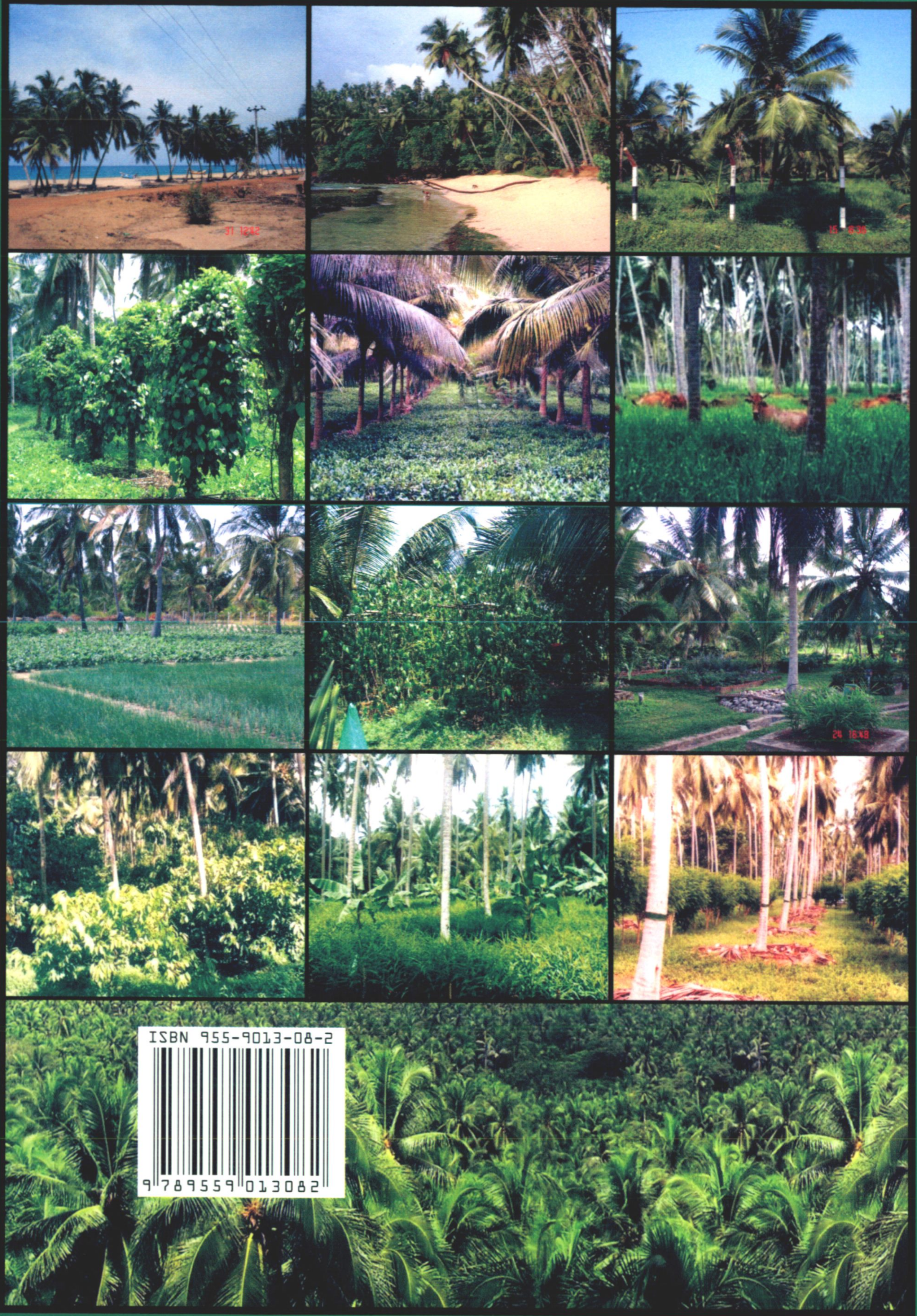

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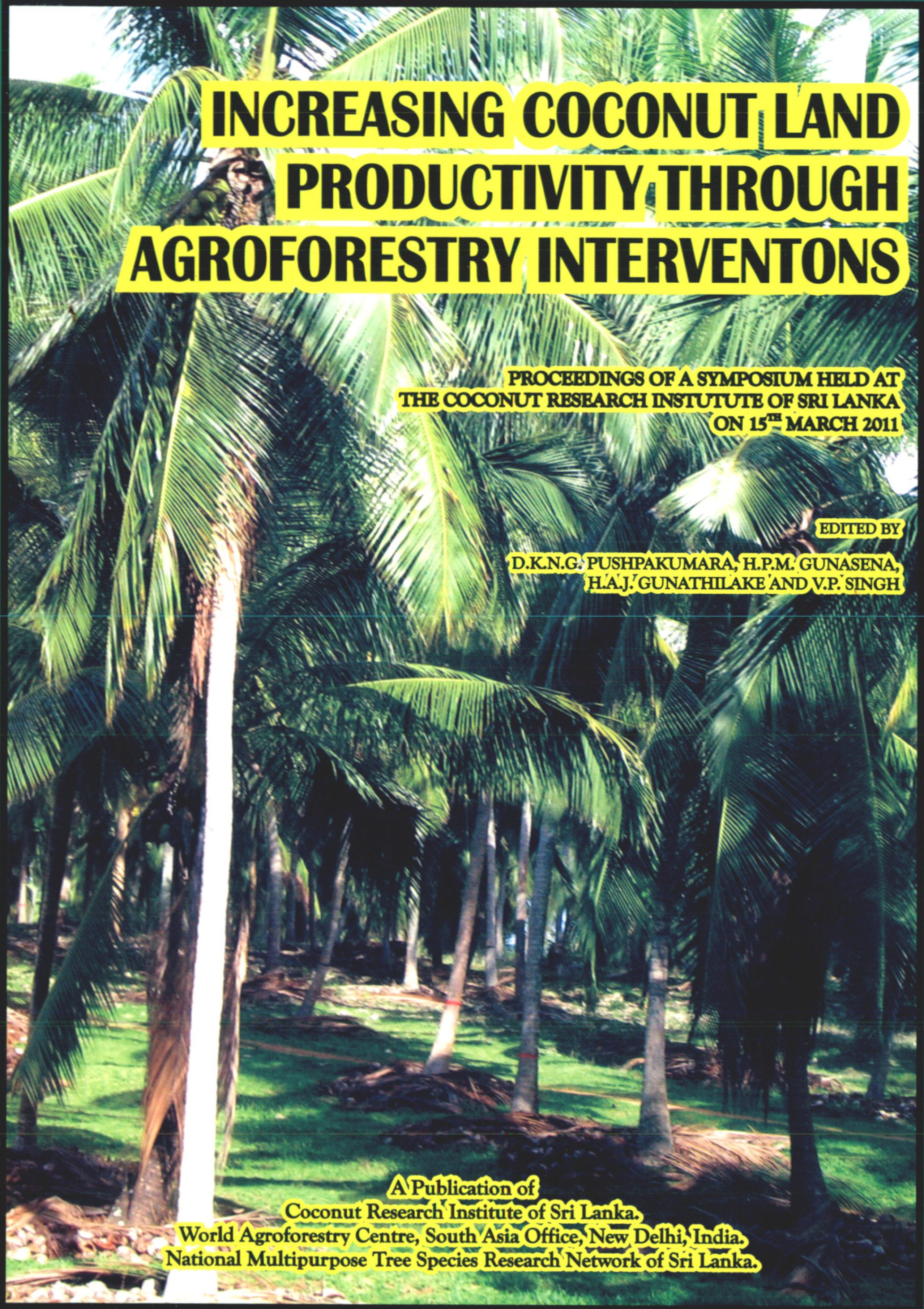
INCREASING COCONUT LAND PRODUCTIVITY THROUGH AGROFORESTRY INTERVENTONS



INCREASING COCONUT LAND PRODUCTIVITY THROUGH AGROFORESTRY INTERVENTONS

PROCEEDINGS OF A SYMPOSIUM HELD AT
THE COCONUT RESEARCH INSTITUTE OF SRI LANKA
ON 15[TH] MARCH 2011

EDITED BY

D.K.N.G. PUSHPAKUMARA, H.P.M. GUNASENA,
H.A.J. GUNATHILAKE AND V.P. SINGH

A Publication of
Coconut Research Institute of Sri Lanka.
World Agroforestry Centre, South Asia Office, New Delhi, India.
National Multipurpose Tree Species Research Network of Sri Lanka.

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PREFACE

Coconut occupies the largest extents of land under perennial crops covering an extent of 394,386 ha. It is next to the staple crop-rice which accounts for 844,000 ha. These two crops are the livelihood crops of the people of Sri Lanka contributing to the main diet of the people. While rice supplies the major portion of carbohydrates, coconut supplies 22% of the calories and 10% of the protein. The per capita consumption of coconut is about 109 nuts amounting to about 2,000 million nuts annually. In the recent past low yields and high prices of fresh coconuts have been a major concern of the coconut industry. The yield of coconut has declined from an average of 2,900 million nuts in 2008 to 2,300 million nuts in 2010. Although a drop of about 10% is normal during the lean months of November-January every year, the current years' yield reduction is about 30%. Due to the inadequate supply of nuts, the desiccated coconut and the oil industries have been badly affected. The decline of coconut yields has increased the prices of fresh nuts ranging from Rs. 50-65 per nut, consequently increasing the cost of living and total cost of the food basket.

The decline in coconut yield has not been spontaneous but occurring gradually over the years. Although reliable data is not available up to 2010, the coconut extents have declined from 433,164 million ha in 1962 to 394,386 ha in 2002; a reduction of 38,328 ha. The land fragmentation in the coconut growing areas has been substantial due to urban and industrial development. As a result of land fragmentation, the smallholder extents have also increased and their productivity is generally low. Another problem in coconut plantations is that the palms are senile and many are over 50 years old. These palms, due to their age are low productive. The rate of replanting is very low, except in some large estates. It is very essential to replant the old palms systematically, but no such programme currently exists. Another major issue is the number of palms per unit area. The optimum palm number per acre should be 64, but under field situation this number is about 50 or less. Infilling with high yielding hybrids is necessary to improve the productivity of these plantations. The other major concern in coconut is the level of management. Most of the coconut lands are under smallholdings and their management level is very low. The smallholdings account for 323,489 ha or 70% of the total coconut growing area. The fertilizer use in coconut is very low: on an average only 8-10% of the coconut growers apply fertilizers. Recently, the government approved a fertilizer subsidy for coconut. This subsidy is available for all coconut growers at Rs. 1,000/= for 50 kg of fertilizer. It is expected this incentive will promote fertilizer use and increase yields in a few years.

The application of fertilizer alone will not be adequate for sustainable soil fertility management. The fertilizers are costly and not environment-friendly. Therefore, other sustainable soil management strategies have to be explored.

The recycling of natural resources at minimum cost will be an option for the coconut growers. The principles of using natural resources for productivity improvement of agricultural enterprises have been embedded in agroforestry. It is a dynamic, ecologically based natural resource management system through purposeful integration of trees, crops and livestock on farms, in spatially or temporally interacting combinations. The agroforestry systems are proven interventions for the improvement of soil fertility of agricultural lands.

Sri Lankan farmers and the coconut growers have been practicing various forms of agroforestry for soil improvement. In coconut, intercropping with fertilizer trees, timber trees, fruit species, spices, pastures and cover crops are common. The Coconut Research Institute (CRI) has undertaken research on agroforestry and identified the tree and livestock species that are suitable for various ecological regions where coconuts are grown. Intensive research has also been undertaken on fertilizer trees such as *Gliricidia*, *Calliandra*, and other leguminous species for soil fertility improvement in coconut lands.

The use of agroforestry in degraded coconut lands will increase productivity and profitability. This is due to the improvement of soil fertility through increase in organic matter recycling as in the case of natural forests, nitrogen fixation through the use of leguminous species, enhanced nutrient uptake, reduction of soil losses due to crop cover, improved soil physical properties such as porosity-promoting vigorous growth of trees, improve chemical properties of the soil, reduce soil acidity and salinity and increase carbon sequestration. Many benefits can be gained if agroforestry is incorporated into coconut cultivations.

The objective of this symposium was to appraise the coconut growers on the importance of maintaining soil fertility through agroforestry interventions to increase the profitability of coconut lands. The symposium deliberated on several issues on incorporation of trees, crops and livestock into coconut plantations, specifically, what tree species and livestock are most profitable for coconut grown in different agro-ecological regions, the technologies available to promote agroforestry and the need for up-scaling to meet specific needs, the research priorities on agroforestry, the economic benefits of coconut based agroforestry systems and socio-economic benefits that could be achieved through agroforestry interventions for sustainable management of coconut lands.

Considering the importance of agroforesry, the Coconut Research Institute jointly with the World Agroforestry Centre (ICRAF) South Asia Office and ICRAF Sri Lanka program along with the National Multipurpose Tree Species Research Network of Sri Lanka, organized this symposium to discuss the ways of improving the productivity of coconut lands through agroforestry interventions. Mr. Anura Siriwardena, Secretary, Ministry of Coconut Development and Janatha Estate Development was the Chief Guest and Dr. V.P. Singh, Regional Coordinator of the World Agroforestry Centre, New Delhi, India was the Guest of Honour. The Directorate and staff of the Coconut Research Institute, university academics and many coconut growers participated in this symposium. Several eminent researchers from the universities and institutes' staff contributed to this symposium by presenting papers on agroforestry research and development.

The Coconut Research Institute of Sri Lanka, ICRAF Sri Lanka program and the Regional Office of the World Agroforestry Centre, New Delhi, India acknowledges the contributions and the support received from all the participants to make this event very productive to develop the coconut sector of Sri Lanka. The funding of this proceeding by the Regional Office of the World Agroforestry Centre is also gratefully acknowledged.

Prof. D.K.N.G. Pushpakumara
Prof. H.P.M. Gunasena
Dr. H.A.J. Gunatilake
Dr. V.P. Singh

Editors
June 2011

MESSAGE FROM HON. JAGATH PUSHPAKUMARA

Minister of Coconut Development and Janatha Estate Development

First of all, I regret my inability to be present at this important occasion when the Coconut Research Institute is discussing how the coconut land productivity could be improved through agroforestry interventions.

I very much appreciate the initiative taken by the Chairman and members of the Coconut Research Board and other staff of the Coconut Research Institute for organizing this symposium in partnership with the World Agroforestry Centre south Asia and Sri Lanka programs and the National Multipurpose Tree Research Network. The World Agroforestry Centre has scientists with wide experience in developing agroforestry systems for the tropics, and I believe their experience will be harnessed at this symposium to develop appropriate agroforestry systems to improve the productivity of coconut lands in Sri Lanka.

I also noted from the agenda that the Coconut Research Institute has been successful in getting the most eminent speakers in this field, from the research institutes, universities and the World Agroforestry Centre. Therefore, this dialogue should bring forth new ideas and concepts that my ministry could consider to develop the coconut industry.

In Sri Lanka coconut occupies a prominent place and in extent covers 394,386 hectares, next to the staple crop paddy which accounts for 844,000 hectares. Coconut is a livelihoods crop and it is interwoven with the traditions and culture of Sri Lankan people. We produce about 2,800 million nuts and consume 2,000 million nuts annually. The excess above the consumption needs are used for oil and desiccated coconut production. The productivity of coconut has been low, on the average 6,000-7,000 nut per hectare. The low productivity has been attributed to many factors; land fragmentation, land allocation for urban development, senile palms and low replanting rates, lack of optimum plant densities, low levels of management in particular sub-optimal fertilizer use and most importantly the eroded and degraded soils due to decades of coconut cultivation. At the initiative of my Ministry, the government has approved a fertilizer subsidy of Rs. 1,000 per 50 kg, for all coconut growers from 2011. Although this is a considerable burden to the government costing Rs. 2,280 million annually, this incentive is expected to increase the fertilizer use and consequently the coconut yields.

However, the use of chemical fertilizer alone will not be a long term solution to improve the productivity of coconut soils. As this symposium deliberates, various options have to be considered to improve the coconut soils using renewable natural resources available to the coconut growers. These options should be affordable and eco-friendly. Agroforestry involves such interventions which could improve soil fertility, increase land use intensity while enhancing the incomes of the coconut growers.

The coconut growers of Sri Lanka have been practising various forms of agroforestry such as intercropping with fruit trees, spices, pastures, cover crops and fertilizer trees such as *Gliricidia* and incorporation of livestock. The research conducted by the Coconut Research institute, other research centers and universities have amply demonstrated the benefits of agroforestry systems for productivity improvement of coconut and other agricultural lands. In my view, it is necessary to review the information available, identify the constraints and upscale the potential systems for different agro-ecological regions where coconuts are grown.

Finally, I am very pleased with this initiative of the Coconut Research Institute and the direction it is taking to develop the coconut industry. I hope that the incorporation of agroforestry into the coconut lands will reshape the industry to meet the aspirations of the coconut growers and support the economic development of the country.

I wish your deliberation all success.

ADDRESS BY MR. ANURA SIRIWARDENA
Secretary, Ministry of Coconut Development and Janatha Estate Development

Prof. Gunasena, Chairman, Coconut Research Board, Dr. Jayasekera, Director and other staff of the Coconut Research Institute, Mr. Hemakumara, Nanayakkara, President's Advisor on Agriculture, Dr. V.P Singh, Regional Coordinator, World Agroforestry Centre, New Delhi, India, Dr. P. Rman, M.S. Swaminathan Foundation, Chennai, India,

Distinguished Delegates, Ladies and Gentlemen,

It is certainly a privilege for me to address the inaugural session of this Symposium on Increasing Productivity of Coconut Lands through Agroforestry Interventions. I have been informed that the Coconut Research Institute (CRI) has organized this symposium jointly with the World Agroforestry Centre south Asia and Sri Lanka programs and the National Multipurpose Trees Research Network of Sri Lanka. As the Secretary of the Ministry, I am very happy that a partnership has been established by these three institutions to discuss issues relating to increasing the productivity of coconut lands.

I was informed that the Regional Office of the World Agroforestry Centre has assisted the Coconut Research Institute to find solutions to the Coconut Leaf Wilt Disease that is destroying the coconut plantations of the Southern region of Sri Lanka. On behalf of my country and the Ministry, I am grateful, to Dr. V.P Singh, the Regional Director of the World Agroforestry and to Prof. D.K.N.G. Pushpakumara, Liaison Scientist for the World Agroforesry Centre in Sri Lanka for assisting us on many previous occasions.

Ladies and Gentlemen,

The Coconut Research Institute was under the Ministry of Plantation Industries until recently. Recognizing the importance of coconut as a livelihood crop, the government decided to create a separate Cabinet Ministry of Coconut Development and Janatha Estate Development. This new Ministry comprises the Coconut Research Institute, Coconut Cultivation Board, Coconut Development Authority and two plantation companies, Chilaw Plantations and Kurunegala Plantations.

The Coconut Research Institute has a long history; it was established in 1929 and was the first ever research institute established in the world devoted to coconut. So, the Coconut Research Institute has been serving this nation for the past 80 years, supplying the improved hybrid coconut varieties and technologies for cultivation, processing and value addition. Unlike other plantation crops, coconut is a truly multipurpose crop and every part of the tree has some useful purpose The total extent under coconut is 394,386 hectares, an area equivalent to 20% of the cultivable land of the country. It is grown in most parts of the country except in high elevations. It is in the coconut triangle, which covers the North Western and a part of the Western provinces where most of the coconut is cultivated.

Sri Lanka produces about 2,800 million nuts annually, and nearly 2,000 million nuts are being used for local consumption. The per capita consumption is around 109 nuts and the balance is exported as coconut oil, desiccated coconut and other kernel-based products. As you may be aware, coconut is a livelihood crop for the people of Sri Lanka. It supplies 22% calories and 10% protein in the diet of Sri Lankans. The fresh coconuts and coconut oil in daily diets provide the above nutrients requirements.

Coconut is basically a smallholder crop with extents below 10 acres accounting for 698,168 acres, while the estate sector accounts for 6,280 acres. The smallholder coconut extents are scattered in home gardens and that accounts for 538,300 acres. The productivity of these lands is extremely low due to poor management levels. Most of them do not apply fertilizers or use soil fertility improvement measures. Recent reports of the Fertilizer Secretariat shows only 8-10% of the coconut growers are using fertilizers on their lands. This is a serious concern for my Ministry, which led to the initiation of a fertilizer subsidy to the coconut growers in 2011. Under this subsidy all coconut growers, even those having one coconut palm in their home gardens will be eligible for the coconut fertilizer subsidy. The cost of this subsidy to the government is Rs. 2,280 million. It is expected that this incentive will promote fertilizer use and improve the coconut productivity in the next 3 years. However, in the long term the fertilizer subsidy alone may not be the solution to overcome the low productivity of coconut lands.

Ladies and Gentlemen,

In discussing long term options, agroforestry will be the most appropriate practical and sustainable solution to maintain the fertility of coconut lands. Agroforestry is a collective term for land use-systems involving trees combined with crops and/or animals in the same land.

The coconut growers in Sri Lanka have been practising various forms of agroforestry to maintain their lands and for economic sustenance. Incorporating timber trees such as teak and mahogany on the land boundaries is a common practice. More recently, growing high value fruits such as mango, rambutan, pineapple and papaw has become as popular as intercrops. The cultivation of spices, mainly pepper, cinnamon, and coffee has been an age-old practice. The inclusion of livestock mainly cattle, buffaloes, goats and sheep is also common among both smallholdings and estates.

I have been informed that the Coconut Research Institute has conducted several research projects on agroforestry to enhance the productivity of coconut lands. As an outcome of this research the use of Gliricidia tree as a green manure is recommended by the Coconut Research Institute and is being practised by both large and small coconut growers.

Coconut is normally grown as a monocrop; coconut palms are widely spaced, 26 x 26 feet and this leaves plenty of space to grow other crops. It is my view that agroforestry is the best option by which coconut lands could be made more productive and profitable. I believe that this symposium will bring forth answers to this question and how agroforestry could be promoted for the long term sustenance of soil fertility and improvement of the productivity of coconut lands.

In particular, I hope that the symposium will find answers to the following questions:

a) What are the best agroforestry models that could be introduced to coconut grown under different agro-climatic conditions of the country?
b) To what extent will these systems improve soil fertility on long term basis, and whether the application of fertilizers could be phased out at some stage?
c) Whether the incorporation of trees and livestock will have beneficial effects on impending climate change and coconut yields?
d) The extent to which the growers are likely to benefit economically?
e) What mechanisms could be used to promote agroforestry among the coconut growers?
f) What research can be up-scaled and what additional research is needed to incorporate agroforestry in coconut lands?

Ladies and Gentlemen,

I am very pleased that the Coconut Research Institute, National Multipurpose Tree Research Network and the World Agroforestry Centre have been able to organize this symposium on coconut land productivity improvement. I am also very impressed that the Coconut Research Institute has been able to forge a long term international link with the World Agroforestry Centre that will mutually benefit both institutions. This symposium is most timely as we are facing a coconut crisis and we are looking for long term solutions to improve the productivity of coconut industry of Sri Lanka. My Ministry is very keen to know the recommendations of this symposium, and I request the organizers to identify the priority research and development areas on which my Ministry could make investments.

I wish you success in your deliberations

Thank you all.

REVIEW OF COCONUT BASED AGROFORESTRY SYSTEMS IN SRI LANKA

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Abstract

Coconut (Cocous nucifera L.) is a traditional and the largest plantation crop in Sri Lanka covering an area of nearly 20% of agricultural lands in the country. The morphological characteristics of the coconut palm and the wider plant spacing associated with its root system allow non used open spaces in the plantations for the development of integrated farming systems. This unused land area by coconut could be effectively utilized to obtain various products and services. The low Land Equivalent Ratio suggests that coconut monocropping is a less-efficient land use system. The fast economic expansion and rapid population growth, has placed considerable pressure on the land area under coconut cultivation. During the last two decades, the extent of land area under coconut plantation has declined and many holdings are increasingly fragmented and diverted for industrialization and urbanization, yet the demand for coconut cultivation and products are increasing. In this context, this paper discusses the need for well planned coconut based agroforestry systems in Sri Lanka addressing the land management issues/challenges of the country. Coconut based agroforestry systems are first categorized into eight major systems and several sub systems for easy understanding, and each major system is described based on system characters. Impacts of coconut based agroforestry systems in terms of advantages and disadvantages are discussed. The future of coconut based agroforestry in Sri Lanka in terms of potential against land management issues/challenges is critically discussed.

Introduction

Coconut (*Cocous nucifera* L.) is a traditional and the largest plantation crop in Sri Lanka covering an area of 394,386 hectares or nearly 20% of agricultural lands in the country (CBSL, 2010). It is well adapted species to a range of agro-climatic zones. In Sri Lanka, coconut is grown primarily as a rainfed crop; hence production is highly related to annual rainfall as well as its distribution pattern (Liyanage, 1994). It is primarily a small holder crop and about 80% of holdings in the country are either small with an average holding size of around 0.6 ha. About 700,000 farm families depend on their income on coconut plantation hence influence on their social and cultural lives (Gunathilake, 2004; CBSL, 2010). It also plays a significant role in the national economy by contributing about 1.5% to the gross domestic products of the country (CBSL, 2008).

The morphological characteristics such as the unique leaf canopy and un-branched nature of the coconut palm and the conventionally adopted wider planting spacing associated with the coconut root system which normally clusters within 2 m horizontally and 30-130 cm vertically of the stem allow non-used open spaces in the plantations. Liyanage (1994) stated that 75% of the area under coconut plantation remains unutilized below its potential from the age of 20 years and thereafter. The area available for cultivation in young plantations (age 0-5 years) could be as high as 80-90%. This unused land area by coconut could be effectively utilized to obtain various products and services. Studies conducted in Sri Lanka and elsewhere also indicated the low Land Equivalent Ratio (LER) suggesting that coconut monocropping is a less-efficient land use system. Further, the fast economic expansion and rapid population growth, has placed considerable pressure on the natural resource base of the country including land area under coconut cultivation. During the last two decades, the extent of land area under coconut plantation has declined by about 9% (CBSL, 2008) and many holdings are increasingly fragmented and diverted for industrialization and urbanization (Waidyanatha, 1997), yet the demand for coconut cultivation and products are increasing.

Agroforestry is a dynamic, ecologically based, natural resource management system that integrates trees on farms and in the agricultural landscape, diversifies and sustains production for increased social, economic, and environmental benefits for land users at all levels (WAC, 2009). Agroforestry in this context involves growing/rearing appropriate but high value trees and crops/livestock together in well planned and systematically managed cycles as a specialized way of farming. Agroforestry horizons have been expanding by research during the last few decades. The national research systems in Sri Lanka (particularly the Coconut Research Institute, Departments of Agriculture and Export Agriculture, Universities) and elsewhere, particularly in south Asia have generated significant scientific outputs in this area and are poised to continue. Thus, an increasing range of agroforestry innovations and options are becoming available to farmers, planners and managers. The desire for more environmentally responsible agricultural practices and systems has provided an ideal context for developing and implementing agroforestry in coconut plantations of Sri Lanka. This has become imperative as a result of environmental degradation due to the ever-increasing pressure on lands, which affects the sustainability of rural livelihoods in the country and calls for immediate ingenious interventions in land use that will enhance land and soil productivity and guarantee environmental stability.

Despite Sri Lanka's long history of occurrence of 29 agroforestry systems (Nanayakkara, 1991), it has received little attention from institutes and policy makers. Further, although agroforestry is practisced in most areas of Sri Lanka in various forms, its economic, social and environmental potential in land management is still largely unexploited. Tapping this potential will require a systematic approach that involves understanding farmer-knowledge and perception, ecological understanding of areas, socio economics and livelihood-improvement potential, marketing of agroforestry products (Leaky and Simons, 1998).

In this context, this paper reviews the current knowledge and developments of coconut based agroforestry systems (CBAS), and critically analyses the future requirements for coconut based agroforestry systems (CBAS) in terms of maximizing ecological, economic and socio cultural benefits from coconut plantations in Sri Lanka.

Classification of coconut based agroforestry in Sri Lanka

Five coconut based farming systems have been identified in Sri Lanka (Liyanage, 1994; Gunathilake and Liyanage, 1995). They are: (i) intercropping; (ii) mixed cropping; (iii) multiple cropping; (iv) alley cropping; and (v) mixed farming. The same authors at different occasions have defined the above systems as coconut based agroforestry systems (CBAS). The review of literature clearly indicated that the development and management of coconut based agroforestry systems depend on several factors. They are (i) environmental (e.g. climatic factors, mainly rainfall, soil types, elevation), (ii) economical (e.g. marketability, profitability) and (iii) sociological (e.g. social customs remaining in the area, (iv) present level of resource utilization such as use of family labour, managerial skill of farmers).

Having considered all the factors and their impacts on development of agroforestry, authors defined eight major coconut based agroforestry systems for Sri Lanka based on:

(i) components of intercropping, mixed cropping or mixed farming (annual and perennial nature of crops, and presence of cover crops, grasses and livestock species);

(ii) occurrence of other trees such as fertilizer trees; (iii location and uniqueness of the system (i.e. along coastal belt).

Within each system, variations or sub systems can be identified based on:

(i) agro-ecological region;
(ii) age of coconut plantations (0-5 years and mature stand);
(iii) density of the coconut plantations (recommended density or low density);
(iv) type of crop species;
(v) season of crop cultivation (*yala* or *maha*); and
(vi) level of management. Each major system is described below.

