Drought	Whole year
Control	995	4412
Antistress 350 ppm	1124	4775
Hicodhan 1000 ppm	1101	4791
Humipic 1000 ppm	1140	4764
MOP, urea 1% each	1102	4760
C.D. P = 0.05	100	298

Table 5. Effect of NK foliar and anti-transpirants on carbohydrate reserve in roots.

Treatment	% carbohydrate
Control	10.6 ± 0.7
Antistress 350 ppm	12.3 ± 0.6
Hicodhan 1000 ppm	12.3 ± 0.3
Humipic 1000 ppm	13.0 ± 1.1
MOP, urea 1% each	13.4 ± 0.3

Impact of Biozyme and triacontanol based formulations on productivity as a result of enhanced photosynthesis (Table 6), favourable partition of assimilates (Table 7), and effective utilisation of nutrients in field grown mature tea have been observed.

Table 6. Effects of biostimulants on photosynthesis (mg $CO_2.dm^{-2}.hr^{-1}$).

Treatment	Photosynthesis
Control	7.65
Biozyme 1000 ppm	10.16
Paras photosynth 2 ppm	9.32
C.D. P = 0.05	0.91

Table 7. Effects of biostimulants on assimilate translocation (%).

Treatment	% translocated
Control	10.4
Biozyme 1000 ppm	21.5
Paras photosynth 2 ppm	18.0

The increase in photosynthesis, higher mobilisation of photosynthates, improved shoot water potential (Table 8) and reduction in number of banji shoots brought about by the treatments corroborate the improved productivity (Table 9) achieved without affecting the quality of made tea or health of the bushes. No taint or detectable residue of chemicals have been observed.

Table 8. Effects of biostimulants on turgidity (- bars).

Treatment	Turgidity (- bars)
Control	12.5
Biozyme 1000 ppm	11.0
Paras photosynth 2 ppm	11.5
C.D. P = 0.05	0.7

Table 9. Effects of biostimulants on productivity (KMTH).

Treatment	Productivity (KMTH)
Control	4412
Biozyme 1000 ppm	4824
Paras photosynth 2 ppm	4836
C.D. P = 0.05	298

Carbohydrate reserve, an index of health of tea bushes, has not been unduly deflected by the treatments, in spite of their application in the past four years; health of the bushes has not been impaired despite higher crop harvested (Table 10).

Table 10. Effects of biostimulants on carbohydrate reserve (%).

Treatment	% Carbohydrate reserve
Control	10.6 ± 0.7
Biozyme 1000 ppm	13.8 ± 0.9
Paras photosynth 2 ppm	13.2 ± 0.7

4. Conclusions

Considering the results of the field experiments in mature tea, it may be inferred that foliar application of MOP mixed with urea, 1% each, imparts drought tolerance, promoting the early crop resulting in about 6 to 8% overall crop increase every year. The health of the bushes is preserved and the leaves sustain higher rate of photosynthesis and favourable partition of assimilates due to high turgidity of the cells.

Application of anti-transpirants, such as Antistress, Hicodhan and Humipic imparts drought tolerance in young and mature tea. Combination of NK foliar with any of these anti-transpirants is being evaluated to promote cost effectiveness.

Application of biostimulants, Biozyme alternated with TRIA based Paras Photosynth or any other similar formulation helps in breaking the yield barrier without affecting the quality of made tea or health of the bushes. Hence, these practices of foliar application of NK, anti-transpirants and biostimulants can be integrated very well into the crop management of tea plantations for sustained higher productivity.

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Partitioning of Assimilates and Productivity of Tea

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1. Introduction

Unlike in other crops, economic yield of tea constitutes a small fraction of the total dry matter produced by the bush. A major part of the photosynthates is lost in respiration. The balance is distributed among various organs. The fact that a small fraction of assimilates is partitioned into pluckable shoots makes the possibility of increasing partitioning in favour of pluckable shoots an attractive proposition. Magambo and Cannell (1981) observed that the main opportunity for increasing tea yield was in increasing harvest index and not total biomass.

The harvest index of tea has been reported to vary from 7.5% (Hadfield, 1976) to 9-12% (Barua, 1989) in N.E. India. At high altitude in Kenya (2178 m) only 8% of the total dry matter produced (including roots) or 11% (when roots were excluded) was allocated to the harvested shoots (Magambo and Cannell, 1981). For South India, the harvest index has been reported to be 14.7% (Sharma and Ranganathan, 1985).

It has been reported that only around 40% of the assimilates contributed towards productivity as well as other metabolic processes. The balance remained in the mature maintenance leaves. The magnitude varied depending on the source-sink relationship (Manivel and Husain, 1982). It has also been reported that the top maintenance foliage contributed maximum to yield (Manivel and Husain, 1982).

It is now accepted that yield of tea is generally sink limited (Tanton, 1979; Squire, 1985). Partition of growth can be diverted to actively growing shoots if their number can be increased.

In this context, it is interesting to note that major percentage of potential buds did not develop into pluckable shoots (Jain and Tamang, 1988). Activation of even a small proportion of these buds could make significant contribution to increase the productivity.

2. Partition of growth

A large part of the dry matter synthesised by plants is lost in respiration. The balance is distributed among various plant organs. Hadfield (1976) computed the annual gross and net productivity in tonnes dry weight per hectare and as percent of gross productivity. The figures are given below.

Table 1. Respiration and annual net productivity in a 20-year old section of tea bushes.

