Assessment of the Impacts of and Adaptations to Climate Change in the Plantation Sector, with particular reference to Coconut and Tea, in Sri Lanka.

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Progress Report for the period
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by

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1. Project Summary

1.1 Title

Assessment of the Impacts of and Adaptations to Climate Change in the Plantation Sector, with particular reference to Coconut and Tea, in Sri Lanka.

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PROGRESS REPORT

A. Brief Summary

Work on the time series analysis of climatic data was continued on a seasonal basis for each station separately. Linear regression analysis of data of each station was carried out separately for the two seasons. Mapping of climatic data with elevation dependency was completed for the base-line period and the climate scenarios for 2100 were developed using the integrated assessment software SimCLIM and GCM data. Quality control of rainfall data was undertaken.

In the coconut sector, data required for crop modeling exercise including response to major nutrients, the variation in growth and assimilate partitioning pattern of coconut seedlings under elevated CO_2 concentrations, pattern of dry matter increase in developing coconuts, water requirement by the coconut palm, response of adult coconut palms to irrigation and soil physical parameters of some coconut growing soils were quantified. The crop yield, in terms of copra content, showed a significant increasing trend ($p < 0.005$) for all four major nutrients (N, P, K and Mg), irrespective of land suitability class for coconut and soil series. An alternative set of empirical models were developed to predict annual national yield and yield per hectare in the major coconut growing agro-ecological region on the basis of quarterly rainfall data. The model was used to estimate the national annual yield in two other agro-ecological regions with a percentage error in the range -10% to 10%. An economic valuation of climate variability on coconut production was also carried out.

In the tea sector, data analysis on crop yield under different agro-ecological and climatic conditions was continued, and previous results were further refined. CO_2 trials and collection of other data necessary for crop modeling were continued. Analysis of cost-benefits of various adaptation options was continued. The stakeholder survey was continued.

A resource person from the International Global Change Institute, New Zealand conducted a training workshop to assist the team members in downscaling GCM data and interpolating climate data into maps, as a perquisite to the forthcoming workshop on integrated assessment modeling. The team members were subsequently able to produce an improved set of maps.

A programme to develop crop models suitable for coconut and tea was undertaken with the assistance of a crop modeler from the Indian Agricultural Research Institute. The initial workshop was already held, and the second phase of training will continue in early 2004 at IARI.

B. Tasks performed and outputs

1. General

1.1 Progress Review Meetings

The study teams met three times during the period under review, on July 28th, October 03rd and December 02nd in order to:

- Review the progress in the previous month/s and plan the work for the ensuing months,
- Brief by the participating members to non-participating members on the knowledge and information gathered at meetings attended by the members,
- Discuss the follow up activities and plans for the proposed workshop on Crop Modeling to be conducted by Dr N Kalra and second phase of the Integrated Assessment Modeling to be carried out with IGCI, NZ during the course of the year (subsequently postponed for early 2004).
- Review the results of the data analysis and quality control exercise carried out by the 4 participating institutes.
- Discuss the budget for the ensuing period.

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All meetings were well attended.

1.2 Capacity Building Programmes

1.2.1 Training on Socio-Economic Modeling at Yale University, USA

Dr Neil Fernando of CRI underwent a three-week training programme at the School of Forestry and Environmental Studies, Yale University, USA under the supervision of Professor R Mendelsohn, followed by a study visit to the International Research Institute (IRI) for Climatic Prediction, New York, during 12th October to 8th November 2003. The training was given at no cost to the project. The objective of the training was to develop an economic impact model to analyse the socio-economic impacts on coconut sector due to climate change. The theoretical background of measuring the climate change impacts, a review of the alternative approaches for measuring the climate change impacts, and their weaknesses were covered in the programme. A novel approach called "Ricardian Approach" was also covered. Finally, an empirical Ricardian Model was developed to measure the climate change impacts with improved accuracy. The abstract and the introduction to a paper written on the work carried out during the training programme is given in Annex I.

1.2.2 Training on Short Term Climate Prediction at the International Research Institute (IRI) for Climatic Prediction, New York, USA

Dr Sarath Peiris of CRI underwent a 3-week training programme on short term climate prediction at the International Research Institute (IRI) for Climatic Prediction of University of Columbia, during 01 – 23, November, 2003. The training was given at no cost to the Project or to Dr Peiris. The objective of the programme was to first establish a relationship between crop yield and seasonal rainfall and next develop a statistical downscaling method to predict seasonal rainfall enabling long-term and medium term yield prediction. The IRI carries out research which is related to short-term climate prediction on national, regional and global scale using dynamic and statistical models. Dr Lareef Zubair of the project team, presently working at IRI, facilitated the training programme. A detailed report on the work carried out by Dr Peiris at IRI, is given in Annex II.

1.3 Local Training Programmes attended

Ms C H Piyasiri (RA) and Mr. M S S Chandra Kumara (RA) of CRI attended a Certificate course on GIS and Gio-Informatics conducted by the Post-Graduate Institute of Agriculture of the University of Peradeniya from 01-06 December, 2003.

2. Data Collection

2.1 Coconut Sector

Data on the following parameters were collected during the period under review, particularly for the purpose of developing a suitable dynamic crop model for coconut. The detailed results are given in Annex III.

2.1.1 Response to major nutrients

Data on response of coconut yield (copra or nuts) to major nutrients (N, P, K and Mg) in different Agro Ecological Regions (AER) and Land Suitability Classes (LSC) was collected, depending on the availability.

2.1.2 Major nutrient removal

Data on the amount of major nutrients removed by the nuts and fronds during different periods of the year were collected.

2.1.3 Response to CO_2 Enhancement

The experiment on the impact of CO_2 enhancement on shoot and root growth, dry matter assimilation and partitioning was continued using two open top chambers. The net assimilation data revealed that about 20-30% of yield increase is possible with CO_2 enhancement. The first destructive harvest was done in December 2003. An increase in the shoot and root development was observed with CO_2 enhancement.

2.1.4 Pattern of biomass increase in developing coconuts

The variation in weight of a nut in different developing bunches of coconut, from fertilized female flower (1M) to mature coconut (12M), was quantified for developing crop models. Samples were collected during just after a rainy period (June, wet) and after a 3-month dry period (April, dry).

2.1.5 Seasonal nut fall

Seasonal nut fall in developing coconut bunches in relation to the time of opening of spadix and consequent dry periods were collected.

2.1.6 Water requirement of coconut palm

Data on the water requirement of the coconut palm in relation to the age group, which is required for irrigation during dry periods (adaptation measure), were collected.

2.1.7 Soil moisture parameters

The estimated soil moisture parameters (vol / vol %) in different horizons of Andigama (S4) and Madampe (S1) soils were collected.

2.1.8 Soil physical properties

Soil physical properties of major soil series (A, AB and B horizons) were collected from the wet, intermediate and dry zones for the development of crop models.

2.1.9 Socio-economic data

A time series of crop yield data was collected from a field survey of 31 estates covering all agro-ecological regions.

2.2 Tea Sector

2.2.1 Crop yield and growth data

Factors contributing to yield variations of tea were also studied. Accordingly, measurements on yield components such as shoot density, rate of growth of shoots and shoot weight etc, net assimilation rate and transpiration of tea bushes under different treatments were taken. Results are being summarized for statistical analysis

2.2.2 CO_2 elevation studies on Tea

Effect of CO_2 on productivity is being studied by conducting field experiments at high and low elevations. Tea Leaf Area index (LAI) and yield increased with enhancement of ambient CO_2 in both elevations. The response to CO_2 fertilization was high in the low elevations compared to high elevations. Elevated CO2 in the low and high elevation has increased tea yield by about 25-35% compared to ambient CO2. Results for the last 6 month period (July-December, 2003) are given in the table 1.

Table 1- Levels of CO_2 on Productivity

Location	Leaf area Index		Yield (kg ha^{-1})		Transpiration efficiency	
CO_2 Level	Ambient	Elevated	Ambient	Elevated	Ambient	Elevated
Low-Elevation			2393	3257		
High Elevation	6.86	8.30	5488	6770	39.8	50.2

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3. Data Analysis

3.1 Meteorological Data

A detailed trend analysis of temperature and rainfall data was carried out covering the period, 1931-1990. The analysis was carried out with and without filtering data through a low pass filter, according to the two main cultivation seasons, Yala (May – August) and Maha (October – February). Analysis without applying Gausian low-pass filter was carried out on a monthly basis. Correlations were obtained within every each main meteorological station.

3.1.1 Time series analysis of temperature

Trend analyses for mean maximum air temperatures have shown increasing trends for both Yala and Maha seasons over the period of 1931-2000 at most of the stations except at Nuwara-Eliya where there is no significant increase in the maximum air temperature. Mean minimum air temperatures for both Yala and Maha seasons have shown increasing trends except at Kurunegala where a decreasing trend has been indicated. Trend analyses for mean air temperatures have shown increasing trends at all stations both during the Yala and Maha seasons. The results are given in Annex IV.

3.1.2 Time series analysis of rainfall

In the case of rainfall, decreasing trends have been indicated during both Yala and Maha seasons except at Puttalam during the Yala season where an increasing trend has been shown. The results are given in Annex IV.

3.1.3 Mapping of Meteorological Data

The software used by the IGCI team for mapping climate data, ANUSPLIN, was purchased from the Australian National University enabling the team at the Meteorology Department to undertake the mapping exercise by themselves. Climate data were arranged according to the formats which can be fed to ANUSPLIN programme. The interpolation of baseline data; mean monthly temperature and rainfall for 1961-90 period, using ANUSPLIN was completed with elevation dependency. These maps are shown in Annex V.