The defined major systems are:

(i) Coconut based annual crop agroforestry system (CBACAS);
(ii) Coconut based perennial crop agroforestry system (CBPCAS);
(iii) Coconut based silvo pastoral system (CBSPS);
(iv) Coconut based *Gliricidia* system (CBGS);
(v) Coconut based coastal agroforestry system (CBCAS);
(vi) Coconut based homegarden agroforestry (CBHA)
(vii) Coconut based alley cropping (CBAC)
(viii) Coconut based cover crop system (CBCCS)

Coconut based annual crop agroforestry systems (CBACAS)

Coconut based annual crop agroforestry system (CBACAS) represents intercropping of seasonal/annual crops in coconut plantation where coconut acts as the woody perennial. Among annual seasonal crops pluse and cereals, tubers and yams, ginger, turmeric, chillies and vegetables are grown in small scale in Sri Lanka (Peiris *et al.*, 2006). Intercropping with annuals such as ginger, cassava and vegetables (Plate 1) are popular among coconut growers due to short payback period and easy management practices. However, the popularity of some of these annual crops depends on geographical location and ethnic preference. It is reported that vegetables generate even 5-fold profit over coconut in Kalpitiya area where density of coconut plantation is usually lesser than the standard 156 palms per ha. If crop components are properly selected and crop and coconut trees are properly managed, significant yield advantages can be achieved from CBACAS systems.

However, no statistics are available on the extent of CBACAS, though this system is highly suitable for the dry and intermediate zone of Sri Lanka during the *maha* season due to less competition for soil moisture. It is possible to grow seasonal annual crops during the *yala* season only under supplementary irrigation.

Plate 1: Coconut based annual crop agroforestry systems. Coconut with manioc in the wet zone (top left), coconut with vegetables in the dry zone (top right), coconut with bean (bottom left) and coconut with onion (bottom right).

Coconut based perennial crop agroforestry systems

Coconut based perennial crop agroforestry system (CBPCAS) refers to a farming system in which perennial or semi-perennial crops and some multi purpose trees are grown together in mature coconut stand of 20-25 years and above (Plates 2a and 2b). Mixed cropping and multiple cropping are practisced in this system. The CBPCAS is particularly popular among smallholders due to scarce land resource. Export agricultural crops such as cocoa, pepper, coffee, cloves, cinnamon, vanilla, arecanut; fruit trees such as avocado, rambutan, lime, lemon, cashew; plantation crops such as tea are considered as the most commonly used perennial crops in coconut plantations where the growth period exceed 10 years. Banana, pineapple, passion fruit, papaya, betel are intercropped as semi-perennials with the growth period of 2-5 years (Gunathilake, 2007; Peiris *et al.*, 2006; Somasiri *et al.*, 1993). It is claimed that about 90% of the pineapple in Sri Lanka are being cultivated under coconut (Liyanage and Gunathilake, 1997).

According to Gunathilake (2007) and Peiris *et al.* (2006) cashew is the most popular perennial intercrops in coconut plantations in the dry and dry intermediate zones and pineapple, betel and pepper are widely grown in the intermediate zone whereas tea and cinnamon dominated in the wet zone areas. Tea as a mixed crop in coconut plantations is now becoming popular among growers particularly in the southern part of Sri Lanka. Banana is intercropped in coconut lands in all agro-climatic zones. A crop combination of pineapple and banana is the most popular systems in the wet and intermediate zones (Liyanage and Gunathilake, 1997). Cocoa, pepper, coffee, have been cultivated under coconut over several decades in Sri Lanka. Recently, rambutan was found to be a popular cash crop in the wet zone. However, the area under even CBPCAS has not been estimated.

Plate 2a: Coconut based perennial crop agroforestry systems in Sri Lanka. Coconut with spices and banana mixed cropping (top left), coconut with tea (top right), coconut with coffee (middle left), coconut with cashew (middle right), coconut with cocoa (bottom left) and coconut with cloves (bottom right).

Plate 2b: Coconut based perennial crop agroforestry systems in Sri Lanka. Coconut with banana and fruit crops (top left), coconut with ginger and banana (top right), coconut with betel leaf (bottom left) and coconut with soursop (bottom right).

Coconut based silvo pastoral agroforestry system (CBSPAS)

This refers to a farming system in which livestock, mainly cattle and small ruminants such as goats form the major component with facilities for grazing or cut and carrying under coconut plantations (Plate 3). Forage cultivation and livestock-raising under coconuts is now widely accepted as one of the methods by which the coconut farmer can increase the farm income and food and nutritional supply.

Much research has been conducted on the use of different pasture species and suitable cattle breed for different areas of coconut plantations (Santhirasegaram, 1966). The practice of rearing various types of livestock to increase income of the growers and to improve soil fertility through the recycling of livestock wastes had been recommended by the CRI. There is still a large potential for raising goats on natural/improved pastures integrated with nitrogen fixing trees in the dry and intermediate zones. It has been reported that the carrying capacity of goats with improved pasture (*Brachiaria milliformis* and green panic) and *Gliricidia* (tree fodder) is 15 goats per hectare in the dry zone (CRI, 1997).

The mean stocking rate for cattle was 3 (irrespective of land extent) and it varied from 8 among small holders to one among large holders. *Gliricidia* foliage contains 22% crude protein with high digestibility; hence it is suitable as an animal feed (Liyanage *et al.,* 1993; Perera, 1990). Popularizing of buffalo farming under coconut was commenced as a result of the CRI experiments because buffaloes are well known as efficient converters of roughages. A five-year experimentation with buffalo in coconut lands at Makandura Seed Garden reported that maintenance of one buffalo per hectare is possible and such farming is beneficial to increase coconut yield over no grazing or cover cropping with *Pueraria* (CRI, 2003).

Plate 3: Coconut based silvo pastoral agroforestry systems. Coconut with pasture in the intermediate zone (top left), coconut with goats (top right), coconut with cover crops (bottom left) and coconut with pasture and cattle (bottom right).

Beside ruminants in coconut lands, it has been found that there is a large potential for developing poultry farming. This system is referred to as "Free range poultry farming in coconut lands". Trials commenced by the CRI showed that CPRS x indigenous poultry breeds are the ideal for small coconut holder's lands. Profitability of this system is always above the intensive poultry farming. This technology is now well taken by growers and the system is expanding as an environmental friendly organic farming. Further, contribution of this system to reduce poverty among rural community is also considerable.

The diagnostic survey conducted by CRI found that coconut livestock production system was practisced by 42% of the growers. The organic waste from the livestock system was used to reduce the cost of fertilizer and improve the soil condition by 26% of the growers. The majority of the growers practiced dairying (27%) followed by poultry (10%). It is estimated that about 25% of the national herd of cattle in Sri Lanka is concentrated in coconut growing areas grazing on natural pastures (Jayawardena, 1988). However, the area under this system was also not known in Sri Lanka.

Coconut based *Gliricidia* agroforestry system (CBGAS)

Coconut based *Gliricidia* agroforestry system (CBGAS) refers to a farming system in which *Gliricidia* serve as a multi purpose and fertilizer tree component in coconut stand (Plate 4). *Gliricidia* is one of the well known green manure trees and now it is identified as a cost effective *in situ* method of fertilizing in coconut plantations (Gunathilake, 2011) and tea (Premathilake, 2011) and rubber plantations (Samarappuli *et al.*, 2011).

Plate 4: Coconut based *Gliricidia* agroforestry systems.

Application of *Gliricidia* lopping to a palm supplemented with required nitrogen, phosphorus, potassium and magnesium produced the same nut yield of coconut compared with those fertilized with recommended nitrogen, phosphorus, potassium and magnesium mixture (Gunatilake, 2004). No statistics are available on area under this system.

Coconut based coastal agroforestry system

In Sri Lanka, coconut based coastal agroforestry system represents a highly adapted sustainable production system based on highly diversified salinity resistant vegetations of perennial mixed cropping comprising a variety of tree crops (mainly coconut) with multiple uses and to a lesser extent with livestock (Plate 5).

Plate 5: Coconut based coastal agroforestry systems. Well developed coconut based coastal agroforestry in southern Sri Lanka (top left), coconut based coastal agroforestry systems after Tsunami in southern (top right) and eastern Sri Lanka (bottom).

The importance of the well developed CBCAS has been recognized when Tsunami impacted the coastal regions in 2004. Thereafter, many initiatives were taken to enhance vegetation structure and composition using various type of species. Further, well managed CBCAS will supplement ecosystem services provided by mangrove and coastal vegetation systems and make an important interplay with highly urbanized systems. However, the CBCAFS is yet the least studied of all coconut based agroforestry systems in Sri Lanka and need immediate attention to identify how such systems make environmental and ecosystem services and economic benefits to the country.

Coconut based homegarden agroforestry (CBHGA)

In Sri Lanka, homegarden agroforestry system represents a century's old, traditional, sustainable system of production based on highly diversified portfolio of perennial mixed cropping comprising a variety of tree crops with multiple uses (perennial food crops, fruits, vegetables, roots, tubers, medicinal plants, spice crops and timber tree species) and to a lesser extent with livestock (Plate 6; Pushpakumara *et al.*, 2010). This system has continuously provided high level of nutritional and diet diversity to households while medicinal plants, spice, timber and fruit tree species provide substantial additional income. There are about 1.42 million homegardens in the country accounting for about 868,000 hectares or 12% of total land area in the country (FSMP, 1995). It is also reported that the area under homegardens has been increasing steadily during the last 30 years at a rate of 1% or 8,000 hectares annually since 1980s. They are typically established in small holdings and varying in size from 0.4-2.0 ha. The composition and structure of plants and animal species of homegardens have been studied and are probably results of a combination of farmer selection, natural evolution and occasional recommendations by researchers and extension workers (Pushpakumara *et al.*, 2010).

It is widely accepted that the system evolved over time under the influence of resource constraints to optimize the productivity of land. It is estimated that homegardens of Sri Lanka consist of over 38 million coconut palms (Ariyadasa, 2007). The most important canopy crops of homegardens in terms of frequency of occurrence are coconut followed by arecanut, jackfruit and mango. This implies that homegardens are diverse and considered as coconut based agroforestry systems because of the occurrence of coconut as a frequent and dominant species than the other species. Sub systems of homegardens can be observed based on agro-ecology and management levels. Socioeconomic benefits and environmental services of homegardens are relatively well studied in Kandyan homegardens. However, the collective impact of homegardens on Sri Lankan economy has not been properly studied.

Plate 6: Coconut based homegarden agroforestry systems (top, dry zone homegardens, bottom Kandyan homegardens).

Coconut based alley cropping system (CBAS)

Alley cropping in coconut plantations has been developed mainly to improve the establishment and early growth of coconut seedlings, especially in areas in the semi-dry-intermediate and dry zones of Sri Lanka (Plate 4; Liyanage, 1994). In this system, hedge rows of fast growing nitrogen fixing tree species such as *Gliricidia* and *Leucaena* are established 4.0 m x 5.0 m (2,000 plants/ha) between coconut palms planted in the avenue system, at a spacing of 10 m x 6 m (165 palms per ha) along the east-west direction. During the early stage of coconut palm, the legume trees perform several functions, namely partial shade for coconut seedlings (30-40%), favorable micro-climate, and subsequently NFT's are pruned periodically and applied to coconut as a green manure, which saves inorganic nitrogen application. It is reported that about 50 kilograms of *Gliricidia* fresh leaves is sufficient to meet the annual nitrogen requirements of a mature coconut palm (Liyanage and Gunathilake, 1997). During the rainy season, alternate alleys may be used to cultivate seasonal annual crops.

Coconut based cover crop agroforestry system (CBCAS)

In this agroforestry system coconut serve as the woody perennial and cover crops are mainly used to protect soil erosion and improve soil fertility (Plate 3). *Pueraria phaseloides, Calapogonium mucunoides* and *Centrocema pubacens* are commonly used leguminous cover crop species in coconut plantations. Legume cover cropping is a CRI recommended practice for coconut in the wet and intermediate zones. In some instances, natural grasses without grazing are also used as cover crops. This agroforestry system is popular among large estates (Somasiri *et al.*, 1993). Coconut based cover cropping is not common in the dry zone areas due to competition for moisture during the dry season.

Impacts of coconut based agroforestry systems

Compared to coconut monoculture, the lands under CBAS are more favorable and stable for sustainable agricultural production. This is because CBAS provide many benefits as described below.

1. **CBAS diversify and integrate the components within the system, and support sustainability**

Inclusion of other trees, crops and pasture/animal species into the coconut monoculture system and their co-existence with coconut help to increase species diversity within the farming unit (Plate 7). When such components are fully integrated in the system, all the components will complement each other with positive and synergistic interactions than competition with negative interactions. Thus, the system's productive functions perform more efficiently. It is generally recognized that the farming systems with a high degree of diversity are likely to be more stable and give the farmer more security, provided the components are chosen and established well. Thus, in addition to coconut production, various other crops and their products can be harvested. Further, mixed cropping system such as cocoa+coffee+black pepper helps to enhance activities of beneficial organisms such as pollinators (particularly honey bees) because of complementary effects of CBAS compared to coconut monoculture (CRI, 1995).

2. **CBAS increase productivity at farm level**

As Liyanage (1994) reported, the main objective of CBAS is to increase overall productivity from the unit holdings without adversely affecting the coconut production because cumulative effects of trees, crops and animal components on coconut yield are of primary concern to coconut growers. If component trees and crops are properly selected, established and maintained, in addition to coconut, the CBAS provide many other trees, crops and/or animal products (Plate 7). There is sufficient data from Sri Lanka to show that coconut palms have benefited from CBAS, due to complementary effects between trees, crops and/or animal components in the systems (Liyanage and Dassanayake, 1993; Liyanage *et al.*, 1988). Land equivalent ration (LER) exceeding unity in agroforestry systems over coconut monoculture has been reported indicating the yield advantage with agroforestry (Peiris *et al.*, 2003a).

There are many examples of satisfactory performances of perennials under coconut. Mixed cropping experiment with various crop combinations (coconut+cocao, coconut+coffee, coconut+pepper, coconut+cloves, coconut+ cinnamon) conducted from 1977-1987 showed that coconut yield increased by 5-34% whereas copra yield increased by 13-31% (Liyanage and Dassanayake, 1993). Higher nut yield, per palm has been reported for many other crop combinations (coconut+pepper+coffee, coconut+banana, coconut+ pineapple, cononut+ginger, coconut+pineapple, coconut+yam, coconut+pineapple+ginger +cashew, coconut+NFTs+pasture+goat) compared to monocropping (Gunathilake, 2007). Integration of *Gliricidia* with coconut plantation has given 19% more nut yield compared to coconut monoculture (Liyanage *et al.*, 1993).

There are many examples of satisfactory performances of annuals under coconuts, root and tuber crops (cassava, sweet potato, taro, cocoyam), grain legumes (cowpea, ground nut, soyabean, winged bean), cereals (maize), spices and condiments, vegetables and leafy vegetables (bushitao, winged bean, brinjal, thampala, mukunuwenna, nivithi) once intercropped with coconut provide comparable yield compared to monocroping (Liyanage and Dassanayake, 1993).

Long term experiment (1956-1963) carried out by Santhirasegaram (1966) has shown that cultivation of improved pasture species in areas receiving more than 1,500 mm rainfall also increased nut yield (by 6%). The effect of grazing and improved pasture management techniques on coconut yields has revealed that as in the case of intercropping, the pasture will not have depressive effects on the yield of coconut palms if fertilizers are applied to both coconut and pasture (Santhirasegaram, 1966; 1967; 1975; Santhirasegaram *et al.*, 1969).

Therefore, it is clear that the high productivity of coconut lands can be achieved through the adoption and proper management of CBAS (Plates 7 and 8).

3. CBAS maintain or improve soil fertility

In Sri Lanka, more than 50% of the coconut growing land area is located in inherently low fertile soils, especially in soil suitability classes S3-S5 (Somasiri *et al.*, 1994). This problem is further aggravated by a low organic matter input added into the soil from coconut monoculture and the decline in mineralization of organic nutrients. The complementary effects of agroforestry practices on better coconut yield are generally explained based on improvements in soil physical, chemical and biological properties (Liyanage, 1994). Improvements in soil quality attributes can be explained based on the dynamics of litter production and decomposition, which plays a fundamental role in maintaining higher soil organic matter and water relations in such systems. Further, the tree components by virtue of their deep roots intercept, absorb and recycle nutrients from subsoil that would have been otherwise lost by leaching, thereby making the nutrient cycle more effective. In addition, horizontal transfer/sharing of nutrient ions between the rhizospheres of the neighboring plants is also probable, provided that coconut and tree components interact with one another. The presence of livestock, through its continuous supply of manure, also permits the efficient recycling of a portion of the nutrients locked up in its feed. Further, the dense canopy cover provided by the trees/crops protects soil against the direct action of rain, thus reducing surface runoff. A dynamic equilibrium can be expected with respect to organic matter and plant nutrients on the garden floor due to the continuous addition of leaf litter and its constant removal through decomposition.

Improvement of soil physical (bulk density, soil moisture, water holding capacity), chemical (organic matter content, total nitrogen, available phosphorus, exchangeable potassium), and biological properties (earthworm population) in agroforestry systems compared to coconut monoculture have been reported by Liyanage and Dassanayake (1993) and Liyanage and Jayasundara (1988). Further, it is reported that agroforestry systems increases leaf nitrogen, phosphorus and potassium content (Liyanage, unpublished; Liyanage and Dassanayake, 1993). It is also reported that incorporation of *Gliricidia* foliage into the soil as green manure improved the fertility of degraded soils (Liyanage, 1994). Higher water availability in intercropping systems has been reported by CRI (2007).

4. **CBAS achieve high and early economic benefits at farm level and increase employment opportunities**

As Liyanage (1994) stated, the net income obtained from a unit holding under coconut is the lowest among plantation crops grown in Sri Lanka. In this regard, coconut based agroforestry systems can provide a high and consistent income than monocropping (Liyanage *et al.*, 1985; Ranathunge *et al.*, 1988). Further, agroforestry practices ensure a reasonable cash flow during the pre-bearing period. Reductions of the use of fertilizer, weeding and inter-cultivation costs have been identified as other economic benefits. Economic analysis of selected annuals, perennials and grasses and animals in various systems shows that different CBAS helps to achieve higher economic benefits compared to monoculture coconut plantations (Gunathilake and Liyanage, 1996).

Liyanage *et al.* (1985) and Ranathunga *et al.* (1988) have shown that agroforestry systems will provide high and constant income than coconut monocropping. Profitability of different mixed and intercropping systems have been reported by CRI (1982-1986) and Abeygunawardena and Fernando (1992). Further, Abeygunawardena and Fernando (1992) have also shown that agroforestry can also substantially raise the monitory value of the coconut lands, where mean land value has been increased (8-115%) as a result of coconut intercropping compared to coconut monocropping. Comparisons of different agroforestry models with coconut monoculture revealed that net percent value and benefit cost ratio are higher in agroforestry models, where some models are more profitable than others. Further, payback period can also be reduced substantially (Peiris *et al.*, 2003a; 2003b).

Coconut based agroforestry systems with nitrogen fixing trees reduce the use of chemical fertilizer inputs, through recycling of nutrients preventing nutrient losses, by biological nitrogen fixation and by adding organic matter to understory vegetation. It has been shown that application of 50 kilograms of fresh *Gliricidia* leaves around the manure circle of the palm could supply the entire nitrogen requirement of the tree, thereby reducing the cost of production by as much as 40% (Gunathilake and Liyanage, 1992), hence increase economic benefits.

Results of experiments on annual intercropping in coconut lands revealed that for some annuals, coconut intercropping gives high net returns and economic return but the degree of profitability varies with the type of intercrop and location. Compared to other plantation crops such as tea and rubber, coconut is low labour intensive crop and one hectare require 120-150 man days per year (Liyanage, 1994). Since additional labour inputs are required to manage crops, livestock and pasture, coconut based agroforestry enhance employment opportunities. It is suggested that agroforestry practices in coconut lands increase labour requirement by 300% (ARTI, 1992). Further, CBAS are a simple but effective risk minimizing strategy suited for the uninsured farming practices adopted by many smallholders. Thus, careful selection of species and systems based on agro-ecology and other factors is necessary.

5. CBAS create favorable microclimate and environmental services

The CBAS creates a favorable microclimate for the coconut and various level of shade loving understory crops by increased utilization of sunlight, reduced soil temperature, and also increased soil moisture over coconut monoculture system (Plate 7). Further, the inter-planted trees may also act as barriers to movement of insects, mask the odors emitted by other components of the system, and shelter natural enemies. However, clear experimental evidences on such interactions are limited in Sri Lankan coconut based agroforestry systems, despite the fact that the relevance of pest and disease interactions with agroforestry measures has been recognized for long.

Plate 7: Coconut based agroforestry systems can convert 1 hectare land to 2 hectares if properly planned and implemented (top, coconut monoculture plantations, bottom left coconut with *Gliricidia* and pepper [photos from Kurunegala Plantation Limited], bottom right coconut with pasture).

Plate 8: Coconut based agroforestry need better science and management for optimum benefits (pruning of cocoa is necessary for optimum yield [photos from Kurunegala Plantation Limited]).

Coconut based agroforestry systems can play a significant role in the adaptation to climate change by changing the micro-climate, protecting the environment by provision of permanent cover, improving efficiency of the use of soil, water and climatic resources, reducing carbon emission and increasing carbon sequestration, in addition to providing opportunities for crop diversification and soil fertility improvement. Agroforestry has importance as a carbon sequestration strategy because of the carbon storage potential in its multiple plant species and soil as well as its applicability in agricultural lands and in reforestation. The potential seems to be substantial; but it has not been adequately recognized (Plate 8).

It is reported that in the global and local scale that the number of trees in forests is steadily declining, although the number of trees in farmland is increasing (World Agroforestry Centre, 2010). Thus, implementation and management of CBAS in agricultural landscapes is providing essential products and services that can relieve the pressure on the forest domain. CBAS ensure biodiversity conservation in managed ecosystems, which have become a vital issue after the Convention of Biological Diversity (Secretariat of the Convention of Biological Diversity, 2006). Carbon sequestration is yet another potential benefit from such mixed species production systems.

Generally, the value of the coconut based agro ecosystem is based on the direct use as food, raw materials and fuelwood, but the services rendered to the ecosystem should also be covered. A more comprehensive functions and services of coconut based ecosystems are presented by Magat (2007) (see Appendix 1 for details). Evaluations of such functions are essential aspects in trying to understand and value the total benefits of the systems.

Constraints for coconut based agroforestry in Sri Lanka

Despite the positive attributes of CBAS, and various incentives given by the Government of Sri Lanka to encourage CBFS and CBAS to optimize land use, the relative slow progress made is a reflection of the presence of several constraints (Liyanage, 1993). They are:

1. **Physical constraints:** Since coconut is largely a rainfed crop, more frequent and longer dry periods and drought due to adverse weather will impact heavily on coconut production when intercropped, particularly in poor soil conditions due to limited ground water availability which lead to lack of adoption of CBAS in such soils.

2. **Institutional constraints:** Price fluctuations of coconut as well as intercropped crop species and poor marketing facilities of such products have been cited by growers as constraints to adoption of CBAS. Further,

lack of well established credit facilities, inadequate funds for long term research on agroforestry systems, lack of coordination between Government Departments engaged in agroforestry research in coconut lands and poor research and extension linkages are also identified as constraints.

3. **Technical constraints:** As Peiris *et al.* (2003a; 2003b) suggested all agroforestry interventions require additional resources (labor, capital etc.). Further, it has been shown that, although the net present value and cost-benefit ratio and return to labor are higher for intercropping compared to coconut monocropping, return to labor and cost-benefit ratio yet continued to be sufficiently attractive for the coconut monoculture (Fernando *et al.*, 1996). Several intercropping systems demand for management of the crops, trees and its inputs, and a skilled knowledge compared to coconut monocropping (Fernando *et al.*, 2000). The competitive negative interactions, both for above- and below-ground resource capture, are probable in multi strata systems, especially when the tree canopy shades the palms either partially or completely or when the root systems overlap. The age at which competitive interactions begin also may vary with the initial stocking and growth rates of individual trees. In situations where shading the principal crop is a concern (e.g., multistrata systems), pruning and thinning of the associated trees are essential tree management options to limit competition and encourage temporal complementarily in resource use. This is an important cultural practices in CBAS since production of other tree crops depends on relevant pruning and thinning techniques and coconut growers are not trained for such plant management techniques. However, the major drawback of annuals as intercrops is their need for regular inter-cultivation, which is labour-intensive. Besides, most annuals are adversely affected by shade. Coconut farmers just producing nuts or copra spend 60-90 days a year in his small-scale farm of 1-5 ha. In contrast with same size diversified farm requires an almost year-round stay.

4. **Socio economic constraints:** At national level, land fragmentation, shortage of hired and family labor, absentee landlords, theft of harvestable products, ethical and religious reasons for raising livestock are considered as socio-economic constraints (Liyanage and Gunathilake, 1997).

5. **Pest and disease prevalence:** Agroforestry may also increase pests if trees in the system is increased and expand food availability to insects by serving as alternate hosts. Interactions among component species of a system also may alter the physiological status of one or more species, making them either vulnerable to or robust against insect attack.

Future of coconut based agroforestry systems in Sri Lanka: way forward

According to the foregoing discussion it is clear that each CBAS has its advantages and disadvantages. It is estimated that over 20% of coconut plantations (i.e. area of about 80,000 ha) could be used more productively and profitably with CBAS. It has been identified that shift from coconut monoculture to coconut based agroforestry as a national priority for the future development strategies for coconut sector due to the higher population densities and land fragmentations and low productivity in major coconut growing areas (Liyanage and Gunathilake, 1997; Gunathilake, 2011). However, adoption of CBAS is limited despite all efforts made during the last few decades. Hence, this section examines the potential pathways to enhance benefits of CBAS into the economy of Sri Lanka through an integrated approach.

Such discussion however needs to consider the current land use issues/challenges of the country and particularly in major coconut growing areas. As a developing country, the major national issues of Sri Lanka are land degradation, poverty, malnutrition and hunger. With large scale natural resource degradation, the depletion of soil fertility, loss of biodiversity and depletion of water resources and agroecosystem function (Ministry of Forestry and Environment, 1999), the better use of farm land is imperative, particularly given that the existing farm lands are fragmented and new land for agriculture is no longer available (except in northern and eastern provinces), yet the demand for coconut is increasing.

Further, there is ample scientific evidence to conclude that climate change is taking place, and plantation agriculture is one of the high priority sectors where the impacts of climate change exceed tolerance limits with implications for the livelihoods of millions of people who depend on this sector (Ranasinghe, 2011). Five divisional secretariat divisions (DSD) have been identified as highly vulnerable areas to drought exposure due to climate change impacts (Ministry of Environment, 2010b). The extent of coconut plantations in theses DSDs accounts for 88,069 hectares which is about 20% of coconut plantations in Sri Lanka. A total of 354,789 population of whom 77,656 are below the poverty line are living in these areas. Further, the same report indicated that 7 additional DSDs are moderately vulnerable to climate change accounting for 108,340 hectares of coconut plantations. Out of 12 DSDs with high or moderate vulnerability to drought, 9 are in the Kurunegala district where coconut is the dominant plantation crop. Although the exact manifestations of climate change on all crops are not precisely known, the projected changes in intensity and frequency of storms, droughts and floods that could alter hydrological cycles and precipitation, increase of temperature that could impact on success of pollinators and pollination process can be expected to have major implications on coconut production. Hence adaptations to climate change would require better preparations. In this regard, agroforestry has been identified as one of the strategies to adaptation to climate change shocks in Sri Lanka (Ministry of Environment, 2010a) because functionally diverse communities and ecosystems tend to adapt to climate change and climate vulnerability better than low diverse monocropping system (SCBD, 2010). Therefore, in future, coconut plantation strategies need to consider this information and research should be directed accordingly.

Therefore, at present, the challenge is to set a priority for coconut lands and identify suitable agroforestry systems for different agro-ecological regions and establish/implement them and market as labeled/certified agroforestry products. Prerequisite for this would be mapping of coconut based agroforestry and identifying suitability for different agroforestry and then setting targets for production of nationally important agricultural products from defined areas to address key challenges of the country. Strategies suitable for poverty alleviation may not be suitable for increasing coconut productivity; hence, a pragmatic approach for each case with substantial area is necessary. For example, if properly planned and implemented, coconut based agroforestry can produce 100% pineapple and ginger requirement of the country. Similarly, these systems may be able to produce 20% of chili and 10% groundnuts and over 40% of spices such as pepper and cloves from coconut based agroforestry. Once targets are identified a package for a unique combination in a defined agro-ecology to implement must be developed as Waidyanatha (1997) suggested with support services such as agricultural credit and improved extension delivery. This demands greater interdepartmental collaboration, creating a need for a new collaborative approach rather than distribution of planting material and fertilizer alone.

During the last two decades, a large number of coconut based agroforestry models have been established and tested by the CRI (Peiris *et al.*, 2003a; 2003b). Different models have their own merits and demerits. However, agroforestry is a science-based solution to problems faced by farmers which places the strategic importance of agriculture in today's context. From farmers and production systems perspectives agroforestry provide improved on-farm productivity, building assets, generating income, and livelihood options. In environment and biodiversity perspectives agroforestry reduces pressure on natural habitats, landscape connectivity, habitat restoration, and ecosystem resilience. This can be achieved in Sri Lanka if CBAS can be practisced. Therefore, in future, in addition to the establishment of new models, restructuring and introducing several technical interventions by adopting a farmer participatory approach can achieve conversion of the existing farms into viable operational models. In this respect, the farms should be visited by a multi-disciplinary scientific team along with officers of agricultural and allied departments and aspects such as size of the holding, present cropping/farming situation, tastes and preferences of the farmer, innovativeness of the farmer, interventions desired by the farmer, technical feasibility for implementing suggested interventions, local market, economic aspects etc should be considered. Appropriate interventions should be decided after thoroughly analyzing the existing situation and based on the on-farm farmer-participatory discussions. Improving farm management is crucial for adoption to agroforestry. For this purpose, four woody interventions for agroforestry are available for production and productivity improvements, environmental benefits and economic advantages of coconut lands (i) replacement (harvest existing tree species and replace with improved (or not) once of the same species); (ii) substitution (harvest existing tree species and replace with different species); (iii) expansion (increase individuals of the same species of number of different species); and (iv) management (better management of the existing and new trees (spacing, thinning, pruning, harvesting).