	Dry weight (t/ha)	%
Annual respiratory loss	22.4	60.5
Harvested tea shoots	2.8	7.5
Leaves	4.0	10.8
Pruning stems	3.4	9.1
Addition to permanent frame	2.0	5.4
Addition to root system	2.5	6.7
Total	37.1	100.0

Barua (1989) reported results of a study on six clones averaged over a period of ten years under shaded condition (will be roughly equivalent to the growth made by six-year old bushes). Only 35.4-37.4% of the dry matter produced by a plucked tea bush remained on the plant. 63-66% was lost in metabolic respiration. Tanton (1979) estimated respiratory losses in Malawi to be at 67%.

Studies on six clones at Tocklai (Barua, 1989) and five clones in Kenya (Othieno, 1982) have shown that partition of growth into various plant parts is influenced by clones as well as by place. Comparable clones produced almost equal amounts of dry matter in a year in both the places but with a different pattern of partition. In Kenya, weight of plucked shoots accounted for 11% and that of roots 17% of the net gain in a year. The corresponding mean figures in Assam were 30 and 8%.

3. Factors affecting partition of assimilates in tea

There are three principal processes of growth in plants (Snyder and Carlson, 1984), namely:

- Expansion of organs
- Production and storage of dry matter
- Partition of dry matter.

Rate of development is largely controlled by temperature when other factors are not limiting. Leaf area expansion is also a temperature dependent process when other factors are not limiting. In all crops, major determinant of yield is the proportion of dry matter partitioned to economic yield.

The factors affecting partitioning of assimilates are:

1. Genotype
2. Environment
3. Nutrients
4. Management: pruning, plucking, bush population
5. Shade
6. Age

3.1. Genotype

Genotypes vary in their ability to convert assimilates to pluckable shoots. Barua (1989) has reported that China plants converted a higher fraction of assimilates into crop shoots compared to Assam plants. This could be due to the larger number of shoots produced by China plants. Magambo (1978) found that the highest yielding clone was not necessarily the one with the highest rate of dry matter production. It could be a clone which diverted the highest proportion of dry matter to new leaf production. Wadasinghe and Wettasinghe (1983) studied the growth of four TRI clones and concluded that the superior performance of TRI 2023 was due to its ability to partition greater fraction of the photosynthates for production of shoots and to its quick regeneration from prune. The lowest yielding clone DN diverted most of the photosynthates towards production of roots and stems. However, the well developed root system of DN was one of the reasons for its drought tolerance.

Thus, high yielding clones are likely to have a smaller bush frame and root system. At the same time, clones having a smaller root system are likely to be more vulnerable to adverse environment, particularly moisture stress.

3.2. Environmental factors

Snyder and Carlson (1984) have reviewed the effect of environmental factors on partitioning of dry matter in agricultural crops. Barua (1989) has also discussed the effect of environmental factors on growth partitioning in tea. This subject is briefly discussed below:

Temperature: Temperature has a great influence on growth processes as well as on partitioning. Nakayama and Harada (1962) found that growth was most rapid and leaf size was maximum at 30°C. Growth of tea shoots ceased at 12-13°C. Barua (1989) has discussed the observations on partition of growth in Kenya (Othieno, 1982) and Tocklai.

The clones of Othieno's trial and the high yielding clones of Tocklai produced almost equal amounts of dry matter in a year but with a different pattern of partition. In Kenya, weight of plucked shoots accounted for 11% and that of roots 17% of the net gain in a year. The corresponding mean figures in Assam were 30 and 8%. This has been explained to be due to the lower temperature in Kenya which caused slowing down of shoot growth resulting in increased partition of assimilates to other parts of the plant.
Snyder and Carlson (1984) also observed decrease in the amount of dry matter partitioned to storage organs in cassava under conditions of high temperature and high leaf area index.

Light: Snyder and Carlson (1984) observed that more light, duration or intensity, increased biomass and usually increased the proportion of root weight and economic yield of many crops. Normally, production of assimilates increases with increase in irradiance level. However, partitioning of assimilates would depend on the relative capacity of source and sink. In tea, long days are favourable for growth and yield. Better growth of shoots was recorded by Mitsui and Harada (1926) when days were long. Effect was more pronounced on length of internode. In N.E. India, shade has been found to exert favourable influence on growth and partition of assimilates to the production of plucked shoots (Anon., 1973). Shoots were heaviest at 50% light intensity.

Water and humidity: Insufficiency of water usually increases the proportion of root to total biomass as well as root to shoot in agricultural crops (Caloni *et al.*, 1980). Rainfall, soil moisture and atmospheric humidity are interrelated. Growth of tea suffers if available soil moisture in the root zone becomes less than 50%. Growth of shoots is also affected adversely when the saturation deficit exceeds 23 mbar in the afternoon (Tanton, 1982). Such adverse conditions can affect partition of growth to shoots adversely.

3.3. Nutrients

There are no experimental data reporting the effect of various nutrients on the partitioning of growth in tea. However, there are many experiments which show the effect of different nutrients on yield of tea. Thus, response to nitrogen and potash is universal and there is significant N×K interaction. Response to phosphorus is less universal and is also less in quantitative terms. This is probably due to the relatively small amounts in which it is required. Many soils are able to meet this requirement particularly at low levels of yield. Response to zinc is also fairly widespread. Response to magnesium, sulphur and other nutrients is more location specific.

Nitrogen being most widely deficient, its application results in increase of both economic and total yield in tea. Increase in yield is brought about by increase in the number of growing shoots. Insufficiency of nitrogen usually increases the proportion of root to total biomass as well as root to shoot in agricultural crops (Caloni *et al.*, 1980; Snyder and Carlson, 1984). Auxilliary branching in soybean was suppressed by low levels of N. Clark (1985) also reported that in case of deficiency of some nutrients, notably N and P, roots became relatively stronger sinks for carbohydrates.