3.1.4 Development of future climate scenarios

The development of future climate scenarios was carried out using SimCLIM software for which elevation dependent baseline climate maps and General Circulation Model (GCM) outputs were required. First, Digital Elevation Model (DEM) data were downloaded from USGS GTOPO 30 website, which has a 1 km resolution not adequate for our purpose. Hence, the downloaded data were extracted and interpolated to 500m resolution, which is need for SimCLIM, using IDL software.

The GCM data produced by CSIRO in Australia relevant to whole globe as well as for six grid points covering Sri Lanka, were downloaded. The extracted data were interpolated to 0.004 deg resolution, using Inverse Distance Weighted (IDW) method.

The interpolated baseline climate data and GCM fields were imported to SimCLIM software to generate the climate scenarios for 2100. Some examples are shown in Annex V.

3.1.5 Quality control of climate data

The quality control of climate data was continued. The results are given in Annex VI.

3.2 Coconut Sector

3.2.1 Correlation of yield with fertilizer application

Development of regression models was carried out to determine the relationship between yield and major nutrients, Nitrogen, Phosphorous, Potassium and Magnesium in different agro-ecological regions having different types of soils. Data were obtained for each of these soil types. The yield was expressed in terms of copra produced per ha. The summary of data and trend analysis is given in Annex VI.

3.2.2 Alternative Model for National Yield Prediction

A new statistical model was developed to predict national yield using quarterly rainfall data. Rainfall in each Agro-Ecological Region (AER) was aggregated based on three monthly scales such as January to March (JAM), April to June (AMJ), July to September (JAS) and October to December (OND). It was found that the national yield in a given year was significantly correlated with rainfall during JFM on the previous year ($p < 0.05$) in all seven regions and rainfall during JAS on the following year in all AERs except two dry regions (DL3 and DL5). There was no significant correlation between yield and rainfall two years prior. The best empirical model developed using quarterly rainfall alone was able to explain about 50% of the inter-annual variability. A detailed report on the study is given in Annex VII.

3.2.3 Influence of the sea surface temperature

National annual coconut yield and bi-monthly coconut yields showed a significant response to both sea surface temperature (SST) and SST anomalies in both current and the previous year, which could be useful to find impact of climate change as SST can be used as large scale weather variable to predict future climate. Attempts were made to develop statistical downscaling model to estimate quarterly rainfall in coconut growing areas using SST anomalies via canonical correlation analyses.

3.2.4 Economic valuation of climate variability

In order to estimate the economic value of climate variability on coconut production, past yield were grouped into three groups namely, (i) shortage extremes (< 10% percentile), (ii) average and (iii) glut extremes (> 90% percentile) based on 10% and 90% percentiles of the annual national coconut production array. The foregone income to the economy in crop shortage extremes varied between US $ 54 million to US $ 73 million while the additional income accrued in crop glut extreme varied between US $ 42 million to US $ 87 million. A paper showing the details of the analysis is given in Annex VIII.

3.3 Tea Sector

3.3.1 Dependence of productivity on climatic factors and zone

Crop yield was analyzed according to the agro-ecological zone of origin; intermediate up country (IU), intermediate mid country (IM), wet up country (WU), wet mid country (WM), and wet low country (WL). The dependence of crop yield with rainfall and temperature in each of the agro-ecological zones was also analyzed. The results are given in Annex IX.

3.3.2 Adaptation Measures

In order to minimize adverse effect of increasing temperatures in the low and (or mid) grown tea where the temperatures are higher than the optimum for tea and minimize drought effects in all elevations, following adaptation measures were proposed. Details of the relative impact of these adaptation measures on mitigating adverse effects of climate change were collected by literature surveys.

1). Shade management
2). Soil Fertility amelioration
3). Intercropping tea with other cash crops
4). Diversification of marginal tea lands
5). Fertigation

Shade management:

One of the main effects of climate change is the increase in temperature. Increase in temperature during dry months increases the leaf temperature and transpiration. As a result, VPD increases during the mid part of the day in the dry months. Increase in VPD above the critical level tend to close stomata and reduces the photosynthesis.

Soil Amelioration

Tea soils in most of the tea growing areas are reported to have been debilitated. The nutrient and water holding capacity of these soils is poor. Hence, soil improvements mainly addition of organic matter will minimize drought damages while increasing productivity. Experimental results have shown that about 25% increase in tea yield can be achieved by increasing 1% of organic carbon in tea soils. Availability of organic manure or compost and supply of labour have been identified as limitations for soil improvements.

Intercropping

Intercropping in tea and diversification of unproductive tea lands are also considered as suitable adaptation measures for enhancing productivity of existing tea lands. Intercrops such as rubber or coconut not only give physical shade to tea but also give an additional income to tea growers. Existing marginal tea lands will be become further unproductive and abandoned due to adversities of climate change. Hence, it is proposed that such lands should be converted to any other suitable crop/timber production systems. Further such lands could be planted with green manure crops or any other suitable grasses to be harvested and used for soil improvements in potential tea fields. Social implications such as resistance by workers (loss of jobs due to reduction of land area under tea) and sometimes, poor returns from the intercrops when compared with mono-cropping of tea have been identified as limitations in this adaptation.

Fertigation

Fertigation is aimed at supplying water during dry months and nutrients efficiently. The experiments presently being conducted at different locations have shown that about 50-100% increase in productivity of tea lands can be achieved by fertigation. Only dry periods are concerned the increase in productivity under fertigation is reported to be about 300%. However, lack of an assured and perennial water sources is a limiting factor in the adoption of large-scale fertigation in tea lands.

4. Follow up on the Training Workshop on Integrated Assessment of Climate Change Impacts

4.1 Preparatory Workshop on SimCLIM held on 27-29 August, 2003 at Colombo by Dr Xianfu Lu of International Global Change Institute, Waikato, New Zealand

In view of the difficulties experienced by the team members in downscaling GCM data and interpolating them for use in developing climate scenarios applicable for Sri Lanka, IGCI volunteered to make available the services of Dr Xianfu Lu at their expense, to conduct a 3-day training workshop, particularly with a view to prepare the local team for the forthcoming IAM workshop. The workshop was held during 27-29 August, 2003 in Colombo. Most of the team members attended the workshop. The objective of the workshop was to

- Review the preparations required for the SriLankaCLIM stage II development workshop including procedures to create spatial climatologies for temperature and precipitation in Sri Lanka using station observational long-term average datasets; and procedures to obtain, process, and interpolate GCM simulated climate change patterns for Sri Lanka; developing baseline climatologies and climate change scenarios; incorporation of crop (impact) models using DLL files, and interpolation procedures applying ANUSPLIN software

- Develop Scenario method within SimCLIM including creation of baseline climatologies (long-term average of climate fields), developing normalised climate change patterns from GCM experiments and superimposing climate change scenarios onto baseline climatologies to generate climate scenarios

- Explain procedures for developing Normalised Climate Change Patterns from GCM experiments by obtaining monthly, tri-decadal average “raw” GCM outputs from the IPCC DDC website (http://ipcc-ddc.cru.uea.ac.uk), extracting the data points for the “window” covering Sri Lanka, and interpolating the extracted data points to create spatial climate change patterns by using a distance-weighting average technique.

4.2 Training Workshop on Development of Crop Models held on 26-29 October, 2003 by Dr Naveen Kalra of Indian Agricultural Research Institute, New Delhi, India

The use of SlimCLIM model requires a crop model that simulates the growth of coconut and tea under different climatic as well as other external factors. Most crop models that are available are applicable only for annual crops rather than for perennial crops such as coconut and tea. Hence there was a necessity to develop dynamic crop models suitable for the two crops, coconut and tea. The services of Dr Naveen Kalra of the IARI, New Delhi, a reputed crop modeller, was obtained to train our team in the development of a crop model for these two crops, that could form an input to SimCLIM. A 3-day workshop was held in Colombo on 26-29 October with the objective of:

- Familiarising the members on the basics of dynamic crop modelling.
- Introducing the members to the Fortran Simulation Translator (FST) software that is being used for crop modelling.
- Reviewing some models that have already been developed, through a step-by-step procedure, and
- Identifying the data requirements for developing a dynamic model for coconut and tea.

As a follow up to this programme, the PI, Dr Ratnasiri visited Dr Kalra at his laboratory in IARI on 17th December, to discuss the second phase of the programme where several members are expected to visit IARI to finalize the crop model development exercise. It was decided that 5 team members would visit IARI for a 2-week programme commencing 2nd February, 2004.

4.3 Second Phase of SimCLIM Workshop

The second phase of SimCLIM workshop which was due to be held in December, 2003 had to be postponed for February, 2004, in view of the delay in the development of the crop model, which would go as an input to SimCLIM.

C. Difficulties Encountered

1. Climate Scenario Development

The SimCLIM software posed some problems, as it was not very user friendly. The colour schemes of maps of various parameters varied from map to map, thus making it impossible to compare visually the patterns of different maps. It was also not possible to show the increment of changes of a parameter over a given time interval.

2. Coconut Sector

- The data on soil physical parameters, nutrient response, irrigation and coconut yield were not available for all the land suitability classes (LSC) and Agro Ecological Regions (AER).

- The non-availability of nut yield data on district and AE region basis posed a difficulty.

- The lack of detailed phenological data posed a problem in building the crop models.

3. Tea Sector

- The non-availability of socio-economic data as required for building suitable models.

- The lack of detailed phenological data posed a problem in building the crop models.

D. Tasks within the next 8 months

Continue gap-filling data collection, particularly as required for building crop models.

Improve on the scenario development to project the climate as well as socio-economic conditions in the current century.

Improve on the data analysis to get a better understanding of the behavior of the two crops under changes in climate.