It is well accepted that agroforestry addresses the issues such as soil fertility management, the rehabilitation of degraded farming systems, loss of biodiversity, carbon sequestration, and soil and watershed protection. Although the value of coconut as an economic commodity has been widely recognized, the assessment of the environmental services and functions of coconut has not yet been adequately made. The economic analysis has been assessed from different vantage points, but not in an integrated manner. Thus to capitalize the importance of CBAS, total economic valuation of CBAS should be undertaken. Coconut growers who store carbon in trees, crops and soils should be rewarded with payments (carbon credits) and such intervention will be an investment for replanting and under planting of coconut. It clearly appears that more research or reference data under different conditions (variety-tall vs dwarf, environmental and farming conditions, and ecosystems) should be generated to come up with an objective assessment of the ecological potential of coconut in relation with carbon sequestration. For this also identification and mapping of different CBAS and their extent is necessary.

In agroforestry development, the focus must be oriented to a whole landscape approach for the benefits to reach the nation. The right policy support will be critical in seeing the potential of CBAS fully developed in Sri Lanka. Therefore, it is necessary to identify agroforestry policy initiatives with goals to accelerate the positive changes in government support that can enhance the multifunctional roles of agroforestry. The policy initiatives and other complementary actions will stimulate acceleration in deploying agroforestry for food and nutritional, ecological and environmental and economic securities of coconut plantations in Sri Lanka. However, only, a few studies have included detailed information on the long-term impacts of inter-planting woody perennials in the coconut plantations and many such studies involving seasonal and annual crops were conducted. Available reports on inter-planting of multipurpose trees in the interspaces of coconut palms do not reflect the full spectrum of species grown in coconut-based agroforestry systems. Further, organic coconut farming is being promoted for general adoption by the farmers. Organic villages can also be set up to increase the organic coconut production to facilitate marketing. Different agroforestry systems through intensive integrated farming involving diverse tree species and arable crops with or without livestock components could be developed into tourism spots with the integration of additional facilities such as sales outlets for coconut-based agroforestry foods and beverages, handicrafts can be labeled and marketed separately. Such ecotourism potential may also need to expand if coconut plantations are to be economical in the future.

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Appendix 1: Direct and indirect functions and services in coconut based agroforestry.

Ecosystem functions	Ecosystem services	Ecosystem services in coconut based agroforestry systems
Direct uses		
Portion of gross primary production extractable as food	Food production	Production of edible pith, tender nut, nut with soft kernel, and fresh coconut sap (toddy), vinegar, treacle
Portion of gross primary production extractable as raw materials	Raw materials for various industries	Production of coconut, copra, oil, fuel, animal feeds, ekel, lumber and others
Indirect uses		
Regulation of atmospheric chemical composition	Gas regulation	CO_2 plant uptake (carbon sequestration)
Storage and retention of water	Water supply	Improvement of water infiltration rate and moisture retention
Retention of soil within an ecosystem	Erosion control and sediment retention, and nutrient losses	Prevention of soil loss by runoff, or other removal processes, storage of transported silt and clay by control ground cover
Soil formation process	Soil formation	Weathering of rocks and accumulation of organic matter (OM)
Soil water conservation and suppression of weeds	Weed control & reduction of soil evaporation	Coconut fronds and husks for production of crops
Storage, internal cycling, processing & acquisition	Nutrient cycling	Cycling of nutrients in husk, fronds, spadix, including nitrogen fixation by legumes grown between trees
Stabilization of ecosystem integrity in response to environmental stress	Disturbance regulation	Variability of farmers' incomes resulting from tsunami, typhoon damages.

Habitat for resident & transient populations	Refuge	Nurseries, habitat for migratory species, regional habitats for local species
Provision of opportunities for ecotourism and recreational activities	Recreation	Agro-eco-tourism like Resort, beaches with CBCAS
Provision of opportunities for non-commercial uses	Socio-cultural	Aesthetic, artistic, educational, spiritual, and/or scientific values of ecosystems

Source: modified from Magat, 2007.

FERTILIZER TREES FOR ENHANCING COCONUT LAND PRODUCTIVITY

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Abstract

Coconut has been commercially cultivated for more than 200 years in Sri Lanka. For the last few decades, it has been showing yield stagnation due to depletion of soil nutrients. The movement of most of coconut products likes nuts, fruits and stem taken out of the system has aggregated the low fertility in coconut lands. Coconut palms are generally spaced 8 x 8 m apart, thereby, 75% of the area remains below the production potential. This land area can be made available for agroforestry interventions in mature coconut lands. Cocoa, coffee, pepper, clove, nutmeg, cinnamon, rambutan, durian, lime, grafted cashew, arecanut, mango and tea are the popular mixed crops. Studies conducted at Coconut Research Institute (CRI) indicated that none of the agroforestry systems affect coconut production in areas where there is less competition for moisture and when both coconut and crops are properly managed. In several systems, considerable improvements in nut yield (16-25%) and copra yield (4-18%) have been observed. Coconut based agroforestry systems, particularly with NFT's offer much scope for reducing the use of fertilizer inputs through biological N fixation, recycling of nutrients and by adding organic matter. Among them, Gliricidia sepium has been the best species. Gliricidia provides fertility, fodder and fuel from coconut plantations. Fifty kilograms of Gliricidia foliage per palm per year is sufficient to meet total N requirement of a coconut palm. Results of field experiments showed that application of 50 kilograms of Gliricidia leaves produce the same nut yield of 20 kilograms of goat manure per year or 3 kilograms of inorganic "Adult Palm Mixture". It is important to note that by application of in situ grown Gliricidia leaves and ex situ supplied other organic manures nut yield of coconut was not significantly varied. This proves that application of foliage of in situ grown Gliricidia is the best means to overcome issues such as organic manure availability and transport of manure. It is also assumed that Gliricidia is mining nutrition from deeper layers to surface of soils thorough the process of pruning and decomposition of foliage. NFT's particularly Gliricidia is ideal for integration with other materials such as paddy straw for feeding cattle, goat and buffaloes. A model consisting biogas unit and a wood gassifire has produced green electricity equivalent to 5,700 units per year. Application of effluent of biogas significantly improved soil fertility and thereby coconut yields too. This paper also discusses the integration of perennial inter crops and livestock with special emphasis of NFT's as integrated agroforestry systems to enhance soil fertility in coconut plantations.

Introduction

One of the main benefits of agroforestry is the maintenance of soil fertility. This hypothesis is based partially on studies on the efficient transfer of nutrients from litter to trees in natural ecosystems. The assumption is that trees in agroforestry systems will likewise transfer nutrients to intercropped plants. Most of the coconut plantations are established in lateritic soils that are sandy to sandy loam in texture. These soils are generally infertile and dominated by the low activity clays; hence low in cation exchange capacity. Light texture causes excessive leaching during rainy season. Coconut is a perennial crop, and requires large amount of plant nutrients due to removal of nuts and other palm parts such as fronds, husks, shells and stems. Hence, *in situ* biomass production, decomposition, nutrient recycling should be given high priority in crop and land management. This could be achieved by integrated farming with other trees, crops and livestock. NFT's and other agroforestry interventions may have a vital role to play in maintaining soil fertility of coconut plantations for high agricultural productivity. This paper discusses effects of nitrogen fixing trees (NFTs) and agroforestry on coconut land management especially on coconut yield, soil physical, chemical and biological properties.

Nutrient budget of monoculture coconut

All intensively cultivated soils would eventually require fertilizers to compensate for the harvest removal of nutrients. The removal of N, P, K and Mg per hectare of exclusive coconut plantation that produce 7,500 nuts is presented in Table 1. Removal of potassium is the largest among the nutrients followed by N. Amongst the biomass components shell and kernel deplete high amount of N. A large amount of K is consumed by husks, fronds, and kernel and coconut water. The fertilizer doses recommended by the Coconut Research Institute (CRI) for N, P and Mg are well below the amounts depleted from soils. For example, K removal is 265 kilograms per ha, but recommended dose is 240 g per hectare (Table 1). Larger amounts of N, P and K are removed from the coconut growing soils than added, which results in a negative balance every year. The depletion may ultimately lead to soil nutrients degradation. Calculated values show that in 2009, nutrient removal by nuts was equivalent to 26,952 metric tons of urea. 12,067 metric tons of Eppawala rock phosphate (ERP) 60,919 metric tons of muriate of potash (MOP) and 13,856 metric tons of dolomite. The leaves of coconut contain 45% mineral mass of N, therefore recycling of leaves may partly compensate the N loss. In general, other sources of N available in coconut lands could be either leguminous cover crops (e.g.: *Desmodium ovalifolium*, *Pueraria* spp.) or NFT's (e.g.: *Gliricidia sepium*, *Calliandra calothyrsus*). There is an opportunity to compensate N losses through the use of organic manures, and recycling of plant materials. Agroforestry with NFT's *in* *situ* cultivation would be the best approach to compensate for the loss of soil nutrients in coconut lands.

Table 1: Annual nutrient removal by coconut monoculture (7,500 nuts or 150 palms per ha).

Plant part	Nutrient removal (kg per ha)			
	N	P	K	Mg
Inflorescence	7.9	1.9	16.3	3.2
Fronds	33.4	3.3	43.6	20.3
Nuts				
Nut water	0.3	0.1	3.3	0.1
Shell	1.8	0.1	3.1	0.2
Kernel	19.9	2.8	10.5	1.6
Husk	10.6	1.2	63.2	2.5
Total	73.9	9.3	139.9	27.9
Equivalent (kg)	Urea 160	ERP 71	MOP 279	Dolomite 232
Application (kg)	Urea 120	ERP 90	MOP 240	Dolomite 150

Note: Annual removal of N, P, K, and Mg by nuts only

NFT's in coconut lands

Much emphasis has been given to the possibility of incorporating nitrogen fixing trees (NFT's) as an essential component of the coconut based agroforestry systems. NFT's has become increasingly popular due to their ability in providing a number of useful products and services to the coconut farmer. Theses include products like green manure, animal fodder, fuelwood, mulching and fencing material and service like live support for certain intercrops like black pepper and vanilla, soil fertility improvement, erosion control, weed suppression and shade for young coconut (Liyanage and Jayasundara, 1988).

Growth performance and biomass productivity are the factors that affect the soil fertility in selected coconut based agroforestry system. Liyanage *et al.* (1993) studied growth performance and biomass yield of four NFT's (*viz: Acacia auriculiformis, Calliandra calothyrsus, Gliricidia sepium and Leucaena leucocephala*) and their effect on coconut yield. The tree species have been planted in double rows of 2 m x 1 m in the avenues of coconut. This experiment showed that the coppicing ability of *Gliricidia* followed by *Calliandra* was superior to that of *Leucaena* and *Acacia* as indicated by a higher number of coppice shoots/roots

(6.4 and 4.7 per tree, respectively) six months after pruning. Although *Gliricidia* and *Leucaena* at initial pruning were similar. *Leucaena* showed significant reduction in total dry matter over *Gliricidia*. Among the tested NFT's, *Gliricidia* produced the highest leaf (45 g per tree) and stem (592 g per tree). With regard to leaf crude protein content, *Gliricidia* had the highest N value of 3.6% and crude protein of 22.5%. Due to the compatibility between coconut and NFT's, nut yield of coconut has also been increased by 15-26% in different NFT's plantings.

Another study conducted to evaluate the growth and biomass production of four multipurpose tree species (*viz; A. auriculiformis, A. mangium, C. callothyrus. G. sepium and L. leucocephala*) and their effect on coconut production in a 45 year-old coconut plantations, showed that at initial pruning of *Gliricidia* produced the highest leaf biomass (488 g per tree) whereas leaf dry matter in *Leucaena* (257 g per tree) was comparable with *Calliandra* (225 g per tree). *Leucaena* was the tallest indicating that it is not a bushy type unlike the rest which is an important character in coconut lands. In other evaluation of bush covers (viz; *G. sepium* and *L. leucocephala*) produced the highest dry matter yields of more than 3,000 kilograms per hectare per year.

Gliricidia also performed better than *Leucaena* producing 3,400 kilograms dry matter per hectare when compared with 2,010 kilograms per hectare in *Leucaena* after four years (CRI, 1998). Further, Liyanage *et al.* (1990) studied the growth and biomass productivity of six selected NFT's species (*A. auriculiformis, A. mangium, C. calothyrsus, Enterolobium cyclocarpum, G. sepium and L. leucocephala*) and showed that growth of *Enterolobium* and *Acacia* at 2nd and 4th years after planting was more vigorous than *Leucaena* or *Gliricidia*. Further, they found that growth performance of *Leucaena* was significantly better than in *Gliricidia* in the low country intermediate zone of Sri Lanka. Among the above NFT species, *Leucaena, Gliricidia* and *Calliandra* have been identified as the most promising candidates as green manure for coconut and dry season fodder for livestock, in addition to the high potential for use as renewable fuelwood sources.

Effects of mulching on soil microclimate have been studied using leaf mulches from six NFT's (*A. auriculiformis, A. mangium, C. calothyrsus, E. cyclocarpum, G. sepium, L. leucocephala* (Liyanage *et al.*, 1990). It has been showed that mulching with leaves from tree legumes significantly improved the soil microclimate during the dry period. This has been evident from the significant reduction in soil temperature at 5 cm depth and diurnal variation, substantial increase in moisture retention at 5 cm depth and, by a marked reduction in weed growth in mulched plots over un-mulched control plots. Of the NFT's species, pruning from *A. auriculiformis, A. mangium,* and *Gliricidia* were found to be more effective as surface mulch than those from *Leucaena*, *Calliandra* and *Enterolobium*.

Effects of intercropping tree species on coconut yield

The main concern among coconut growers on the inter cultivation of tree species under coconuts is the competition by trees for soil moisture and nutrients. Therefore, growers are reluctant to adopt such agroforestry systems in spite of the fact they improve soil conditions, and supply green manure and fuelwood. It is obvious that unmanaged and unsystematically planted trees compete with the main crop coconut. However, systematically planted and well managed trees will not interfere with the functions of the coconut palm.

Long term studies conducted by the CRI have shown that there is little effect on both nut and copra yields of coconut due to intercropping either food crops or non-food tree crops as far as coconut, the main crop, is managed well. Table 2 indicates results from a field experiment conducted at Rathmalagara estate, Madampe (low country intermediate dry zone) to study the effect of inter-planted NFT's on the yield of coconut. It was revealed that the coconut yields are hardly affected by the under grown tree crops which were pruned periodically, 2-3 times a year.

Table 2: Effects of different NFT's on coconut yield in the low country dry intermediate zone (Andigama Series, moderately shallow phase).

Treatment	Nut yield (nuts/palm/year)	Copra yield (kg/palm/year)
	Average for 4 years (1992 -1995)	
Acacia auriculiformis + Coconut	76	14.6
Calliandra calothyrsus + Coconut	73	14.6
Gliricidia sepium + Coconut	68	13.0
Gliricidia sepium + Coconut	69	13.1
Coconut only	65	12.9
Significance	NS	NS

Source: Liyanage, 1998 (Unpublished).

In another study at Kohombe estate, Kakkapalliya, mahogany and teak were planted (four trees per coconut square) in a 50 years old coconut plantation to rejuvenate soil and finally to harvest timber with felling of coconut at the end of 60 years of economical life span. So far, no competition between coconut and timber trees was observed. This has been proved by the foliage analysis of 14th frond of coconut (Table 3). This shows that there is no significant variation of major plant nutrients between plots of monoculture coconut and coconut with timber trees.

Table 3: Foliar nutrient status of 14th frond of coconut.

System	N (%)	P (%)	K (%)	Mg (%)	Ca (%)
Coconut	2.2	0.12	1.4	0.20	0.40
Coconut + timber trees	2.4	0.15	1.2	0.26	0.48
Sufficiency range	1.9- 2.1	0.11- 0.13	1.2- 1.5	0.25- 0.35	0.35- 0.50

Mixed cropping in coconut lands in relation to soil fertility

Mixed cropping refers to an agroforestry system in which perennial food and cash crops are grown in association with mature coconut palms. Cocoa, coffee, pepper, cinnamon, cloves, nutmeg, rambutan, mulberry, lemonine, grafted cashew are suitable for growing in mature coconut holdings in the wet, intermediate and dry zones of Sri Lanka. Several on-station and on-farm experiments were conducted to develop suitable mixed cropping systems to increase productivity of coconut lands in different agro-ecological regions and to study the effect of mixed cropping on coconut production. Tables 4 and 5 show the complementary interaction between coconut yields and perennial mixed crops (Gunathilake and Liyanage, 1995). The experiment clearly indicated that mixed cropping increase overall productivity from unit holdings without adversely affecting the coconut production.

Table 4: The effect of mixed cropping systems on coconut yield (1977-1989) at Sri Kandura estate, Dodanduwa (wet zone).

Cropping system	Mean yield (nuts /ha/yr)	Increase (%)	Mean copra yield (mt/ha/yr)	Increase (%)
Coconut only (control)	6123	-	1.79	-
Coconut + cocoa	7504	22	2.18	22
Coconut + coffee	8216	34	2.26	26
Coconut + pepper	6424	05	2.03	13
Coconut + clove	7191	17	2.13	19
Coconut + cinnamon	7623	26	2.35	31

Table 5: Effect of mixed cropping models on coconut yield in on-farm trials in different agro-ecological regions.

Crop model and agro-ecological region	Mean nut yield nuts/ha/yr			Mean copra yield g/nut		
	No Mixed Crop	With Mixed Crop	Increase (%)	No Mixed Crop	With Mixed Crop	Increase (%)
Coconut +pepper coffee+ ginger (WL3)	6,406	7,427	16.0	197.3	217.8	10.4
Coconut + cacao + pepper + ginger (WL2)	5,738	6,657	16.0	197.7	219.5	11.0
Coconut +pepper + coffee+ NFT's (IL1)	4,541	6,970	53.5	204.1	237.6	16.4
Coconut + mango + lime + banana (IL3)	6,688	6,934	3.7	202.3	229.3	13.3
Coconut + cashew + banana (IL3)	5,139	6,794	32.0	163.6	185.4	13.3

Further, several perennial intercrops like bud-grafted cashew has shown complimentary effect even under harsh climate conditions prevailing in the dry zones (Table 6), Generally, bud-grafted cashew demand very low level of nutrients; hence nutrient competition between coconut and cashew is minimal.

This yield increment of coconut was because of the complimentary effects of agroforestry systems by perennial intercropping on soil fertility in terms of soil physical, chemical and biological properties (Table 7) with nutrient supplying trees grown under coconut. The coconut palm also serves as an economic shade tree by providing conditions to compliment the growth of several shade loving/shade tolerant crops such as cocoa, coffee and pepper.

Nutrient budget of coconut integrated with *Gliricidia*

Sanchez (1995) described that soil nutrients are considered among the least resilient component of sustainability. Nutrient budgets are a tool for determining whether there is an adequate balance of nutrients that are being depleted. As described earlier in monoculture coconut ecosystem, the nutrient balance is inadequate. One option to balance nutrient budgets is inorganic fertilizers application. The other option is to apply organic fertilizers supplemented with other sources to meet the balance of P, K, Mg requirements.

Table 6: Coconut yield as affected by cashew intercropping in Rathmalagara estate, Madampe.

Treatment	Nuts/Palm/Year				
	2004	2005	2006	2007	2008
No cashew	79	50	80	70	70
Bud-grafted cashew	75	51	70	77	56
Air layered cashew	70	40	78	79	61
Seedling cashew	67	51	74	62	70
Significance	n.s.	n.s.	n.s.	n.s.	n.s

Table 7: Effect of mixed cropping on soil fertility (0-15 cm depth).

Cropping System	Physical		Chemical				Biological
	Bulk density (g per cm)	Soil moisture	Organic carbon (%)	Total N (ppm)	Avail.P (ppm)	Exch.K (meq per 100 g	Earthworms (no.m-2)
Coconut only (control)	1.56	9.06	0.86	957	9.6	0.14	28
Coconut +cocoa	1.26	18.55	1.42	1,184	29.4	0.18	214
Coconut + coffee	1.23	12.91	1.36	1,022	27.8	0.15	218
Coconut + pepper	1.27	11.20	1.27	1,461	55.9	0.12	191
Coconut + clove	1.19	11.30	1.20	1,154	32.3	0.18	204
Coconut + cinnamon	1.25	10.69	1.46	1,249	28.9	0.16	233

Source: Gunathilake and Liyanage, 1995.

In an experiment conducted at Rathmalagara Estate, during 1990-1999, coconut palms had been fertilized with inorganic fertilizers and organic sources supplemented with P, K, and Mg. Nut yield showed that integration of leguminous cover crops or trees were able to produce equivalent yield compared to palms fertilized with inorganic fertilizers (Table 8).

In an organic farming model having un-replicated 24 coconut palms, it was shown that N supply by *in situ* grown *Gliricidia* produced an equal number of nuts in comparison to palms fertilized with goat manure (Table 9) and there was no difference in nut production between *in situ* grown *Gliricidia* lopped twice a year and applied to coconut palms.

Table 8: Comparison of inorganic and organic nitrogen supplemented with phosphorus, potassium and magnesium on nut yield of coconut (1990-1999).

Treatments (palm per year)	Nut yield (nuts per palm per year)
APM - 800 g urea +600 g ERP+1,600 g MOP + 1000 g dolomite	76
Pueraria cover + 300 g ERP+1,000 g MOP +500 g dolomite	77
Gliricidia 50kg +300 g ERP+1,000 g MOP + 500 g dolomite	66
Gliricidia + *Puraria* +300 g ERP+1,000 g MOP + 500 g dolomite	76

Source: CRI, 1990-1999.

Table 9: Effect of application of *Gliricidia* loppings and externally supplied, goat manure on coconut yield.

Treatments	Coconut Yield (nuts)								Average for 7 years
	2003	2004	2005	2006	2007	2008	2009	2010	
3 kg of APM+ 1kg of dolomite	40	63	74	86	65	89	76	69	70
50 kg of *Gliricidia* + 230 coconut husks + 600 g of ERP +1 kg of dolomite	35	79	55	85	57	81	91	71	69
5kg of Goat manure +130 coconut husks +600g of ERP+1kg of dolomite	41	51	75	104	65	87	94	69	73
50kg of *Gliricidia* + 230 coconut husks + 600g of ERP + 1 kg of dolomite + *Pueraria* cover crop	34	62	60	79	58	84	88	76	68

Role of NFT's in mixed farming in coconut lands.

Mix farming refers to an agroforestry system in which livestock, mainly cattle, goats and sheep from farm form the major component with facilities for grazing on natural and improved pasture grown under coconut. Crop/livestock integrated system is more suitable for less fertile marginal coconut lands (Liyanage, 1993) because the system provides valuable organic manure for coconut. Experiments carried out at the CRI has shown that the nutritive value of pastures could be improved by the introduction of NFT'S such as *Gliricidia* and *Leucaena*. These systems can overcome the seasonal feed shortage and competition for soil N between pasture and coconut.

In a mixed farming model established in a 0.8 hectare of mature coconut stand in the intermediate zone, four Jersey x local crossbred cattle have been raised successfully on improved mixed pasture integrated with *Gliricidia* and *Leucaena* established as a single row in the center of the coconut avenue and along the fence (Liyanage *et al.*, 1988).

In this study, 4% urea treated paddy straw mixed with *Gliricidia* loppings in the ratio 3:1 proved to be an excellent source of supplementary feed to tide over scarcity of pasture herbage during the dry season. Table 10 shows the productivity increases with the mixed farming model.

Table 10: Performance of pasture/fodder/NFT's and cattle in mixed farming system.

Component	Productivity
Coconut yield (monoculture)	10,934 nut/ha (period 1987-91)
Coconut yield (mixed farming)	12,095 nut/ha (Period 1987-91)
Brachiaria milliformis	17.95 t/ha/yr (DM)
Pueraria phaseoloides	7.46 t/ha/yr (DM)
Leucaena leucocephala	7.19 t/ha/yr (fresh fodder)
L. leucocephala + *Gliricidia sepium*	2.0 t/ha/yr (fresh Fodder)
Jersey x local cattle	306-681 g/head/day (live weight gains) 3.48 1/day (milk yield 1st location) 5.201 1/day (2nd location)

Source: Liyanage and Dassanayake, 1993.

In another study it has been shown that *Gliricidia* foliage mixed with *B. milliformis* pasture in 1:1 ratio improved feed intake and resulted in higher live weight gains (700 g per head per day) of cattle (Liyanage and Jayasundara, 1988). They also found that mixing paddy straw with *Gliricidia* loppings to be excellent source of supplementary fodder for cattle during the dry season.

Recent work undertaken at the CRI has shown the potential for raising goats on improved pasture integrated with *Gliricidia* (in the fence) and *Leucaena* (a row of 1 m apart in the center of the coconut avenue) in the intermediate zone of the coconut triangle. It has been found that, this system facilitates to raise 10 improved goats (Sri Lankan Boer) per ha, with sufficient feed (Gunathilake *et al.*, 2004, Unpublished). Further, the dung of 10 goats per hectare is sufficient to supply the total annual N demand by coconut palms of 156 trees per ha.

Gliricidia as a fertilizer tree to enhance coconut yield

Gliricidia is now popular as the 4th plantation crop due to its multiple uses (Gunathilake and Wasantha, 2004). It has the ability to fix atmospheric N and enrich soils by green manuring. On the other hand, it is a valuable animal feed supplement for protein.

Management of soil fertility in coconut plantations is now being addressed to sustain coconut yields economically. As at present, soil degradation is obvious. Application of chemical fertilizers is not the answer for management of sustainable soil fertility. Hence, the application organic/green manure for coconut as well as other crops is becoming a popular practice. It has been clearly demonstrated that *Gliricidia* could be grown successfully in coconut plantations without any detrimental effect on coconut (Anon, 2000).

A study has been conducted in a 50 year old coconut plantation, planted with three rows of *Gliricidia*, 1 m apart in the avenue of coconut keeping 1 m distance within a row giving density of 3,750 trees per hectare in land extent of 20 hectares including 80,000 *Gliricidia* trees. The objectives were to study the productivity of *Gliricidia* for green manuring of coconut and for fuelwood production. The results showed that inter-cultivation of *Gliricidia* in coconut lands improved microclimate by increased utilization of sunlight, reduce soil temperature and as a result, soil moisture has been elevated in soils of coconut with *Gliricidia* over coconut with no *Gliricidia* plants. Nutrition of coconut palms was increased in *Gliricidia* plots and this was prominent in nitrogen probably due to fixation of atmospheric N by *Gliricidia* (Tables 11a; 11b; 11c). Except K, other plant nutrients such as P, Ca and Mg levels were also elevated in soils with *Gliricidia* plus coconut that assumed *Gliricidia* is mining nutrition from deeper lagers to surface of soils through the process of pruning and decomposing of foliage (Gunathilake and Wasantha, 2004).

It has been reported that the foliage of *Gliricidia* contains about 4% nitrogen and is therefore an excellent source of green manure for coconut palms. On decomposition, this can restore the physical condition of the soil. The CRI recommendation is to incorporate 50 kilograms of fresh prunnings from *Gliricidia* into soil, to a depth of 15-20 cm aiming to meet the entire N requirement of a palm (Liyanage, 1993). The use of this technique can result in a substantial saving when compared with the cost of using chemical fertilizers.

Table 11a: Effect of *Gliricidia* intercultivation on coconut nutrition indicated at 14th leaf.

Situation	N (%)	P (%)	K (%)	Mg (%)	Ca (%)
Coconut alone	1.66	0.11	0.91	0.35	0.39
Coconut + *Gliricidia*	2.5	0.12	0.84	0.33	0.54
Sufficiency range /level	1.9-0	0.11-0.13	1.2-1.5	0.25-0.35	0.35-0.5

Table 11b: Effect of *Gliricidia* intercultivation on soil N, P, K, Ca and Mg.

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

Table 11c: Effect of *Gliricidia* intercultivation on soil organic matter (%).

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

An experiment has been conducted over 10 years (1990-99) to study the supplementation of N for coconut palms by foliage of *Gliricidia* (50 kilograms per palm per year equaling to 800 g of urea per palm per year) instead of inorganic N by Adult Palm Mixture and details of treatments are indicated in Table 12. The result revealed that there was no difference in nuts production of palms fertilized with green manure N by *Gliricidia* and inorganic N by urea suggesting that inorganic N could be supplemented by incorporation of foliage of *Gliricidia* (Anon, 2000).

Application of organic manures such as green tree loppings, cattle, goat, poultry manures plays a significant role in restoring the fertility of degraded marginal coconut lands. The issues associated with organic fertilizers are the high volume, bulkiness, unavailability to find large quantities and their transport. The remedy to those is *in situ* production of organic martial within the coconut lands. To study this long term experiment over 7 years has been conducted at Rathmalagara estate, CRI in a coconut plantation aged 50 years and different treatments are detailed in Table 12. In this, comparison has been done with application of *in situ* grown *Gliricidia* loppings for palms along with *ex situ* supplied cattle dung. Table 12 shows that over the period of seven years, there were no significant difference between *in situ* production of organic matter and *ex situ* supplied organic materials. Hence, intercultivation of *Gliricidia* for green manuring is the best solution for soil fertility improvement. Further, there was no difference in nut production between palms with *in-situ* grown *Gliricidia* manuring and palms with application of inorganic APM coconut fertilizer mixture (Anon, 2000).