Morchiladze (1988) found that for intensive shoot growth nitrogen was required (in the presence of P) and for root development P was required.

Potassium is essential in the synthesis and transfer of starch and sugars and counters the adverse effect of high levels of N. Under conditions of deficiency, K^+ is transported from mature leaves to growing points initially causing deficiency in mature leaves. Synthesis of amino acids and proteins is accelerated in the presence of adequate K. K also helps in the translocation of plant metabolites from the roots to the shoots. Ranganathan and Natesan (1985) reported that applied N is efficiently utilised only when K supply is adequate. Doman and Gregor (1975) observed that exogenously applied foliar K could affect phloem loading in *Beta vulgaris*. Asher and Ozanne (cf. Clark, 1985) found that root shoot ratios of 14 spp were generally highest at low external concentrations of K and decreased with increasing concentration.

Clark (1985) concluded that nutrient uptake decreased quickly after the loss of photosynthetic tissue. This implies that nutrient uptake responds to metabolic demand resulting from the production of photosynthates.

Bonneure and Willson (1992) concluded that for unshaded tea, increase in yield was directly proportional to the amount of N applied. Response to N increased in the second and subsequent years of the pruning cycle ultimately declining in the final year (Eden, 1976). This is probably related to the yield and metabolic demand. Application of zinc in unpruned years is known to increase yield by increasing the number of actively growing shoots.

3.4. Management factors

Plucking: Plucking has a profound effect on partition of growth because it determines the size of source and sink. The number of maintenance leaves and severity of plucking determine the size of source. The severity of plucking - janam, fish leaf, single leaf - determines the regeneration of shoots and their number. Harder pucking, eg., fish leaf compared to single leaf or janam compared to the above two, would give increased shoot yield and reduced growth of leafy and woody tissue.

Magambo and Cannell (1981) reported that plucked bushes produced 30% less dry matter and 64% less wood per year than unplucked bushes.

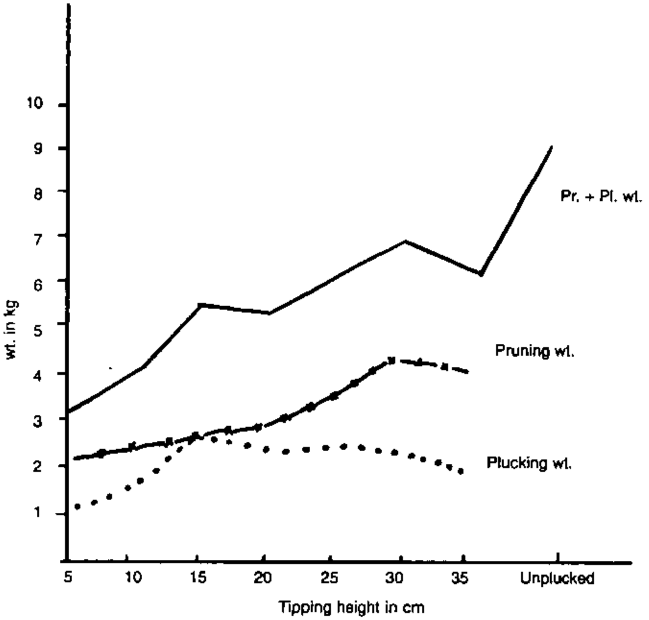

Fig. 1. Effect of tipping height on top growth of tea.

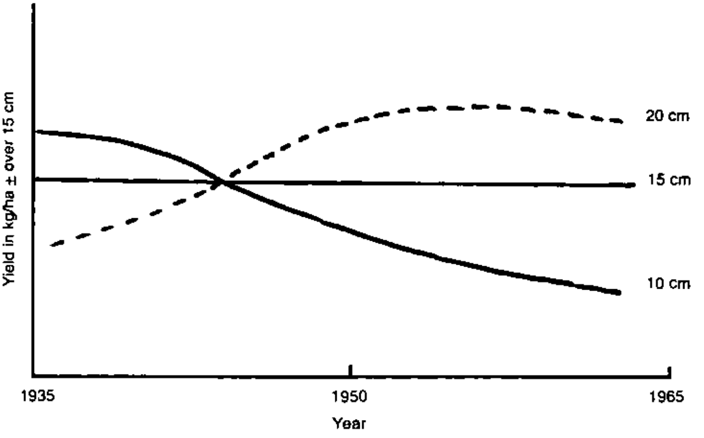

Fig. 2. Long-term effect of different tipping heights on yield.

Barua and Wight (1959) showed that combined weight of plucked shoots and prunings increased with increase in tipping height from 5 cm to 35 cm and total top growth was maximum in unplucked bushes. Plucking weight was maximum at 15 cm tipping when plucking accounted for 50% of the top growth. Thereafter, the proportion of plucking continued to decrease.

Plucking system should be such as to generate a large number of shoots and to harvest them at a stage when they have been able to create significant metabolic demand from the source leaves.

Pruning: Pruning serves the dual purpose of regenerating new source leaves and stimulating vegetative growth. It should be resorted to only when required as a large part of the growth in the year of prune does not contribute directly to economic yield. Increased yield obtained in the second and subsequent years of longer pruning cycles is due to less diversion of assimilates to stems and maintenance leaves.

Stand density: As a generalisation, the economic yield of vegetative shoot crops will maximise at the highest plant density. However, in the case of tea, the relationship is parabolic. Higher density gave increasing yield till full ground cover was obtained. Thereafter, there was a decline in yield due to severe interplant competition. Increased density suppressed stem and root growth (Rahman *et al.*, 1981).