Extending the study 1 with spatially interpolated climatologies

Launching the rapid field survey of 100 farmers to estimate the Empirical Ricardian model

Analyzing the economic feasibility of adaptation strategies
Developing a sector model employing the linear Programming approach

The development of the crop models for coconut and tea by team members with the assistance of Dr Naveen Kalra of IARI.

Training in the development of a suitable socio-economic model with the assistance of Dr Joyashree Roy of University of Javdpur, Calcutta, India.

The development of the Integrated Assessment Model, SriLankaCLIM with the assistance of the International Global Change Institute, New Zealand, for undertaking impacts and adaptation studies. A supplementary grant was received from AIACC for this purpose.

Apply the above models to study the impacts to the coconut and tea industries due to anticipated climate change, and evaluate the cost benefits of various adaptation strategies.

E. Anticipated Difficulties within the next 8 months

The main concern is to what extent the proposed integrated assessment model would meet the requirement of the project.

There is pressure from international and regional lending institutions to restructure the plantation sector institutions, for which the Government of Sri Lanka has agreed in principle. It is anticipated that projects would be re-prioritized and the research staff assigned with new responsibilities. This would mean that the team members may have less time to spend on the project.

F. Presentations

Roundtable presentation titled “Climate change, variation and coconut industry in Sri Lanka: Some concerns”, Neil Fernando, 2 November 2003, IRI, Palisades, USA

Annex I

Effect of Climate Change and Variability on Coconut Yield: A Sri Lankan Case Study[1]

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(1 November 2003)

ABSTRACT

This study analyses the influence of climate change and variability on coconut yield in Sri Lanka using a time series of crop yield data collected from a field survey of 31 estates (panel) and long term temperature and rainfall variables collected from the proximate weather measuring stations. Multiple regression preceded by correlation analyses was employed. Both the crop-climate and crop-weather models exhibited extremely poor fits, which could readily be attributed to using of climate data collected from a coarse spatial resolution. Despite poor model fits, coefficient estimates of explanatory variables reveal that long term variations of both temperature and rainfall have small yield effects. Whereas the annual variability of rainfall, especially in the first inter monsoon (March to April), has significantly influenced the annual crop. Although robust conclusions are warned due to the inadequate spatial resolution of climate data, this data limitation itself provides a useful precursor to extend the analysis with spatially interpolated climatologies.

INTRODUCTION

The coconut palm (*Cocos nucifera* L), which is popularly known as the "Tree of Heaven" for its innumerable uses to the mankind, is a perennial tree crop grown in 86 humid tropical countries in the world, covering about 11 million ha. The estimated world coconut production is about 52 billion nuts, more than half of which comes from South East Asia, mainly the Philippines, Indonesia, Thailand, and about a fourth from South Asia, mainly India and Sri Lanka, and the remainder from the Pacific, Latin America and Africa (Liyanage, 1999). The Sri Lankan share of global coconut production is about 5-6 per cent. Coconuts contribute some 2 per cent to the GDP of Sri Lanka and 22 per cent of the per capita calorie intake in the diet, being second only to rice paddy, the staple food of Sri Lankans. The estimated land area under coconuts in Sri Lanka is 441 861 ha, which is some …..per cent of cultivable lands in the country. It provides livelihood for some 500 000 people both in terms of direct and indirect employment, representing about 5 per cent of the total workforce, and contributes 2.5 per cent to export earnings. Being almost exclusively a rainfed crop, national production depends greatly on rainfall. In recent times,

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[1] Working paper prepared while M T Neil Fernando was in a training visit (13 October to 2 November 2003) at the Yale School of Forestry and Environmental Studies, USA, under the guidance of Professor Robert Mendelsohn and Pradeep Kurukulasuriya.

a scientific consensus is emerging that increasing concentrations of atmospheric GHGs could alter the global temperatures and precipitation patterns. These changes are expected to involve considerable effects on almost all sectors across the globe, including agriculture. Since a considerable number of livelihoods and the national economy depend on coconuts, it is worthwhile to investigate if the coconut sector is likely to experience such effects. Therefore, the objective of this work is to examine the influence of climate change and variability on coconut yield, which will improve our scientific understanding of climate sensitivity of the Sri Lankan coconut sector.

METHODOLOGY

Data

Coconut yield data

A time series of pick-wise[2] coconut yield data was collected from 31 coconut estates located in different agro-ecological regions in Sri Lanka, by making personal visits during July to September 2003 (Annex Table A1). As searching and compiling of crop data from old records of estates was a tremendously time consuming task, several visits were necessitated to the same estate. Different estates have crop data for different time periods (unbalanced panel data) as shown in Annex Table A1, and finally however 580 coconut yield observations were available for the analysis. Because different estates have different coconut acreage, the time series of coconut yield were converted to per acre basis, enabling a common comparable basis.

Climate data

The types of climate data include monthly-averaged Tmin, Tmax, Tmean and monthly total rainfall. They were collected from the closest climate observational stations to chosen estates, but the closest station for some estates happened to be well away some 50 km. Consequently, the coconut yield of such estates might not be satisfactorily explained by the climate. As shown in Annex Table A1, the same observational station had to be chosen for a number of estates, simply because of the non-availability of any other close station. Hence, there is a clear necessity for interpolating station observational climate data to improve their spatial resolution, thereby increasing the relevance of climate variables on coconut yields.

Analysis

Multiple regression analyses preceded by correlation tests were employed using SAS Windows Ver. 8. The analysis was carried out in two steps. First step involves the investigation of relationship between climate normals (30-year average both temperature and rainfall) and coconut yield, while the second step involves the examination of the annual weather variation (temperature and rainfall) on coconut yield. The first and second steps thus respectively analyze the climate change and climate variability effects on coconuts.

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[2] Usually one coconut bunch emerges in a month thus enabling 12 harvests in a year. But traditionally Sri Lankan growers practice bimonthly picking although a few practices monthly picking.

Annex II

A report of the visit to the International Research Institute (IRI) for Climatic Prediction, New York, USA: 1-23 November, 2003

T S G Peiris, Coconut Research Institute, Lunuwila. Sri Lanka

Introduction

One of my responsibilities for the on-going project, Assessment of Impacts of and Adaptation to Climate Change in Coconut Industry, is to establish a relationship between crop yield and seasonal rainfall and develop a statistical downscaling method to predict seasonal rainfall enabling long-term and medium term yield prediction. On that aspect I got an opportunity to explore to the relevant tools at the International Research Institute (IRI) for Climatic Prediction, New York, USA from 1-23 November, 2003. The IRI carried out research related to the short-term climate prediction on national, regional and global scale using dynamic and statistical models.

Work carried out

- Enhance my empirical statistical model used to predict national annual coconut production using new diagnostic methods. The new variables are the quarterly rainfall in different agro-ecological region as against the classical seasonal rainfall. The predicted value for 2004 is 2900 million nuts.
- Found a clear relationship between El Nino phenomenon and the national coconut yield. More details have to be investigated.
- Familiarize myself with the basis of IRI data library which would be useful to download various large scale weather variables and different Global Climate Model (GCM) outputs at different resolutions. The downloading those data would be useful in developing climate models for short-term predictions on local scale.
- Got exposure for development of statistical downscaling method to a specific location (region) using GCM output. Statistically significant relationship was identified between quarterly rainfall of our agro-ecological regions (local scale) and sea surface temperature – SST (large scale).
- The discussion with many scientists at IRI was useful to update my knowledge on various statistical techniques in analyzing climate variability and various aspects of climatology.

Benefits

- Identification of significant association between El Nino and national yield would enable to given early warnings for the growers as changes in ENSO system influences seasonal climate (temperature and rainfall) in Sri Lanka.

- Identification of relationship between large scale weather parameters and local scale weather variables could be useful to predict quarterly rainfall and consequently projection of annual yield with longer lead time (say 2-3 years)

- The exposure to the development of statistical downscaling method to interpolate GCM output would be useful in developing future climate change scenarios.

- The experience gained will enhance my knowledge on climate change analyses which in turn would be beneficial to produce significant contribution to the climate change project and to the coconut industry.

- I was able to discuss and sketched out ideas for a proposal on developing a climate information system in the CRI. This would be useful to improve the prediction of climate in coconut growing areas.

- From both statistical and dynamic models developed by IRI has predicted the near average sea surface temperature to continue for the next half of year 2004 and the change for development of El Nino or La Nina conditions is believed to be less than that of an average year. As quarterly rainfall has a good relationship with SST, I would predict that the year 2005 would also have high likelihood of better production year for coconut.

Acknowledgements

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Annex III

Progress or work done at CRI

1. Nutrient Response Data

To develop crop models, data on response of coconut yield (copra or nuts) to major nutrients (N, P, K and Mg) in different Agro Ecological Regions and Land Suitability Classes was collected, depending on the availability. The following data collections were completed.

- Response of copra yield to Nitrogen, Phosphorous and Potassium in IL1 (Bandirippuwa Estate, Intermediate Wet, S2 Sandy loam)
- Response of copra yield to Nitrogen, Phosphorous, Potassium and Magnesium in IL1 (Marandawila Estate, Intermediate dry, S2 Sandy loam)
- Response of copra yield to Nitrogen, Phosphorous and Potassium in WL3 (Naiwala Estate, Veyangoda, Wet, S4 Boralu)
- Response of copra yield to Nitrogen, Phosphorous, Potassium and Magnesium in WL2 (Monrovia Estate, Rathgama, Wet, S4 Gravel)
- Response of copra yield to fertilizer application – recommended dose (Yield increase of unfertilized plantation over time)

2. Nutrient removal data

The data on amount of major nutrients removed by the nuts and fronds during different periods of the year were collected.