Table 12: Comparison of inorganic and organic nitrogen supply supplemented with P, K and Mg on nut yield of coconut (1990-1999).

Treatments (per palm per year)	Average nut yield (nuts per palm per year)
APM -800 g urea +600 g ERP+1,600 g MOP+ 1,000 g dolomite	76
Pueraria cover + 300 g ERP+1,000 g MOP+500 g dolomite	77
Gliricidia 50 kg +300 g ERP+1,000 g MOP+ 500 g dolomite (*in situ*)	66
Gliricidia +*Pueraria* +300 g ERP+1,000 g MOP + 500 g dolomite	76

***Gliricidia* for bioenergy *vs* soil fertility improvement in coconut lands**

Along with the price increases of fossil fuels and electricity, there is also an increased realization in the country that traditional energy is going to be more expensive with time. Therefore, a greater utilization of alternatives has to be actively promoted by the state to sustain the economic growth of the country. Further, self reliance is now viewed as an important aspect in both food and energy in view of global political and economic developments. Hence, development of alternative energy production systems within the plantation / agriculture sector is vital for national energy security and sustainable agricultural production. Gunathilake and Joseph (2008) conducted a study to maximize farm income through an integrated (Coconut + Gliricidia + paddy straw + cattle) farming system using the theoretical model given below (Figure 1) and to develop a sustainable bio energy system to meet energy requirement of the household.

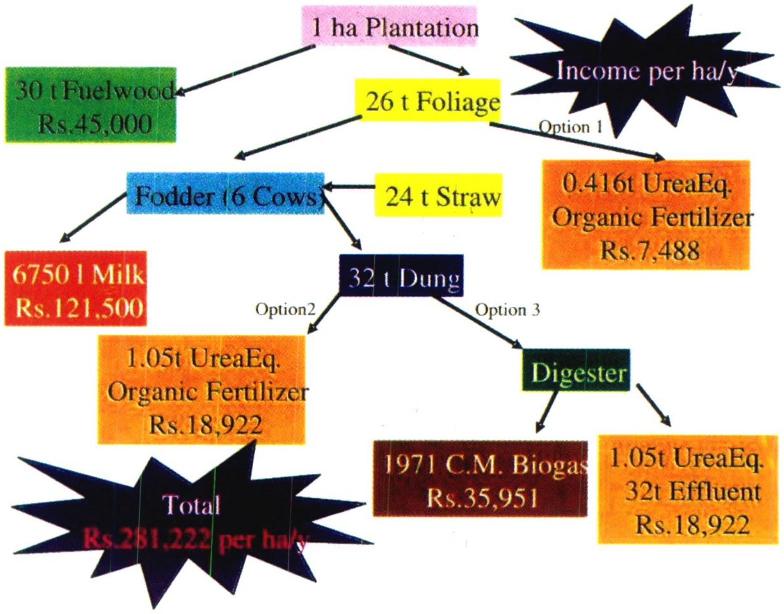

Figure 1: **Theoretical model prior to the trials consists of coconut, buffalo, Gliricidia, paddy straw and natural grasses to produce green energy.**

To study this concept one hectare of coconut land (156 palms per ha) planted with *Gliricidia* (2,500 trees per hectare in double rows in avenues of coconut) and available natural pasture and outside supplied paddy straw coupled with six buffaloes were mixed into a farming model to examine the total productivity and potential of green energy production by wood and biogas. Biogas has been used to run a 0.75 hp engine and wood of *Gliricidia* has been used to energize a 3.5 kW gassifire for generating electricity. Soils of the model have been enriched by adding the effluent of biogas. They found that the fertility of soils (N, P, K, Mg and moisture holding capacity) improved significantly over soils sampled outside the model. Tables 13 and 14 show that effluent of biogas is more fertile than dried buffalo dung. As a result of application of biogas effluent instead of buffalo dung, nut yield of coconut palms increased from 30 to 60 nuts per palm per year over a period of two years. This model proved that direct *Gliricidia* foliage fed to buffaloes and then dung converted to biogas effluent and application to coconut palms is more beneficial than direct application of *Gliricidia* foliage to coconut palms as a green manure. Further, one hectare of coconut/*Gliricidia*/natural pasture/paddy straw with six buffalos is able to produce green energy equivalent to 5,700 units of electricity.

Table 13: Soil nutrient levels (N, P, K, Mg, Ca and Na) within the model and outside at Ratmalagara estate, Madampe.

Nutrient	Depth (cm)	System (inside)	System (outside)
N (mg/kg)	15	139.6	1,068.81
	30	2,399.3	1,103.61
P (meq/100 g)	15	23.99	11.43
	30	8.16	4.14
K (meq/100 g)	15	1.101	0.260
	30	0.891	0.189
Mg (meq/100 g)	15	1.109	0.667
	30	0.891	0.285
Ca (meq/100 g)	15	1.545	1.152
	30	1.273	0.518
Na (meq/100 g)	15	0.026	0.040
	30	0.025	0.022

Table 14:Analysis of buffalo dung and biogas slurry at the Ratmalagara estate, Madampe.

	N (%)	P (%)	K (%)	Mg (%)	EC (Us/cm)	pH
Cow dung	1.31	0.56	0.93	0.64	3.41	7.14
Biogas slurry	2.96	1.08	1.02	0.52	3.07	6.69

It is evident that marginally suitable soils could be elevated by improved coconut land management as practised in this model by adopting integrated system with combinations of livestock and crops including NFT's such as *Gliricidia*.

Conclusions

Despite the problems, and considering the low productivity and poor returns from existing monoculture coconut plantations in Sri Lanka, there is a critical need to maximize the use of coconut lands. Thus a, shift from the traditional monoculture system to agroforestry based farming systems has become a national priority in order to satisfy the growing demand for food, fodder, timber and fuelwood for the rapidly increasing population in the major coconut growing areas. In this regard, sustainable soil and land management should be the concept to avoid soil fertility degradation. To achieve this, high biomass production, nutrient recycling, atmospheric nitrogen fixation, reduce soil erosion, increase facility for macro and micro nutrient activity are several issues for consideration. The information above indicates that integrated tree farming and NFT's will play a vital role to enhance soil fertility in coconut lands.

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SOIL FERTILITY AND WATER MANAGEMENT THROUGH COCONUT BASED AGROFORESTRY SYSTEMS

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Abstract

Nutrient status, moisture levels, microbial mediated processes and N mineralization rates were assessed and compared in the pure coconut, man-made forest and natural forest soils in Ratmalagara estate belonging to the intermediate zone of Sri Lanka. The micro nutrient status and physical and physico-chemical parameters of the coconut soil and natural forest soils in dry, intermediate and wet zones were also determined. Soil samples were collected from the center of the four coconut palms at the depth of 0-30 cm in coconut lands, man-made forests and natural forest soils. For mineralization studies, undisturbed soil samples were collected at 1 m and 2 m away from coconut palms [2 m and 1 m away from Nitrogen Fixing Trees (NFTs)] in man-made forest. The standard methods were followed for the determinations of nutrients, moisture, microbial mediated process, N mineralization rate, physical and physico-chemical parameters. The major nutrients such as N, P, K, Mg and organic carbon have shown significantly ($P \leq 0.05$) high values in natural forest soils and followed by man-made forest soils and then coconut soil. The increase of the above nutrients were 64%, 114%, 90%, 700% and 180%, respectively in forest soils vs coconut soils and the increase values have shown as 35%, 43%, 70%, 300% and 80% in man-made forest vs coconut soils. The microbial mediated process such as the number of total bacterial and fungal colonies and CO_2 evaluation were also decreased in coconut soils compared to the man-made forest and natural forest. The micro nutrient levels were also high in natural forest soils compared to the coconut soils in the soils taken in three agro-ecological regions. The lowest available micronutrients were Zn and Cu at all sites irrespectively of coconut and forest soils. The mineralization rates were increased closer to NFTs rhizosphere than coconut rhizosphere. The physical and physico-chemical parameters were also high in forest soils than in coconut soils. The introduction of NFT such as Gliricidia, can enhance the nutrient levels as well as moisture levels in coconut lands. The nutrient and moisture depletion rates were high in coconut soils compared with natural forest soils. Thus, introduction of NFTs to the monocrop coconut lands, the nutrient pool, moisture retention and other physical, chemical and biological parameters can be enhanced to be used by coconut palms.

Introduction

Coconut is a major plantation crop of Sri Lanka. Growing a number of other crops in association with coconuts is a widespread practice in all coconut growing areas of the country. The general practice is that other crops can profitably be grown between or under the coconut palms during different growth stages and thus the overall productivity of the land can substantially be increased.

Coconut is cultivated in 394,386 hectares which is 20% of the total cultivated area of Sri Lanka. It is the most widely cultivated plantation crop in the island and second only to rice (0.87 million ha) in terms of the area under the crop (Liyanage *et al.*, 1986). Coconut is ubiquitous in Sri Lanka with its prevalence mostly confined to the north western province (Puttalam and Kurunegala Districts), western province (Gampaha, Kalutara and Colombo Districts), southern province (Galle, Matara, and Hambantota Districts) and some part of northern and eastern provinces (MPI, 2008; Tennakoon, 2005). It is a wide spread practice in all coconut growing areas of Sri Lanka to grow a large number of other crops in association with coconuts. The practice has been encouraged by the Government of Sri Lanka since 1973 by introducing several subsidy schemes. Soil fertility can be expressed as the ability of a soil to supply plant nutrients efficiently to the crops and this depends on the amount of organic materials and humas present in the soil. This paper assesses the soil fertility status on coconut monoculture, manmade forests and natural forests in terms of soil physical, chemical and biological properties and soil moisture status.

Assessment procedure

Selection of agroforestry systems

Five different agroforestry systems were selected based on coconut monoculture, man-made forest and natural forests in three different agro-ecological regions. Comparison of coconut, man-made forest and natural forest was done using coconut monoculture and man-made forest with NFTs (*Acacia* and *Leucaena*) in sites at Ratmalagara estate of the Coconut Research Institute (CRI) and a site of natural forest adjoining the Ratmalagara in intermediate zone for the assessment of nutrients and micro-biological parameters. In addition to that comparison of coconut lands with natural forest in 3 different agro-ecological regions was focused with coconut lands and adjoining forest soils at Pallama (dry zone), Ratmalagara (intermediate zone) and Walpita (wet zone) for CEC, micronutrients, physical and physico-chemical parameters. In the case of coconut intercropping with *Gliricidia*, the site at Ratmalagara estate at Madampe in intermediate zone was selected for the moisture and nutrient assessment. Furthermore, N mineralization rates were compared in coconut with different NFT's that were *Acacia*, *Calliandra*, *Gliricidia* and *Leucaena* at Ratmalagara in Intermediate zone. Apart from that, coconut land in

Makandura estate of the CRI and adjoining forest land were selected for the assessment of moisture depletion curve and nutrient depletion assessment.

Sampling and sample preparation

Soil samples were collected from the center of four coconut palms at the depth of 0-30 cm in coconut lands, man-made forests and adjoining natural forest land. Six sampling points were selected from each site of coconut, man-made and natural forests. For the microbiological parameters, soil samples were collected at the depth of 0-15 cm of coconut, forest and man-made forest sites. The samples were sieved using 2 mm sieve and mixed well to get a composite sample. The soil samples were air-dried at room temperature for 48-72 hours. Then portions of the air-dried soil samples were ground for nitrogen and organic carbon analysis. Fresh soil samples were used for the microbiological and moisture determination as well as mineralization studies.

For N mineralization, plastic tubes (50 mm diameter and 30 cm long) were inserted to a depth of 15 cm near to (in two distances) nitrogen fixing trees and coconut palms. A total of 40 plastic tubes were placed at two distances (i.e. 1 m and 2 m away from base) of both coconut palms and NFTs separately, and tubes were removed 2 weeks (Time 1) afterwards. The same procedure was followed by inserting other set of (40) plastic tubes for the period of 4 weeks of field incubation period (Time 2) at the same distance from the coconut and NFT's.

Analysis of samples

Standard methods were used for the chemical analysis. Soil samples were digested and followed by analysis using auto analyzer for total N (Blackmore *et al.*, 1981; Tropical Soil Analysis, 1982). Available P was estimated by using spectrophotometer after extracting 2.5% ($^{v}/_{v}$) acidic acid (Somasiri and Wijebandara, 2004). Exchangeable bases (Na, K, Ca and Mg) were estimated using ammonium acetate extraction method and readings were taken from an atomic absorption spectrophotometer (Tropical Soil Analysis, 1982). Moisture levels pH and EC were determined using (Black *et al.*, 1965) method. Organic carbon measurement was done using by Walkley and Black (1934) and Nelson and Sommers (1982). Cation exchange capacity was estimated using saturated NH_4^+ method (Black, 1965). The micronutrient analysis was done using Perchloric acid digestion (Hesse, 1971). Standard methods were used for total bacterial and fungal colonies (Parnkinson *et al.*, 1971) and CO_2 evolution (Kibble, 1966). For mineralized N (NH_4-N and NO_3-N) extracted by 2 M KCl and NH_4-N and NO_3-N concentrations were determined spectrophotometrically using a rapid flow injection analyzer (Marr and Cresser, 1983).

Soil fertility in agroforestry and other systems

The results showed that in continuous cultivation of coconut for a long term even with the recommended management practices caused substantial reduction of major nutrients of N, P, K, Mg in comparison with those of man-made forest and natural forest soils. The percentage of the above major nutrients of N, P, K and Mg were 64%, 114%, 90% and 700% in coconut vs forest and the values of the above nutrients were 35%, 43%, 70% and 300% in coconut vs man-made forest soils.

The nutrient levels in the soils of coconut monoculture, man-made forests and forests in the Ratmalagara estate (intermediate zone) are given in Figures 1, 2, and 3.

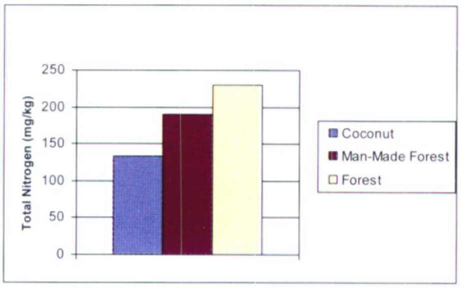

Figure 1: Total N in soils of coconut monoculture, man-made forest and forest soils.

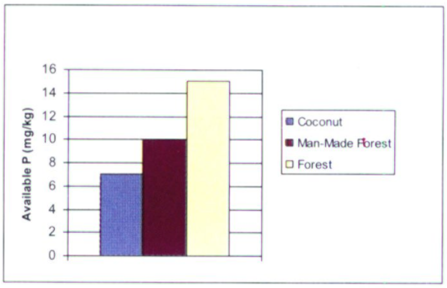

Figure 2: Available P in the soils of the coconut monoculture, man-made forest and forest soils.

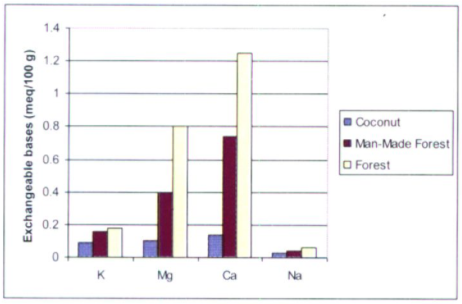

Figure 3: Exchangeable bases (K, Mg, Ca and Na) in soils of the coconut mono culture, man-made forest and forest soils.

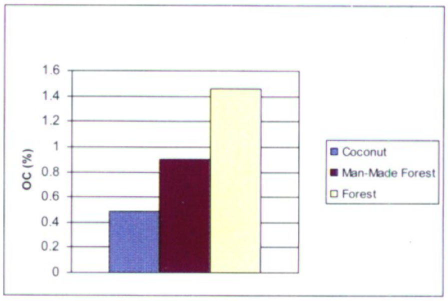

Figure 4: Organic carbon content in the soils of coconut monoculture, man-made forest and forest soils.

Total N, available phosphorus as well as exchangeable bases such as K, Mg, Ca and Na have shown significantly higher values ($P \leq 0.05$) in the forest soils and thereafter man-made forest than that of coconut soils. Figure 4 shows the organic carbon content of the different systems and it also clearly showed that significantly high ($P \leq 0.05$) value has been gained in the forest soils and followed by man-made forest and coconut soils. The organic carbon has shown 180% increase between forest and coconut soils while it was 80% between man-made forest and coconut soils.

The microbiological parameters such as the number of total bacterial colonies, the number of total fungal colonies and microbial activity as CO_2 evolution in the coconut, man-made forest and forest soils of the Ratmalagara in intermediate zone have shown in Figures 5, 6 and 7, respectively. The highest values of the above parameters were in the forest soils and followed by man-made forest soils and then coconut soils. The microbial activity has increased by 200% in forest soils in comparison with coconut soils and the increase between man-made forest and coconut soils was 50%.

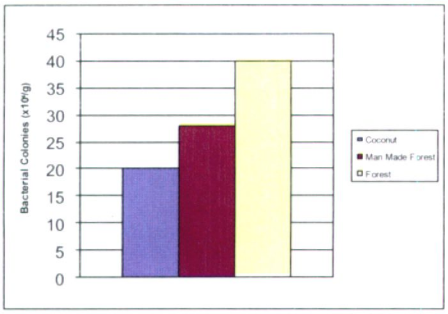

Figure 5: **Number of total bacterial colonies in soils of coconut mono culture, man-made forest and forest soils.**

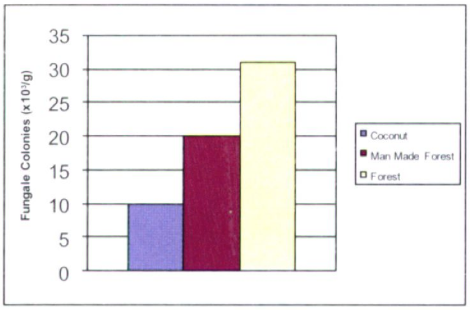

Figure 6: **Number of total fungale colonies in soils of coconut mono culture, man-made forest and forest soils.**

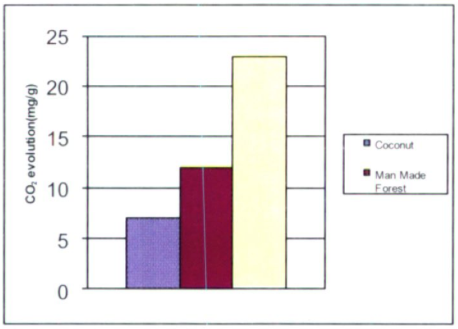

Figure 7: **Microbial activity in soils of coconut mono culture, man-made forest and forest soils.**

Figures 8, 9 and 10 show the micronutrient levels of coconut soils and forest soils in three agro-ecological regions viz-a-viz Pallama site in dry zone, Ratmalagara site in intermediate zone and Walpita site in wet zone. A reduction of almost all analyzed micronutrients such as Zn, Cu, Fe, Mn and Cl was observed in coconut soils in comparison with the adjoining natural forest soils. The highest available micronutrients are Fe, Mn and Cl in the all sites irrespective of coconut or forest soils. The Zn and Cu levels were considerably very low at the all sites of both forest and coconut soils.

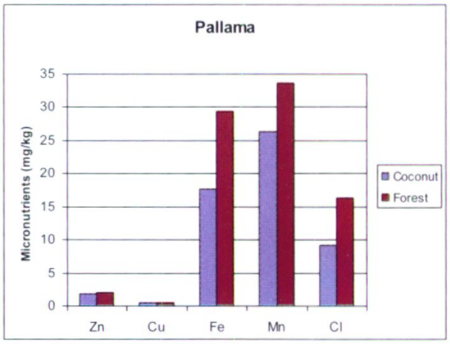

Figure 8: Micro nutrient levels of coconut soil and adjoining forest soils in Pallama site of dry zone.

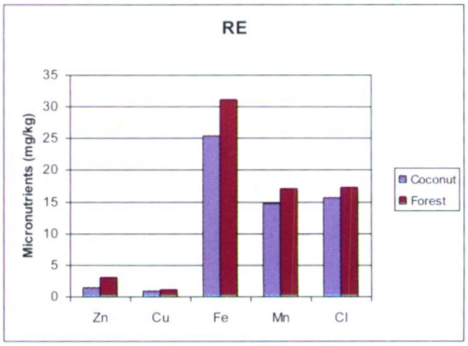

Figure 9: Micro nutrient levels of coconut soil and adjoining forest soils in Ratmalagara site of Intermediate zone.

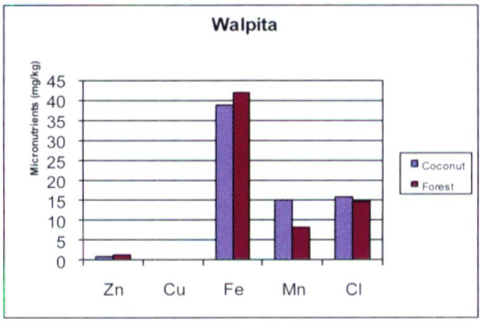

Figure 10: Micro nutrient levels of coconut soil and adjoining forest soils in Walpita site in wet zone.

Soil fertility assessment in coconut monoculture and coconut based crop (*Gliricidia*) lands at Ratmalagara estate is given in Table 1.

Table 1: **Nutrients and organic carbon content in coconut and coconut + *Gliricidia* land at (a) 0-15 cm and (b) 15-30 cm soil depths.**

Crop System	N (mg/kg)		P (mg/kg)		K (meq/ 100 g)		Mg (meq/ 100 g)		OC (%)	
	a	b	a	b	a	b	a	b	A	b
Coconut only	490	327	3.4	Trace	0.38	0.43	0.66	0.58	0.46	0.50
Coconut+ *Gliricidia*	644	471	8.1	5.6	0.58	0.66	0.91	0.91	0.76	0.55

The highest values were obtained in coconut + *Gliricidia* soils than those of only coconut soils at the two depths i.e. 0-15 cm and 15-30 cm. Moisture levels of the coconut and coconut + *Gliricidia* cultivated soils were determined at three depths 0-15 and 15-30 and 30-45 cm at 30 days dry spell and 45 days dry spell (Table 2).

Table 2: **Soil moisture (%) of coconut and coconut + *Gliricidia* plantation at Ratmalagara estate.**

Crop system	Moisture % in 30 days dry spell			Moisture % in 45 days dry spell		
	0-15 cm	15-30 cm	30-45 cm	0-15 cm	15-30 cm	30-45 cm
Coconut only	4.7	4.8	5.2	2.2	3.4	3.6
Coconut + *Gliricidia*	4.0	4.9	5.6	4.1	4.6	5.2

Moisture content has shown the highest value in the coconut based *Gliricidia* soils than that of coconut monoculture soils. Net N mineralization rates in NFT's and coconut soils are given in Table 3. Net N mineralization showed highly significant difference ($P \leq 0.001$) in the soil samples taken 1 m away from different NFTs than coconut palms. The highest net N mineralization was reported from 1 m away from *Gliricidia* trees followed by *Leucaena, Calliandra* and *Acacia*. The lowest net N mineralization was recorded in samples taken from coconut monoculture. Furthermore, the highest net N mineralization rates were recorded at 4 weeks incubation period than that of 2 week incubation period.

Table 3: Net nitrogen mineralization (kg/ha) in different nitrogen fixing trees and coconut tree.

Plant Type	N mineralization (kg/ha)			
	2 weeks after field incubation		4 weeks after field incubation	
	1 m away from coconut	2 m away from coconut	1 m away from coconut	2 m away from coconut
Acacia	1.9	3.1	2.2	3.7
Calliandra	2.6	4.6	3.9	9.2
Gliricidia	4.9	8.7	5.9	15.5
Leucaena	4.1	6.4	5.4	7.8
Coconut monoculture	1.2	1.7	2.2	1.5

Figure 11 shows the cation exchange capacity of the coconut and adjoining forest soils in the Pallama (dry zone) Ratmalagara (intermediate zone) and Walpita (wet zone) sites. The significantly high ($P \leq 0.05$) values have been shown in the forest soils in all 3 sites compared with 3 coconut soils in 3 agro-ecological regions. The CEC values have increased as 90%, 37% and 59% in Pallama (dry zone) Ratmalagara (intermediate zone) and Walpita (wet zone), respectively.

Physical and physico-chemical parameters such as pH, electrical conductivity and bulk density of the 3 sites namely Pallama, Ratmalagara and Walpita coconut and forest soils are shown in the Figures 12, 13 and 14, respectively.

The pH and EC have shown the highest values in the forest soils than those of coconut soils in the all 3 sites, while the bulk density has received the lowest values in the forest soils. The bulk density has shown 32% increase in Pallama (dry zone) site coconut soils than that of Pallama forest soils. The bulk density in coconut soils of Ratmalagara (intermediate zone) and Walpita (wet zone) has shown 15% and 8% increases, respectively than that of forest soils.

Figure 15 shows the nutrient depletion in coconut land and the adjoining forest land in Makandura site in the wet zone. This has clearly shown that the all nutrients except P, Fe and Cl were highest in the forest soils than that of coconut soils. The highest depletion of nutrients have been shown in the coconut soils compared with the adjoining forest soils.

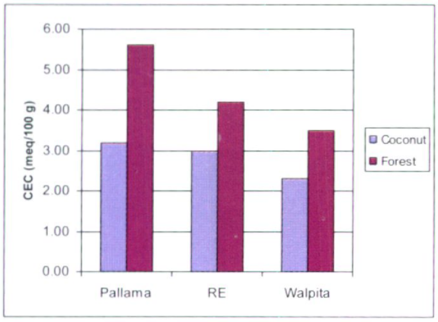

Figure 11: Cation exchange capacity of coconut soils and forest soils of Pallama, RE and Walpita sites.

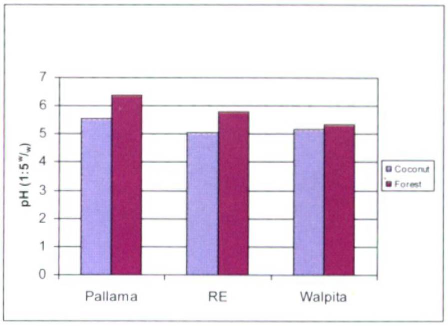

Figure 12: pH of coconut soils and forest soils of Pallama, RE and Walpita sites.

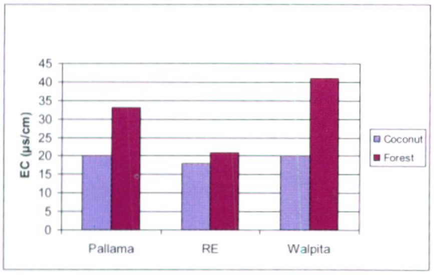

Figure 13: Electrical conductivity of coconut soils and forest soils of Pallama, RE and Walpita sites.

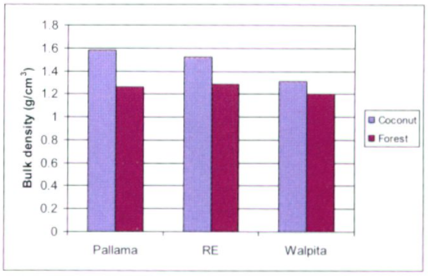

Figure 14: Bulk density of coconut soils and forest soils of Pallama, RE and Walpita sites.

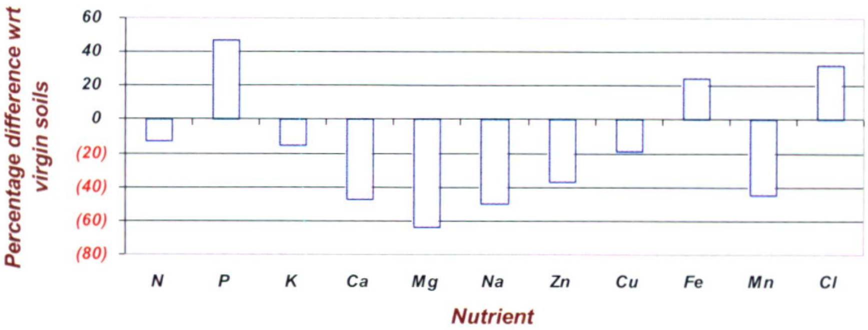

Figure 15: Differences of macro and micro nutrients in Makandura coconut soils *vs* virgin soils.

Moisture depletion pattern in Makandura site (coconut and forest) has been shown in Figure 16. This clearly shows that comparatively lower moisture enrichments were indicated in the coconut lands compared to the forest lands throughout the sampling period.

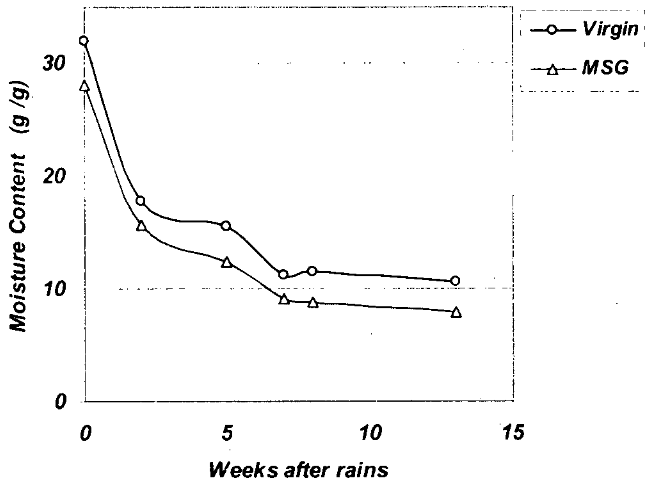

Figure 16: Moisture depletion pattern in coconut and forest soils at Makandura site.