3.5. Shade

In N.E. India, shade has been found to increase productivity by influencing photosynthesis (through regulation of leaf temperature, light intensity, leaf area) and partition of growth. Harvest index averaged 14.3% more under tree shade and 10.1% more under bamboo screen compared to full sun. Tree shade increased the proportion of both pluckings and prunings; bamboo screens only of pluckings while full sun increased the proportion of frame and roots (Anon., 1973).

3.6. Age

Respiratory losses are maximum from the bush frame followed by top hamper and roots. As the bush advances in age, the bush frame and consequently unproductive wood increases and so does the respiratory loss. Hadfield (1976) estimated the total dry weight of 20-year and 50-year old bushes in one hectare (excluding leaves) to be 45 and 86 tonnes per ha and computed the respiratory loss to be 60% and 70% of gross productivity, respectively.

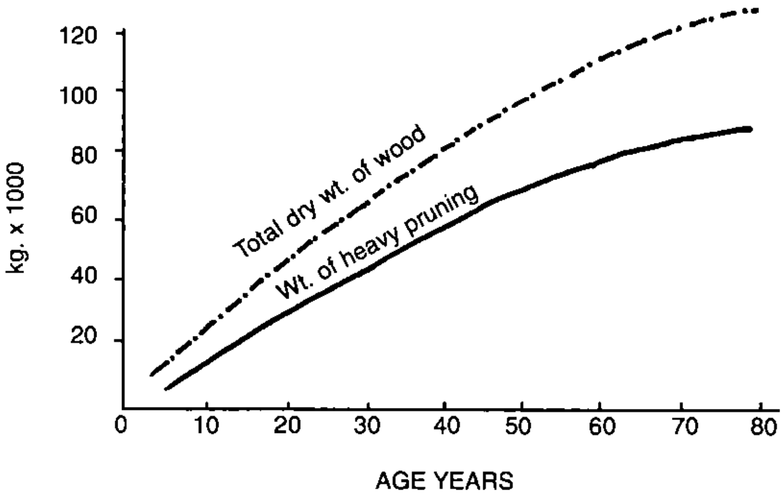

Fig. 3. Effect of age on wood production (dry weight in tonnes).

4. Possibilities of increasing harvest index

The effect of different factors on partition of growth has been reviewed. The possibilities of increasing partition of assimilates to shoots are listed below:

- Increase number of growing shoots by plucking, nutrition, shade
- Use of clones with high shoot density, low proportion of root and frame and high harvest index
- Use of PGR to release dormant buds
- Increase shoot weight and rate of shoot growth
- Reduction of respiratory losses
    - * by reducing bush frame
    - * by shade under high ambient temperature
- Mobilisation of assimilates from maintenance leaves to growing shoots
- Proper nutrient management to increase sink capacity and shoot growth.

5. Conclusions

Considering the role of partition of assimilates in maximising productivity, it is essential that research in this area is intensified. Growth analysis in tea is tedious, time consuming and complex but it is essential to elucidate the role of different factors. Some of the areas suggested for research are:

- Development of clones with high harvest index, low photorespiration and good tree and bud quality

- Use of PGRs for activating dormant buds on the bush frame
- Possibilities of mobilising assimilates from maintenance leaves to growing shoots (Manivel and Husain, 1982)
- Effect of different nutrients and PGRs on shoot development
- Analysis of components of shoot growth (Squire, 1985)
- Measurement of productivity and partitioning in highest yielding tea fields (Squire, 1985).

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Water Relation and Photosynthesis of Clonal Tea as Influenced by the Levels of Nitrogen and Potassium

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Summary

Evapotranspiration (ET) and photosynthesis rate of vegetatively propagated mature tea (TRI 2024) plants were measured in a long-term fertilizer trial in selected plots with different rates of nitrogen (224, 336 kg of N as SA/ha/annum) and potassium (70, 140 kg of K_2O as MOP/ha/annum). It was found that ET rates were reduced with increasing levels of applied potassium during dry periods. Nitrogen levels, on the other hand, did not show any significant effect on the ET rates. Higher level of potassium and nitrogen had a more favourable plant-water relationship as shown by water release characteristics of leaf. Photosynthetic rate was less affected at high level of nitrogen and potassium tested during dry weather. The yield record suggest that there was a significant yield response to higher potassium level during the dry period. Better water use efficiency was achieved more with increased level of potassium than nitrogen during moisture stress.

1. Introduction

Vegetative production per unit of water used was greater in the fertile soil than in less fertile soil (Montgomery and Kiesselback, 1912). Viets (1962) concluded in his review article that adequate nutrition of crops is a major factor of importance in the efficient water use and conservation of water. It was shown that grass yields increased when nitrogen fertilizers were applied without change in evapotranspiration (Scofield, 1945; Weaver and Pearson, 1955). The importance of nitrogen (Hewitt, 1952; Minshell, 1975; Nagarajah, 1981) and potassium fertilizers (Humble and Hsiao, 1969; Fisher, 1972; Nagarajah, 1979; Bo Larsen, 1981) on plant water relation is reported.

Drought susceptible varieties of clonal tea in many parts of the tea plantations of Sri Lanka are frequently subjected to water stress during dry weather. During dry weather, there is usually a crop loss. In extremely dry conditions, there are casualties. Therefore, efficient use and conservation of water is of practical importance. The following study was undertaken to find out whether increasing levels of nitrogen and potassium has any effect on the water use and photosynthetic rate of drought susceptible mature clonal tea during dry weather.