Table 1: *Estimated amounts of nutrient removal by nuts and fronds of coconut palm during the year*

Harvest	Nitrogen (as N g)		Phosphorous (as P g)		Potassium (as K g)		Calcium (as Ca g)		Magnesium (as Mg g)	
	Nuts	Fronds	Nuts	Fronds	Nuts	Fronds	Nuts	Fronds	Nuts	Fronds
May-June	14,589	2,147	1,648	155	26,740	668	1,365	2,340	1,207	794
July-August	10,353	1,263	1,059	79	18,075	347	1,513	1,653	858	374
Sep-October	6,774	2,901	623	173	13,246	465	709	3,708	874	831
Nov-December	4,467	1,819	549	155	11,843	498	903	2,024	570	547
Jan-February	5,829	1,711	518	150	9,796	452	767	2,379	405	766
March-April	5,555	2,413	660	182	14,966	953	729	3,963	560	1,109
Total	47,567	12,254	5,057	894	94,666	3,383	5,986	16,067	4,474	4,421

3. Experiment on CO_2 Enhancement

The experiment on the impact of CO_2 enhancement on shoot and root growth, dry matter assimilation and partitioning was continued using two open top chambers. The net assimilation data revealed that about 20-30% of yield increase is possible with CO_2 enhancement. The first destructive harvest was done in December 2003. An increase in the shoot and root development was observed with CO_2 enhancement. The summary of data is given below.

Table 2: *Variation in leaf production rate, leaf area development and weight of roots, shoot and leaves under ambient (350-360 ppm) and enhanced (550-600 ppm)* CO_2 *concentrations.*

Treatment	Leaf production rate No / 6 months	Leaf area development cm^2 / 6 months	Root weight (g)		Shoot wt (g)		Leaf wt (g)	
			Fresh	Dry	Fresh	Dry	Fresh	Dry
Enhanced CO_2	4.58	4716.3	205.4	42.9	334.0	64.8	290.6	86.6
Ambient CO_2	4.36	4688.8	138.1	34.2	321.6	60.4	263.7	78.3

4. Pattern of biomass increase in developing coconuts

The variation in weight of a nut in different developing bunches of coconut, from fertilized female flower (1M) to mature coconut (12M), was quantified for developing crop models. Samples were collected during just after a rainy period (June, wet) and after a 3-month dry period (April, dry). A longer dry period has drastically reduced the weight of nuts at early developing stages, which will result in a reduction in the final weight of nut and fruit components.

Table 3: *The mean weight of fertilized flower (1M) to mature nut (12M)*

Period	1M	2M	3M	4M	5M	6M	7M	8M	9M	10M	11M	12M
Wet-June	41	103	289	588	1451	2248	2878	2463	2508	2283	1952	1854
Dry-April	7	18	33	79	176	369	765	1652	2650	2746	2468	2287

5. Seasonal nut fall in developing coconut bunches in relation to the time of opening of spadix and consequent dry periods.

The two dry periods of the year in the main coconut growing areas are January to February and July to August. Thus the two periods, February to March and August to September that follow in the wake of these two dry periods, are the periods of moisture stress giving rise to higher immature nut fall. The extent of such immature nut fall will be dependent on which period of nut development coincides with these moisture stresses. If the developing bunches meet a period of moisture stress in the second two months of the nut development (which happens to be the most susceptible period), then nut fall should be relatively higher than otherwise. Following table confirms the expectations.

The bunches that open during December to January and June to July meet the periods of moisture stress February to March and August to September respectively in their second two months of development. It was observed that the immature nut fall is highest for these two groups of bunches

Table 4: *Seasonal nut fall in relation to dry periods*

Period of opening of spadix	**Initial no. of female flowers per 100 inflorescences**	**Stage of development at which period of moisture stress is met**	**Total nut loss within first 6 months per 100 inflorescences**
Dec / Jan	1527	2nd two-months	1172
Feb / Mar	1621	1st two-months	1066
Apr / May	1634	3rd two-months	904
June / July	1874	2nd two-months	1205
Aug / Sep	1585	1st two-months	1055
Oct / Nov	1367	3rd two-months	937

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6. Water requirement of coconut palm

The water requirement of the coconut palm in relation to the age group is required for irrigation during dry periods (adaptation measure). Therefore, the following data was collected.

Table 5: *Water requirement of coconut palms in different ages*

Age of palm (years)	Water requirement (L / palm /day)
1	5
2	5
3	10
4	15
5	20
6	24
7	28
8	32
9	36
10 and above	40

When consider the water requirement of an adult palm, 40 L water / day is equal to 3.2 mm of Rain Fall per day, and it equals to 1168 mm of RF per yr. Therefore, it may not be possible to cultivate coconut under rain-fed condition if the RF is less than 1168 mm per annum.

Table 6: *Response of yield (No of nuts / palm / year) of adult coconut palms to irrigation – Ratmalagara Estate, S4 Boralu*

	1999	2000	2001	2002
Without irrigation	71	50	62	38
With irrigation	91	63	90	56
% increase	28	26	45	47

Watering @ 40 L palm / day

7. Soil moisture parameters of major coconut growing soils

The estimated soil moisture parameters (vol / vol %) in different horizons of Andigama (S4) and Madampe (S1) soils are given below. Highly compacted clay with gravel in the B horizon of Andigama series could replenish the available water fraction from their pores, and could result in creation of severe water stress in dry periods. Dry soil condition in Andigama series and high soil resistance are the major soil physical constraints limiting the function of coconut roots. High RAW in Madampe soils could enhance the water and nutrient absorption process in the root-soil inter phase.

	Soil series and horizon					
Parameter	Andigama series			Madampe series		
	A	AB	B	A	AB	B
Field capacity (10 kPa)	15.86	15.65	17.09	9.87	10.41	10.97
Permanent Wilting Point (1500 kPa)	6.81	9.29	13.6	4.15	3.73	4.28
Available Water	9.05	6.38	3.54	5.71	6.18	6.70
Readily Available Water (10-100 kPa)	6.46	4.55	2.20	3.96	5.30	5.68
Infiltration rate (cm/h)	4.6			15.2		
Time taken to wet the soil profiles (hrs)	7			4		

8. Soil Physical properties

Soil physical properties of major soil series (A, AB and B horizons) in wet, intermediate and dry zones were collected for the development of crop models.

Physical properties of **A horizon** of major soil series in the **wet zone**

	FC (%)	PWP (%)	TAW (mm)	BD (g /cm3)	TP (%)	Macp (%)	Micp (%)	Sand (%)	Silt (%)	Clay (%)
Katunayake	6.80	4.12	4.20	1.48	44.1	37.30	6.80	88.80	1.40	9.80
Pallama	17.90	4.12	31.6	1.46	44.8	26.90	17.90	86.30	3.99	9.70
Boralu	19.40	9.90	11.40	1.51	42.6	27.40	15.20	77.10	6.70	16.20

Physical properties of **AB horizon** of major soil series in the **wet zone**

	FC (%)	PWP (%)	TAW (mm)	BD (g /cm3)	TP (%)	Macp (%)	Micp (%)	Sand (%)	Silt (%)	Clay (%)
Katunayake	8.61	2.45	21.6	1.44	45.6	37.01	8.61	88.80	1.40	9.80
Pallama	14.20	6.35	51.8	1.44	45.6	31.57	14.20	83.50	3.70	12.30
Boralu	18.70	12.39	29.0	1.61	39.4	20.70	18.70	68.36	8.60	23.01

Physical properties of **B horizon** of major soil series in the **wet zone**

	FC (%)	PWP (%)	TAW (mm)	BD (g /cm3)	TP (%)	Macp (%)	Micp (%)	Sand (%)	Silt (%)	Clay (%)
Katunayake	9.40	3.77	147	1.41	46.7	37.3	9.40	87.90	1.00	11.10
Pallama	18.50	8.60	110	1.46	44.9	26.50	18.46	75.40	8.10	18.30
Boralu	23.10	17.20	24.8	1.60	38.9	15.80	23.10	59.87	10.40	27.70

Physical properties of **A horizon** of major soil series in the **intermediate zone**

	FC (%)	PWP (%)	TAW (mm)	BD (g /cm3)	TP (%)	Macp (%)	Micp (%)	Sand (%)	Silt (%)	Clay (%)
Melsiripura	32.54	16.72	12.7	1.04	60.6	28.1	32.54	71.64	12.55	19.66
Ambakele	15.80	4.92	10.9	1.49	43.8	28	15.80	84.60	4.40	11.20
Madampe	9.80	4.19	8.4	1.50	43.4	38.4	9.80	86.10	2.68	11.00
Rathupasa	8.70	4.37	16.9	1.46	44.9	36.2	8.70	89.90	2.00	8.10
Welipalassa	8.94	3.17	5.7	1.44	45.7	36.8	8.90	87.53	3.44	9.00
Kurunegala	20.40	11.08	9.3	1.49	43.8	23.4	20.40	83.40	7.20	9.92
Wariyapola	28.40	18.46	9.9	1.52	42.8	14.4	28.40	78.40	13	8.57
Maho	22.40	12.56	9.8	1.48	44	21.6	22.40	79.66	12.80	7.52
Andigama	15.20	5.60	14.4	1.52	42.6	27.4	15.20	82.85	4.80	12.32
Sudu	4.04	2.70	0.8	1.38	47.9	43.9	4.04	95.24	4.40	0.00

Physical properties of **AB horizon** of major soil series in the **intermediate zone**