The reduction of nutrients in both major and micro nutrients in cultivated soils may be due to the high removal of those nutrients by coconut palms without comparable replenishment of nutrients by nutrient recycling or fertilizer application. The major nutrients such as N, P, K and Mg annually remove from the coconut pure land in land suitability classes S_1 to S_3 (nut yield potential is 75-110 or more palm per year) was 740 g, 118 g, 1,553 g and 213 g per palm, respectively. On the other hand above major nutrient removal from coconut pure plantation in land suitability classes S_4 to S_5 (nut yield potential is 50-75 or less per palm per year) annually was 424 g, 95 g, 1,248 g and 143 g, respectively (Tennakoon, 2010). Therefore, the removal of nutrients from pure coconut plantation can be minimized by introducing the agroforestry trees or other inter crops to the coconut lands, because these studies clearly showed that the soil nutrient pool was enriched in the coconut land with other agroforestry systems. The reduction of organic carbon (i.e. 180% and 80%) in coconut *vs* natural forest and coconut *vs* man-made forest, respectively indicate a substantial reduction in application of organic materials to coconut soil which ultimately leads to retention of nutrients and water holding capacity thus contributing to a grater nutrient leaching. Moreover, coconut cultivation caused a reduction of soil pH in all estates.

NFTs such as *Gliricidia, Acacia, Calliandra* and *Leucaena* in coconut plantations led to a significant improvement in the soils and micro climate (Gunathilake *et al.*, 2004). There was a reduction of soil temperature underneath the NFT's as well as natural forests canopy which may have general benefits that increase in root activity, a reduction of soil moisture losses and a reduction of CO_2 evolvement.

Soil fertility improvement by NFT's is the key for development of degraded soils and agriculture. As an example one hectare of *Gliricidia* with coconut produced approximately 24 metric tons (fresh weight) of leaf biomass annually (Gunathilake *et al.*, 2004). Organic materials are considered as important resources for building soil fertility. In general NFTs enhance soil mediated processes by activity of microorganisms due to high organic content of NFT rhizosphere. The increase of density of microorganisms used in soil rhizosphere, helps to breakdown organic materials in the NFT rhizosphere (Tennakoon and Liyanage, 1977).

Release of root exudates from NFT may also stimulate the growth of microorganisms (Killham, 1994). In addition to the fixing of N, those NFT plants with the addition of organic manure, after decomposition of falling leaves also supply nutrients for the rapid growth of microorganisms in NFT rhizosphere than coconut monoculture rhizosphere. Therefore, these increased microorganism population may help to perform autotrophic as well as heterotrophic nitrification and mineralization process in the NFT rhizosphere. Thus, the introduction of NFTs in the coconut monoculture, the nutrient availability, moisture and microbial mediated processes can enhance and rebuild the nutrient pool in the coconut lands.

Conclusions

The essential nutrients such as macro and micro depletion are higher in coconut lands followed by man-made forest and natural forests. The physical and physico-chemical parameters are also greater in the forest soils and followed by man-made forest and then coconut soils. The microbial mediated process can be enhanced after introducing of NFT's in coconut monocropped lands. By introducing of NFT's to the coconut land, the nutrient availability, moisture retention as well as other chemical, physical and biological parameters can be enhanced gradually. Thereby soil fertility can be enhanced. The nutrient removal from pure coconut lands could also be minimized due to the introduction of NFT's. Therefore, integration of NFT's with coconut would increase soil quality such as physical, chemical and biological parameters and thereby supply the required nutrients to the coconut palm. The coconut/NFT tree based integrated system helps to minimize additional input of fertilizers in coconut plantations, thus saving on fertilizer cost.

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INTEGRATED PEST MANAGEMENT IN COCONUT BASED AGROFORESTRY SYSTEMS

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Abstract

Coconut based agroforestry systems have great potential in bestowing multiple benefits to the growers. One important consideration within the context of coconut based agroforestry systems is the management of pests in the system. Pest problems in coconut based agroforestry could arise mainly from two sources: by introducing pests with importation of plants into the system and by some peculiar features of agroforestry systems. These problems become more prominent when successful natural enemies of the introduced pests are not present in the new system. Pests of coconut have drawn the attention of many scientists who have conducted a large number of studies in coconut growing countries all over the world. Pests of other potential components in the coconut based agroforestry have also been studied extensively. However, pest management within the context of coconut based agroforestry has not been the focus in any of those studies. Pests of coconut based agroforestry systems would fundamentally be the pests of components in the system. Nevertheless, their influence on the components of the system will be different when they are raised as components in the agroforestry system. This is largely because the bio-ecological factors governing the population dynamics of pest populations and their natural enemies are not necessarily the same in coconut monoculture and in coconut based agroforestry systems. Fundamental aspects of pest management in agroforestry systems and strategies for pest management in coconut based agroforestry systems are described in this paper. Future directions to fill the gaps in knowledge on pest management within the context of coconut based agroforestry are also discussed.

Introduction

Agroforestry is defined as a land-use system in which woody perennials (trees, shrubs, etc.) are grown in association with herbaceous plants (crops, pastures) and/or livestock in a spatial arrangement, a rotation or both, and in which there are both ecological and economic interactions between the tree and non-tree components of the system (Young, 1989). Essentially agroforestry systems are diverse ecological systems of distinctive arrangement of components in space and time. Major components in an agroforestry system include trees and shrubs, crops, pasture, livestock and other components such as bees and fish in specialized systems. Like any other cropping system, environmental factors govern the performance of the components in the agroforestry system.

Pest management is an important aspect in agroforestry systems where interactions are more complex than in simple systems. Pests can damage the crops in the agroforestry system and thereby can seriously affect the sustainability of that system. Pest problems in agroforestry systems are likely to arise from introduction of pests through importation of wild plants into the system or due to some peculiar features of the system (Epila, 1986). Pests in agroforestry systems are essentially the pests of individual components of the agroforestry system. Composition of pests of any particular crop, whether it is in a monoculture or polyculture system, usually remains constant in most of the cases but the activities and the dynamics of these pests are likely to differ in the two systems. More precisely, interactions between the pests and their natural enemies in the agroforestry system may be different from those in mono-culture systems. This is largely because the bio-ecological factors that govern the activities and dynamics of the pests and their natural enemies in the two systems are not the same. Among the factors that govern the activities of pests in an agroforestry system, the dynamics of the pest and its natural enemies, degree of interaction between the components of the system, composition of the plant species in the system and the type of the system are the most important.

Interactions among the components in an agroforestry system can be positive (reduced pest damage) or negative (increased pest damage) or neutral (no change in pest damage) in relation to monocultures. Plant diversity in areas surrounding crops has been observed to increase the density and diversity of the natural enemies (Altieri and Letourneau, 1982; Zacarias and Moraes, 2002). Studies have shown the importance of agroforestry systems in pest management because they modify the micro climatic conditions, increase niche availability and provide foods for natural enemies and competitors of pests and affect the arthropod diversity (Stamps and Linit, 1998; Linit and Stamps, 1995; Altieri and Nicholls, 2002; Barbar *et al.*, 2010).

Among many factors that govern the pest situation in agroforestry systems, the most important factors are the diversity of the vegetation in the system, taxonomic relatedness of the host plants of the pests, host range of the pest and the potential of biological control in the particular system. Higher the diversity in the vegetation, lower will be the pest incidences. For example, in a monoculture, specific pests, may find concentrated sources of food over a large area which facilitates the continuous build up of pest populations (Root, 1973). When plants that belong to the same or closer taxonomic group are grown together, food for the pests are available continuously in those plants as most of the pests can share plants of the same or close taxonomic groups. Even the plants belonging to different taxonomic groups can support the population build up of certain pests. In some cases, the same stage of the pest can attack a range of host plants. Alternatively, different stages of a pest can damage different plant species (Yudin *et al.*, 1986; Ghosh *et al.*, 1986). Vegetation diversity does not always reduce the pest populations and the severity of the pest damage may depend on the relative abundance of the host plants. Therefore, careful manipulations are necessary to achieve the expected targets in pest management in agroforestry systems. Higher vegetation diversity increases the potential for biological control of the pests in the system. The presence of alternative prey/food, shelter/habitats and certain chemicals that are secreted by some component plants in the system will enhance the efficiency of natural enemies (Smith, 1969; Doutt and Nakatta; 1973, Altieri *et al.*, 1983). Other factors that govern the pest situation in agroforestry systems are microclimatic changes, interactions among the plants, masking effects of the plants, availability of physical barriers to the movement of pests, arrangement of plants in the system, intentional introduction of exotic plants and accidental introduction of pests into the system, domestication of components which has resulted in plants deficient in defense mechanisms against pests, competition between the components particularly on nutrients, water and light and management practices.

Pest management in coconut based agroforestry systems

Potential pest problems in coconut agroforestry systems may be different from many other agroforestry systems due to unique features of the system (perennial, tall plant, differences in agronomic practices etc.). Even the dynamics, severity levels and the control strategies of the known pests of coconut would be different when coconut is grown as a component in agroforestry systems. Components in the agroforestry system will greatly influence the stability of the pests and their natural enemies.

Strategies for pest management in coconut based agroforestry systems

(i) Composition of the components (choice of the plant species)

Selection of the component plant species should be done based on the agro-ecological regions because different companion crops are recommended for different agro-ecological zones. Further, selection criteria of components should preferably be based on increasing useful attributes in the system that can be used as suitable pest management tools. Thus, like any other agroforestry system, the components in the coconut based agroforestry systems should thoroughly be screened before combining them as a system.

One major important requirement in agroforestry from the pest management point of view is the provision of conditions for the survival of natural enemies of the pests. Usually generalist natural enemies are more suitable as biological control agents of pests in perennial crops (McMurtry and Croft, 1996) and they can feed, survive and reproduce on an array of foods. Components in the agroforestry system have to be cautiously selected in such a way that, by selecting suitable components, the system creates favorable conditions for the natural enemies of the pest either by providing alternative food/prey or shelter. For example components plants that can provide alternate foods such as pollen could ideally be selected in areas where the coconut mite (*Aceria guerreronis*) would be an important pest. Plants that can provide suitable pollen would enhance the survival of *Neoseiulus baraki*, the predatory mite of the coconut mite. Plants with undesirable characters (e.g. toxic to natural enemies and pollinators) should also be avoided. Component plants in coconut based agroforestry systems could be manipulated to enhance the conservation of biological control agents of the pests.

Components in the coconut based agroforestry systems would supplement the income loss due to pest damages. For example, holistic approach has been introduced in India to reduce the income loss due to coconut mite infestations (Nair, C.P.R., Personal Communication). Income from timber plants, legume food crops, *Gliricidia*, pastures, ornamental plants, livestock products and other food crops would supplement the income loss to the grower due to pest damages.

(ii) Taxonomic relations of plants

Any agroforestry system with plants that are taxonomically far apart with a narrow pest complex and those having resistant cultivars would be stable when pest management is considered. The number of experiments and reviews indicated the reduction in pest incidence in diversified vegetations when compared to monocultures (Altieri and Letourneau, 1982; Altieri, 1980). Weeds in crop fields also, directly or indirectly, influence the behaviour and dynamics of insects on the crop (Pimentel, 1961; Dempster, 1969; Root, 1973; Horn, 1981).

The diversity of pests feeding on or in association with coconut is enormous: a large number of insect pests (e.g. red palm weevil - *Rhynchophorus ferrugineus*, black beetle - *Oryctes rhinoceros*, coconut scale - *Aspidiotus destructer* etc.), acarine pests (e.g. coconut mite - *A. gurreronis*, red palm mite - *Raoiella indica*) and mammalian pests are among them. These pests are either polyphagous or oligophagous or monophagous. Oligophagous and monophagous pests can survive and reproduce on many component plants in a coconut based agroforestry system. Therefore, coconut based agroforestry systems with closely related plants such as ornamental palm species and betel nut palm (*Areca catechu*) can harbor more pests such as black beetle, coconut scale, red palm mite and many mammalian pests. These plants may contain some common chemicals that are sought by the pests and also facilitate the multiplication of pest populations over a longer period of time on different plant species. Conversely, these plants may enhance the survival of natural enemies of the pests. Therefore, careful selection of component plants that are taxonomically far apart, with desirable attributes to enhance the effect of natural enemies, and perhaps with undesirable attributes for the pests to develop beyond economical threshold levels has to be done.

(iii) Host range of the pest

Specialized pests such as coconut mite would show lower population densities in higher plant diversity. Introduction of component plants in the system should be done to minimize the alternative hosts of pests with limited or broad host range. For examples, ornamental palm species, banana, pineapple and sugarcane will increase the black beetle incidence and plants belonging to Arecaceae (coconut, date palm, areca palm, canary palm, christmas palm, fan palm and many other ornamental palms), Musaceae (banana, plantains), Zingiberaceae (ginger) and "bird of paradise" (Strelitziaceae) will increase the red palm mite incidence.

Ideally plant species that have narrow host range are more suitable for agroforestry systems. Introduced plants would become host plants to native pests in the system or with time, pest, especially with a higher reproductive rate would switch over from their indigenous food plants to new host plants which could have concentrated food sources (Epila, 1986).

(iv) Introduction of exotic plants and pests

When introducing exotic plants into the agroforestry system, it is necessary to comply with phytosanitory and quarantine measures in order to avoid introducing unnecessary plants that would eventually become weeds in the system. In case of an accidental introduction of an exotic pest into the system without possible biological control agents, search for natural enemies has to be done in the origin of the pest and introduce with caution into the system (classical biological control approach).

(v) Micro-climate

The most prominent consequence of tree crop combination in terms of changing micro-climate is the shade. This will directly or indirectly affect the activities of the pests and their natural enemies by reducing temperature, increasing humidity and protecting from direct sunlight. Shade will regulate the light intensity on different crop components in the system which will in turn affect the interactions between the pests and their host plants.

(vi) Management practices

Management practices need to be devised in such a way that they will not increase the pest populations but enhance the natural enemy activities and increase the plants' withstanding power against the pests. For examples cattle raising and the use of organic fertilizers may increase the black beetle incidence in the system and proper weed management will reduce the damage caused by yellow spotted locust (*Aularches miliaris*) and mammalian pests. Vigour of the coconut palms and the other plants in the system improved by proper management practices such as fertilizer application and moisture conservation is important in making the components in the system more tolerant to the pests.

The tendency nowadays is to integrate all suitable control methods including chemical methods to manage the pest below economic threshold levels. In case where we have to implement chemical control methods to augment other control measures or as an effort to bring down pests populations as fast as possible, toxicity of those chemicals on non-target animals will aggravate the pest problems by disturbing the balance between the pests and their natural enemies.

(vii) Competition for resources (water, nutrients)

Competition is not eliminated completely and recycling does not take place totally in coconut based agroforestry systems. Many nutrients (e.g. potassium) are removed from the system as harvest. Pests can also remove a certain amount of vegetation, mulch and organic matter in the system. This can be more serious when systems are established in poor or marginal soils and areas with low rainfall. Nutrient imbalances such as potassium deficiencies caused by differential absorbance of nutrients by component plants may make them susceptible to some pests. Therefore, selection of components and management practices has to be designed with care to avoid competition among the components as much as possible.

Directions for future research in pest management in coconut based agroforestry systems

Pest management in coconut based agroforestry is an important area of research. Combination of plants in each coconut based agroforestry system is unique and therefore, each system has to be studied separately.

The first step in designing pest management in coconut based agroforest system is to make an inventory of pests for each and every component in the system. Of many animals that visit or live in coconut based agroforestry system, only a hand full of animals is pests. Others may be pollinators, natural enemies of pests, animals that feed on other food sources in the system (e.g. fungivores), those who are in search of shelter in the system or may be mere "transit passengers" who would stay in this system temporarily until they reach their desired destination. Identification of the role of each and every animal in the systems is important. Additionally the role of each component in the system, whether it enhances the natural enemies or whether they have direct benefit to the grower or whether they will benefit the grower indirectly by improving the vigour of the plants to combat against the pest has to be identified.

The composition and the dynamics of pests and their natural enemies may change with the age of the systems. For example red palm weevil would act as a pest of coconut of 3-15 years old whereas coconut mite is a pest only on bearing palms. Black beetle can damage the palm at any stage but an economical damage is observed in the seedlings and the young palms. Coconut caterpillar can cause an economic damage at any stage of the palm. Changes in the dynamics of pests may be true with other components in the coconut agroforestry system. Therefore, continuous observations should be made by frequent entomological surveys. Data should be collected on the dynamics of the existing pests, new pests should be identified by authentic identification services and preserved samples, photographs, diagrams and any other relevant information should be made available for future references.

Once the key pests are identified, biological and ecological aspects of them have to be investigated mainly on population fluctuations with peak periods of populations, pre-disposing abiotic factors governing the dynamics of pests, natural enemies of pests and their vulnerable stages. This information is useful in pest forecasting which is an important component in pest management in coconut based agroforestry systems.

Loss of crop in coconut monoculture and polyculture may be different. Estimation of crop loss due to the pest damage is an important aspect to be studied. Crop loss in coconut or any other crop where harvest is directly taken can be estimated using standard methods used in estimating crop loss in the particular crop. However, methods to estimate the losses caused by pests on other components in that systems have to be devised. For example if any plant is used as a plant for soil enhancement, even a small loss of vegetation may influence the system significantly. Methods for estimation of losses have to be determined for each and every system separately because the role of each component in the systems will be different from system to system.

If a new component is intended to be introduced into the coconut based agroforestry system, its pests and their natural enemies should be studied in its natural original habitat and in case that some of the pests were accidentally introduced into the system with the introduced component, natural enemies of the pest have to be introduced from their original habitats. The knowledge on pests and their natural enemies in their original habitat is thus of immense importance.

Studies on multipurpose trees with small pest complexes or with resistance to pest damage, component plants with insecticidal properties, allelopathic characters and refuge hosts, information on tree crop combinations with best pest reduction capabilities, best tree crop arrangement (temporal, spatial) to minimize pest populations, agronomic and cultural practices to reduce pest populations within agroforestry context, pest threshold levels and integrated pest management strategies have to be conducted in coconut based agroforestry systems.

One important aspect that should not be neglected is the indigenous knowledge on pest management. Practices that are adopted by traditional growers may differ from area to area. Therefore a systematic survey has to be conducted in all areas where agroforestry would be practised to identify such practices, evaluate them scientifically and test the feasibility of using those methods, especially in organic coconut cultivation.

Pest management in agroforestry systems would be more costly than when coconut is grown in a monoculture because pest problems in coconut based agroforestry systems seems to be more complex than we expect. Need to practice present control methods or to devise new control tactics will most probably come as added cost to the grower. Pest management strategies within the context of coconut based agroforestry systems should therefore be designed in consultation with the economists in order to avoid heavy burdens that the growers could experience from the pest management practices.

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INTEGRATION OF LIVESTOCK IN COCONUT BASED AGROFORESTRY SYSTEMS

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Abstract

Land is a limiting factor in Sri Lanka; hence land available under plantation crops especially under coconut can be used for rearing livestock and thereby can increase the livestock production in the country. Integrated farming is a method of farming in which two or more enterprises are combined to get maximum efficiency from resources used, considering their relationships and interactions provided that an output from one enterprise would be an input for another. Integration of livestock into a cropping system is important to increase subsistence security by diversifying the food generating activities of the farm family as well as to transfer nutrients and energy between animal and crops. Ruminant production in the coconut triangle is based on the semi-intensive management system with tethered grazing of natural feed resources under coconut and other perennials. This farming system causes regular supply of organic matter to the soil as daily excretion of faeces and urine (weight to weight basis) in ruminants. Daily excretion of faeces and urine amount to 9.5% and 3.5% of body weight of animals. Integration of coconut/livestock could also enhance the coconut production in the system. This increase in coconut production is associated with the increase in fertility of soils due to animal manure as well as the harvesting of weeds by animals and thereby reducing the competition for moisture and other nutrients by crops. It can be concluded that livestock production in coconut plantations on a low input, low output system of rearing can increase the animal production as well as the crop production in a given land area. Low nutritional inputs into the system through livestock increase the yield of herbage and coconut and, maintain high soil fertility levels economically.

Introduction

Integrated farming is a method of farming in which two or more enterprises are combined to get maximum efficiency from resources used, considering their relationships and interactions provided that an output from one enterprise would be an input for another. Integrated farming with crop and livestock is known in present and past agricultural production systems. It is very common to use mixed farming systems in both developed and developing countries to increase agricultural output and/or the sustainability of farming. Integration of livestock into a cropping system is important to increase subsistence security by diversifying the food generating activities of the farm family as well as to transfer nutrients and energy between animal and crops *via* manure and forage from cropped areas and of draught power.

Silvo pastoral system

Silvo pastoral system is the growing suitable trees in combination with livestock raising on the same piece of land (Premaratne and Premalal, 2005). There are three individual components: trees, pasture/fodder grass or legumes and livestock. Income from trees would take at least 6-10 years but livestock raising is a quick means of income to the farm family. Livestock will graze weeds and help to control them. If grasses are allowed to grow uncontrolled, fire hazards during the dry period could be deleterious to all plants. Livestock could keep the grass short and remove dry standing hay, thereby reducing the risk of uncontrolled burning (Premaratne and Premalal, 2005).

Cattle and buffalo grazing on natural pasture under coconut are a common scenario in Sri Lanka. Coconut-livestock farming system provides a steady income throughout the year with less risk than intercrops. Livestock graze on weeds also reduce the cost of weeding. Animals and poultry provide milk, meat and eggs and thereby self sufficiency in food supply for the farm family and recycle the nutrient within the system reducing pollution and improving the soil fertility and increasing land productivity. Animals can perform numerous functions in small holder systems. Keeping livestock to secure subsistence is particularly important when cropping risks are high. Livestock serve as a buffer when crop yields do not meet family needs and can act as a savings account, with offspring as interest. Diversification in livestock keeping extends the risk reduction strategies of farmers beyond multiple cropping and thus increases the economic stability of the farming system. Spreading risk by practicing both crop and livestock production may lead to lower productivity within each sector than in specialized farms, but total production per unit area may be increased, as both crop and livestock yield can be gained from the same area of land.

Even though there are lot of advantages of integrated crop livestock farming, some disadvantages can also be identified. Silvo pasture system requires double expertise for crop and livestock farming. However, most of the traditional farmers have the knowledge in both aspects. Grazing animals could also increase the erosion due to soil compaction and overgrazing of the sward as well as increase the rate of land use. Integration of livestock under coconut especially during the early part of tree growth can damage the trees and thereby can reduce the growth of trees. There is a risk of disease transmission through the faeces of animals and need more capital to start the business. There is also a continuous labor requirement for both crop and animal farming.

Ruminant production in the coconut triangle is based on the semi-intensive management system with tethered grazing of natural feed resources under coconut and other perennials. This farming system causes regular supply of organic matter to the soil as daily excretion of faeces and urine (weight to weight basis) in large ruminants (cattle and buffalo) and small ruminants (sheep and goat). The livestock themselves can do the work of collecting, transporting and depositing the nutrients and organic matter in the form of urine and dung. Daily excretion of faeces and urine amount to 9.5% and 3.5% of body weight of animals.

Fluctuations in fertilizer prices and uncontrollable soil erosion have depleted the fertility of coconut lands. Hence the use of locally available conventional sources of manure is a vital agronomic practice in these lands. Animal manure could increase the soil fertility as well as the physical characteristics of soils without changing the soil acidity or the nutrient availability. It is a cheaper source of nutrients compared to inorganic fertilizer. According to previous work, tethering of a buffalo weighing 350 kilograms to a coconut palm for 10 days or a cow (neat cattle) weighing 250 kilograms for 14 days would provide the nutrients requirement of the palm for 1 year. Table 1 presents the nutrient composition of different animal manures.

Table 1: Nutrient composition of animal manures (oven dry basis).

Manure	N (%)	P (%)	K (%)
Cattle manure	1.2-1.9	0.2-0.5	0.5-1.1
Farmyard manure	1.2-1.8	0.4-0.6	1.1-1.9
Goat manure	2.2-3.4	0.3-0.7	1.5-2.5
Pig manure	1.0-2.0	0.6-0.9	0.4-0.9
Poultry manure			
Broiler litter	2.0-2.3	0.6-1.0	1.7-2.0
Layer litter	1.8-2.4	0.6-1.2	1.6-2.0

Source: Tennekoon and Bandara, 2003.

According to Table 1, it is clear that animal manure contain nitrogen as well as other nutrients in large amounts. Amount of nutrients in manure depend on the species of animal and the management practice used. Goat manure and poultry manure contain high amount of nitrogen, phosphorous and potassium compared to other species of animals. Table 2 presents the nitrogen availability of different animal manures.

Table 2: Nitrogen availability of different animal manures (head/day).

Species	Adult live Wt (kg)	Dung (kg, DM basis)	N (%)	N production (g)	N production (kg/yr)
Buffalo[#]	350	4.6	0.8	36.8	13.4
Cattle[#]	250	3.2	0.73	23.3	8.5
Goat	20	0.3	1.32	4.0	1.5
Sheep	20	0.3	0.91	2.7	1.0
Chicken	2	0.05	3.9	$2x10^4$	0.07
Duck	3	0.06	3.0	$0.8X10^4$	0.07

Sources: Devendra, 1992; [#] Premaratne, Unpublished.

Integration of livestock under coconut

According to literature, different models of mixed crop-livestock systems are available (Jayasundara and Marasinghe, 1989; Liyanage *et al.*, 1989; Ibrahim and Jayathilake, 1999) and the basic mixed-crop livestock system is shown in Figure 1.

According to Figure 1, solar energy, inherent soil fertility and water are external resources and these resources flow directly or indirectly to the crop system such as plantation crop, intercrop, fodder legumes and grazing areas. The crops provide feed to livestock directly/indirectly and the livestock provide power for crop production and nutrients to increase the soil fertility and thereby to increase the crop production. On the one hand, both crop and livestock provide food to humans which are important for the survival of mankind. So it is a sustainable system which could thrive for many years. On the other hand this system-approach will reduce air pollution, water pollution and environmental pollution due to the recycling of nutrients (Figure 2).

Land is a limiting factor in Sri Lanka therefore land available under plantation crops especially under coconut can be used for rearing dairy cattle and thereby can increase the milk production in the country. At present, the total production of milk in Sri Lanka is only sufficient for 26% of national requirement and the per capita consumption of milk in Sri Lanka is 110 ml per day (Central Bank, 2008). The price paid to a liter of milk was Rs. 30 to 45 depending on the fat content of milk during the year 2010. The milk production is almost a smallholder enterprise in Sri Lanka and most of the farms are crop-livestock mixed farms. A distinct feature in local dairy farms is animals are grazed (free or tethered) on vacant areas such as government lands, fallow fields, coconut lands or stall fed with cut grass usually comprising of weed cut from the roadsides (Zemmelink *et al.*, 1999; Ranawana, 2008) as majority of farmers do not have a land of their own for dairy cattle farming. Therefore, the main sources of roughage for dairy cattle in Sri Lanka are the weeds and grasses that grow on road sides and vacant areas. The micro climate under coconut will help to rear superior cross bred animals and thereby increase the milk production of animals.

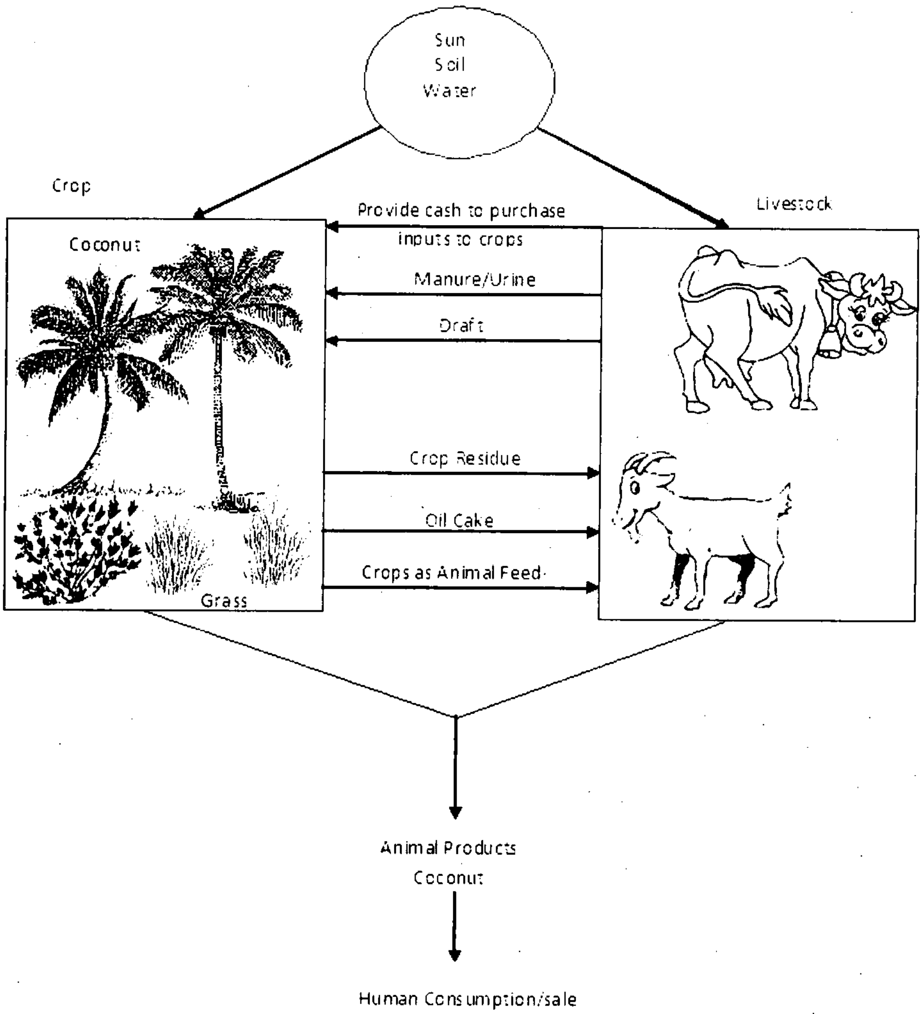

Figure 1: Schematic presentation on integration of livestock under coconut.