2. Materials and methods

The above investigation was carried out in a long-term NPK experiment at the Tea Research Institute of Sri Lanka, Talawakelle (60.33' N; 800.40' E; 1382 m AMSL).The experiment is of 3 x 3 x 3 factorial design replicated twice with 6m x 6m plots. There were 3 levels of nitrogen (112, 224, 336 kg N/ha/yr as sulphate of ammonia), 3 levels of potassium (0, 70, 140 kg K_2O/ha/yr as muriate of potash) and 3 levels of phosphorus (0, 30, 60 kg P_2O_5/ha/yr as saphosphosphate). The above experiment commenced in 1962. Each experimental plot consisted of 36 plants of clone TRI 2024 at a spacing of 1.2m x 0.6m.

2.1. Estimation of evapotranspiration

Evapotranspiration was estimated only in plots receiving 224 (N_1) and 336 (N_2) kg of nitrogen with 70 (K_1) and 140 (K_2) of K_2O with constant levels of phosphorus (30 kg P_2O_5). To estimate the evapotranspiration, the following water balance equation was used:

$$ET = RFe - \Delta M - U$$

where ET = evapotranspiration, RFe = rainfall, ΔM = change in soil moisture storage down to rooting depth of the crop and U = drainage beyond the rooting depth.

During dry periods, RFe = 0, U is considered as negligibly small when compared to M or ET over short periods (Slayter, 1961). To measure the soil moisture storage neutron moisture meter (Troxler model 1255) was used from 15 to 150 cm depth at 15 cm increments from the soil surface. Soil moisture at 0-15 cm depth was measured gravimetrically and later converted to volumetric moisture content. Four measurements were taken for each treatment with two measurements in each plot in 1983, 1984, 1985 and 1986 dry periods.

2.2. Measurement of photosynthesis

Net photosynthesis was measured using IR gas analysing system (Model Li-Cor 6200) on three mother leaves per plot on the plucking table from 09.00 hrs to 15.00 hrs at hourly intervals at the end of the dry period (on 24th and 25th of March 1994). Three measurements were taken from each leaf and mean of the 9 measurements was calculated. Along with photosynthetic rate, leaf temperature, leaf conductance (inverse of stomatal resistance) were also measured on the same leaves. Photosynthetic rates, leaf temperature and stomatal conductance were plotted as a function of time and presented below.

3. Results and discussion

Mean of evapotranspiration (ET) rates calculated from soil moisture changes for various dry periods is in Table 1.

Table 1. Evapotranspiration (mm/day).

1. N_1K_1	5.0
2. N_1K_2	3.9
3. N_2K_1	4.6
4. N_2K_2	3.4
LSD (P=0.05) = 0.9	

At both nitrogen levels, the mean ET rates were significantly less when potash level was increased from 70 kg/ha to 140 kg/ha. Similarly, mean ET rate was less when nitrogen level was increased from 224 kg/ha, but it was not significantly different. It is known that ET rates largely depend on soil, plant and climatic factors. Since climatic conditions were more or less the same over the experimental area, the differences found in ET rates could well be attributed to plant and soil factors. Among the plant factors, age, root system, crop canopy, size and distribution of stomata and the manner in which it responds to soil moisture stress determine the ET rates. Since the experimental plants are of the same age and there was a complete ground cover, it is reasonable to assume that these two factors would have contributed very little to the observed differences in ET rates. Also, unlike annuals, tea being a perennial crop, it is reasonable to assume that the root system would have developed to its maximum and remained almost constant. In other words, other than periods after pruning, total biomass could be assumed to be constant during the periods of measurements for all four treatments. Such an assumption was also made reported for Douglas-Fir forest (Nayamah and Black, 1977). The soil moisture depletion curves of all four treatments for periods from 3rd December 1984 to 20th December 1984 is presented in Fig. 1. From the Figure, it is clear that the water extraction from the soil is confined to a depth of 90 cm from the surface in all the treatments indicating that the root system is mainly confined to this region of soil. This confirms the earlier observation made on the effective rooting depth of clone TRI 2024 (Nagarajah and Ratnasuria, 1981). Though it was reported that fertilization increases deeper root penetration for grain crops like winter wheat, corn and sorghum (Kmock *et al.*, 1957; Olson *et al.*, 1964; Edward, 1982), it was not evident in tea for different fertilizer levels. Probably, this is due to the presence of well compacted gravelly layer found at 82.5 cm to 97.5 cm depth and that the fertilizers were broadcasted.