	FC (%)	PWP (%)	TAW (mm)	BD (g /cm3)	TP (%)	Macp (%)	Micp (%)	Sand (%)	Silt (%)	Clay (%)
Melsiripura	30.75	20.83	26.8	1.20	54.9	24.15	30.75	69.21	11.70	19.10
Ambakele	16.10	5.85	40.1	1.54	41.9	25.80	16.10	80.70	8.00	12.30
Madampe	9.90	4.35	36.0	1.50	43.4	33.50	9.90	85.40	3.30	11.80
Rathupasa	10.40	3.85	11.1	1.54	41.9	31.50	10.4	88.60	1.90	10.10
Welipalassa	13.00	3.43	47.9	1.52	43.0	30.0	13.0	86.30	5.60	8.20
Kurunegala	15.50	11.24	6.4	1.52	43.3	27.8	15.5	79.74	9.70	10.54
Wariyapola	27.21	21.68	17.7	1.54	41.9	14.28	27.61	75.55	12.80	11.61
Maho	19.50	15.20	15.5	1.55	41.6	22.72	19.5	77.27	16.30	6.38
Andigama	15.21	9.01	31.0	1.58	40.4	25.19	15.21	80.10	5.10	16.00
Sudu	5.05	2.18	9.8	1.40	47.2	42.2	5.05	93.10	4.76	2.10

Physical properties of **B horizon** of major soil series in the **intermediate zone**

	FC (%)	PWP (%)	TAW (mm)	BD (g /cm3)	TP (%)	Macp (%)	Micp (%)	Sand (%)	Silt (%)	Clay (%)
Melsiripura	30.40	20.27	268	1.31	50.7	20.30	30.40	66.90	15.68	20.70
Ambakele	22.00	10.12	173	1.59	40.0	18.00	22.00	78.70	10.00	12.30
Madampe	10.98	4.38	142	1.50	43.4	32.42	10.98	84.60	2.40	13.10
Rathupasa	12.98	5.47	183	1.44	45.7	32.68	12.98	87.20	2.40	10.70
Welipalassa	13.72	4.03	146	1.55	41.6	27.91	13.32	85.60	7.00	7.40
Kurunegala	18.60	11.90	77	1.48	44.2	25.60	18.60	77.20	13.92	13.70
Wariyapola	26.20	18.50	83	1.55	41.7	15.50	26.20	74.25	12.30	12.05
Maho	24.90	17.16	81	1.60	40.8	15.58	23.10	70.01	22.40	7.60
Andigama	16.38	12.34	32	1.62	39.6	23.40	16.38	70.55	6.40	23.10
Sudu	6.34	2.38	63	1.50	43.8	37.46	6.34	93.20	3.90	2.90

Physical properties of **A horizon** of major soil series in the **dry zone**

	FC (%)	PWP (%)	TAW (mm)	BD (g /cm3)	TP (%)	Macp (%)	Micp (%)	Sand (%)	Silt (%)	Clay (%)
Borupana	5.11	2.12	5.70	1.47	44.5	39.4	5.11	90.20	1.50	7.77
Gambura	9.70	2.10	6.10	1.46	44.9	35.2	9.70	85.58	3.81	10.62
Wilpattu	16.00	5.50	9.50	1.45	45.3	29.3	16.00	83.94	6.40	9.64
Kalpitiya	4.90	3.24	2.50	1.35	49.1	45.1	4.00	90.90	1.39	7.39
Mavillu	10.60	3.10	6.80	1.49	45.2	34.6	10.30	89.92	1.55	8.52
Welikatiya	7.06	2.03	5.00	1.38	46.0	38.9	7.10	90.80	2.10	7.09

Physical properties of **AB horizon** of major soil series in the **dry zone**

	FC (%)	PWP (%)	TAW (mm)	BD (g /cm3)	TP (%)	Macp (%)	Micp (%)	Sand (%)	Silt (%)	Clay (%)
Borupana	5.50	1.83	29.0	1.48	44.20	38.7	5.50	89.70	1.53	8.76
Gambura	16.2	6.81	6.60	1.48	44.20	28.0	16.20	81.96	11.70	6.3
Wilpattu	21.18	7.70	9.40	1.45	45.30	24.1	21.18	81.63	8.20	10.0
Kalpitiya	7.64	3.10	21.0	1.43	46.00	38.4	7.64	92.20	0.90	7.8
Mavillu	11.92	3.90	7.90	1.50	43.30	32.2	11.12	85.54	5.2	9.9
Welikatiya	7.57	1.91	20.4	1.43	46.00	38.4	7.57	89.50	2.4	8.08

Physical properties of **B horizon** of major soil series in the **dry zone**

	FC (%)	PWP (%)	TAW (mm)	BD (g /cm3)	TP (%)	Macp (%)	Micp (%)	Sand (%)	Silt (%)	Clay (%)
Borupana	13.87	5.07	250	1.53	42.30	36.60	5.74	89.20	3.50	8.30
Gambura	14.83	6.12	248	1.51	43.10	28.27	14.83	79.20	8.70	13.90
Wilpattu	15.20	6.20	256	1.48	44.30	20.70	23.60	80.90	9.02	10.30
Kalpitiya	4.16	2.03	29.4	1.47	44.50	40.34	4.16	91.20	1.00	7.40
Mavillu	11.90	3.90	224	1.52	42.60	30.30	11.90	81.20	8.11	10.70
Welikatiya	6.60	1.56	77.6	1.45	45.30	38.30	6.60	89.20	3.70	7.10

FC-Field capacity, PWP-Permanent wilting point, TAW- Total available water, BD- Bulk density, TP- Total porosity, Macp- Macro pores, Micp- Micro pores

Annex IV

Results of Trend Analysis of Meteorological Data 1931-90

Linear regression analyses have been carried out for mean maximum air temperature, mean minimum air temperature, mean air temperature and for rainfall. The results are given in Annex I.

The highest mean maximum air temperature trend has been recorded as +0.0325^{0}C per year at Puttalam during the Yala season and the lowest rate of increase of 0.0013^{0}C per year has been at Nuwara-Eliya during the Maha season The coefficient of determination (R^2) is very small at Nuwara-Eliya for mean maximum air temperature both during the Yala and Maha seasons. For the mean minimum air temperatures, the highest temperature trend has been +0.0328^{0}C per year, (at Nuwara-Eliya during Maha season) and the lowest has been –0.0013^{0}C per year at Kurunegala in the same season. The rate of variation of the mean minimum air temperatures during both Yala and Maha were negative at Kurunegala and the R^2 has been very small. The highest mean air temperature trend has been observed during the Maha season at Anuradhapura, which is about +0.0312^{0}C per year and the lowest, is about +0.0014^{0}C per year at Kandy during Yala. The highest decrease of rainfall has been observed at Trincomalee, about 5.24mm per year, during the Yala season. The lowest rainfall decrease has been at Batticaloa during the Yala season (about 0.39mm per year, where the R^2 is also very small). Positive trend (+0.99mm per year) has been observed at the Puttalam meteorological station during the Yala season with a R^2 value of about 0.10 (Table 1 and 2)

Table 1

Station	Mean Maximum Temp.^{0}C				Mean Minimum Temp.^{0}C			
	Slope (^{0}C/Year)		R^2		Slope (^{0}C/Year)		R^2	
	Yala	Maha	Yala	Maha	Yala	Maha	Yala	Maha
Anuradapura	+0.0233	+0.0322	0.75	0.65	+0.0197	+0.0239	0.76	0.78
Badulla	+0.0297	+0.0266	0.88	0.81	+0.0038	+0.0139	0.15	0.45
Baticaloa	+0.0144	+0.0107	0.42	0.78	+0.0084	+0.0072	0.61	0.53
Colombo	+0.0104	+0.0205	0.55	0.85	+0.0102	+0.0215	0.62	0.79
Galle	+0.0149	+0.0198	0.40	0.73	+0.0025	+0.0198	0.04	0.73
Hambantota	+0.0100	+0.0128	0.12	0.63	+0.0044	+0.0071	0.31	0.51
Kandy	+0.0174	+0.0123	0.81	0.62	+0.0203	+0.0076	0.53	0.29
Kurunagala	+0.0184	+0.0195	0.63	0.53	-0.0017	-0.0013	0.02	0.01
Nuwara-Eliya	+0.0022	+0.0013	0.01	0.01	+0.0184	+0.0328	0.77	0.88
Puttalam	+0.0325	+0.0252	0.93	0.84	+0.0011	+0.0023	0.01	0.05
Ratnapura	+0.0070	+0.0153	0.35	0.66	+0.0062	+0.0067	0.12	0.25
Trincomalee	+0.0257	+0.0040	0.99	0.12	+0.0287	+0.0036	0.91	0.09

Table 2

Station	Mean Temperature				Rainfall			
	Slope (^{0}C/Year)		R^2		Slope (mm/Year)		R^2	
	Yala	Maha	Yala	Maha	Yala	Maha	Yala	Maha
Anuradapura	+0.0215	+0.0312	0.80	0.84	-2.8092	-4.2733	0.51	0.32
Badulla	+0.0219	+0.0152	0.91	0.77	-1.0642	-1.7825	0.10	0.13
Baticaloa	+0.0090	+0.0115	0.75	0.72	-0.3946	-2.3745	0.03	0.06
Colombo	+0.0155	+0.0161	0.80	0.80	-0.5904	-0.9978	0.01	0.02
Galle	+0.0090	+0.0115	0.54	0.61	-2.9810	-3.4592	0.20	0.12
Hambantota	+0.0076	+0.0099	0.70	0.73	-1.3315	-2.9527	0.20	0.30
Kandy	+0.0014	+0.0148	0.70	0.90	-3.6611	-3.3922	0.21	0.20
Kurunagala	+0.0084	+0.0091	0.70	0.50	-0.8947	-0.0758	0.02	0.00
Nuwara-Eliya	+0.0109	+0.0170	0.74	0.72	-2.7606	-1.2368	0.22	0.12
Puttalam	+0.0168	+0.0138	0.90	0.80	+0.9889	-0.6947	0.10	0.03
Ratnapura	+0.0062	+0.0110	0.14	0.72	-3.9919	-2.3050	0.20	0.12
Trincomalee	+0.0164	+0.0146	0.90	0.81	-5.2451	-0.8947	0.31	0.14