Several workers have shown that integration of coconut/livestock could enhance the coconut production (Santhirasegaram, 1966; Ferdinandez, 1973; Liyanage, 1986; Liyanage *et al.*, 1989; Jayasundara and Marasinghe, 1989; Liyanage, 1990; Liyanage and Pathirana, 1992; Liyanage and Dasanayake, 1993; Reynolds, 1995; Pathirana *et al.*, 1996). Liyanage *et al.*, (1989) demonstrated over a three year period that the integration of *Brachiaria milliformis/ Pueraria* *phaseoloides/ Leucaena leucocephala* and *Gliricidia sepium* and grazing heifers with coconuts had no negative effects on nut and copra yields of palms in a 45 year old plantation where palms were spaced at 8.4 X 8.4 m (137 palms/ha).

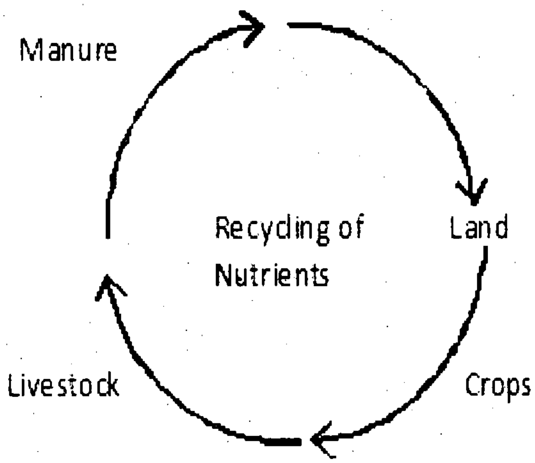

Figure 2: Land application of animal manure.

Jayasundara and Marasinghe (1989) reported that the nut and copra yield of the integrated system was 11% higher than on the mono culture system and Liyanage and Dassanayake (1993) noted that by the fourth year there was about 17 and 11% increase in nut and copra yield, respectively on the integrated system. Table 3 presents the effect of mixed farming on the yield of coconut in the coconut triangle of Sri Lanka.

Table 3: Effect of mixed farming on the yield of coconut.

Farming system	1987		1988		1989	
	Nuts/ha	Copra kg/ha	Nuts/ha	Copra kg/ha	Nuts/ha	Copra kg/ha
Integrated system	12,624	2,170	10,592	1,822	16,072	3,319
Monoculture system	12,416	2193	10,642	1,884	13,600	2,980
Increase (%)	-	-	-	-	17.5	11.5

Source: Liyanage and Dassanayake, 1993.

According to Liyanage and Dassanayake (1993), this increase in coconut production may be associated with the increase in fertility of soils due to animal manure as well as the grazing of weeds by animals and thereby reducing the competition for moisture and other nutrients by crops.

Forage tree legumes can also be cultivated as a source of mulch, nitrogenous fertilizer, shade tree, fuelwood, agroforestry tree, supportive crop for intercrops like pepper and, as an animal feed in coconut lands. Rapid growth rate, the ability to grow as a live fence and use of sticks to generate biofuel are added advantages of these tree fodder legumes. Use of this organic manure will help to cut down the cost of fertilizer as well as to increase the physical properties of soil compared to inorganic fertilizer. Table 4 presents the mean coconut yield when intercropped with different fodder legumes (Somasiri, 2010; Somasiri *et al.*, 2011)

According to Table 4, coconut yield in *Leucaena* plots were higher ($p<0.05$) than that of *Acacia* and *Gliricidia* plots. Liyanage *et al.* (1993) reported a mean coconut yield of 73-79 nuts per palm per year when intercropped with legume fodder trees compared to control plots which had an average value of 62 nuts/palm/year indicating a 15-26% increase in yield. They further noticed that nitrogen fixing trees were capable of maintaining coconut yields during the dry season and they have exerted a greater yield advantage during the wet season in comparison to those in the control plots. In addition, cultivation of fodder legumes could increase the soil fertility and can provide feed to ruminants. Table 5 gives the composition of fodder legumes and grasses which can be grown under coconut.

Table 4: Mean coconut yield when intercropped with different fodder legumes.

Leguminous fodder	Nuts/palm/year	Nuts/ha/year[#]
Gliricidia sepium	79	12,640
Leucaena leucocephala	129[a]	20,640
Calliandra calothyrsus	108[a, b]	17,280
Acacia mangium	86[c]	13,760
Control	80[c]	12,800

[#]Yield per hectare was calculated based on 160 palms per hectare (Liyanage, 1999).

*Means having different superscripts in a column differ significantly ($p<0.05$).

Sources: Somasiri, 2010; Somasiri *et al.*, 2011.

Table 5: Composition of fodder legumes and grasses (%).

Species	DM	Ash	Crude Protein	Ether Extract	Crude Fiber
Erythrina lithosperma	32.5	11	15.5	4.0	3.5
Gliricidia sepium	19.0	8.9	27.6	6.6	7.5
Leucaena leucocephala	28.0	15.0	36.0	3.4	12.7
Tithonia diversifolia	14.5	11.7	26.4	6.7	11.1
Brachiaria brizantha	20.0	8.4	10.8	2.0	28.6
Panicum maximum (Guinea A)	21.0	11.8	14.3	12.0	33.3

Sources: Premaratne, 1993; 1996.

Conclusions

It can be concluded that livestock production in coconut plantations on a low input, low output system of rearing can increase the animal production as well as the crop production in a given land area. Nutritional inputs into the system through livestock increase the yield of herbage and coconut and maintain the soil fertility levels economically. Therefore, integration of livestock with coconut will provide economic benefits to the farmer and sustainability of farming for many years to come.

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SOCIO-ECONOMIC ASPECTS OF COCONUT BASED AGROFORESTRY SYSTEMS IN SRI LANKA

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Abstract

Coconut Research Institute with its long term research effort, has introduced many coconut based agroforestry-systems. These cropping models are tested in most of the areas of the country through its adoptive research program. The coconut based agroforestry systems are characterized with the concepts of competition, complexity, profitability and sustainability. The most specific feature which agroforestry system has is the long-term sustainability which generates as the result of the perennial crops. However, still the issue is whether competition leads to reduction of productivity, profitability and sustainability of the coconut cultivations. This paper summarizes the available research findings of the Coconut Research Institute related to the socio-economic aspects of coconut and coconut based farming systems.

Introduction

Principally agroforestry systems consists of complex farming practices which maximize the objective functions such as maximum utilization of land, maximizing profit, optimizing the food needs, optimizing the consistency of income generation. According to the Sanchez (1987; 1995), development of agroforestry as a science, should be based on the four key features: (i) competition; (ii) complexity; (iii) profitability; and (iv) sustainability. Socio-economic and ecological complexity are typical in agroforestry systems. These complexities are created through the incorporation of many tree species, crops and livestock into the system.

The scientific understandings of agroforestry systems are very young, and theoretical understanding is yet to be developed for proper management of the system (Sanchez, 1995). Agroforestry is a traditional practice of growing tress on farms for the benefit of the farm family. It has a long history, at least 1,300 years (Brookfield and Padoch, 1994), even though tree domestication started much earlier (Simmonds, 1985). Agroforestry was brought from the realm of indigenous knowledge into the forefront of agricultural research less than two decades ago and was promoted widely as a sustainability enhancing practice that combine the best attributes of forestry of agriculture (Bene *et al.*, 1977). Agroforestry is a concept which evolves with the domestication of human beings (Simmonds, 1985). Even though the term agroforestry seems to be growing forest, this term represents the activities of complete system of growing trees along with crops and livestock with the view to enhancing crop-livestock productivity, improving soil properties and producing fuelwood, timber and other non-wood products. With years, people have generated the knowledge bases with inductive reasoning as most of the farmers gained experiences through their own experimentations without pre-assumptions. These knowledge bases have developed over the years through experience of their cropping practices. This generated knowledge is now available for the present researchers to conduct deductive research as they have supportive evidences to build up their researchable hypothesis.

The two key principles related to the agroforestry systems are competition and complexity which in turn lead to the features of profitability and sustainability. In examining the coconut based agroforestry systems, first the grower has to make a judgment whether monocrop or mixed crop is profitable and sustainable as well as think of competition and complexity. These main key criteria will decide the successful adoption of agroforestry systems in the farmers' field. Today it is high time to think of these crop based agroforestry systems including coconut, as world is facing serious food and economic crisis. This crisis has added values to the natural resources as well as on production systems influencing to increase the production efficiency. Coconut being the small holders crop (more than 70% of coconut lands), it is difficult to adopt the concept of monocrop into the system as a land owner has to utilize these available small lands to satisfy their unlimited needs.

Coconut being the perennial crop it takes years to complete its life cycle. Due to this reason, investors are facing the problem in recovering their initial investment costs till the coconut palms reached a stable production stage. Increasing input prices and yield reduction has become a burning issue in the coconut growing sector today. One of the strategies that grower can adopt is incorporation of alternative land use systems to enhance the land productivity of monocrop lands. Many cropping systems have been introduced by the researchers of the institutes such as Coconut Research Institute (CRI), Departments of Agriculture and Export Agriculture. Even though these multipurpose cropping systems are viable, the adoption of the innovations depend on the technical, economical, institutional and personnel preferences for the technologies (Fernando, 2000). Further, it is reported that there exists the important differences and similarities in terms of their socio-economic, demographic and occupational characteristics in coconut monocropping and coconut based intercropping systems (Fernando, 2002). These characters will contribute in adopting these farming practices in the farmers' lands.

Even though these cropping systems are viable under research as well as in the farmers field, these are becoming less attractive to the growers. Therefore, it is vital to investigate the socio-economic aspects of coconut based agroforestry systems. Thus, the objectives of this paper are to (i) identify the existing the coconut based agroforestry systems; and (ii) discuss the socio-economic aspects of the above systems. The paper presents the summarized information generated from different studies and to provide the background for further research studies and for policy purposes.

Coconut based agroforestry systems in Sri Lanka

Coconut is mainly cultivated as monocrop with the density of 64 palms per acre. Studies of the CRI have revealed that this is as the optimal density for monocrop coconut cultivation. Scientific understanding revealed that coconut roots use only about 25% of soil in the coconut square. Therefore other plants can be accommodated to utilize the unused land (Mahindapala and Pinto, 1991). According to the statistics, around 505,852 coconut growers own less than 1.2 hectares category and they manage their lands as mixed cultivations specially incorporating intercrops into the system. Apart from that there are medium level growers (above 1.2 to 8 ha) (Department of Census and Statistics, 2002) with very good potential of practicing agroforestry systems to cover their income gaps and to enhance their existing income levels.

Coconut based farming systems are mainly comprised of annual, semi-perennial, perennial crops and in some models livestock components are also included. Agronomy Division of the CRI has introduced around 64 cropping models including crop and livestock components for coconut based farming systems. These crop-livestock combinations have been tested by the CRI and the results have shown that most of those crop combinations contribute additional income to the growers. Among the many cropping systems tested for coconut based farming systems, only a few are popular among the coconut growers. This may be mainly due to the profitability and the area specificity of cropping systems. Table 1 present the most common cropping models which farmers prefer to adopt in coconut plantations.

Profitability of coconut and coconut based farming system

Coconut being a perennial crop, it takes around 3-5 years to start flowering and it will take 17-20 years to pay back the initial investment cost even under well managed conditions. Further studies of the Agricultural Economics Division of CRI have revealed that the main contributors for these initial cost components are fertilizer (around 28 percent) and labour (around 35 percent). As a result of this income-lag growers have to wait around 20 years to earn a satisfactory income. One of the strategies which growers can adopt is incorporation of intercrops into the system. Figure 1 presents the pay-back periods of 0.4 hectare land which is grown in land suitability class S4.

Table 1: Coconut based agroforestry models in Sri Lanka.

No.	Type of model	Component
1	Intercropping	Pineapple
2	Intercropping	Pineapple, Banana
3	Intercropping	Pineapple, Banana, Ginger
4	Mixed crop	Pepper, Banana, Ginger
5	Mixed crop	Pepper, Coffee, Ginger
6	Mixed crop	Cashew, Lime and Banana
7	Mixed crop	Pepper, Coffee, Banana and Ginger
8	Mixed farm	Pepper, Pasture, Cattle

These agroforestry systems may consist of mainly semi-perennial crops and a few perennial crops where semi-perennial crops can contribute to compensate the initial investment costs of coconut plantation. Figure 2 shows the recovery process of initial investment cost when we incorporate intercrops into the system. This data clearly indicated that the intercropping system with coconut substantially reduced the pay back period and increase the net profit (Figures 1 and 2).

Annual gross margins and Internal Rate of Return (IRR)

Annual gross margins gives an idea of net return to invested variable cost while Internal Rate of Return (IRR) gives the idea of maximum interest rate which investor can borrow for the identified investments.

Table 2 shows the gross margins calculated for mixed farming systems. The calculated results implied that mixed farming systems generate higher gross margins when compared with the monocrop systems. Initially cash flow shows very high negative values in the mixed cropping systems when compared with the monocrop systems. This is because of the very high initial investment costs required in establishing the corp.

Net Present Value (NPV)

Agronomy Division of CRI has established around 26 intercropping models in different coconut growing areas of Sri Lanka. The experiment result revealed that calculated Net Present Values (NPV) vary from marginal to four to five times higher than the monocrop systems (Peiris *et al.*, 2003). This variation is due to the nature of the crop as crops such as pepper, cocoa and pepper takes around 3 to 5 years to start to produce economic yields.

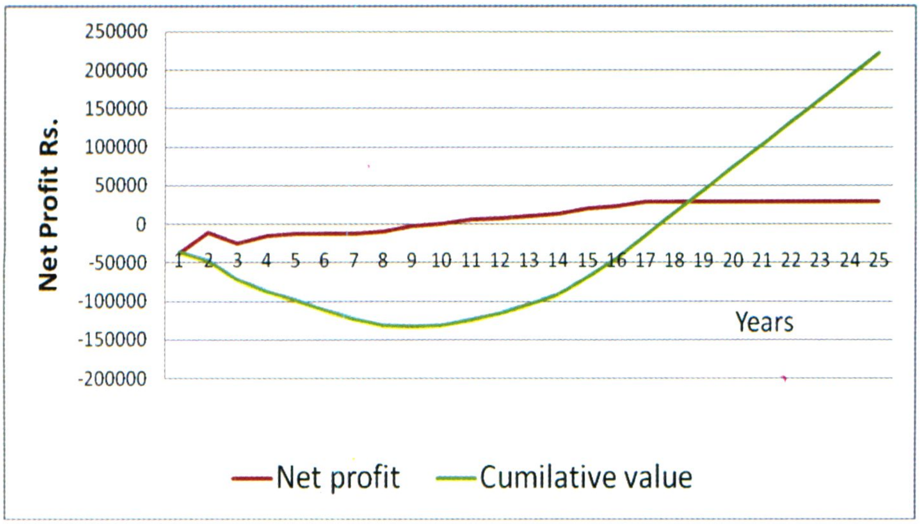

Figure 1: Pay-back period of monocrop cultivation (Rs./ac).
Note: Returns were calculated considering nut price as Rs. 23.00

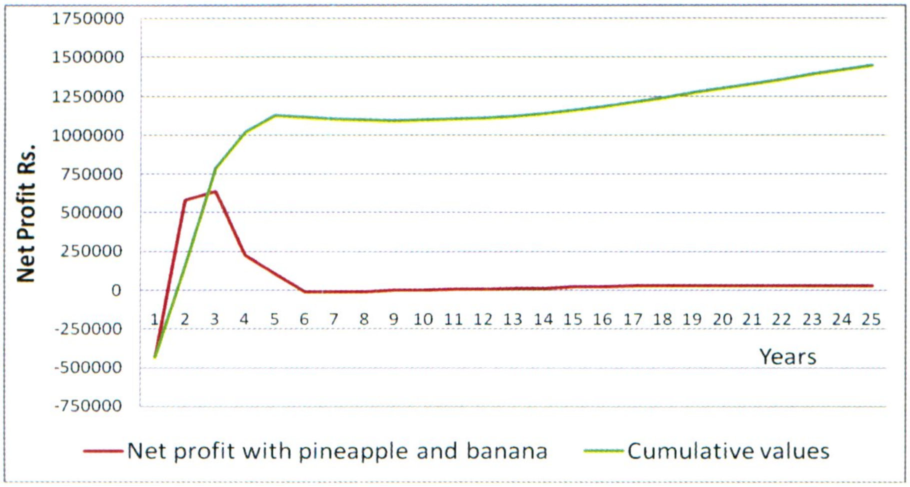

Figure 2: Payback period of coconut cultivation with intercrops (Rs./ac).

Benefit Cost Ratio (BCR)

This is one of the parameters which we can be used to measure financial viability as well as the complexity of coconut based agroforestry systems. When a crop model becomes complex generated Benefit Cost Ratio (BCR) value becomes smaller when compared with the monocrop system as agroforestry models specially intercrop models require more resources to generate output than the monocrop models. Even though these models utilize more resources, the generated returns to investments are very high when compared with the monocrop systems.

Table 2: Summary of crop gross margins and production parameters.

Crop and units	No of plants	Gestation period (years)	Considered period for gross margin calculation (years)	Gross margins Rs./ac	IRR
Main crop					
Coconut (nuts)	64	17	25	221,351	7
Fruit crop					
Banana (bunch)	400	0	5	200,053	107
Pineapple (fruit)	4,000	1	5	1,349,534	235
Passion fruit (kg)	400	1	5	535,578	200
Papaya (kg)	325	1	4	591,845	243
Tree crops/beverages and other crops					
Cashew (kg)	40	3	10	530,971	78
Rambutan (kg)	32	3	10	810,428	141
Pepper (kg)	350	4	10	939,254	156
Cocoa (kg)	430	4	10	195,269	128
Betel (leaves)	1,000	0	5	692,909	733

These crop-livestock combinations have been tested by the CRI and the results have shown that most of those crop combinations contribute additional income to the growers. Besides that, there are micro-climatic effects created as the result of added cropping system.

Adoption of coconut based farming systems

Technology adoption of the farmers depends on mainly four key factors namely technical, economical, institutional and personnel or social. Among these factors one of the main indicators which influence the growers desire is the socio-economic factors. Nair, (1989), reported that the literature is full of descriptions of agroforestry systems at the household level but the literature related to the underlying socio-economic process is limited: household level, how different communities react to a different policy environment and how farmers intensify their land use in response to demographic pressure. Coconut Research Institute of Sri Lanka conducted a survey to identify the socio-economic aspects of coconut based farming systems (Fernando, 2000). The result of the study revealed that the growers preferences on different cropping systems. Table 3 present the rate of relative participation of growers on coconut based farming systems.

Table 3: Growers preference on different intercropping systems.

No	Cropping system	No of farmers practising	Percentage
1	**Coconut, pineapple, banana**	30	26.50
2	**Coconut, banana**	15	13.27
3	**Coconut, pineapple**	14	12.39
4	**Coconut, betel**	7	6.19
5	**Coconut, betel, banana**	6	5.31
6	Coconut, pepper	4	3.54
7	Coconut, pineapple, pepper	4	3.54
8	Coconut, pineapple, banana, ginger	4	3.54
9	Coconut, ginger, banana	3	2.65
10	Coconut, pineapple, banana, betel	3	2.65
11	Coconut, banana, pepper, coffee	3	2.65
12	Coconut, pepper, banana	2	1.77
13	Coconut, banana, rambutan	2	1.77
14	Others	16	14.15
	Total	113	100.00

Source: Fernando *et al.*, 2000.

The study revealed that basically five cropping combinations are popular among the growers. Except coconut and betel, all other crops are semi-perennial crops. These crops generate very high gross margins from the year two and most of these crops reach the uneconomical level after five years.

Heterogeneity of resource base

Coconut occupies 394,836 hectares of land in Sri Lanka, occupying 70% of lands as small holders' lands (Department of Census and Statistics, 2002). Even though coconut covers 20% of the agricultural land extent in the country, still coconut has not been able to generate satisfactory income for the growers to continue their living. This is mainly due to the reasons of size of holding, irregular cultivations, low productivity and mismanagement. As a result most of the coconut growers are engaged in other income generating activities such as other occupations, rice and vegetable cultivation, livestock farming and intercropping. Fernando, (2002) reported that relative proportion of income sources of growers are intercrops, occupation followed by coconut and rice, respectively. This indicates that the importance of adopting coconut based farming systems in coconut lands.

Land holding size and resource base

Even though farmers are categorized into different groups considering the land holding sizes, research findings have revealed that there exist very high disparities among the farmers in the same land holding size category. These farmers have been categorized into three categories as resource poor farmers, middle level and affluent farmers (Fernando, 2002). Even though group one farmers are considered as resource poor farmers, they are the real farmers who can engage in farming activities full time. They use family labor for their farming activities but they are always cash scarce farmers. The affluent farmers are part time farmers and heavily involved in off-farm income generating activities (Fernando, 2002). These farmers do not want to make their system complicated and try to avoid complexities in their cultivations. They prefer to continue on monocropping. Middle level farmers with the land extent of the range of above 1.2 hectares up to 8 hectares have the very high potential of popularizing the agroforestry systems. Therefore, these characters are important in integrating agroforestry systems into the coconut lands.

Labour utilization and labour availability

Intercropping systems demand more labour when compared with the monocrop systems. Study conducted by the Agricultural Economics Division of CRI revealed that there exist the special differences of availability of labour for farming practices (Pathiraja *et al.*, 2010). Apart from that poor participation of younger generation in labour force is a crucial issue in the coconut triangle as well as in other coconut growing areas. According to the study, results of Pathiraja *et al.* (2010) the highest participation of younger generation was reported in Kurunegala district of Sri Lanka (33.3% out of 120 respondents). Another issue related to the labour is gender-specific labour shortage. The results of this study showed that there exist special differences of labour shortage in relation to the gender as this mostly depends on the availability of other source of employments in the area. Mostly there is a very high correlation with female labour availability with the availability of Export Processing Zones close to the coconut growing areas. As agroforestry system demands more labour with the increasing complexities, it is necessary to identify and make a judgment in advance about the labour availabilities before establishing labour demanding cropping systems.

Conclusions and policy implications

Agroforestry systems are becoming as a popular strategy today in enhancing the biological productivity, financial profitability as well as in achieving social acceptability. This paper investigated the existing theoretical and empirical evidences on agroforestry systems with special reference to coconut based farming systems. Findings of the research have concluded that even though agroforestry systems create complexities of the cropping systems, it generates additional benefits to the growers. Further, economically active age group is more vulnerable to adopt coconut based intercrop systems even though there are disparities of availability of labour for farming. Therefore, strategies related to popularization of coconut based agroforestry systems should be based on the special recommendations by giving special attention on technical and financial viability while the system should be sustainable and socially acceptable.

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ENVIRONMENT SERVICES OF COCONUT BASED AGROFORESTRY SYSTEMS

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Abstract

Agroforestry has importance as a carbon sequestration strategy because of the carbon storage potential in its multiple plant species and soil as well as its applicability in agricultural lands and in reforestation. The potential seems to be substantial; but it has not been even adequately recognized. There is enough scientific evidence to conclude that climate change is happening, and plantation agriculture is one of the high priority sectors where the impacts of climate change exceed tolerance limits with implications for the livelihoods of millions of people who depend on this sector. Coconut based agroforestry systems can play a significant role in the adaptation to climate change by changing the micro-climate, protecting the environment by provision of permanent cover, improving efficiency of the use of soil, water and climatic resources, reducing carbon emission and increasing carbon sequestration, in addition to providing opportunities for crop diversification and soil fertility improvement. This paper discusses the potential of coconut based agroforestry systems in carbon sequestration and storage, moderating micro-climate and improving productivity of the plantations.

Introduction

Adoption of agroforestry systems is a strategy for optimum utilization of resources, thereby increasing the productivity and returns from coconut lands. The radiation transmitted below the coconut canopy and the distribution pattern of coconut root system permit an enormous potential for agroforestry in coconut lands (Lamanda *et al.*, 2008). Agroforestry systems can produce a range of environment, economic and socio-economic benefits. However, to date, research in agroforestry systems has mainly focused on their efficacy in crop and pasture productivity, soil and water conservation, moisture and light competition, nutrient cycling, and changes in soil physical and chemical properties, while their potential role in acting as a carbon sink and to be integrated into global carbon trading system has been overlooked (Liyanage and Dasanayake, 1993; Gunathilake and Liyanage, 1995; Vidhana Arachchi and Liyanage, 2003; Ilany and Ashton, 2010). The importance of agroforestry systems in CO_2 mitigation has become more widely recognized from both industrialized and developing countries in recent years (Rao *et al.*, 2007; Takimoto *et al.*, 2008; Fang *et al.*, 2010), but there is still paucity of quantitative data on specific systems. Although coconut is a multipurpose perennial tree crop that can sequester carbon for about 70 years and has the possibility of growing in tropical environments as carbon sinks, little attention has been paid to collect scientific data on carbon sequestration potential in coconut based agroforestry systems. Since coconut palm is a sun-loving crop, the trees or crops selected for coconut-based agroforestry systems should be grown underneath coconut or in avenue planting systems. Gunathilake and Liyanage (1995) have identified different types of coconut based agroforestry systems in Sri Lanka and those that include tree crops are likely to have a greater capacity to sequester carbon in the long-term, than the systems with short-term crops or with ruminants, because of their more complex and diverse configurations.

In addition, the full genetic potential of many crops and varieties can only be realized when environmental conditions are close to optimum. Any change in these conditions will have a direct impact on the production and economic viability of crops and ecosystems. Tree based agroforestry systems offer a promising option to moderate the effects of heat stress and improve the micro-climatic condition of the ecosystems. Therefore, the focus of this paper is to discuss the potential environmental benefits of coconut based agroforestry systems with special reference to carbon sequestration and moderating micro-climate.

Carbon cycle in agroforestry systems

In considering the carbon cycle of a coconut based agroforestry system, if there are no inputs from organic fertilizers, all the carbon inputs come from the Gross Primary Production (GPP; the sum of the photosynthesis of the plants). A significant part of this carbon uptake is lost through autotrophic respiration (plant respiration; growth and maintenance respiration of different plant components). The fraction of GPP that is not lost through plant respiration is used to produce new biomass, thus contribution to the Net Primary Production (NPP, the sum of visible growth and litter production). The stand growth is the difference between NPP and litter production. Litter inputs to the soil are decomposed by soil micro organisms. The part that is not oxidized is transferred to the soil organic matter (SOM) pool. Emission of CO_2 through litter decomposition and subsequent SOM oxidation by soil micro organisms both contribute to the heterotrophic respiration. Therefore, the net ecosystem exchange of CO_2 between the agroforestry system and the atmosphere is the difference between CO_2 uptake through photosynthesis, and CO_2 emission through ecosystem respiration (plant autotrophic respiration and soil heterotrophic respiration (Roupsard *et al.*, 2008).

Carbon sequestration and storage capacity in coconut agroforestry systems

Carbon sequestration in agroforestry systems are highly variable, depending on the agro-climatic and soil conditions, land-use types, species involved, age of trees and crops and management practices. Montagnini and Nair (2004) reported an average carbon storage by agro forestry systems as 9, 21, 50 and 63 Mg carbon per hectare in semi-arid, sub-humid, humid and temperate regions, respectively whilst IPCC (2007) reported an average amount of carbon stored in the aboveground compartments of agroforestry systems as 40-150 Mg carbon per ha. However, detailed studies on carbon sequestration and carbon storage in trees, crops and soil of coconut based agroforestry systems are not available in Sri Lanka, except the recent study conducted at the Coconut Research Institute (CRI) to quantify the above parameters (Ranasinghe and Thimothias, unpublished). In this study, the carbon sequestration potential and carbon stocks of a coconut-grass system (25-26 year old tall x tall coconut (*Cocos nucifera* L. variety typica) and a mixed grass cover) under highly suitable for coconut (Land Suitability Class (LSC) S_2) and moderately suitable for coconut (S_4) soils in wet (WL_3, high moisture availability), intermediate (IL_{1a}, moderate moisture availability) and dry (DL_3, low moisture availability) agro-climatic conditions were estimated. The results revealed that on S_2, the carbon stock in above-ground biomass of coconut palms (B_{palm}) does not reduce along a decreasing moisture gradient from WL_3 to DL_3. However, on S_4, B_{palm} is greater in IL_{1a} which has intermediate moisture availability compared to other two agro-ecological regions (AER). The values of B_{palm} vary between 17 and 25 Mg carbon per hectare depending on the growth condition and coconut stem is found to be the main C storage organ which stores about 56-70% of the total C stock of palms (Figure 1). In this study, the total carbon stock in the grass cover (B_{grass}) is lower in DL_3, irrespective of the LSC, compared to the respective values in WL_3 and IL_{1a}. Furthermore, on S_4, B_{grass} is not affected by the decreasing moisture availability from WL_3 to IL_{1a} whilst on S_2, B_{grass} shows the maximum value in IL_{1a}. The values of B_{grass} vary between 0.7 and 1.9 Mg carbon per hectare depending on the growth condition (Figure 2).