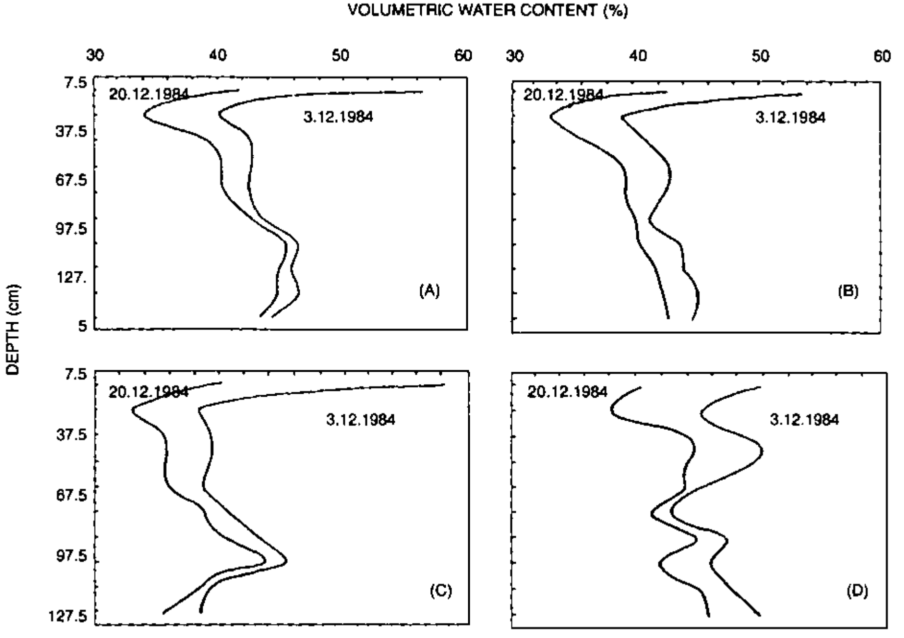

Fig. 1. Soil water depletion under different treatments.
(1) A - N_1K_1; (2) B - N_1K_2
(3) C - N_2K_1; (4) D - N_2K_2

It was shown that adequate potassium levels in leaves result in more turgid guard cells around the stomates (Nelson, 1982); stomates with relatively lower K level are sluggish in opening and closing and lose a considerable amount of their capacity to respond to rapidly changing transpirational conditions. The ET rates reported for various K levels also demonstrate the above fact. It was also reported that plants with extra nitrogen were able to maintain their turgidity better under a condition of limited water supply. Relatively lower ET rates reported at higher nitrogen level (336 kg/ha) and higher potassium level (140 kg/ha) may be due to increased turgidity found in the guard cells.

In our study, however, the ET rates under higher nitrogen level (336 kg/ha) were not significantly different from those of the lower nitrogen level (224 kg/ha). This could have been due to active growth phase of each treatment not coinciding with others during the periods of moisture measurements (Carlson, Alessi and Michelson, 1959). It was shown for beans and coffee that transpiration rates were higher for nitrogen supplied plants when compared to nitrogen deficient plants when soil moisture was relatively higher; as soil moisture approached wilting range, the transpiration rates of N supplied plants dropped below those of N deficient plants (Shimshi, 1970; Tesha and Kumar, 1978). This could be another reason for not getting any significant difference in ET rates for nitrogen levels in our studies, as our analysis was done on pooled data for higher and lower moisture regimes.

Among the soil factors, the treatments receiving higher dose of fertilizer may have relatively higher salt concentration in soil solution. Higher salt concentration in soil solution increases the osmotic potential of soil water, thus limiting the availability of water to the plant. This could probably be another reason for lower water extraction and hence ET rates of the treatments receiving higher levels of N and K. The water release characteristics of the leaves (Krishnapillai *et al.*, 1988) are presented in Fig. 2.

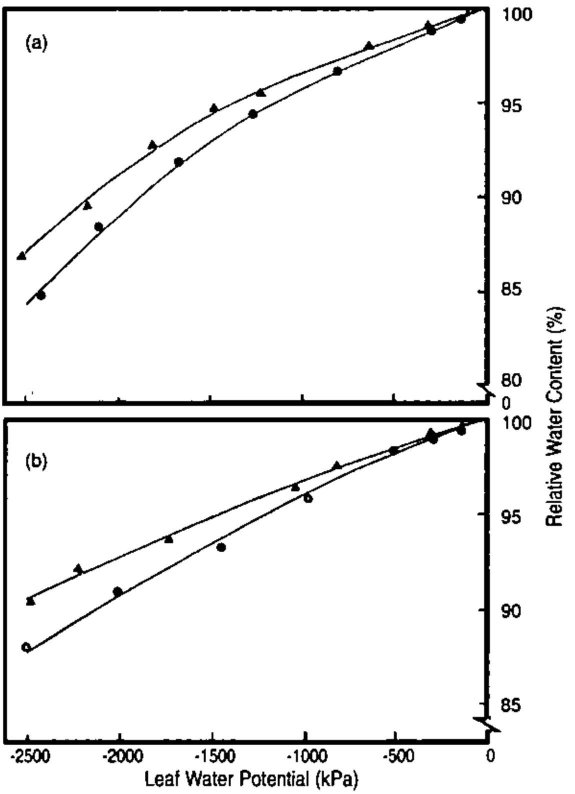

Fig. 2. Water release characteristics of leaf under different fertilizer levels.
a) ▲—▲ N_1K_2; ●—● N_1K_1 b) ▲—▲ N_2K_2; ●—● N_2K_1

At both nitrogen levels, plots receiving higher dose of potassium (K_2) always had higher relative water content than K_1 level at the leaf water potentials studied (Fig. 2), indicating a greater resistance to dessication. It was shown that large decrease in leaf water potential per unit of relative water content confers drought resistance (Weathery and Slatyer, 1957; Jarvis and Jarvis, 1963). These trends support the earlier observation of ET rates reported for different treatments. It was observed that at N_2 level, relative water content was closer to 90% at -2500kPa whereas in N_1 level, it was below 90%. This indicates the importance of higher N and K levels in maintaining the favourable water status of the tea plant during moisture stress.

Photosynthesis rate

The photosynthesis rate of mature leaves under N_1 and N_2 levels are presented in Figs. 3 and 4, respectively.