Annex V

Annual averages of Precipitation (1961-1990 baseline period)

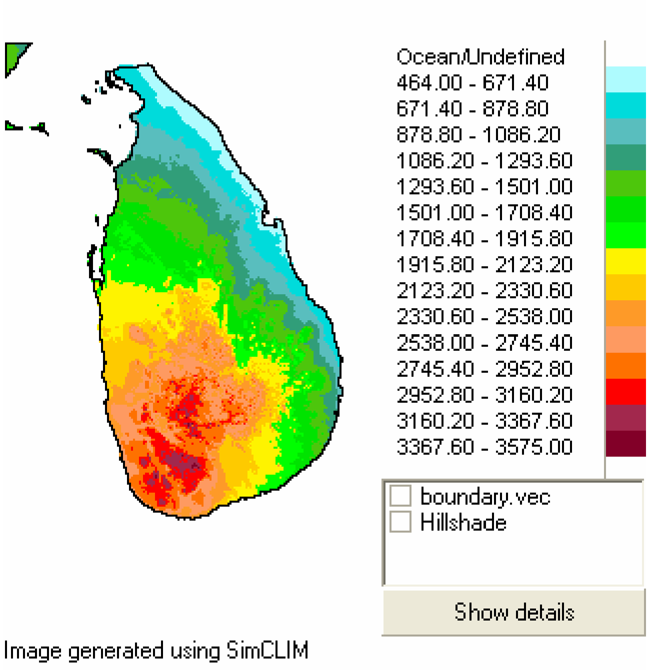


Image generated using SimCLIM

Annual averages of Mean temperature (1961-1990 baseline period)

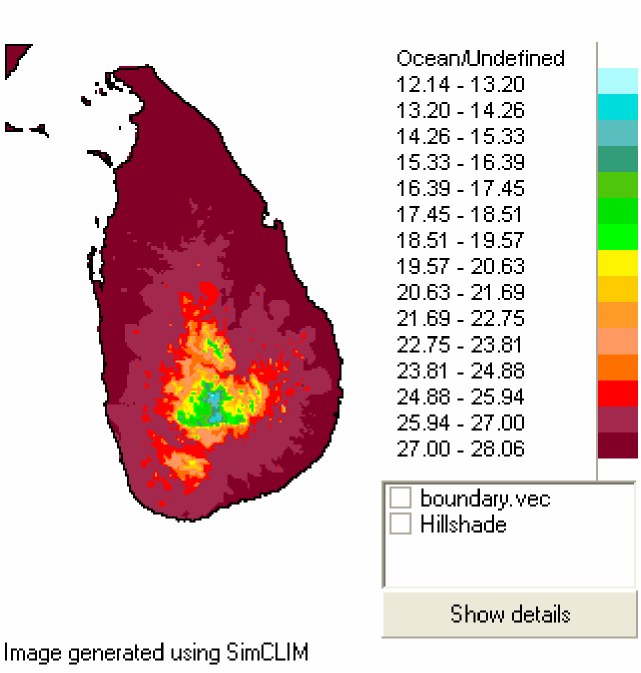
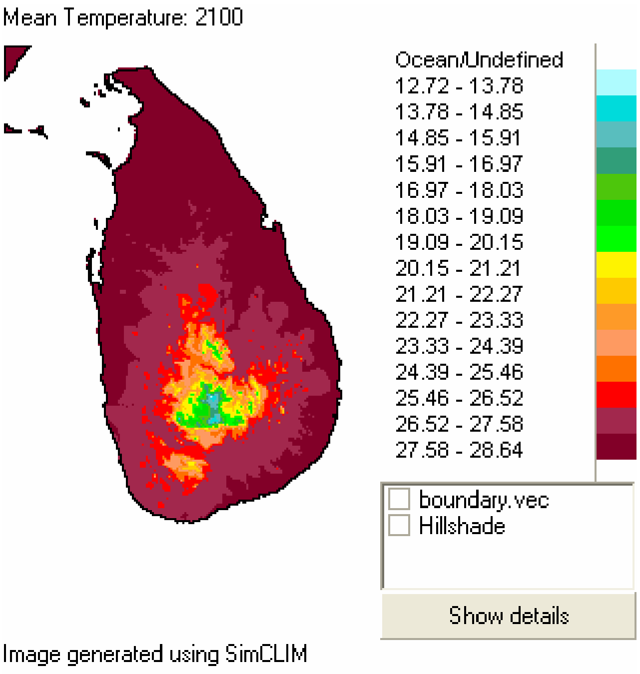
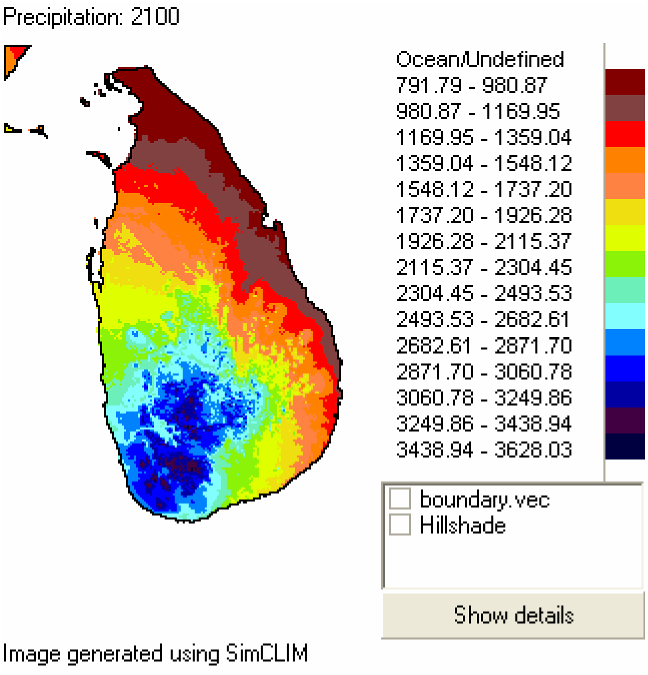


Image generated using SimCLIM

Climate scenarios for Sri Lanka (2100 Annual Mean temperature)



Climate scenarios for Sri Lanka (2100 Annual Precipitation)



Annex VI.

Results of Fertilizer Application to Coconut

1. *Response of yield to Nitrogen*

AER	LSC	Soil series	Level of N (x)	Copra Kg / ha (y)	Regression equation (y = mx + c) and r^2
IL1- Int. wet	S2	Sandy loam	N_0	1554	Y= 47.33x+1509, r^2 = 0.95
			N_1	1597	
			N_2	1670	
			N_3	1688	
IL1 – Int. dry	S2	Sandy loam	N_0	2509	Y=-70.13x+2584.5, r^2 = 0.93
			N_1	2419	
			N_2	2413	
			N_3	2325	
			N_4	2205	
WL3 - Wet	S4	Boralu	N_0	1429	Y= 10.8x+1482.6, r^2 = 0.08
			N_1	1537	
			N_2	1579	
			N_3	1557	
			N_4	1473	
WL2 - wet	S4	Gravel	N_0	1042	Y= 335.43x+870.23, r^2 = 0.92
			N_1	1623	
			N_2	2039	
			N_3	2293	
			N_4	2385	

N_0- 0 Kg Ammonium sulphate
N_1- 1.103 Kg Ammonium sulphate
N_2- 2.206 Kg Ammonium sulphate
N_3- 3.309 Kg Ammonium sulphate
N_4- 4.412 Kg Ammonium sulphate

2. *Response of yield to Phosphorous*

AER	LSC	Soil series	Level of P (x)	Copra Kg / ha (y)	Regression equation (y = mx + c) and r^2
IL1- Int. wet	S2	Sandy loam	P_0	1521	Y= 42.8x+1520.5, r^2 = 0.60
			P_1	1657	
			P_2	1672	
			P_3	1659	
IL1 – Int. dry	S2	Sandy loam	P_0	2161	Y=110.43x+2054.9, r^2 = 0.99
			P_1	2278	
			P_2	2391	
			P_3	2499	
			P_4	2602	
WL3 - Wet	S4	Boralu	P_0	1458	Y= 17.6x+1462.2, r^2 = 0.65
			P_1	1508	
			P_2	1537	
			P_3	1544	
			P_4	1528	
WL2 - wet	S4	Gravel	P_0	1880	Y= -37.967x+1991, r^2 = 0.43
			P_1	1952	
			P_2	1951	
			P_3	1876	
			P_4	1728	

P_0- 0 Kg Saphos phosphate
P_1- 0.826 Kg Saphos phosphate
P_2- 1.652 Kg Saphos phosphate
P_3- 2.478 Kg Saphos phosphate
P_4- 3.304 Kg Saphos phosphate

3. *Response of yield to Potassium*

AER	LSC	Soil series	Level of K (x)	Copra Kg / ha (y)	Regression equation (y = mx + c) and r^2
IL1- Int. wet	S2	Sandy loam	K_0	1363	Y= 151.77x+1247.8, r^2 = 0.95
			K_1	1583	
			K_2	1750	
			K_3	1813	
IL1 – Int. dry	S2	Sandy loam	K_0	2394	Y=-11.9x+2420.8, r^2 = 0.59
			K_1	2402	
			K_2	2404	
			K_3	2382	
			K_4	2344	
WL3 - Wet	S4	Boralu	K_0	951	Y= 276.8x+684.6, r^2 = 0.99
			K_1	1243	
			K_2	1526	
			K_3	1797	
			K_4	2058	
WL2 - wet	S4	Gravel	K_0	1484	Y= 144.3x+1444.3, r^2 = 0.84
			K_1	1785	
			K_2	1982	
			K_3	2074	
			K_4	2061	