Total C stock in the top soils (0-20 cm depth) (B_{soil}) of the coconut-grass system reduces from WL_3 to DL_3 and from S_2 to S_4 though the magnitude of difference between S_2 and S_4 vary with the agro-ecological regions. Furthermore, B_{soil} is the lowest in DL_3, irrespective of the land suitability classes, compared to the respective values in WL_3 and IL_{1a}. The values of B_{soil} in a coconut-grass system vary between 14 and 44 Mg carbon per hectare depending on the growth condition (Figure 3). Consequently, in a coconut grass agroforestry system the total ecosystem carbon stock ($B_{tot-eco}$) reduces along a decreasing moisture gradient from WL_3 to DL_3 and decreasing soil fertility gradient from S_2 to S_4. ($B_{tot-eco}$) vary between 32 and 72 Mg carbon per hectare and this wide range is mainly attributed to variations in agro-ecological condition of the region, physical, chemical and biological factors of soils therein resulting in differences in palm growth, litter production and litter decomposition (Figure 4).

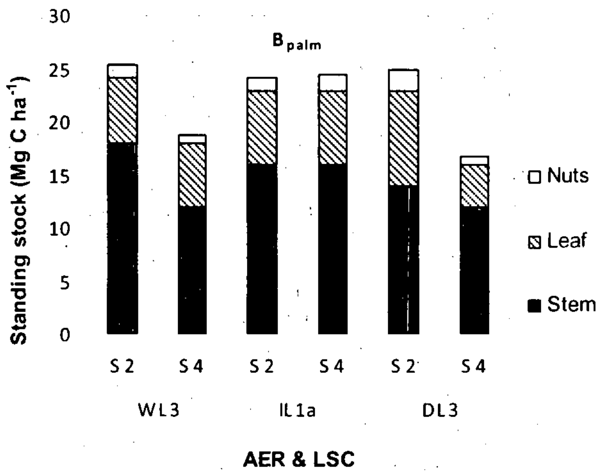

Figure 1: Carbon stock of coconut palms (B_{palm}) (Mg carbon per ha) in terms of its components (stem, leaf, nuts) of a coconut-grass agroforestry system on S_2 and S_4 land suitability classes (LSC) in WL_3, IL_{1a} and DL_3 agro-ecological regions (AER).

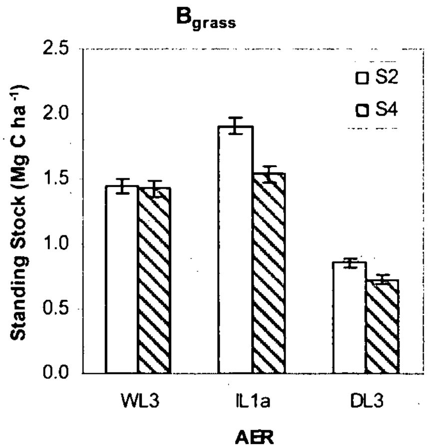

Figure 2: Carbon stock (Mg carbon per ha) of grass cover (B_{grass}) of a coconut-grass agroforestry system on S_2 and S_4 land suitability classes in WL_3, IL_{1a} and DL_3 agro-ecological regions (AER) (Note: Values are means ± standard error of mean).

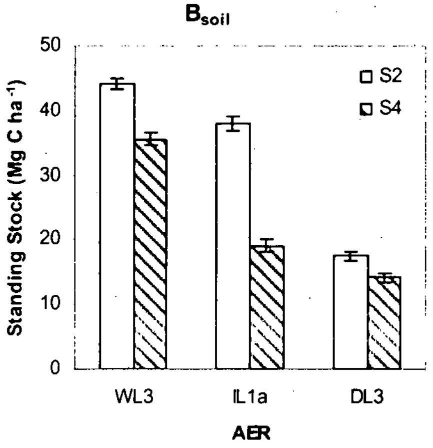

Figure 3: Carbon stock (Mg carbon per ha) in top soil (B_{soil}) of a coconut-grass agroforestry system on S_2 and S_4 land suitability classes in WL_3, IL_{1a} and DL_3 agro-ecological regions (AER) (Note: Values are means ± standard error of mean).

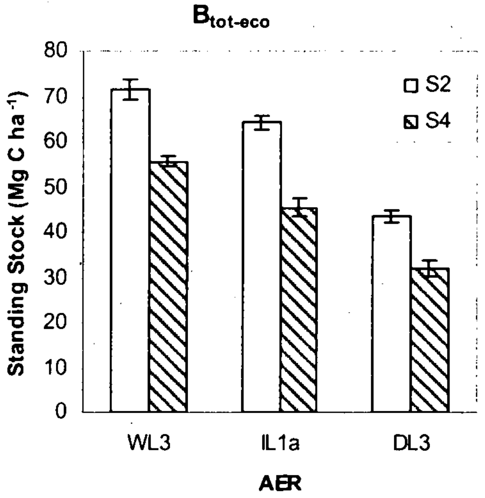

Figure 4: The total ecosystem carbon stock ($B_{tot-eco}$) (Mg carbon per ha) of a coconut-grass agroforestry system the total on S_2 and S_4 land suitability classes in WL_3, IL_{1a} and DL_3 agro-ecological regions (AER) (Note: Values are means ± standard error of mean).

The contribution of carbon stock in coconut palms (B_{palm}) and sub soil (B_{soil}) to the total ecosystem carbon stock ($B_{tot-eco}$) varied with the AER. Whilst the carbon stock in coconut palms accounted for about 35%, 45% and 55% of the total ecosystem carbon stock, soil carbon stock accounted for about 63%, 52% and 42% in the WL_3, IL_{1a} and DL_3, respectively. Grasses (B_{grass}) contributed only 2-3% in the carbon stock of ecosystems irrespective of the agro-ecological region (AER) or land suitability classes (LSC). Supporting the fact, a case study with Vanuatu red dwarf x Vanuatu tall high-yielding coconut hybrid (19-22 years old) grown under 'optimal conditions' revealed a total palm carbon stock of 34.13 Mg carbon per hectare out of which 5.0 Mg carbon per hectare was found in course and fine roots (Navarro *et al.*, 2008). In the same study, the grass cover has about 1.8 Mg carbon per hectare and, consequently, the total carbon stock in coconut and grass was about 36 Mg carbon per hectare (carbon stock in soil has not been estimated in this study).

There are several methods used by researchers all over the world to measure the carbon input to an agroforestry system. Some of them are eddy covariance method using flux towers at canopy level of forests, image analysis of forest covers using hemispherical photography methods, direct dry matter sampling methods, light use efficiency models and measuring Gross Primary Production (GPP, photosynthesis) of plants in the total ecosystem. However, the quantified data on total carbon inputs by different coconut based agroforestry systems are not available to date. The study at CRI, described above, carbon absorption by the coconut-grass system was measured as the GPP (photosynthesis) of coconut trees. On highly suitable soils (S_2), GPP does not reduce along a decreasing moisture gradient from WL_3 to DL_3. However, on moderately suitable soils (S_4), GPP reduces from WL_3 to DL_3. These results could be explained with the differences in rate of photosynthesis and functional leaf area of coconut palms under different growth conditions. GPP by the grass cover was not measured in that study, thus, the GPP of coconut palms ($GPP_{coconut}$) is considered as the GPP of total ecosystem. The values of GPP in a coconut grass system vary between 1.2 and 2.9 Mg carbon per hectare per month depending on the growth condition (Figure 5). For the purpose of comparison, if the highest GPP observed in WL_3 (2.9 Mg carbon per hectare per month) is extrapolated for the whole year, it will be equal to a value of about 34.8 Mg carbon per hectare per year which is comparable to the GPP value of 39.0 Mg carbon per hectare per year, obtained by eddy-covariance method, for a high yielding coconut plantation under optimal conditions with a grass cover (Navarro *et al.*, 2008).

The information on carbon emission by agroforestry systems is lacking in most of the carbon sequestration studies published in Sri Lanka. However, in a proper carbon assessment study, carbon emission from ecosystems should include the respiration of plants (autotrophic respiration) and soil (heterotrophic respiration) of the system. In the same study at CRI, described above, carbon output from the system was measured as the CO_2 emission by plant and soil respiration. The total respiration of above-ground parts of coconut ($R_{a(palm)}$) and its components, growth respiration (R_g) and maintenance respiration (R_m) show a different response to a decreasing moisture gradient on different LSCs. R_g, R_m and $R_{a(palm)}$ are not affected by the land suitability class or decreasing moisture gradient from WL_3 to IL_{1a}. However, the $R_{a(palm)}$ on S_2 in DL_3 is higher mainly due to significantly higher R_m of these palms compared to the respective values under other growth conditions. This was mainly attributed to greater dry weight of stem and higher nut load of these palms compared to other growth conditions. Maintenance respiration (R_m) of coconut palms is about five fold higher than the R_g irrespective of the land suitability class or moisture availability. The autotrophic respiration of the grass cover $R_{a\text{-}grass}$ was not estimated in this study. Thus, the autotrophic respiration (R_a) of coconut palms is considered as the R_a of the total coconut-grass system (root respiration of coconut and grass was not estimated in this study). Therefore, the values of R_a in a coconut-grass system vary between 0.47 and 0.96 Mg carbon per hectare per month depending on the growth condition (Figure 6).

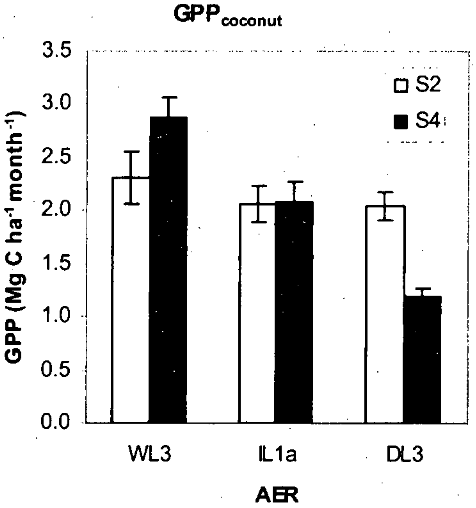

Figure 5: Gross Primary Production (GPP) of a coconut-grass agroforestry system (Mg C ha^{-1} $month^{-1}$) on S_2 and S_4 land suitability classes in WL_3, IL_{1a} and DL_3 agro-ecological regions (AER) (Note: Values are means ± standard error of mean).

For a high yielding coconut hybrid grown under optimal conditions with a grass cover, $R_{a(palm)}$ was 20.96 Mg carbon per hectare per year out of which about 6 Mg carbon per hectare per year was attributed to the respiration of root and inflorescences (Navarro *et al.*, 2008). For the purpose of comparison, if the highest $R_{a(palm)}$ observed in the above described study (0.958 Mg carbon per hectare per month) is extrapolated for the whole year, it will reach to a value of about 11.5 Mg carbon per hectare per year (excluding root and inflorescence respiration) which is little lower than the values shown by Navarro *et al.* (2008). In the same study at CRI, soil respiration was measured as the soil CO_2 emission by soil microbial respiration (R_{soil}) *ex situ*. On S_2, R_{soil} does not reduce along a decreasing moisture gradient from WL_3 to IL_{1a}. However, on S_4, R_{soil} is maximum in IL_{1a} which has intermediate moisture availability. In WL_3, where moisture availability is higher, R_{soil} of S_4 is lower than its maximum in IL_{1a} and equal to the respective values on S_2 and S_4 in DL_3, mainly due to soil physical and biological properties. R_{soil} can vary with the soil temperature and soil water content, depending on the type of the agroforestry system (Jiang *et al.*, 2005). The values of R_{soil} in the coconut-grass system vary between 0.30 and 0.80 Mg carbon per hectare per month depending on the soil condition and moisture availability (Figure 6). Consequently, the total respiration of the eco-system ($R_{tot-eco}$), does not reduce from WL_3 to DL_3 on S_2, however, on S_4, $R_{tot-eco}$ is maximum in IL_{1a}. The values of $R_{tot-eco}$ in a coconut-grass system vary between 0.80 and 1.60 Mg carbon per hectare per month depending on the soil condition and moisture availability (Figure 7). The contribution of $R_{a(palm)}$ and R_{soil} to the $R_{tot-eco}$ vary with the growing condition.

The net ecosystem carbon balance (carbon sequestration rate) of an agroforestry system can be estimated as the difference between carbon absorption and carbon emission. For smallholder agroforestry systems in the tropics, potential carbon sequestration rates range from 1.5 to 3.5 Mg carbon per hectare per year (Montagnini and Nair, 2004). This information is not available for different coconut based agroforestry systems to date. However, the same study at CRI, reported above, estimated the carbon sequestration potential of coconut-grass systems under different growth conditions. In this study, they showed that coconut plantations in all three agro-ecological regions on two land suitability classes have the potential to act as carbon sinks and the net carbon exchange rates (carbon sequestration rates) ranges from 0.4 to 1.9 Mg carbon per hectare per month. On S_4 which is moderately suitable for coconut, net carbon balance reduces along a decreasing moisture gradient from WL_3 to DL_3. However, on highly suitable S_2, the carbon balance does not show a significant reduction along a decreasing moisture gradient from WL_3 to DL_3. The highest carbon sequestration rate was shown by the coconut plantations in the S_4 soil of the WZ which was mainly attributed to the lower soil respiration and higher photosynthesis of palms in these plantations compared to others (Table 1).

Potential of carbon trading

According to the current carbon market, an average value of US $ 11 per Mg of CO_2 can be used to estimate the annual revenue that can be obtained from net carbon balance in coconut plantations. In the coconut-grass system described above, mean C balance can be estimated as 9.3 Mg carbon per hectare per year which is equivalent to 34.03 Mg CO_2 sequestered per hectare per year. Therefore, a coconut grass agroforestry system of 25-26 years of age has carbon credits (per hectare per year) worth of US $ 375 (Rs. 41,250.00). The net revenue per hectare could be worked out by the difference between present scenario (with carbon project) and the baseline scenario. Nevertheless, if the coconut based agroforestry systems that are viable independent of carbon payments are selected, any income received from carbon payments can be treated as an additional return for the service to the environment.

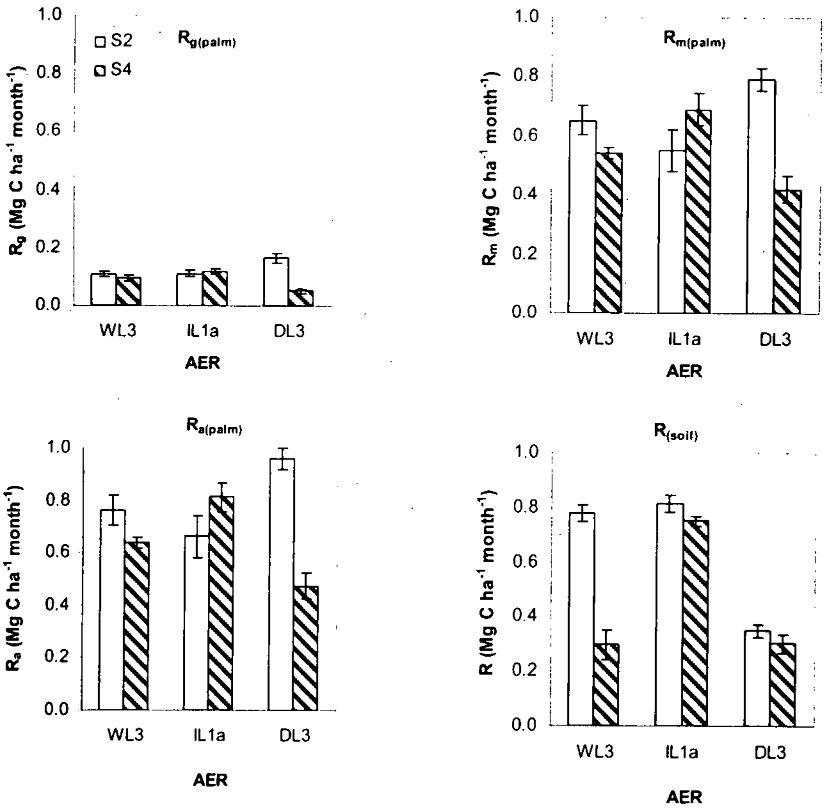

Figure 6: **Growth Respiration, $R_{g\,(palm)}$ (Mg carbon per hectare per month), maintenance respiration ($R_{m\,(palm)}$) and total respiration ($R_{a\,(palm)}$) of coconut palms and soil microbial respiration (R_{soil}) of coconut-grass agroforestry system on S_2 and S_4 land suitability classes in WL_3, IL_{1a} and DL_3 agro-ecological regions (AER)** (Note: Values are means ± standard error of mean).

Micro-climate in coconut based agroforestry systems

Trees on farm can bring about favourable changes in the micro-climatic conditions by influencing radiation flux, air temperature, soil temperature and vapour pressure deficit all of which will have a significant impact on modifying the reproductive performance, rate and duration of photosynthesis, evapotranspiration, conservation of soil water and fertility, and subsequently, a sustainable plant growth and productivity. The research data on the impact of different coconut based agroforestry systems on microclimatic factors are scarce in Sri Lanka. However, Rao *et al.* (2007) have reported that agroforestry systems can reduce soil surface temperature by about 4 ^{0}C and increase Relative Humidity (%RH) (at two meters above ground) by about 12%. Soil microbial activity of different agroforestry systems can vary with the soil temperature and soil water availability, depending on the type of the plantation (Jiang *et al.*, 2005). Therefore, in areas, where a major constraint to establish a crop is high temperature, coconut based agroforestry systems may be a good option to improve micro-climate and soil fertility, and use those lands for sustainable agriculture.

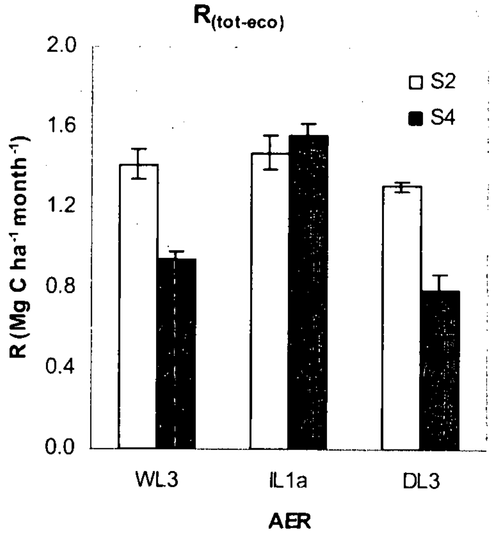

Figure 7: Total ecosystem respiration ($R_{(tot-eco)}$) of coconut-grass agroforestry system on S_2 and S_4 land suitability classes in WL_3, IL_{1a} and DL_3 agro-ecological regions (AER) (Note: Values are means ± standard error of mean).

Table 1: Summary carbon balance (carbon sequestration rate) of a coconut-grass system on S_2 and S_4 land suitability classes (LSC) in the wet (WL_3), intermediate (IL_{1a}) and dry zones (DL_3).

LSC	Carbon sequestration rate (Mg carbon per hectare per month)		
	WL_3	IL_{1a}	DL_3
S_2	0.90 ± 0.30	0.59 ± 0.21	0.73 ± 0.27
S_4	1.94 ± 0.17	0.52 ± 0.25	0.40 ± 0.19

However, while there is general consensus on the beneficial effects of tree based agroforestry in moderating and ameliorating the microclimatic conditions, there is still considerable uncertainty on the productivity and economic benefits of these systems (Kho, 2000). This is partly due to the complex interactions common with agroforestry systems. The major biophysical factors influencing the performance of these mixed systems are crop and tree type, number and distribution of trees, age of trees, management of crop, tree and soil, and climate impacts on crop and tree during different seasons.

Future studies on coconut based agroforestry systems

The benefits of coconut-based agroforestry systems may vary with the type of crops, age of plantations, type of management etc. Therefore, if scientific data on environment benefits of different coconut based agroforestry systems are available, the systems with higher environmental, financial and social benefits can be screened and prioritized in new planting programmes. Therefore, the work at CRI on carbon sequestration in coconut plantations has to be extended to estimate the carbon sequestration potential and microclimatic condition of coconut based agroforestry systems and its impact on financial and economic viability of coconut plantations during its economic life span.

Conclusions

It is clear that agroforestry systems are a viable strategy for carbon sequestration and moderating micro-climate. However, planting trees *per se* would not result in the expected benefits. To achieve high environment benefits, correct trees and crops should be used with correct density, and the soil should be managed properly to avoid the loss of baseline carbon. Coconut based agroforestry systems offer a *win-win* opportunity by acting as sinks for atmospheric carbon while helping to attain food security, increase farm income, improve soil and discourage deforestation.

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GLIRICIDIA RUBBER AGROFORESTRY SYSTEM FOR SUSTAINABLE BIOMASS PRODUCTION

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Abstract

Performance of Gliricidia under rubber in terms of wood and foliage yield, nitrogen contribution, addition of green manure, carbon sequestration, shade tree and animal fodder are discussed. The results revealed that 2.5 m x 8.0 m spacing had higher wood yield compared to 4.3 m x 4.4 m spacing of rubber suggesting that 2.5 m x 8.0 m spacing should used to obtain better wood yield of Gliricidia with rubber. This nature of Gliricidia indicates that the tree is environmentally friendly and economically viable to grow for fuelwood with rubber. The value of Gliricidia loppings in enhancing the organic carbon status, cation exchange capacity (CEC), and porosity of the soil was clearly shown by the experimental data. At the same time it also suggest that the higher soil moisture content with Gliricidia, increases the water uptake and along with the water, nutrients are also taken up thereby increasing the growth of rubber plants especially during the dry periods. Data also revealed that with the incorporation of Gliricidia leaves, 50% of the nitrogen requirement of rubber during its immature period could be cut down. Further, 100% annual nitrogen requirement of a mature rubber tree could be cut down by incorporating of 15 kilograms of fresh Gliricidia leaves. In the event of extending the rubber plantations in the country to non traditional areas like Moneragala district, eastern and northern provinces planting of Gliricidia in rubber plantations will lead to significant improvement in the micro-climate. The energy producers using Gliricidia biomass could benefit from the carbon credits under the Cleaner Development Mechanism (CDM) formulated under the Kyoto Protocol.

Introduction

In Sri Lanka, more than 99% of electricity is generated from both hydro and thermal power system. Since thermal electricity generation capacity has gradually increased, as the performance of larger hydro system has deteriorated during the last decade. Sri Lanka has no proven fossil fuel reserves, and mostly depends on imported fuel for electricity generation. As a result Sri Lanka has one of the highest energy prices in the region (Central Bank of Sri Lanka, 2009). Biomass energy for electricity generation is becoming more promotional and indispensable sector in the future and from different sources of bioenergy, fuelwood or dendro power is the easiest and cheapest method to generate power. Experience with dendro power over the past two decades has demonstrated that *Gliricidia sepium* (*Gliricidia*) has been the most suitable and profitable wood for biomass power generation (BEASL, 2005).

With the capacity of fixing atmospheric nitrogen, *Gliricidia* offer opportunities to increase soil nitrogen levels and thereby reducing the cost of fertilizers as well as the amount of foreign exchange for importing fertilizer. Further, *Gliricidia* has been identified as a good source of green manure, when integrated with chemical fertilizer, it will be able to address the problem of low productivity associated with degradation of soil physical, chemical and biological properties. *Gliricidia* foliage, rich in crude protein and minerals makes it an ideal fodder for ruminant livestock such as cattle, goat and sheep. One of the well known uses of *Gliricidia* is its role as a live supports for intercrops such as pepper and passion fruit. *Gliricidia* can also be used as a shade tree and as a wind barrier.

Wide plant spacing is used in rubber in order to meet the growth requirements of the mature tree and during the early years after planting, the young rubber plants provide very little protection to the soil. It is, therefore, recommended to adopt suitable practices that would provide sufficient ground cover during the early stages of the growth. The importance of growing leguminous ground covers has been emphasized by several researchers who regarded activities which increase soil organic matter and promote biological diversity as a strategic approach in soil and water management. (Yogaratnam *et al.*, 1979; Yogaratnam *et al.*, 1984; Samarappuli, 1992a; Samarappuli *et al.*, 1999). Growing of *Gliricidia*, a tree legume may be considered useful in this regard. This paper highlights the performance of *Gliricidia* as a successful tree legume species that can be grown between the rows of rubber plants which could provide wood material as energy for dendro power and leaf material as green manure.

Methodology

Four field experiments are in progress, three in the intermediate zone (at Nottinghill estate, Kahapathwela; Dammeria estate, Passara; Nalanda estate, Naula) and the other experiment in the wet zone (at Dorset division, Clyde estate, Tebuwana) to study the performance of *Gliricidia* as a successful tree legume species that can be grown between the rows of rubber plants which could provide wood material as energy for dendro power and leaf material as green manure. Single row of 900 plants of *Gliricidia* with double rows of 1,800 plants of *Gliricidia* in between rubber trees having two different spacing were investigated. Performance of rubber with *Gliricidia* and the effect on soil was studied.

Performance of *Gliricidia* as a tree legume

Performance of *Gliricidia* under rubber in terms of wood and foliage yield, nitrogen contribution, addition of green manure, carbon sequestration, shade tree and animal fodder are discussed in this section.

As an energy source: The data on wood yield of *Gliricidia* under rubber with 4.3 m x 4.4 m spacing suggests that *Gliricidia* was capable of giving 0.3 to 1.1 metric tons and 0.8 to 2.5 metric tons of wood yield at 30% moisture during the first and fourth year of planting in the intermediate zone for single and double row systems, respectively (Table 1). In the wet zone, for the first and second years *Gliricidia* was capable of giving 0.5 to 5.2 metric tons and 1.2 to 10.7 metric tons wood yield at 30% moisture for single and double row systems, respectively (Table 2). However, wood yield of *Gliricidia* under rubber with 2.5 m x 8.0 m spacing gave higher yield than 4.3 m x 4.4 m spacing (Table 3).

Table 1: Wood yield of *Gliricidia* in rubber agroforestry in intermediate zone of Sri Lanka.

Age (Years)	Wood yield at 30% moisture (mt/ha/yr)	
	900 plants/ha (Single row)	1,800 plants/ha (Double row)
1	0.3	0.8
2	1.1	2.5
3	0.8	1.0
4	0.4	0.6
5	0.3	0.4

Table 2: Wood yield of *Gliricidia* in rubber agroforestry in wet zone of Sri Lanka.

Age (Years)	Wood yield at 30% moisture (mt/ha/yr)	
	900 plants/ha (Single row)	1,800 plants/ha (Double row)
1	0.5	1.2
2	5.2	10.7

The *Gliricidia* wood yield in wet zone was four times higher than in the intermediate zone. It was also observed that with a single row system the decrease of wood yield from second year of planting to third year of planting was 27%, while with double row system it was 60%. This seems to suggest that with 4.3 m x 4.4 m spacing, double row planting of *Gliricidia* is not suitable for better performance under rubber. Further, the results revealed that 2.5 m x 8.0 m spacing had higher wood yield compared to 4.3 m x 4.4 m spacing of rubber suggesting that 2.5 m x 8.0 m spacing should be used to obtain higher wood yield of *Gliricidia* with rubber.

Table 3: Wood yield of *Gliricidia* under rubber agroforestry with different spacing.

Age (Years)	Wood yield at 30% moisture (mt/ha/yr)			
	900 plants/ha (Single row)		1,800 plants/ha (Double row)	
	4.3 x 4.4 m	2.5 x 8.0 m	4.3 x 4.4 m	2.5 x 8.0 m
1	0.3	0.4	0.5	0.4
2	1.1	2.9	2.5	2.5
3	0.8	9.5	1.0	11.9
4	0.4	4.0	0.6	6.2
5	0.3	5.2	0.4	7.2

Hence, the data collected indicate that on average 7 metric tons per hectare of *Gliricidia* wood can be obtained from rubber and *Gliricidia* based agroforestry system during the immature stage of rubber. It has also been estimated that 4 metric tons of fuel wood is equivalent to 2 tons of coal or 1 tons of diesel oil (Ministry of Science and Technology, 2008). Many industries in Sri Lanka require a source of thermal energy for various needs. The cost of this energy constitutes a large fraction of cost of production due to the high price of fossil fuels. The use of imported fossil fuels also causes a large drain on foreign exchange from the country. This requirement can easily be fulfilled by the use of *Gliricidia* wood. Biomass energy for electricity generation is also becoming more promotional and indispensable sector in the future as heavy reliance on fossil fuel electricity generation in Sri Lanka and high fuel prices. Demand for *Gliricidia* wood has been already established and prices are currently varied from Rs. 1.60 to 2.50 per kilogram (at 20% moisture level) depending on the size of the wood sticks. Growing *Gliricidia* as a fuelwood crop with plantation crops such as rubber can also reduce the destruction of natural forests to obtain firewood. Encouragement is, therefore, now being given for the supply of fuelwood from lands that are being used for the estate crops and this will be a good opportunity for small holder farmers to earn an additional income and also to alleviate poverty in rural areas. *Gliricidia* is, therefore, can be considered as a good renewable agroforestry tree species. Once it is established, from the second year onward the tree could be lopped to a maximum of three lopping cycles per year without affecting its growth. This nature of *Gliricidia* indicates that the tree is environmentally friendly and economically viable to grow for fuelwood with rubber.

As a green manure: The biomass yields of *Gliricidia* for different treatments are given in Tables 4 and 5. *Gliricidia* leaves and tender stems are rich in carbon and can be used as a source of green manure to address the problem of low soil productivity associated with degradation of soil physical, chemical and biological properties.

Table 4: Biomass yield of *Gliricidia* in wet and intermediate zones under rubber agroforestry at 2 years of planting.