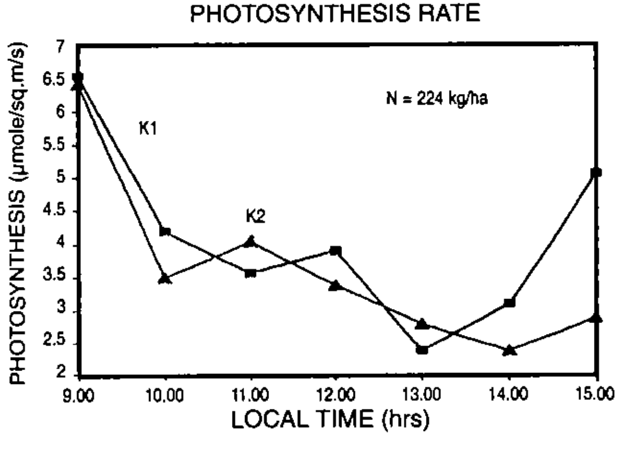

Fig. 3. Photosynthesis rate (224 kg N/ha).

From Fig. 3, it is clear that during early part of the day, when the plant is less stressed, there is no difference in photosynthesis rate at both nitrogen levels. However, after midnoon, when the plants are stressed, the leaf under higher levels of potassium (K_2) at lower nitrogen level showed a marked decreased in photosynthetic rate compared to lower level of potassium (K_1). This is probably due to the closing of stomates at K_2 level to maintain a favourable plant water status (Krishnapillai *et al.*, 1988).

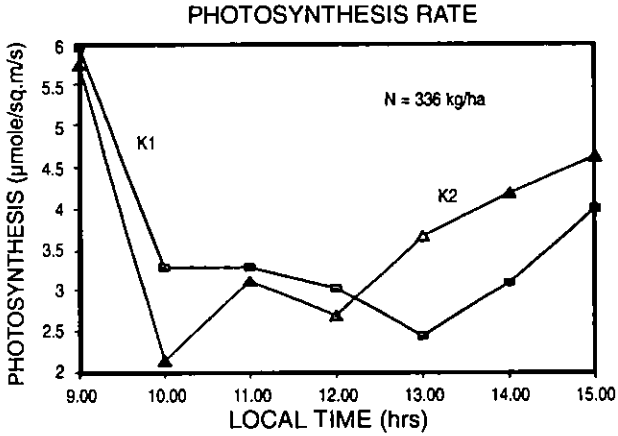

Fig. 4. Photosynthesis rate (336 kg N/ha).

However, at the higher nitrogen level, after midnoon, there is a higher rate of photosynthesis at K_2 level compared to K_1 level. This is probably due to higher relative leaf water content found in the K_2 level compared to K_1 level. Also, Gupta *et al.* (1988) demonstrated that sensitivity of photosynthesis to water stress was affected by K status in wheat plant. There was less efflux of potassium from the chloroplast stroma to cytoplasm in 6 millimolar K^+ plants than in 2 millimolar K^+ plants. Similar mechanism may be operating in tea at K_2 level to keep the photosynthetic rate relatively high.

Stomatal conductance

The stomatal conductance of leaf for two nitrogen levels are presented in Figs. 5 and 6. During early part of the day, there is hardly any difference in stomatal conductance between both potassium levels at both levels of nitrogen. However, after midnoon, higher potassium levels showed increased stomatal conductance especially at higher level of nitrogen (N_2).

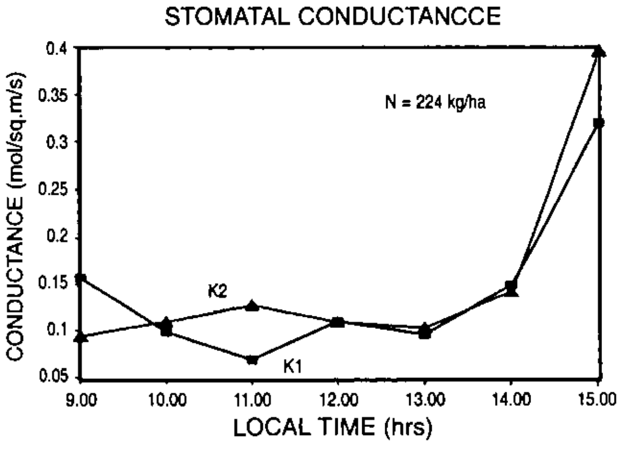

Fig. 5. Stomatal conductance (224 kg N/ha).

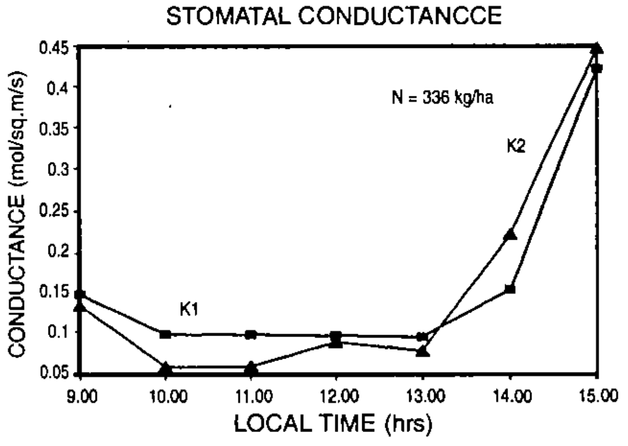

Fig. 6. Stomatal conductance (336 kg N/ha).

Leaf temperature

Leaf temperature for two nitrogen levels are presented in Figs. 7 and 8. The mean leaf temperature in all the treatments at 9.00 hrs is around 30-32°C.