K_0- 0 Kg MOP 60% K_2O
K_1- 0.376 Kg Ammonium sulphate
K_2- 0.752 Kg Ammonium sulphate
K_3- 1.128 Kg Ammonium sulphate
K_4-1.816 Kg Ammonium sulphate

4. *Response of yield to Magnesium*

AER	LSC	Soil series	Level of Mg (x)	Copra Kg / ha (y)	Regression equation (y = mx + c) and r^2
IL1 – Int. dry	S2	Sandy loam	Mg_0	2299	Y=17.571x+2333.4, r^2 = 0.25
			Mg_1	2394	
			Mg_2	2438	
			Mg_3	2430	
			Mg_4	2370	
WL2 - wet	S4	Gravel	Mg_0	1772	Y= 47.1x+1735.9, r^2 = 098
			Mg_1	1836	
			Mg_2	1889	
			Mg_3	1930	
			Mg_4	1960	

Mg_0- 0 Kg Muriate Of Potash (MOP) 60% K_2O
Mg_1- 0.376 Kg MOP 60% K_2O
Mg_2- 0.752 Kg MOP 60% K_2O
Mg_3- 1.128 Kg MOP 60% K_2O
Mg_4-1.816 Kg MOP 60% K_2O

5. *Response of yield (of an unfertilized coconut plantation) to fertilizer application*

Year after fertilizer application	Increased no. of nuts / ha	Increased wt of copra Kg / ha
1	1400	284
2	1975	401
3	2110	429
4	2200	447
5	2450	498
6	2890	587
7	3400	691
8	3660	744
9	3700	752
10	3700	752
	$y = 270.09\ x + 1263$	$y = 54.939\ x + 256.33$

Annex VII

Alternative Model for National Coconut Yield Prediction

The yield of an estate in a given year is influenced by the seasonal climate, in particularly rainfall during one and two years prior to the harvest, provided that other external factors are non-limiting. However, other external factors can't be estimated due to lack of data on national scale and it is necessary to develop models using spatial rainfall and temperature. A better empirical model ($R^2 = .95$) developed using seasonal rainfall and was reported in the last interim report by Peiris (2003). Seasons were the classical NEM, FIM, SWM and SIM. The disadvantage of the use of this model in long-term prediction is the difficult of predicting seasonal rainfall.

As prediction of rainfall by three monthly moving basis using selected GCM outputs are being carried out by IRI (2002), another model was developed to predict national yield using quarterly rainfall. Rainfall in each AER was aggregated based three monthly scales such as January to March (JAM), April to June (AMJ), July to September (JAS) and October to December (OND). It was found that the national yield in a given year was significantly correlated with rainfall during JFM on the previous year ($p < 0.05$) in all seven regions and rainfall during JAS on the following year in all AERs except two dry regions (DL3 and DL5). There was no significant correlation between yield and rainfall two years prior. The best empirical model developed using quarterly rainfall alone was able to explain about 50% of the inter annual variability.

Therefore prior to evaluate effect of climate on yield, technology effect was removed as described in the previous report. It was assumed that, Yield = constant + technology effect + climate effect + noise effect. The effect of the use of fertilizers, control of pest and diseases and the use of irrigation, moisture conservation practices etc can be considered as technology effects and this technology effect was estimated using log-linear trend model. The de-technology data (after removing technology effect from the observed data) was then regressed with quarterly rainfall. It was found that significant correlation coefficients were increased compared with that of original data. The list of significant correlation is shown in Table 1.

Table 1. Status of significant of the correlation between de-technology data and seasonal rainfall in different AERs

Lag period	Period	IL1	IL3	WL4	WL3	WL2	DL3	DL5
Zero	JFM	*	ns	**	ns	*	ns	**
	AMJ	Ns	ns	ns	ns	ns	ns	Ns
	JAS	Ns	ns	ns	ns	ns	ns	Ns
	OND	Ns	ns	ns	ns	ns	ns	Ns
1 year	JFM	***	***	***	***	***	****	***
	AMJ	*	ns	**	***	***	ns	Ns
	JAS	*	**	*	*	**	ns	Ns
	OND	Ns	ns	ns	ns	ns	ns	Ns
2 year	JFM	Ns	ns	ns	ns	ns	ns	Ns
	AMJ	Ns	ns	ns	*	ns	ns	Ns
	JAS	Ns	ns	**	*	ns	ns	Ns
	OND	Ns	*	ns	*	ns	ns	Ns

The results further confirm the importance of rainfall during January to March of previous year in all the regions and rainfall during July to September of previous year in all regions except two dry regions. The identified best fitted model contains five variables as given in Table 2.2. The significant seasonal variables are rainfall during January to March in WL3 (RF_T1WL3) and WL4 (RF_T1WL4), rainfall during April to June in WL2 (RF_T2WL2) and in IL3 (RF_T2IL3) and rainfall during July to September during WL4 (RF_T3WL4). All coefficients were significant at least at the 5% level (Table 2.2). It was found that there is no powerful mluticollinearity among the five significant variables.

Table 2.1 Results of ANOVA for selecting variables

Source	DF	SS	F value	Pr > F
Model	5	4331634	25.63	<.0001
Error	45	1520982		
Corrected total	50	5852616		

Table 2.2 Summary of the parameters in the model

Variable	Parameter	SE	Pr > F	Partial R-Square
Intercept	-823.386	122.592	<.0001	
RF_T1WL4	0.748	0.33452	0.030	0.0289
RF_T1WL3	0.674	0.286	0.023	0.3696
RF_T2IL3	-0.649	0.244	0.010	0.031
RF_T2WL2	0.784	0.127	<.0001	0.195
RF_T3WL4	0.570	0.119	<.0001	0.116

The correlation between observed and predicted values is 0.83 (p< 0.0001). The percentage of the errors of the predicted values for the period from 1951 to 2002 varied from –10% to 10% with an exceptional error percentage of –25% in 1987. This particular year was severe ELNINO year. The prediction was extremely good after 1988 (Table 3).

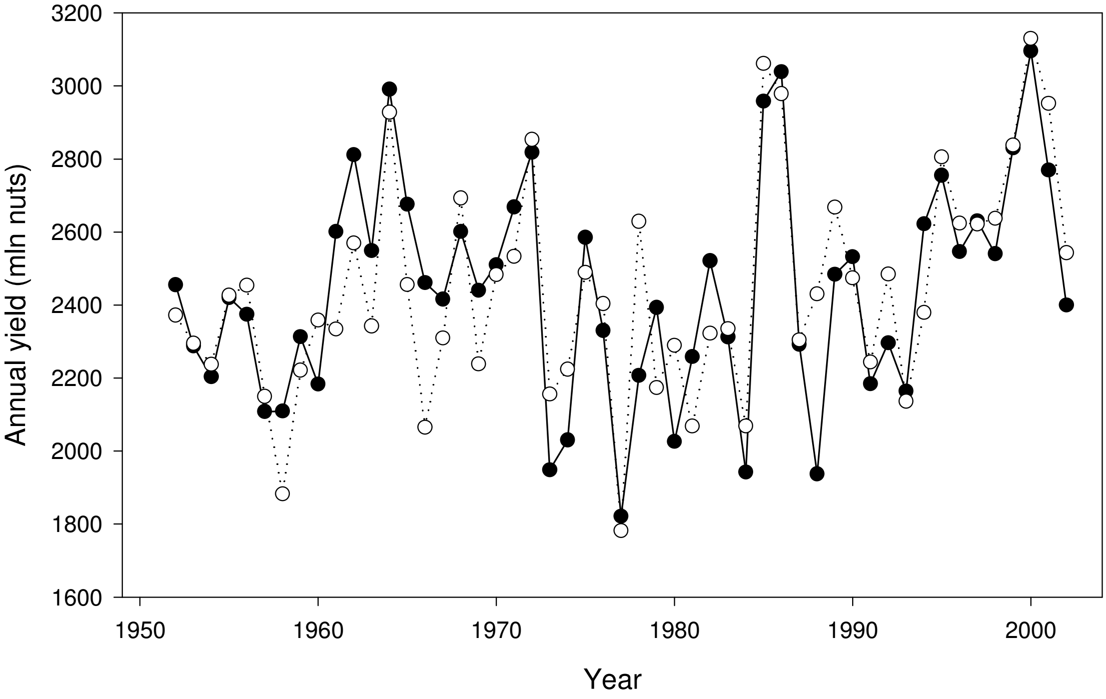
Table 3. Distribution of percentage error of the predicted values after 1988

Year	Actual	Forecast	% Error
1988	2484	2668	-7.4
1989	2532	2474	2.3
1990	2184	2243	-2.7
1991	2296	2485	-8.2
1992	2164	2136	1.3
1993	2622	2379	9.3
1994	2755	2805	-1.8
1995	2546	2624	-3.0
1996	2630	2621	0.3
1997	2540	2637	-3.8
1998	2830	2838	-0.3

1999	3096	3130	-1.1
2000	2769	2952	-6.6
2001	2400	2543	-6.0

The plot of observed and predicted values is shown in Fig. 1.

Fig. 1 Comparison between observed and predicted yield



Therefore this model can be used to predict both short-term and medium term prediction of national yield. Though this is not a spatial model, as policy makers are concern this model would be very useful. This model too can be incorporated in to SriLankaClim.

3.2 ENSO Influence on National Coconut Production

Sea surface temperature (SST, ^{0}C) and sea surface temperature anomalies averaged over the region of the eastern equator known as NINO3.4 ( ) are commonly used as a continuous measure of ENSO strength. Monthly SST values obtained from IRI database were aggregated into quarterly means.

There was significantly negative correlation between quarterly NINO3.4 index with both national yield (prior to remove technology effect) and de-technology yield. The correlation coefficients are higher with de-technology yield (Table 4). It confirms the clear influence of ENSO on coconut yield.