Location	Biomass yield (mt/ha/yr)	
	900 plants/ha (single row)	1,800 plants/ha (double row)
Wet zone	1.9	3.7
Intermediate zone	1.5	2.8

Table 5: Biomass yield under rubber agroforestry.

Age (years)	Biomass yield (mt/ha/yr) 900 plants/ha (single row)	1,800 plants/ha (double row)
1	0.8	0.8
2	3.9	5.9
3	7.1	10.9
4	4.3	8.0
5	5.1	8.0

The value of *Gliricidia* loppings in enhancing the organic carbon status and the cation exchange capacity (CEC) of the soil was clearly shown by the experimental data (Table 6). Although decomposition of organic matter is rapid under tropical conditions, organic matter tends to accumulate in the form of mulch of decaying leaves of *Gliricidia* due to continuous lopping and mulching (Plate 1). Moreover, it is possible that some relationship exists between organic carbon content and the various soil parameters (Samarappuli, 1995; Samarappuli, 1992b). Soil bulk density and porosity were highest in mulched plots compared to other management practice (Table 7). Higher percentage of porosity in tree legume plots may be due to its higher organic matter content. It was reported that organic matter serves as a substrate for biological activity. Microbial gums and filamentous fungi are known to thrive well under increased organic matter content and this probably contributed to increased porosity, which results in better crumb structure. Thus, as expected lower bulk density was found with *Gliricidia*. A thick layer of mulch also prevents the direct impact of raindrops on the soil surface (Samarappuli, 1996; Plates 1 and 2).

Among the two situations that were tested for their effects on moisture conservation in rubber plantations, mulching with *Gliricidia* exhibited the highest soil moisture storage capacity of 31.5 cm in comparison with other practice of no *Gliricidia* (Table 8).

Table 6: Effect of incorporation of *Gliricidia* loppings on organic carbon and CEC.

Treatment	Organic C(%)	CEC (cmol/kg)
Without *Gliricidia*	1.00[a]	3.6[a]
With *Gliricidia*	2.15[b]	5.8[b]

Note: Means with the same letter in a column are not significantly different.

Table 7: Effect of incorporation of *Gliricidia* loppings on soil bulk density and porosity.

Treatment	Bulk density (g/cm^3)		Porosity (%)	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm
Without *Gliricidia*	1.42[a]	1.58[a]	54[a]	49[a]
With *Gliricidia*	1.04[c]	1.10[c]	66[c]	53[b]

Note: Means with the same letter in a column are not significantly different.

Table 8: Effect of incorporation of *Gliricidia* loppings on soil moisture storage capacity.

Treatment	Soil moisture storage capacity (cm)
Without *Gliricidia*	21.9[a]
With *Gliricidia*	31.5[b]

Note: Means with the same letter in a column are not significantly different.

Mulches reduced the rate of evaporation of soil moisture thus allowing moisture to remain in the soil for a longer period. Mulches would also influence the moisture content of the soil by their effect on water intake through the immediate surface layer and also by decreasing losses due to evaporation and probably by suppressing weed growth. The soil under mulch had high water holding capacity than the soil under other management practice. This is possibly due to improved soil structure by mulching and higher organic matter content. Increasing the organic matter content of the soil results in improved structure, which decreases crusting and surface sealing and permits greater infiltration (Samarappuli, 1993), thereby increasing the water holding capacity. Similarly, mulching had been found to be very effective in not only avoiding runoff and soil erosion (Samarappuli and Yogaratnam, 1984), but also in preventing evapo-transpiration losses. Any reduction in evapo-transpiration of soil moisture would be beneficial to crop growth in the same manner as additional water intake by the soil would perform.

At the same time it also seems to suggest that the higher soil moisture content, increases the water uptake and along with the water, nutrients are also taken up thereby increasing the growth of rubber plants especially during the dry periods (Table 9; Plates 1 and 2).

Table 9: Effect of *Gliricidia* on growth of rubber plants at 5 years after planting.

Treatments	Girth (cm)
Control	41.9[a]
Gliricidia 900 sticks/ha (single row)	46.8[b]
Gliricidia 1,800 sticks /ha (double row)	48.3[b]

Note: Means with the same letter in a column are not significantly different.

As a nitrogen contributor: The data in Table 10 suggests that leaves of *Gliricidia* are a valuable source of nitrogen (N) fertilizer. The total quantity on nutrients supplied depends on the total leaf biomass yield, which, will vary according to the ecological zone, management during growth, number of loppings made and spacing between rubber and *Gliricidia* (Table 11).

Table 10: Amount of nutrients in *Gliricidia* leaves.

Nutrient	Amount (%)
N	4.08
P	0.25
K	1.49
Mg	0.48

Table 11: Quantity of nutrients supplied under rubber with 2.5 m x 8.0 m and 4.3 m x 4.4 m spacing.

Age (Years)	Quantity of nutrients (kg/ha/yr)							
	900 plants/ha (Single row)				1,800 plants/ha (Double row)			
	N	P	K	Mg	N	P	K	Mg
1	7.4	0.42	2.7	0.86	7.0	0.40	2.6	0.81
2	36.0	2.06	13.2	4.21	54.1	3.11	20.0	6.36
3	65.6	3.97	24.3	7.70	100.0	5.78	37.2	11.81
4	40.0	2.29	14.8	4.60	70.0	4.01	25.8	8.21
5	47.0	2.68	17.3	4.6	74.0	4.22	27.2	8.64

Plate 1: Rubber *Gliricidia*-cover crop agroforestry system.

Plate 2: Incorporation of *Gliricidia* as a mulch in rubber plantations.

Data revealed that with the incorporation of *Gliricidia* leaves, 50% of the N requirement of rubber during its immature period could be cut down. With this capacity of fixing atmospheric nitrogen *Gliricidia* offer opportunities to increase soil N levels and thereby reduce the cost of N fertilizers as well as the amount of foreign exchange used for importing N fertilizer (Table 12). It is known that 1 kilogram of urea equivalent of nitrogen could be obtained from 50 kilograms of fresh *Gliricidia* leaves (Gunathilake and Wasantha, 2005). Apart from it, since phosphorous, potassium and magnesium are also supplied by fresh *Gliricidia* leaves the amount of these fertilizers could also be reduced during the immature period of rubber. Further, 100% annual N requirement of a mature rubber tree could be cut down by incorporating of 15kg of fresh *Gliricidia* leaves.

Table 12: Nitrogen requirement of rubber and quantity of nitrogen supplied by *Gliricidia*.

Age (Years)	N requirement (kg/ha)	N supplied by *Gliricidia* (kg/ha)	
		900 plants/ha (single row)	1,800 plants/ha (double row)
1	16.5	7.4	7.0
2	33.0	36.0	54.1
3	50.0	65.6	100.0
4	50.0	40.0	70.0
5	66.0	47.0	74.0

As a shade tree: *Gliricidia* in rubber plantations led to a significant improvement in the soil and micro-climate. Due to the interception of solar energy by the canopy of *Gliricidia*, the amount of radiant energy reaching the soil surface is low which results in reduced atmospheric and soil temperatures to the order of 4 °C compared to open (Table 13). This helps to reduce the evaporation loss of moisture from soil surface. Further, a layer of *Gliricidia* leaf mulch on the soil surface and the canopy of *Gliricidia* trees could serve as a cushion against the destructive action of the rain drops and also could capture most of the rainfall received during the initial stage of rubber planting. Moreover, *Gliricidia* trees are planted as wind breakers in wind prone areas. All these factors will contribute to a significant improvement in the micro-climate of young rubber plantations. In the event of extending the rubber plantations in the country to non traditional areas like Moneragala district, eastern and northern provinces planting of *Gliricidia* in rubber plantations will lead to significant improvement in the micro-climate.

Table 13: Mean soil temperature of soil at 10 cm depth.

Item	Mean soil temperature (°C)
Open condition	33.4
Under *Gliricidia*	29.4
Difference	4.0

As an animal fodder: It is well known that *Gliricidia* leaves are a good animal feed with a good nutritional value. *Gliricidia* is generally used as a high protein supplement to low quality basal feeds such as grass and straw. Supplementation levels vary but are usually in the range of 20 to 40%. It was also reported that a cow needs approximately 8 metric tons of feed annually (Simons and Stewart, 1992). With 20% supplement, a cow requires 1.6 metric tons of *Gliricidia* leaves. According to the data gathered (Table 5), one hectare of rubber with *Gliricidia* can provide 8.2 metric tons of *Gliricidia* per annum which should be sufficient to provide supplementary feed for 5 cows.

As a carbon sink: Like other green plants, *Gliricidia* can also be considered as a plant factory for solar energy conversion and a carbon sink by virtue of the process of photosynthesis. *Gliricidia* has been reported to be a relatively efficient converter of solar energy into dry matter production. Data showed that the total biomass produced by *Gliricidia* in a rubber *Gliricidia* agroforestry system is 22.8 metric tons per year. There is a vital difference between energy production from fossil fuels and biomass. Burning fossil fuels releases CO_2 that has been locked up for millions of years. By contrast burning biomass simply returns to the atmosphere the CO_2 that was absorbed as the plants grew and there is no net release of CO_2, if the cycle of growth and harvest is sustained. Thus, the biomass option is proven to be CO_2 neutral. As such the energy producers using bio mass could benefit from the Carbon Credits under the Cleaner Development Mechanism (CDM) formulated under the Kyoto Protocol. Moreover, the growers can take comfort in the fact that they have contributed to the sustenance of an environmentally friendly, ecologically sustainable crop, while simultaneously contributing to the maintenance of the global carbon balance in the atmosphere.

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INCREASING TEA LAND PRODUCTIVITY THROUGH AGROFORESTRY SYSTEMS

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Abstract

Various agroforestry systems have been introduced since the beginning of tea cultivation in Sri Lanka to date. Most of the systems have been established in a systematic manner by adjusting the spatial arrangement in order to minimize the possible negative effects of heavy shade and competition with tea. Those systems are, establishment of shade trees, green manure crops, export agriculture crops, plantation crops such as rubber or coconut simultaneously in tea lands. Tea being a shade loving plant, it requires about 35-40% shade for proper growth. Hence, both tall and medium shade tree species have been recommended for tea lands. In addition to shade, they also provide more than 20 tons of biomass per hectare per annum through regular lopping of branches and these biomass are a good source of ground cover and add more than ton of carbon together with other nutrients. Various green manure crops are also established in tea fields to produce at least 2 tons of dry matter of biomass per hectare per year, which is rich in carbon and other nutrients. Various plant species with high coppicing ability are also established on double hedge rows under SALT to obtain about 2-7 tons of dry matter per hectare per year with lopping. Being leguminous species, the shade trees can fix atmospheric nitrogen and some amount of it can be transferred to tea. The overall beneficial effects are thus reflected in the tea yield. Under tea/pepper intercropping system, it has been able to generate an annual income of Rs. 400,000-811,000/= per hectare under mid country conditions. Tea/coffee and tea/vanilla intercropping systems are also found to be more beneficial than a cultivation of a monocrop of tea. Tea and rubber system is successful during first 6-10 years after planting as tea is shaded by rubber. Tea cum coconut system may be more beneficial than tea cum rubber system. Among fruit crops, there is a potential for cultivation of lemon (jamanaran) and avocado in the mid country and pears at Udapussellawa area of the upcountry, with tea. There is a traditional tea based mixed cropping system, also known as Kandyan Forest Garden System, in many of the tea small holdings. Various tree species have also been cultivated with tea on an ad hoc manner. However, it is allowed to occupy only about 30% of space by such tree species in tea lands to minimize heavy shading of tea by tall trees. Other plantations such as Gliricidia as a source of fuelwood, cinnamon as an export agricultural crop, Eucalyptus and Pinus as timber species and fruit crops such as banana, pineapple, macadamia and dragon fruit have been cultivated on uncultivated or marginal lands, borders of tea estates to increase the productivity.

Introduction

Agroforestry is defined as an integrated approach of using the interactive benefits from combining trees and shrubs with crops and/or livestock. It combines agricultural and forestry principles to create more diverse, productive, profitable and sustainable land-use systems (USDA-NAC, 1995). According to American Heritage Dictionary, it is a system of land use in which harvestable trees or shrubs are grown among or around crops or on pasture land, as a means of preserving or enhancing the productivity of the land. The World Agroforestry Centre defines it as a collective name for land use systems and practices in which woody perennials are deliberately integrated with crops and/or animals on the same land management unit. There are normally both ecological and economic interactions between woody and non-woody components in agroforestry.

It is a well established management practice for tropical crops that specially require shade (e.g. coffee, tea and cocoa). It is also a low-input system which combines trees with crops in various combinations or sequences. It is an intervention and alternative to unsustainable intensive cropping systems (IAEA, 2008). The basic characteristics of agroforestry systems are the provision of shade, ground cover with their leaf litter followed by addition of carbon and other plant nutrients, and generation of variety of products including food (fruits, spices, aromatic compounds), fuelwood, animal fodder, gums and latex as raw materials. Other perceived benefits include enhanced water use efficiencies, reduced leaching to ground water and improved soil physical and biological properties. In the event of using leguminous trees, they may further enhance these benefits with their capacity to fix atmospheric nitrogen. A substantial portion of this fixed nitrogen may be transferred to companion crops and to the soil.

Agroforestry systems in tea and their impacts on tea land productivity

Being a shade-tolerant tree species other than cultivating of tea as a monocrop, it can also be inter-planted with other crops of economic importance to maximize productivity in tea plantations (Kulasegaram, 1980). Hence, various agroforestry systems are found under tea. The type of companion tree or crop species is dependent upon the climate and weather conditions and soil type of a given location, the demand or market value of the product, farmer preference, the level of shade provided on tea and severity of competition on tea. Severity of competition and shade could be minimized with the adjustment of spatial arrangement of trees. The various agroforestry systems practised in tea are:

1. Tea with shade trees
2. Tea with green manure crops

3. Sloping agricultural land technology (SALT) in tea
4. Traditional tea based mixed cropping system (Kandyan forest garden system)
5. Tea intercropping with export agriculture crops
6. Tea with rubber and tea with coconut intercropping
7. Tea intercropping with fruit crops
8. Agroforestry arrangements on marginal tea lands/boarders/fences
   a) Cultivation of tree species as sources of wood for dendro power generation
   b) Cultivation of timber species
   c) Cultivation of cinnamon
   d) Cultivation of miscellaneous crops such as arecanut/banana/pineapple/macadamia/dragon fruit

Different tea based agroforestry systems and their known benefits are described below.

1. Tea with shade trees

Tea is basically a shade loving plant. It requires about 35-40% shade for optimum growth. Therefore, establishment of shade trees in tea lands is a must (Plate 1). Hence, both tall and medium height tree species have been recommended for tea lands. Shade trees help to cut down solar radiation, reduce ambient temperature thereby to create a micro climate for tea, which is very conducive for growth and to survival particularly during severe dry spells. Some plant casualties could thus be minimized by providing shade. Furthermore, they provide a large quantity of biomass through regular lopping and pollarding of branches. These are used to mulch the ground and this helps to smother weed growth, reduce soil erosion and lower the temperature on the ground surface. Further, with the decomposition of mulch a certain amount of carbon and other nutrients are also added to the soil. A certain amount of biomass is also regularly added to the soil through leaf fall. Most of the medium shade trees are leguminous and they fix atmospheric nitrogen, and some amount of it can be transferred to tea. The large shade trees having deep root systems can transport ground water to upper soil layers where the root system of tea is found. The overall beneficial effects are reflected in the tea yield.

The tree species recommended for up-country and low-country tea lands are different. *Albizzia molluccana* and *Gliricidia sepium* as high and medium shade tree species, respectively are recommended for low-grown tea. *Grevillea robusta* and *Erithrina lithosperma* (dadaps) as high and medium shade tree species, respectively, are recommended for high-grown tea. *A. molluccana/G. sepium* combination and *G. robusta/E. lithosperma* combinations provide 25-26 metric tons and 21-22 metric tons of biomass per hectare per annum (Table 1).

Table 1: Amount of green matter produced by high and medium shade trees in low and upcountry regions.

Low-grown Tea		High-grown Tea	
Tree Species	Green matter yield (mt/ha/yr)	Tree Species	Green matter yield (mt/ha/yr)
Gliricidia	20	Erithrina	15
Albizzia	5-6	Grevillea	6-8
Total	25-26		21-23

Source: Sivapalan, 1993.

Table 2: Total amount of nutrients added to the soil by green biomass supplied by loppings.

	Amount of nutrients (kg dry matter/ha/yr)				
	N	P	K	C	Total monetary value (Rs)
Gliricidia	180	12.6	60	1,112	108,594/=*
Albizzia	60	11.5	21.30	1,000	
Total	**240**	**24.1**	**81.30**	**2,112**	
Grevillea	26	4.58	20.57	700	105,976/=
Dadap	127	25.2	72.60	1,450	
Total	**153**	**29.7**	**93.17**	**2,150**	

Note : * calculated assuming only 50% of NPK will be available for tea plants after mineralization of nutrients (NPK), respectively, through regular loppings and pollarding of branches (Table 1).

Gliricidia and Albizia system has been estimated that 240 N, 24 P, 81 K kilograms per hectare per year and 2.11 tons of carbon per hectare per year are provided. While Grevillea and Dadap supply 153 N, 30 P, 93 K kilograms per hectare per year and 2.15 tons per hectare per year it is assumed that at least 50% of these amounts of NPK will be available for tea following mineralization. The monetary value of these nutrients are thus around Rs. 108,594/= and 105,976/=, respectively for two shade combinations (Table 2) (Annual Report, 1989). In addition, in high-grown tea at elevations over 1,370 m amsl, *Acacia decurrens* and *A. pruinosa* are established as medium shade trees.

2. Tea with wind belts

Other than shade trees, a mixed stand of *Eucalyptus* spp., *Grevillea robusta* and *Hakea saligna* or *Acacia* spp. is also recommeded for up country as wind belts. A mixed stand of *G. robusta* and *Acacia* spp. is recommended for mid country and a mixed stand of *Gliricidia sepium* and *Fragrea fragrans* for the low country.

3. Tea and green manure crops

Apart from shade trees, some other green manure crops are also recommended for tea lands to provide biomass in order to enhance soil properties. *Crotalaria anagyroides* can be established on every 4 tea rows. Other leguminous species such as *Flemingia conjesta, Calliandra calothryrsus, Sesbania sesban* and non leguminous species such as *Tithonia diversifolia, Sambucus javonica, Artimesia vulgaris* can also be established on vacant patches, fences or abandoned lands. Assuming that at least 2 metric tons of dry matter per hectare per annum are produced from green manure crops, it was estimated that about 30 kilograms N, 2.1 kilograms P and 15.5 kilograms P will be available for tea (50%) after mineralization together with 700 kilograms of carbon. Monetary value of these nutrients is about Rs. 35,000/= per hectare per annum.

4. Sloping Agricultural Land Technology (SALT) double hedge row system

The double hedge row system or "*Sloping Agricultural Land Technology*" (SALT), which is a biological system introduced for steep lands, not only minimizes soil erosion but also improves the soil fertility with regular lopping of shoots. Various leguminous plant species with high coppicing ability are planted as hedges along contours at varied distances between two hedges. Tea is planted in between two hedges. Tender shoots of each hedge is lopped at 2-3 month intervals and these loppings are added to the soil where tea is grown (Ekanayake, 1994a). It was estimated that almost 2-7 metric tons of dry matter of shoots per hectare per year could be produced. With 5 tons of dry matter, about 100 kilograms N, 8 kilograms P, 50 kilograms K could be made available for tea (50%) after mineralization, and about 1,750 kilograms carbon are also added to the soil. Monetary value of these nutrients is approximately Rs. 92,343/= per hectare per annum.

5. Traditional tea based mixed cropping system (Kandyan forest garden system)

In a majority of tea small holdings, particularly in the mid country, various types of plants and trees have been traditionally cultivated to meet the needs of small holders (Plate 2). A few coconut, jack, breadfruit trees, fruit trees, pepper, coffee, cloves, arecanut and tree species for timber and medicinal use have been planted in an *ad hoc* manner for a long time. It is difficult to undertake more accurate assessment on the productivity of this nature of system as the farmers do not keep records for each crop. The disadvantage of such system is heavy shading of tea thereby tea growth could be hampered and tea could easily be vulnerable for fungal diseases. Hence, according to Tea Smalholder Development Authority (TSHDA) about 30% of the space of a tea land is allowed for such tree species and the balance trees have to be removed.

6. Tea intercropping with export agriculture crops

The term intercropping refers to cultivation of a mixture of crops planted in a defined pattern of spatial arrangement (Plate 2; Bavappa and Jacob, 1982). The intercropping of two or more crops on the same land has a number of advantages such as better land utilization, higher productivity, enhanced net returns, favourable cost benefit ratio, reduced risk of dependence on a single crop, and generation of additional employment opportunities. With planting of both crops at correct spacing each component crop is benefitted. As a consequence, the Land Equivalent Ratio and Land Economic Ratio of > 1 could be achieved from such tea lands.

Spice crops such as pepper (*Piper nigrum*), coffee (*Coffea arabica*), clove (*Syzygium aromaticum*) have been gaining economic importance during the last two decades. As such, there was greater attention paid to planned mix cropping of tea among tea small holders. Mixed cropping combinations such as tea/pepper, tea/pepper/coffee, tea/vanilla have been practised in some tea small holdings and in to a very little extent in the corporate sector. Under mid country conditions, it has been recorded that 1.0-1.5 kilograms and 6-7 kilograms of dry pepper per annum could be obtained from a vine trained to a *Gliricidia* shade tree and *Grevillea* shade tree, respectively. It was able to generate an annual income of Rs. 400,000/= 811,000/= per hectare per annum from a tea and pepper intercrop in the mid country (Table 3).

However, it was able to harvest 1,300-2,500 kilograms of fresh pepper per acre per annum under tea and pepper intercropping system, where pepper was planted at closer spacing (10'X 12') in Galaha area. The value of this harvest under the current market price is around Rs. 208,000/= to 400,000/= per acre per annum.

Coffee variety *arabica* is recommended at a spacing of 6 x 6 m for mid country. It was recorded that about 0.7 kilogram of dry seeds from a single tree per annum could be harvested. From a tea and coffee intercrop in the mid country 3,000-5,000 kilograms of fresh tea leaf per hectare per year and 300-400 dry coffee seeds per hectare per year could be harvested. The monetary value of these were Rs. 225,000/=- 360,000/= per ha.

Table 3: Mean annual yield and income from tea and pepper intercrop system in the mid country region.

Crop	Annual yield	Annual income (Rs)
Tea	4,000-10,000 (kg fresh leaf/ha)	240,000/= - 600,000/= per ha
Pepper	1000-1300 kg fresh seeds/ha)	160,000/=-211,200/= per ha
Total (Tea /Pepper)		400,000/=- 811,200/= per ha

Source: Ekanayake, 2003.

Since clove is endowed with a large compact canopy which casts a thick shade on tea, it is best planted along field boundaries, at a spacing of 12 x 12 m. It is possible to harvest about 10-12 kilograms of dry cloves from a tree annually and valued at Rs. 9,000-10,800/= under the current market price. Similarly, vanilla (*Vanilla fragrans*) could be trained to medium shade *Gliricidia* planted at 6 m apart. First harvest expected in 3 years after planting and from a well managed crop is around 400 -500 kilograms per ha.

7. Tea intercropping with rubber and coconut

During the last three decades the intercropping with tea has been extended to rubber and coconut as well. Particularly, tea/rubber and tea/coconut are intercropped in the low country and some parts of the mid country (Ekanayake, 1994b). The relevant guidelines on tea/rubber and tea/coconut intercropping systems have been issued by the Tea Research Institute (Anon, 1996; 2000). For tea and rubber intercropping, a special subsidy scheme is in operation, where a grower can get 75% of the tea subsidy and 75% of the rubber subsidy. For tea and coconut intercropping, the grower can get the subsidy for the 75% tea component and inputs such as coconut seedlings and fertilizer from the Coconut Development Board.

a) Tea and rubber intercropping

During the early 1980s, investigations on tea and rubber intercropping were initiated by the TRI, in collaboration with the Rubber Research Institute. After several years of experimentation, two systems of rubber planting were recommended by the TRI. In the first system, rubber rows are spaced 12 m apart, where 7 rows of tea at a spacing of 1.2 m x 0.6 m could be accommodated between two rows of rubber, the nearest tea row being 2.4 m away from the rubber row. In the second system, there are double rows of rubber at a spacing of 2.4 m planted in a triangular manner, with two double rows spaced 18 m apart. In between two double rows of rubber, it is possible to accommodate 11 rows of tea, at a spacing of 1.2 m x 0.6 m. Land utilization in both systems is therefore more than unity. As a result, the land utilization in the first is 150% and in the second systems is 155%.

Investigations have shown that in the first system when rubber reaches tapping stage i.e. 6 -7 years after planting, the growth and yield of tea were affected due to excessive shading from rubber. Tea pruned weights were lower, recovery of tea bushes after pruning was poor and tea casualties were over 30%). As a result there was a progressive decline in per bush yield of tea.

Performances of the second system, where rubber was planted at wider spacing of 18 m apart, were also good at initial phase. However, with further spreading of rubber branches, laterally tea was highly shaded and there was a sharp yield decline 10 years after. Hence, tea could be intercropped with rubber for a period of about 10 years (TRI, 2000-2009).

b) Tea and coconut intercropping:

Tea and coconut intercropping is also recommended for áreas conducive for the cultivation of both these crops. The tea and coconut inter-cropping system could be adopted in three ways (a) new planting of both crops; (b) intercropping tea in existing coconut lands; and (c) intercropping coconut in existing tea lands. For the new planting of both crops (a), coconut rows are at three spacing, namely 9.75, 11.0 and 12.0 m, and tea is planted at a 1.2 x 0.6 m spacing. The land utilization varies from 157 % to 163%. Tea in existing coconut lands (b), the conditions required for intercropping tea in existing coconut lands are that the age of coconut should be at least 25 years, in order to have adequate light for growth of the tea and the coconut should be planted at a spacing of 8 x 8 m or more. Tea can be planted in between rows of coconut, or in the whole area, leaving a diameter of 1.8 m round each coconut palm as the manure circle. Intercropping coconut in existing tea lands (c) can be done in agro-ecological regions suitable for cultivation of coconut.

In observational trials it was found that tea under coconut thrives well compared to rubber, since more light is filtered through coconut fronds enabling the tea crop for proper utilization of sunlight. Root competition of coconut with tea roots is also found to be less.

8. Intercropping with tea and fruit crops

There is a potential of intercropping tea with lemon (jamanaran), avocado (*Persea americana*) in the mid country area and pears in the Nuwaraeliya district. Jamanaran could be planted at a space of 18 x 18 m in a tea land as its branches are spread covering a wider space. From a well-grown mature tree it is able to harvest about 2,000 fruits annually.

9. Agroforestry arrangements on marginal tea lands/borders/fences

a) Cultivation of tree species as sources of dendro power generation

The lands, which are not suitable for tea, can also be diversified to timber and fuelwood species (De Silva 1979). Hence, there are feasibilities of planting of species such as *Gliricidia sepium*, *Calliandra* and *Cassia spectabilis* for dendro power generation in different tea growing regions. Hence, these species have been planted at 3 different spacing (i.e. 1x1 m, 1x2 m and 2x2 m) in low-, mid- and up-country and Uva region. It was recorded almost 18-22 metric tons of mean stem weight of *Gliricidia* (at moisture level of 20%) from a hectare at second or third lopping under the conditions of low-country and Uva region when planted at 1x1m spacing. Hence, it could be expected at least twice to that of the above fuelwood yield at a mature phase of *Gliricidia* in future. In addition, it was able to harvest 5.2 metric tons of biomass of green leaves and tender stems together with above *Gliricidia* stems (TRI, 2010).

b) Cultivation of timber species

On a long term-basis, timber plantation could also bring a supplementary income to tea estates from the sale of timber to pulp mills (Plate 3). Tree species such as *Eucalyptus grandis*, *Pinus caribaea*, *Alstonia macrophylla* and *Swietenia macrophylla* are cultivated on abandoned lands, banks and ravines. Field establishment of such species is easy. A well-grown 30 year old Mahogany tree could be sold at Rs. 25,000/= and Eucalyptus tree of same age could be sold at Rs. 50,000/=. Hence, it is worth planting even a few trees on such lands at very low capital and input cost. Besides, such system supplies not only the factory fuelwood requirement, but also help to meet the fuelwood needs of the plantation workers.

c) Cultivation of Cinnamon

Some of the tea estates of the corporate sector, particularly in the low country have now moved to cultivate cinnamon as a miscellaneous crop in the abandoned tea lands or uncultivated lands as it thrives well in marginal soils. It is more profitable under the current market price, as the grower can earn some income within a year with low capital investment and at low input cost thereby increasing the productivity of the entire tea property.

Plate 1: Medium shade tree species *Gliricidia sepium* (left) and high shade species *Grevillea robusta* (right) in a tea cultivation.

Plate 2: A traditional tea lands with various trees and crops.

Plate 3: Timber cultivation in the ravine (left) and *Gliricidia* cultivation in an uncultivated block (right) of a tea estate.

d) Cultivation of miscellaneous crops

Apart from the above crops banana, pineapple and some non-traditional crops such as *Macadamia integrifolia* and dragon fruits (*Hylocerus undatus*) are also cultivated on uncultivated lands of some tea estates in order to increase the productivity. Arecanut (*Areca catechu*) is cultivated along the fences of tea small holdings as an avenue crop as this has also become a very good source of income. Finally, with the modern day crisis of shortage of agricultural and forest land, agroforestry is well positioned to provide a perfect balance and a solution. Agroforestry systems today seems as a sustainable method particularly in tea small holding sector, while being economically and environmentally viable.

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