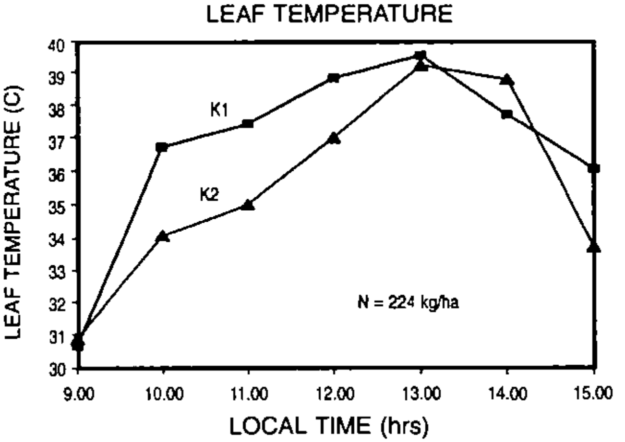

Fig. 7. Leaf temperature (224 kg N/ha).

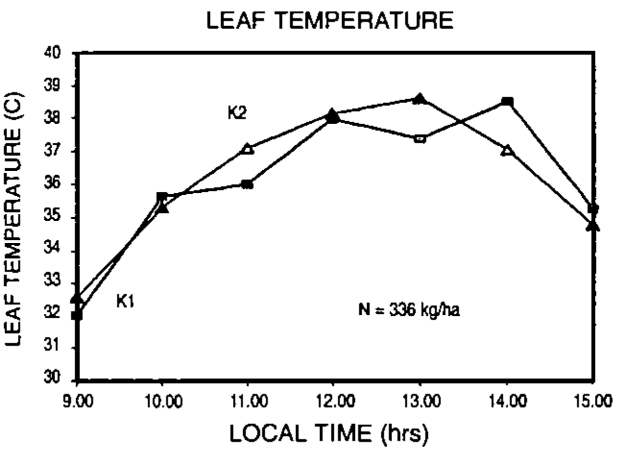

Fig. 8. Leaf temperature (336 kg N/ha).

Maximum leaf temperature of 39.4°C was observed in lower nitrogen levels around 13.00 hrs. The leaf temperature mainly depends on ambient air temperature and transpiration rate. Since ambient air temperature is almost the same at a given time, the differences observed between the treatments are mainly due to transpiration rate. The transpiration can cool the leaf by taking over the heat load in the leaf. During the morning period, at lower nitrogen level (N_1), the leaves with lower potassium (K_1) had a higher temperature compared to higher potassium (K_2) level. This may be due to higher transpiration rate found in the K_2 level which cooled the leaf by evaporation. Higher transpiration in K_2 level may be mainly due to the adequate supply of soil moisture. During the afternoon around 13.00 hrs, the transpiration rate in the K_2 level has reduced resulting in higher temperature. Stomatal conductance also confirms the above observation. At N_2 level, the differences in temperature between K_1 and K_2 were not so pronounced as in N_1 levels. However, in the afternoon, when the leaves are stressed, the leaves with K_2 level had a higher stomatal conductance than the K_1 level, resulting in lower leaf temperature.

Yield

The yield of tea is presented in Table 3. Though the mean annual yields did not show any significant difference among the treatments, there was a tendency for the yield to go down at the higher level of potassium (K_2). This may be due to antagonistic effect of higher level of potassium ion on the uptake of magnesium ions, which a constituent of chlorophyll essential for photosynthesis (Godziashvill and Peterburgsky, 1985).

Table 3. Yield (made tea kg/ha).

Period	N_1 (224 kg/ha)		N_2 (336 kg/ha)		L.S.D.
	K_1 (70 kg/ha)	K_2 (140 kg/ha)	K_1 (70 kg/ha)	K_2 (140 kg/ha)	P=0.05
1. Annual yield*	2427	2392	2522	2420	NS
2. Mean yield**	322	360	331	337	NS
3. Yield during 1983	2011	2131	1800	2039	98
4. Yield during 1993	2790	2765	2340	3069	120
5. Yield '93 dry period	361	377	252	391	62

* Mean of 21 years.

** Mean yield of tea during the months of January, February and March of 1973 to 1975, 1976, 1978 to 1980 and 1982, 1983, during which the average rainfall was 17.4, 37.2 and 85.9 mm, respectively.

However, during the dry months (January to March), higher level of potassium application resulted in relatively higher yield which, however, was not significant. This may be due to about 144 mm of rainfall which could have kept the plants relatively less stressed during that period. The slight increase in yield at higher level of potassium could be due to its better plant water status and water economy during dry periods as discussed before. This was further endorsed by the fact there was a higher yield for higher potash level during the driest 1983 (Table 3). During 1983, the annual rainfall was 1434 mm as against mean annual rainfall of 2100 mm. During the dry months of 1983, higher potassium level (K_2) would have maintained a relatively more favourable water status by its influence on transpiration which has a direct effect on water economy of the plant. As a result, the tea plants at higher level of potassium would have been subjected to less water stress during the driest part of the year, resulting in increased yield. When the rainfall is above average as in 1993, there is a positive response to higher level of nitrogen at the higher level of potassium. By looking at the evapotranspiration and yield during dry weather, water use efficiency was highest at N_2K_2 levels.

4. Conclusion

Judicious application of nitrogen (224 kg to 336 kg) and potassium (70 kg to 140 kg) fertilizers helps the tea plant to maintain a relatively more favourable water status during the dry period. It also helps to economise on water use and hence assist in soil water conservation. Also, at higher level of N and K, photosynthetic rate, stomatal conductance were higher during dry weather conditions. Therefore, if adequate nitrogen and potassium fertilizers are applied at the proper times for tea plants before the onset of drought, they could be less affected by dry conditions. During normal weather conditions, there is no yield response to higher potassium (K_2) level at the lower nitrogen (N_1) level. However, at higher nitrogen (N_2) level there was a good yield response. Small increases in yield were seen during the dry months at K_2 level and significantly higher yield during the driest year.

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