Table 4. Correlation between yield and quarterly SST anomalies

Variable	JFM	AMJ	JAS	OND
Original data	-0.28648 (0.0395)	-0.28739 (0.0388)	-0.2381 (0.0892)	-0.26906 (0.0500)
De-technology data	-0.29886 (0.0314)	-0.38751 (0.0045)	-0.29174 (0.0359)	-0.28961 (0.0373)

(Significant levels are shown in parenthesis)

It was also found that there is significantly negative correlation with both original and de-technology data with one year lag SST anomalies. Similar results were obtained when yield were correlated with original SST data and correlations are higher than that was obtained with anomalies.

The results are promising as ENSO3.4 can be taken as proxy large scale weather variable to predict quarterly rainfall. Further, this would be useful to give confident warnings to coconut growers in advance as ENSO phases can be predicted in advance using GCM outputs.

National yield in a given year was partitioned in to six period (bi-monthly intervals) based on the trend within year in IL1 region. The above correlation analyses was carried out bi-monthly data separately and found significant correlation with both SST and SST anomalies. In order to find more details of impact of ENSO the canonical correlation analysis will be used.

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Annex VIII

Economic Value of Climate Variability on Coconut Industry in Sri Lanka: A Preliminary Analysis

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(November, 2003)

Coconut (*Cocos nucifera* L), a perennial tree crop, significantly contributes to the economy of Sri Lanka, occupying about 441 861 ha of land, 21 per cent of total agricultural lands in the country. It contributes some 2 per cent to the GDP, 2.5 per cent to export earnings, 5 per cent to employment. Coconut is also an important food crop in Sri Lanka, in that, it provides about 22 per cent of the per capita calorie intake in the diet, being second only to rice paddy, the staple food of Sri Lankans. Coconut is almost exclusively grown as a rain fed crop in Sri Lanka. Rainfall and temperature are the important climatic factors influencing the coconut yield (Peiris *et al.* 1995), and hence the national coconut production, upon which domestic culinary consumption and processing industry depend. Although the influence of climate variability has been quantified (Peiris *et al.* 1995), its economic value on coconut production has not been estimated, which is the objective of this note. We first identify the climate extreme years, using 1971 to 2001 national coconut production data, employing percentile analysis and then the climate characteristics of the identified extreme years are presented, followed by a simple estimate of economic value of climate variability on coconut production.

1). Identification of extreme years

During 1971 to 2001 (31 years), national coconut production varied from 1821 nuts (minimum) to 3096 nuts (maximum) with a mean of 2435.90 nuts (cv= 14%). The lower and upper bounds of extreme production years were assumed respectively as 10% and 90% percentiles of the production array. Based on percentile analysis, the extreme production years were identified (Table 1).

Table 1: Extreme production years resulted from to percentile analysis

Percentile	Production extreme	Million nuts	Extreme years
10%	Shortage	< 1948	1973, 1977, 1984, 1988
90%	Glut	> 2828	1985, 1986, 1999, 2000

2). Climate characteristics of the extreme years

Some 75% of the lands under coconuts are located in the area called “coconut triangle”, and hence the coconut triangle significantly contributes to the national production in a given year. Therefore, we present the climate characteristics of the identified extreme years only of the coconut triangle.

Since it is well established that the t^{th} year coconut yield is significantly influenced by the rainfall of the $t\text{-}1^{th}$ year, we present in Table 2 the annual total rainfall of the coconut triangle in the immediately preceding years to the identified extreme years.

Table 2:Annual total rainfall of the coconut triangle in immediately preceding years of extreme production years

Production extreme	Year	Rainfall (mm) $_{t-1}$
Shortage	1972	2278
	1976	1574
	1983	1475
	1987	2036
Glut	1984	2451
	1985	2047
	1998	2059.10
	1999	2208.35

As Table 2 shows, there is no discernible relationship between the coconut production and the total rainfall of the coconut triangle in shortage and extreme gluts. This may be at least partly because the distribution of rainfall influences the yield than the total rainfall.

3). Valuation of first order climate impacts on coconut industry

The immediate effect due to variability of rainfall involves the decrease/increase in national coconut production, which we call as the first order effect, the impact of first order effect being negative and positive respectively in the lower and upper production extremes.

The departures of production in each year of the lower and upper production extreme years with respect to the mean production of the 10% to 90% percentile (which is 2432 million nuts), were computed as shown in Table 3. These production departures would not be attributed solely to climate variability, because the changes in other factors such as fertilizer use, level of technology adoption, management etc. would also intervene. The effect of the latter factors could be crudely excluded by considering that only a 60 per cent of the production departures in Table 3 are due to the climate variability because Peirs (2003) found that 60 per cent of the variation of coconut production is explained by climate. The 60 per cent of the production departures were then multiplied by free on board (F.O.B) prices of coconuts to derive the foregone/additional economic values to the economy in nominal terms.

Table 3: Departures of coconut production from the mean in extreme years and their economic values

Production extreme	Corresponding year	Production (million nuts)	Change in production (million nuts) wrpt* mean production - A	60% of column A	F.O.B** price (Rs/nut)	Foregone/incremental Value (Rs million)
Shortage	1973	1948	484	290.4	n.a.	-
	1977	1821	611	366.6	n.a.	-
	1984	1942	490	294	6.48	1905 (73)
	1988	1937	495	297	5.82	1728 (54)
Glut	1985	2958	526	315.6	3.59	1133 (42)
	1986	3039	607	364.2	3.50	1275 (46)
	1999	2828	396	237.6	17.61	4184 (59)
	2000	3096	664	398.4	16.57	6601 (87)

*- with respect to.

**- Free on board.

n.a. – not available.
1 US $ = approx. Rs 95.80 as on 6 November 2003.
Figures in parentheses are million US $.

Table 3 shows that the foregone income to the economy in crop shortage extremes varied between US $ 54 million to US $ 73 million while the additional income accrued in crop glut extreme varied between US $ 42 million to US $ 87 million, all figures in nominal terms.

References

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Annex IX

Productivity of tea plantations in relation to environmental factors in different agro-ecological zones

Although there were fluctuations between years, there was an overall increase in the productivity of tea plantations in Sri Lanka from 1930s to 2002 (Figure 1). Of the total production in 2000, majority (56%) is produced in the low country. The contributions of mid and up country are 18% and 26%, respectively. The share of Up and mid elevations were18 & 2 A significant drop in tea yield has been observed in prominent drought years especially in 1992 where the drop in yield due to drought was about 26% compared to 1991 (Figure 2). Further analysis showed that the yield drop was greatest in the IU (28%) and lowest in the IM (14%). The WU, WL and WM recorded 26%, 25%, and 19% reduction in yield due to 1992 drought, respectively. The potential productivity varies in the descending order of WL, WU, WM, IM, and IU (Figure 3).

The overall increase in productivity in tea lands in Sri Lanka could have been a result of technological improvements such as new clones, fertilizer mixtures etc., and also due to environmental changes. Hence, impact of environmental factors on productivity need to be estimated excluding the influence of technological improvements. This was done by correlating productivity with the environmental factors during the periods when there was no introduction of major technological improvements in the tea sector.

Environmental factors i.e. rainfall and temperature have a combined effect on yield. Multiple regression analysis between environmental factors and yield haven't also given clear relationships. Hence, effect of environmental factors on productivity was studied by separately for dry and wet months of the year. It was assumed that productivity of tea plantations during dry months is affected by rainfall and during wet months by temperature.

Effect of Rainfall on Productivity:

Table 2 – Effect of Rainfall on Productivity of tea lands (dry period)

Agro-ecological zone	Gradient	Intercept	R^2
Up-country wet zone	0.34- 1.20	66 -210	0.30-0.72
Up-country- Intermediate zone	0.46 -9.85	41-218	0.28-0.85
Mid-country-Wet zone	0.28-0.63	49-257	0.32-0.80
Mid-country Intermediate zone	0.31-0.54	80-89	0.23-0.57
Low-country wet zone	0.08-0.77	29-107	0.16-0.87

Effect of rainfall on productivity of tea lands were established by extracting data relating to dry months (January-April). Due to establishment of better relationships, regression analysis was performed with one month lag period i.e. yield vs rainfall of previous month. Positive relationship between rainfall and productivity showed that the tea yield during dry months is significantly affected by the moisture stress. Change in one mm of rainfall could change the productivity by 0.1 -9.9 kg of made tea ha^{-1} during the dry months. The highest response to rainfall was seen in the up-country intermediate zone where soil fertility and the amount of solar radiation were higher compared to upcountry wet zone. The lowest response was seen in the low-country wet zone with less fertile soil.

Effect of Temperature on Productivity of tea lands (wet period):

Table 3 – Effect of temperature on Productivity of tea lands (wet period)

Agro-ecological zone	**Gradient**	**Intercept**	**R^2**
Up-country wet zone	38.8-58.5	405-759	0.16-0.26
Up-country- Intermediate zone	14.1-64.4	38-868	0.04-0.36
Mid-country-Wet zone	-18.4-44.9	701-823	0.21-0.26
Mid-country Intermediate zone	23.6	410	0.18
Low-country wet zone	-47.8-6.2	47-104	0.13-0.19

Temperatures in mid and low grown tea estates were mostly above 25 ^{o}C. Increase in temperature above 25^{o}C reduced productivity in some of the low and mid grown estates. However, some estates recorded a marginal increase in productivity or constant productivity with increase in temperature above 25^{o}C. Hence, all data were pooled and the relationship between temperature and productivity was established. Analysis of pooled data for all regions have shown an increasing trend in productivity with rising temperatures up to about 22 ^{o}C above which the productivity again reduced with increasing temperatures.